Effects of Climate Change on Flooding in the Midwest and Great Lakes Region

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IN CCIA

Indiana Climate Change Impacts Assessment

PURDUE UNIVERSITY

INCCIA Website:

https://ag.purdue.edu/indianaclimate/

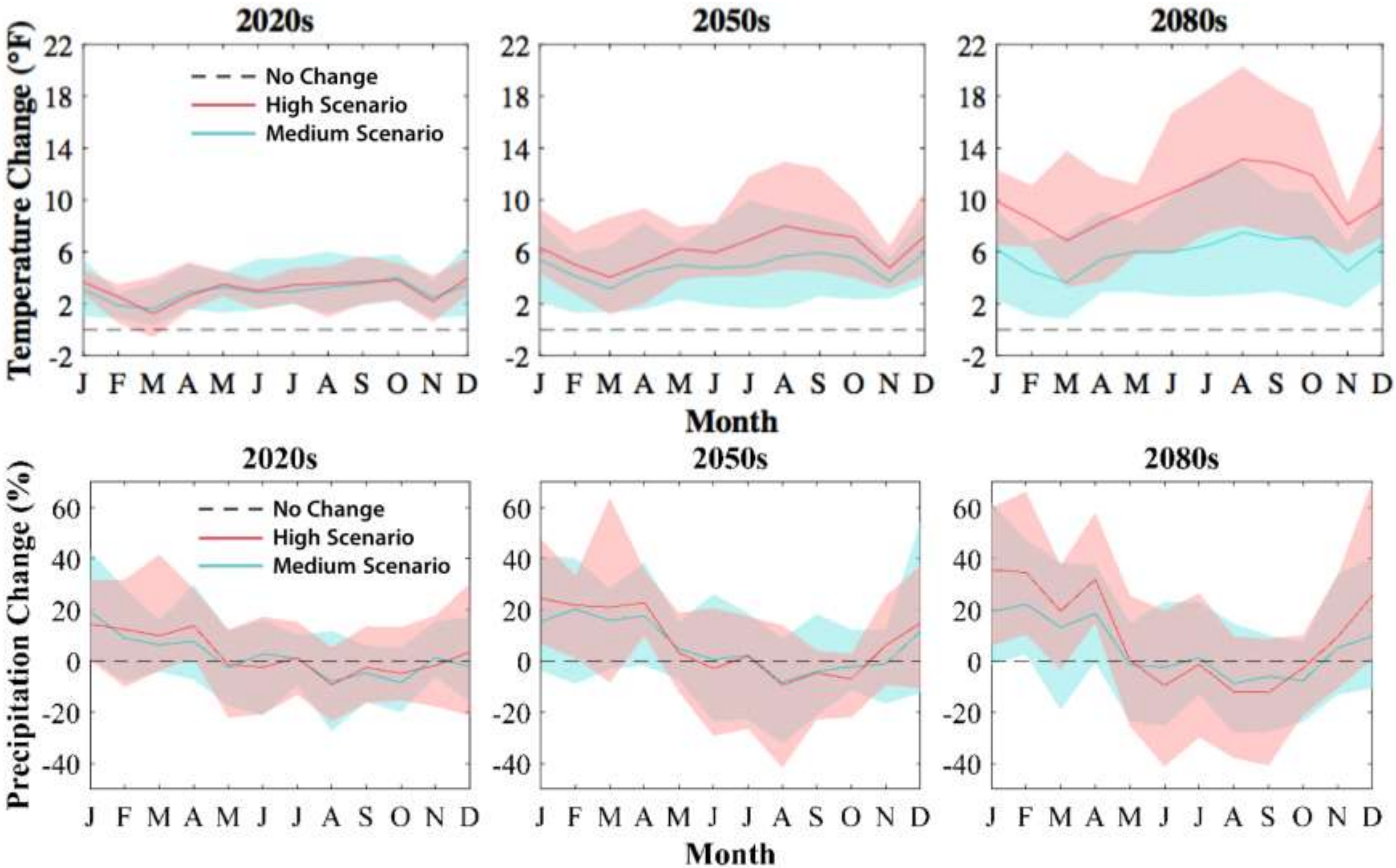
INCCIA Climate Paper:

Hamlet, A. F., K. Byun, S. M. Robeson, M. Widhalm, M. Baldwin, 2019: Impacts of Climate Change on the State of Indiana: Ensemble Future Projections Based on Statistical Downscaling, Climatic Change, DOI: 10.1007/s10584-018-2309-9

Three Interlocking Obstacles to Sustainable and Resilient Human Systems:

- Aging and inadequate infrastructure
- Rising human (urban) populations
- Climate change

Seasonal Changes in Temperature and Precipitation for IN



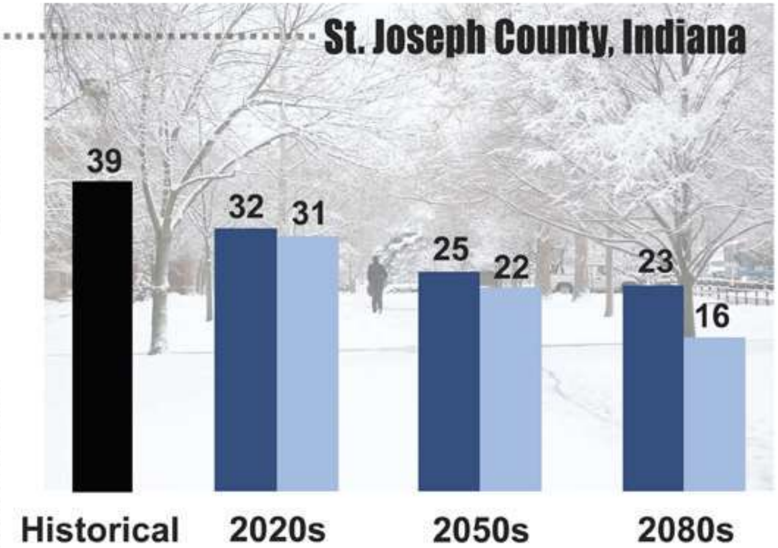
Strong agreement between models: Temperature increases in all seasons. Largest increases in temperature in Summer. Precipitation increases in Winter and Spring, Increases in Annual Precipitation.

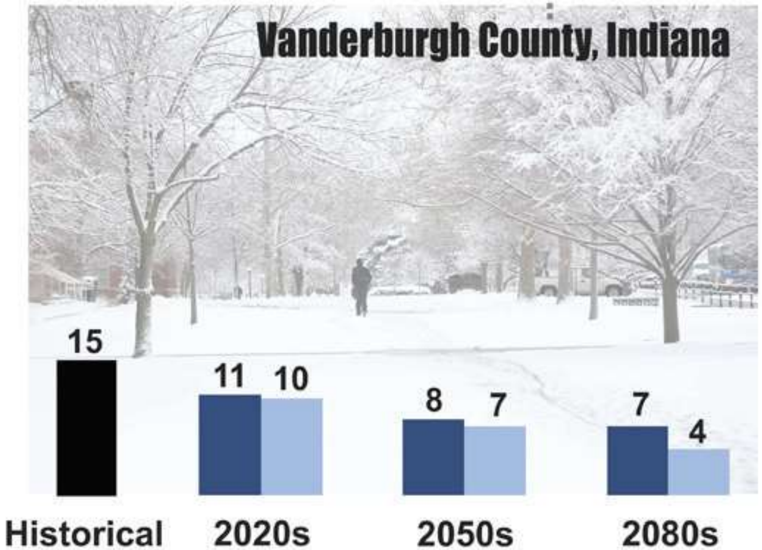
Weaker agreement between models: Summer and Fall precipitation changes: some models higher, some models lower.

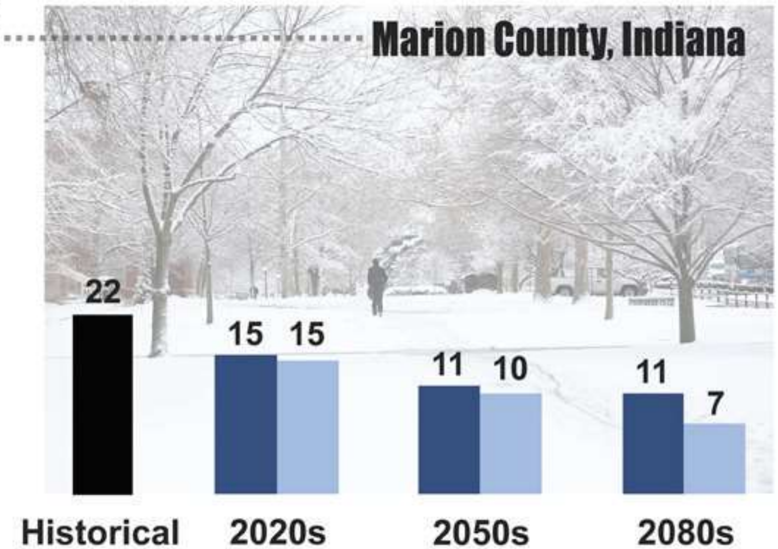
Rain vs Snow

Pecent of precipiation falling as snow (Nov- Mar)

- Observed
- Medium Emissions
- High Emissions







"Historical" is an average for the period 1915 to 2013. "2020s" represents the average 30-year future period 2011 to 2040. "2050s" represents the average 30-year period 2041 to 2070. "2080s" represents the 30-year period 2071 to 2100.

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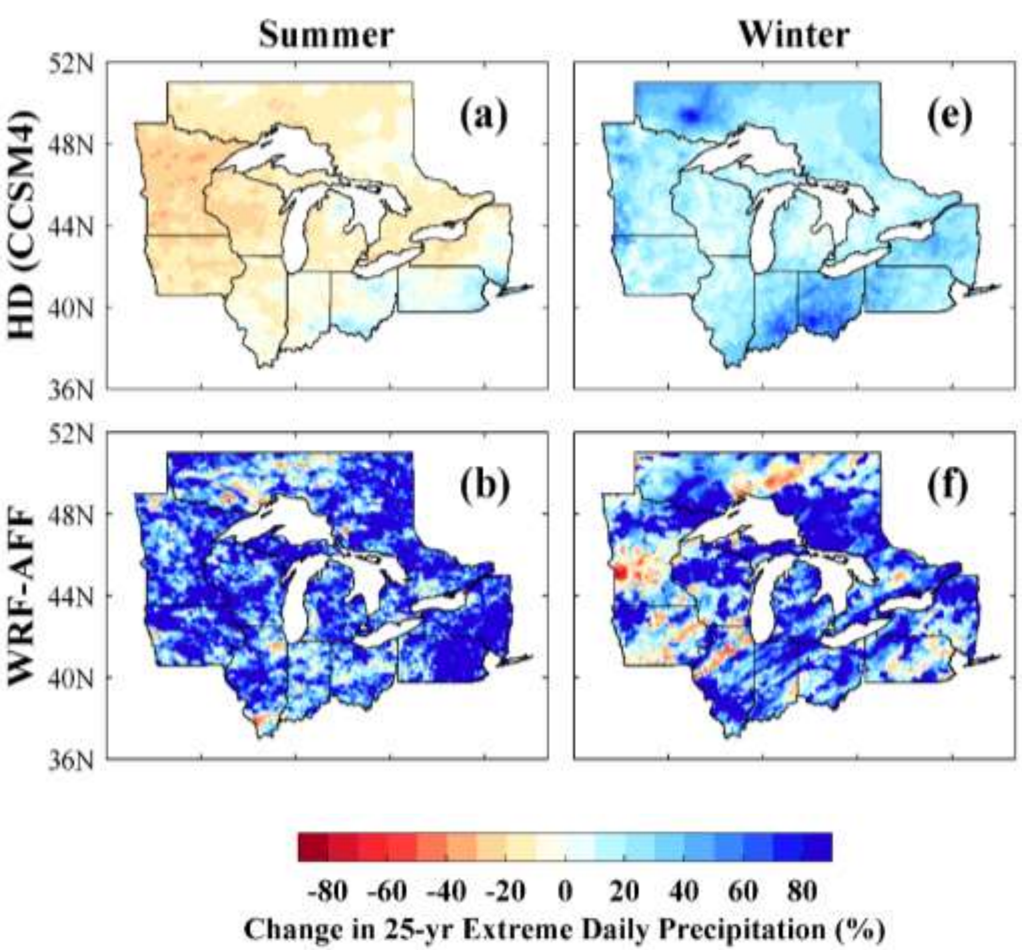
High-Resolution Climate Models Point to More Extreme Storms Even If Summers are Drier Overall

Statistical Downscaling

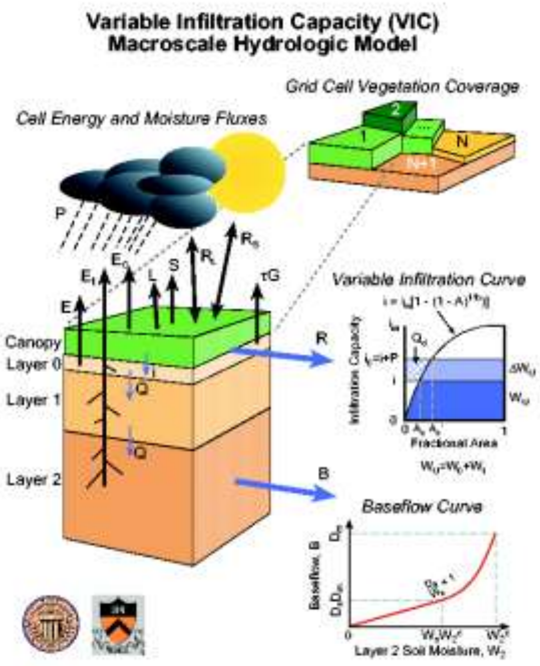
High-Resolution Dynamical Downscaling



Hydrologic Modeling of Extremes

Variable Infiltration Capacity (VIC)

- Large-scale hydrologic model (Liang et al 1994)
- Simulates water & energy storages and fluxes
  - Surface Runoff and Baseflow
  - Evapotranspiration
  - Soil Moisture
  - Snow Water Equivalent
- Meteorological drivers
  - Precipitation
  - Air temperature
  - Wind speed
  - Etc.

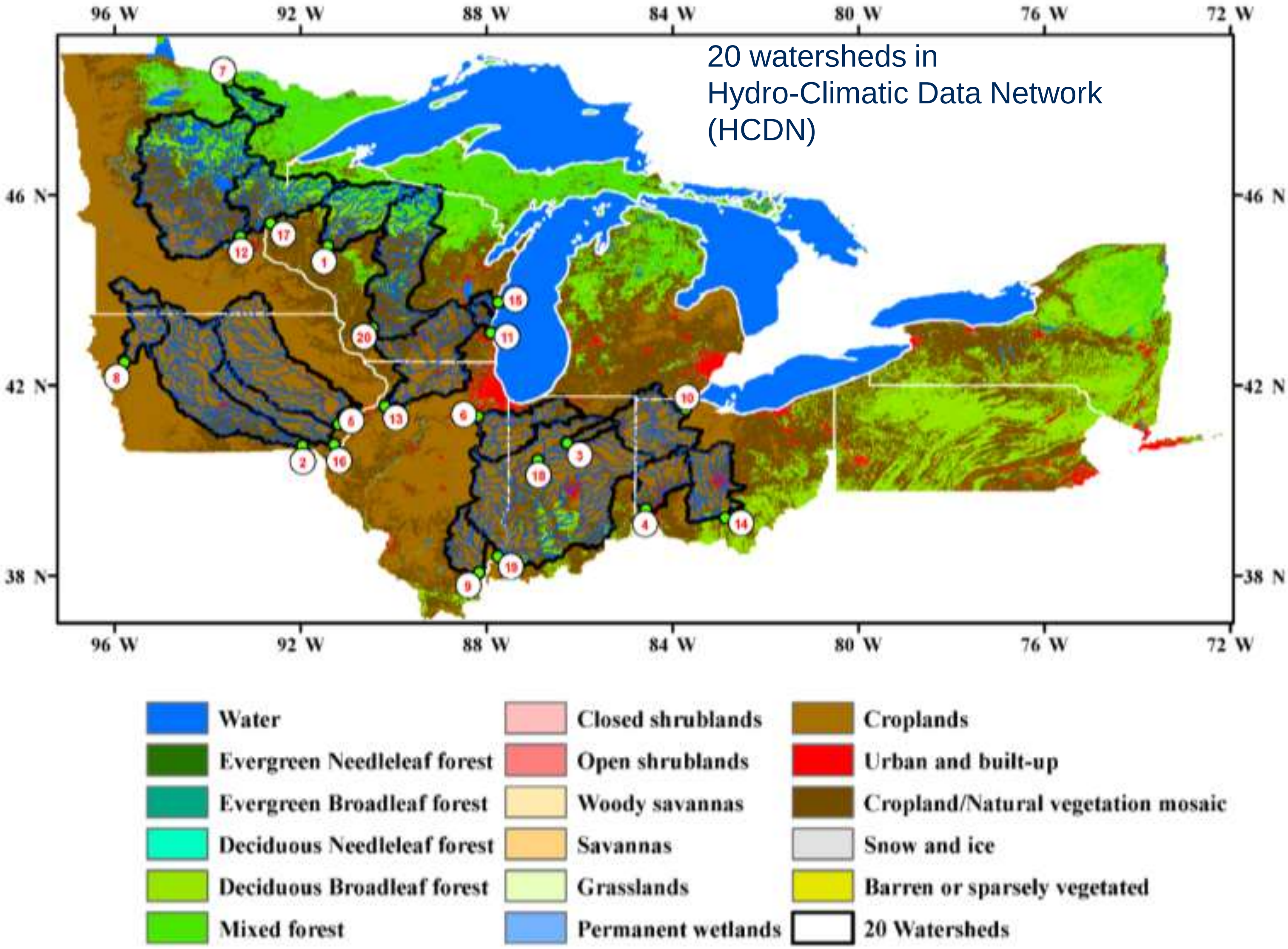


- Historical Run (HR) based on observed data (1915-2013)
- Climate Change Runs (CCRs)

- 6 GCMs
- RCP4.5 and RCP8.5
- 2020s, 2050s and 2080s
- a total of 36 CCRs

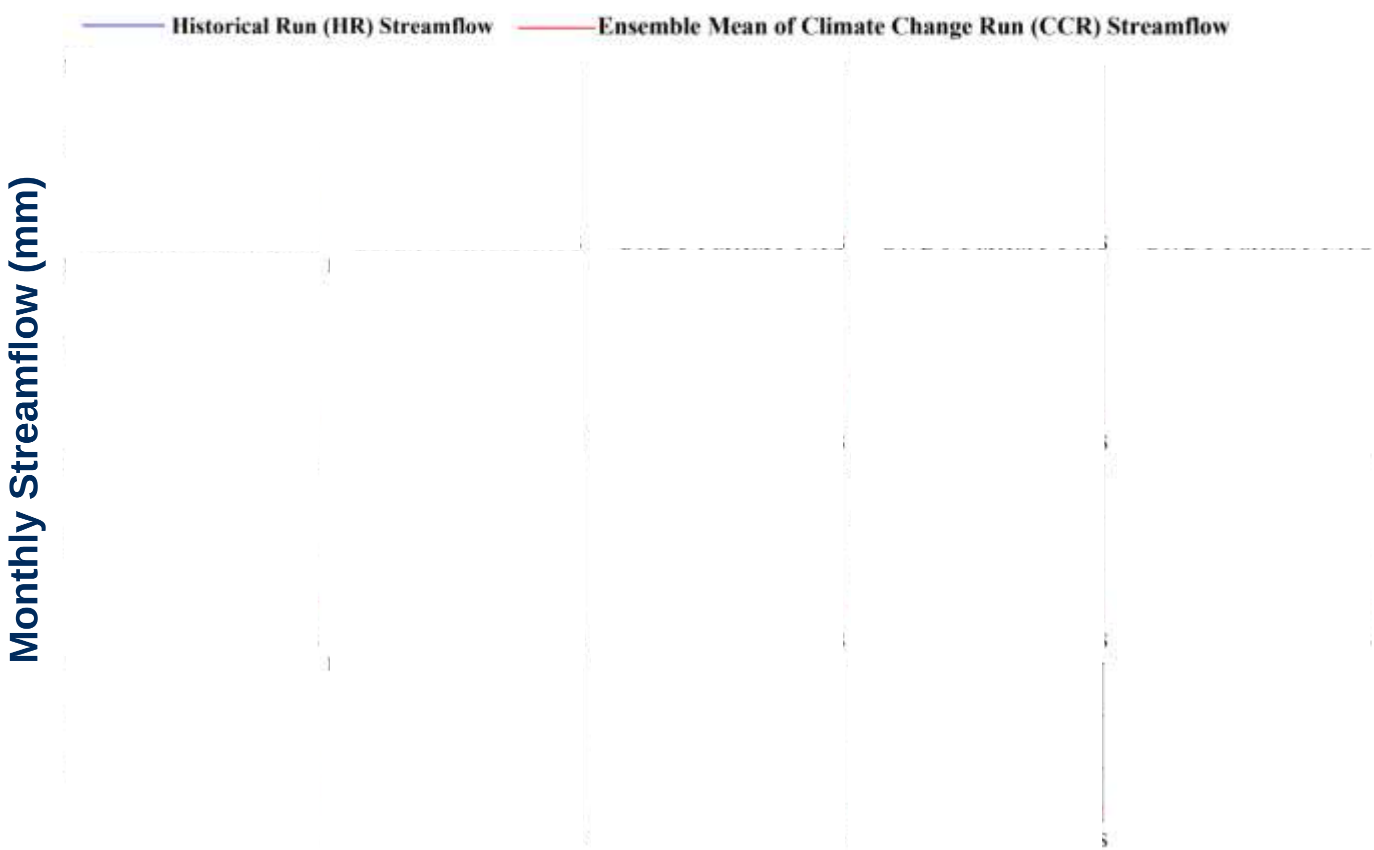
- each CCR has the same structure of daily time series as HR ("1915-2013"), but reflects future 30-yr distribution

Domain of a Regional Case Study

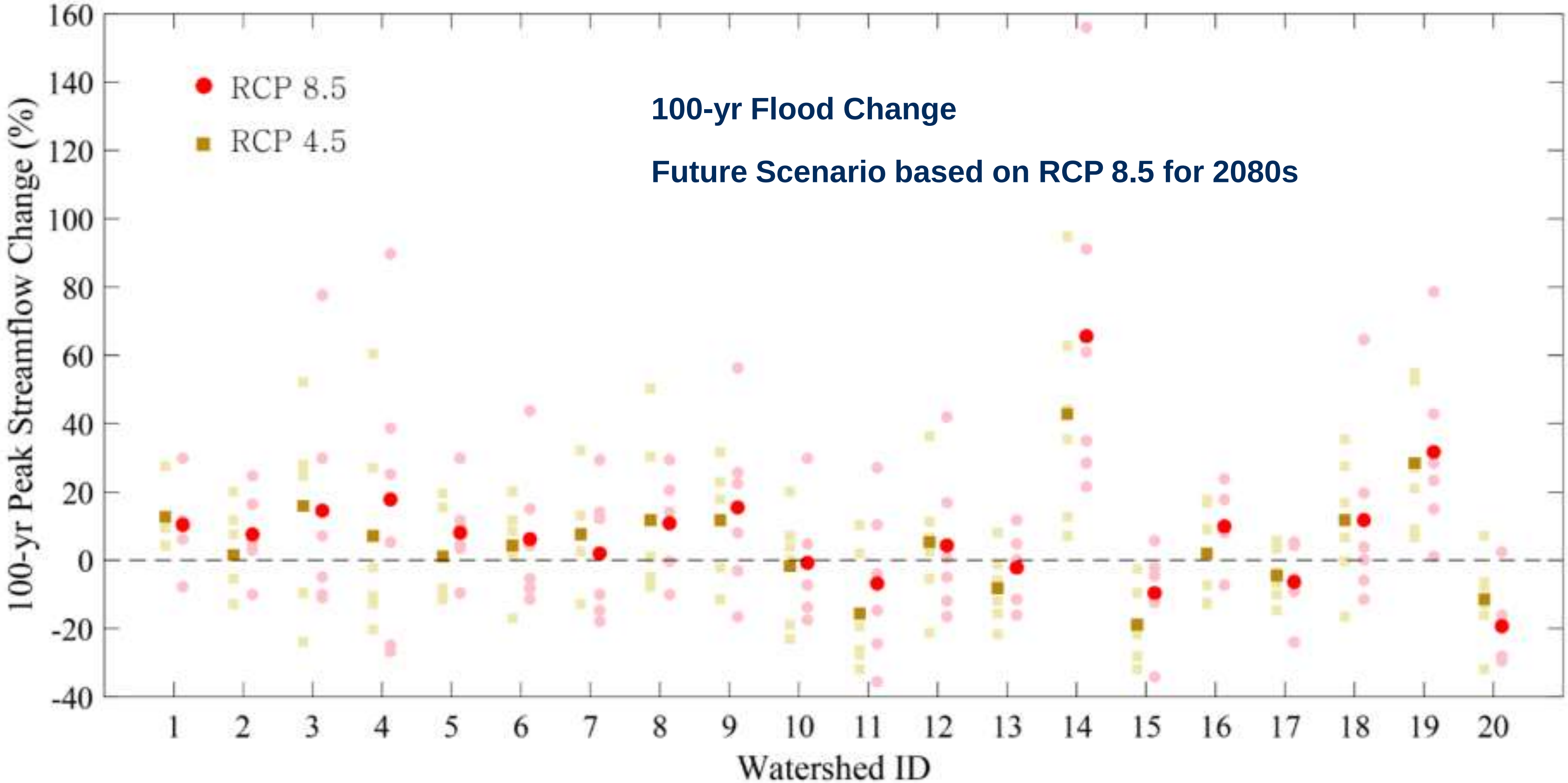


Byun, K., C.-M. Chiu, A.F. Hamlet, 2018: Effects of 21st Century Climate Change on Seasonal Flow Regimes and Hydrologic Extremes over the Midwest and Great Lakes Region of the U.S., Science of the Total Environment, 650(1):1261-1277, DOI:10.1016/j.scitotenv.2018.09.063.

Changes in Monthly Streamflow



Projected Changes in the 100-year Flood



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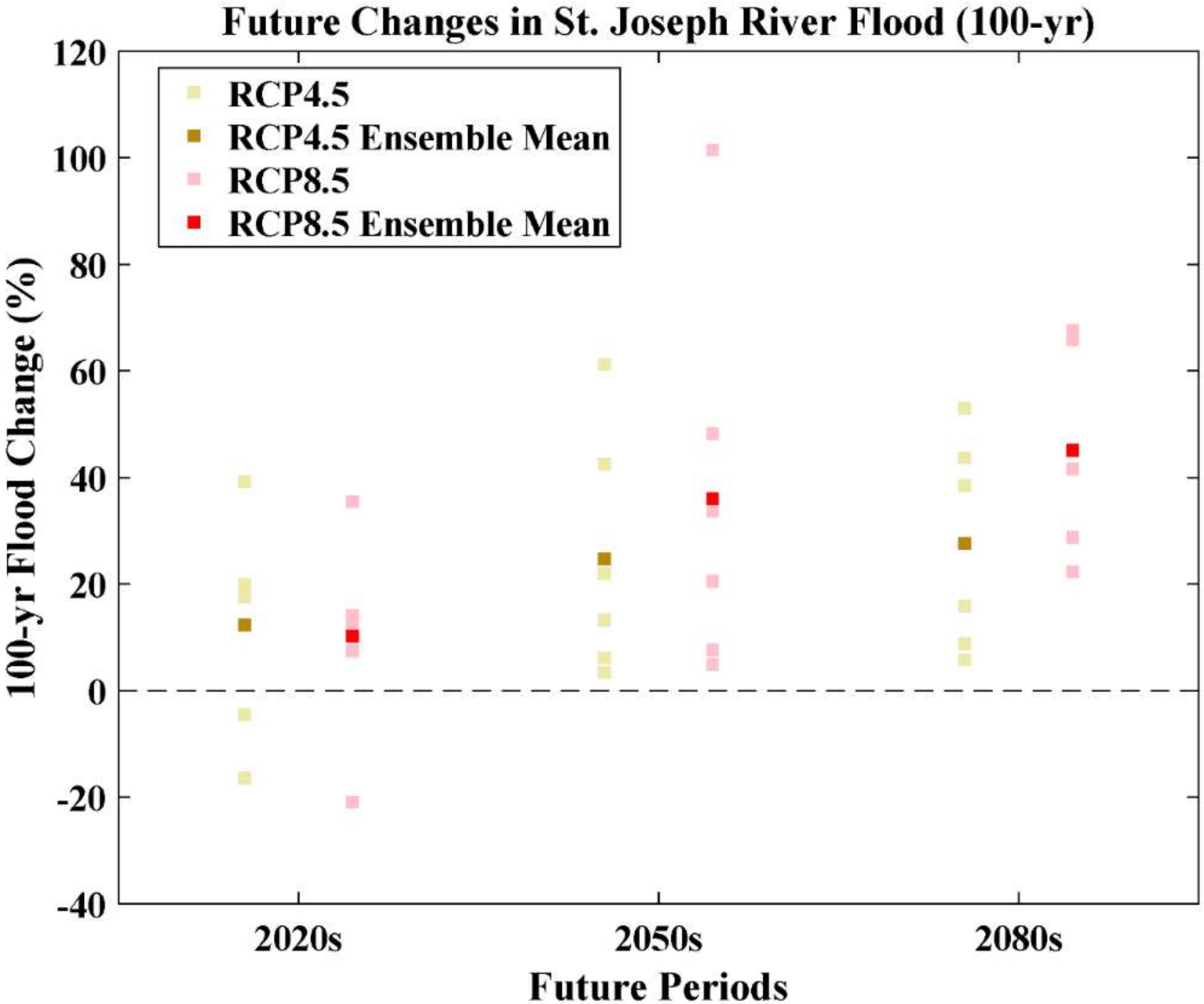
St. Joseph River at Niles, MI
Projected Changes in the 100-yr Flood



Ensemble mean 100-yr event increases by ~45% by the 2080s for RCP8.5

Aftermath of record-breaking rainfall on August 15, 2016,
> 8″ in 24 hours (~1000 year event)

Canoeing on Nokomis Park, August 16, 2016

Record-breaking flooding in the St. Joseph River at South Bend, Feb 21, 2018, due to an extreme rain-on-snow event (~2500 year event!)

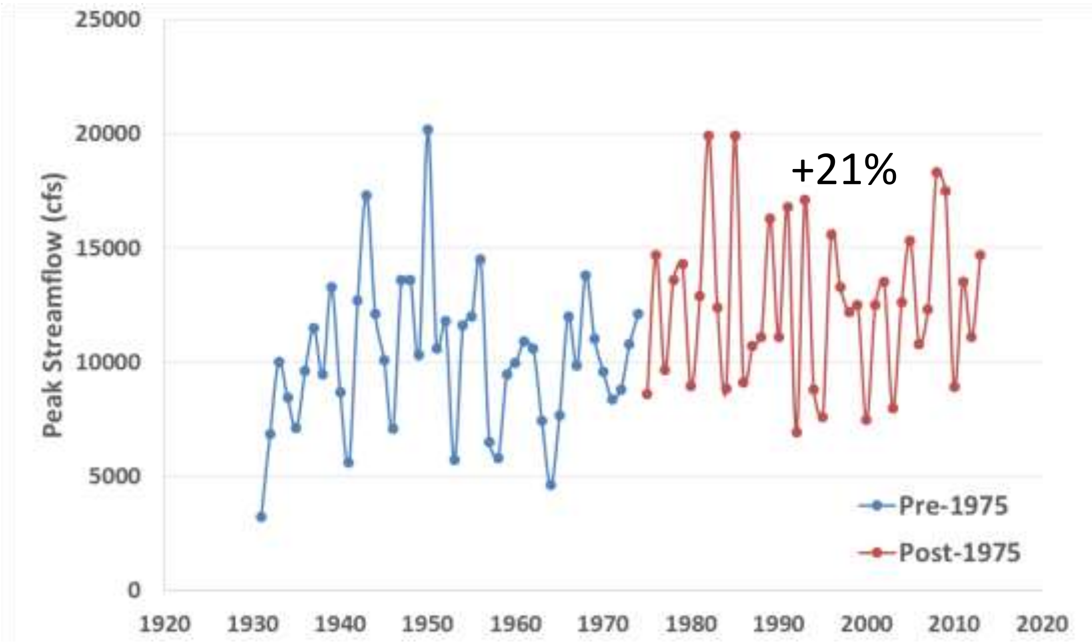
Antecedent Snowpack for the February 2018 Flood

Nokomis Park, February 21, 2018

~8,000 gallons of groundwater in my basement!

Historical Changes in Peak Annual Discharge

- **Non-stationarity of Extremes (St. Joseph River)**



Two-sample Hypothesis Test:

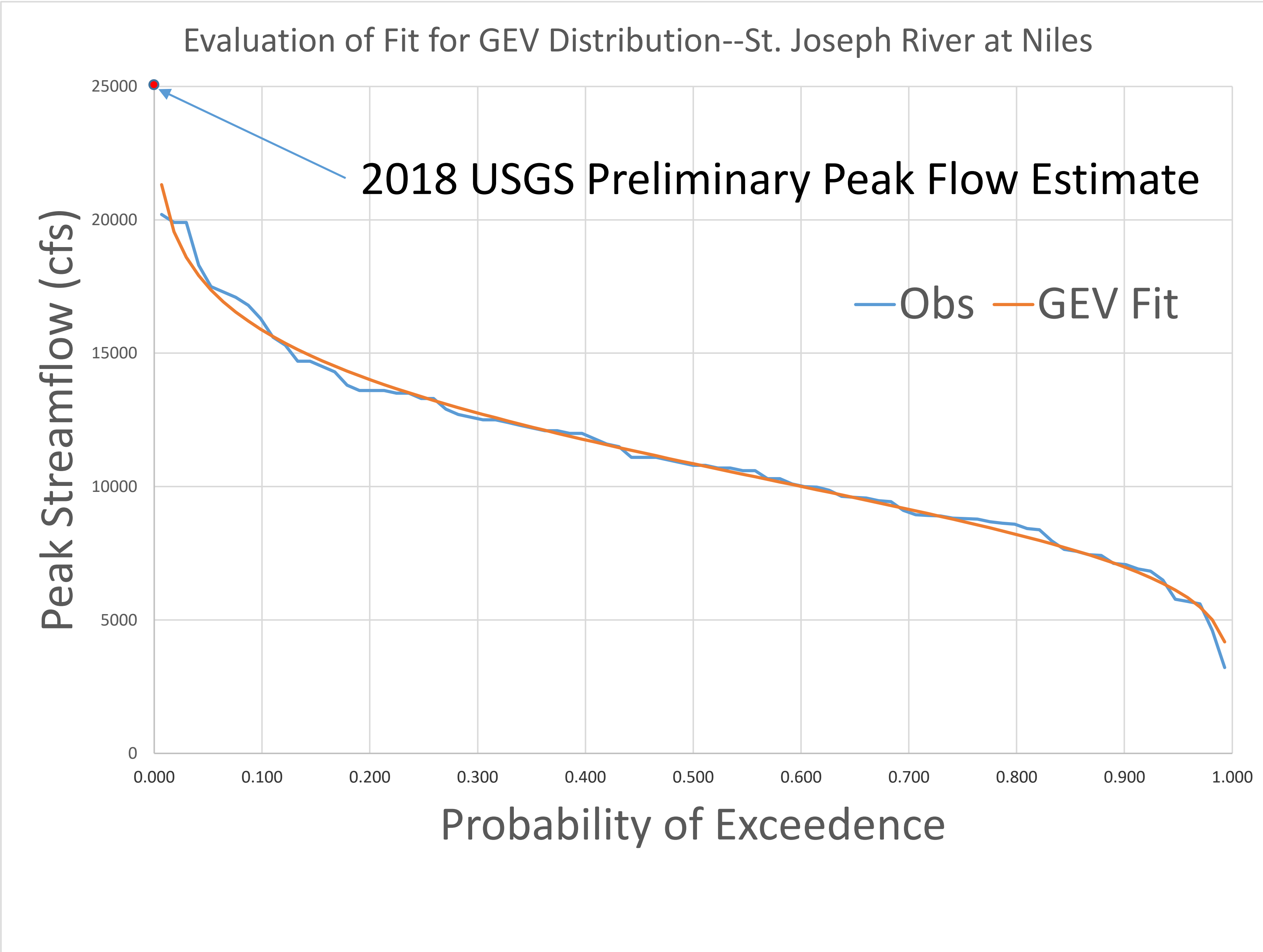
$$H_0\colon \mu_{pre} = \mu_{post}$$

$$z = \frac{(\overline{x_{pre}} - \overline{x_{post}}) - (\mu_{pre} - \mu_{post})}{\sqrt{\frac{\sigma_{pre}^2}{n_{pre}} + \frac{\sigma_{post}^2}{n_{post}}}} = 2.982$$

$$P - value = 0.00143$$
$$(reject\ H_0\ at\ \alpha = 0.01)$$

Post-1975 mean is 21% higher than the Pre-1975 mean.

Of the 10 highest flows on record, 8 have occurred since 1975.


Evaluation of Fit for GEV Distribution--St. Joseph River at Niles
2018 USGS Preliminary Peak Flow Estimate
Obs
GEV Fit
Peak Streamflow (cfs)
25000
20000
15000
10000
5000
0
0.000
0.100
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
Probability of Exceedence

Management Implications

These changes imply dramatically increasing risks for existing human and natural systems over time, and the need to incorporate projected changes into integrated long-term planning has become increasingly important, particularly in the case of infrastructure design.

Some important impact pathways include:

- Urban stormwater management
- River flooding and flood control infrastructure
- Dam safety
- Transportation impacts
- Floodplain development policies and flood insurance
- Emergency management procedures
- Nutrient impacts to the Great Lakes and Gulf of Mexico

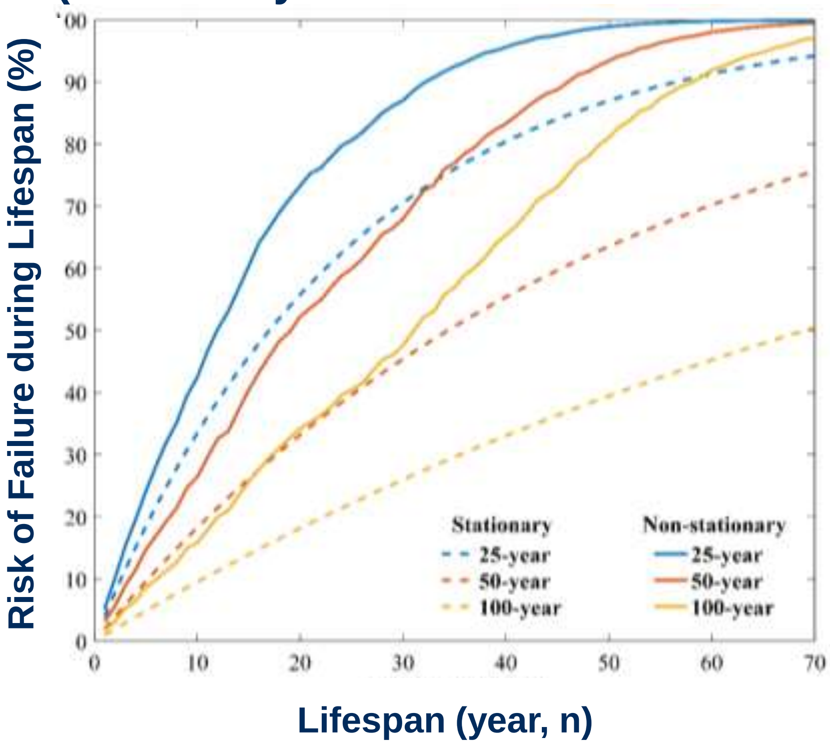
Given the observed changes in the historical record and projections for the future, it is evident that new paradigms are needed for the management of natural resources and the design of infrastructure in a non-stationary environment:

"Stationarity is dead, whither water management?" (Milly et al. 2008)

Milly, A. P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Zbigniew, W., Lettenmaier, D. P., et al. (2008). Stationarity Is Dead : Stationarity Whither Water Management ? Science, 319(5863), 573–574. https://doi.org/10.1126/science.1151915

Estimating the Risk of Failure as a Function of Design Lifespan

- **Evaluation of Risk of Failure during the Lifespan of an Existing Structure (Probability of at least one event above design standard during the design lifespan)**



- Designed by different level of design standards (e.g. 25, 50 and 100-yr) from historical distribution

- Stationary approach (historical distribution):

$$\mathbf{1-(1-q)^n}$$

$$q : probability\ of\ exccedance\ during\ a\ year$$

- Non-stationary approach (super ensemble):

$$\mathbf{1-\prod_{t=1}^{n}(1-q_t)}$$

$$q_t = \frac{\#\ Events\ above\ design\ standards}{\#\ Realizations}$$