# Climate Change:
## High Water Impacts and Adaptation


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WISCONSIN INITIATIVE ON CLIMATE CHANGE IMPACTS

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WISCONSIN INITIATIVE ON CLIMATE CHANGE IMPACTS


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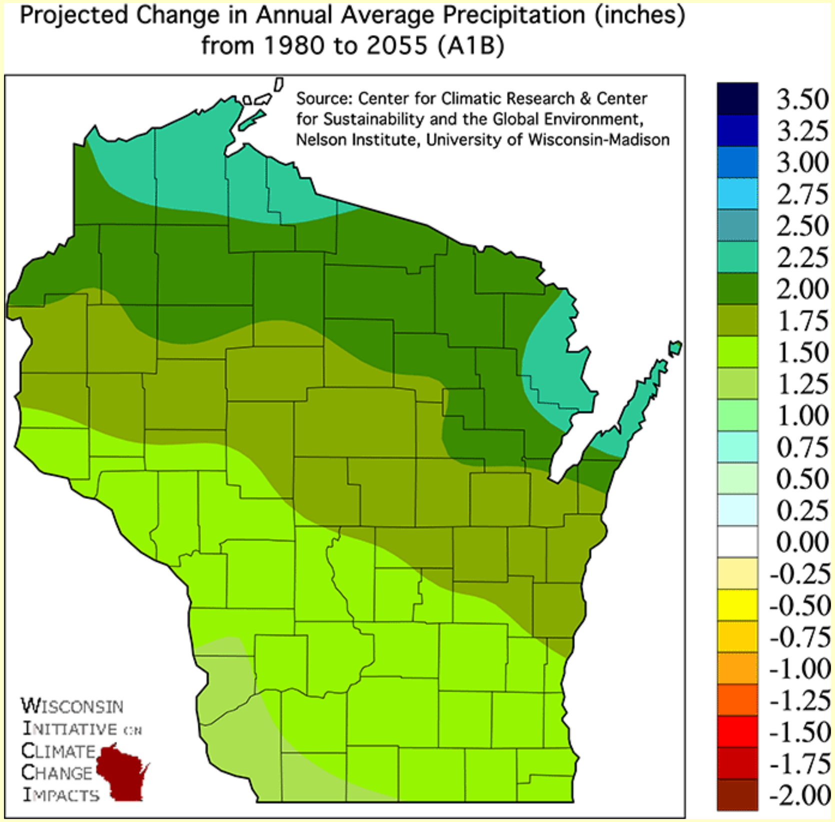
# Overview

What the historical record tells us

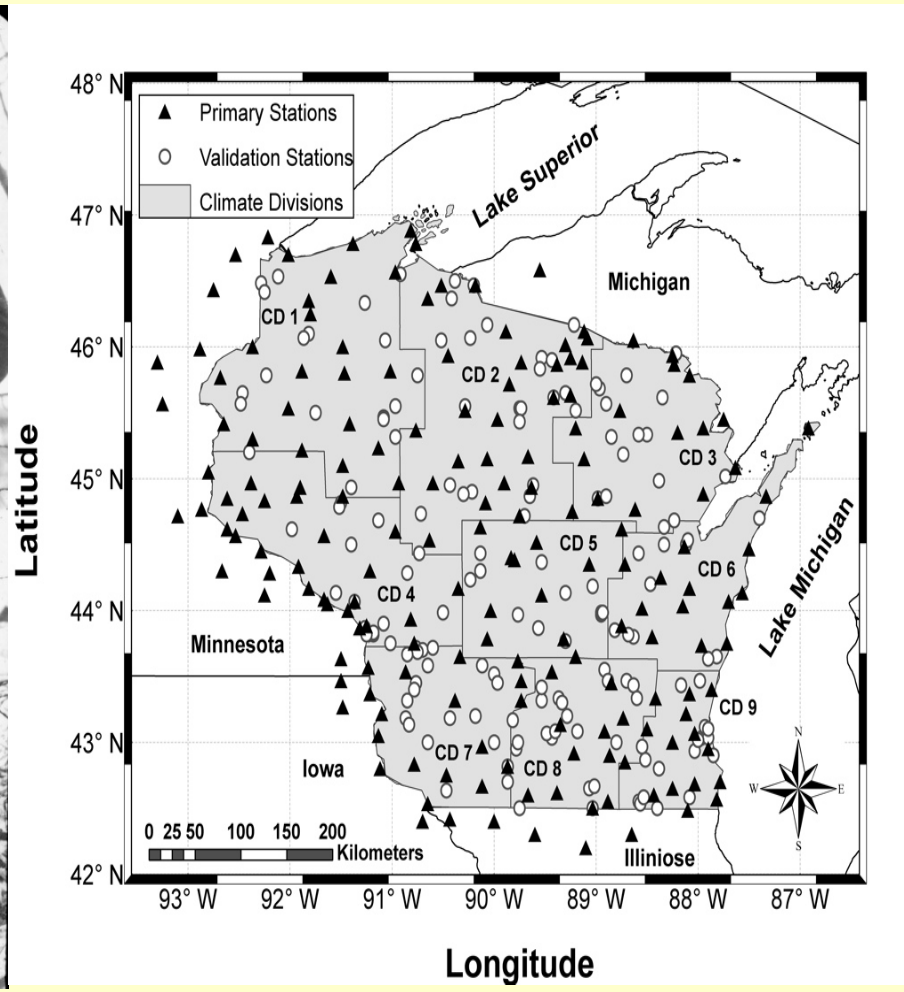
Future scenarios of precipitation

High water impacts

Adaptation strategies



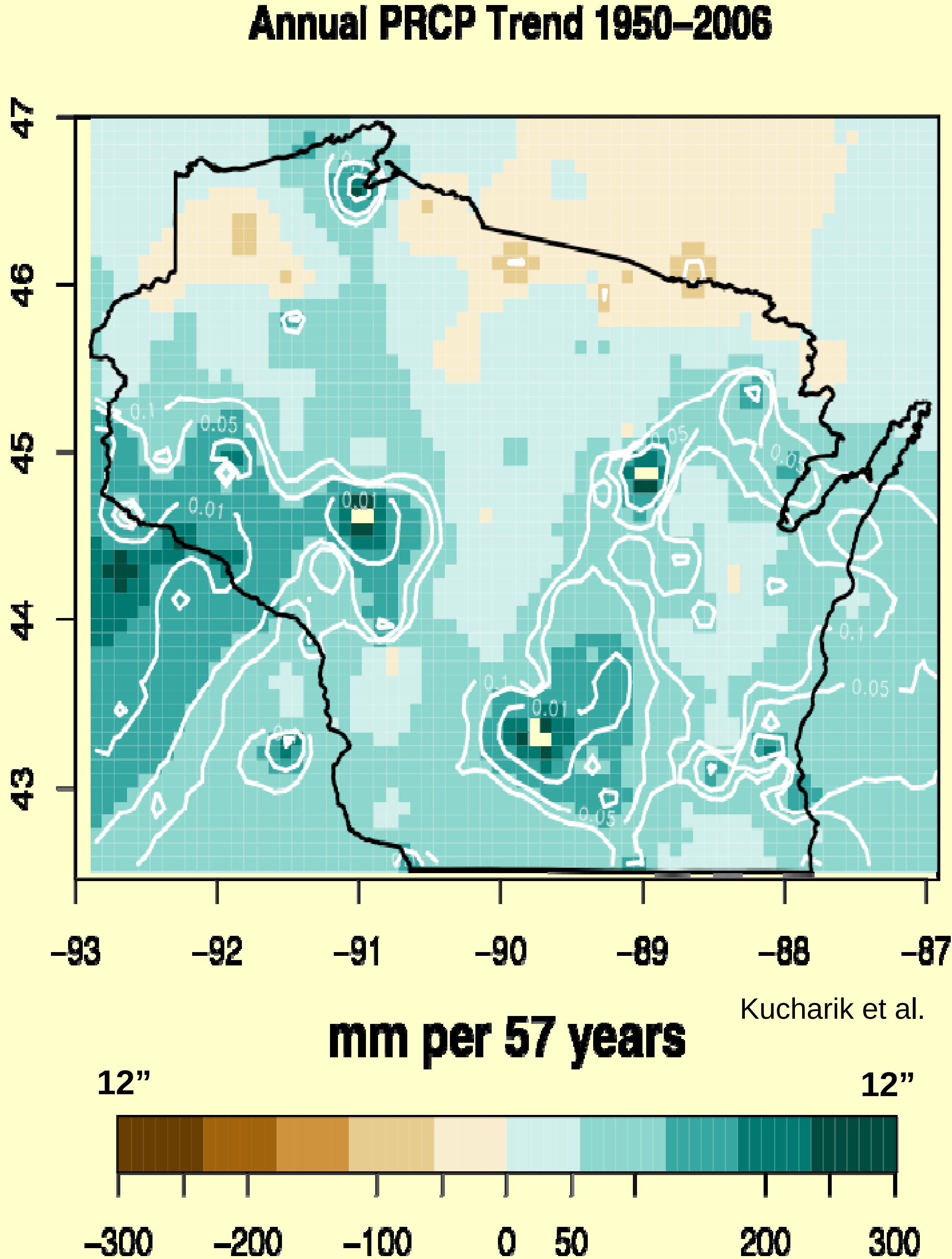

# We’ve been measuring rainfall in Wisconsin since 1870


**1930** **WI Cooperative Weather Stations** **2008**

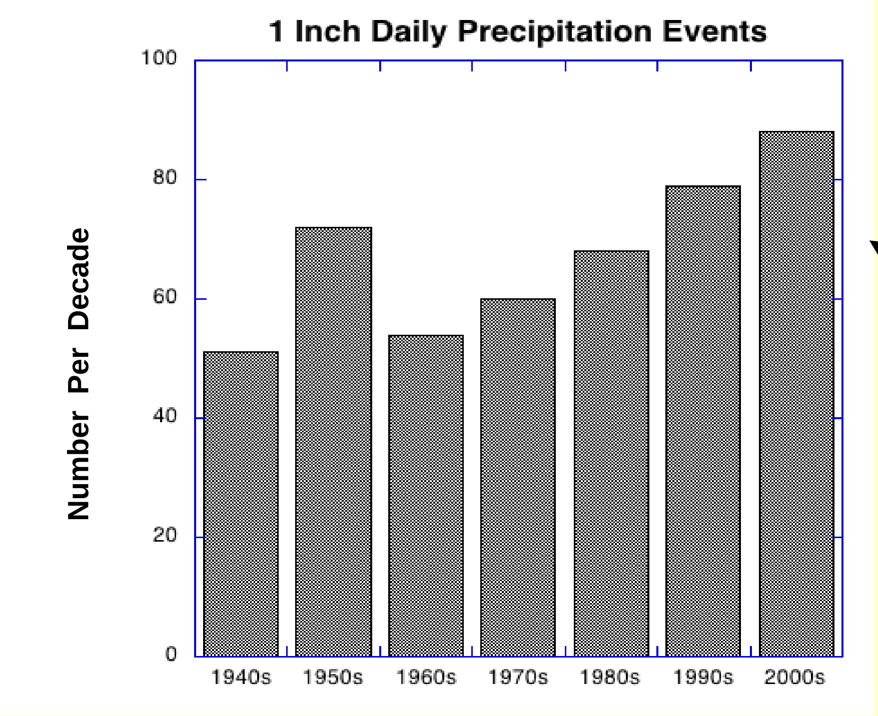
# Examining the historic record

Annual rainfall over southern Wisconsin has increased since 1950 by 2”– 6”



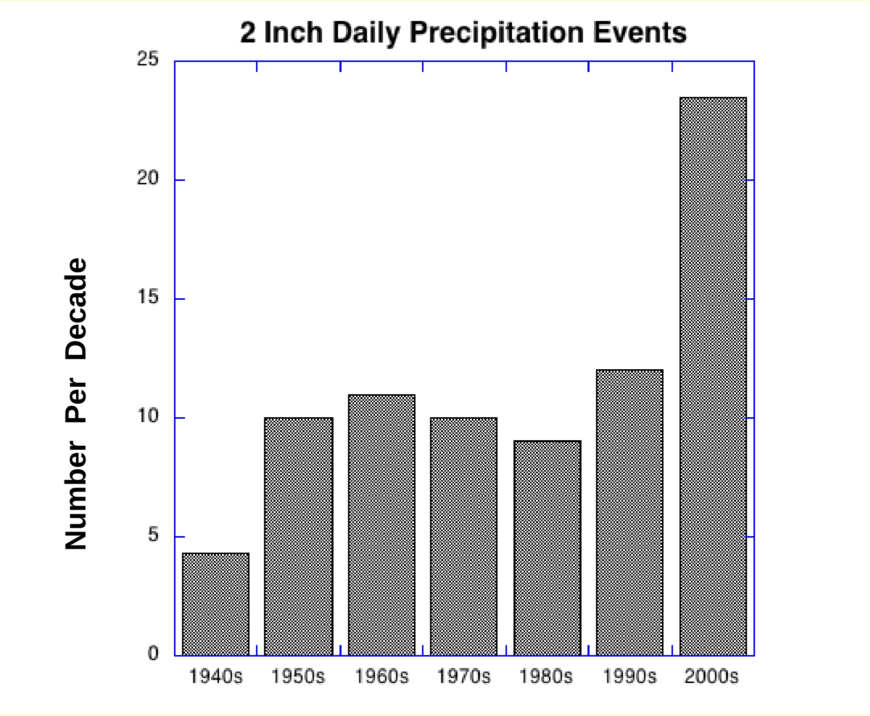
# Measured trends in precipitation at Madison

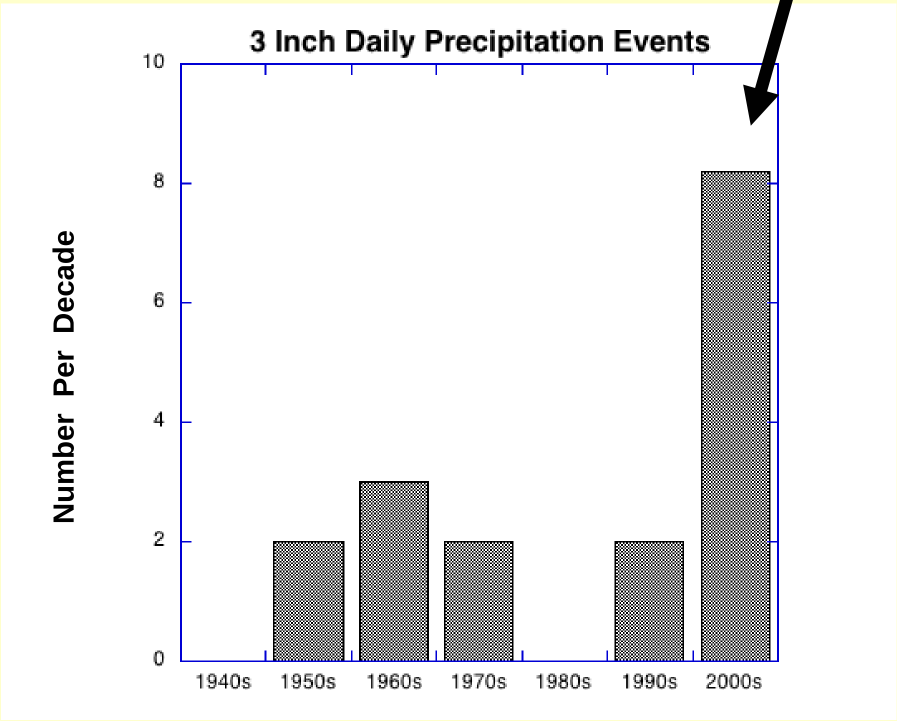
1940 - 2009




Rising trend in typical storms?

Greatest increase in heaviest rainfall?

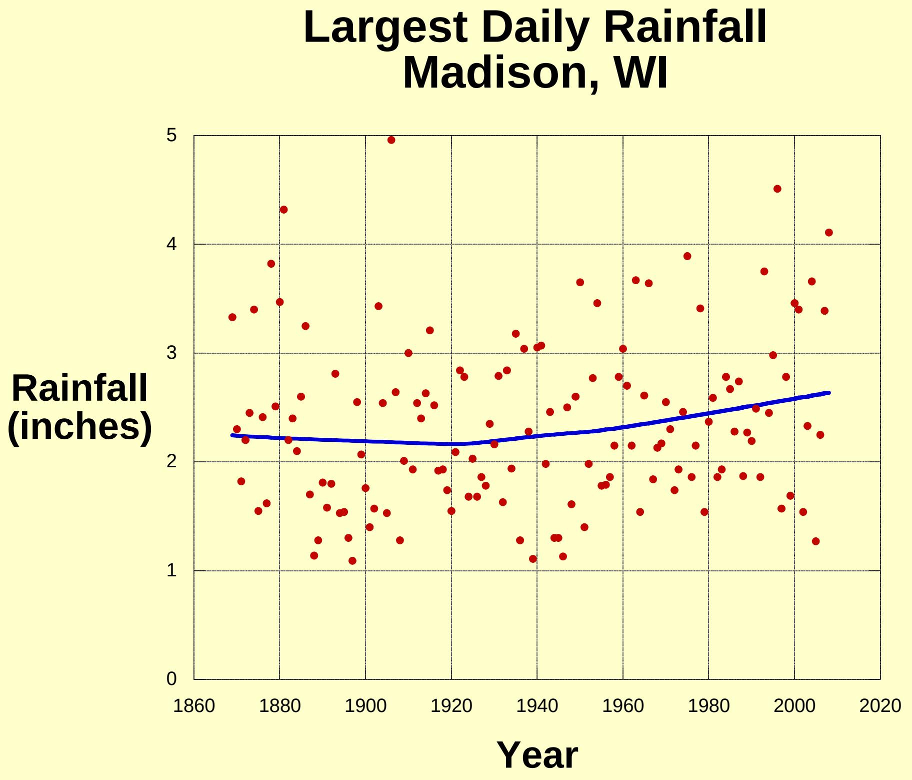


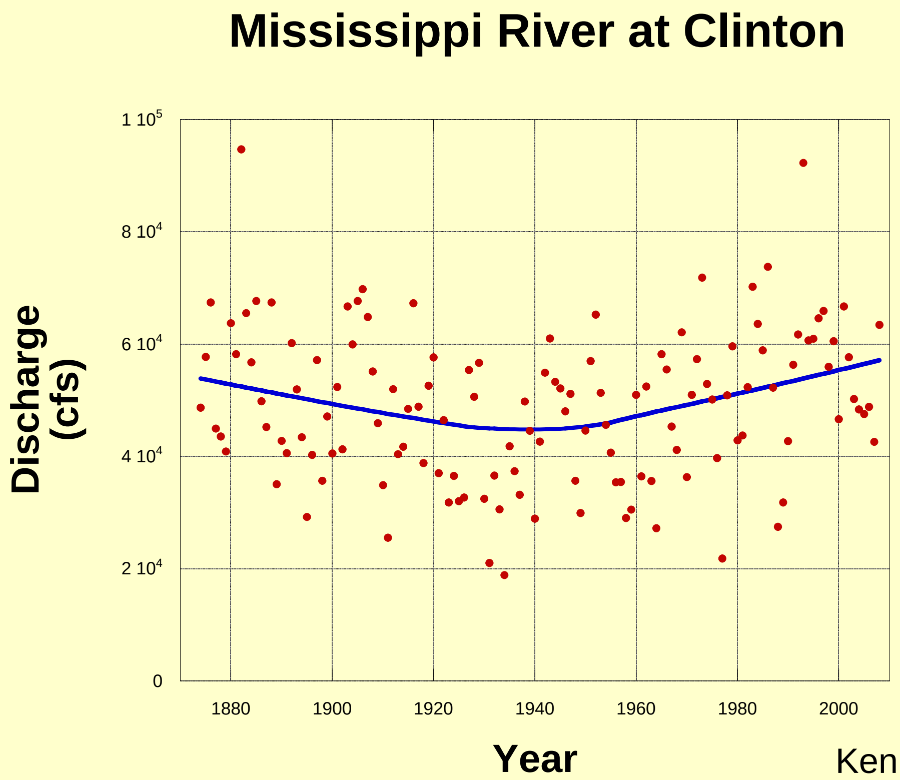

Steve Vavrus, CCR

# Decadal Trends?

The record of heavy rainfall at Madison suggests a drier period during the early 20th century.

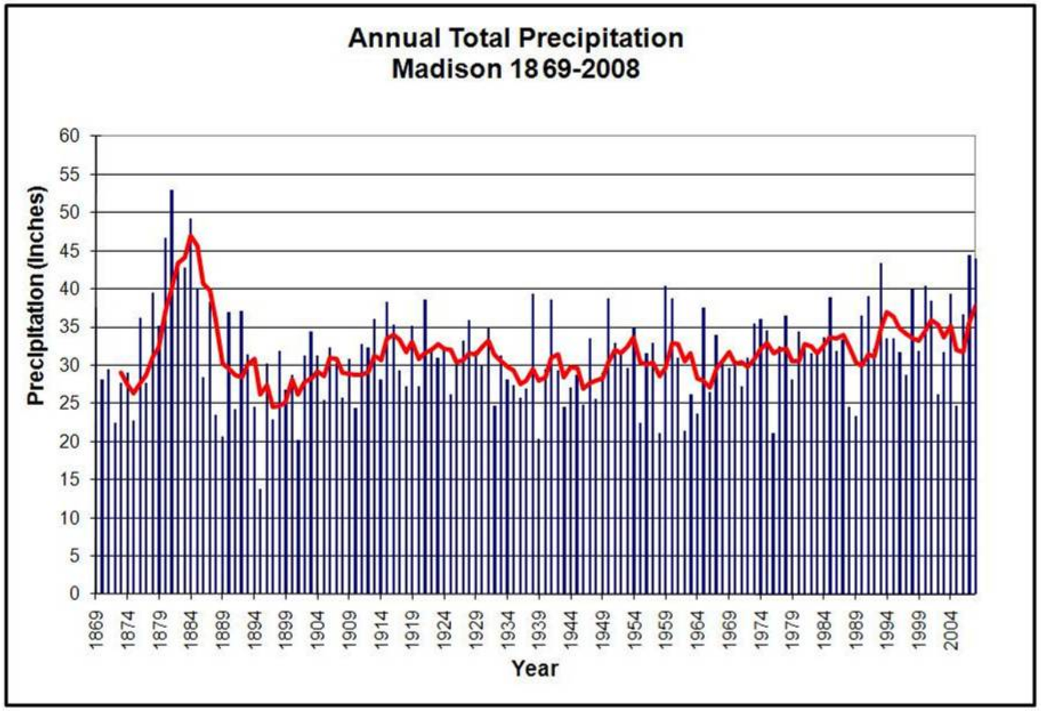


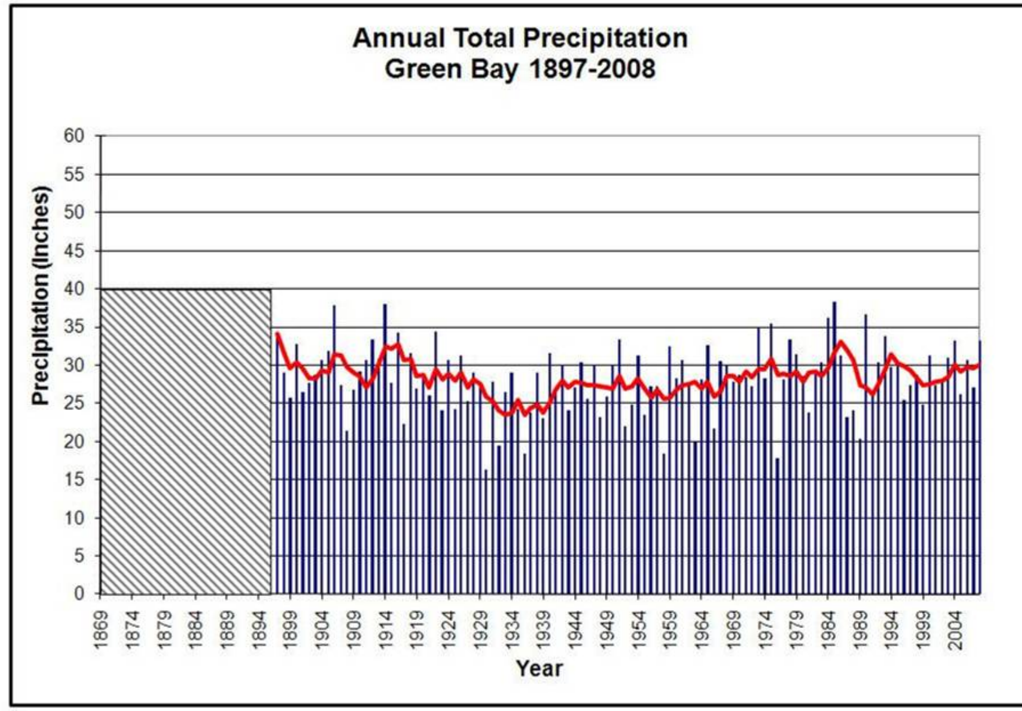

The flow of the Mississippi River at Clinton IA indicates this was a regional effect.

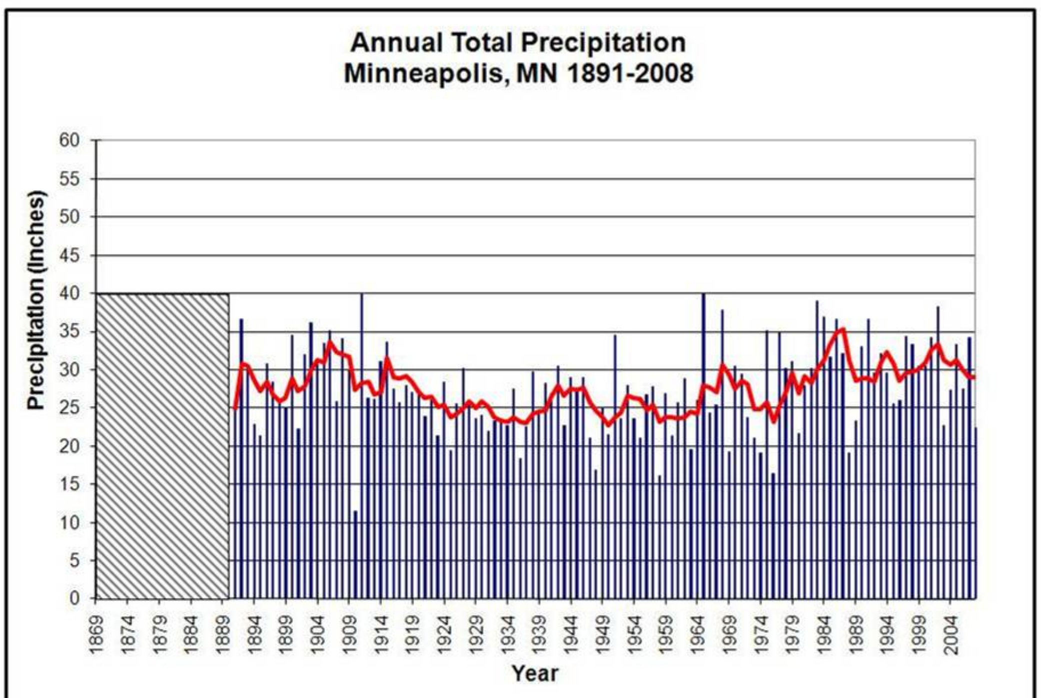


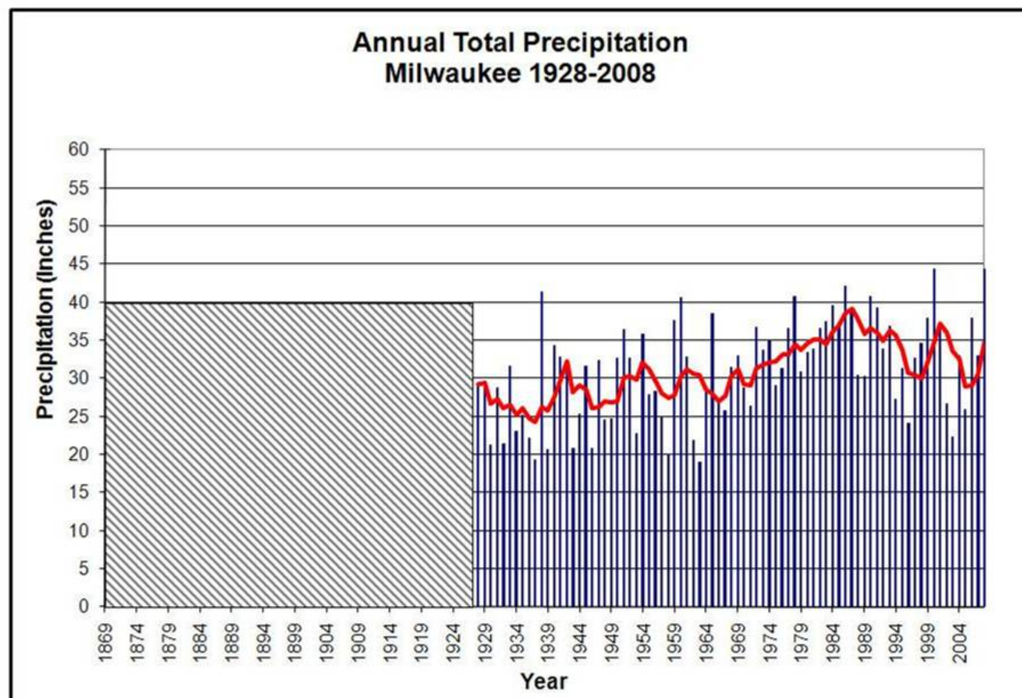

Ken Potter 2009

# Annual Total Precipitation

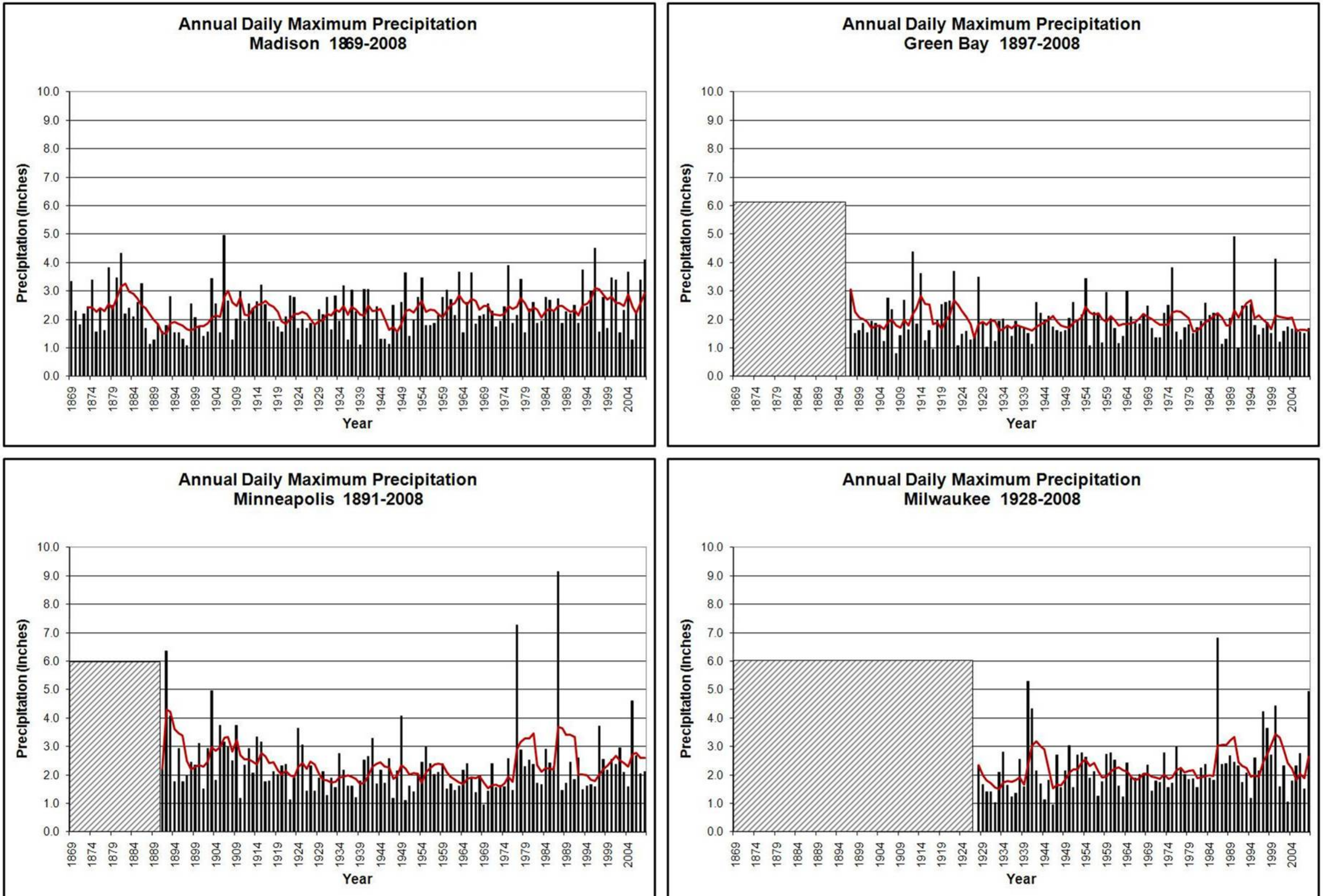


# Annual Daily Maximum Precipitation



| Mann-Kendall Trend Test for Statistical Significance<br>Total Annual Precipitation Full Record | | |
|---|---|---|
| | Change/Decade (In) | Statistically Significant (95%) |
| Madison | 0.225 | No |
| Minneapolis, MN | 0.188 | No |
| Green Bay | 0.066 | No |
| Milwaukee | 1.349 | Yes |

However, these data may not show any long term trend.

| Mann-Kendall Trend Test for Statistical Significance<br>Annual Daily Maximum Preciptation Full Record | | |
|---|---|---|
| | Change/Decade (In) | Statistically Significant (95%) |
| Madison | 0.028 | No |
| Minneapolis, MN | -0.023 | No |
| Green Bay | -0.002 | No |
| Milwaukee | 0.075 | Yes |

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# Number of 2” Precipitation Exceedences

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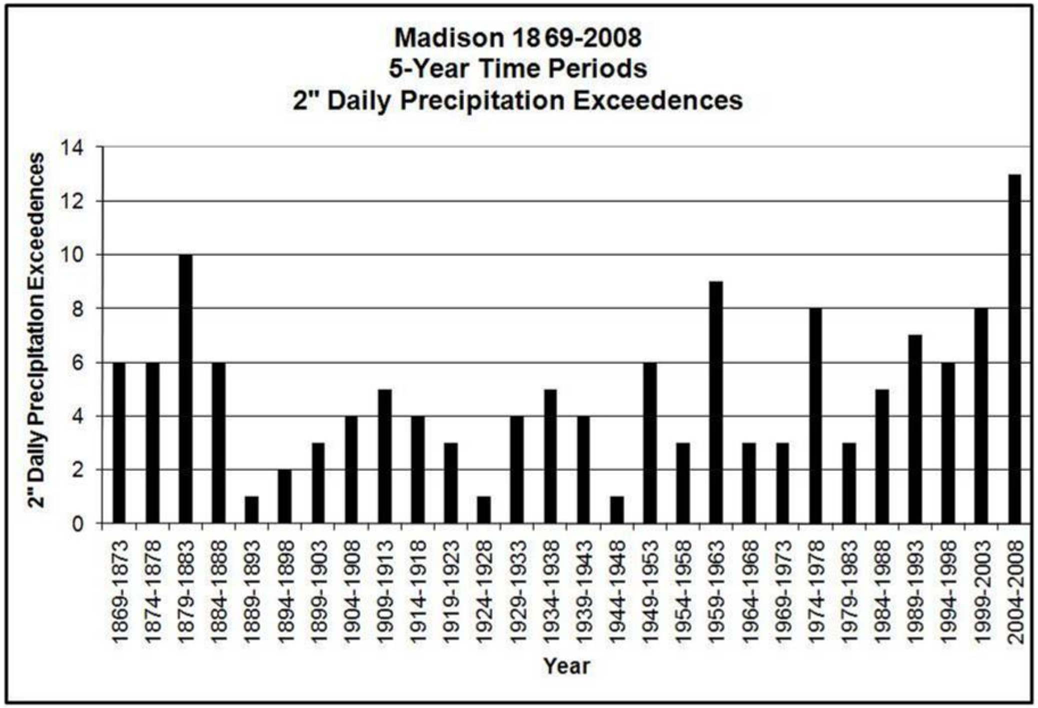
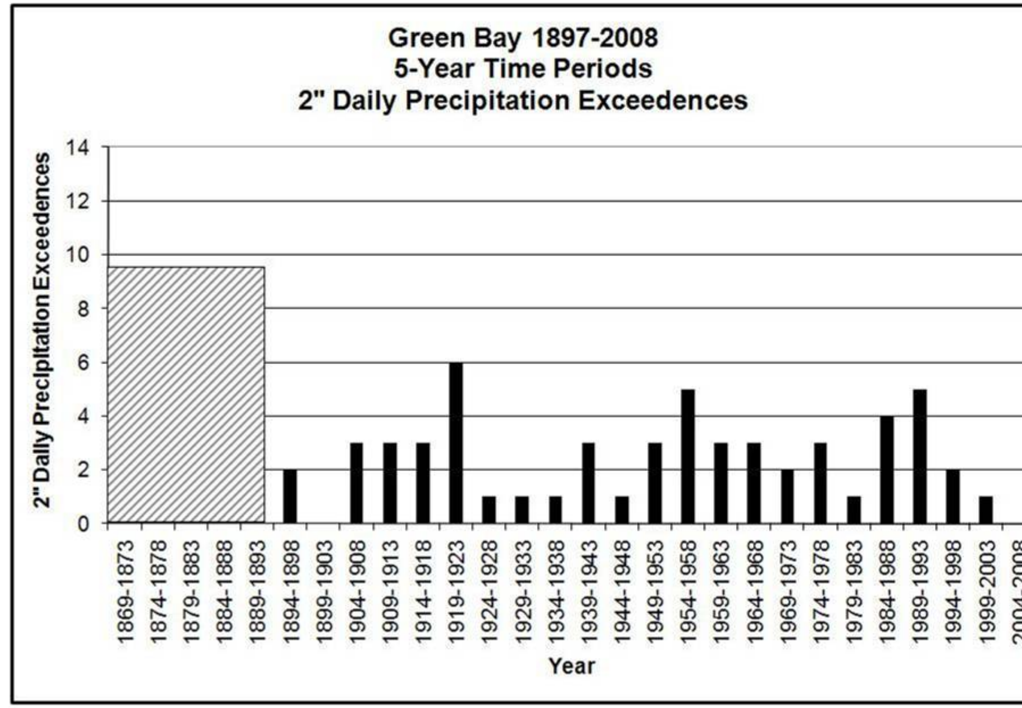
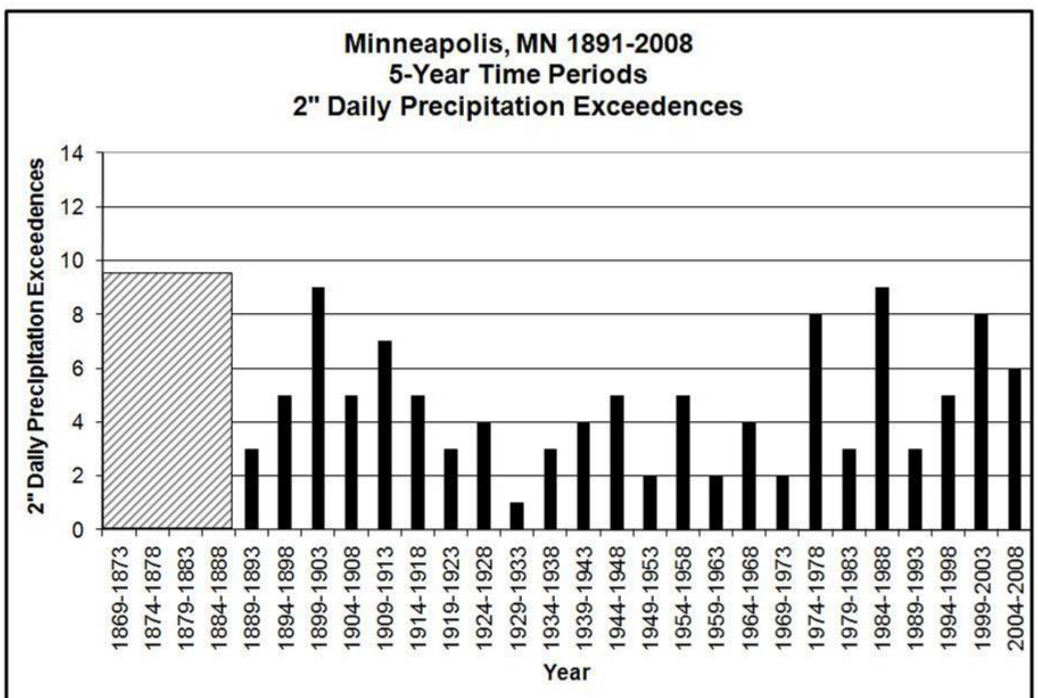
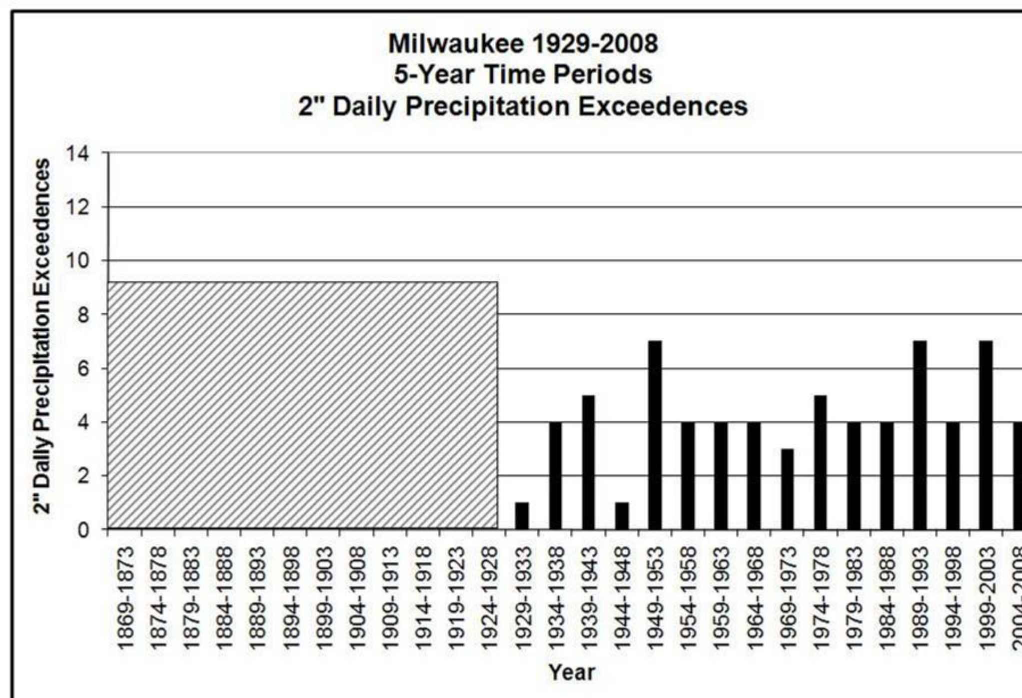


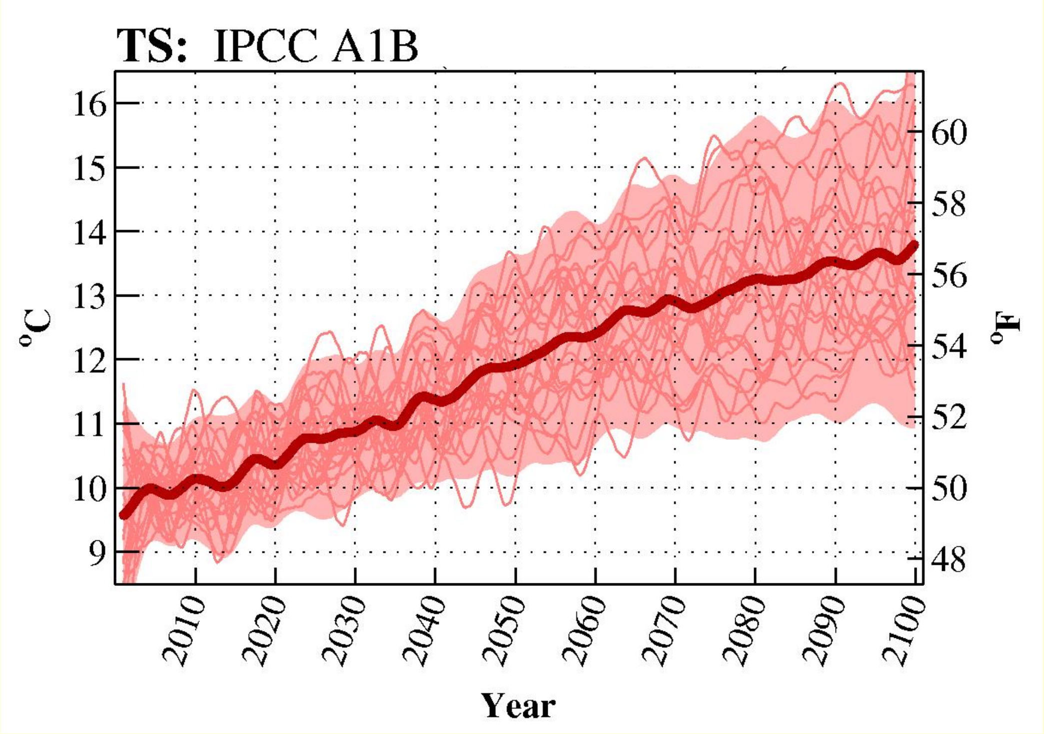
# Results of the Analysis of Historical Data

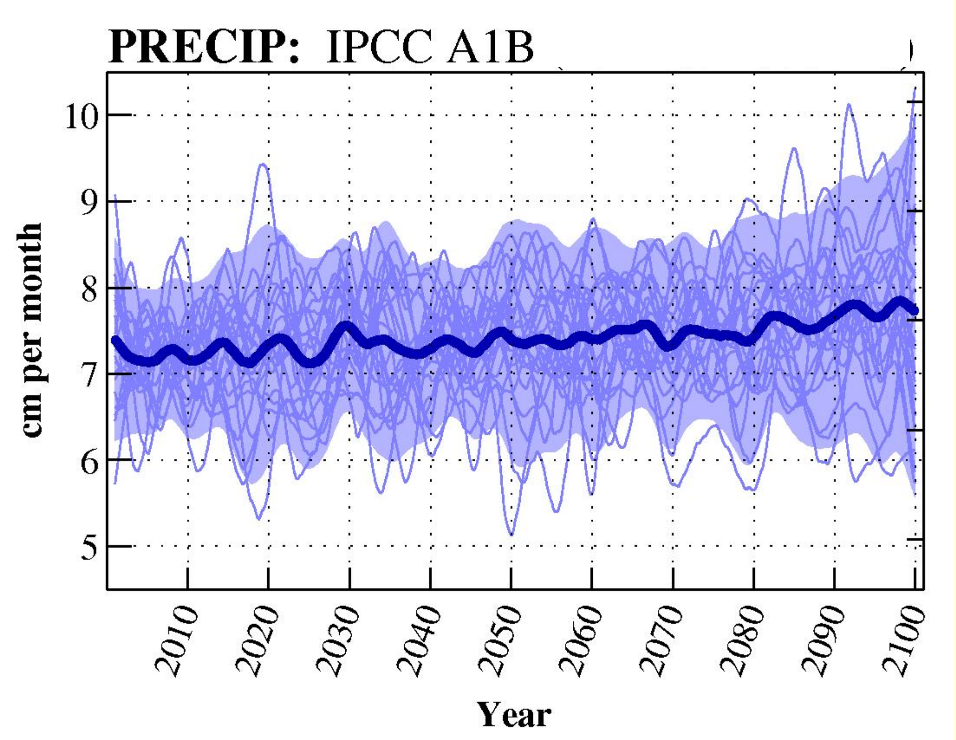
"The analyses of both yearly and intense event variations in the historic precipitation record indicate long-term variation in the magnitude and frequency of large daily rainfalls in Wisconsin….

However, there is no evidence to support changes due to global climate change." – WICCI Stormwater Working Group

# Future Climate Change

## What Global Circulation Models (GCMs) tell us




**Temperature:**
**Warms by 2-6°C (3-10°F) by end of century**

**Precipitation:**
**Less certain and seasonally dependent**

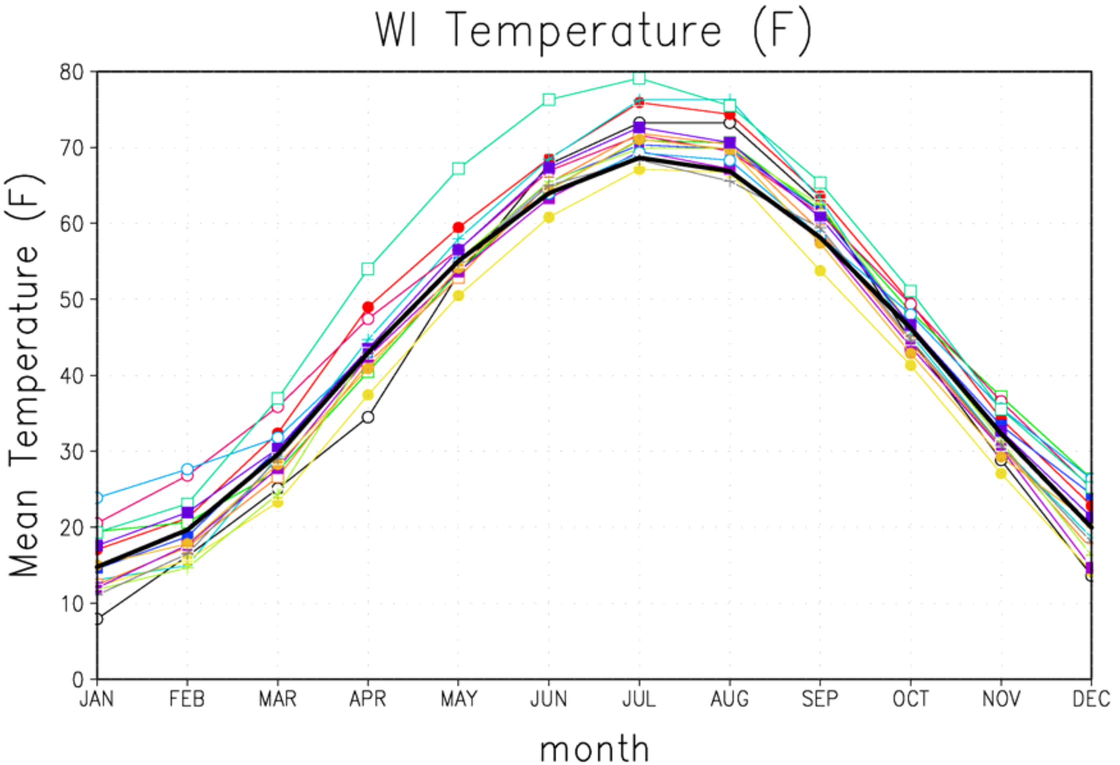
Steve Vavrus, CCR

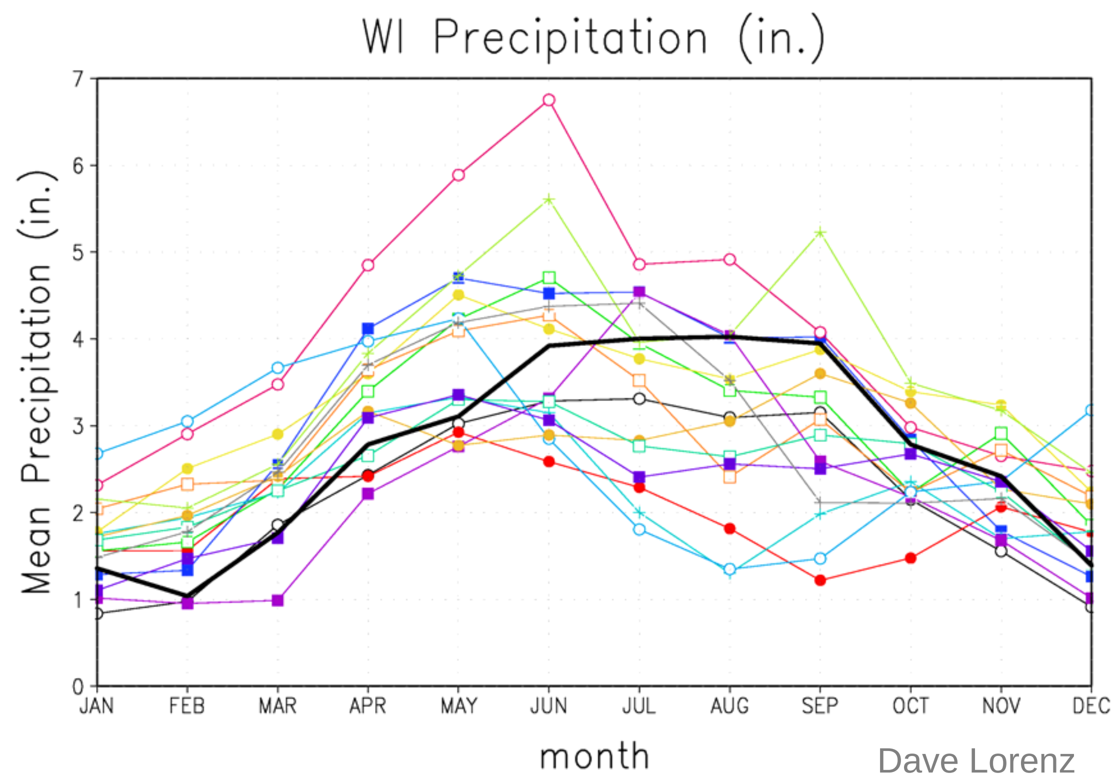
# Training models downscaled to Wisconsin using historic data
(“de-biasing”)

Mean Wisconsin temperature and precipitation for

15 GCMs for 1980-1999

Black line = Observed temperature and precipitation




Dave Lorenz

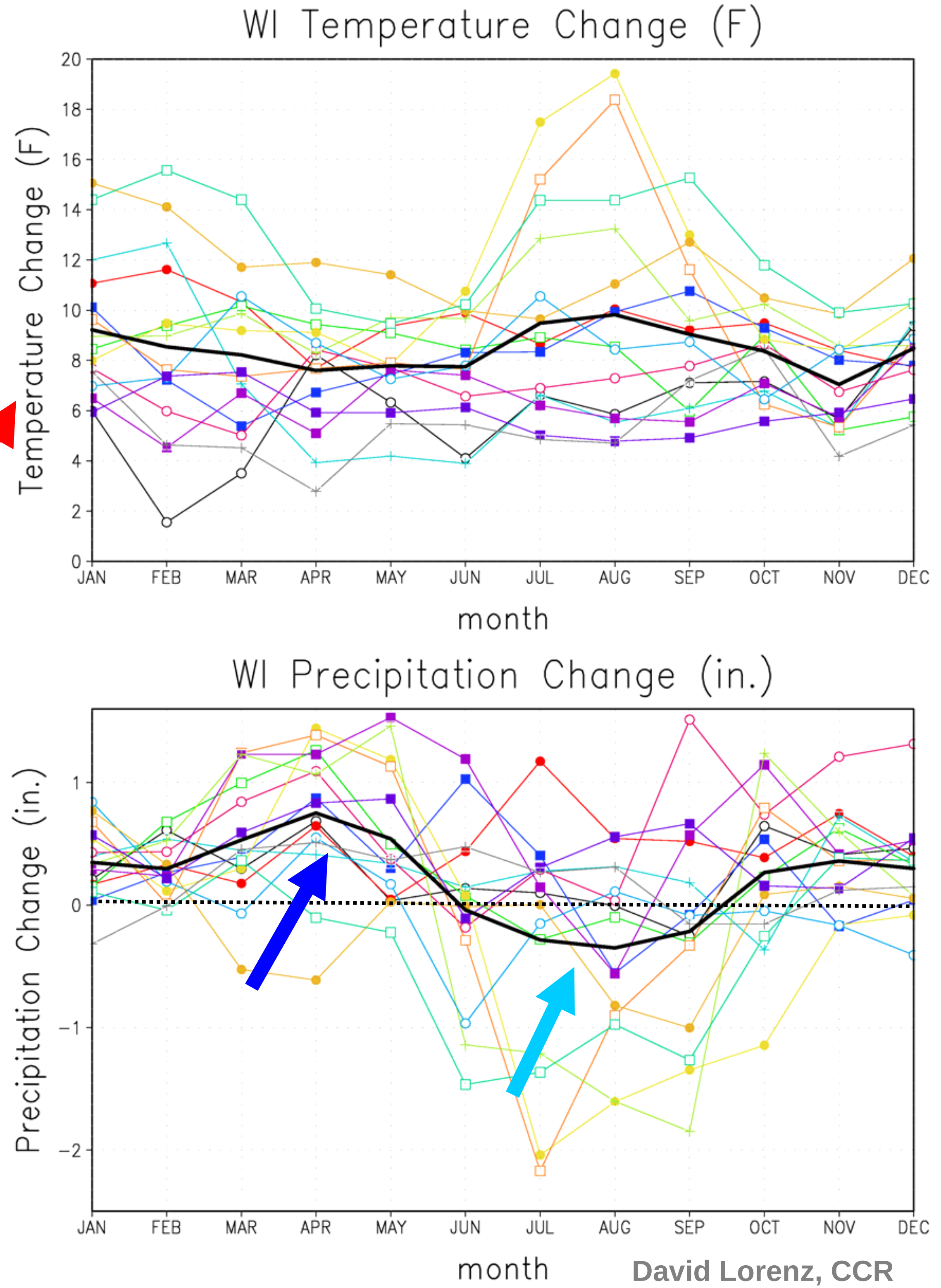
# Change in Wisconsin monthly temperature and precipitation as predicted for 2090 by fifteen downscaled GCMs.

Black line = Average of all models.

January in the 20's

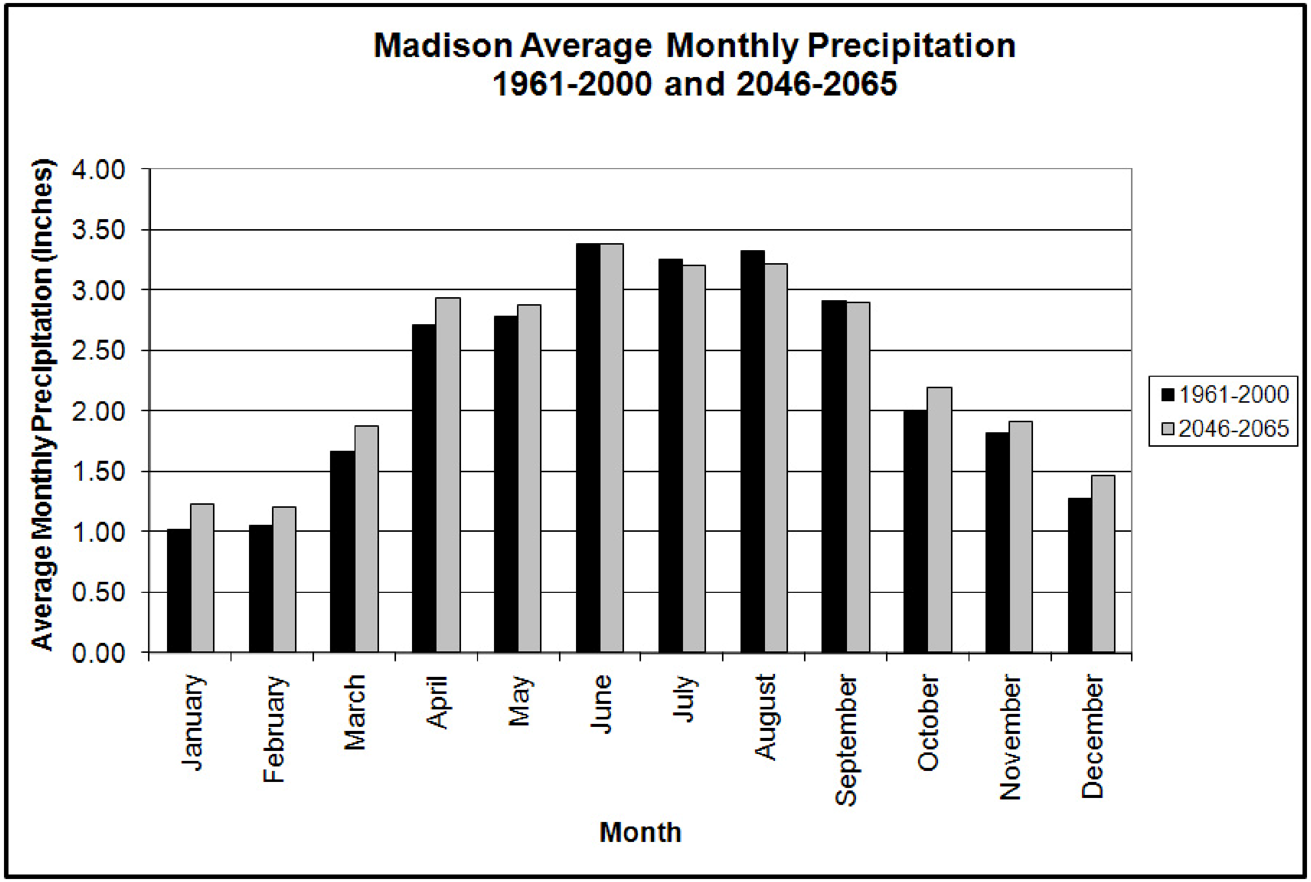
Wetter Spring

Drier Summer
(note uncertainty)




David Lorenz, CCR

# For Madison, monthly precipitation is predicted to change by -3% (August) to +20% (January)




| Madison Average Monthly Precipitation 1961-2000 and 2046-2065 | | | |
|---|---|---|---|
| | **1961-2000** | **2046-2065** | **% Change** |
| **January** | 1.02 | 1.23 | 20.6% |
| **February** | 1.05 | 1.20 | 14.3% |
| **March** | 1.66 | 1.88 | 13.3% |
| **April** | 2.71 | 2.93 | 8.1% |
| **May** | 2.78 | 2.88 | 3.6% |
| **June** | 3.38 | 3.38 | 0.0% |
| **July** | 3.25 | 3.21 | -1.2% |
| **August** | 3.32 | 3.22 | -3.0% |
| **September** | 2.91 | 2.90 | -0.3% |
| **October** | 1.99 | 2.19 | 10.1% |
| **November** | 1.82 | 1.91 | 4.9% |
| **December** | 1.28 | 1.47 | 14.8% |
| **TOTAL** | 27.17 | 28.40 | 4.5% |

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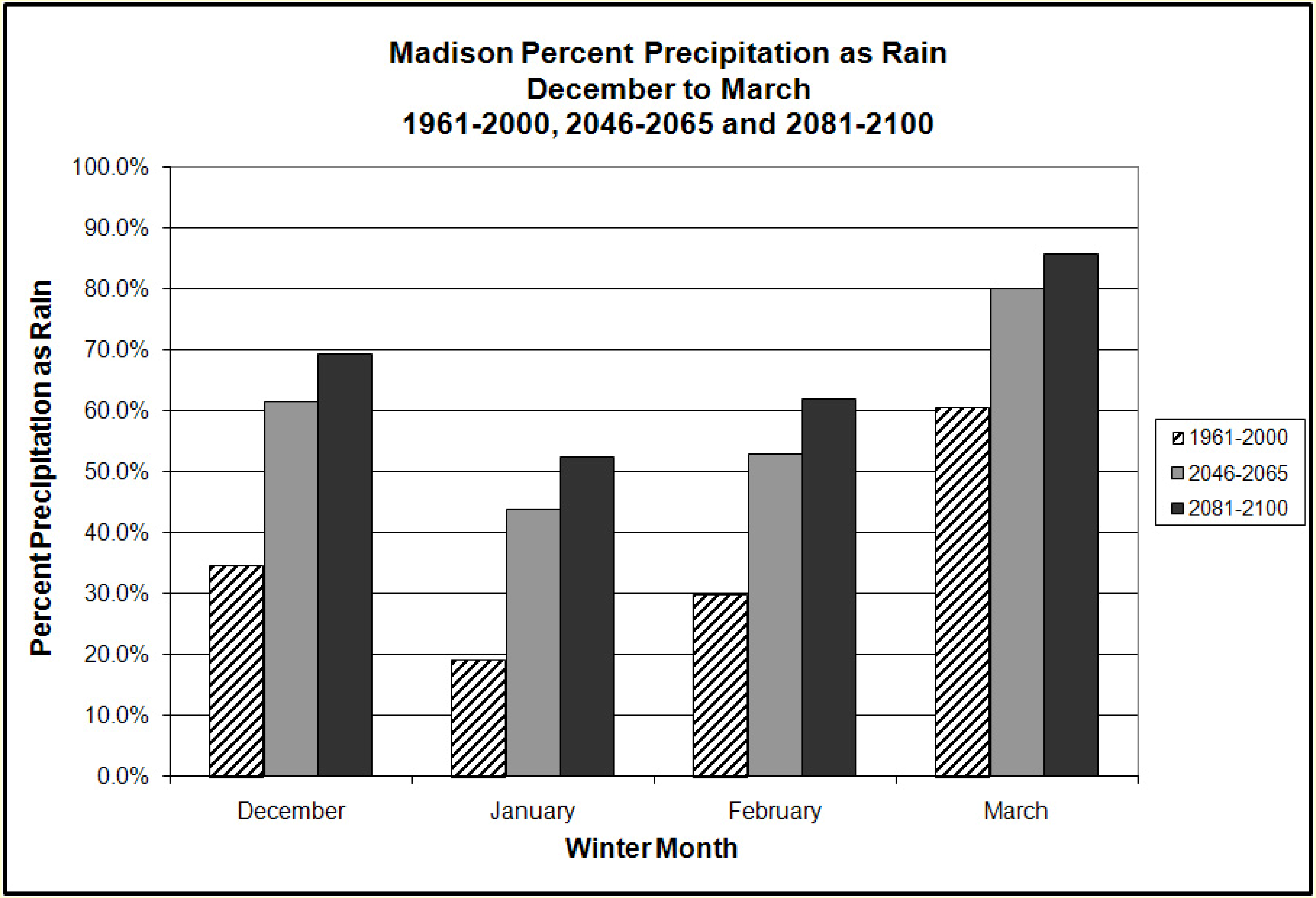
# The % falling as rain during winter is predicted to double

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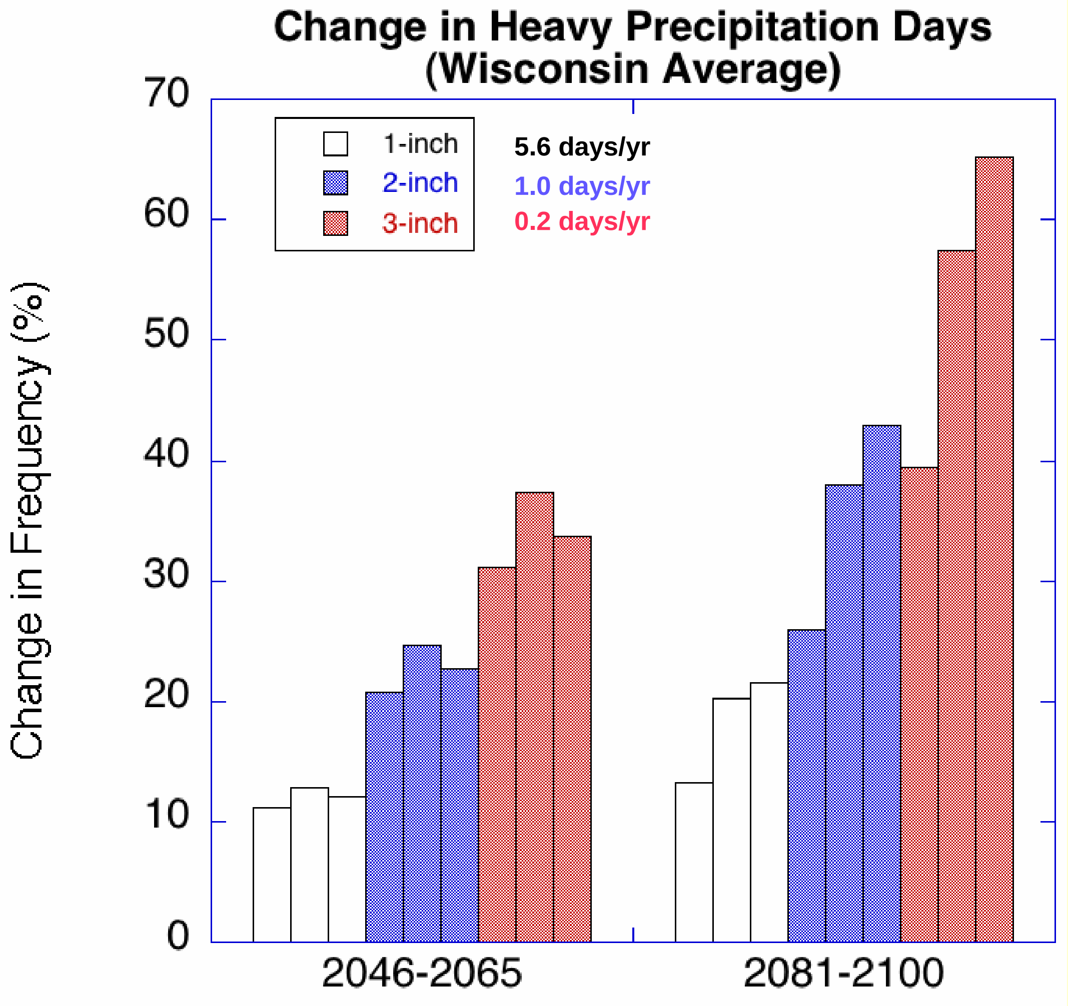
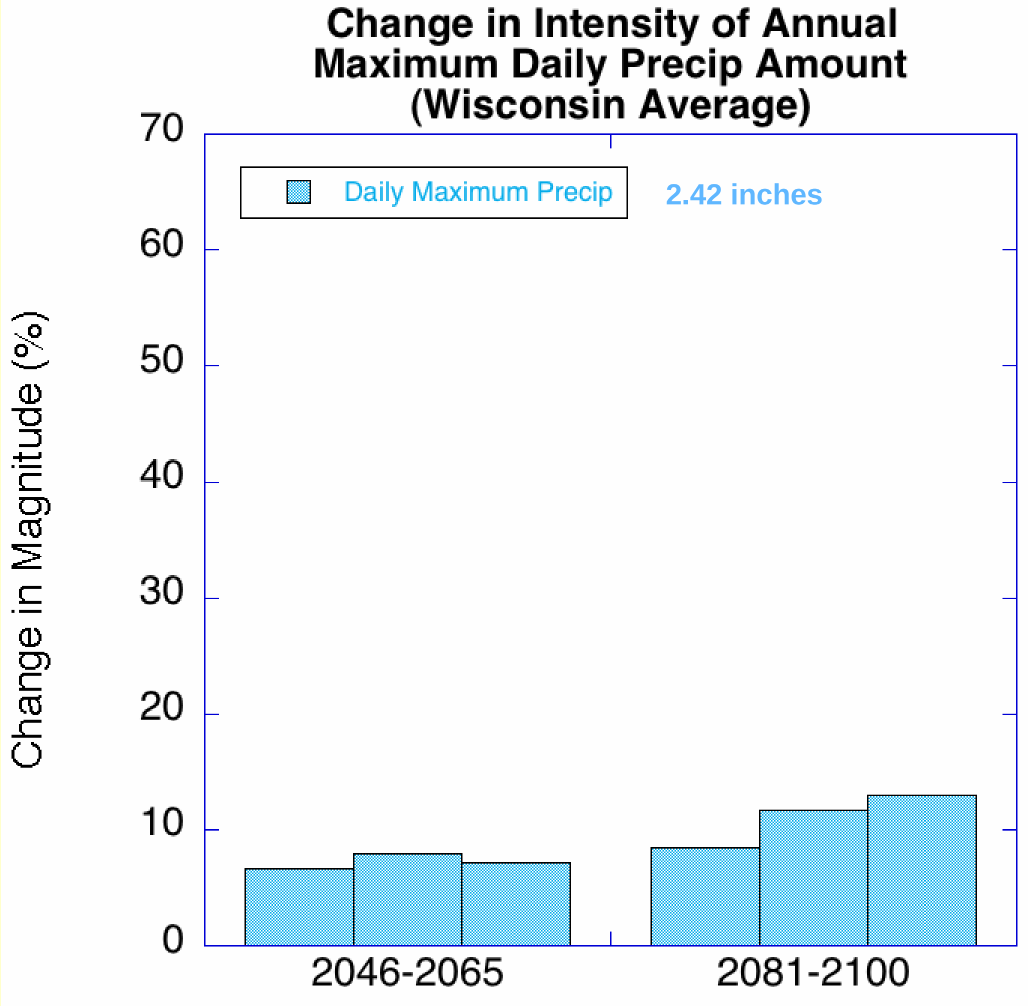
# Intense Precipitation

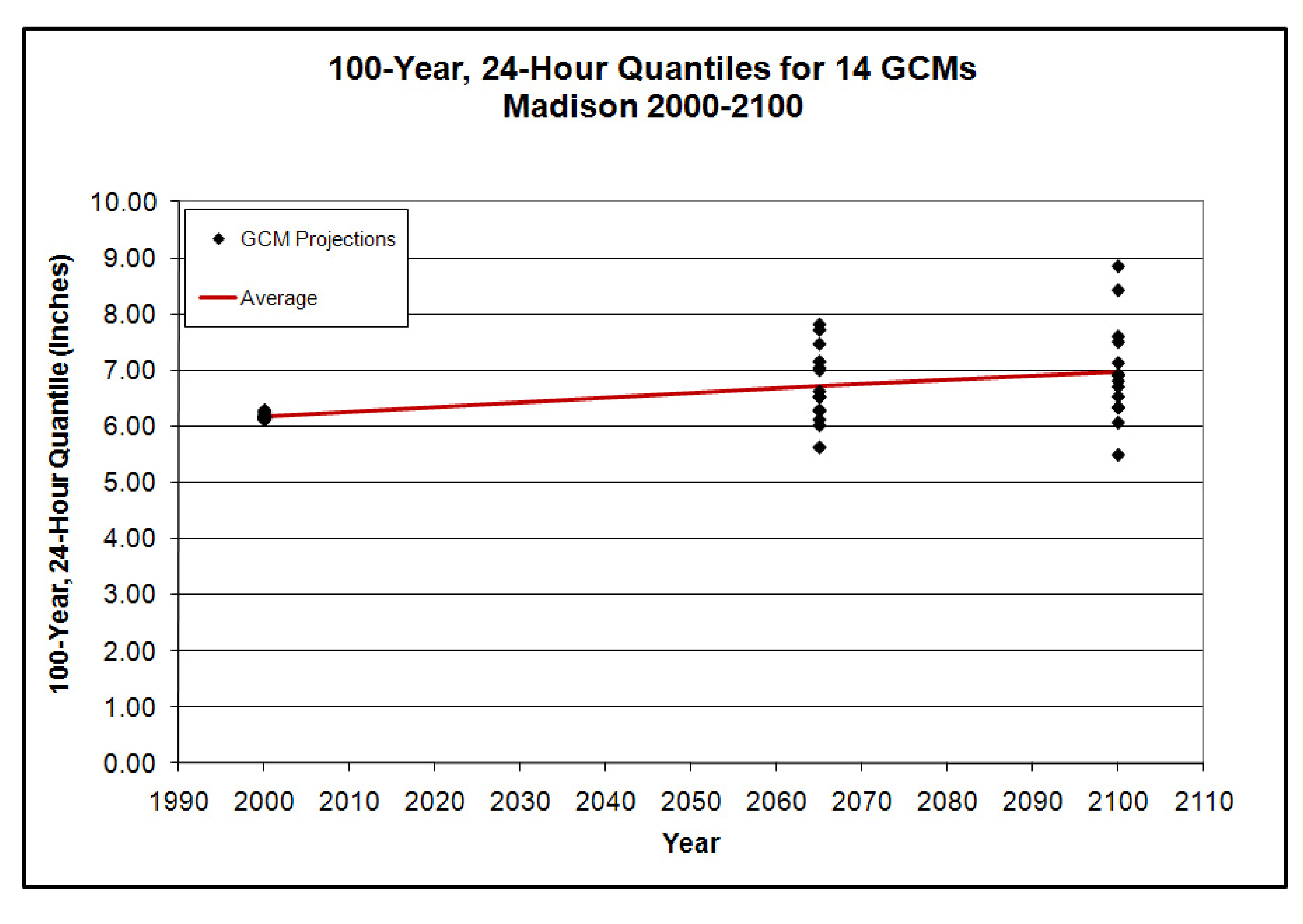
## Increasing in frequency – Moderate increase in intensity




Steve Vavrus

# Heaviest rainfall events are not predicted to increase substantially in number or intensity

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# High Water Impacts

**Upland Runoff**

**River Flooding**

**Urban Flooding**

**Sewer Overflows**


**Groundwater Flooding**

# Flooding

**Stream, River, Lake**
Heavy rainfall over days, preceded by significant rainfall and/or snowmelt

**Local, Urban**
Heavy rainfall over minutes to hours

**Groundwater**
Heavy snow pack and/or persistent heavy rainfall over months or years

# Upland Runoff

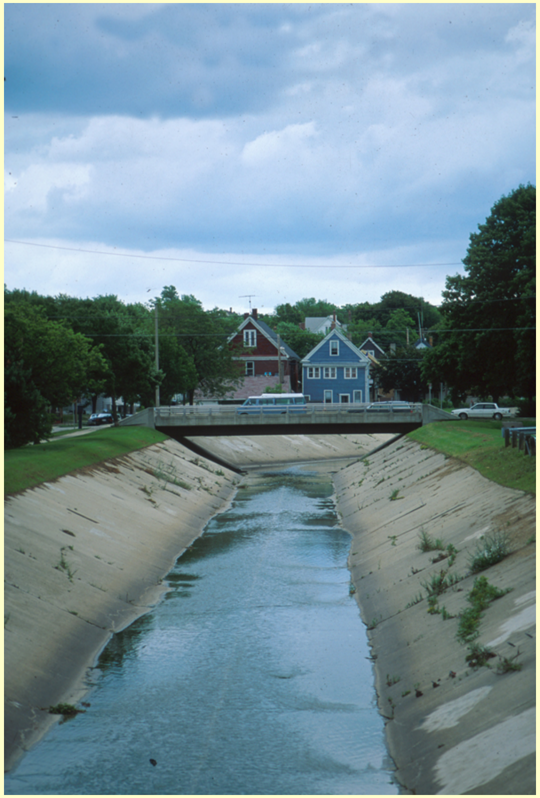
Influenced by springtime conditions

Heavy snow pack = water storage

Frost and high soil moisture =  retard infiltration

Steep slopes and poor ground cover = encourage runoff

**Combined with heavy rainfall……**



# Urban Runoff

## <u>Influenced by the built environment</u>

Impervious surfaces = **no infiltration**

Conveyances = **concentrate flows**

**Combined with heavy rainfall……**

# Groundwater Flooding

<u>Infiltration exceeds transpiration and drainage</u>

Light frost = improves infiltration

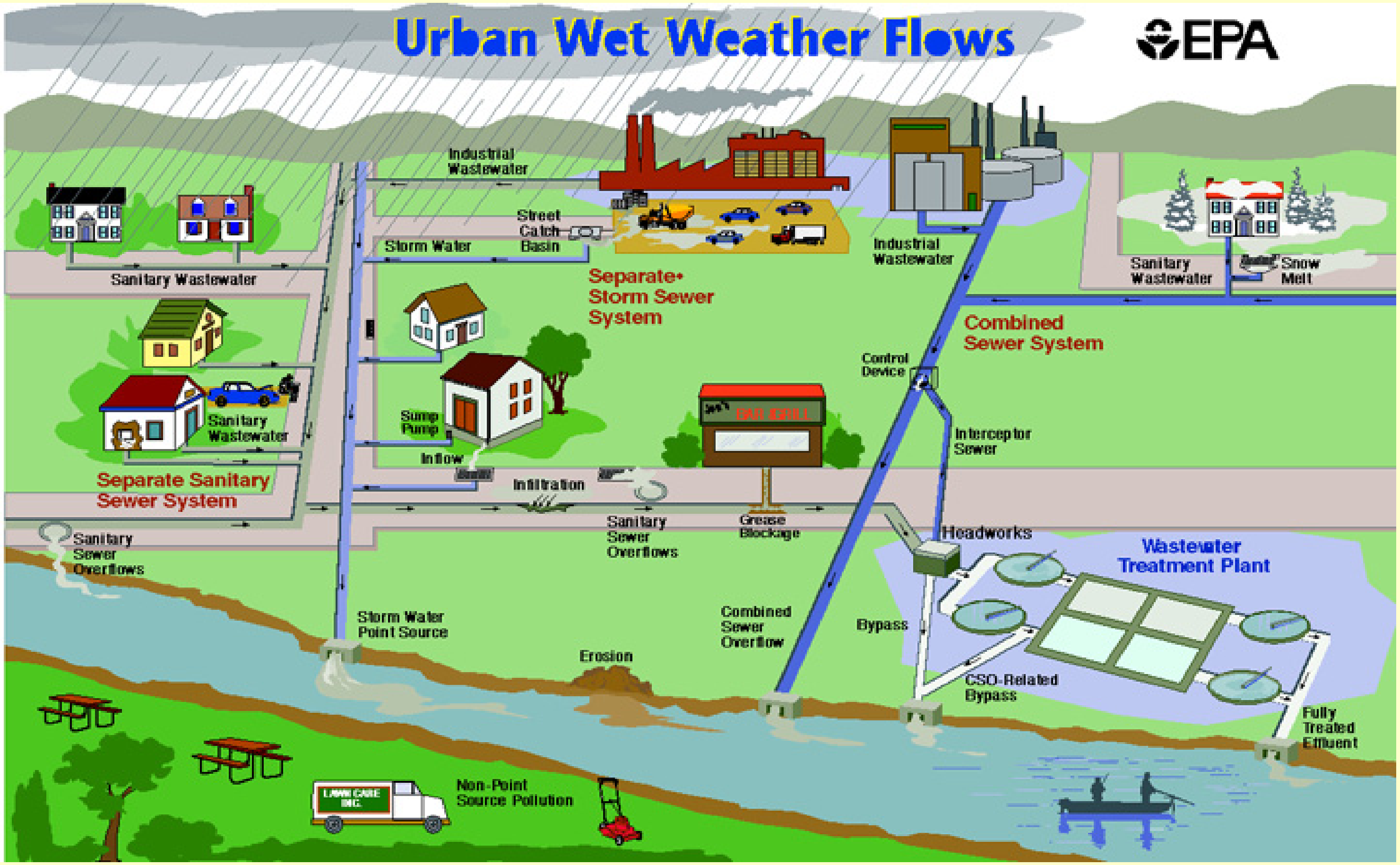
Heavy snow pack = increased moisture available

Early rains = minimal transpiration

Persistent wet weather = exceeds drainage

**Over months to years……**


Peter Gorman



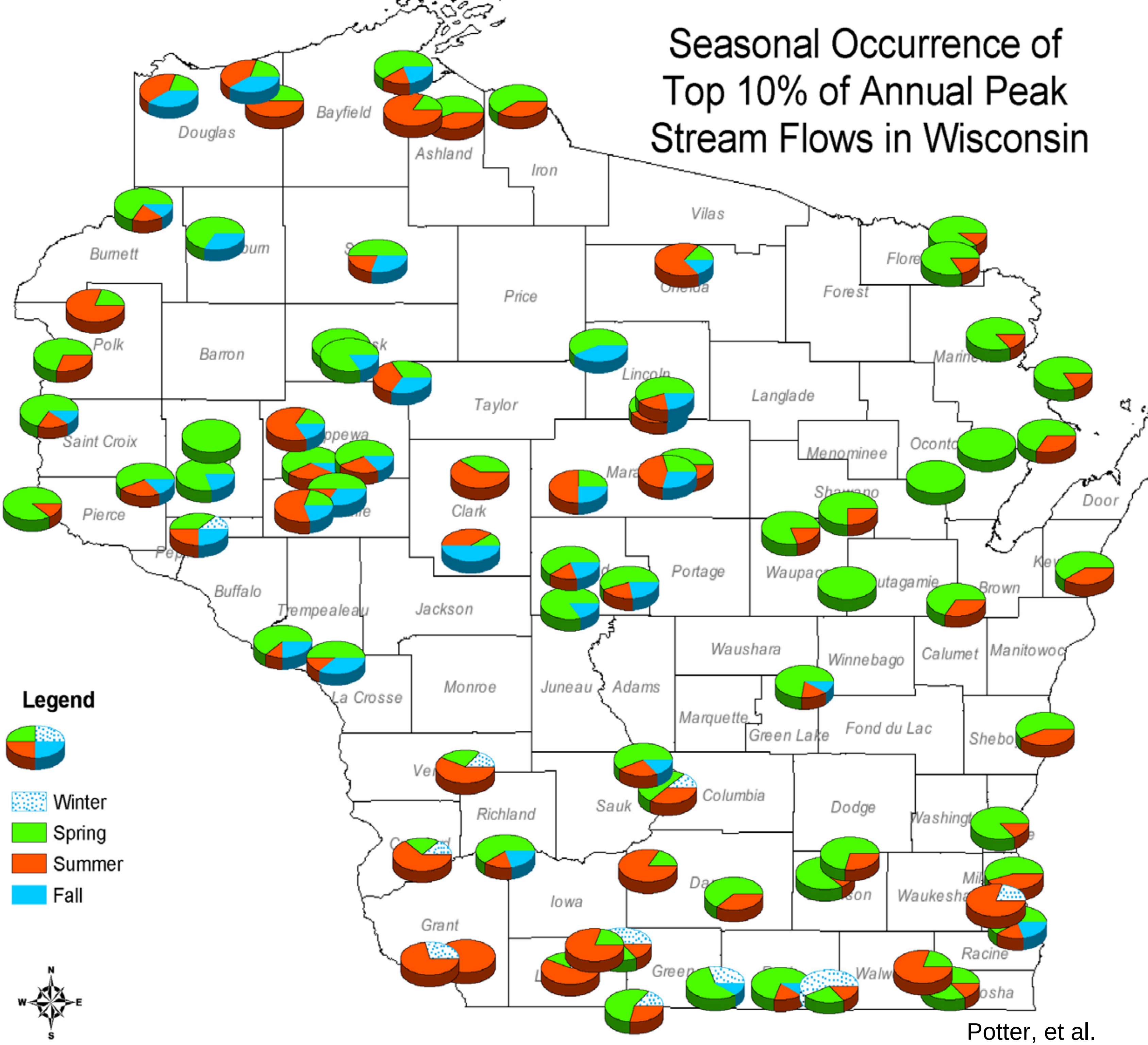

Sanitary Sewer Overflows

Drinking water contamination

# Seasonal Occurrence of Top 10% of Annual Peak Stream Flows in Wisconsin

Wisconsin's high water events occur during spring in many areas of the state.

Climate predictions suggest that early season flooding will increase.

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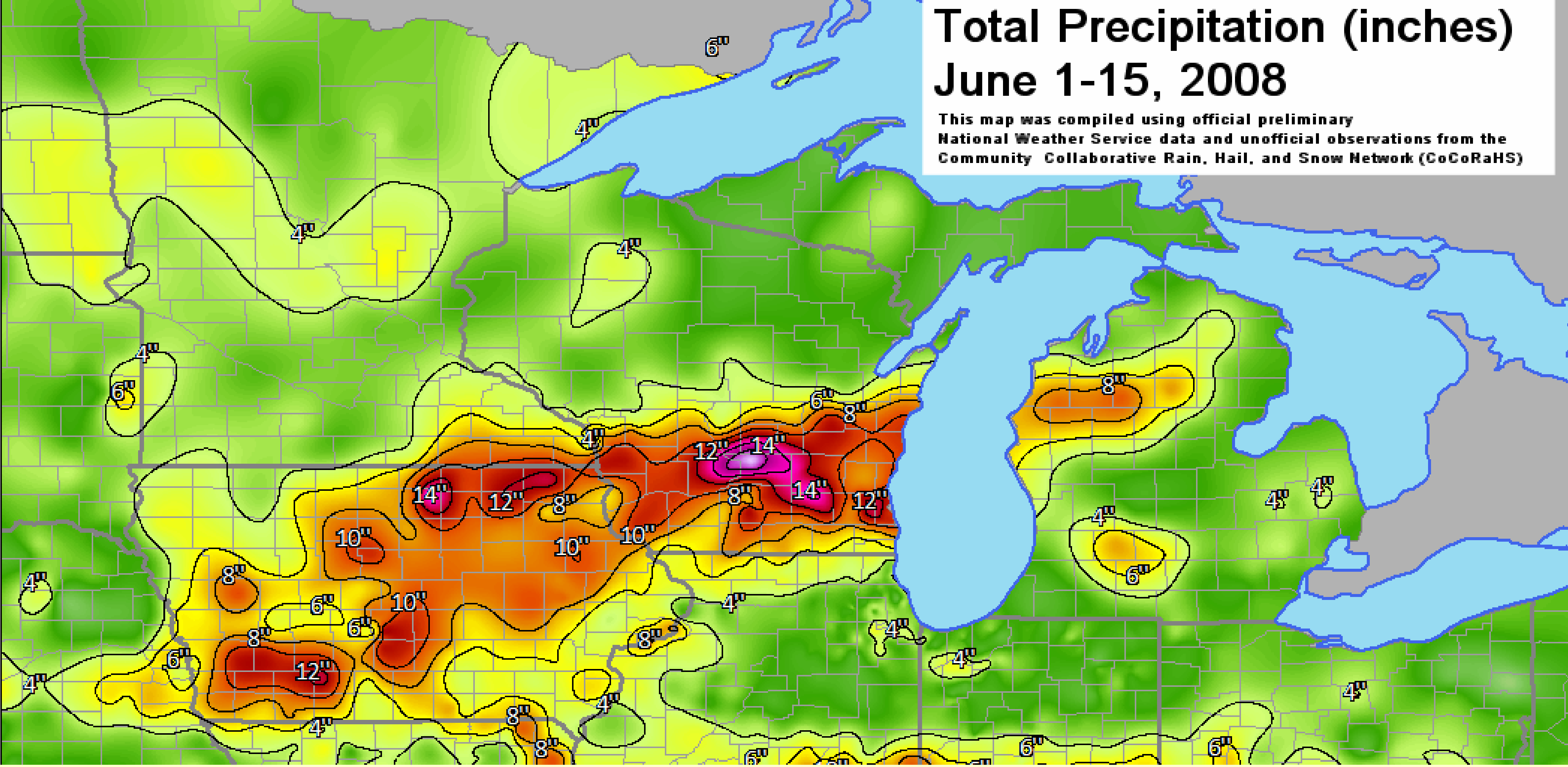



2,500 wells tested; 28% contaminated

161 POTWs diverted 90 million gallons raw sewage

38 river gauges broke records

810 square miles of land flooded

$34M in damage claims paid

Source: FEMA, WEM

# What Do We Think We Can Expect?

Total precipitation and intense precipitation events are projected to increase significantly during the winter and spring months from December to April.

-This has the potential to cause more high water events, especially if the precipitation occurs when the ground is frozen or saturated.

Precipitation occurring as rain during the winter months of December to March is also projected to significantly increase.

- This has the potential to create stormwater management issues and increases the risk of producing high water events during a season where such events currently do not occur in Wisconsin.

Increased precipitation during periods of low evapotranspiration can lead to increased groundwater recharge.

- This has the potential to cause groundwater flooding in agricultural areas and prior-converted wetlands.

Modest increases in the magnitude of intense precipitation events are expected during the 21st century. For example, the 100-year storm event is projected to increase by about 10% by mid-century.

# Unsuccessful Adaptation Strategies

Dredging lakes and streams

Bigger storm drains

More levees

# Successful Adaptation Strategies

**Vulnerability analysis** (i.e. risk & consequence):

Neighborhoods, roadways, impoundments, BMPs, wellheads, agriculture

**Design evolution**:

Surface conveyances, overflow capacity/hardening, distributed detention, POTW infiltration prevention

**Cost evaluation**:

Impact cost vs. risk of failure, link design standards and cost to performance expectations

**Education and Research:**

Training present and future mangers, developing tools for analysis and design, understand the implications of land use

# Vulnerability Analysis

Build upon the experiences of communities that have experienced recent extreme rainfalls to guide a state-wide evaluation of vulnerabilities to climate change impacts, and develop implementation plans to mitigate the identified vulnerabilities.

Consider:

- Floodplains and surface flooding;
- Areas of hydric soils and groundwater flooding;
- Vulnerable infrastructure;
- Stormwater BMPs;
- Sanitary sewer inflow and infiltration;
- Emergency response capacity.

# Design Evolution

Much of our infrastructure is designed with stormwater in mind:

- Roads
- Bridges
- Dams ⟶
- Airports
- Buildings
- Sewers
- Detention Ponds

***Failure can be costly!***

# How much rain do we design for?

A statistical method is used to estimate how often to expect a rainfall of specific intensity and duration.

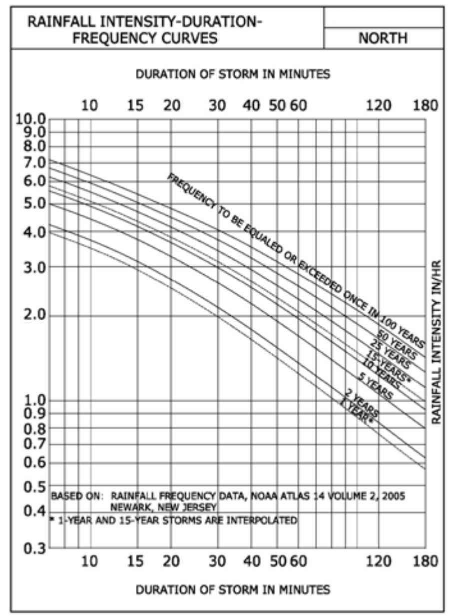



**Table 9. Sectional Mean Frequency Distributions for Storm Periods of 5 Minutes to 10 Days and Recurrence Intervals of 2 Months to 100 Years in Wisconsin**

*Sectional code (see figure 1 on page 4)*

*01 – Northwest*
*02 - North Central*
*03 – Northeast*
*04 - West Central*
*05 – Central*
*06 - East Central*
*07 - Southwest*
*08 - South Central*
*09 - Southeast*

*Rainfall (inches) for given recurrence interval*

| *Section* | *Duration* | *2-month* | *3-month* | *4-month* | *6-month* | *9-month* | *1-year* | *2-year* | *5-year* | *10-year* | *25-year* | *50-year* | *100-year* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08 | 10-day | 1.82 | 2.19 | 2.52 | 2.97 | 3.41 | 3.71 | 4.72 | 5.93 | 6.86 | 8.21 | 9.33 | 10.60 |
| 08 | 5-day | 1.52 | 1.82 | 2.06 | 2.39 | 2.75 | 2.99 | 3.78 | 4.86 | 5.73 | 7.03 | 8.14 | 9.36 |
| 08 | 72-hr | 1.40 | 1.65 | 1.86 | 2.16 | 2.48 | 2.70 | 3.38 | 4.34 | 5.16 | 6.34 | 7.34 | 8.47 |
| 08 | 48-hr | 1.30 | 1.53 | 1.70 | 1.97 | 2.26 | 2.46 | 3.07 | 3.96 | 4.68 | 5.79 | 6.75 | 7.82 |
| 08 | 24-hr | 1.24 | 1.44 | 1.57 | 1.82 | 2.07 | 2.25 | 2.78 | 3.53 | 4.20 | 5.18 | 6.06 | 7.06 |
| 08 | 18-hr | 1.17 | 1.36 | 1.48 | 1.72 | 1.95 | 2.12 | 2.61 | 3.32 | 3.95 | 4.87 | 5.70 | 6.64 |
| 08 | 12-hr | 1.08 | 1.25 | 1.37 | 1.59 | 1.80 | 1.96 | 2.42 | 3.07 | 3.65 | 4.51 | 5.27 | 6.14 |
| 08 | 6-hr | 0.93 | 1.08 | 1.18 | 1.37 | 1.55 | 1.69 | 2.09 | 2.65 | 3.15 | 3.88 | 4.55 | 5.30 |
| 08 | 3-hr | 0.79 | 0.92 | 1.01 | 1.17 | 1.32 | 1.44 | 1.78 | 2.26 | 2.69 | 3.32 | 3.88 | 4.52 |
| 08 | 2-hr | 0.71 | 0.83 | 0.91 | 1.05 | 1.20 | 1.30 | 1.61 | 2.05 | 2.44 | 3.00 | 3.51 | 4.09 |
| 08 | 1-hr | 0.58 | 0.68 | 0.74 | 0.86 | 0.98 | 1.06 | 1.31 | 1.66 | 1.97 | 2.43 | 2.85 | 3.32 |
| 08 | 30-min | 0.46 | 0.53 | 0.58 | 0.67 | 0.76 | 0.83 | 1.03 | 1.31 | 1.55 | 1.92 | 2.24 | 2.61 |
| 08 | 15-min | 0.34 | 0.39 | 0.43 | 0.49 | 0.56 | 0.61 | 0.75 | 0.95 | 1.13 | 1.40 | 1.64 | 1.91 |
| 08 | 10-min | 0.26 | 0.30 | 0.33 | 0.38 | 0.43 | 0.47 | 0.58 | 0.74 | 0.88 | 1.09 | 1.27 | 1.48 |
| 08 | 5-min | 0.15 | 0.17 | 0.19 | 0.22 | 0.25 | 0.27 | 0.33 | 0.42 | 0.50 | 0.62 | 0.73 | 0.85 |

For the Madison area we expect 7” of rain during 24 hours at least once in 100 years.

# Design is based on experience (i.e. history)

For TP-40, data from 200 primary and 5,000 secondary weather stations were used for an analysis of rainfall events during 1938 – 1958.

U.S. DEPARTMENT OF COMMERCE
LUTHER H. HODGES, Secretary

WEATHER BUREAU
F. W. REICHELDERFER, Chief

TECHNICAL PAPER NO. 40

RAINFALL FREQUENCY ATLAS OF THE UNITED STATES

for Durations from 30 Minutes to 24 Hours and
Return Periods from 1 to 100 Years

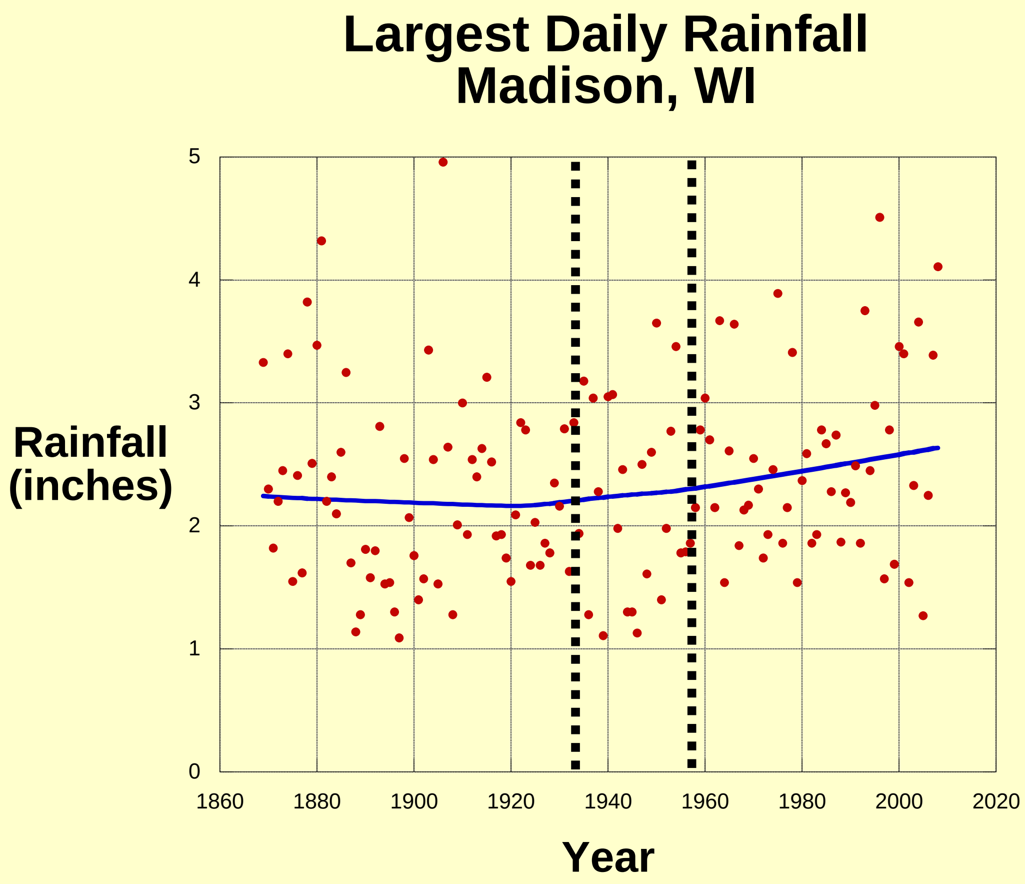
Prepared by
DAVID M. HERSHFIELD
Cooperative Studies Section, Hydrologic Services Division
for
Engineering Division, Soil Conservation Service
U.S. Department of Agriculture

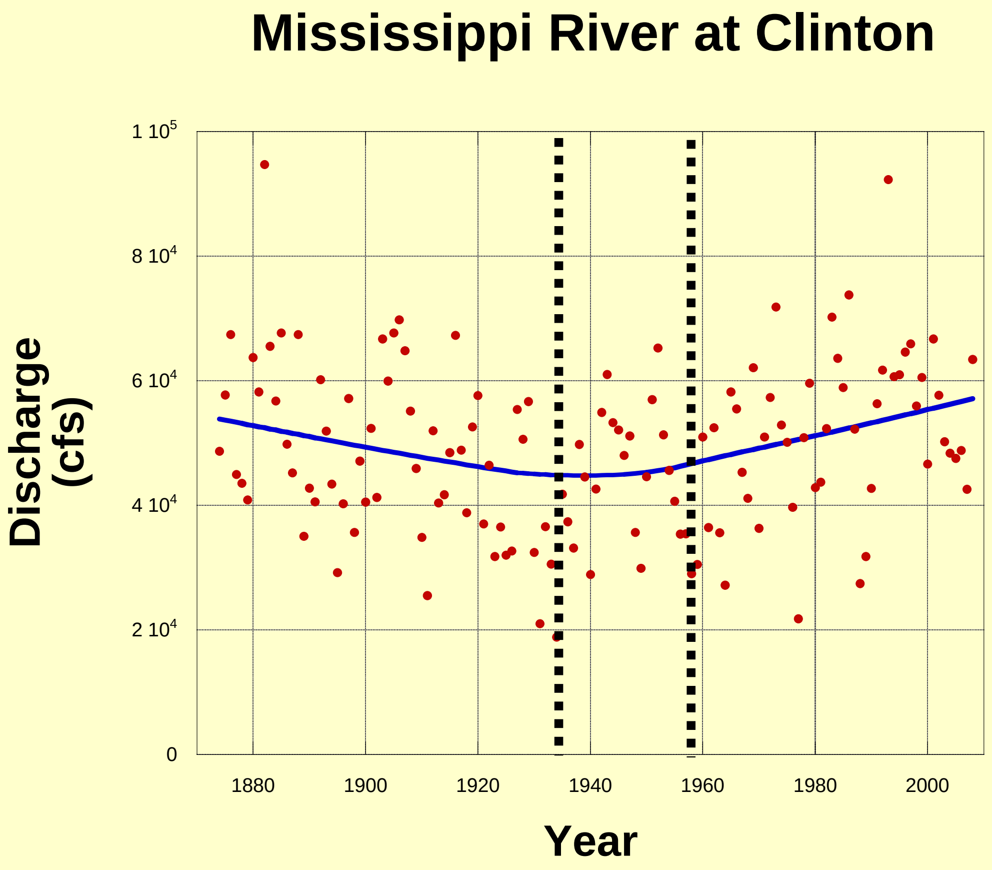
WASHINGTON, D.C.
May 1961
[illegible]ginated an[illegible] January 1963

For sale by the [illegible]ntendent of Documents, U.S. Government Printing Office, Washington 25, D.C. Price $1.25

**(MAY 1961)**

Records suggest that the TP-40 analysis may actually reflect a dry period.




***Should we be designing for a changing climate?***

# Design standards using more representative events

**NOAA Atlas 14 vs. TP-40**

(100-Year Recurrence Interval)

| | 1-hour (%) | 6-hour (%) | 12-hour (%) | 24-hour (%) |
|---|---|---|---|---|
| Illinois n = 43 | 5.9 (-7.7; 15.4) | 9.9 (-2.2; 45.8) | 5.6 (-5.4; 37.8) | 7.0 (-7.9; 46.2) |
| Indiana n = 24 | 7.0 (-5.5; 15.4) | 11.7 (-1.2; 23.3) | 6.5 (-7.2; 21.2) | 9.4 (-2.2; 28.2) |
| Kentucky n = 15 | 2.9 (-1.7; 8.7) | 5.3 (-4.0; 13.2) | 3.5 (-6.8; 8.1) | 9.4 (-2.2; 20.9) |
| Ohio n = 32 | 3.5 (-3.3; 9.4) | 9.8 (0.2; 22.1) | 5.4 (-4.8; 18.2) | 11.3 (-1.8; 26.0) |

Todd, C. E., J. M. Harbor, and B. Tynor, Increasing magnitudes and frequencies of extreme precipitation events used for hydraulic analysis in the Midwest, 2006, *Journal of Soil and Water Conservation*, 61, 179- 184.

# In Short….

Climate predictions indicate an increase in amount and intensity of precipitation, especially in late winter and spring.

Recent precipitation events may be a trend that is consistent with these predictions.

Our runoff management decisions are often based on design models derived from drier conditions.

***We should reevaluate our design criteria to accommodate increased heavy rainfall, and groundwater flooding.***

# Cost Evaluation

Adaptation horizons can be far off:

- Sanitary sewer system planning ~ 30 yr

Unless there is an immediate benefit (i.e. present vulnerability), the discount rate on large projects may offset savings from anticipating impacts in the design.

Ongoing research on this topic….

# Education and Research

Periodically reevaluate and revise climate and hydrologic design models and criteria.

Develop tools and build professional capacity to distinguish the hydrologic effects of local and regional human activities from climate change.

Evaluate and improve strategies for managing high water.

Establish curriculum to build professional capacity for the coming generation of managers.

# Improved Information is Needed

- Fine scale rainfall data
- Real time stream-flow data
- Detailed understanding of sub-watershed characteristics
- Updated estimates of flood profiles
- Robust groundwater monitoring
- Models to predict groundwater impacts
- Locate flood-prone/at-risk areas, wells, septic systems, hazardous materials, petroleum storage
- Identify at-risk road-crossings
- Impact of events on wastewater treatment capacity

# What does all this mean for water resource management?

Should we invest $M's in adapting infrastructure to increases of intense storms predicted by GCMs?

– ***Probably not yet*.**

Should we be certain that our systems can cope with events of the magnitude recently seen?

– ***That would be wise.***

***We need:*** ***Better data***

***Enhanced monitoring and prediction systems***

***Updated engineering design standards***

***Well trained and aware professionals***

# Questions? …wade right in

Wisconsin Initiative on Climate Change Impacts

NOAA

UW Extension Cooperative Extension

College of Engineering University of Wisconsin-Madison