New At-Streamgage Quantiles and Regression Equations for Estimating Peak-Flow Quantiles in Illinois

Illinois Association for Floodplain and Stormwater Management Annual Meeting, March 15, 2023

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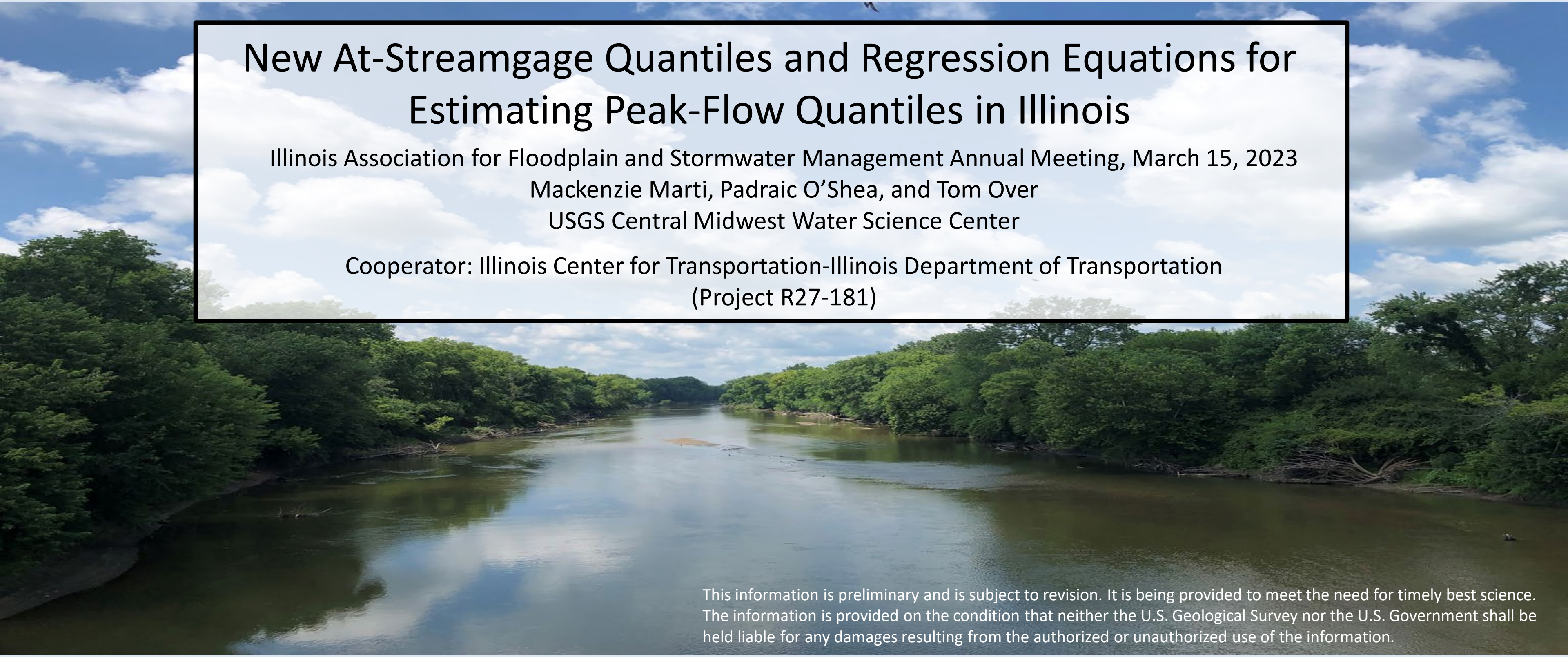
USGS Central Midwest Water Science Center

Cooperator: Illinois Center for Transportation-Illinois Department of Transportation
(Project R27-181)

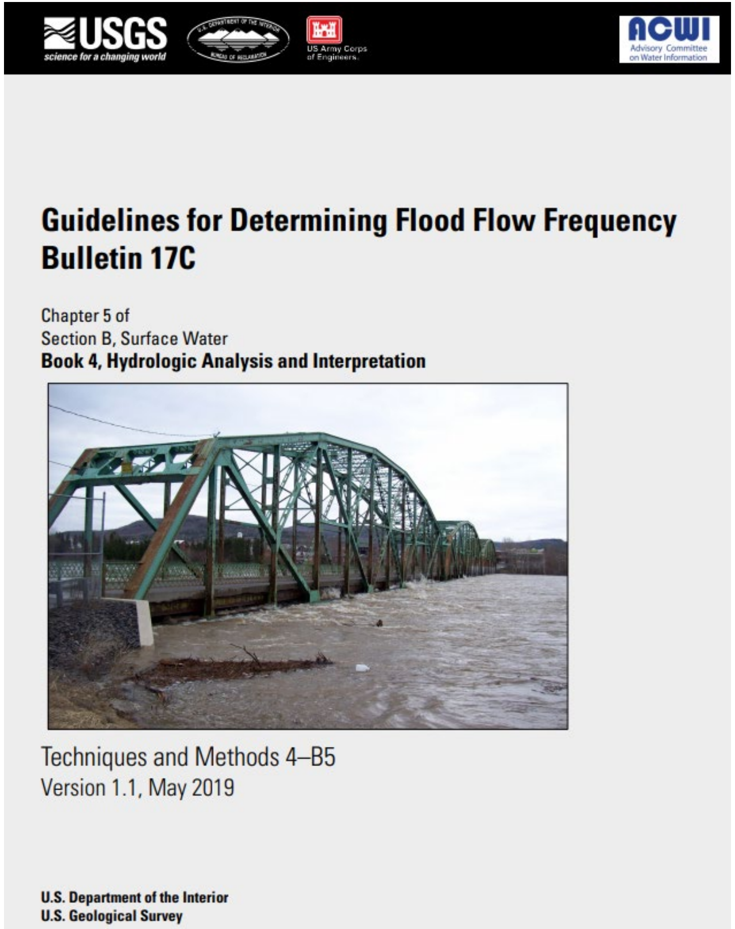


U.S. Department of the Interior
U.S. Geological Survey

Photograph by Lindsey Schafer, U.S. Geological Survey

- Flood-frequency analysis critical for water-resource management applications

- Federal guidelines set in Bulletin 17C


USGS science for a changing world
US Army Corps of Engineers
ACWI Advisory Committee on Water Information

Guidelines for Determining Flood Flow Frequency Bulletin 17C

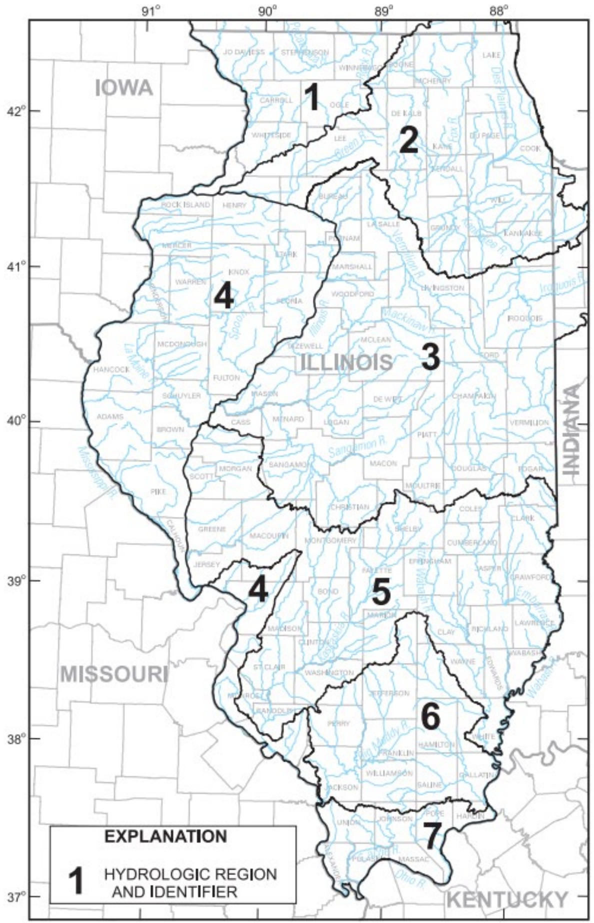
Chapter 5 of
Section B, Surface Water
Book 4, Hydrologic Analysis and Interpretation

Techniques and Methods 4–B5
Version 1.1, May 2019

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

- Previous state-wide flood frequency update and regression equation development was in 2004
  - Through water year (WY) 1999
    - Soong, D.T., Ishii, A.L., Sharpe, J.B., and Avery, C.F., 2004, Estimating flood-peak discharge magnitudes and frequencies for rural streams in Illinois: https://doi.org/10.3133/sir20045103.

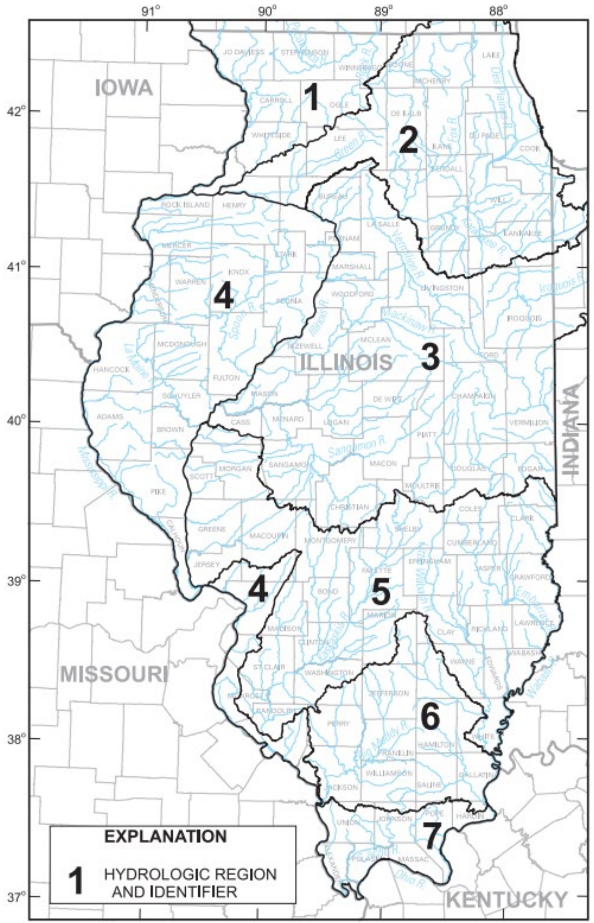
- Northeastern IL (Region 2) updated in 2016
  - Through WY 2009
    - Over, T.M., Saito, R.J., Veilleux, A.G., O’Shea, P.S., Sharpe, J.B., Soong, D.T., and Ishii, A.L., 2021, Estimation of peak discharge quantiles for selected annual exceedance probabilities in northeastern Illinois (ver. 3.0, June 2021): https://doi.org/10.3133/sir20165050.



Soong and others, 2004

Project Goals

- Update GIS base data to high-resolution (1:24,000) streamlines and DEM (10 m)
- Update at-site flood frequency estimates for selected streamgages in Illinois
  - Using data through WY 2017
  - Using updated Bulletin 17C methods
- Develop new regional regression equations (RREs) for rural regions (outside of Region 2)
- Update Region 2 RREs with updated basin characteristic values and additional years of record
- Update StreamStats with new equations and GIS base data



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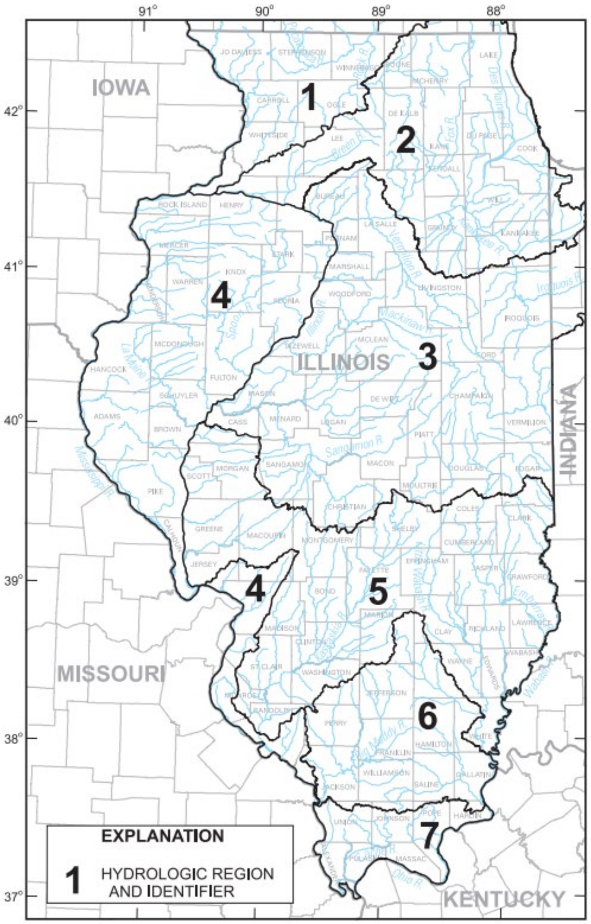

Soong and others, 2004

1. Station selection

↓

2. Estimate at-site flood quantiles

↓

3. Compute basin characteristics for selected basins

↓

4. Develop regional regression equations

USGS

1. Station selection

2. Estimate at-site flood quantiles

3. Compute basin characteristics for selected basins

4. Develop regional regression equations

USGS streamgages

Urbanization analysis

Regulation analysis

All streamgages appropriate for at-site updates

477 streamgages

Streamgages appropriate for at-site updates only

54 streamgages

USGS

1. Station selection

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4. Develop regional regression equations

1. Station selection

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At-site peak-flow data

↓

Perception Thresholds & Flow Intervals

+

Regional Skew

↓

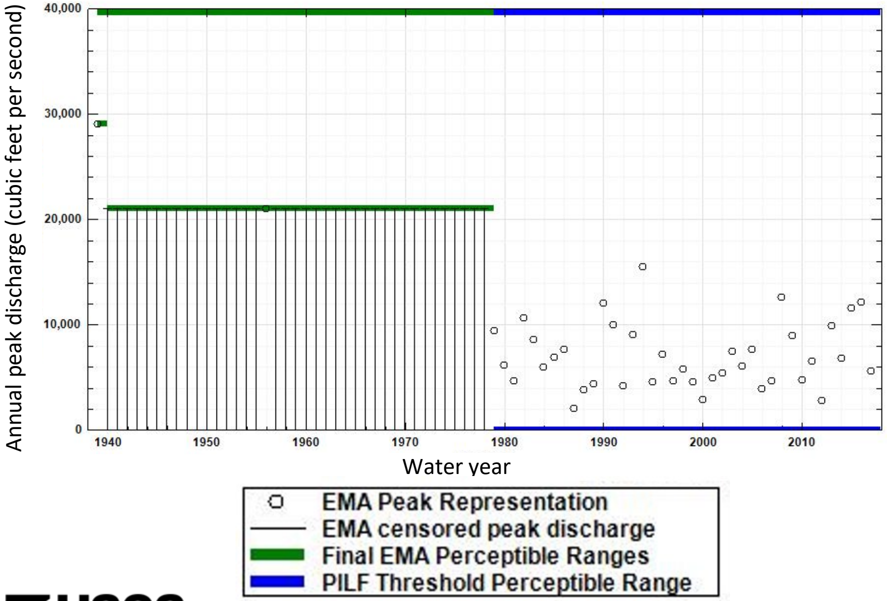
PeakFQ
Expected Moments Algorithm (EMA)
& Multiple Grubbs-Beck test (MGBT)

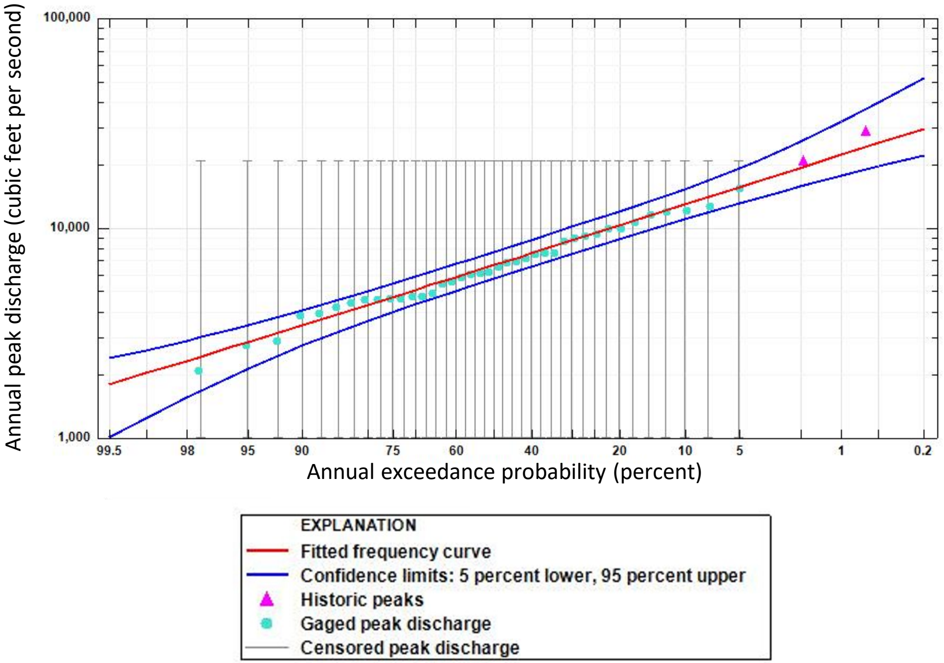
↓

At-site flood quantiles

Annual exceedance probability (AEP)
0.5
0.2
0.1
0.04
0.02
0.01
0.005
0.002

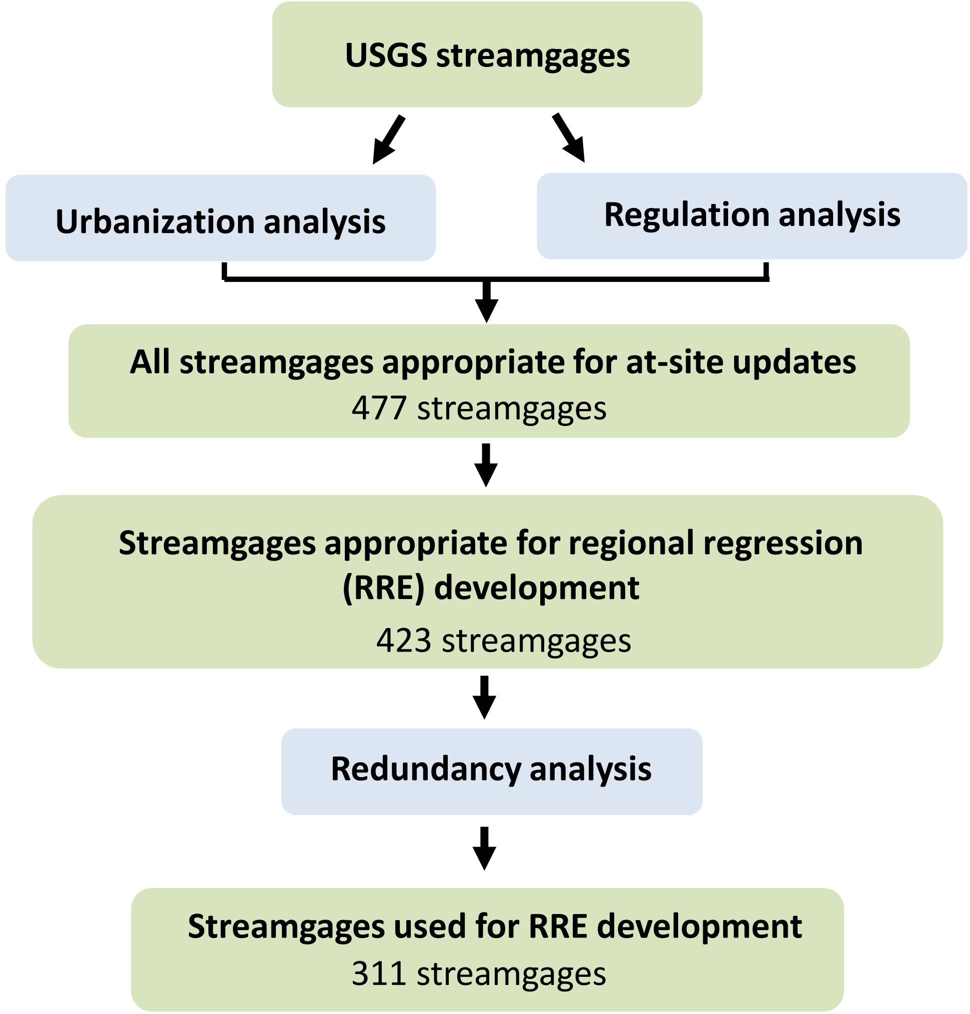
03336645
Middle Fork Vermilion River above Oakwood, IL





USGS

1. Station selection
2. Estimate at-site flood quantiles
3. Compute basin characteristics for selected basins
4. Develop regional regression equations



USGS

1. Station selection

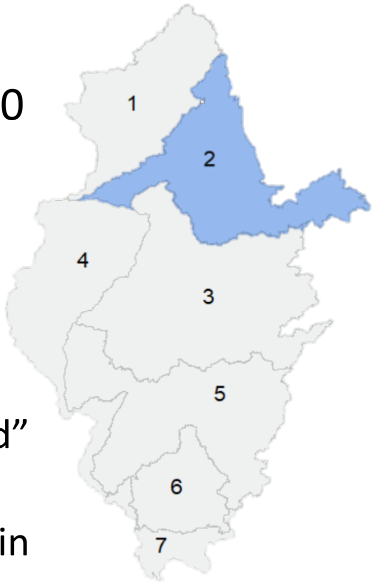
2. Estimate at-site flood quantiles

3. Compute basin characteristics for selected basins

4. Develop regional regression equations

Region 2

- Use same basin characteristics (BCs) as previous 2016 report
  - Scientific Investigations Report (SIR) 2016-5050 (https://doi.org/10.3133/sir20165050)
  - **Drainage area**
  - **NLCD_22_23_24**: 2016 National Land Cover Database (NLCD) urban fractions
  - **DrainageClass1a**: sum of fractions of Soil Survey Geographic (SSURGO) fractions "very poorly drained" and "unknown (likely water)"
  - **DEM_1_0_P**: basin elevation range divided by basin perimeter



1. Station selection

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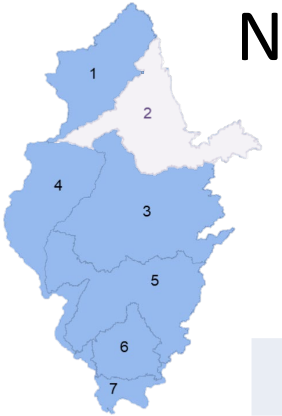

Non-region 2

Computed more than 50 BCs

Data type	**Example basin characteristics**
Morphometric	Basin drainage area (DA), DEM-based basin slope, mean basin elevation
Geology	Quaternary sediment thickness
Land use	Fraction open water, fraction forest
Soils	Permeability, soil slope, texture permeability index
Climate	Seasonal precipitation, precipitation frequency

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1. Station selection

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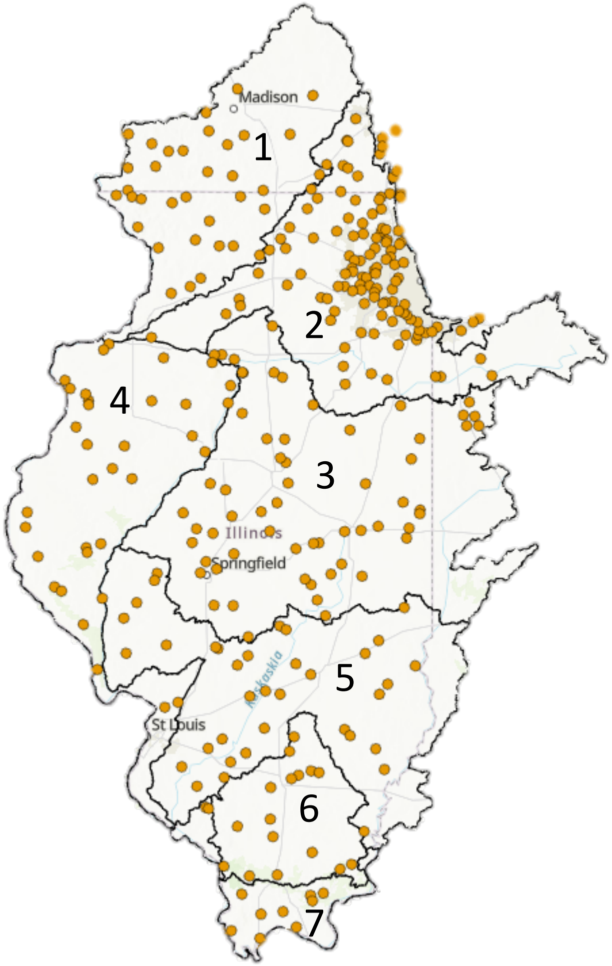

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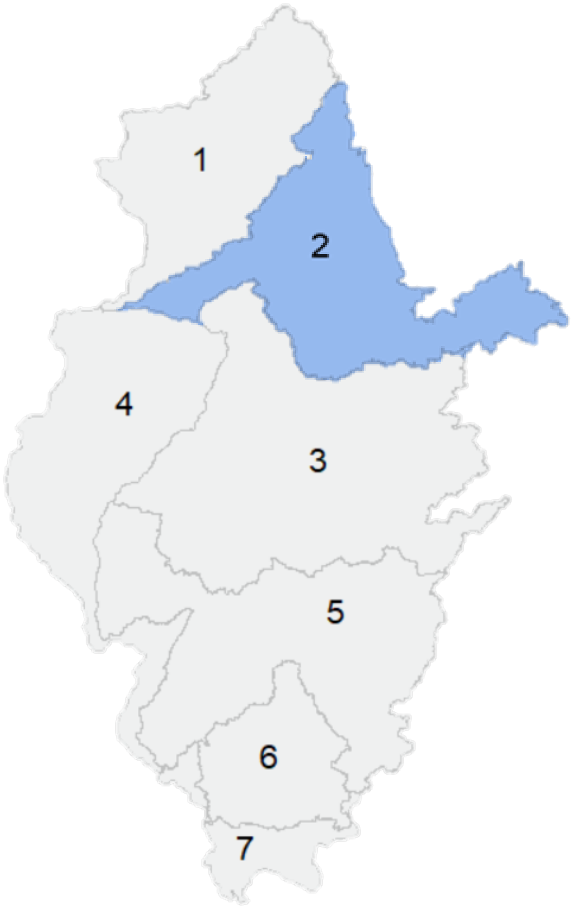
Region 2

- Same basin characteristics as previous 2016 report (https://doi.org/10.3133/sir20165050)

$$log_{10}(Q_p) = a_{0,p} + a_{1,p} log_{10}(DA) + a_{2,p}\sqrt{NLCD\_22\_23\_24}$$

$$+ a_{3,p}\sqrt{DrainageClass1a} + a_{4,p} log_{10}(DEM\_1\_0\_P)$$

where *Q* = discharge, *p* = annual exceedance probability, a_0 represents the intercept value, and $a_{1\text{-}4}$ represents the variable coefficient



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Selecting models for non-region 2

1. Apply search algorithm to find best combination of BCs to predict each quantile in each region
   - Uses ordinary least squares (OLS) regression
   - Produces *many* potential candidate models for each region

2. Candidate models that performed best in step 1 are post-processed using USGS Weighted-Multiple-Linear Regression Program WREG (https://water.usgs.gov/software/WREG/)
   - WREG uses generalized least squares (GLS) regression
   - Those that performed best were selected as the final models

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1. Selecting candidate models with OLS

- Number of BCs used in each model limited by number of streamgages in region (10-20 streamgages per BC)
- Looked at various metrics (R^2, correlation between BCs)
- Considered models for single and combined regions
- Picked candidate models for each AEP for each region

Annual exceedance probability (AEP)
0.5
0.2
0.1
0.04
0.02
0.01
0.005
0.002

USGS

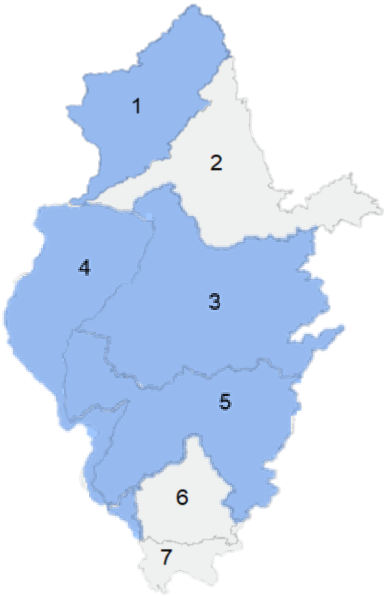
2. Selecting final models with WREG (GLS)

- Considered models for single and combined regions
- Looked at various metrics (pseudo R^2, RMSE, variance, VIF)
- Considered the physical meaning
- Ensured coefficients were statistically significant
- Considered maps of residuals and leverage and influence statistics
- Selected final models
    - Did not revise or combine regions

Annual exceedance probability (AEP)
0.5
0.2
0.1
0.04
0.02
0.01
0.005
0.002

USGS

4. Develop regional regression equations—Non-region 2



Region	Stations	Model
1	35	$log_{10}(Q_p) = a_{0,p} + a_{1,p} log_{10}(\boldsymbol{DA}) + a_{2,p}(log_{10}(\boldsymbol{TPI}) - 3.2259)$
3	60	$log_{10}(Q_p) = a_{0,p} + a_{1,p} log_{10}(\boldsymbol{DA}) + a_{2,p}(\boldsymbol{DEM\_slope} - 55.329)$ $+ a_{3,p} (\boldsymbol{TPI} - 1823.4)/4758.3)$
4	36	$log_{10}(Q_p) = a_{0,p} + a_{1,p} log_{10}(\boldsymbol{DA}) + a_{2,p} log_{10}(\boldsymbol{Soil\_Slope})$
5	36	$log_{10}(Q_p) = a_{0,p} + a_{1,p} log_{10}(\boldsymbol{DA}) + a_{2,p}(\boldsymbol{DEM\_Slope} - 55.329)$

- ***DA:*** Drainage area
- ***TPI***: Texture permeability index
  - TPI = 100*sand fraction + 10*silt fraction + clay fraction
- ***DEM_slope***: land surface slope derived from DEM
- ***Soil_Slope:*** average STATSGO soil slope in basin
  - From Wolock, 1997
  - https://pubs.er.usgs.gov/publication/ofr97656

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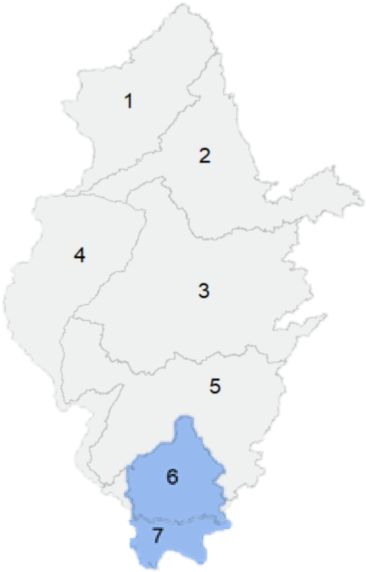
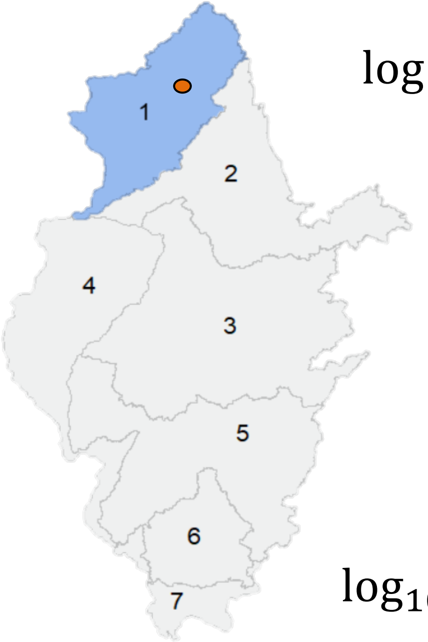
4. Develop regional regression equations—Non-region 2



Region	Stations	
6	16	$log_{10}(Q_p) = a_{0,p} + a_{1,p} log_{10}(\boldsymbol{DA})$
7	9	$log_{10}(Q_p) = a_{0,p} + a_{1,p} log_{10}(\boldsymbol{DA})$

- ***DA:*** Drainage area

Region 1 location X, AEP 0.01



$$\log_{10}(Q_{0.01}) = a_{0,0.01} + a_{1,0.01}\log_{10}(\boldsymbol{DA}) + a_{2,0.01}(\log_{10}(\boldsymbol{TPI}) - 3.2259)$$

AEP	Intercept (a_0)	DA (a_1)	TPI (a_2)
AEP_0.01	2.758	0.568	-1.305

DA: 40 (sq mi)
TPI: 1096 (percent)

$$\log_{10}(Q_{0.01}) = 2.758 + 0.568\log_{10}(\mathbf{40}) - 1.305(\log_{10}(\mathbf{1096}) - 3.2259)$$

$$\log_{10}(Q_{0.01}) = 3.912$$

$$Q_{0.01} = 8{,}413\ cfs$$

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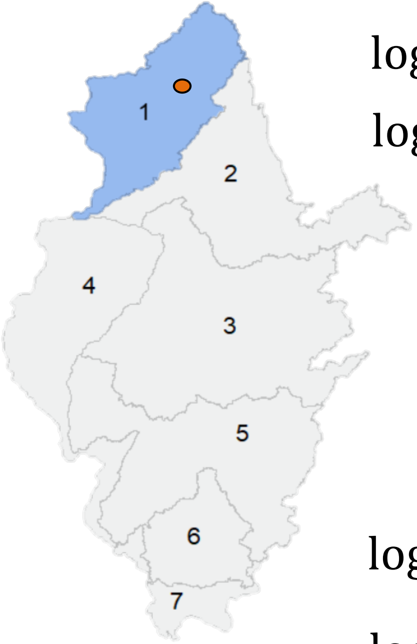
Region 1 location X, AEP 0.01 – Urbanization-adjusted peak-flow



$$\log_{10} Q_{0.01}(U) = \log_{10}(Q_{0.01}) + (b_U)_{0.01}(U - U_0)$$

$$\log_{10} Q_{0.01}(U) = \log_{10}(3.912) + (b_U)_{0.01}(U - U_0)$$

where b_U: Temporal urbanization coefficient, U: Theobald-NLCD urban fraction, U_0: Baseline (median) urban fraction for Region 1

AEP	$(b_U)_{0.01}$	U	U_0
AEP_0.01	0.312	0.12	0.0060

$$\log_{10} Q_{0.01}(U) = 3.912 + 0.312 * (0.10 - 0.0060)$$

$$\log_{10} Q_{0.01}(U) = 3.948$$

$$\boldsymbol{Q_{0.01}(U) = 8,863\ cfs}$$

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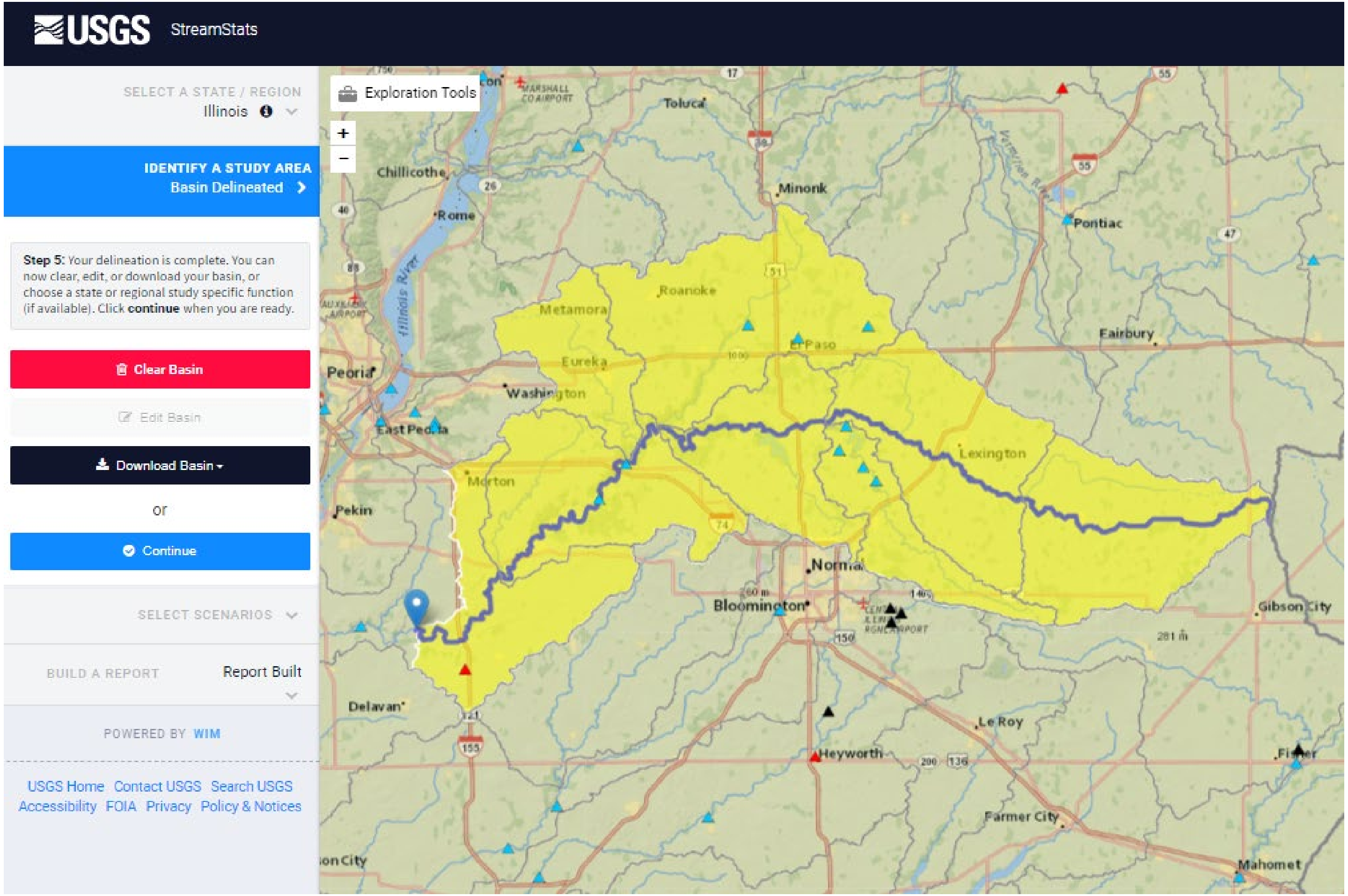
https://streamstats.usgs.gov/ss/


USGS StreamStats
SELECT A STATE / REGION
Illinois
IDENTIFY A STUDY AREA
Basin Delineated
Step 5: Your delineation is complete. You can now clear, edit, or download your basin, or choose a state or regional study specific function (if available). Click continue when you are ready.
Clear Basin
Edit Basin
Download Basin
or
Continue
SELECT SCENARIOS
BUILD A REPORT
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El Paso
Eureka
Peoria
Washington
East Peoria
Lexington
Morton
Pekin
Normal
Bloomington
Gibson City
Delavan
Le Roy
Heyworth
Fisher
Farmer City
Mahomet
Illinois River

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StreamStats Terminology

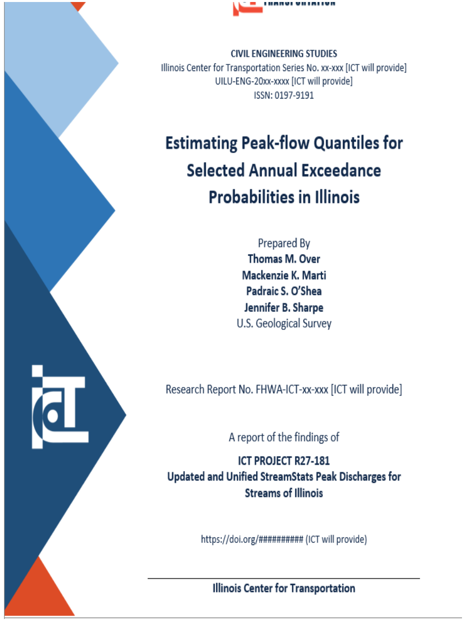
Peak-Flow Statistics Flow Report [Region 3 Peak Unadjusted SIR 2004 5103]

PIl: Prediction Interval-Lower, Plu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PIl	Plu	SE	ASEp	Equiv. Yrs.
50-percent AEP flood	8880	ft^3/s	4780	16500	39.5	39.5	2.7
20-percent AEP flood	15100	ft^3/s	8070	28300	40	40	3.2
10-percent AEP flood	19500	ft^3/s	10200	37300	41.6	41.6	3.9
4-percent AEP flood	25200	ft^3/s	12700	50000	44.2	44.2	4.7
2-percent AEP flood	29500	ft^3/s	14400	60500	46.6	46.6	5.2
1-percent AEP flood	33800	ft^3/s	15900	71600	49	49	5.6
0.2-percent AEP flood	44000	ft^3/s	19200	101000	54.9	54.9	6.2

Peak-Flow Statistics Flow Report [Region 3 Peak Adjusted Using SIR 2016 5050]

Statistic	Value	Unit
Urban 50-percent AEP flood	9220	ft^3/s
Urban 20-Percent AEP flood	15600	ft^3/s
Urban 10-percent AEP flood	20000	ft^3/s
Urban 4-percent AEP flood	25900	ft^3/s
Urban 2-percent AEP flood	30300	ft^3/s
Urban 1-percent AEP flood	34600	ft^3/s
Urban 0.2-percent AEP flood	45000	ft^3/s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Illinois Center for Transportation Series No. xx-xxx [ICT will provide]
UILU-ENG-20xx-xxxx [ICT will provide]
ISSN: 0197-9191

Estimating Peak-flow Quantiles for Selected Annual Exceedance Probabilities in Illinois

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Jennifer B. Sharpe
U.S. Geological Survey

Research Report No. FHWA-ICT-xx-xxx [ICT will provide]

A report of the findings of

ICT PROJECT R27-181
Updated and Unified StreamStats Peak Discharges for Streams of Illinois

https://doi.org/########## (ICT will provide)

Illinois Center for Transportation

Report and datasets

- In review, publication expected fall 2023
- Data releases will be available on ScienceBase
  - https://www.sciencebase.gov/catalog/

StreamStats

- Updated DEM and streamlines
- New basin characteristic layers
- Updated at-site estimates
- Updated peak-flow statistics using new equations
- Expected November 2023

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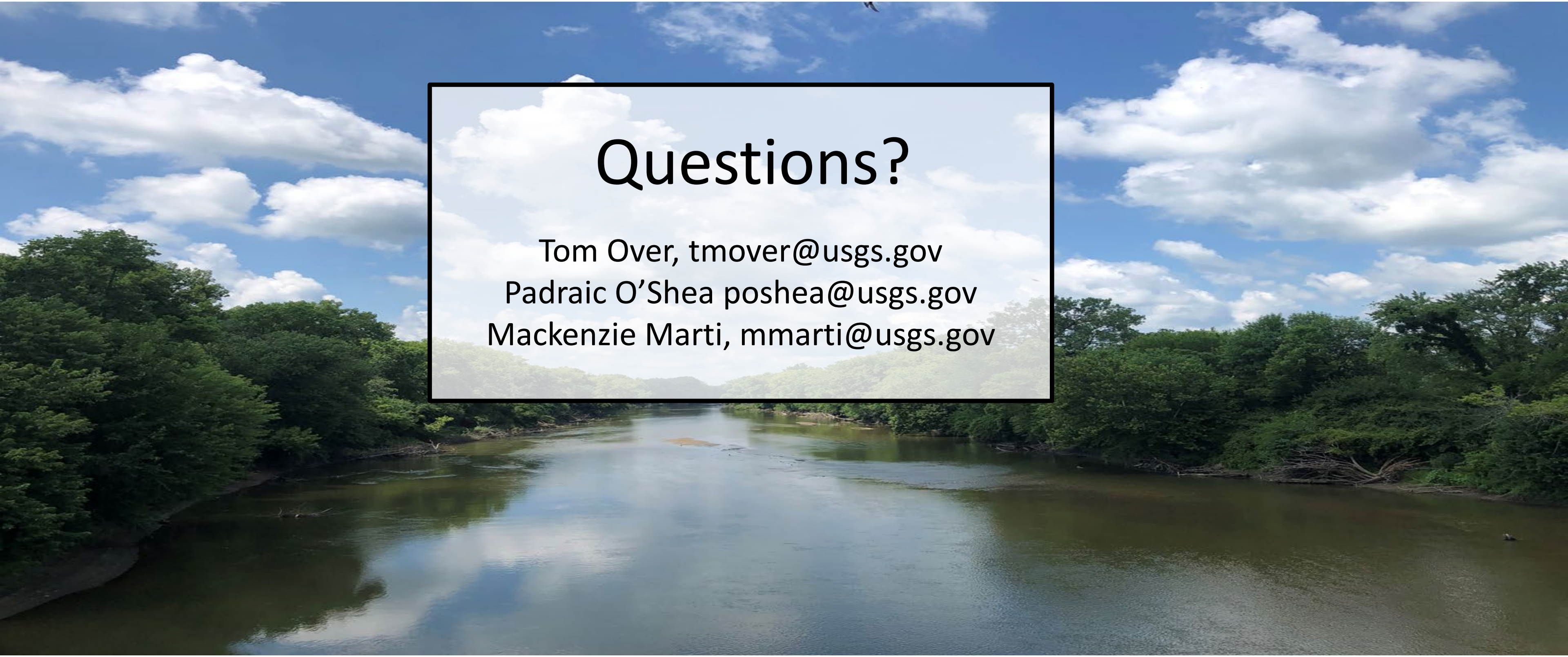

Questions?

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Photograph by Lindsey Schafer, U.S. Geological Survey