Climate Change, water resources, and flood hazards

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U.S. Department of the Interior
U.S. Geological Survey

Stationarity is Dead?

- Water planning: centers around risk/cost tradeoffs
- Underlying ideas from the Harvard Water Program (late 1950's)
- Analysis requires assumptions about the distribution of hydrologic variables (streamflow)

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Milly et.al. 2008, Science

"In view of the magnitude and ubiquity of the hydroclimatic change apparently now underway…stationarity is dead."

"Finding a suitable successor is crucial for human adaptation to changing climate."

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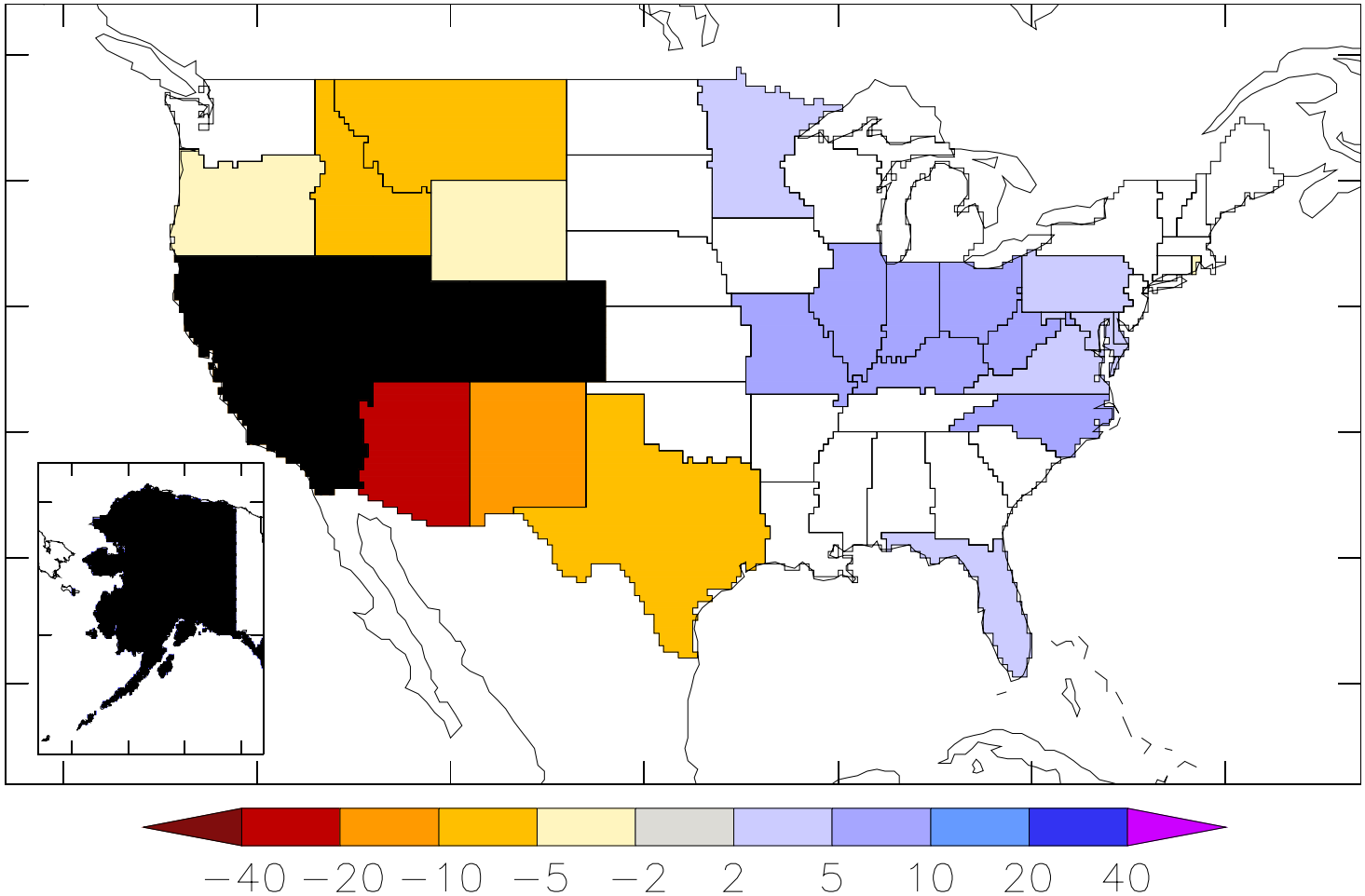
Model-Projected Changes in Annual Runoff, 2041-2060

Percentage change relative to 1900-1970 baseline. Any color indicates that >66% of models agree on sign of change; diagonal hatching indicates >90% agreement.



(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.)

Milly et.al. 2008

"Modeling should be used to synthesize observations; it can never replace them."

"In a nonstationary world, continuity of observations is crucial."

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What do the data actually tell us?

- Flow timing shifts in areas where snow has been significant
- Predominantly increasing low flows
- Predominantly increasing average flows
- Changes in flooding, very unclear
- Changes in ground-water recharge, very unclear

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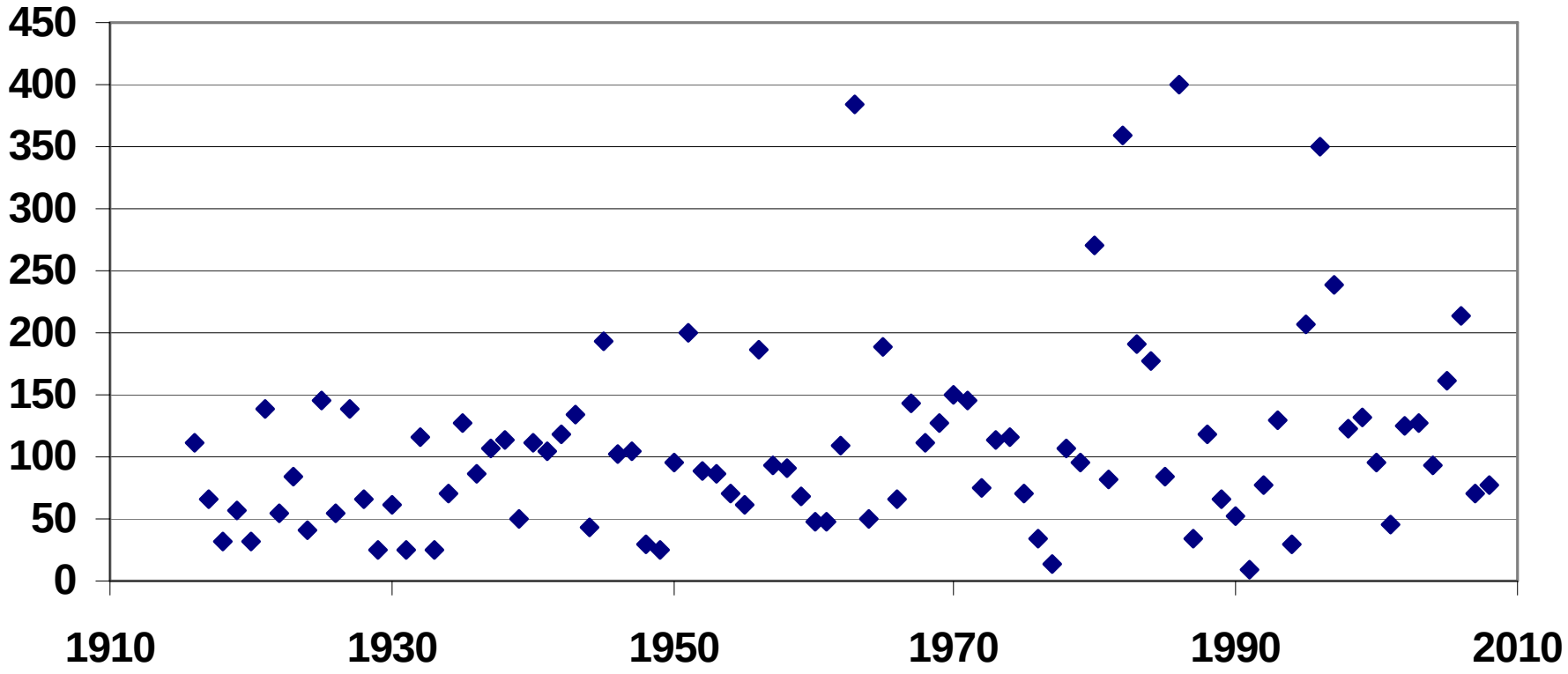
February Streamflows in CFS, Merced River at Happy Isles Bridge, Yosemite National Park, CA



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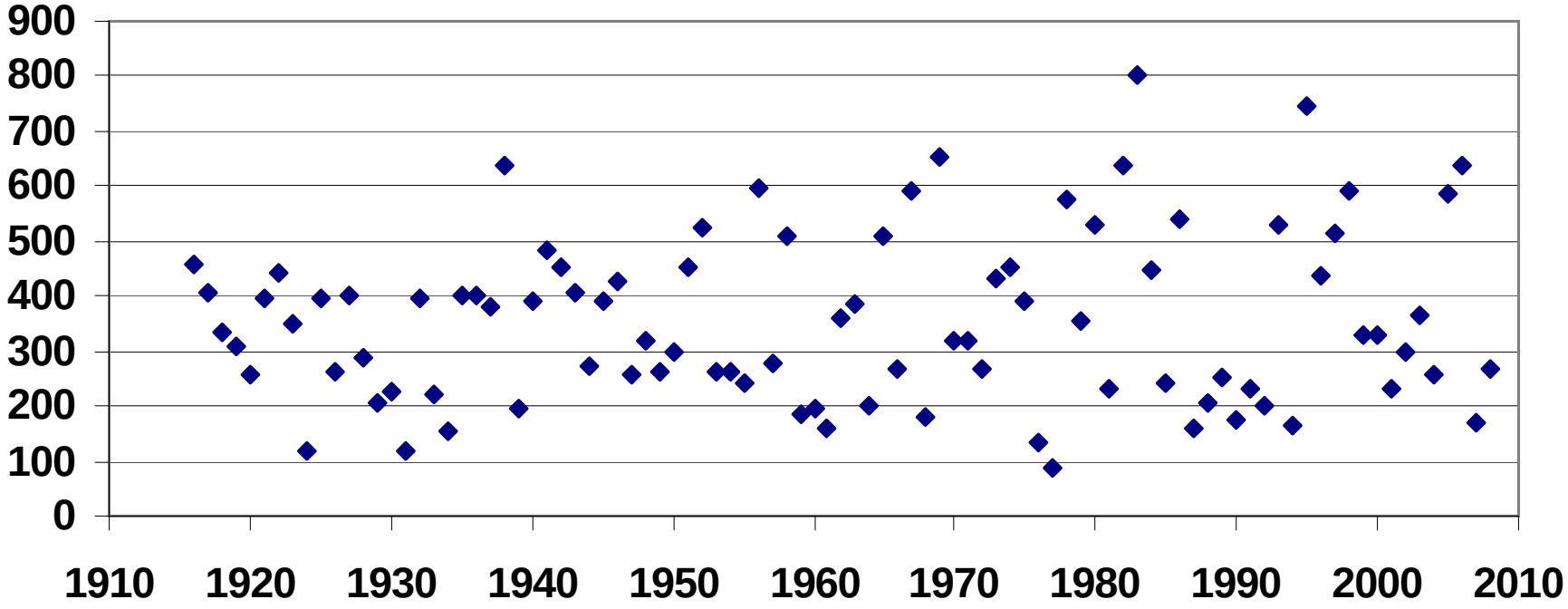
Annual Streamflow in CFS, Merced River at Happy Isles Bridge, Yosemite National Park, CA



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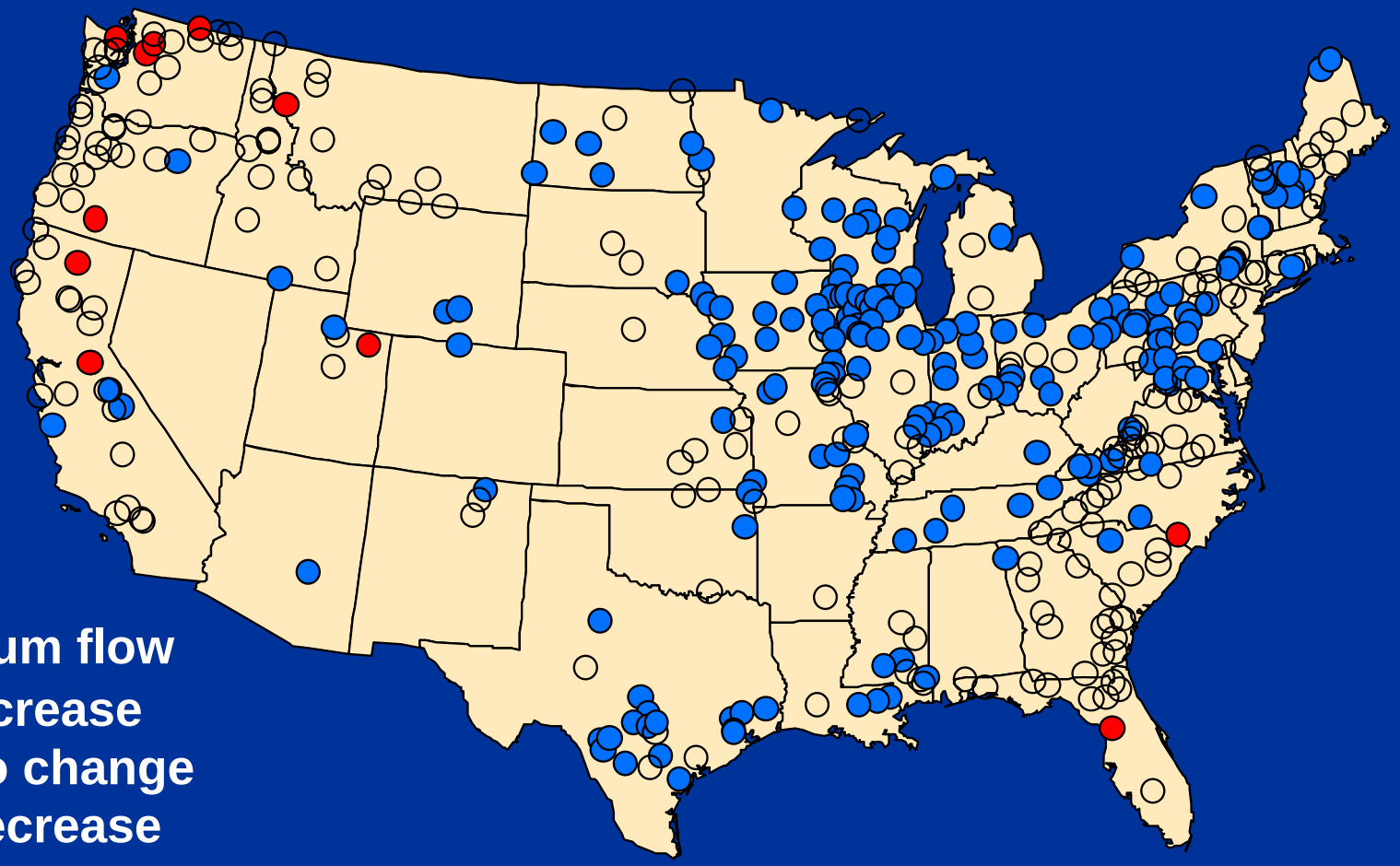
About 50% of the 400 sites show an increase in annual minimum flow from 1941-70 to 1971-99



Minimum flow

- Increase
- No change
- Decrease

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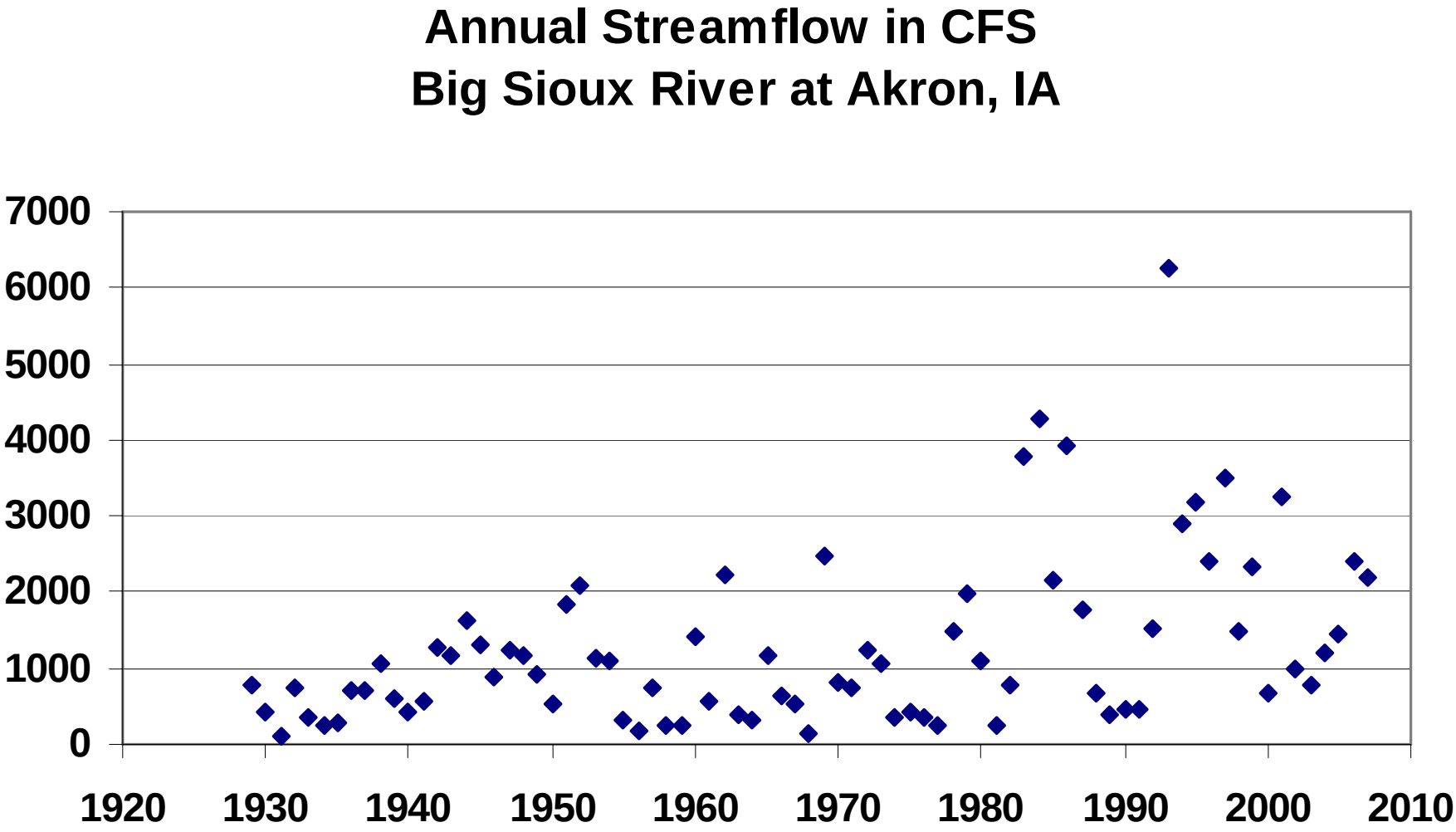
From McCabe & Wolock, Geophysical Research Letters, 2002


Annual Streamflow in CFS
Big Sioux River at Akron, IA
7000
6000
5000
4000
3000
2000
1000
0
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

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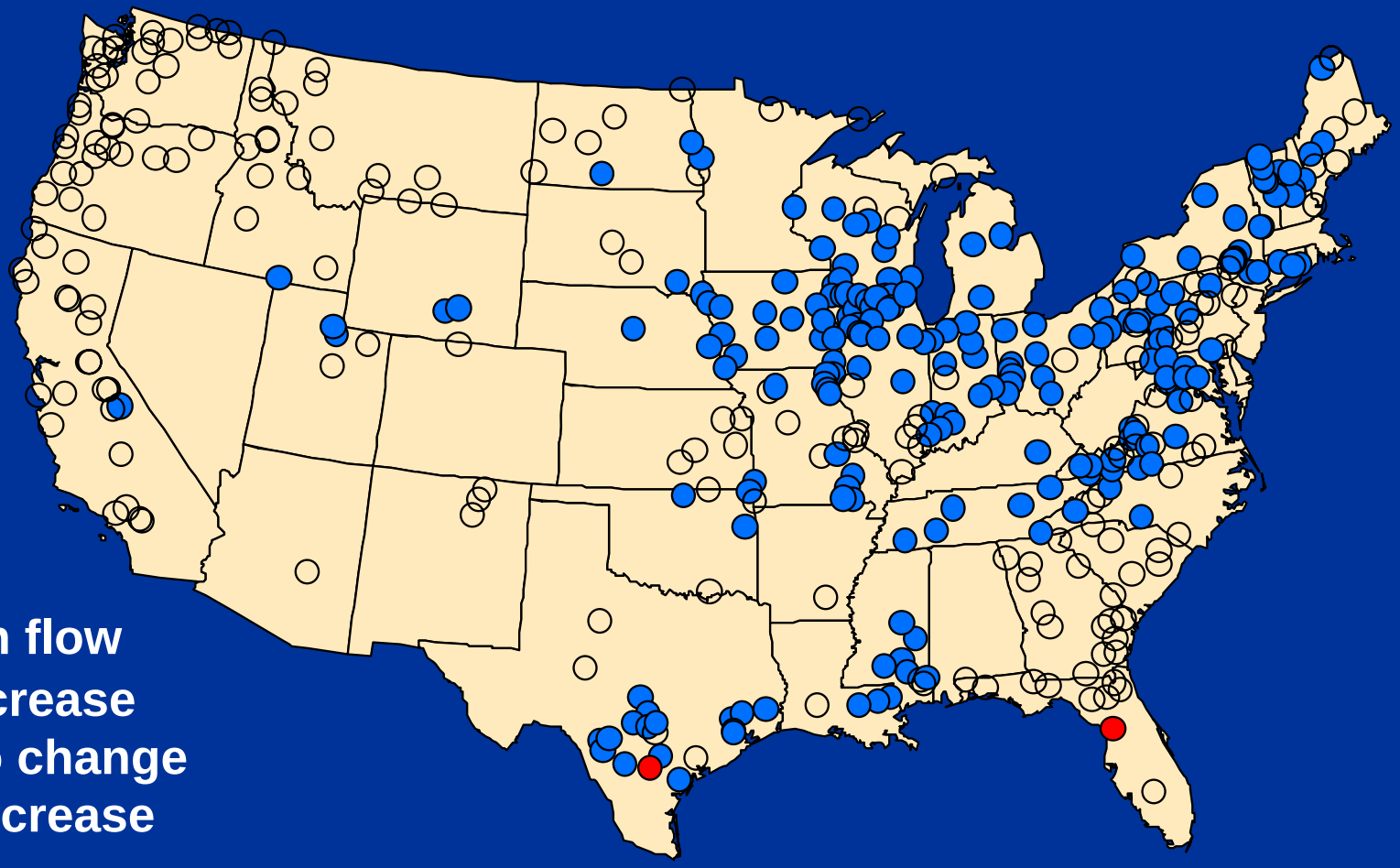
About 50% of the 400 sites show an increase in annual median flow from 1941-71 to 1971-99



Median flow

- Increase
- No change
- Decrease

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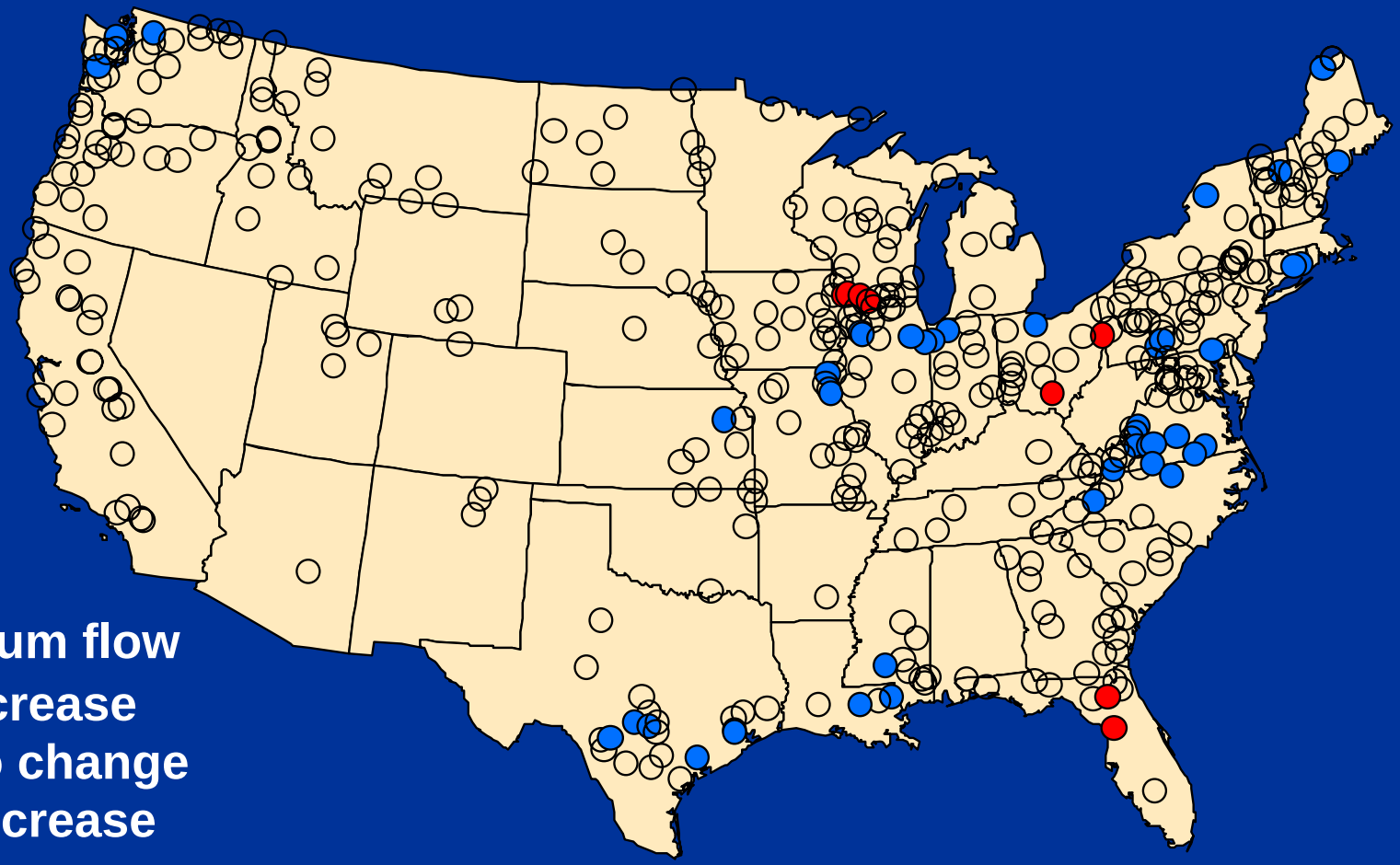
From McCabe & Wolock, Geophysical Research Letters, 2002

About 10% of the 400 sites show an increase in annual maximum flow from 1941-71 to 1971-99



Maximum flow

- Increase
- No change
- Decrease

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From McCabe & Wolock, Geophysical Research Letters, 2002

Let’s talk about floods:

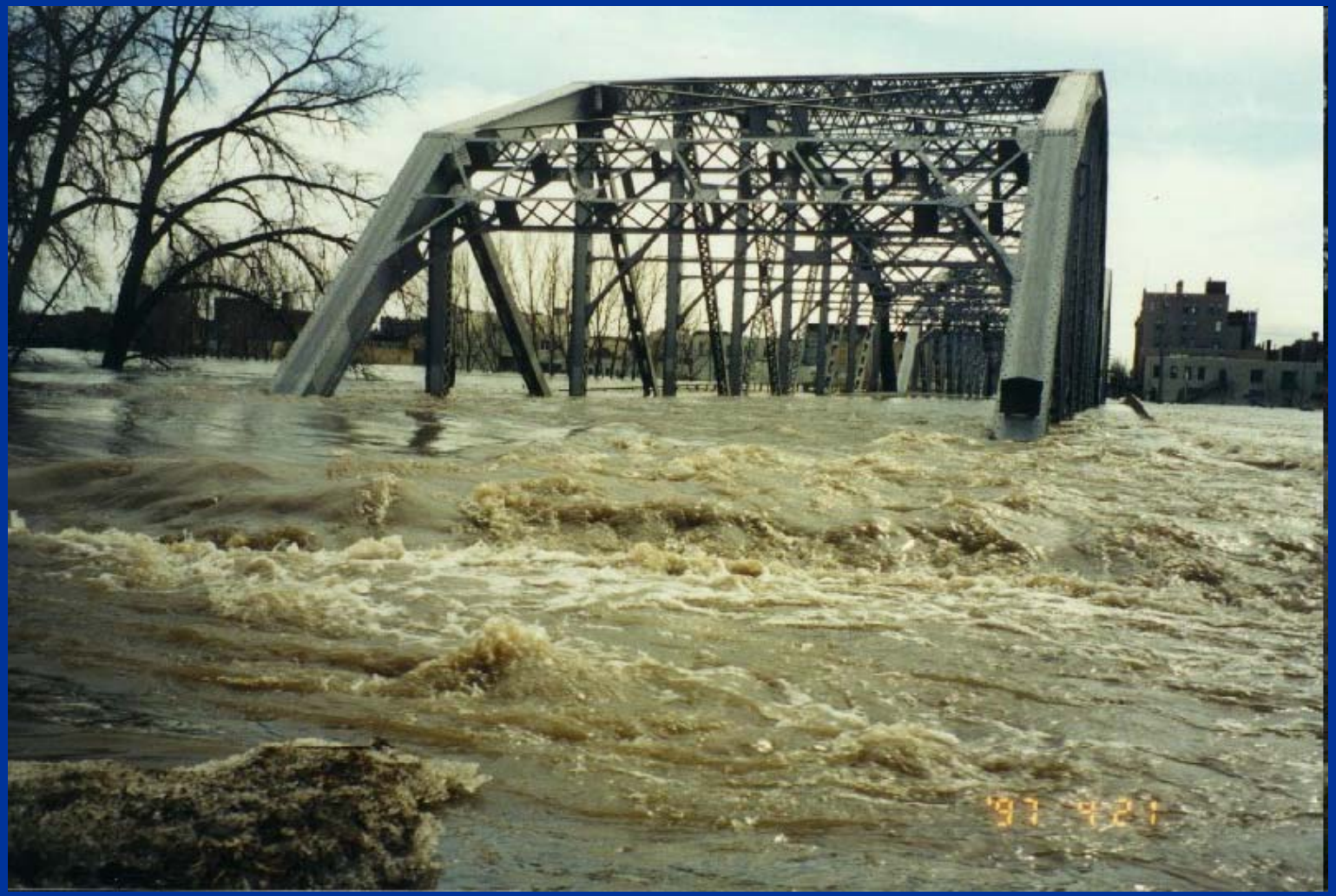

Photo credit: Steve Norbeck, April 21, 1997,
Red River of the North at Grand Forks, ND, discharge 111,000 cfs

What’s the question

- Responsible people want to know how to modify flood risk analysis to account for the greenhouse effect.
- Can we use global climate models?
- What do flood data tell us?

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The models

- Models suggest a substantial rise in “precipitation intensity” (annual total precipitation divided by number of wet days) -- but, how does that relate to large floods?
- All of the models tend to do a poor job of replicating the magnitude of extreme precipitation events.

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Analysis of flood data

- Published studies at national to global scale (with one notable exception) show no general trend towards larger floods.
- Small indication of a step increase around 1970.
- Milly et.al. 2002, looking globally, at very large river basins, at 100-year return period monthly volumes, found a widespread increase.

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Changing flood risk is an important issue in climate-change adaptation: *This particular study approached the issue using:*

- US streamgages
- records, longer than 100 years
- annual maxima
- High-quality data
- minimal impacts of flow regulation

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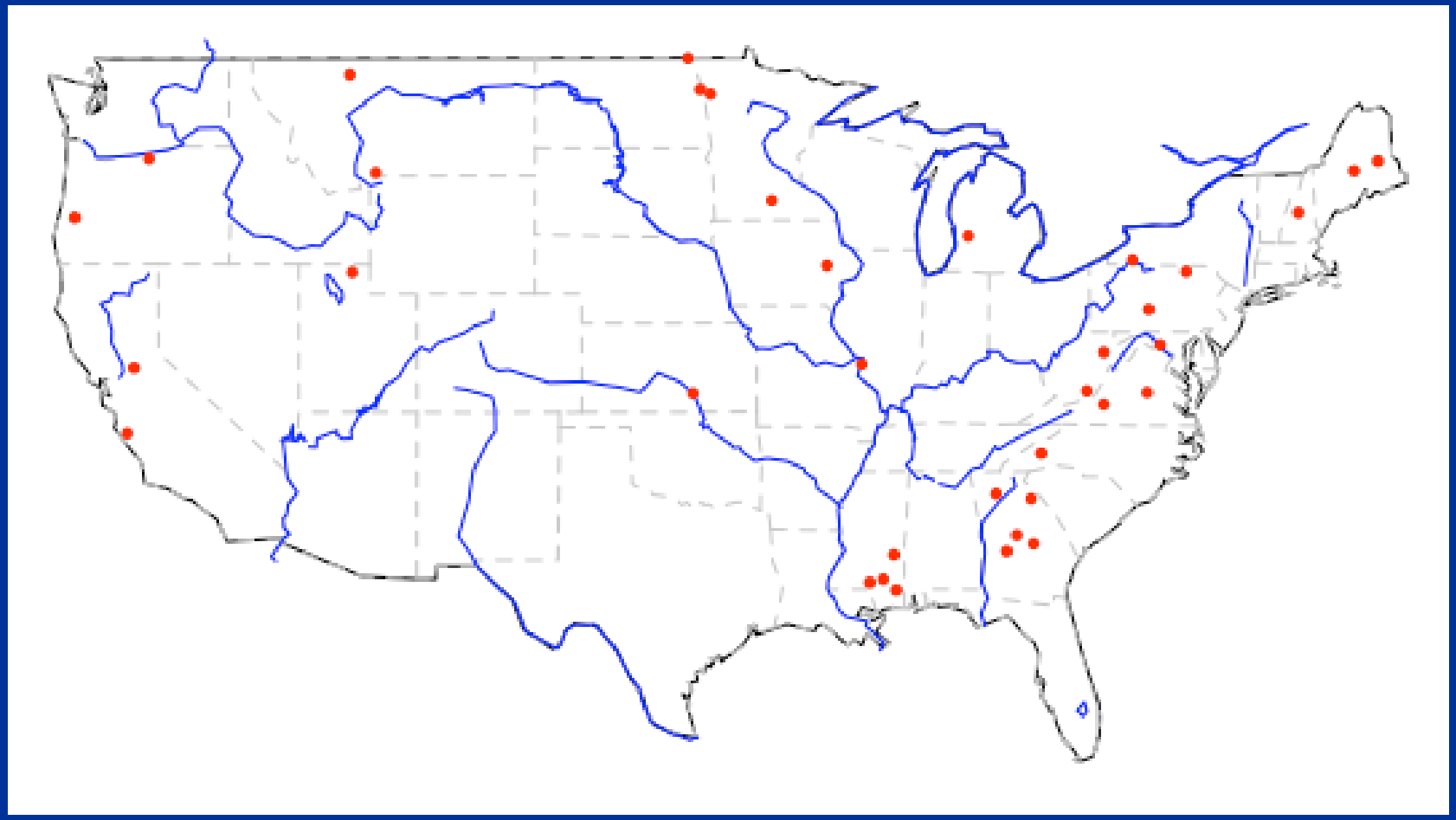
USGS streamgage annual flood peak records used in study (all >=100 years)



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Data sets

- 36 streamgages
  - Average 107 years (through 2007)
  - Range 100 to 126 years
  - A few missing values allowed

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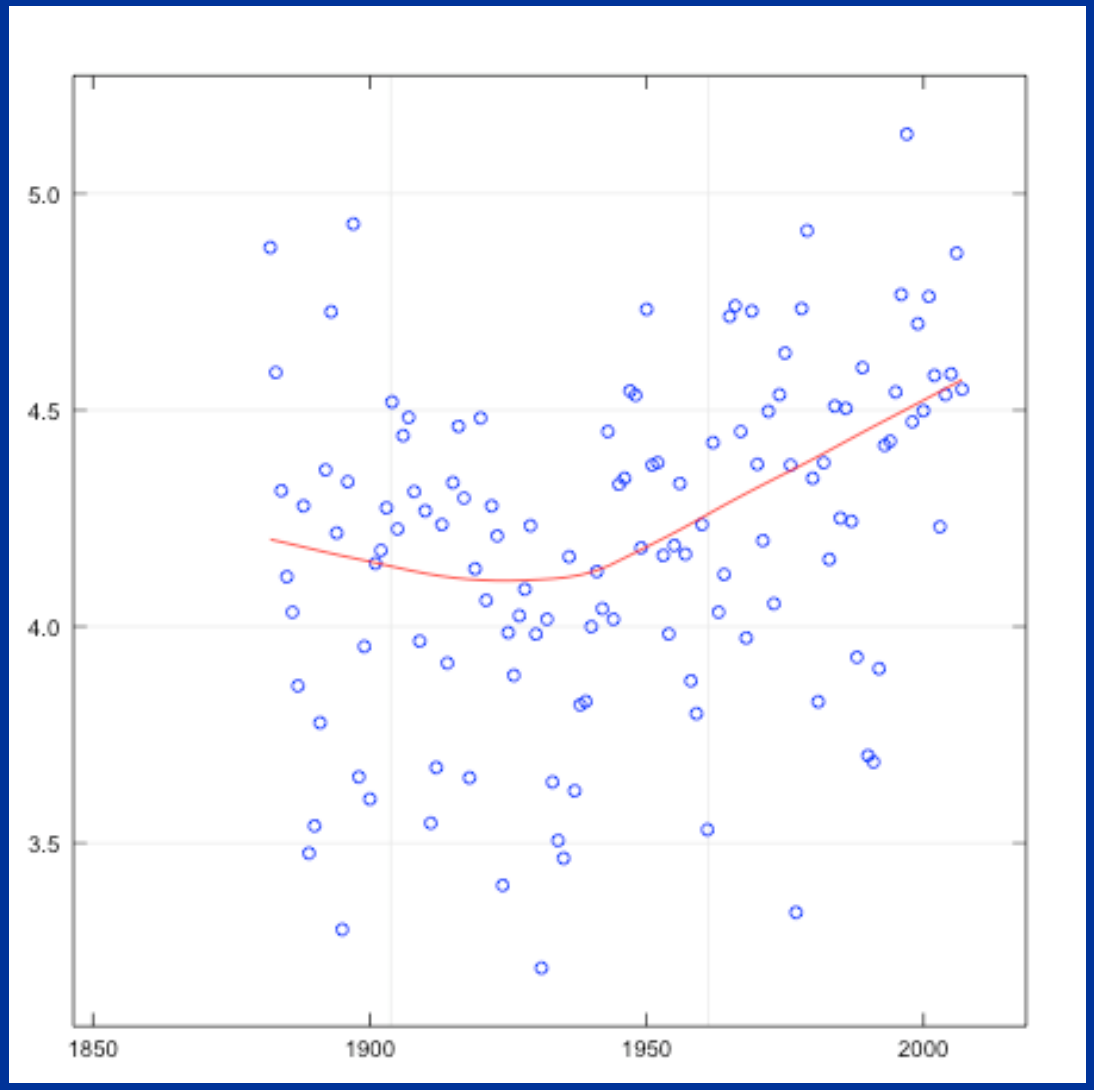
Log of Annual Peak Flood, Red River at Grand Forks, ND

r = 0.32
p = 0.0003



Water Year

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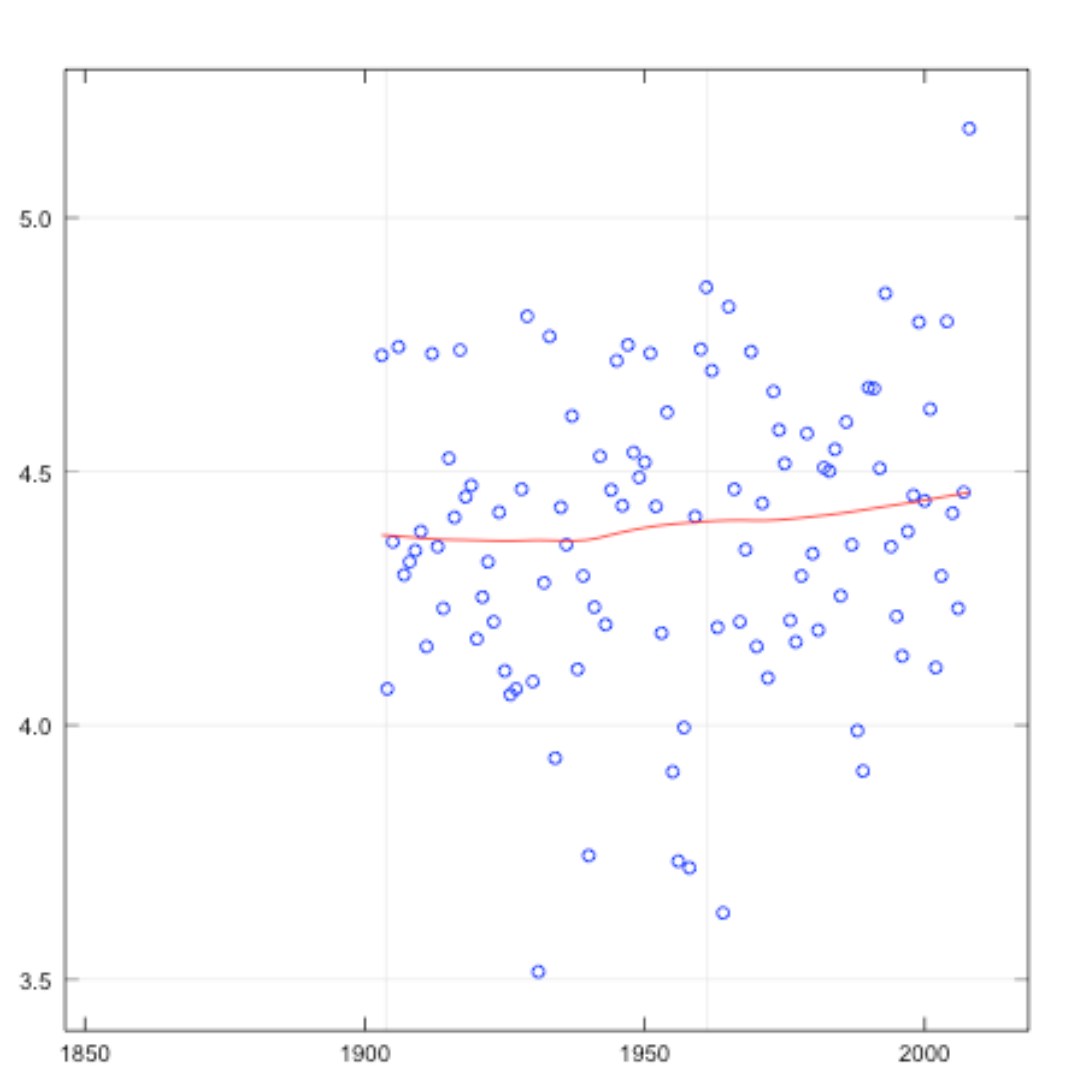
Log of Annual Peak Flood, Cedar River at Cedar Rapids, IA

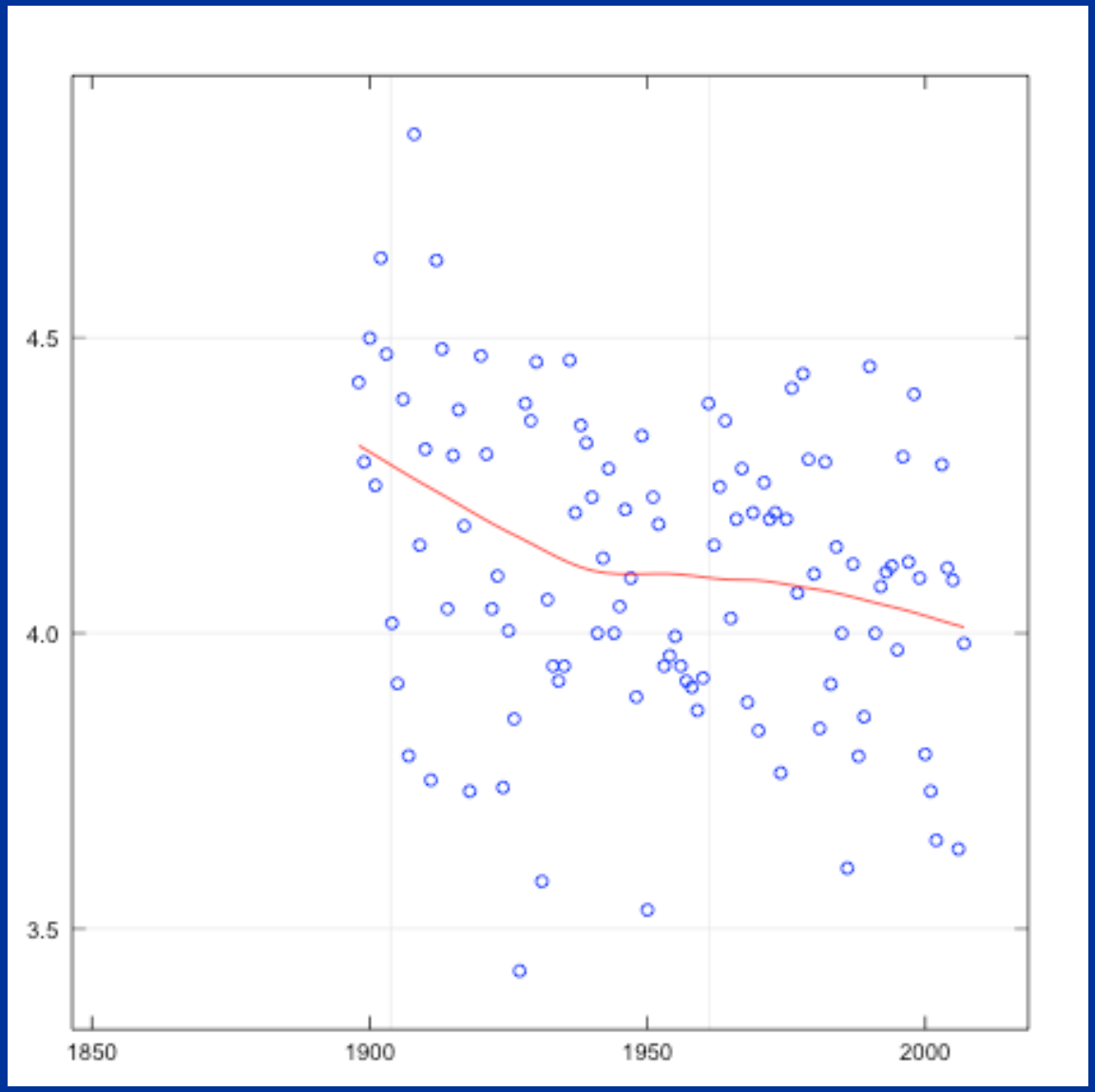


r = 0.12
p = 0.22

Water Year, including 2008

Log of Annual Peak Flood, Broad River above Carlton, GA

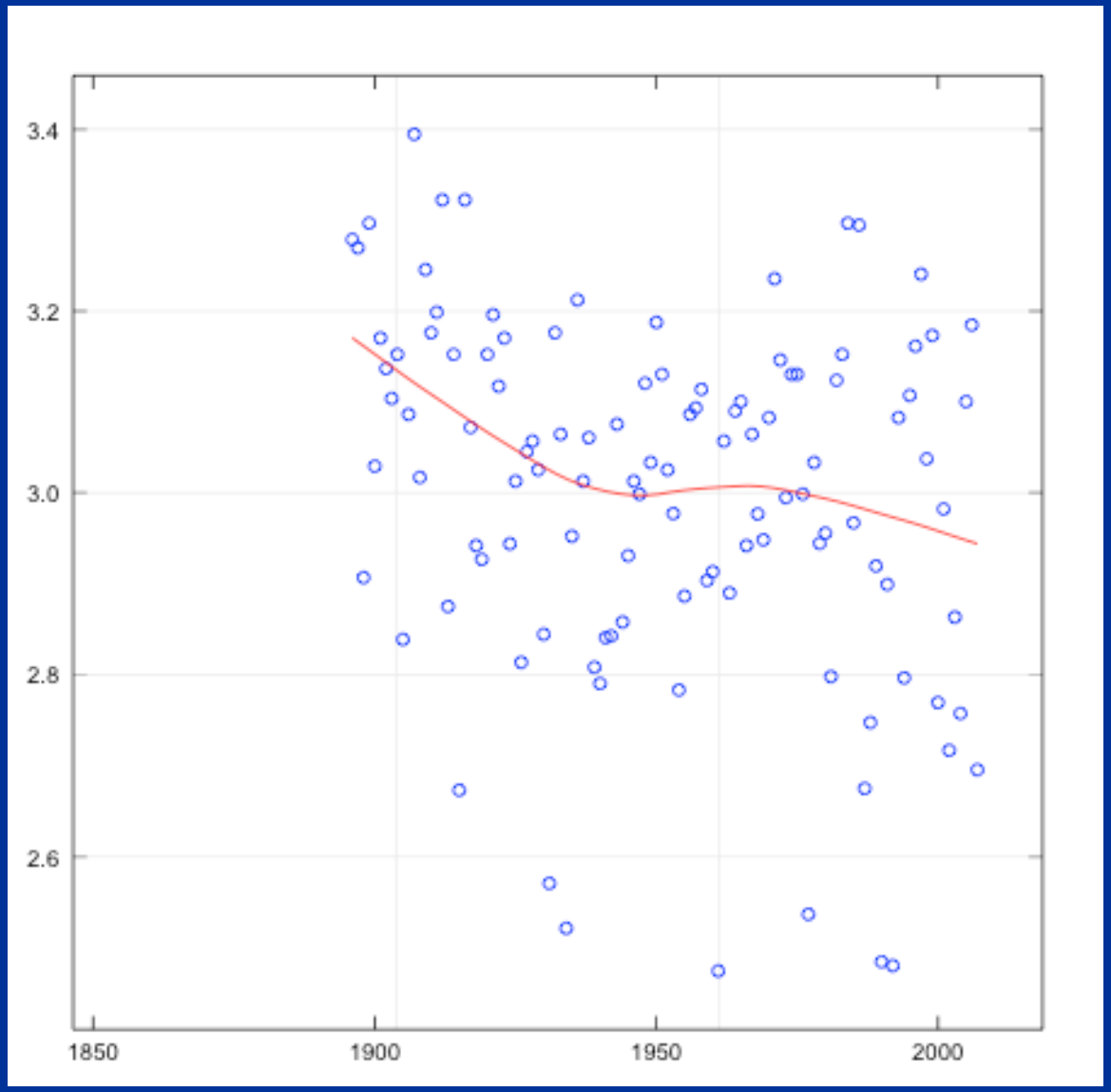
r = -0.26
p = 0.006



Water Year

Log of Annual Peak Flood, Logan River above State Dam, nr Logan UT

r = -0.27
p = 0.004



Water Year

Are floods correlated with Water Year?

	Negative	Positive
All sites	17	19
$\alpha = 0.1$	6	7
$\alpha = 0.05$	5	7
$\alpha = 0.01$	2	5
Which sites significant at $\alpha = 0.01$?	Broad (GA) Logan (UT)	Red Lake (MN) Red (MN/ND) Pembina (ND) Minnesota (MN) Arkansas (KS)

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What do I conclude from the body of work to date?

- At this time there is no scientific basis for revising flood frequency methods for climate change
- But, we need to keep analyses up-to-date – many of our flood and intense precipitation analyses are several decades old

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Now: Back to water resources planning in general

An approach to planning

- Pay attention to what is actually happening hydrologically
- The climate models will not provide quick answers
- Expect quasi-periodic shifts, unrelated to the “greenhouse”
- Expect to be surprised

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An approach to planning

Don't lose track of the other major change drivers

- **Ground water depletion**
- **Eco-flow requirements**
- **Nutrient enrichment**
- **Demographic/Economic/Energy changes**

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Let’s compare two global or continental scale environmental changes – both important to water resources

- Greenhouse gases in the atmosphere
- Nitrate in rivers and aquifers

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Atmospheric CO_2:

- Has increased 30% over the past century and still rising.
- It *may be* important to water supply and waste-water.
- Our ability to predict its impact on water is still highly uncertain.

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Nitrate in rivers: examples of change

- Mississippi River average nitrate concentrations near the mouth of the river have increased by about 200% over the 20th Century, from about 0.5 to 1.5 mg/L.
- Some tributaries of the Mississippi such as the Cedar River in Iowa or Minnesota River have increased as much as 800%.

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Nitrate in ground water: examples of change

Delmarva aerobic surficial aquifer, median rose from 8.8 to 11.4 mg/L (30%) 1988-2001.

•Eastern San Joaquin Valley, shallow ground water median concentrations rose from 1.8 in the 1950's to 6.4 in the 2000's (255% increase).

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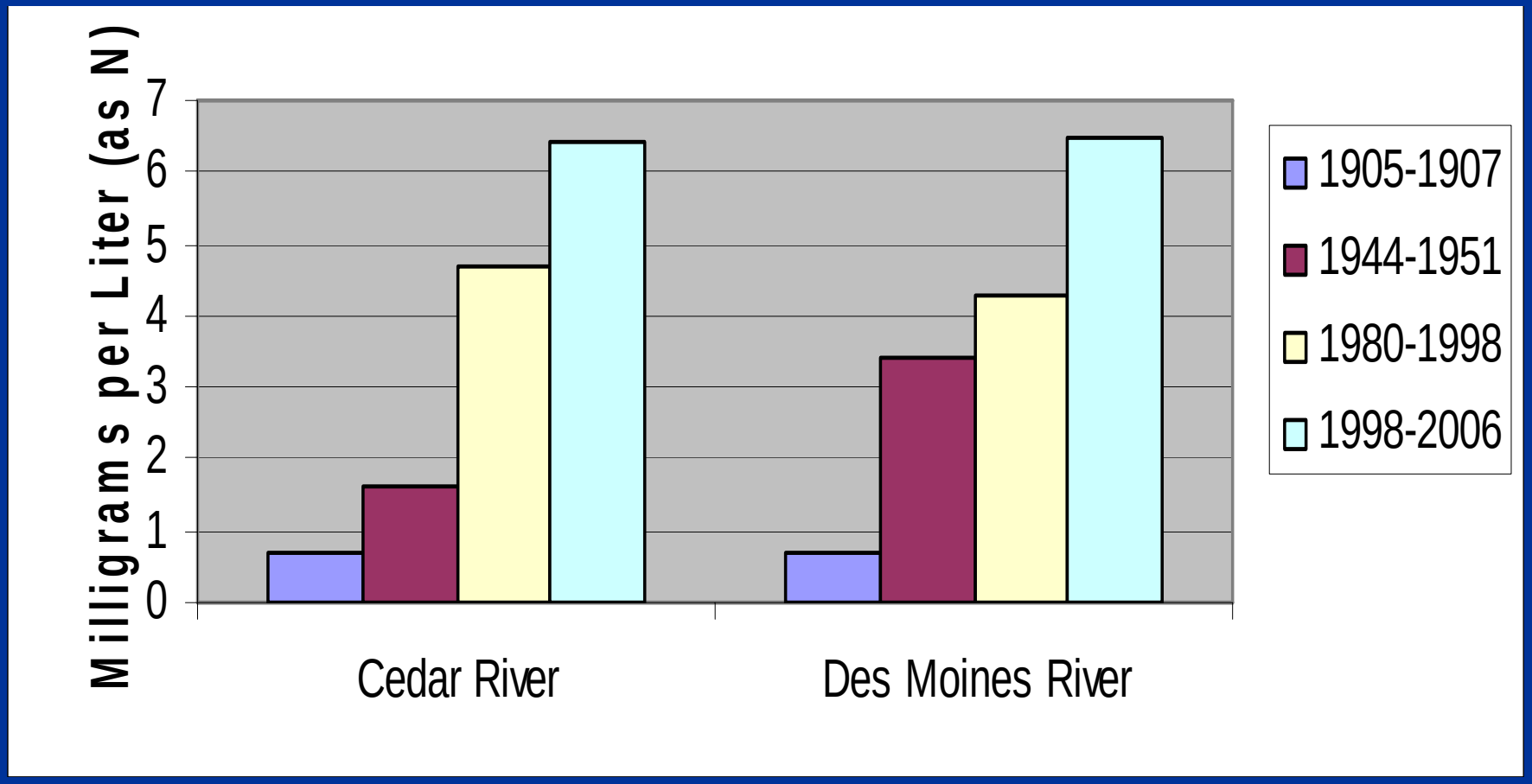
100-year Trends in Nitrate Concentrations in Two Iowa Streams



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* Graph courtesy of John North, Cedar Rapids Water Department, Retired

Nutrients: hypoxia and toxic blue-green algae blooms

Hans Paerl sampling cyanobacteria in Taihu Lake, China

Implications for water:

- Changes in the nitrogen cycle are large.
- Changes in the N cycle are important to human & environmental health.
- Fairly well understood and predictable.
- We need plans to mitigate and adapt to these changes. These plans have great importance to agriculture, energy, and water supply options.

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Ground-water depletion

- Reduced base flow in streams
- Elevated stream temperatures
- Salt-water intrusion
- Subsidence
- Depletion of drought buffer and water for future generations

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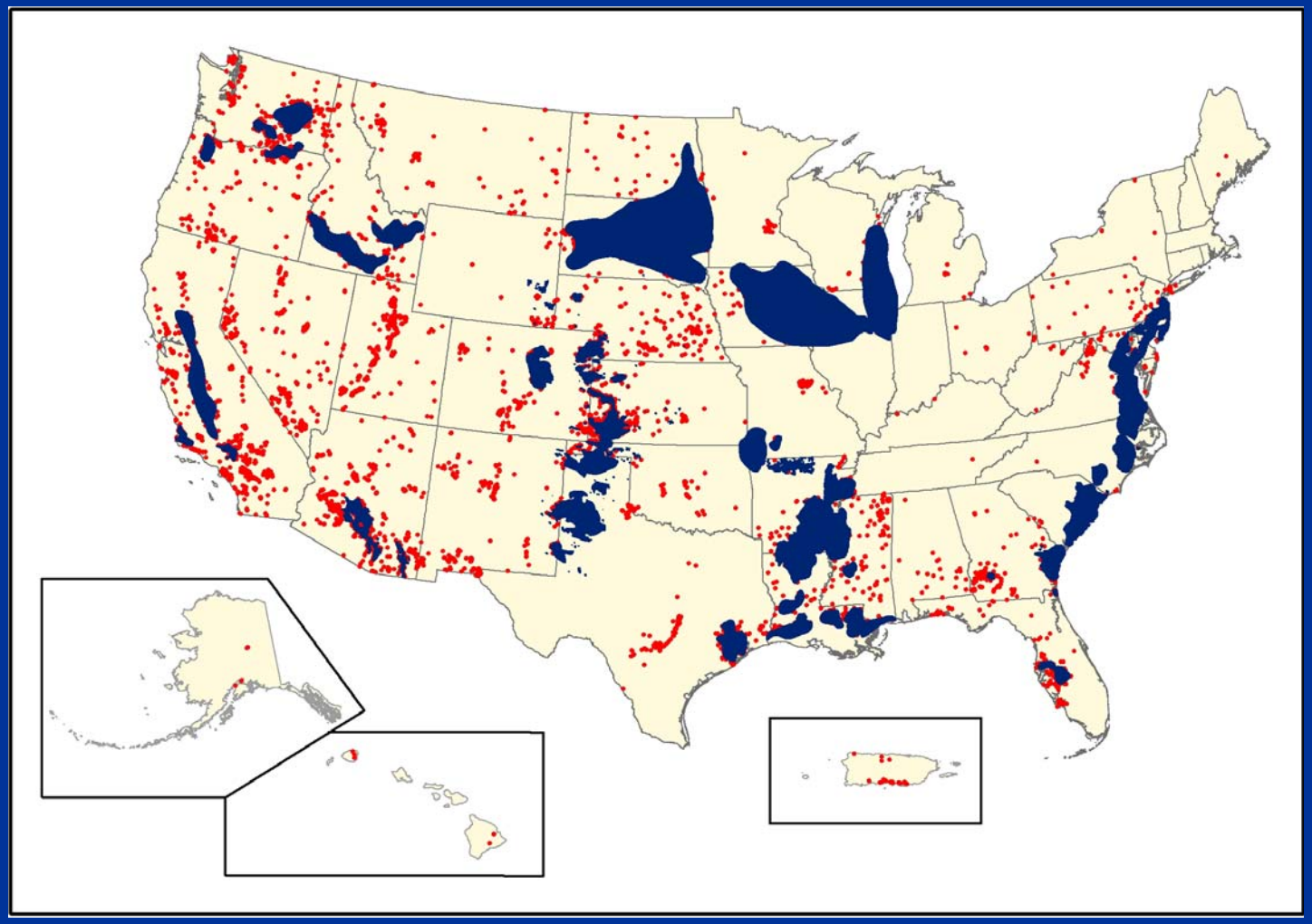
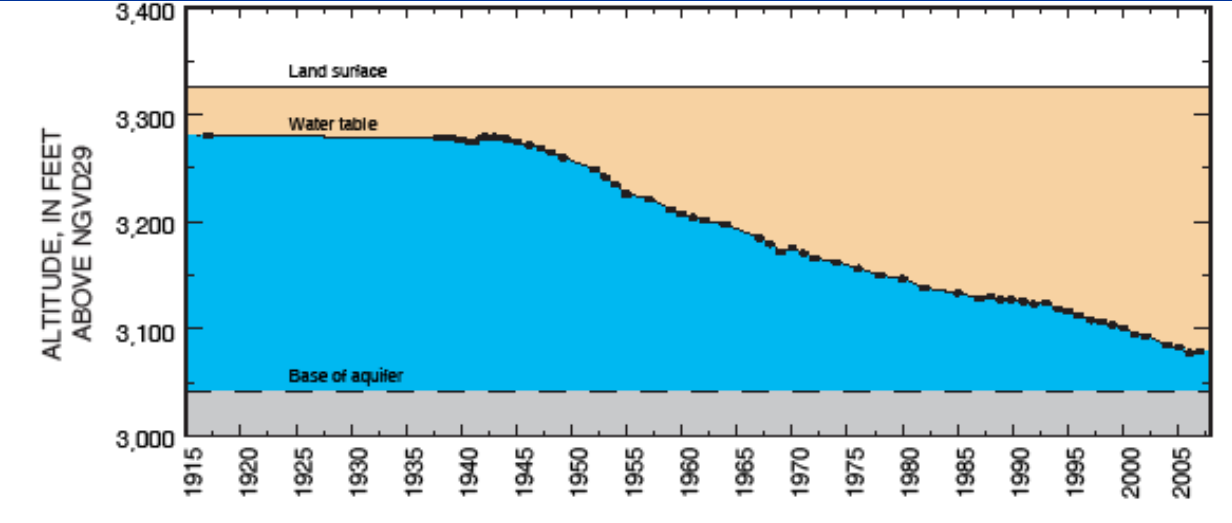
Areas of significant depletion: Declines of >40 ft



(Reilly and others; Circular 1323)

Ground-water depletion on the High Plains

Hale County, TX



A major hydrologic change awaits them in the next decade

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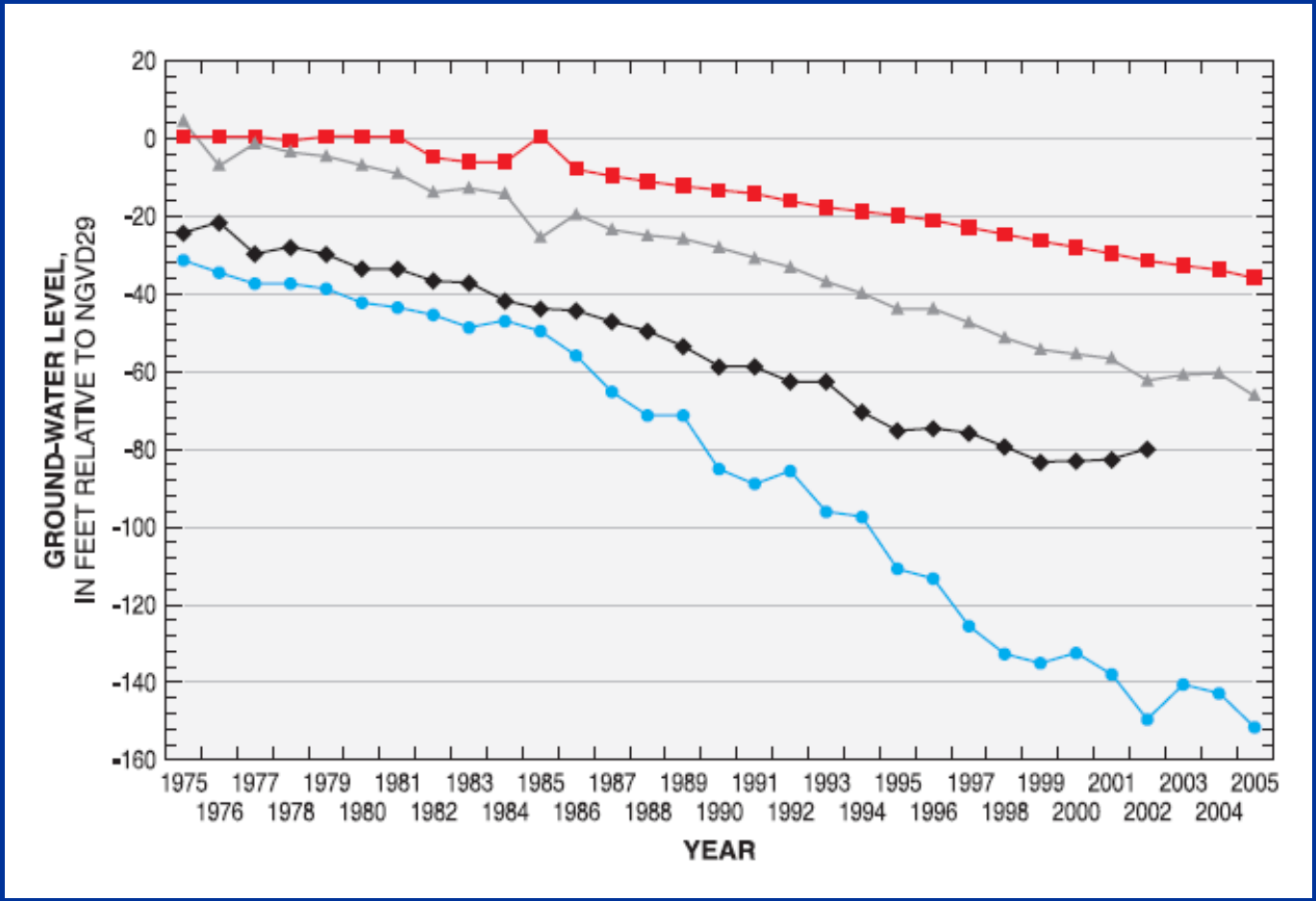
Ground-water depletion is not just a western issue: 4 wells in Calvert & St. Mary's County, Maryland – 1975-2005

Declines as much as 120 feet in 30 years



From:
USGS SIR 2007-5249

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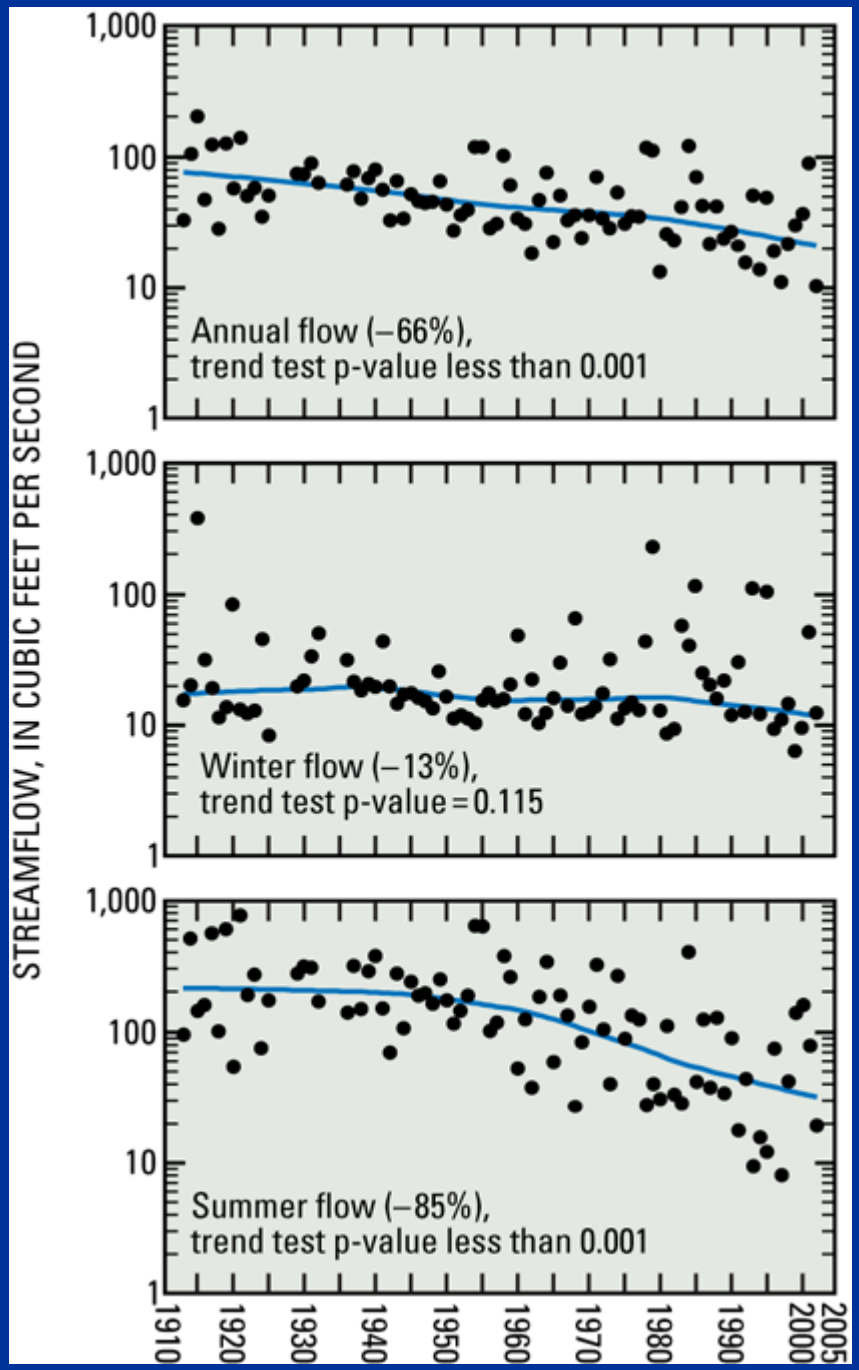
San Pedro River at Charleston, AZ 1913-2002, trends in streamflow

Primary driver is ground-water drawdown



From Blakemore Thomas, USGS Fact Sheet 2006-3004,

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Importance of measurements

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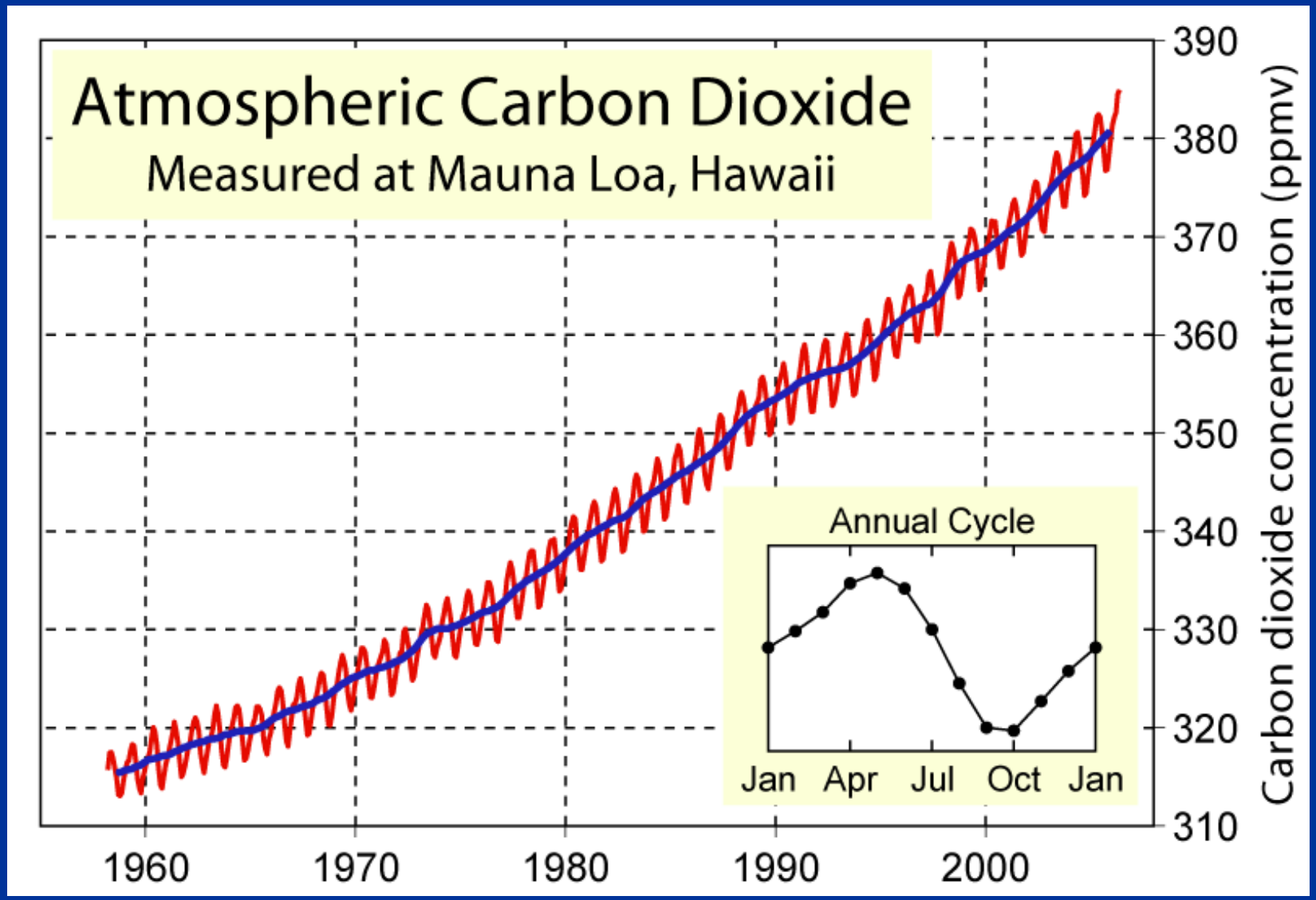
“Recording the Earth’s Vital Signs”



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Science, 2008, p. 1771-1772, Ralph F. Keeling

From Ralph Keeling

A continuing challenge to long-term Earth observations is the prejudice against science that is not directly aimed at hypothesis testing.

At a time when the planet is being propelled by human action …. We cannot afford such a rigid view of the scientific enterprise.

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From Ralph Keeling

The only way to figure out what is happening to our planet is to measure it,

and this means tracking changes decade after decade

and poring over the records.

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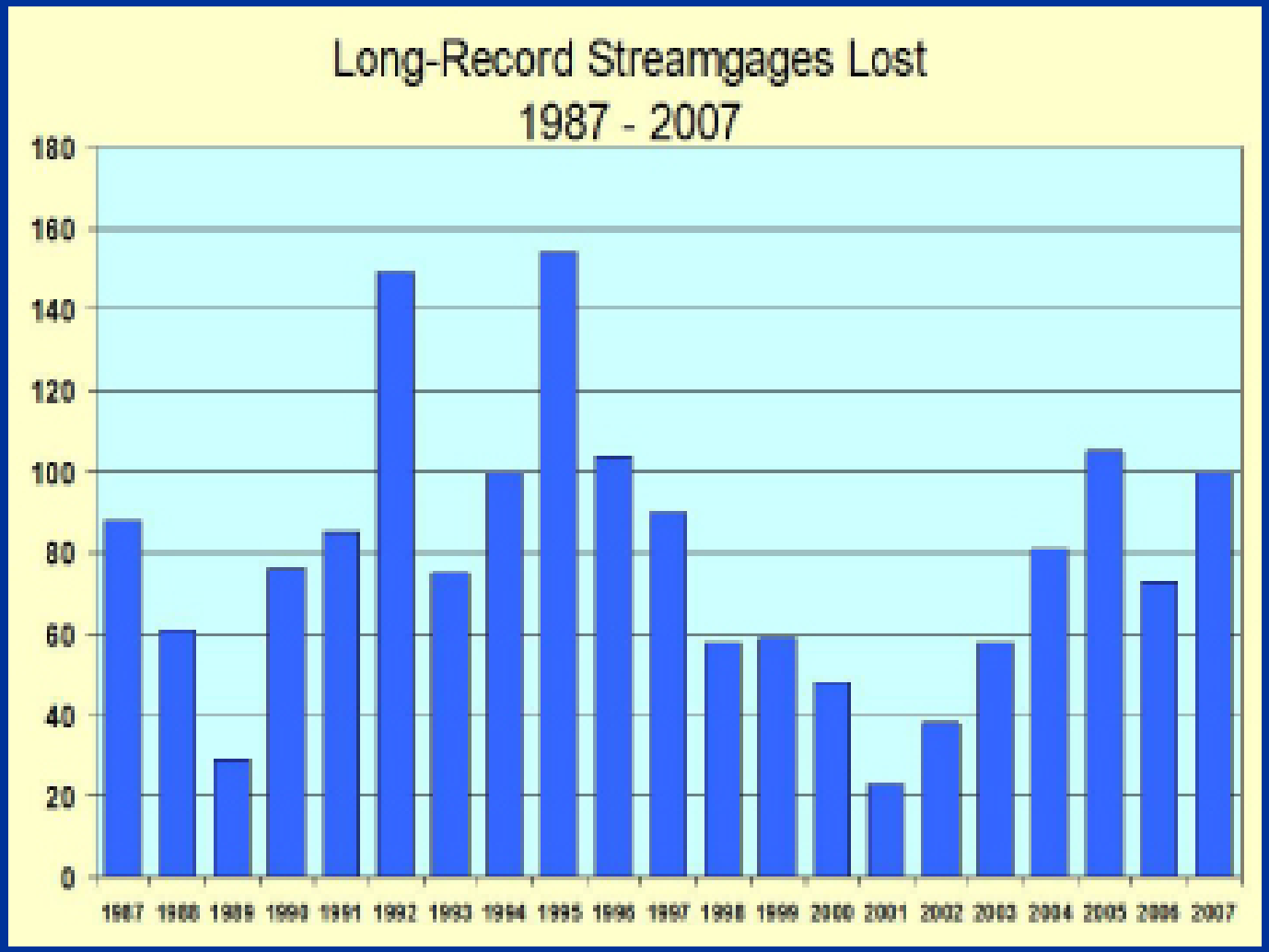
Losses of important scientific assets: streamgages with more than 30 years of record

100 of them shut down in 2007



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Streamgage losses

- Looking at the Pacific Northwest for example.
- At the end of 1979 we had 317 streamgages operating which started in 1930 or before.
- Today, we have 220 of those still operating. A loss of 97 (31%).

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Two emerging schools of thought among the water management community

- Search for “actionable science”
- “Adapt to uncertainty”

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“We Need Actionable Science”

“Data analysis, and forecasts that are sufficiently predictive, accepted, and understandable to support decision-making, including capital investment decision making”

David Behar, San Francisco Public Utilities Commission & Staff Chair of Water Utility Climate Alliance

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“We Need Actionable Science”

“Water managers should take the initiative to clearly communicate their needs for applied science to the climate research community, and must seek opportunities to guide hydroclimate research in directions that will support real-world problem solving”

Western Governors’ Association

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“We Need Actionable Science”

“In order to be actionable, an issue has to be well-defined, and climate change is not…

There is insufficient coordination among the various groups conducting the studies….

If we are to achieve the level of predictability necessary to spur action by the conservative water industry, the research simply must improve.”

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Patricia Mulroy, “Diving in the Deep End”

Seven Steps to Adaptation to Climatic Uncertainty

1. Deny Uncertainty
2. Debate Uncertainty
3. Investigate Uncertainty
4. Attempt to Reduce Uncertainty
5. Accept Uncertainty
6. Plan for Uncertainty
7. Adapt to Uncertainty

Marc Waage, Denver Water & Water Utility Climate Alliance

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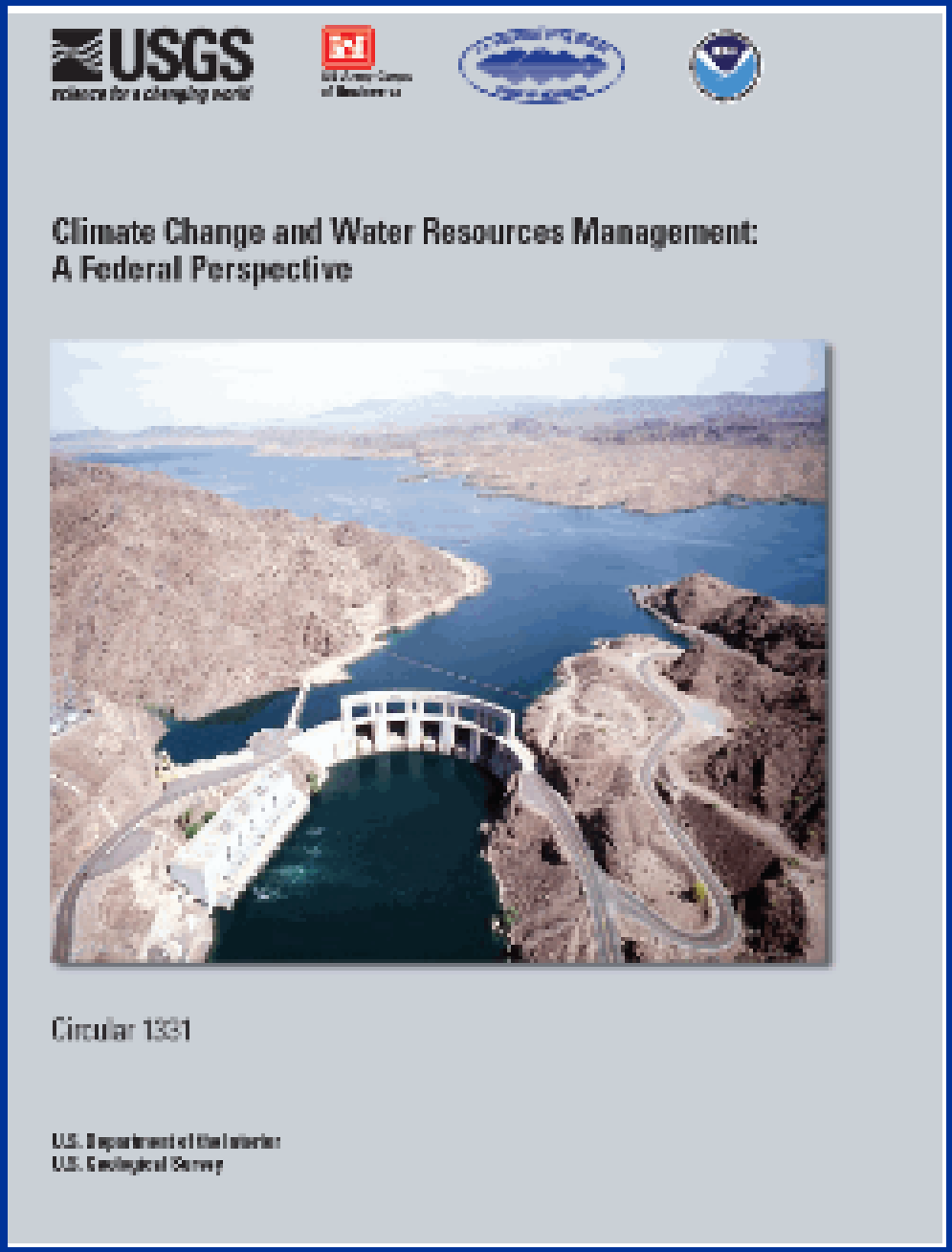
New contribution from 4 federal agencies



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Final thoughts

- Keep monitoring
- Explore the data
- Be prepared for surprises
- Adapt to uncertainty, it won’t go away
- Consider all of the sources of uncertainty
- Focus on flexibility and regional collaboration

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