Determining Present and Future Precipitation Frequency

Dr. Momcilo Markus
Principal Research Scientist, ISWS, Prairie Research Institute
Research Assoc. Prof., Dep. of Nat. Res. and Environ. Sci.
Research Assoc. Prof., Dep. of Agric. and Biol. Eng.
University of Illinois at Urbana-Champaign

Presentation for Interstate Council on Water Policy
November 4, 2020

ILLINOIS

Outline

- Background
- Present Precipitation
  - Bulletin 75 *Illinois Department of Commerce and Economic Opportunity (coordinated by IDNR), 2017-2019*
- Future Precipitation
  - Northeastern Illinois *NOAA, 2015 & USACE, 2016*
  - Northeastern United States and Texas *NOAA, 2017-2020*
- Summary

Rainfall Frequency vs. Rainfall Forecasting

Rainfall Forecasting

- HOW MUCH?
- WHEN?

Rainfall Frequency Estimation

- HOW MUCH?
- HOW OFTEN?

Rainfall Frequency vs. Rainfall Forecasting

Rainfall Forecasting

- HOW MUCH?
- WHEN?

Rainfall Frequency Estimation

- HOW MUCH?
- HOW OFTEN?

Used for long-term planning, mapping, design (highways, airports, urban drainage, flood protection) and other applications.

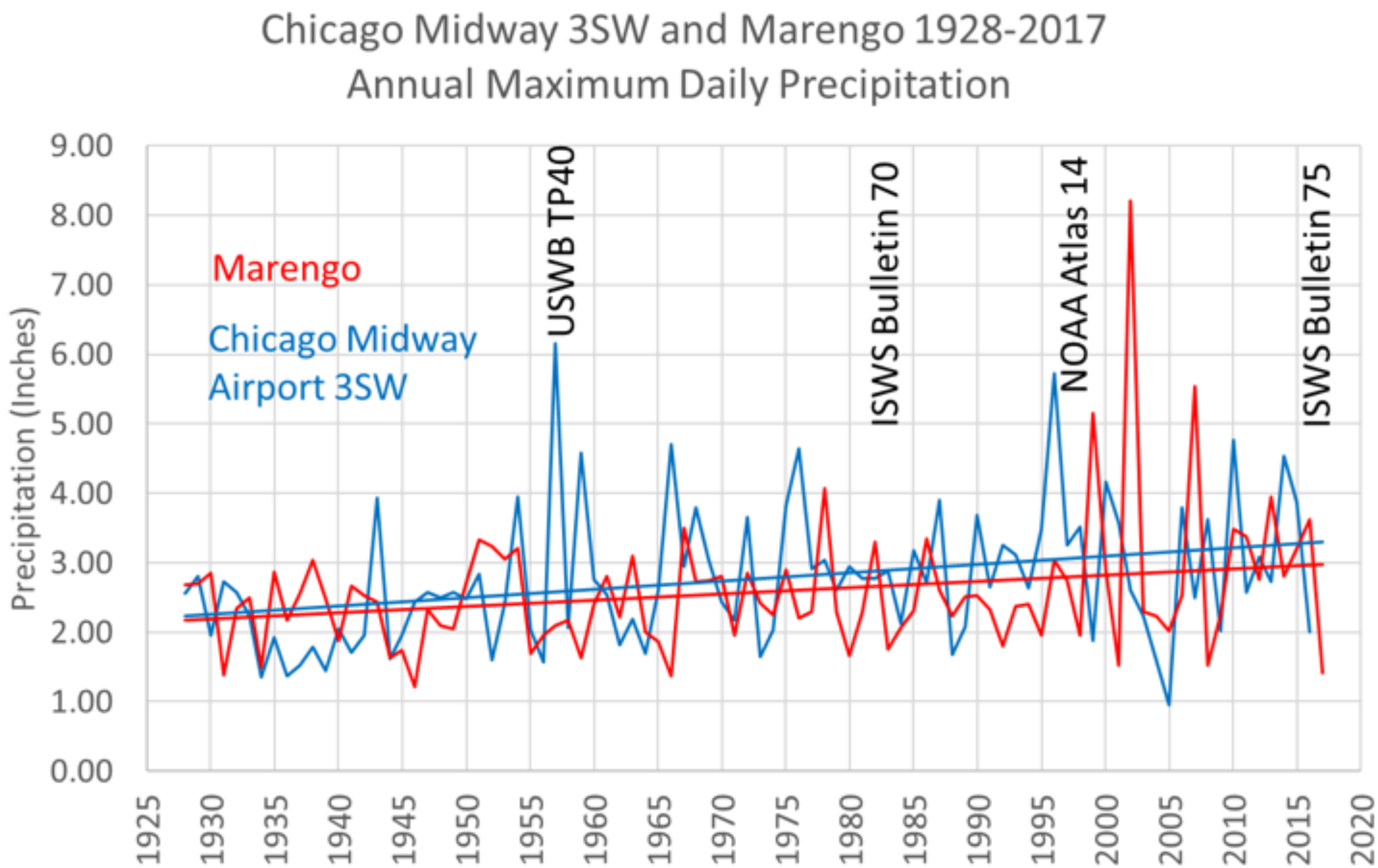
Bulletin 75
Frequency Estimates for Illinois

- Bulletin 75 is a report published by ISWS (2020) containing tables and figures with expected rainfall amounts for selected storm durations and return periods (for example, the 24-hour, 100-year storm for a site in Illinois).
- Bulletin 75 is used by many federal, state and local agencies and consulting companies in Illinois.

Historical progression of rainfall frequency standards for Illinois

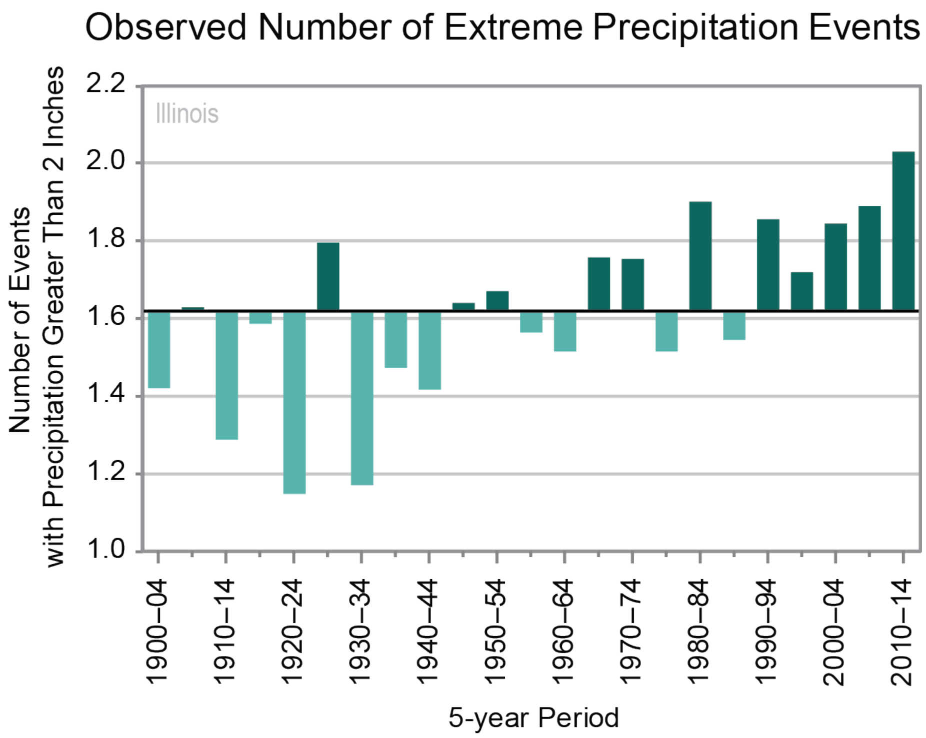
- 1961: Weather Bureau: TP-40 (Hershfield, 1961) Data: 1900-1958
- 1989: Bulletin 70 (Huff and Angel, 1989) Data: 1900-1983
- 2004: NOAA Atlas 14 (Bonnin et al., 2004) Data: 1900-1999
- 2020: Bulletin 75 Data: 1948-2017

(https://www.ideals.illinois.edu/handle/2142/106653)

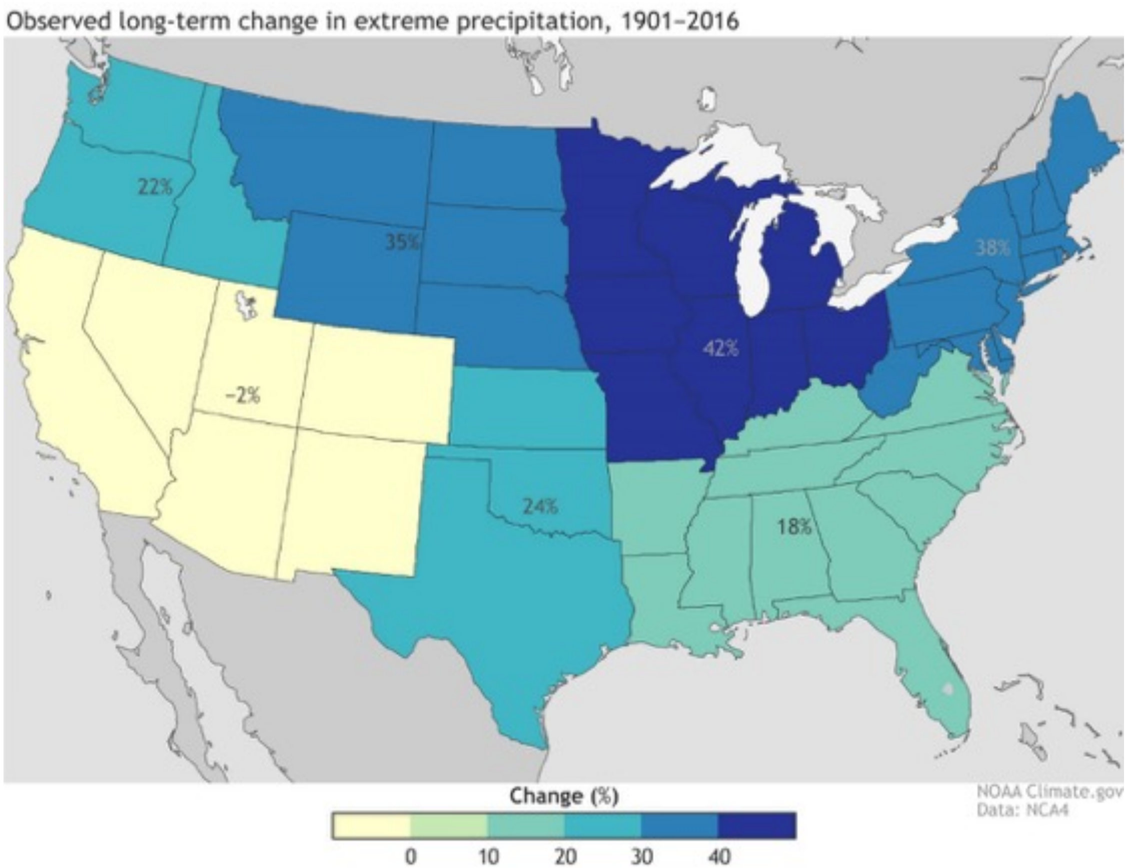


Chicago Midway 3SW and Marengo 1928-2017
Annual Maximum Daily Precipitation
Precipitation (Inches)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Marengo
Chicago Midway
Airport 3SW
USWB TP40
ISWS Bulletin 70
NOAA Atlas 14
ISWS Bulletin 75

Observed trends in frequency of heavy storms in Illinois



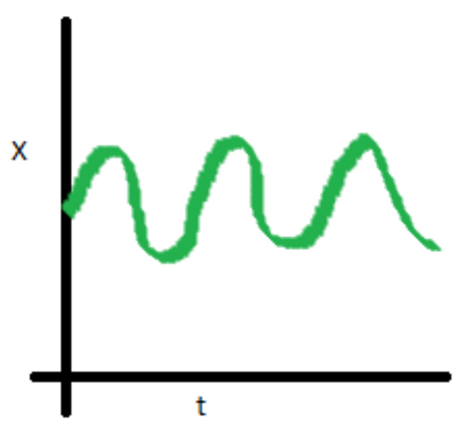
Change in the top 1% of extreme precipitation (the 99th percentile)



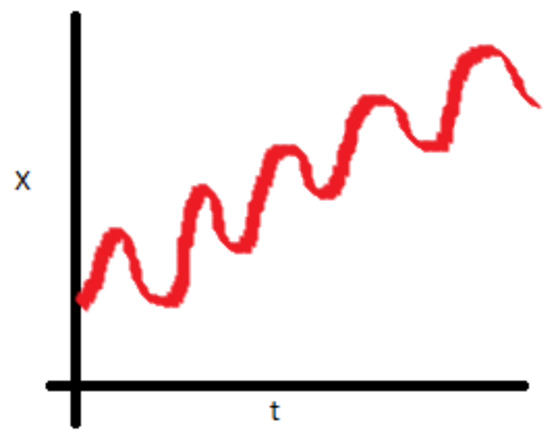
https://science2017.globalchange.gov/

Stationarity of heavy rainfall

- Traditional assumption: Future variability will be like past variability. This assumption is called “stationarity.”



Stationary series



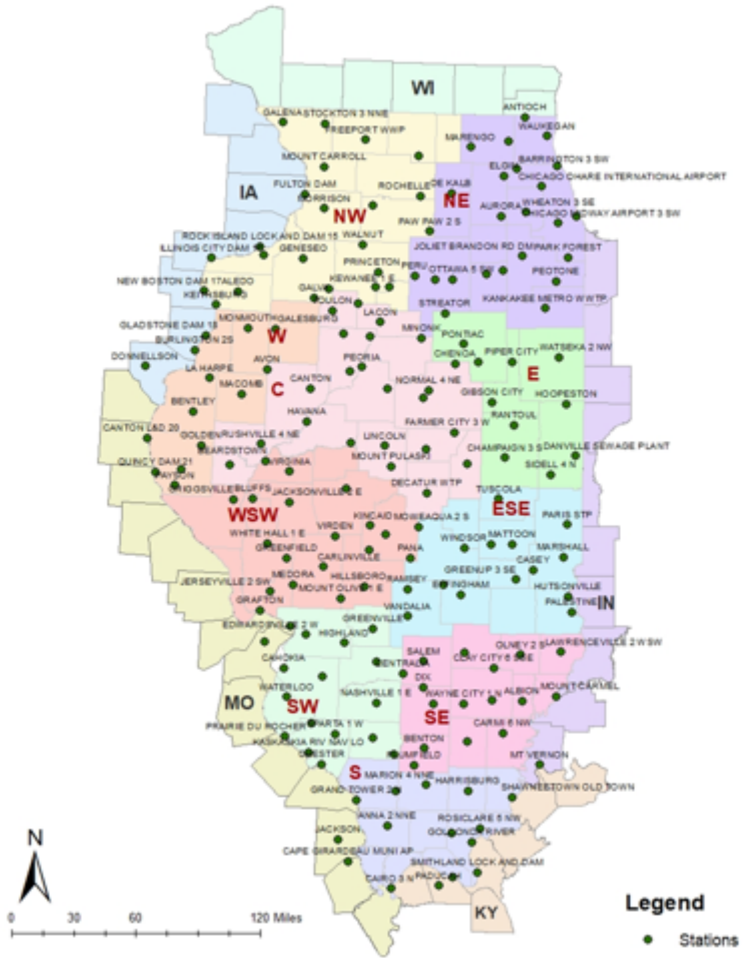
Non-Stationary series

- In the light of observed changes in precipitation, assumption of stationarity may not be adequate for precipitation frequency analysis.

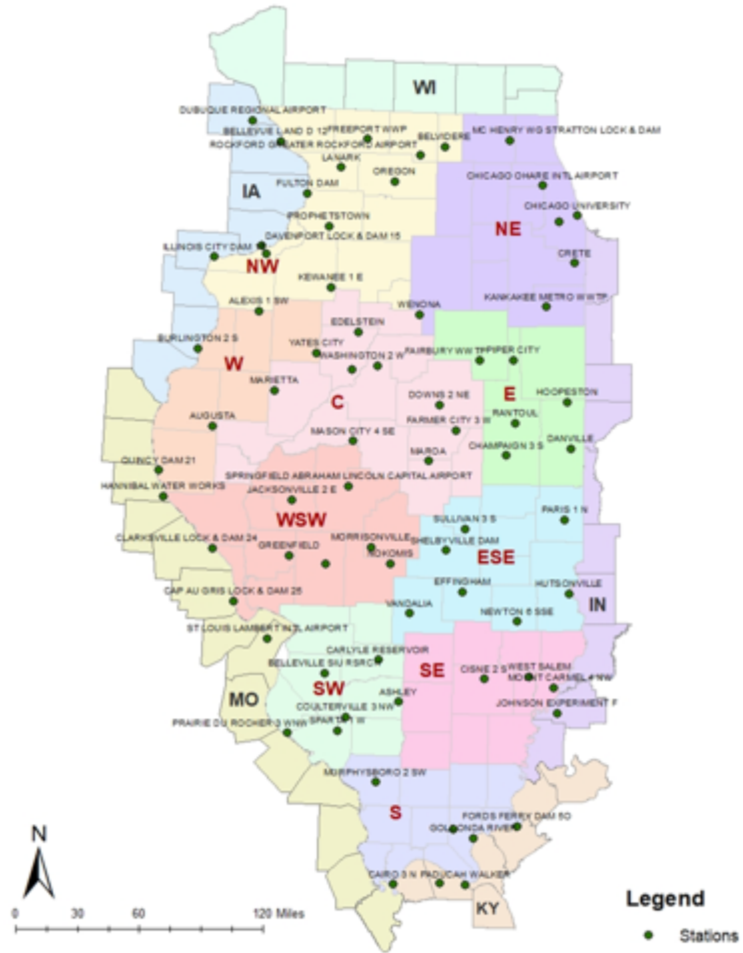
Data Preparation

- Use 1948-2017 data to better represent the current, wetter climate
- Three times as many stations are available from 1948 onward
- Included a Bulletin 70 style adjustment to account for the increasing trend in heavy rainfall events

176 Daily Precipitation
Stations 1948-2017



73 Hourly Precipitation
Stations 1948-2017



Process

- Obtained and QC’d the data
- Selected stations based on availability and length of record
- Calculated the expected precipitation at selected return periods and durations using L-moments before adjusting it for trend

Process

- Adjusted the results from the annual maximum series (AMS) into a partial duration series (PDS) using a standard approach (Langbein's equation (1949))
- Converted the constrained data to unconstrained data using standard conversions

Table 1 Conversion from Constrained to Unconstrained Precipitation Adopted in this Study

From	1 day	2 days	3 days	5 days	10 days
To	24 hours	48 hours	72 hours	120 hours	240 hours
Conversion factor	1.13	1.04	1.02	1.01	1.00

Conversion Ratios

Factors used for X-hour to 24-hour conversions

Storm Duration (hrs)	1	2	3	6	12	18
X-hr/24-hr Ratio	0.47	0.58	0.64	0.75	0.87	0.94

Factors used to calculate frequency estimates for recurrence intervals less than 2 years based on the known estimates for 2 years recurrence interval.

2 months to 2 years	3 months to 2 years	4 months to 2 years	6 months to 2 years	9 months to 2 years	1 year to 2 years
0.470	0.538	0.590	0.672	0.762	0.830

Ratios used to calculate sub-hourly frequency estimates based on the known hourly estimates, x-minute/1-hour

5-minute/1-hour	10-minute/1-hour	15-minute/1-hour	30-minute/1-hour
0.255	0.447	0.574	0.787

Process …

- Averaged the station frequency values into a regional frequency analysis (RFA)

Adjustment for Nonstationarity

- Included a heuristic Bulletin 70 style adjustment to account for the increasing trend in heavy rainfall events.

$$RFA = NAF \cdot RFA_0 = RFA_0 \frac{RFA_2}{RFA_1}$$

Adjustment for Nonstationarity

- Ratio of the 1983-2017 RFA divided by the 1948-1982 RFA

Table 3 Temporal Trend Adjustment Factors for 10 Sections

	Climatic section	24 hrs	48 hrs	72 hrs	120 hrs	240 hrs	Average
1	Northwest	1.07	1.07	1.03	1.05	1.12	1.07
2	Northeast	1.06	1.12	1.13	1.18	1.21	1.14
3	West	1.00	0.96	0.91	0.92	1.02	0.96
4	Central	1.02	0.94	0.94	0.97	1.08	0.99
5	East	0.99	0.94	0.92	0.96	1.02	0.97
6	West Southwest	0.99	0.97	0.98	1.02	1.10	1.01
7	East Southeast	1.05	0.97	1.02	1.01	1.12	1.03
8	Southwest	1.11	1.09	1.10	1.13	1.26	1.14
9	Southeast	1.07	1.09	1.04	1.03	1.09	1.06
10	South	0.96	1.02	1.06	1.03	0.99	1.01

Confidence Intervals for NE Illinois (example)

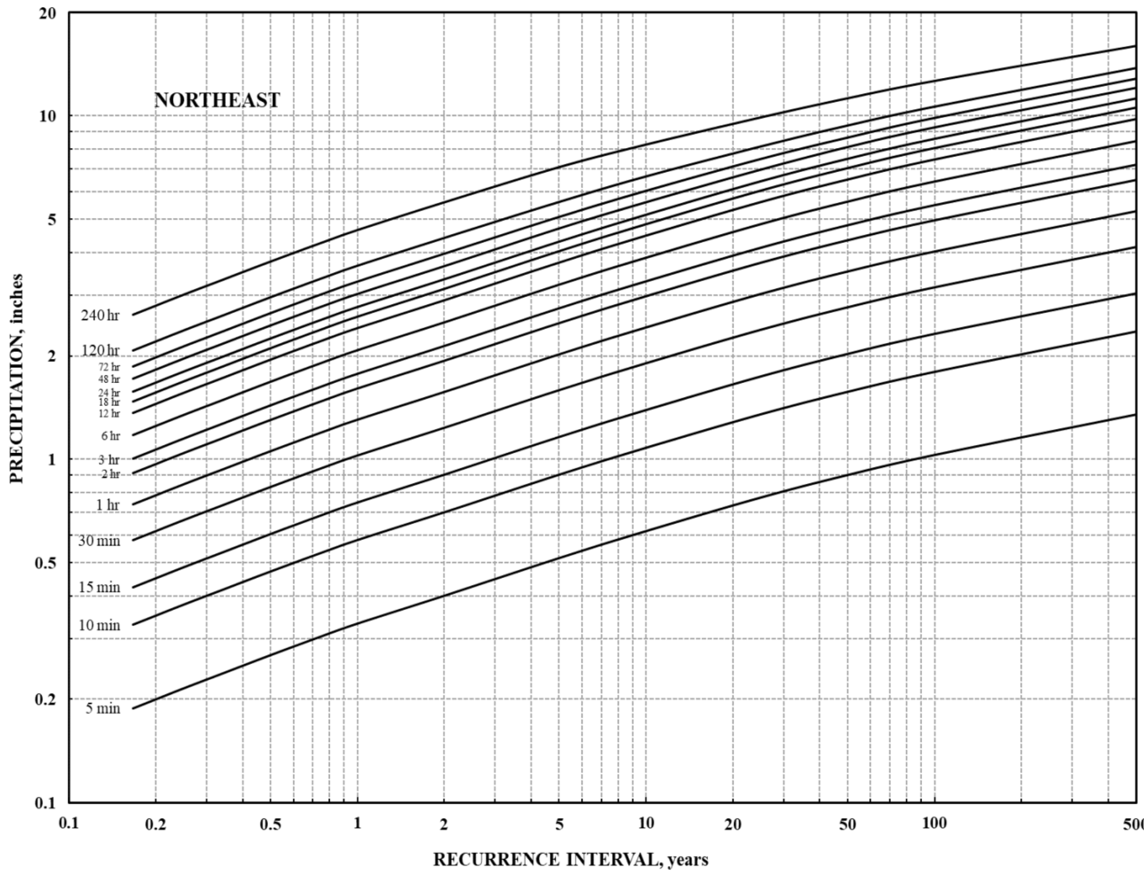
Table 6 Precipitation Frequency Estimates (in inches) with 90% Confidence Intervals (continued)

Storm Code	Section Code	Recurrence interval						
		2-year	5-year	10-year	25-year	50-year	100-year	500-year
5	1	**3.34** (3.00 - 3.69)	**4.22** (3.79 - 4.68)	**5.03** (4.50 - 5.61)	**6.20** (5.51 - 6.99)	**7.20** (6.34 - 8.21)	**8.25** (7.20 - 9.54)	**10.84** (9.16 - 13.00)
5	2	**3.34** (3.00 - 3.69)	**4.30** (3.85 - 4.77)	**5.15** (4.60 - 5.73)	**6.45** (5.71 - 7.26)	**7.50** (6.59 - 8.55)	**8.57** (7.46 - 9.93)	**11.24** (9.48 - 13.63)

Final Table (Example for NE)

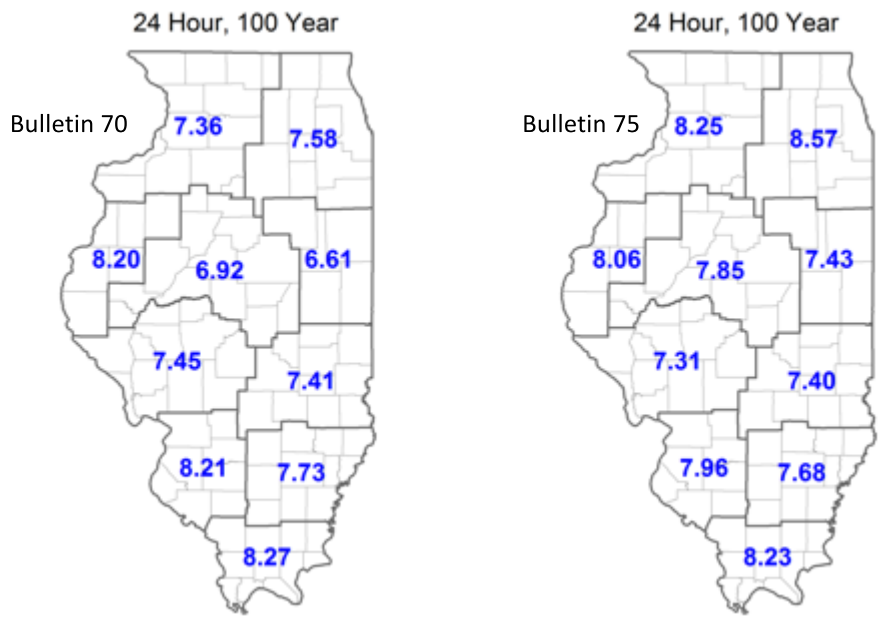
Storm Duration	2-month	3-month	4-month	6-month	9-month	1-year	2-year	5-year	10-year	25-year	50-year	100-year	500-year
5 minutes	0.19	0.22	0.24	0.27	0.31	0.33	0.40	0.52	0.62	0.77	0.90	1.03	1.35
10 minutes	0.35	0.40	0.43	0.49	0.56	0.61	0.73	0.95	1.13	1.42	1.65	1.89	2.47
15 minutes	0.42	0.49	0.53	0.61	0.69	0.75	0.90	1.16	1.39	1.74	2.03	2.32	3.04
30 minutes	0.58	0.66	0.73	0.83	0.94	1.03	1.24	1.59	1.91	2.39	2.78	3.17	4.16
1 hour	0.74	0.84	0.93	1.05	1.20	1.30	1.57	2.02	2.42	3.03	3.53	4.03	5.28
2 hours	0.91	1.04	1.14	1.30	1.48	1.61	1.94	2.49	2.99	3.74	4.35	4.97	6.52
3 hours	1.00	1.15	1.26	1.44	1.63	1.77	2.14	2.75	3.30	4.13	4.80	5.49	7.20
6 hours	1.18	1.35	1.48	1.68	1.91	2.08	2.51	3.23	3.86	4.84	5.63	6.43	8.43
12 hours	1.37	1.56	1.71	1.95	2.21	2.41	2.91	3.74	4.48	5.61	6.53	7.46	9.78
18 hours	1.48	1.69	1.85	2.11	2.39	2.61	3.14	4.04	4.84	6.06	7.05	8.06	10.57
1 day	1.57	1.80	1.97	2.24	2.55	2.77	3.34	4.30	5.15	6.45	7.50	8.57	11.24
2 days	1.72	1.97	2.16	2.46	2.79	3.04	3.66	4.71	5.62	6.99	8.13	9.28	12.10
3 days	1.87	2.14	2.34	2.67	3.03	3.30	3.97	5.08	6.05	7.49	8.64	9.85	12.81
5 days	2.08	2.38	2.61	2.97	3.37	3.67	4.42	5.63	6.68	8.16	9.39	10.66	13.81
10 days	2.63	3.01	3.30	3.76	4.27	4.65	5.60	7.09	8.25	9.90	11.26	12.65	16.00

Table 5.4. Rainfall (inches) for given recurrence interval for Section 2 (Northeast)



NORTHEAST
PRECIPITATION, inches
RECURRENCE INTERVAL, years
20
10
5
2
1
0.5
0.2
0.1
0.1
0.2
0.5
1
2
5
10
20
50
100
500
240 hr
120 hr
72 hr
48 hr
24 hr
18 hr
12 hr
6 hr
3 hr
2 hr
1 hr
30 min
15 min
10 min
5 min

Bulletin 75 vs. Bulletin 70 (100-Yr, 24-Hour Storm)



The increase in NE Illinois is between 13% and 14%

Future projected rainfall frequency

- No observed data
- Climate models generate data based on different modeling assumptions and for a range of climate scenarios.
- Higher uncertainty

U.S. Global Change Research Program

CLIMATE SCIENCE SPECIAL REPORT

- Volume I of the NCA4
- Annual Precipitation will continue to increase (medium confidence)
- Heavy precipitation events will increase in frequency and amounts (high confidence)

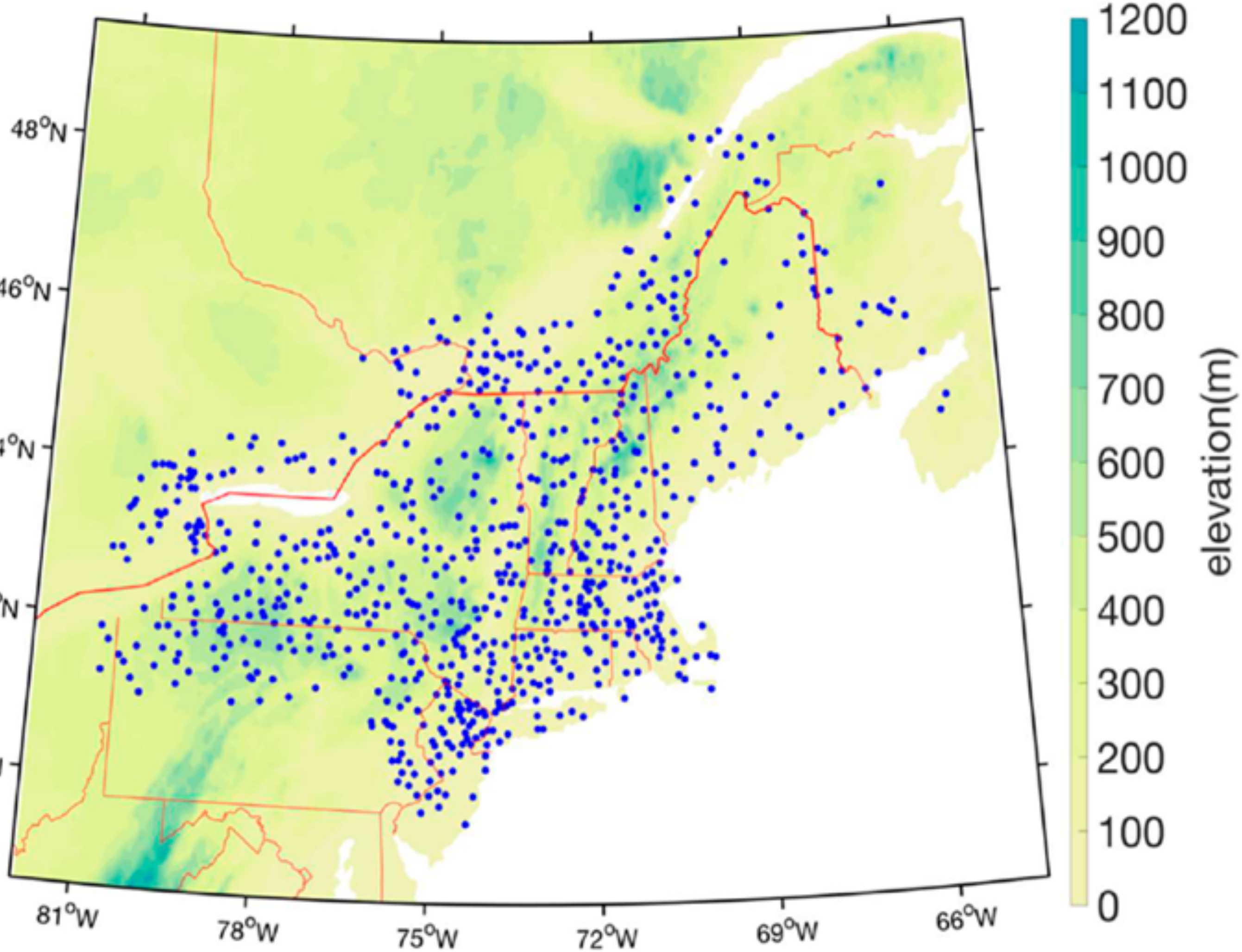
https://science2017.globalchange.gov/

The Northeastern United States (project funded by NOAA)

- Quasi-stationary[1]
  - Moving-window approach
- Nonstationary[2]
  - Frequency distribution parameters are a function of time and other covariates

- 1) Markus, M., Angel, J. R., Byard, G., McConkey, S., Zhang, C., Cai, X., Notaro, M., and Ashfaq, M. (2018). "Communicating the impacts of projected climate change on heavy rainfall using a weighted ensemble approach." *J. Hydrol. Eng.*, 23(4): 04018804.
- 2) Coles, S. *An Introduction to Statistical Modeling of Extreme Values* (Springer, London, 2001)

The Northeastern United States (project funded by NOAA)

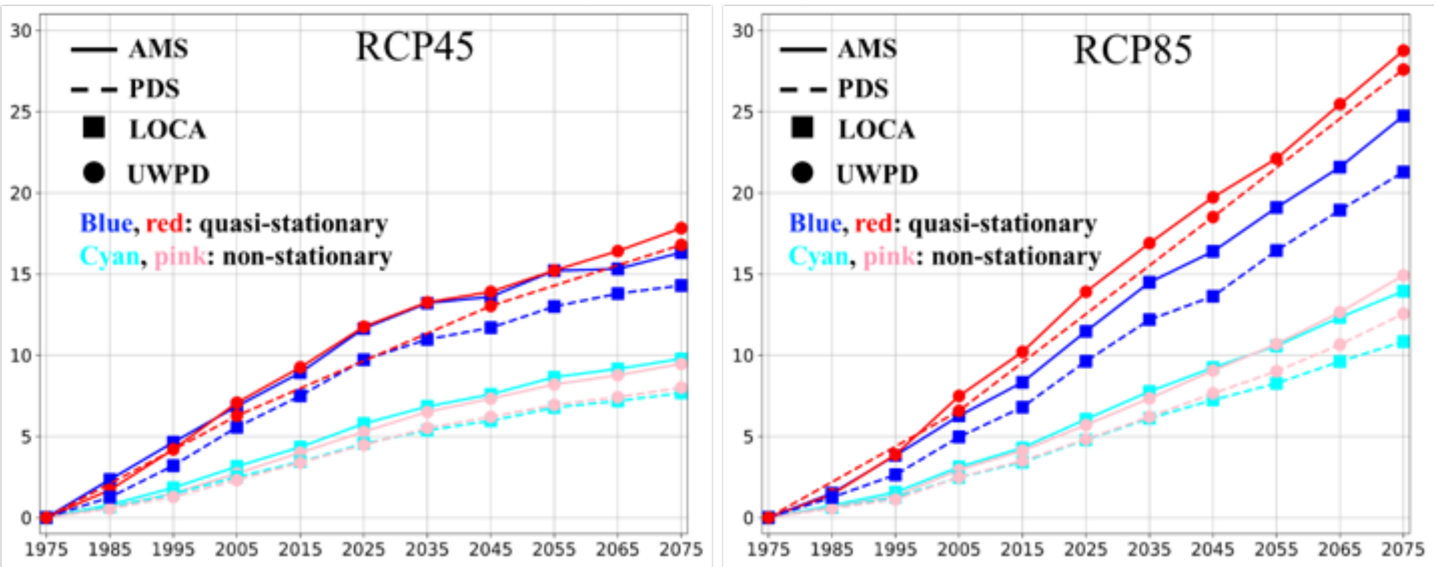


Northeastern United States

Average modeling results for 100-year return period event for scenarios RCP 4.5 and RCP 8.5 for daily data. The results are expressed as a percent (%) increase with respect to 1975.

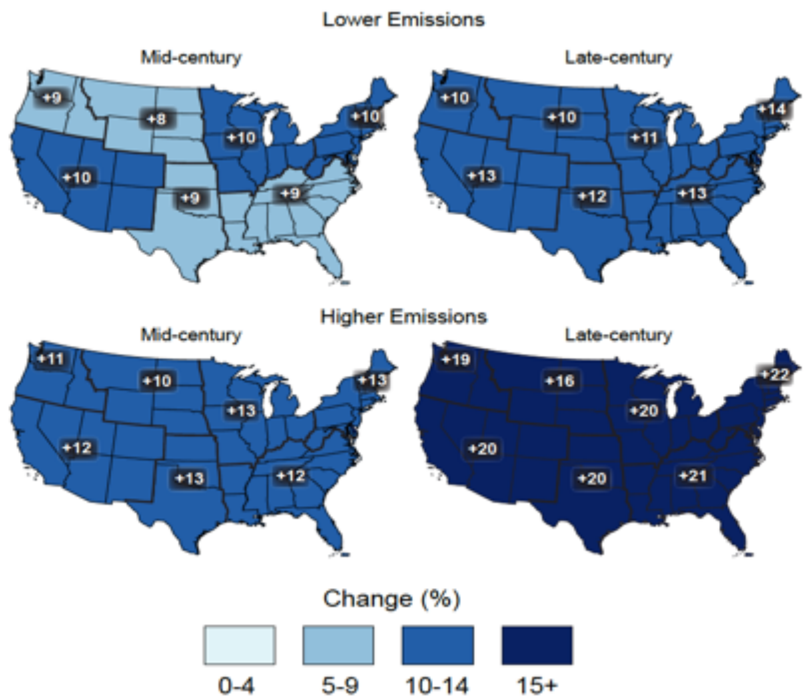
For QS, a 50-year moving window method was used
FOR NS average climate projections and station elevations were used as covariates

100-year return period



FOURTH NATIONAL CLIMATE ASSESSMENT

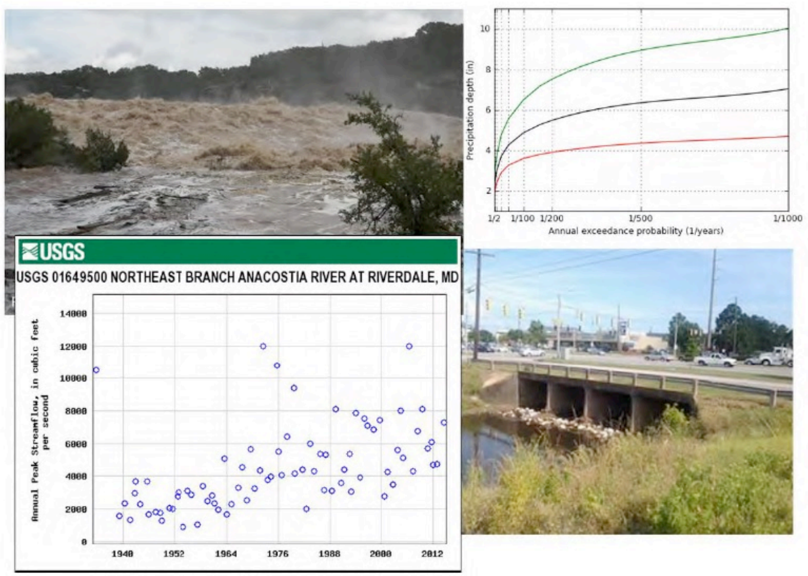
Projected change in the 20-year return period amount for daily precipitation for mid- (left maps) and late-21st century (right maps).



Publication No. FHWA-HIF-16-018
June 2016

U.S. Department of Transportation
Federal Highway Administration

Hydraulic Engineering Circular No. 17, 2nd Edition



Highways in the River Environment- Floodplains, Extreme Events, Risk, and Resilience

Gaps in Existing Knowledge

Tools for balancing the costs of underpreparing versus overpreparing for storms/floods in a future that may not be well predicted by the past are needed.

Summary

- We need to continue with studies and assessments of the changes in frequency of extreme events using observational and climate modeling data.
- We need to design ways to reduce the uncertainty in future projected rainfall and statistical models so that they can be incorporated in our management decisions with higher confidence.
  - Development of climate models and downscaling methods
  - Development of methodologies for analysis of nonstationary precipitation data


Questions/comments?
Email: mmarkus@Illinois.edu