Formulating an Engineering Response to the Effects Global Climate Change for Design of Hydraulic Structures and Flood Protection Works

Presented at IAFSM March 11, 2010

Eric Loucks, PhD, PE, D.WRE, AECOM

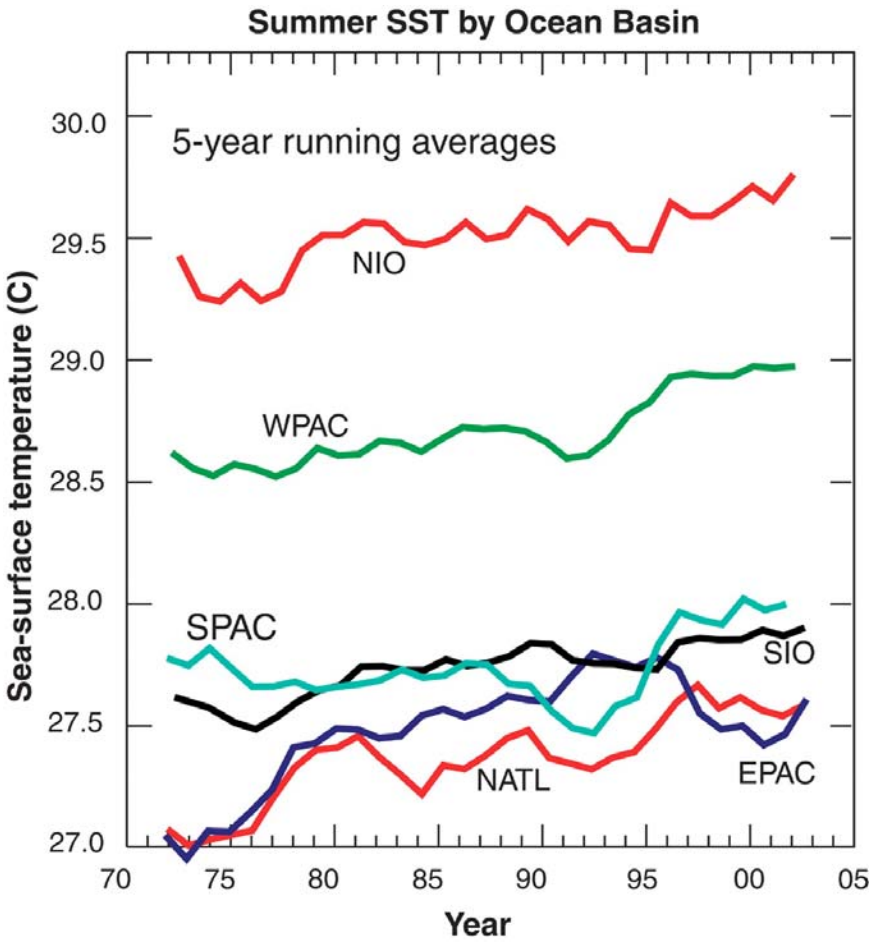
AECOM

Summary

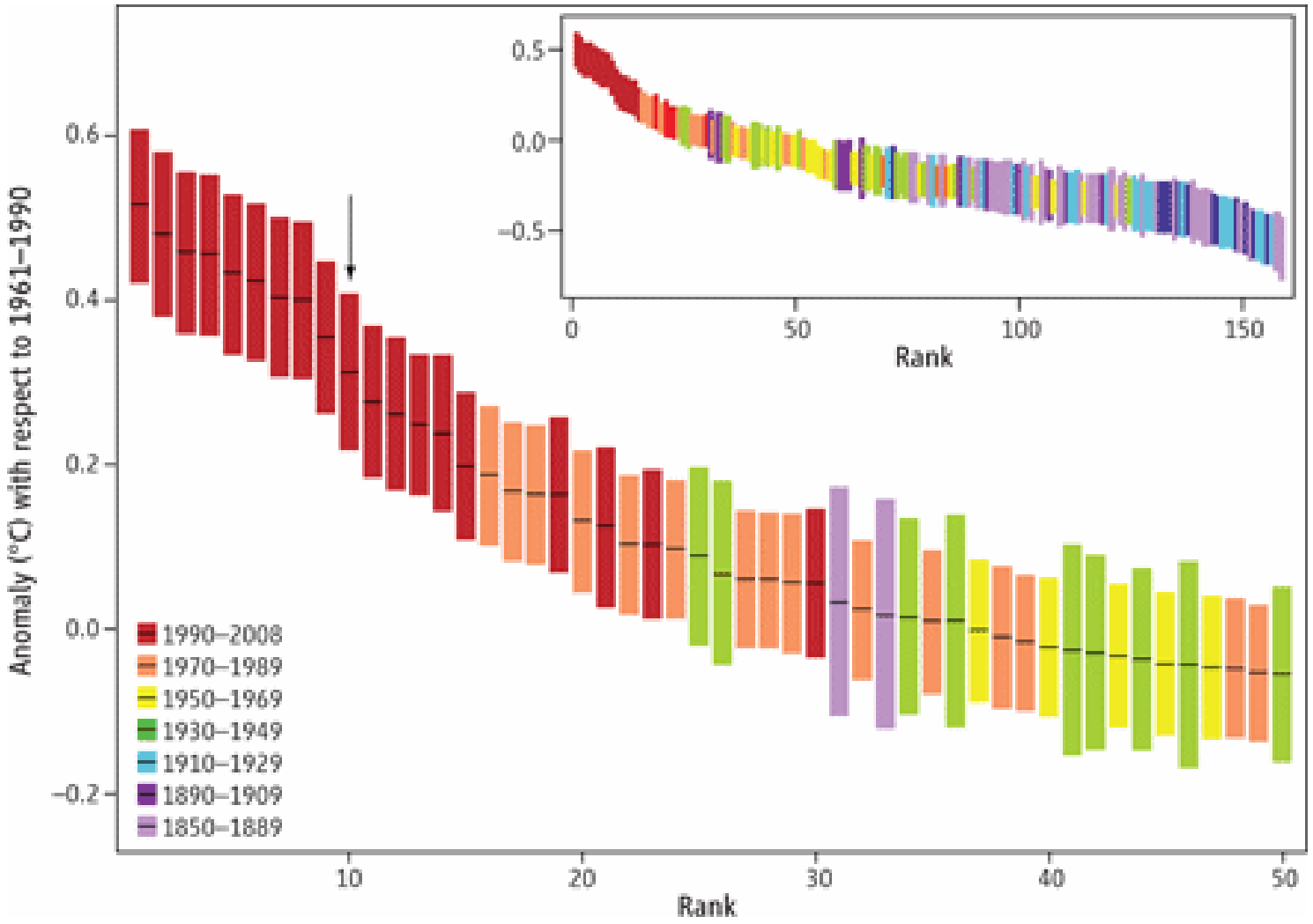
- Climate Change
- Effect on Flood Frequency
- A few Anecdotes
- What Now?

P. J. Webster et al., Science 309, 1844 -1846 (2005)

- The Earth's Atmosphere and Oceans are Warming



J. J. McCarthy Science 326, 1646-1655 (2009)



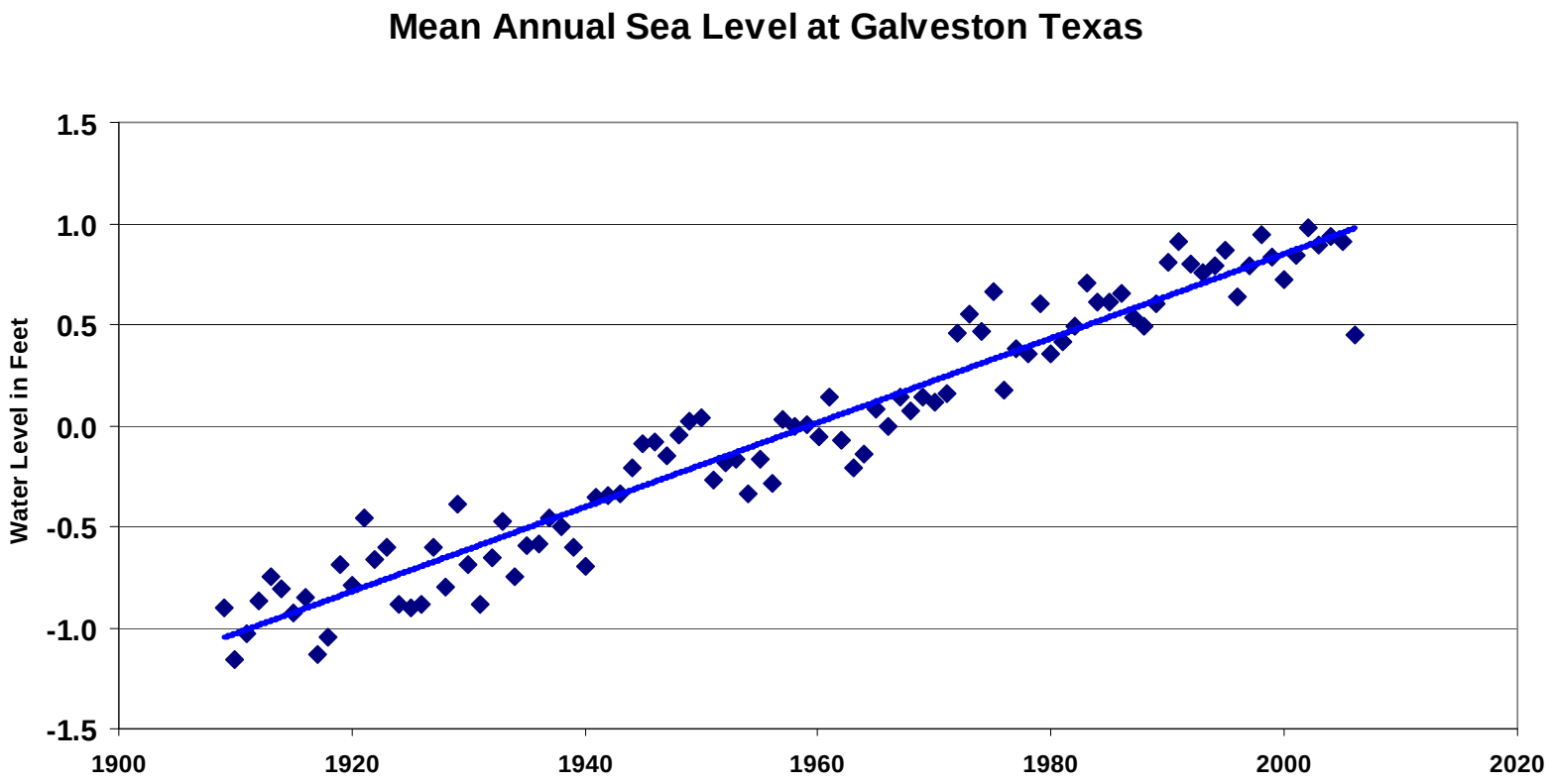
Science
AAAS

AECOM

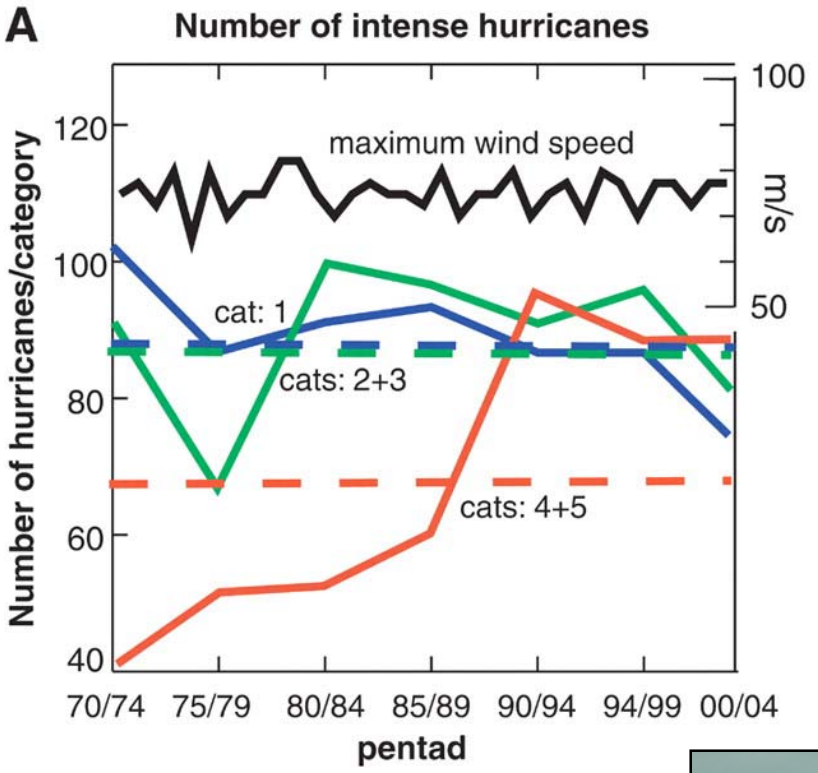
Defining Climate Change

- Air Temperatures are Up
- Ocean Temperatures are Up
- All kinds of other effects
  - Animal Migrations
  - Extinctions
  - Lake freeze/thaw
  - Rainfall Patterns
  - Storm Intensity
  - Sea Level Rise

Sea Level is Rising



P. J. Webster et al., Science 309, 1844 -1846 (2005)



Science
AAAS

AECOM

Hurricane Frequency is Increasing

- Or not

Report: Tropical cyclone activity at 30-year low

USA Today 11/12/08

By Oren Dorell
USA TODAY

The past two years have seen a "remarkable" downturn in hurricane activity, contradicting predictions of more storms, researchers at Florida State University say.

The 2007 and 2008 hurricane seasons had the least tropical activity in the Northern Hemisphere in 30 years, according to Ryan Maue, co-author of a report on Global Tropical Cyclone Activity.

"Even though North Atlantic hurricane activity was expectedly above normal, the Western and Eastern Pacific basins have produced considerably fewer than normal typhoons and hurricanes," he said.

Maue's results dovetail with other research suggesting hurricanes are variable and unconnected to global warming predictions, said Stan Goldenberg, a hurricane researcher with the National Oceanic and Atmospheric Administration.

"The simplistic notion that warmer oceans from global warming automatically lead to more frequent and or stronger hurricanes has not been verified," said Goldenberg, whose research points to periods of high and low hurricane activity that last several decades each.

Maue used a measurement called Accumulated Cyclone Energy (ACE), which combines a storm's duration and its wind speed in six-hour intervals. The years 2007 and 2008 had among the lowest ACE measurements since reliable global satellite data was first available three decades ago.

Northern Hemisphere activity in 2006 was close to average, and the previous two years, 2004 and 2005, which included Hurricanes Katrina and Rita, saw among the highest numbers on record.

Active seasons in one ocean tend to be accompanied by quiet ones in the other, Maue said. When the Pacific is cooler, as it is now, the Atlantic has slower winds aloft, which creates more favorable conditions for hurricanes.

"It tells you that from year to year you have large swings of activity," said Maue, who plans to present his work next month at a meeting of the American Geophysical Union in San Francisco. "If you want to find a global warming signal in all that data it's generally going to be rather small."

Kevin Trenberth, a lead author of the 2007 Intergovernmental Panel on Climate Change assessment, was among several climatologists who made such claims. He said in 2004 that the intense hurricane season that year was "a harbinger of the future." His prediction prompted the resignation from the panel of Chris Landsea, science and operations officer at NOAA's National Hurricane Center, who said there was no basis to make such a prediction.

Trenberth said in response to the latest study that hurricanes can be measured in different ways and by some measures activity is high. "What we expect on a theoretical basis is for duration to increase as well as size ... but there could be fewer storms," Trenberth said.

This year's North Atlantic hurricane season set some records, according to Weather Underground, a forecasting site. Tropical Storm Bertha never made landfall but its 13-day run was a record for the month of July. Tropical Storm Fay in August made landfall in Florida a record four times, and ranked among the four top rainmakers since record keeping began in 1950.

Defining Climate Change

- Given Warmer Atmosphere and Oceans
- Hydrologic Cycle is accelerated
- More water exists in vapor phase
- More precipitable moisture
- More Rain in places where it rains now
- More heavy rain?

Science Vol 319, p. 573, 1 February 2008

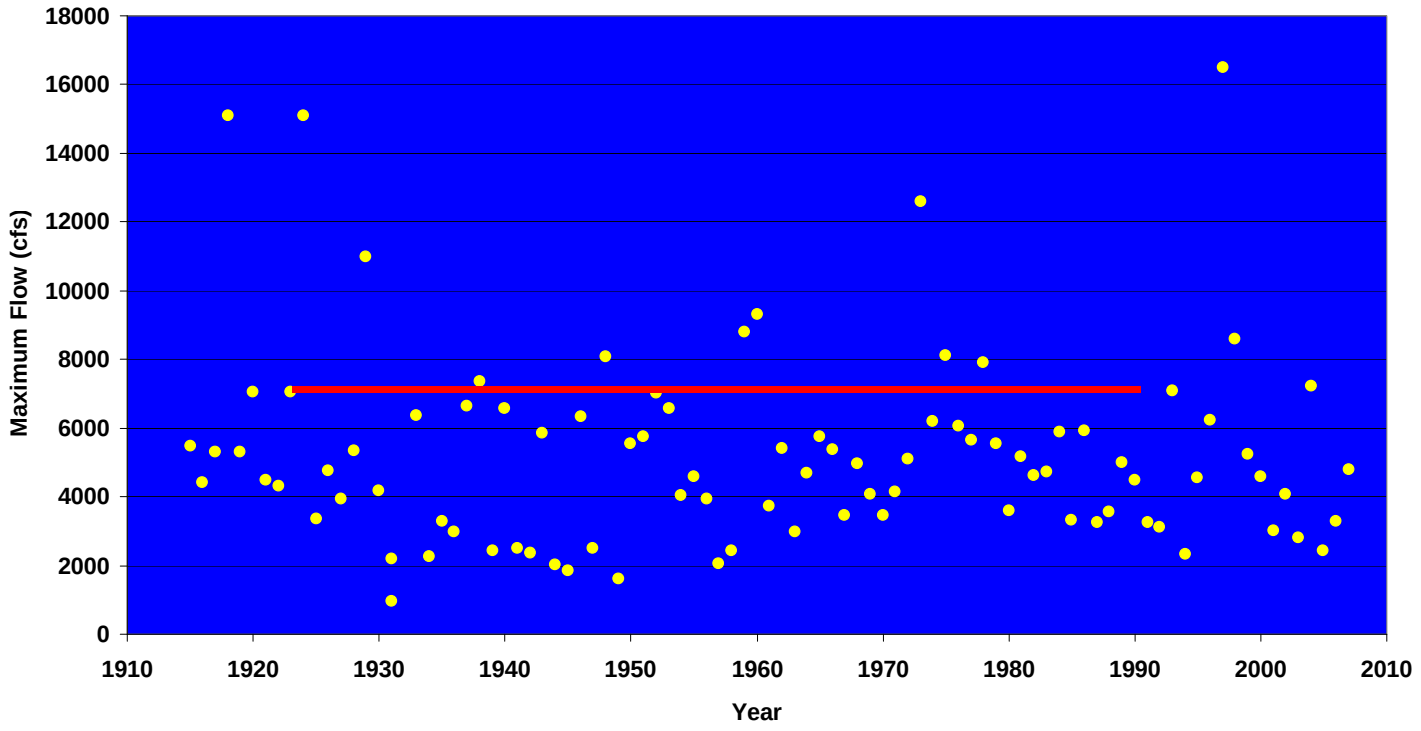
CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

P. C. D. Milly,[1]* Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

What does Stationarity mean?

Stationarity is a consistency of a time series over time. At a minimum, fixed Mean and Variance. Like here on the Milwaukee River



Definition of Stationarity

- A random process y=f(x) is strict-sense stationary if the joint distribution of any set of samples does not depend on the sample's placement. Consequently, first order cumulative distribution functions, e.g., mean and variance, of y are constant. Furthermore, second order cumulative distribution functions (such as autocorrelation and autocovariance) depend only on the distance in placement, x1-x2. For example, a Gaussian process is strict-sense stationary since it is completely specified by its mean and covariance function.
- If the mean is constant and the autocovariance is a function that depends only on the distance in placement, then we call the data wide-sense stationary or simply stationary. Strict-sense stationary implies wide-sense stationary.

Why is it important?

Flood frequency/ flood risk is usually expressed by:

$$Q_n = m_q + K_n s_q$$

Q_n = n-year flood quantile

m_q = mean annual flood

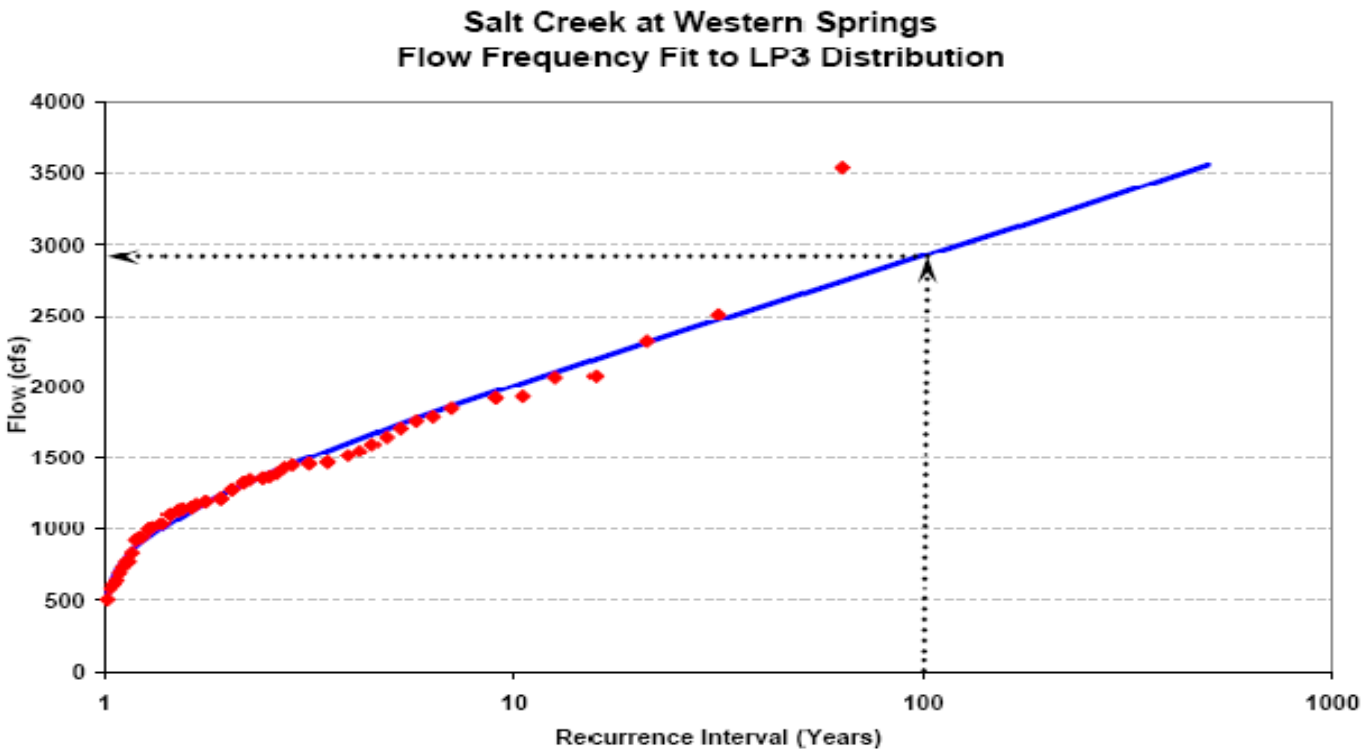
s_q = standard deviation

K = factor based on distribution

Procedure assumes Stationary annual floods

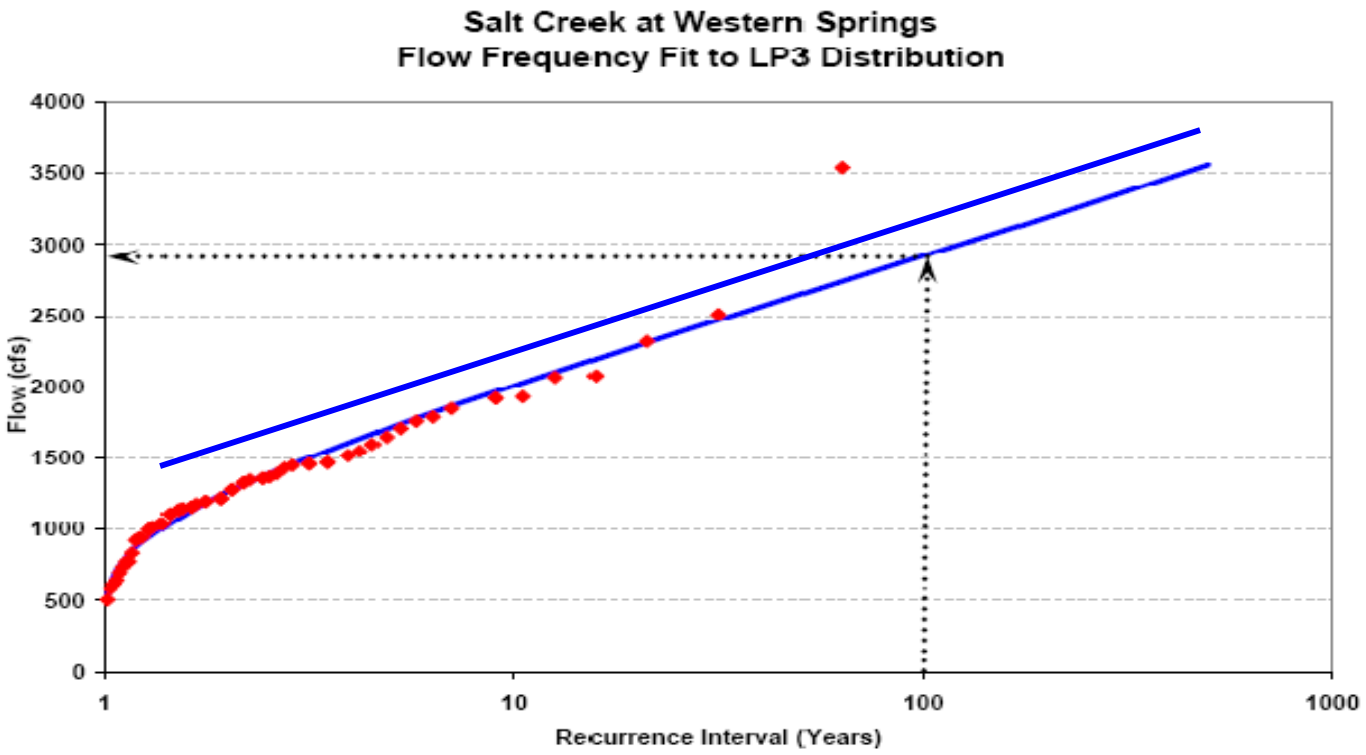
AECOM

Traditional FFA



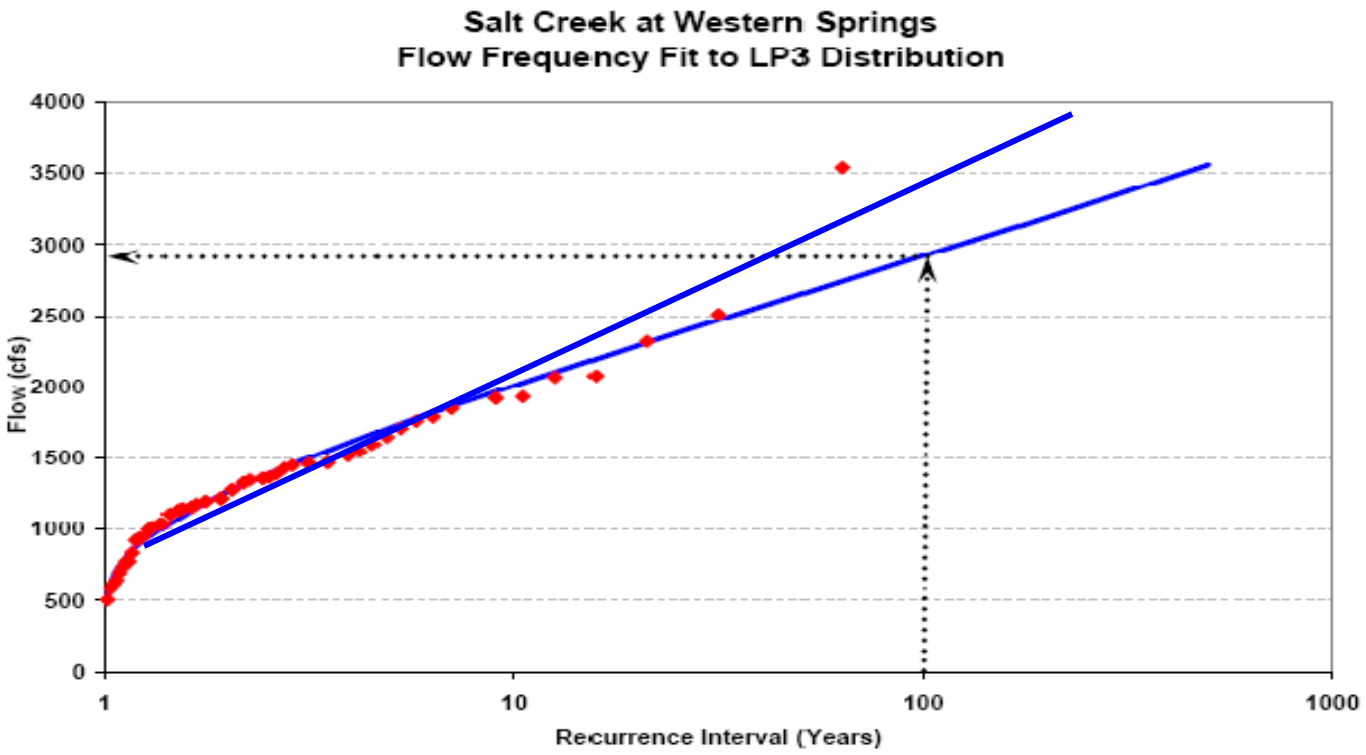
AECOM

Change in Mean



AECOM

Increase in Variance



AECOM

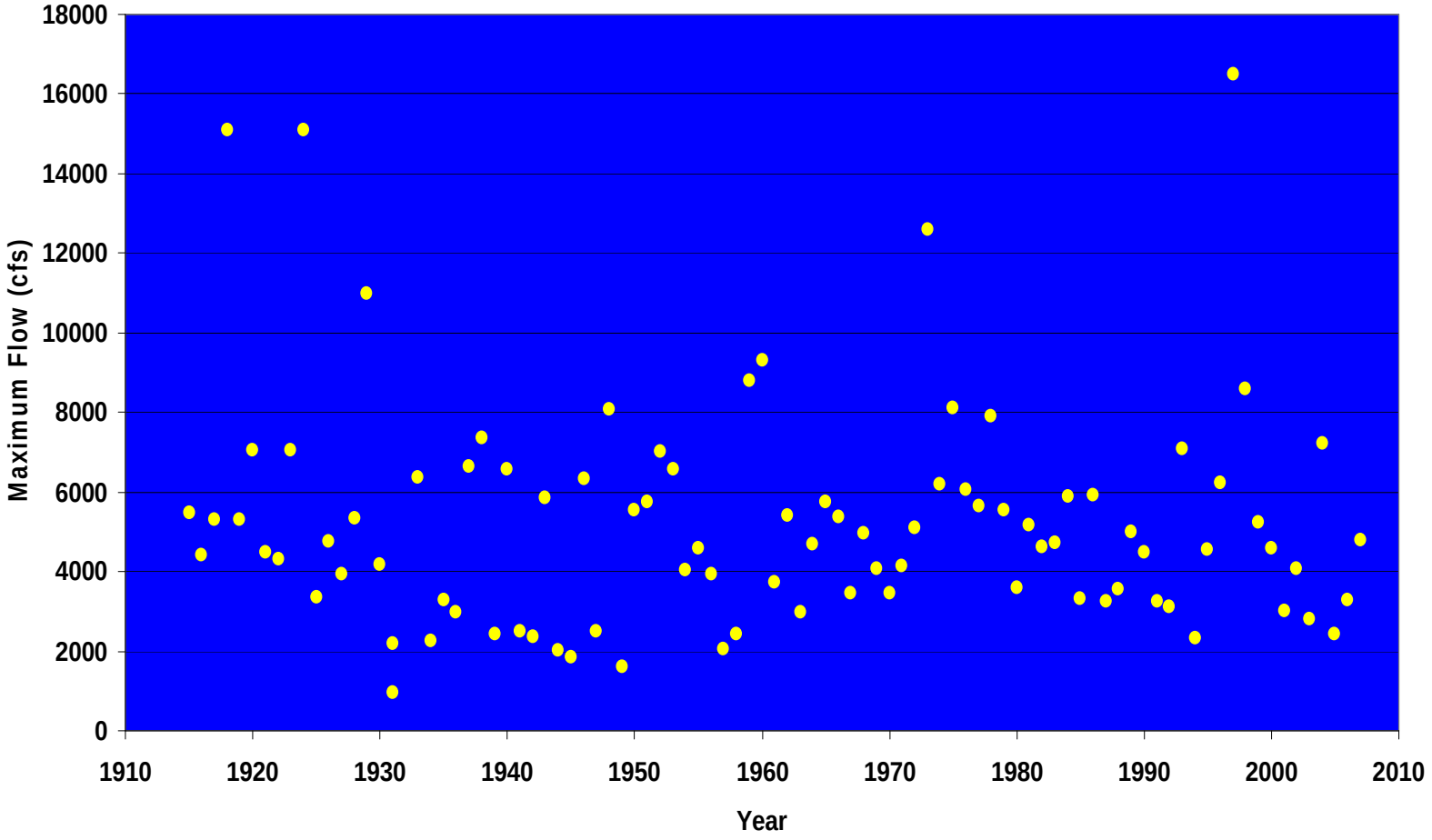
Flood Estimates: How Good Are They?
Ray K. Linsley, *Water Resources Research* 22:9, August 1986

TABLE 1. Effect of Error in Estimated Flood Peaks on Estimated Return Period of a Flood

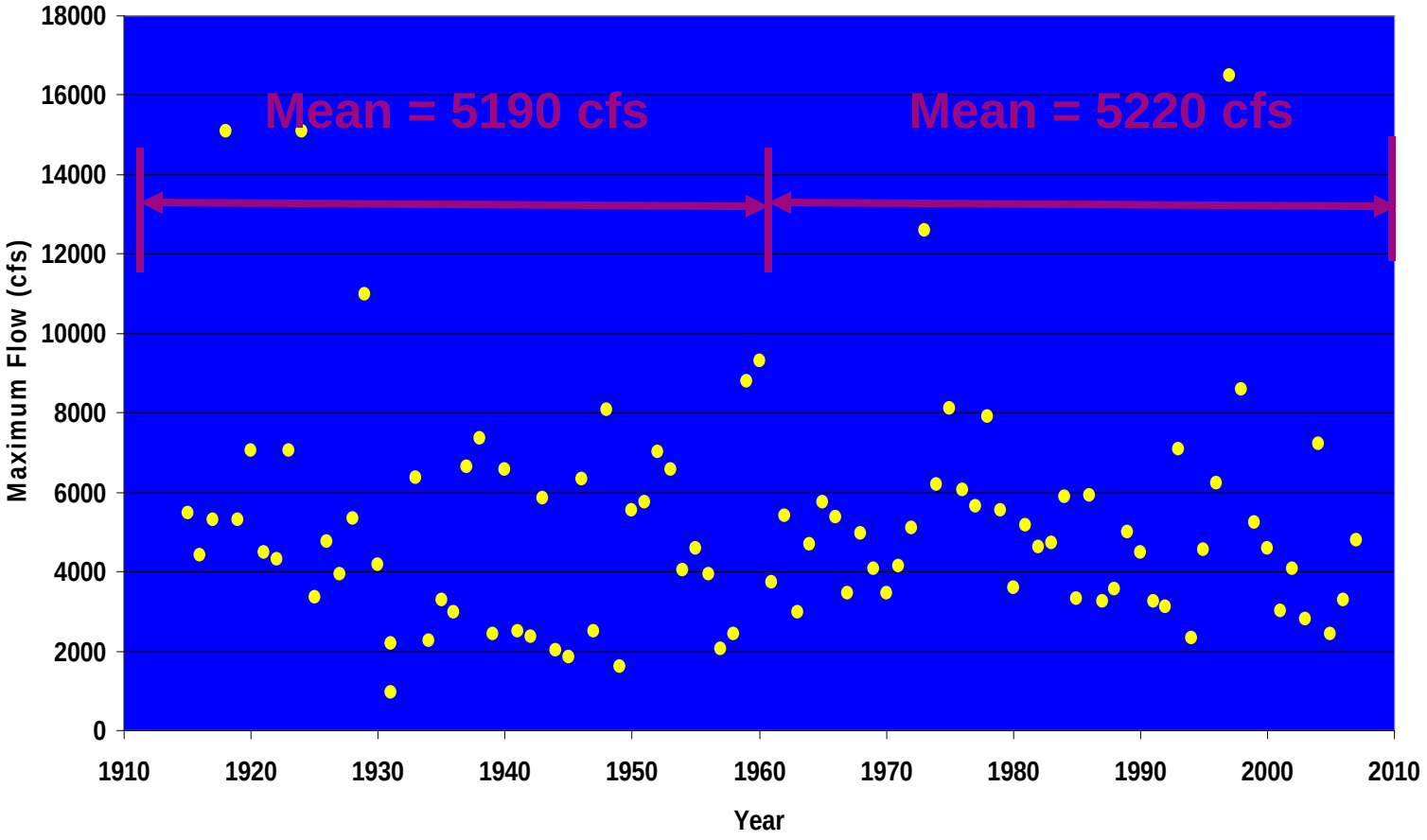
Error of Peak Flow, %	Actual Return Period, years		
	10-Year Intended Return Period	50-Year Intended Return Period	100-Year Intended Return Period
+40	52	520	1000+
+30	34	325	670
+20	24	120	240
+10	19	95	190
−10	7	23	30
−20	5	15	25
−30	3	9	13
−40	2	5	7

Table assumes extreme value distribution and a coefficient of variation of 0.5.

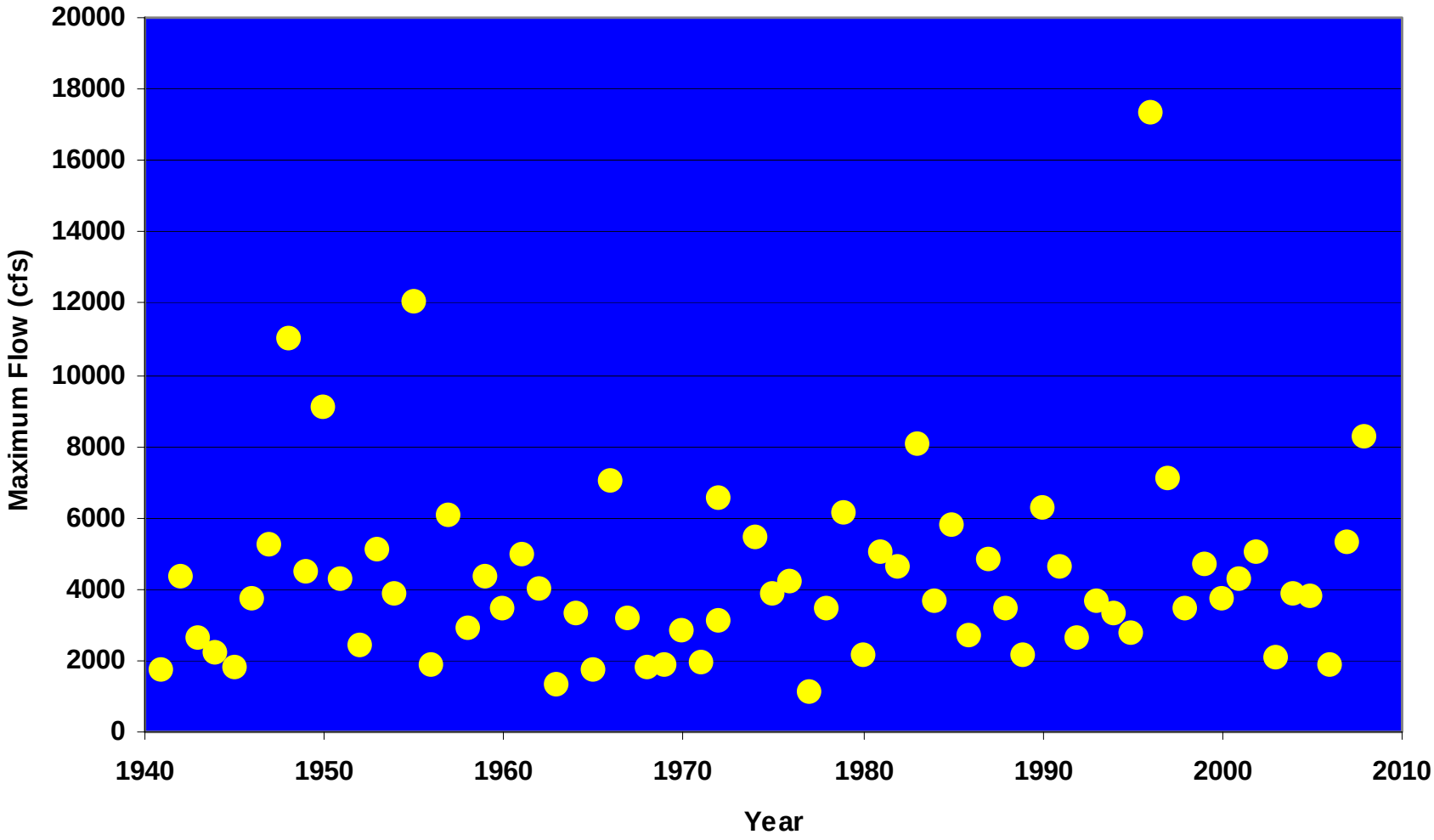
Milwaukee River at Milwaukee
Historical Annual Floods 1915-2007



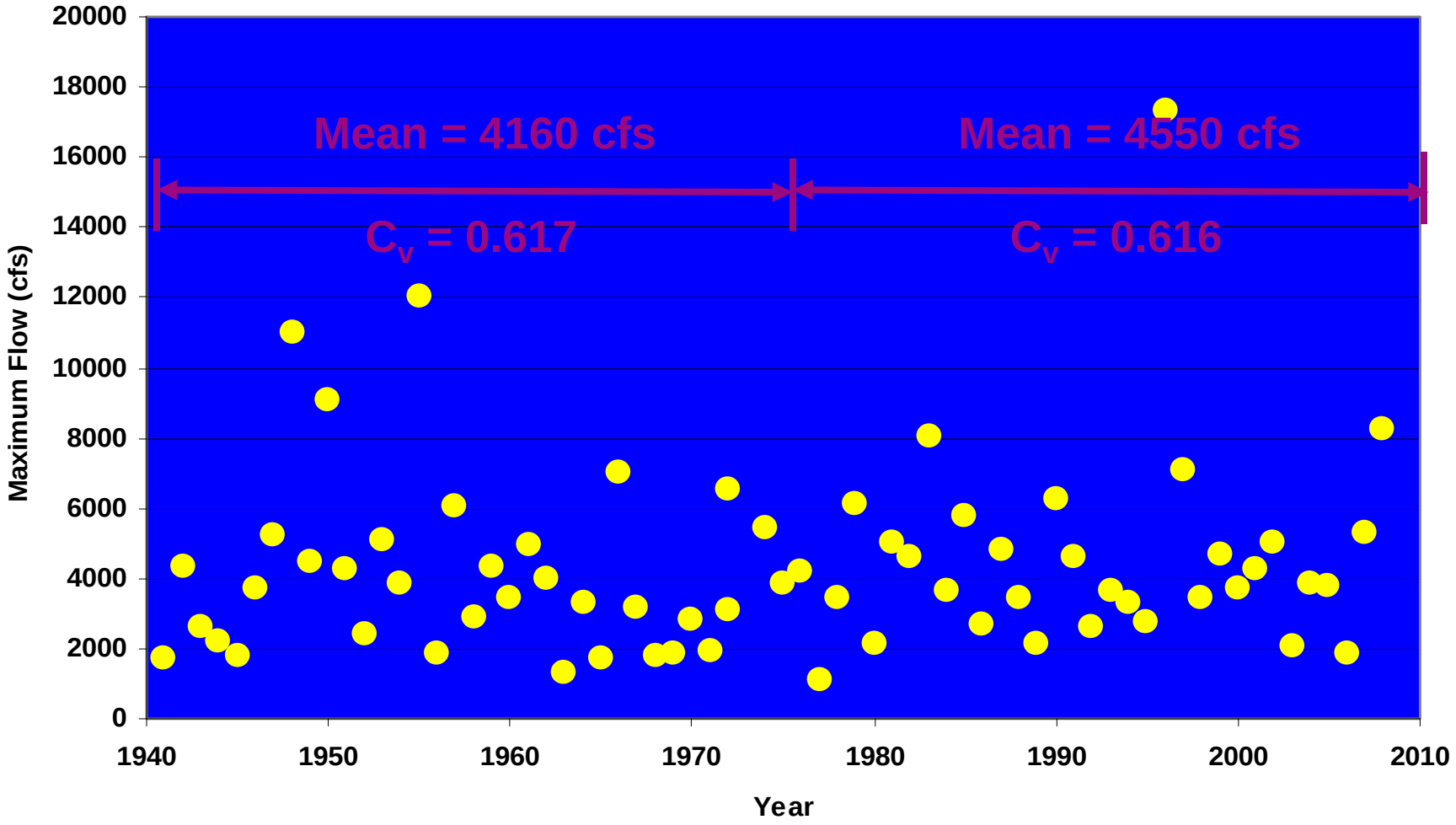
Milwaukee River at Milwaukee
Historical Annual Floods 1915-2007



DuPage River at Shorewood
Historical Annual Floods 1941-2008

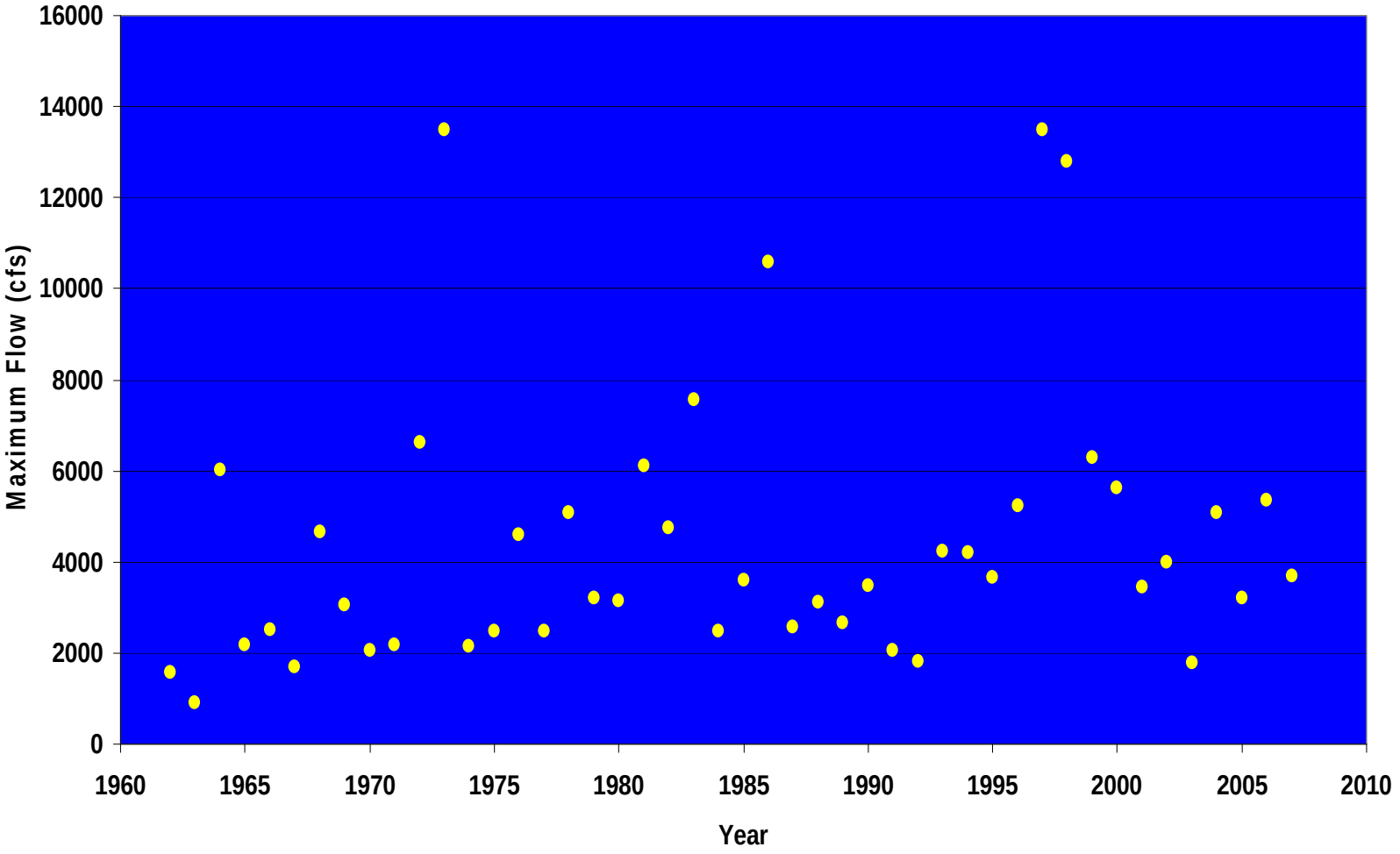


DuPage River at Shorewood
Historical Annual Floods 1941-2008

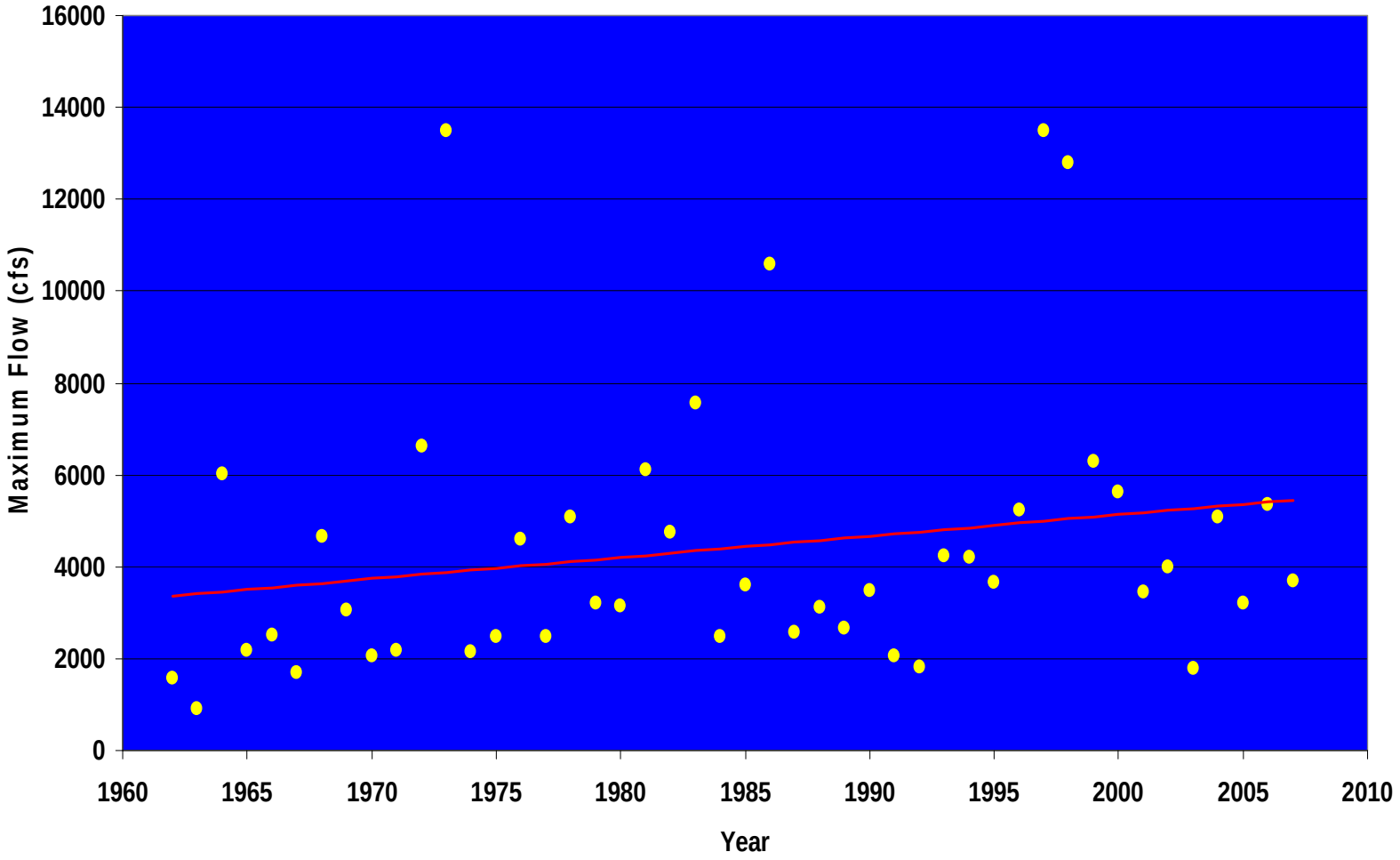


AECOM

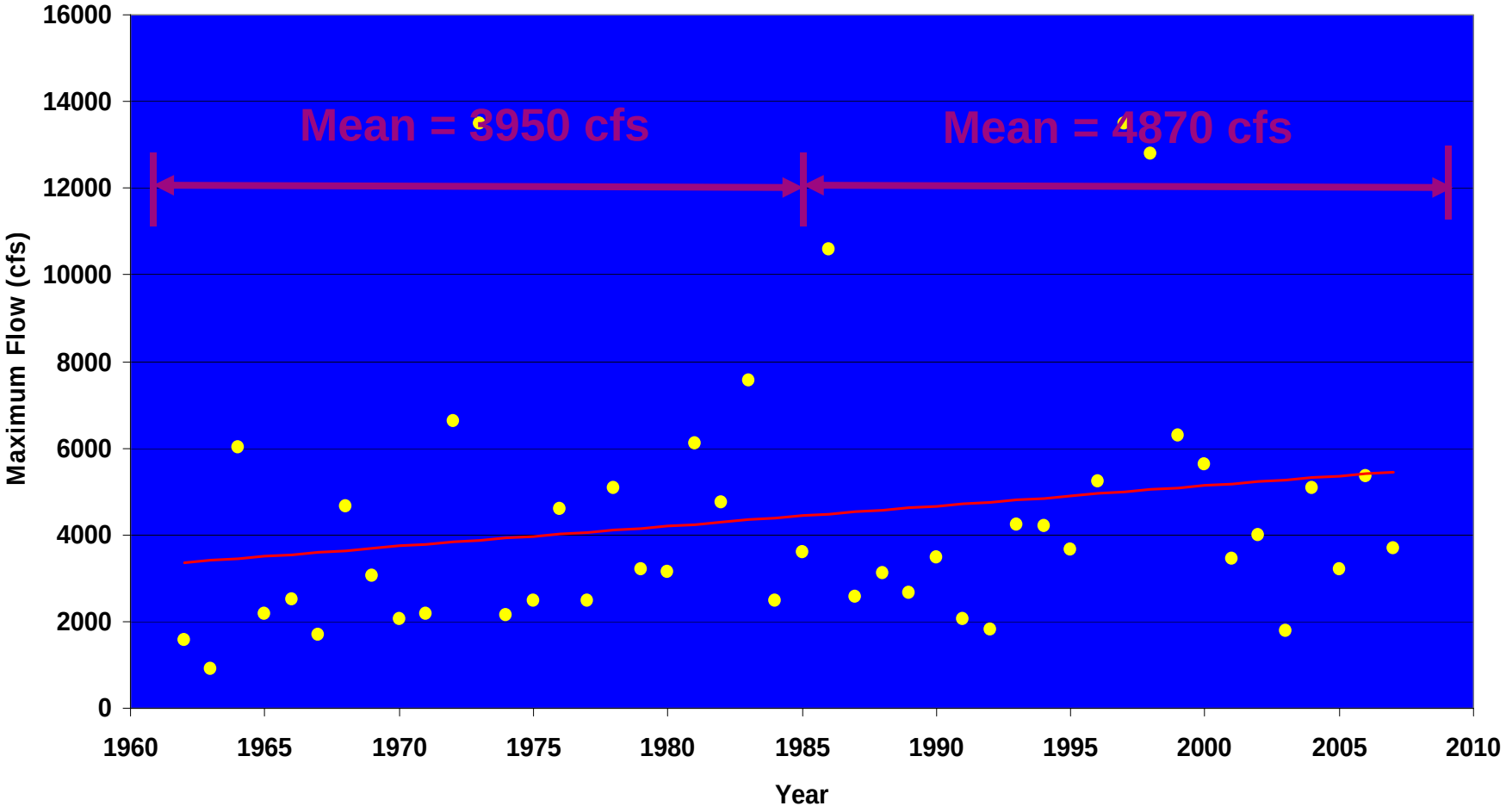
Menomonee River at Milwaukee
Historical Annual Floods 1962-2007



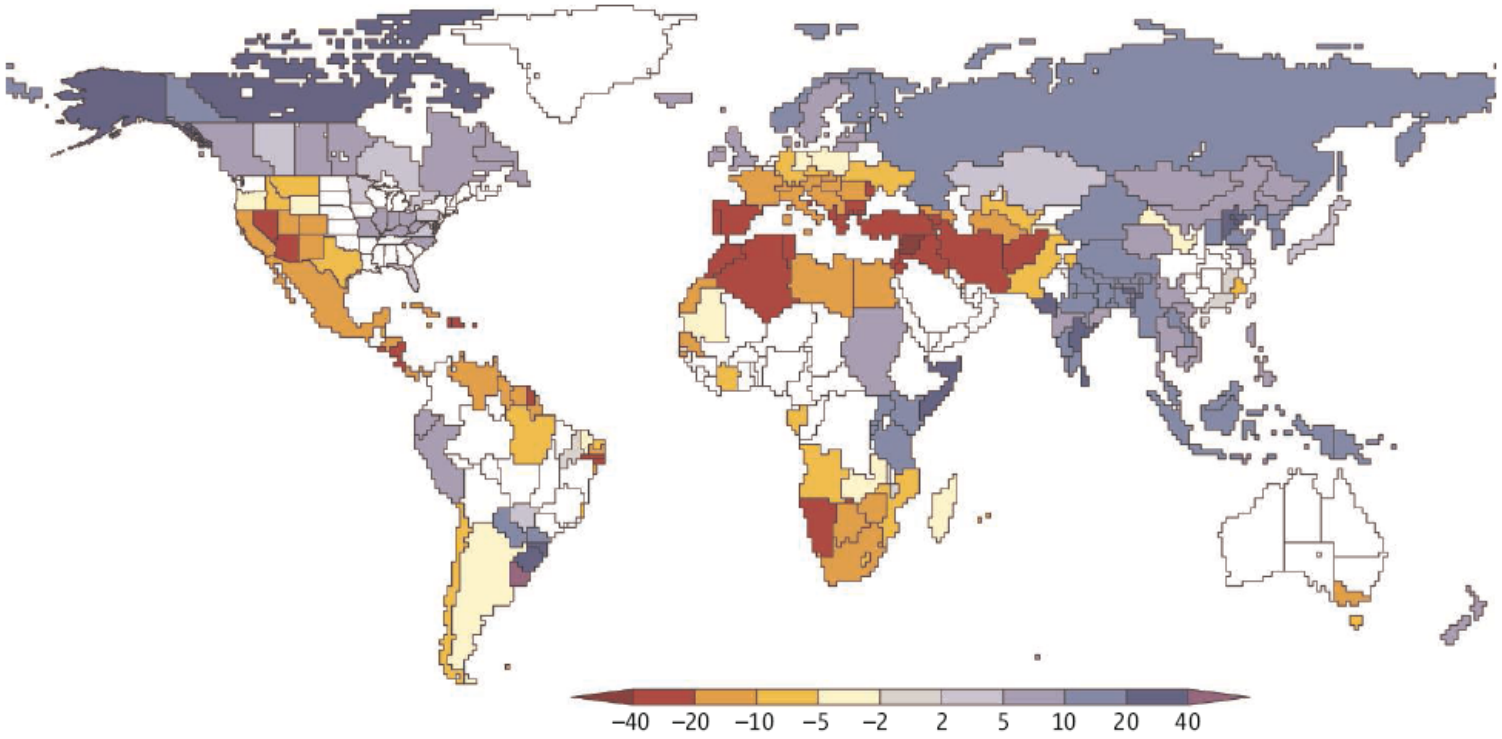
Menomonee River at Milwaukee
Historical Annual Floods 1962-2007



Menomonee River at Milwaukee Historical Annual Floods 1962-2007



Quantifying Climate Change – Use GCMs?



From “Stationarity is Dead” by Milly et al. 2008

Quantifying Climate Change – Use GCMs?

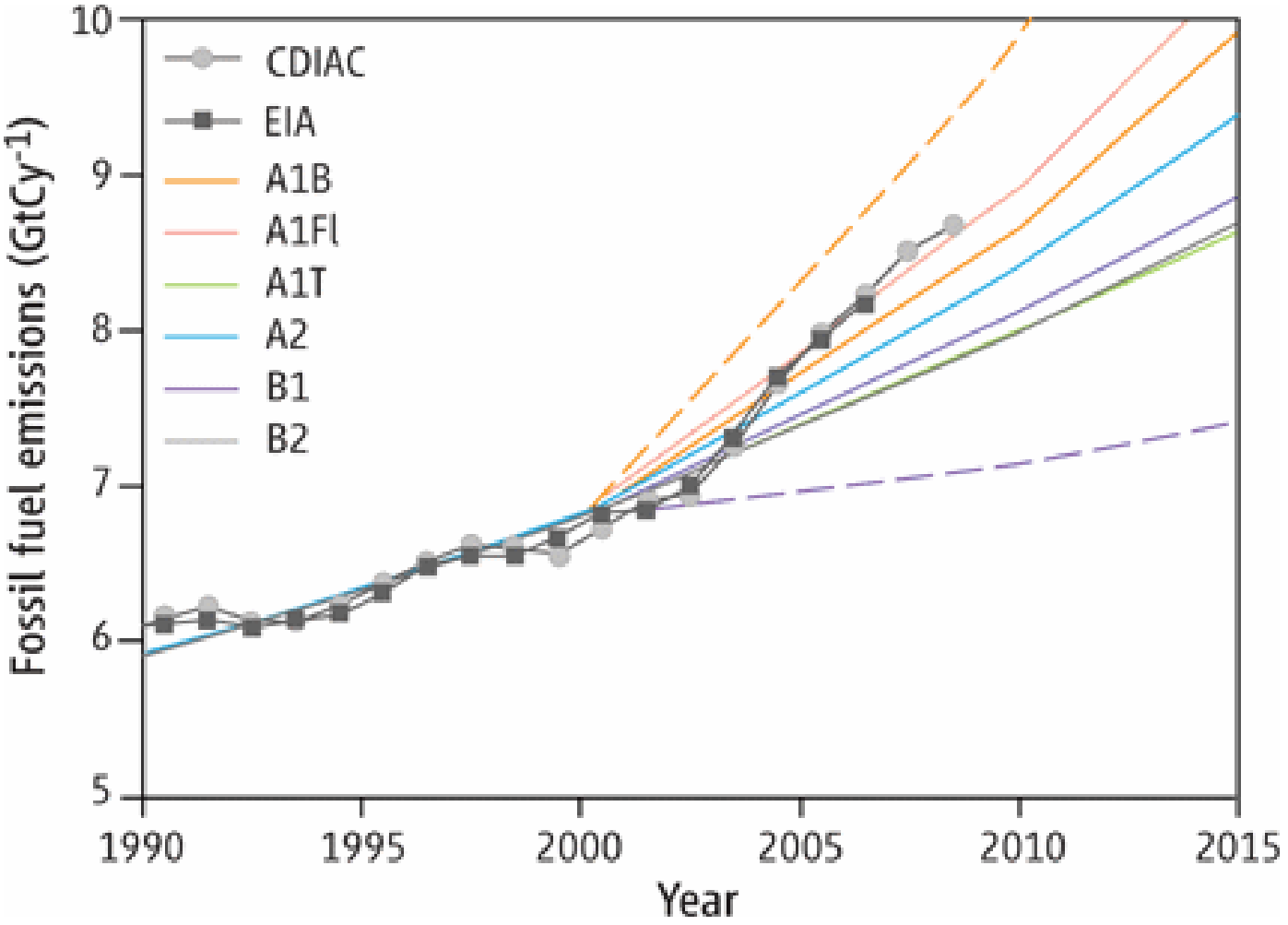
- Global Climate Models (GCM)
  - Choice of Model
  - Choice of Scenario

	MODEL	PERIOD	TYPE	ΔLEVEL
1	GISS	$2XCO_2$	E	-4.30
2	GFDL	$2XCO_2$	E	-8.13
3	OSU	$2XCO_2$	E	-3.25
4	CCC1	$2XCO_2$	E	-5.31
5	MOTR2	2020	T	-4.59
6	CCTR2	2020	T	-2.95
7	GFTR2	2020	T	-1.31
8	HCTR2	2020	T	-1.64
9	CGCM1	2030	T	-2.36
10	HadCM2	2030	T	+0.16
11	CGCM1	2090	T	-4.53
12	HadCM2	2090	T	+0.16

E: Equilibrium model

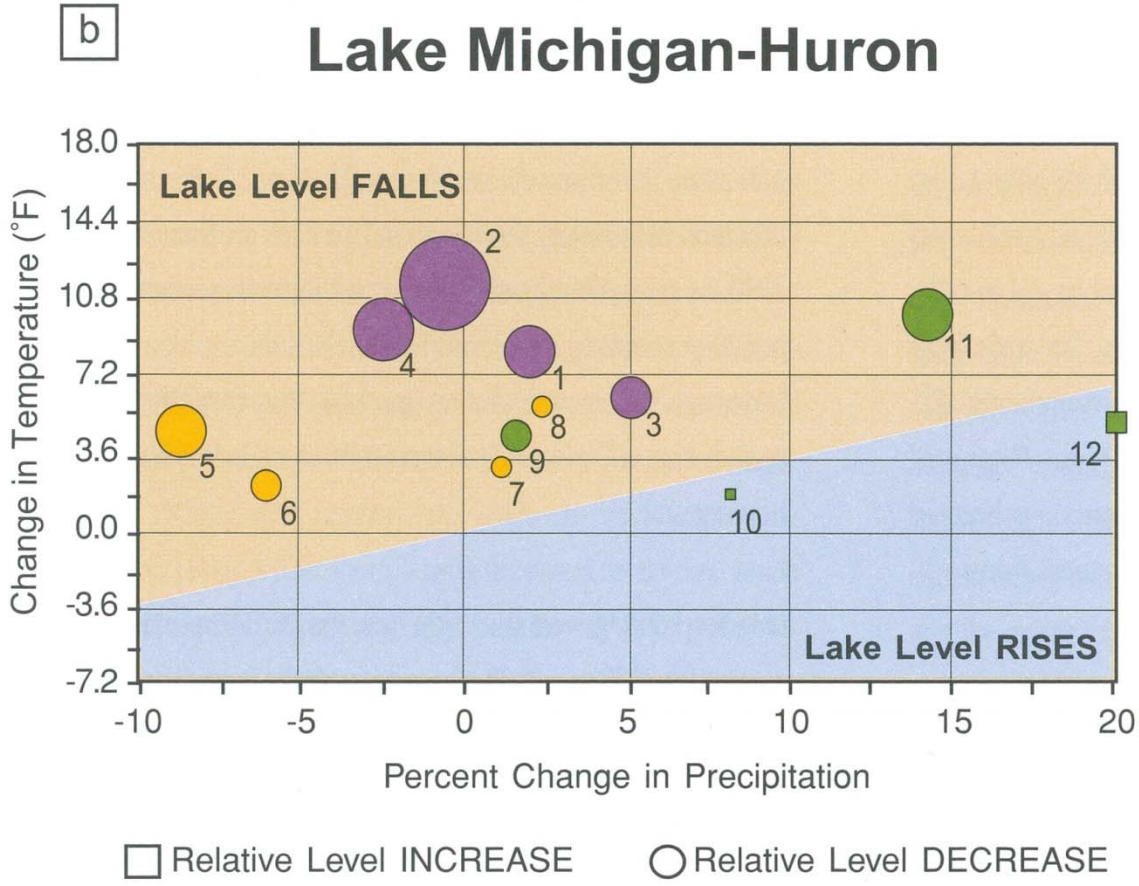
T: Transient model

Fig. 5. Actual CO2 emissions versus IPCC scenarios

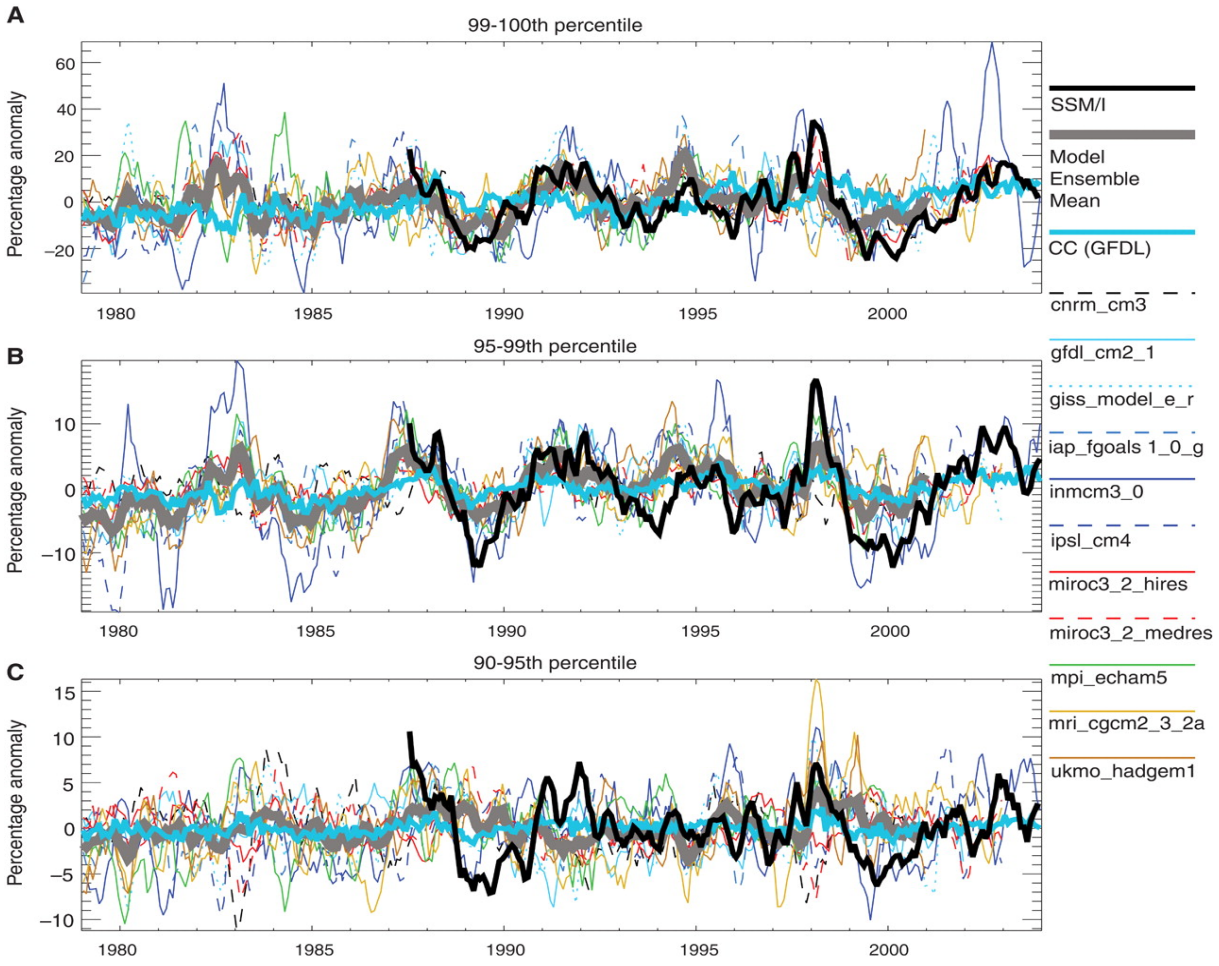


J. J. McCarthy Science 326, 1646-1655 (2009)

Assessing Climate Change



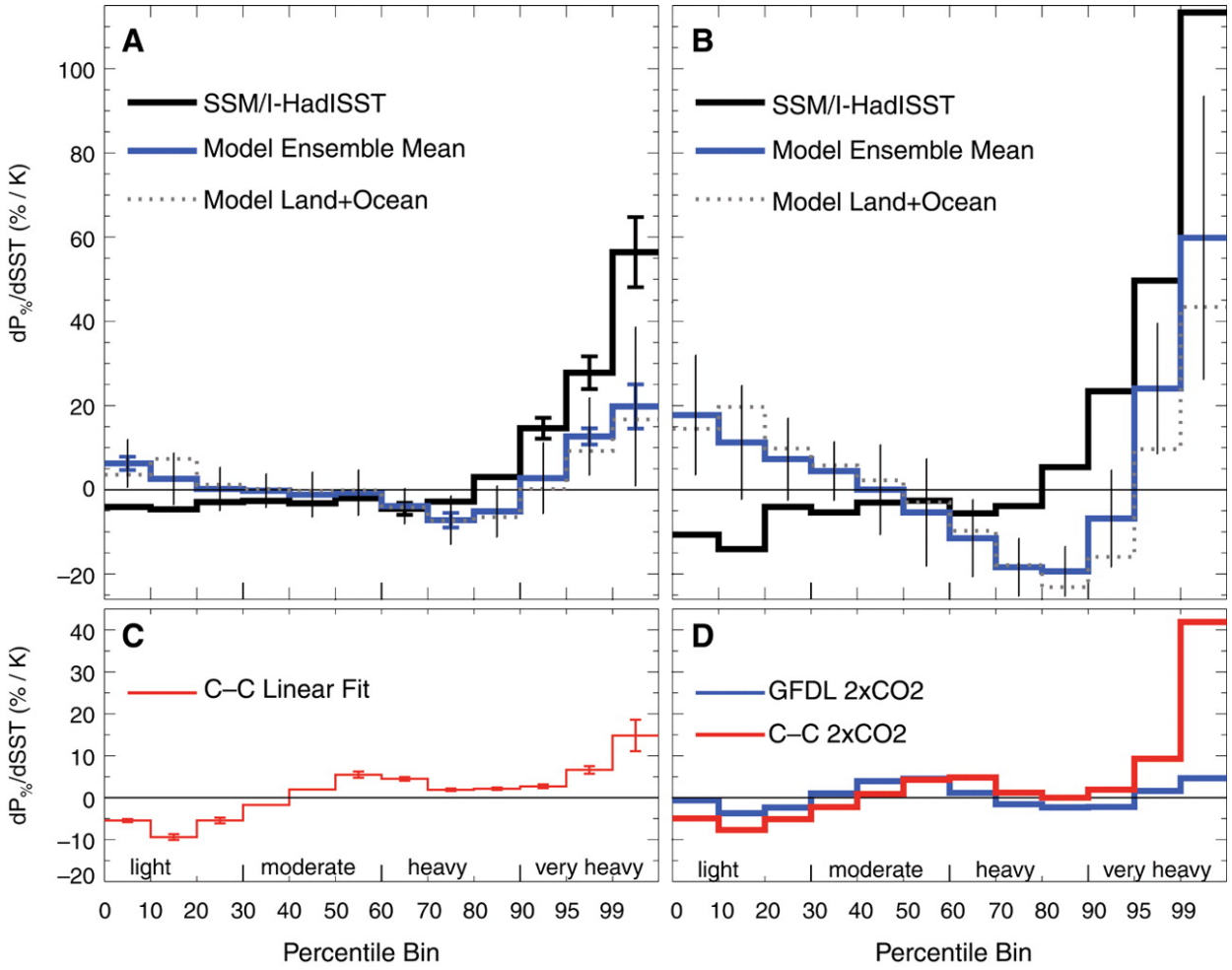
R. P. Allan et al., Science 321, 1481 -1484 (2008)



Science
AAAS

AECOM

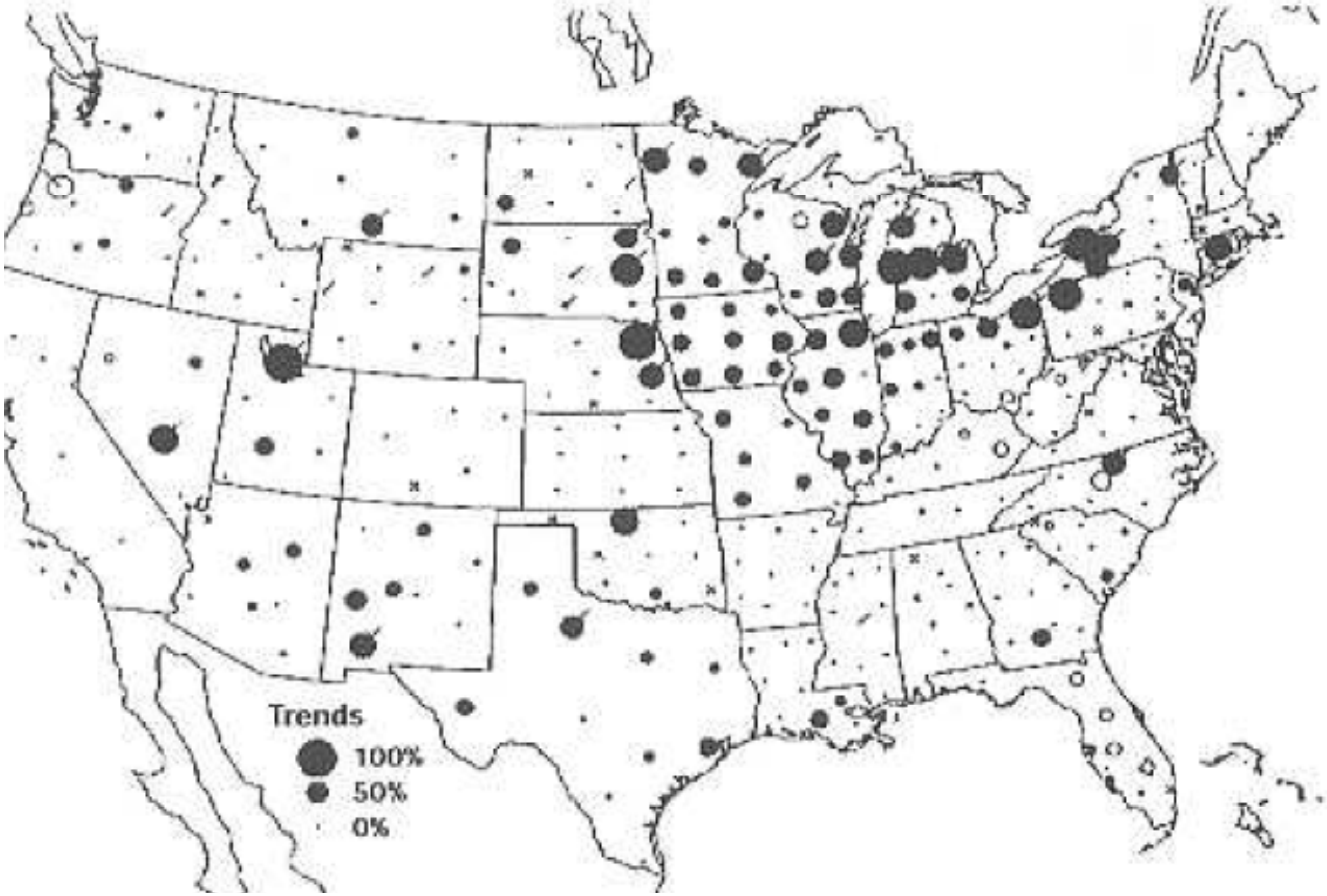
R. P. Allan et al., Science 321, 1481 -1484 (2008)



Science
AAAS

AECOM

Kunkel et al., Journal of Climate 12:2515-27 (1999)



AECOM

The Black Swan: The Impact of the Highly Improbable
By Nassim Nicholas Taleb
Random House, 2007

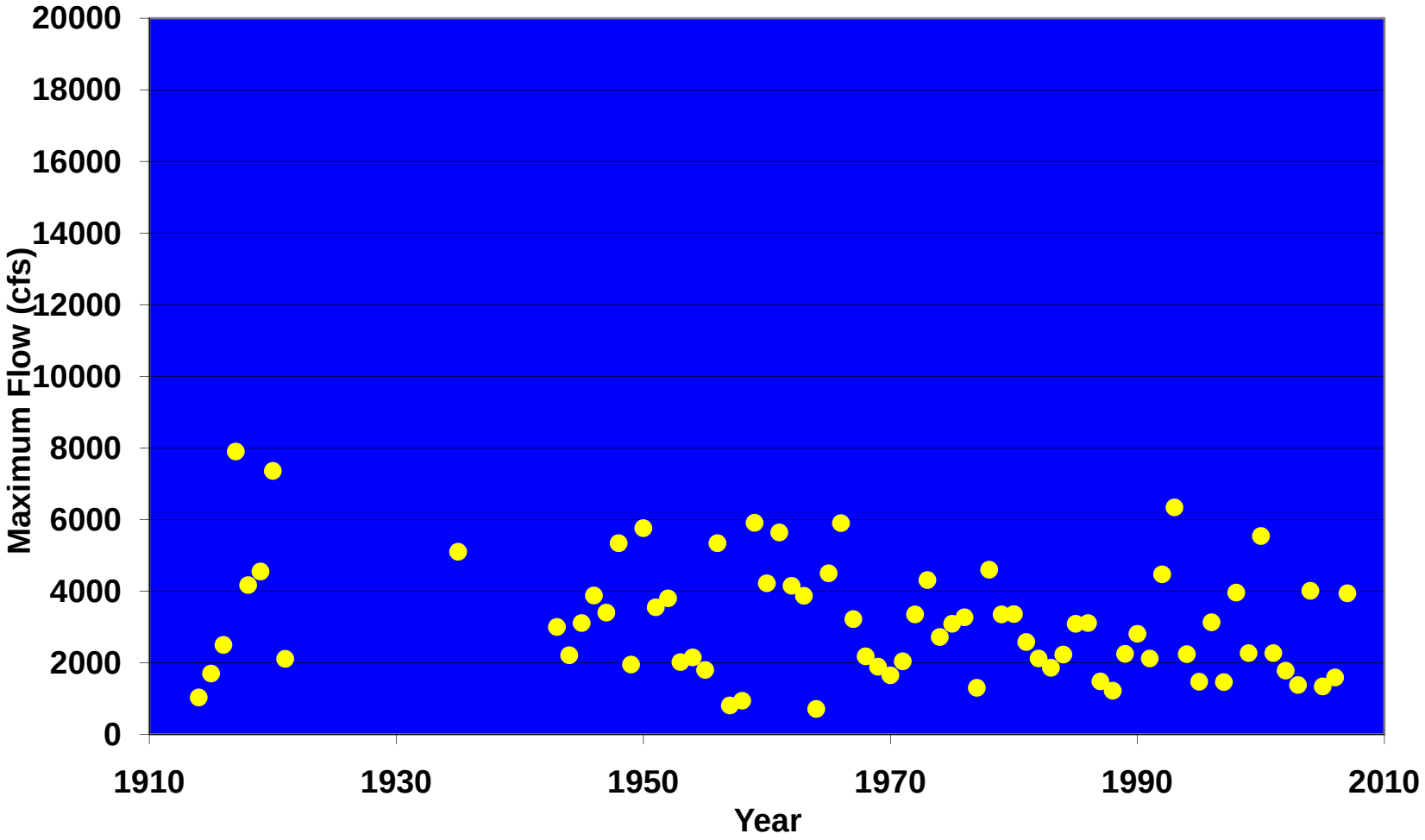
What are Black Swans?

- Events of great impact/consequences
- Unexpected
- Should have seen it coming (had all the warning signs)

Chicago O‘Hare: **September 13, 2008 – 6.64 inches**
August 14, 1987 – 6.49 inches

O’Hare Airport September 13 2008

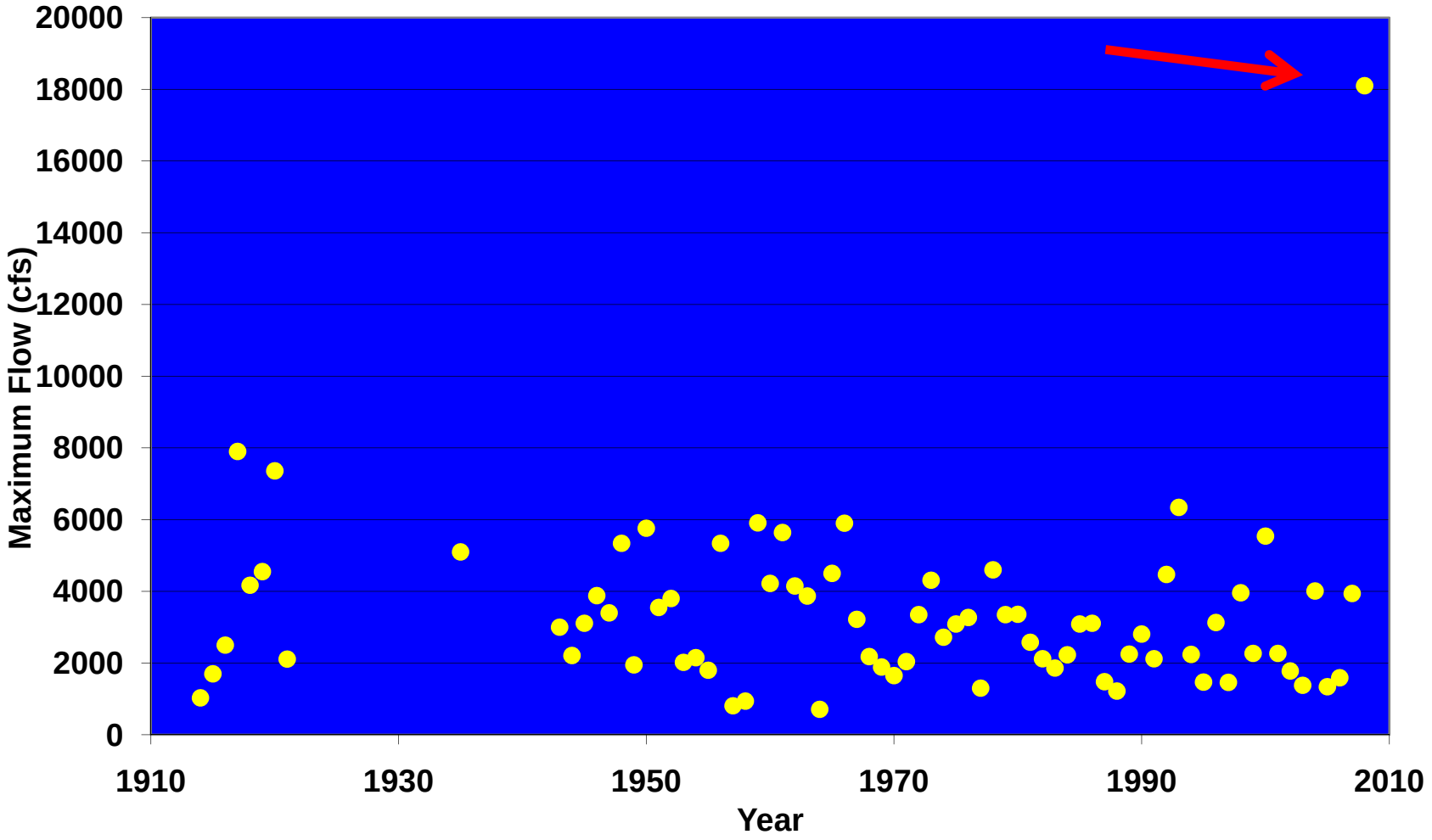
Baraboo River at Baraboo, Wisconsin



AECOM

Baraboo River at Baraboo, Wisconsin

Baraboo River June 8, 2008 – 18,100 cfs



AECOM

Baraboo River
June 8, 2008

Marble Falls, TX – June 28, 2007

16 inches of rain in 6 hours

AECOM

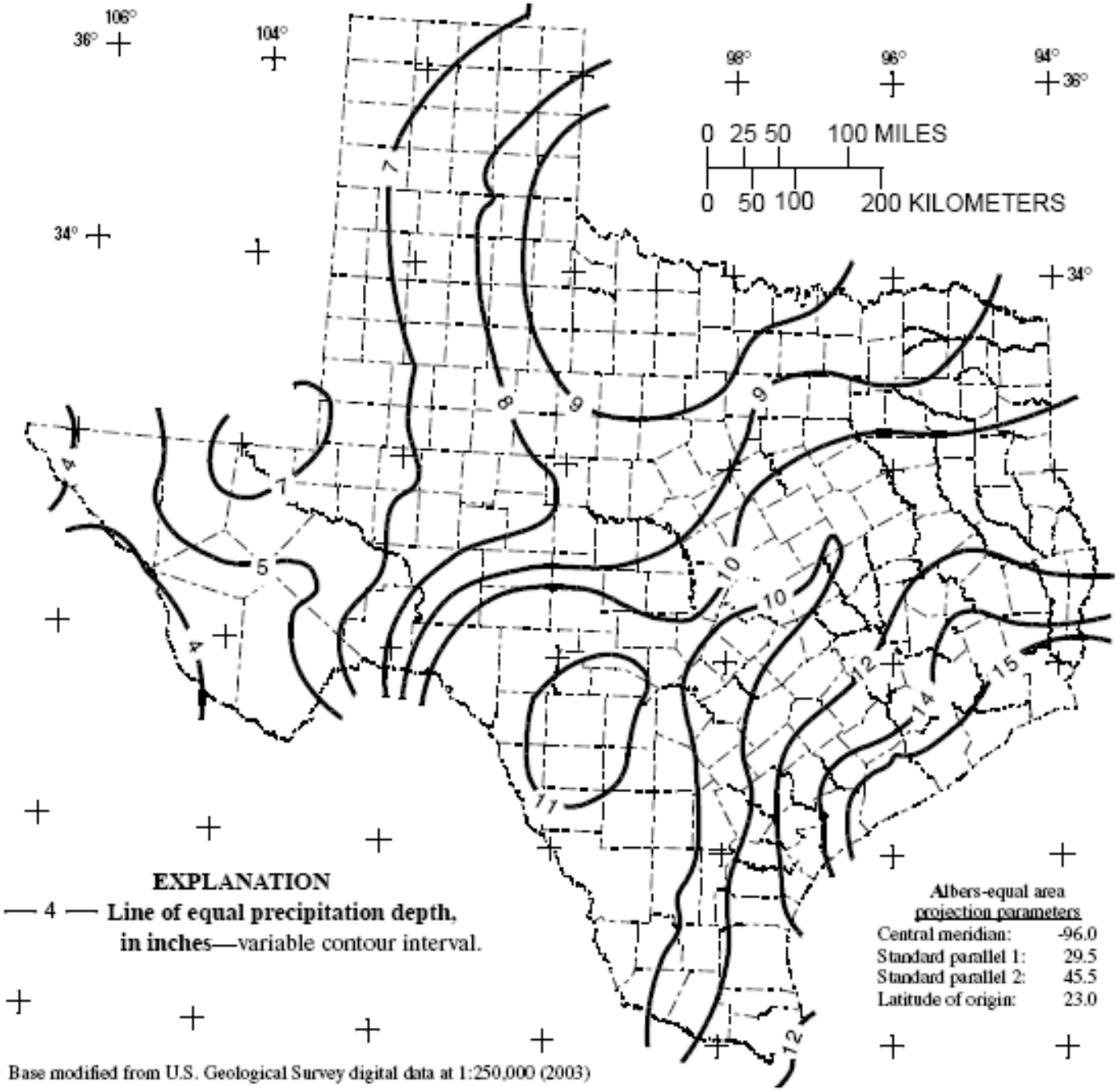
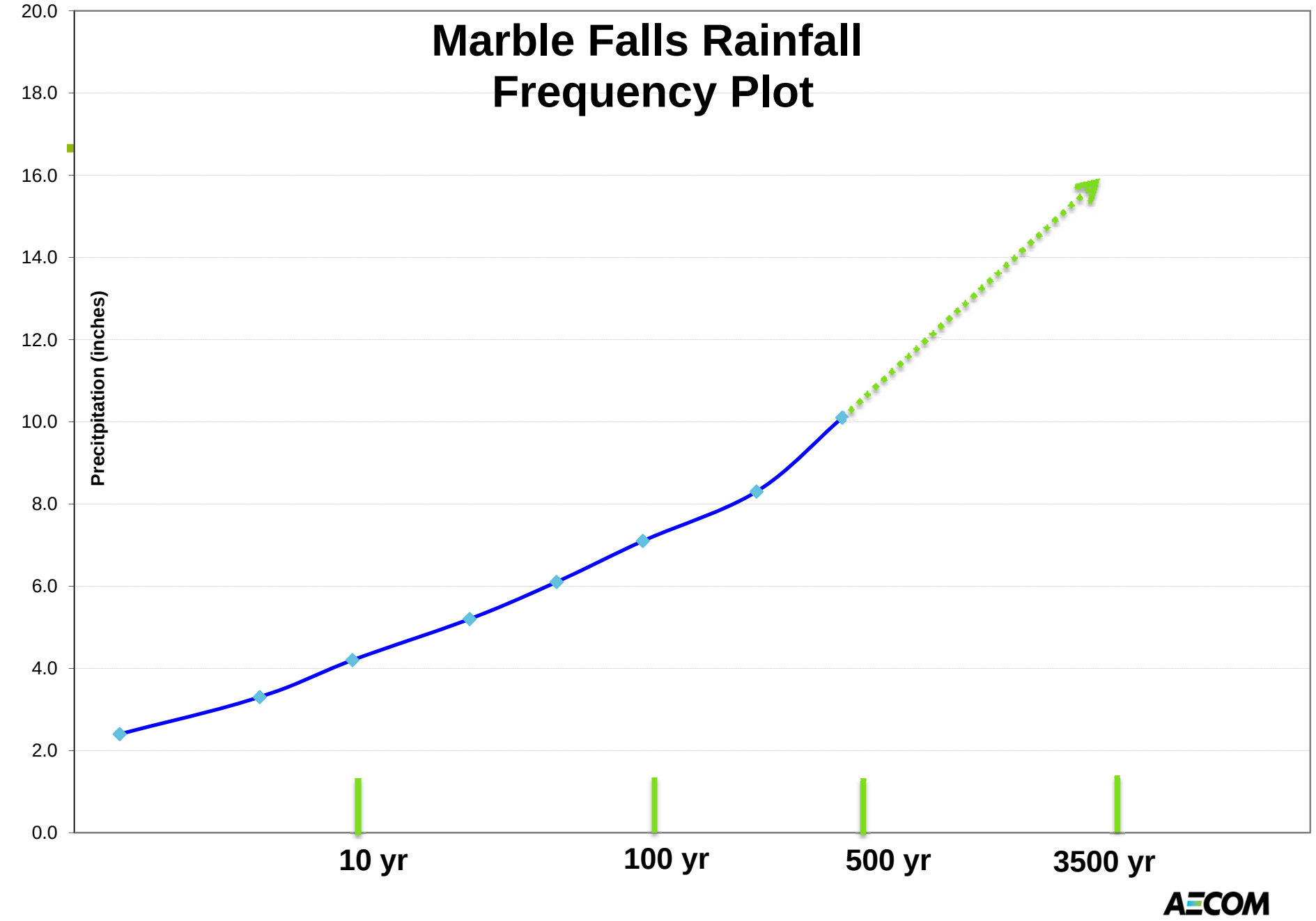
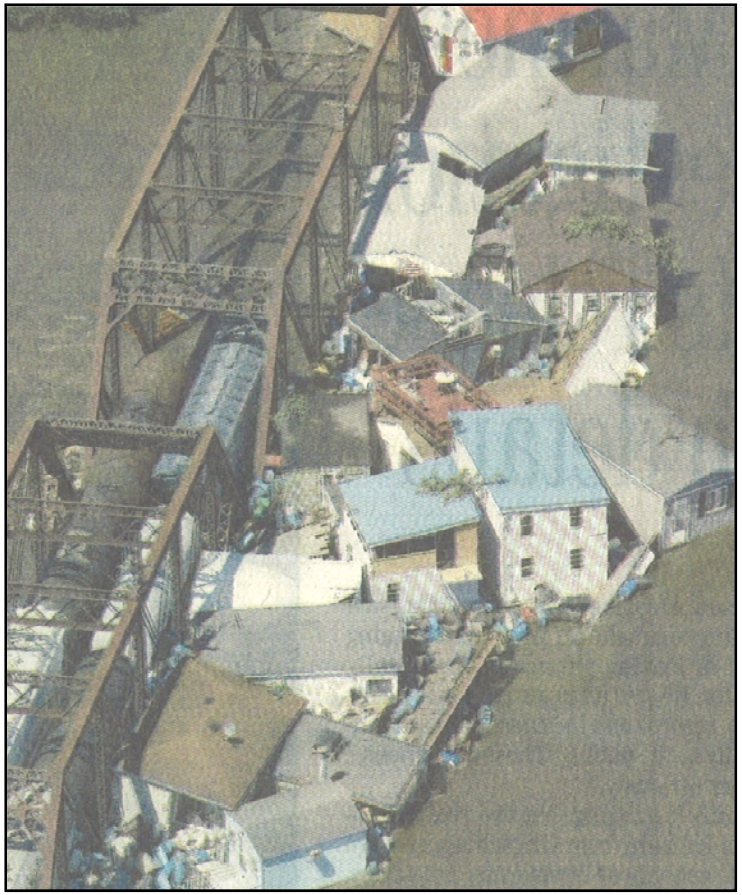


Figure 93. Depth of precipitation for 500-year storm for 6-hour duration in Texas.


Marble Falls Rainfall
Frequency Plot
Precitpitation (inches)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
10 yr
100 yr
500 yr
3500 yr
AECOM

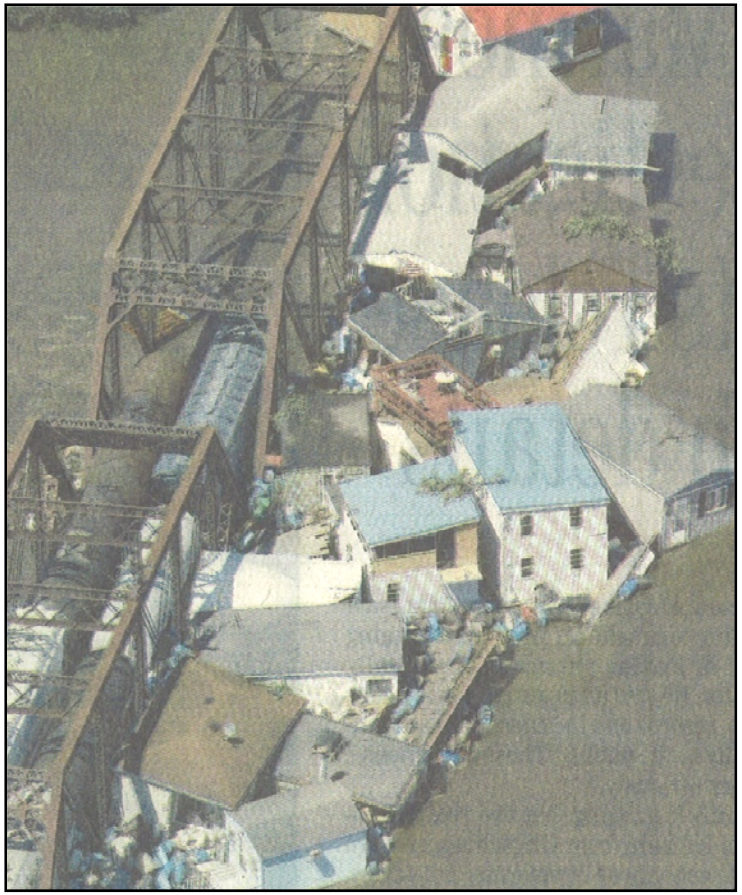
Stationarity is not dead, but it's in deep, deep trouble.

- The profession(s) are not prepared to manage design risk in the face of changing hydrology.
  - Changes are not understood
  - No uniform/accepted techniques for frequency analysis
  - GCM's aren't ready to replace historical records



Stationarity is not dead, but it's in deep, deep trouble.

- Immediate need to revise the practice of risk-based design in Water Resources Engineering



Science Vol 319, p. 573,
1 February 2008

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

P. C. D. Milly,[1]* Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

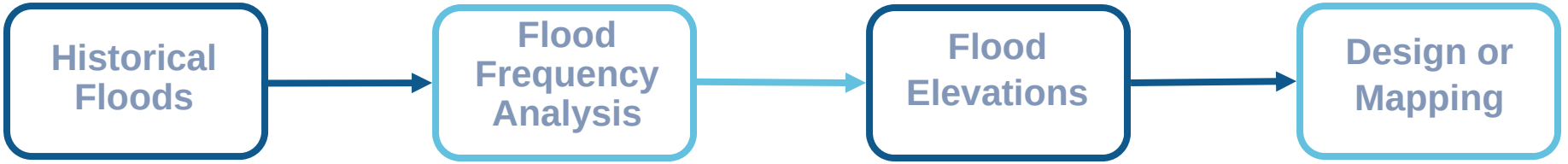
Proposed Solution – nonstationary probabilistic models

Possible Solutions

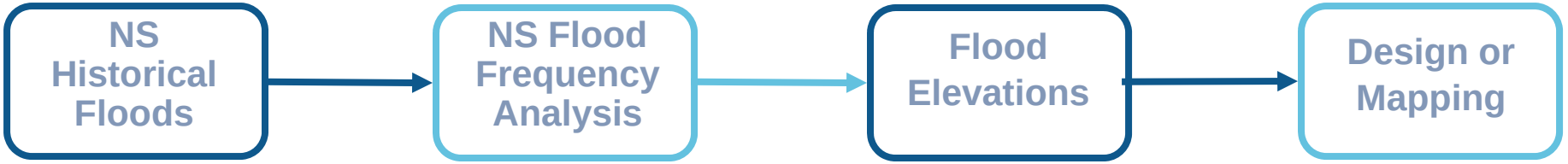
- GCM – Technology not ready but improving
- Watershed Modeling – Technology is Solid
- Proposed Solution - use available data mining tools to develop comprehensive watershed simulation models
- Use Coupled Hydrologic/Hydraulic models to quantify climatic uncertainty
- Examples:
  - DuPage County Illinois
  - Cedric David (UT Austin)

Nonstationary Statistics?

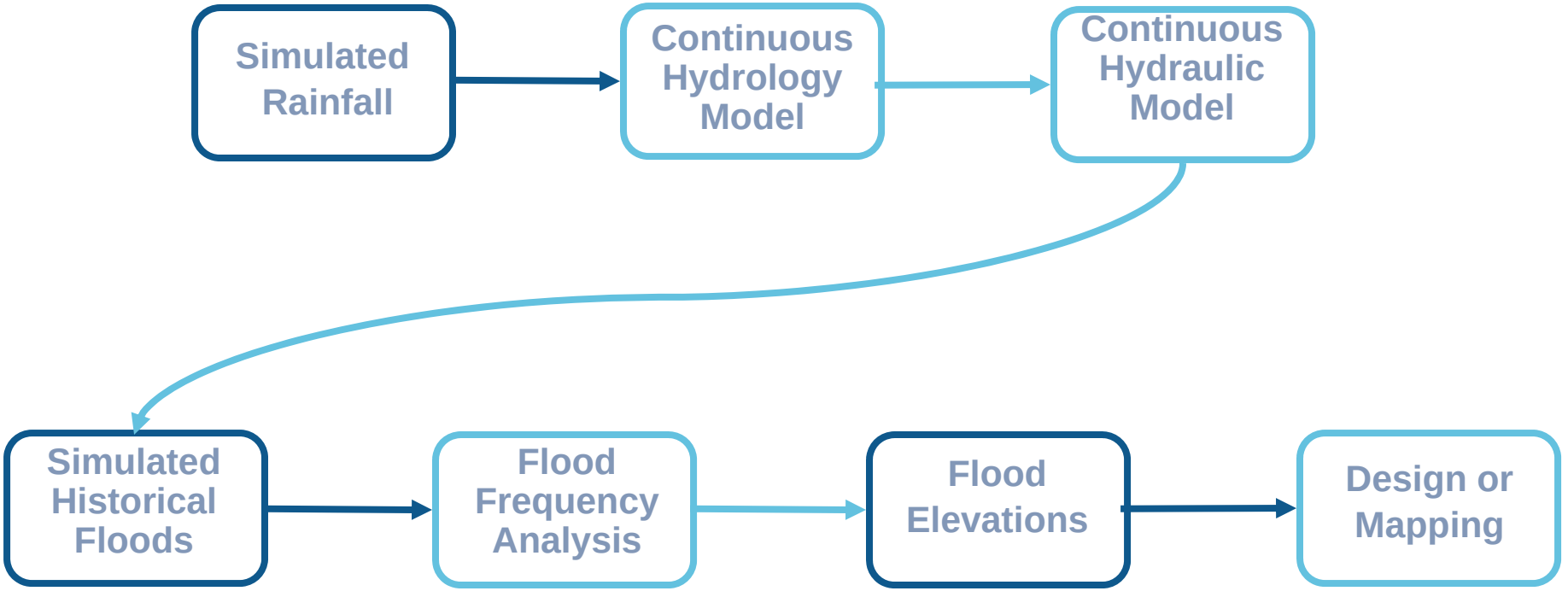
Current Practice



Future?



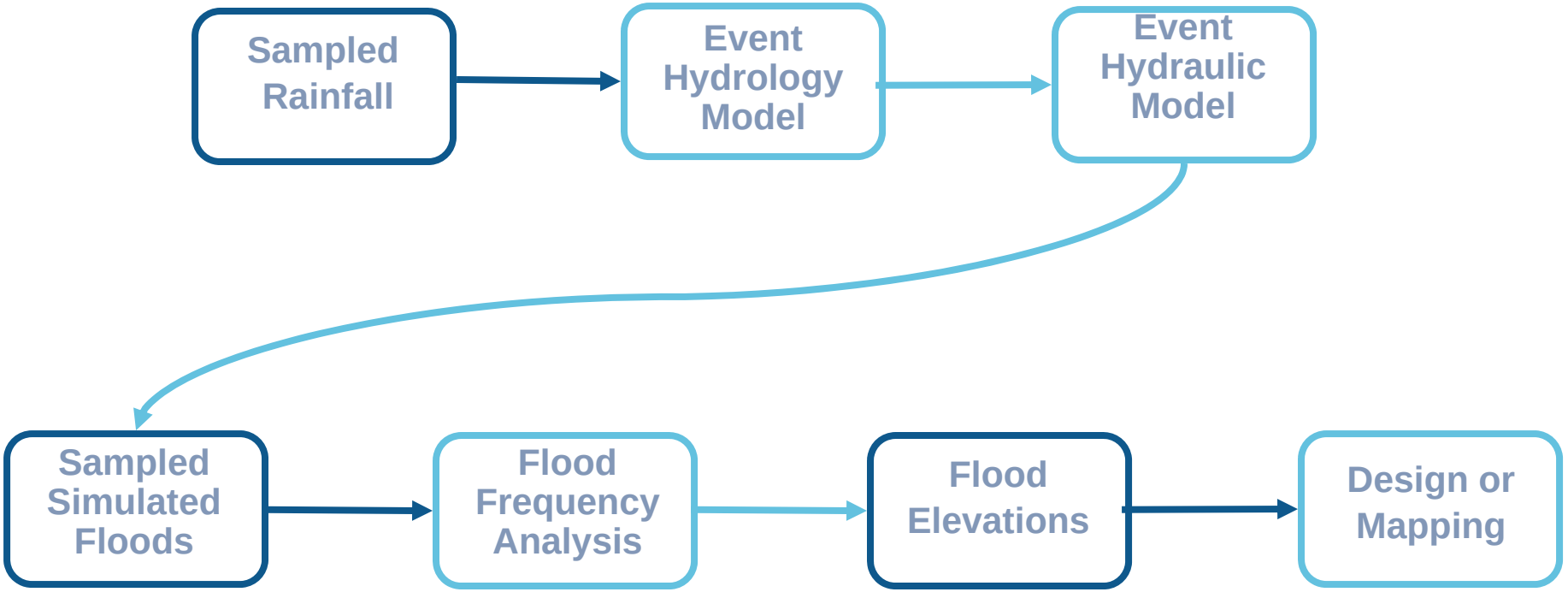
A Better Process – DuPage Approach



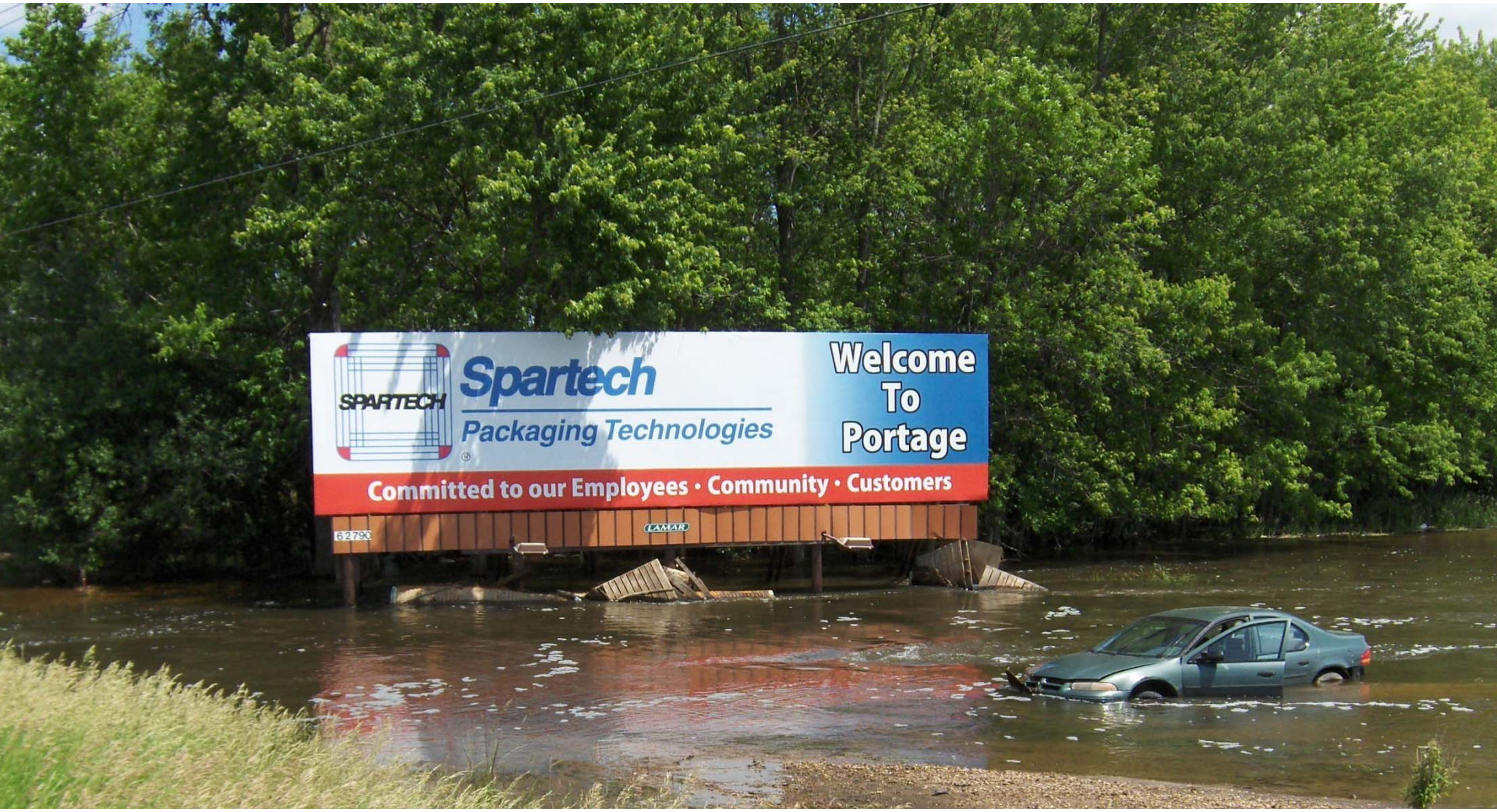
Proposed Modeling Approach

- Estimate local rainfall changes due to global warming
  - Intensity, Frequency
- Prepare a stochastic rainfall model
- Build a comprehensive watershed model leveraging GIS technology
- Generate synthetic streamflow records at locations of interest throughout the watershed
- Use stationary statistical analysis to estimate flood quantiles

Alternatively…



Discussion


SPARTECH
Spartech
Packaging Technologies
Welcome
To
Portage
Committed to our Employees • Community • Customers
LAMAR
62790

Thank You

Eric.loucks@aecom.com