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Identifying and adjusting for effects of urbanization on peak streamflows

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Green and 4th Sts., Champaign, IL, July 30, 1979

Photo Courtesy of *Daily Illini*

General Background:
Comparing rural and urban flood frequency estimation techniques

	Rural:	**Urban:**
Nature of problem:	**Transfer of hydrologic information *in space*, from gaged to ungaged.**	**Transfer of hydrologic information *in both space and time*, from gaged to ungaged and from present to the future of an urbanizing watershed.**
Status of regional regression equations (RREs):	**Widely available (e.g., in StreamStats) and regularly updated.**	**Not as widely available (none in StreamStats?); possible national options: Sauer et al. (1983), Moglen and Shivers (2006).**
Value of simulation models:	**Not clear they are better than RREs (e.g., Hodgkins et al., 2007).**	**Urban watersheds probably more amenable to simulation modeling: surface runoff-dominated, engineered flood-control facilities.**

Project Background: Urban peak estimation in Illinois DOT Drainage Manual

- Regional regression equations (RREs):
  - “standard method” in both rural and urban watersheds
  - not all local agencies accept urban RREs.
- Rural RREs:
  - last updated in 2004 (Soong et al.) with data thru 1999.
  - implemented in StreamStats.
- Urban RREs
  - report published 1979 (Allen and Bejcek) with data thru 1977.
  - not present in StreamStats.

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Estimating imperviousness from population density (Allen & Bejcek, 1979)

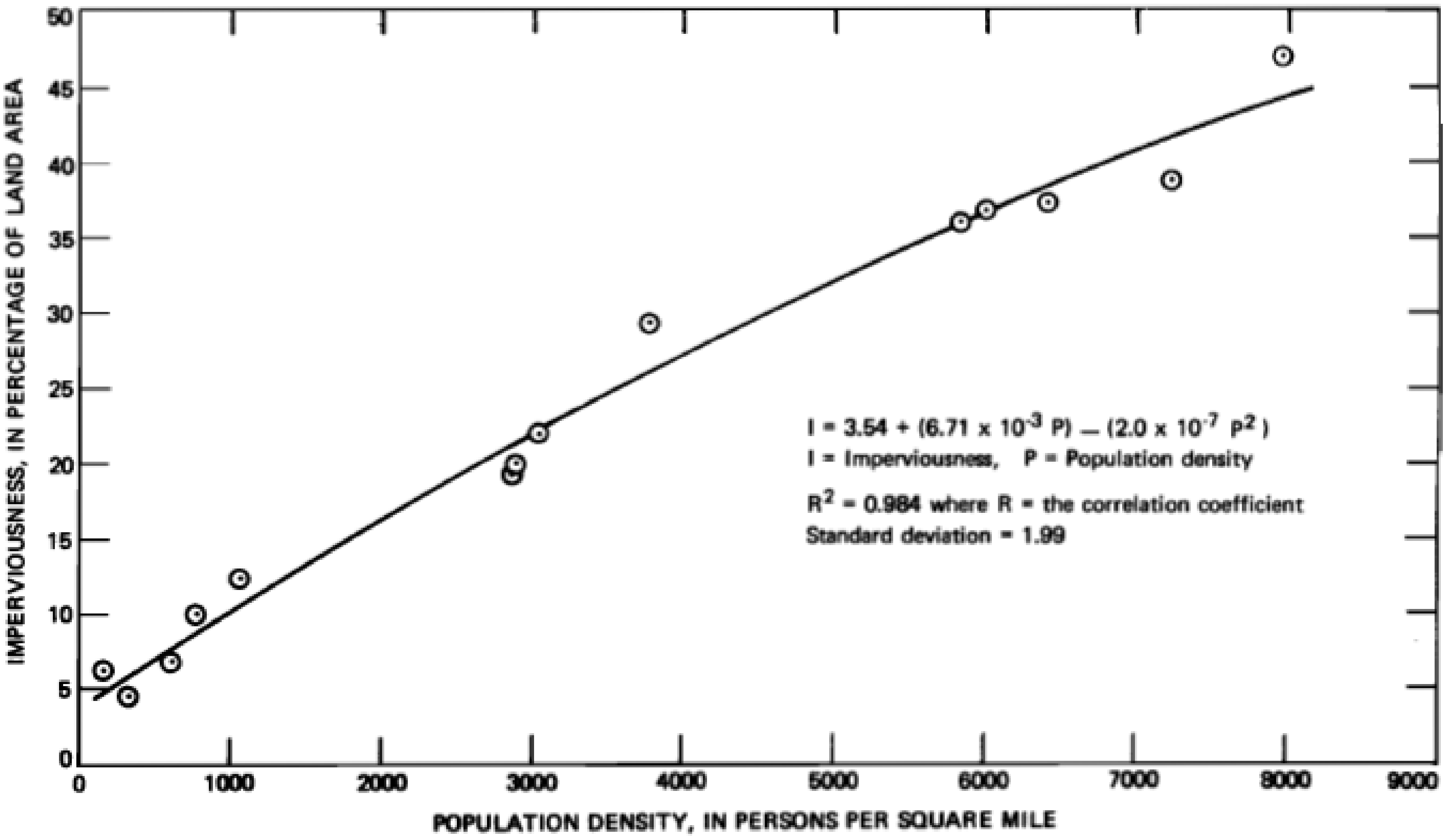

Figure 2.--Relationship between percentage of imperviousness and population density.

Effect of imperviousness on flood peaks in northeast Illinois (Allen & Bejcek, 1979)

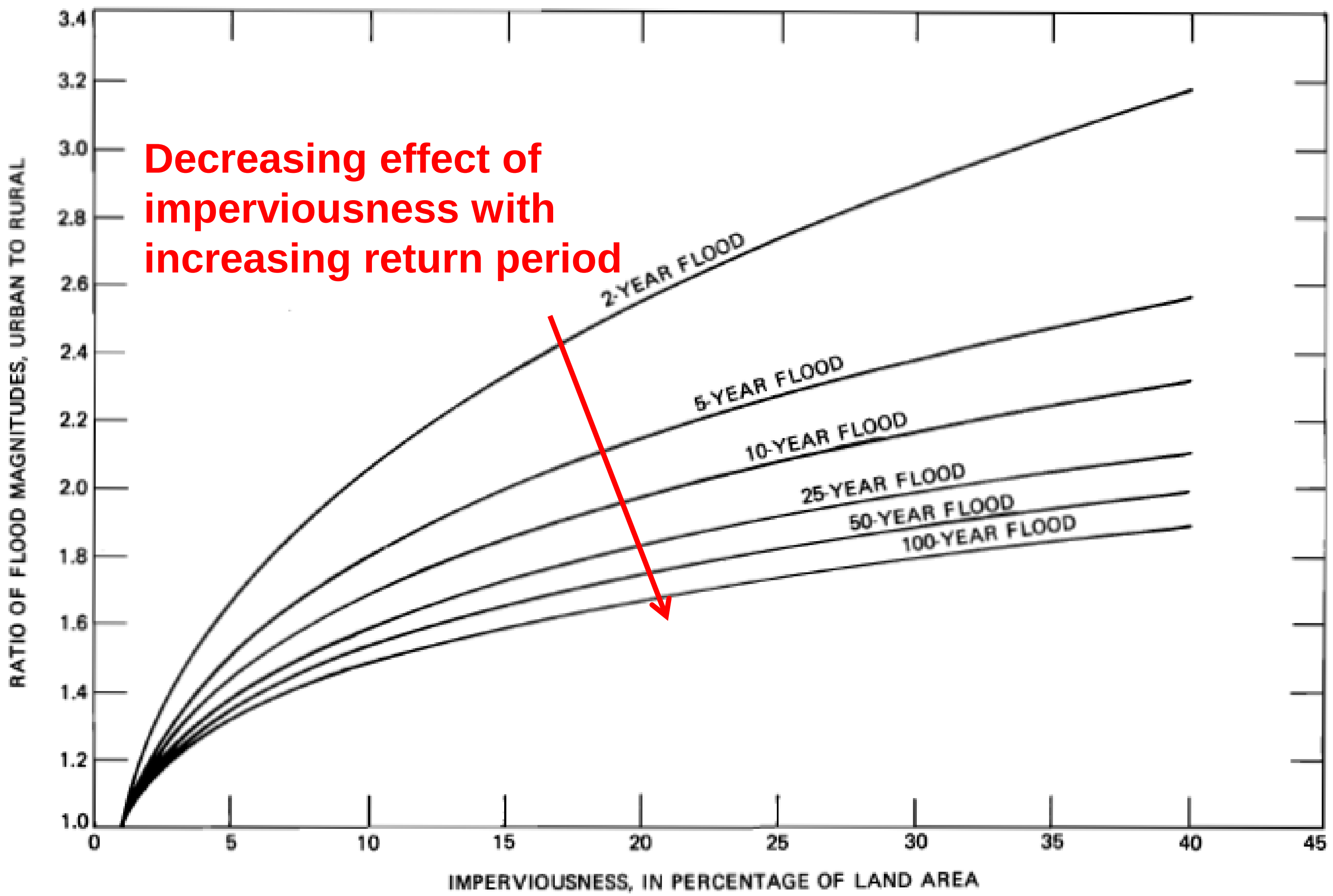

Figure 6.--Effect of urbanization on flood magnitudes in northeastern Illinois.

Reasons for updating Allen & Bejcek (1979) equations:

- 30+ years additional data.
- Changes in nature of development (stormwater detention).
- Enable implementation in StreamStats.

Overview of Project:

- **Phase I: Adjust historical records to present (2010) conditions – topic of this presentation.**
- **Phase II: Compute regional regression equations (RREs) for each flood quantile as an adjustment factor applied to rural RREs for northeast Illinois, which are also being updated:**

  $Q_T = aA^bS^cW^d \rightarrow Q_T = aA^bS^cW^dU^e$

  A = Drainage Area, S = slope, W = fraction of water or wetlands, U = fraction of urbanized land

  (same basic structure as existing Q&B79 equations)

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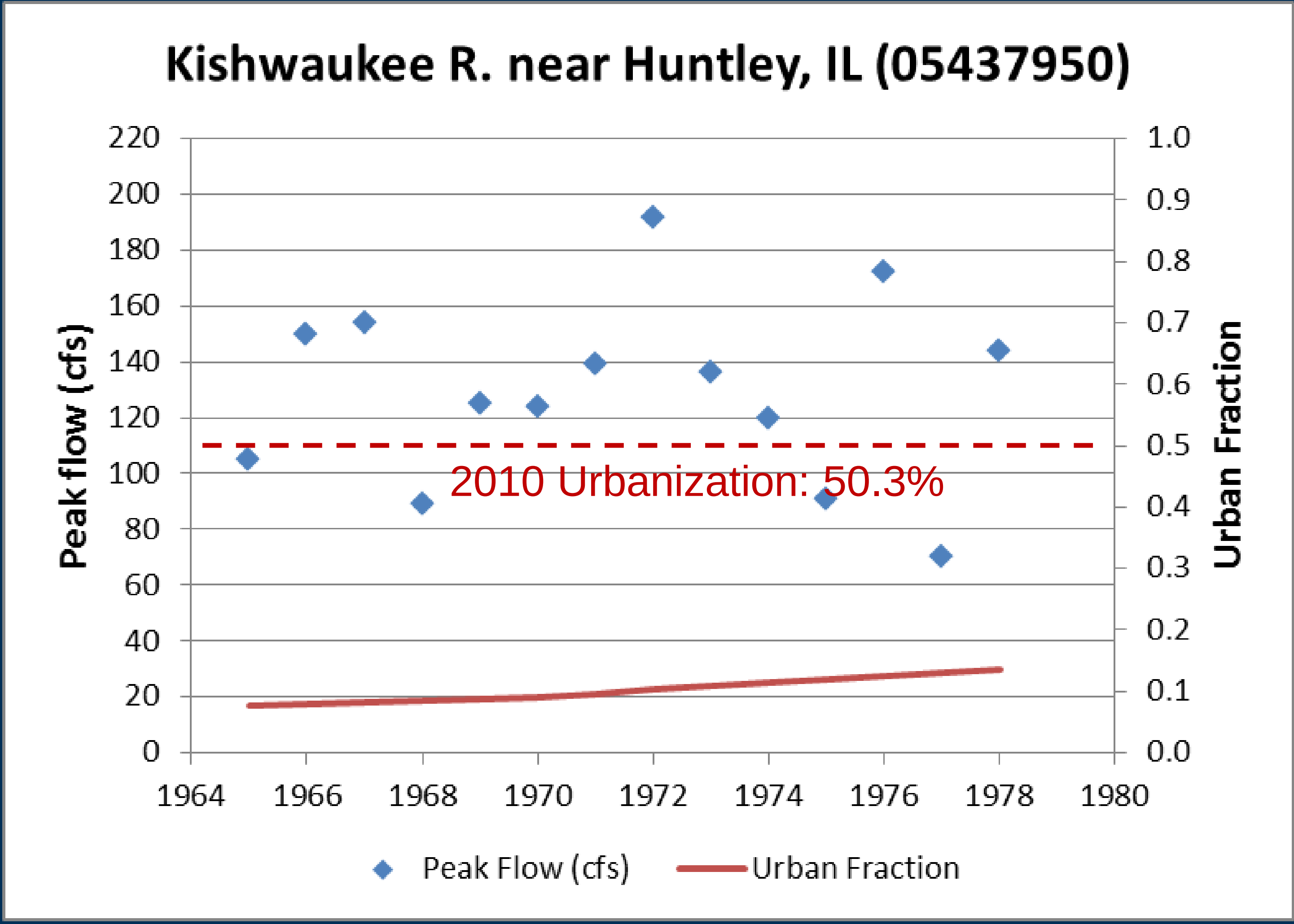
Why adjust?
1a. More records can be used

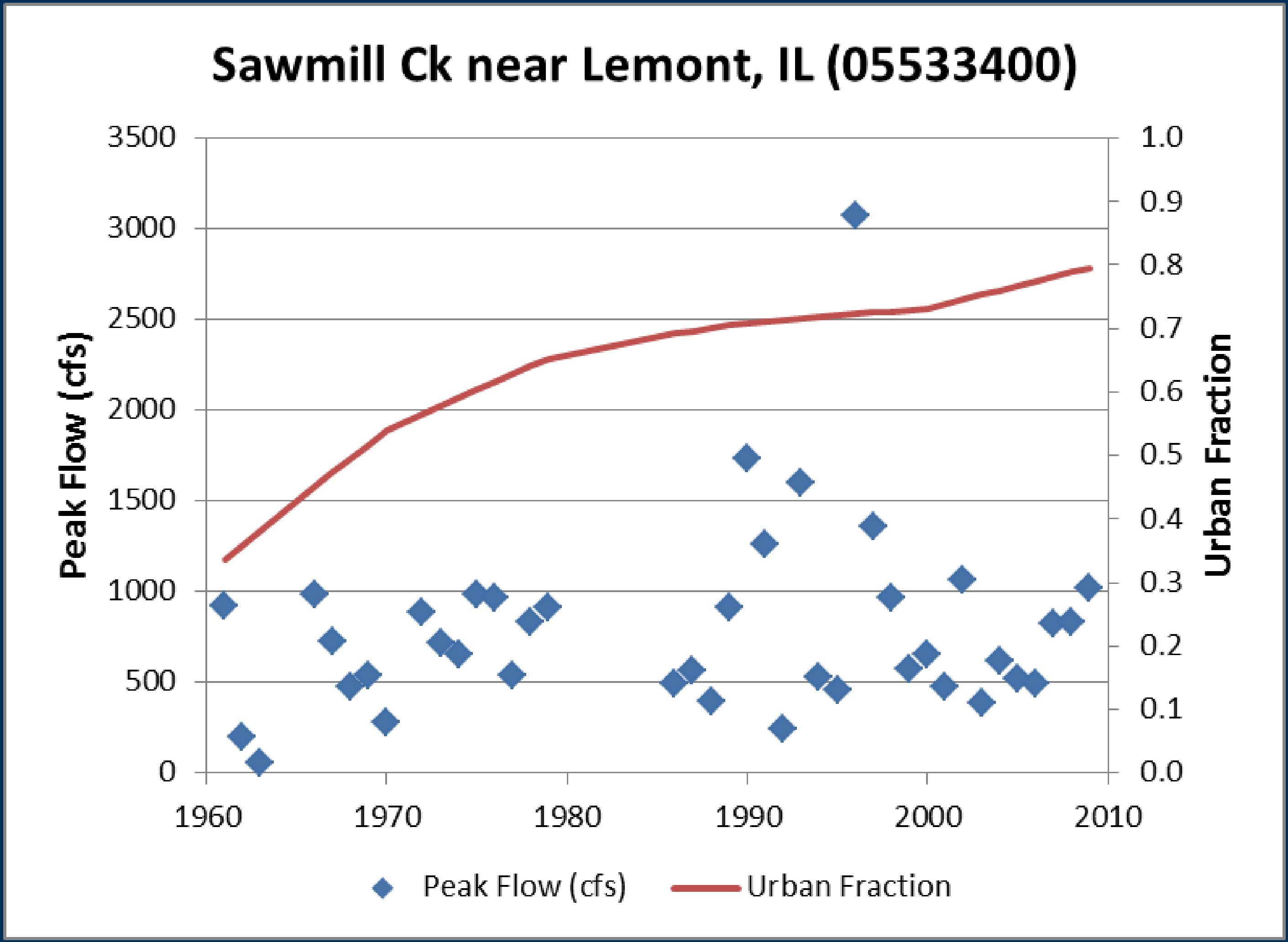
Old Records

- At-site record is not applicable to present conditions.
- To use in a regionalization study as-is, would need to know land use during 1970s.



Why adjust?
1b. More records can be used

Records with urbanization - related trends



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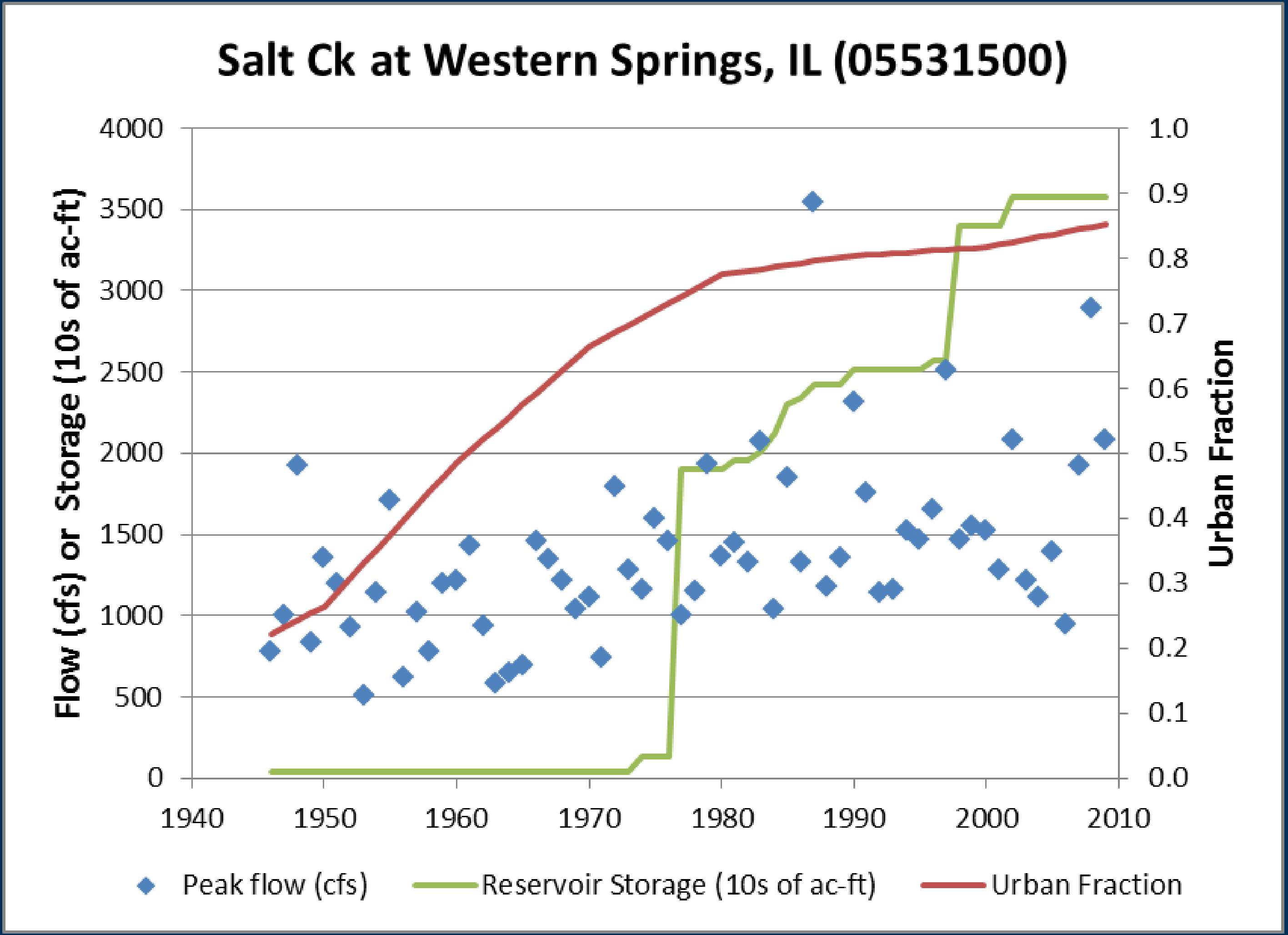
Why adjust?
1c. More records can be used.

Records with trends and construction of major flood-control facilities



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Why adjust?

2. Yields an additional product:
At-site flood peak record consistent with present land-use conditions.

3. Scientific value:

- **Direct observation of past effects of urbanization**
- **Allows testing of swapping of space for time:**
  Do effects of differences in urbanization between watersheds agree with effects of changes in urbanization over time?

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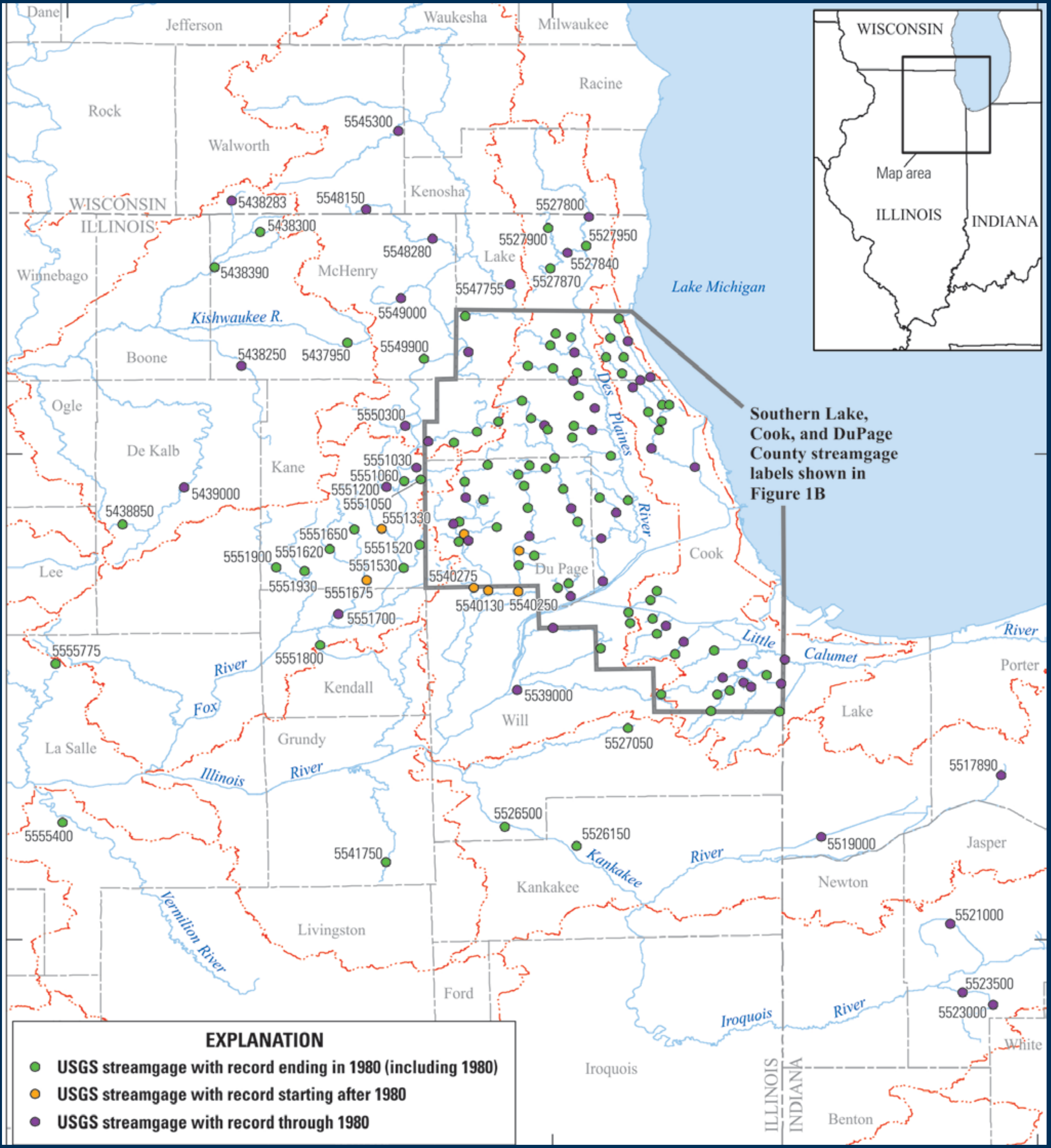
Steps in adjustment

1. Select and process input data
    - Select stations
    - Split peak flow records into segments at years when major flood control facilities built (“urbanization” considered as land use change).
    - Create annual urbanization and precipitation data sets.
2. Apply regression technique to obtain regional coefficients showing effect of urbanization and precipitation.
3. Adjust peaks to present urbanization.

Adjustment step 1

Data Used for Adjustment

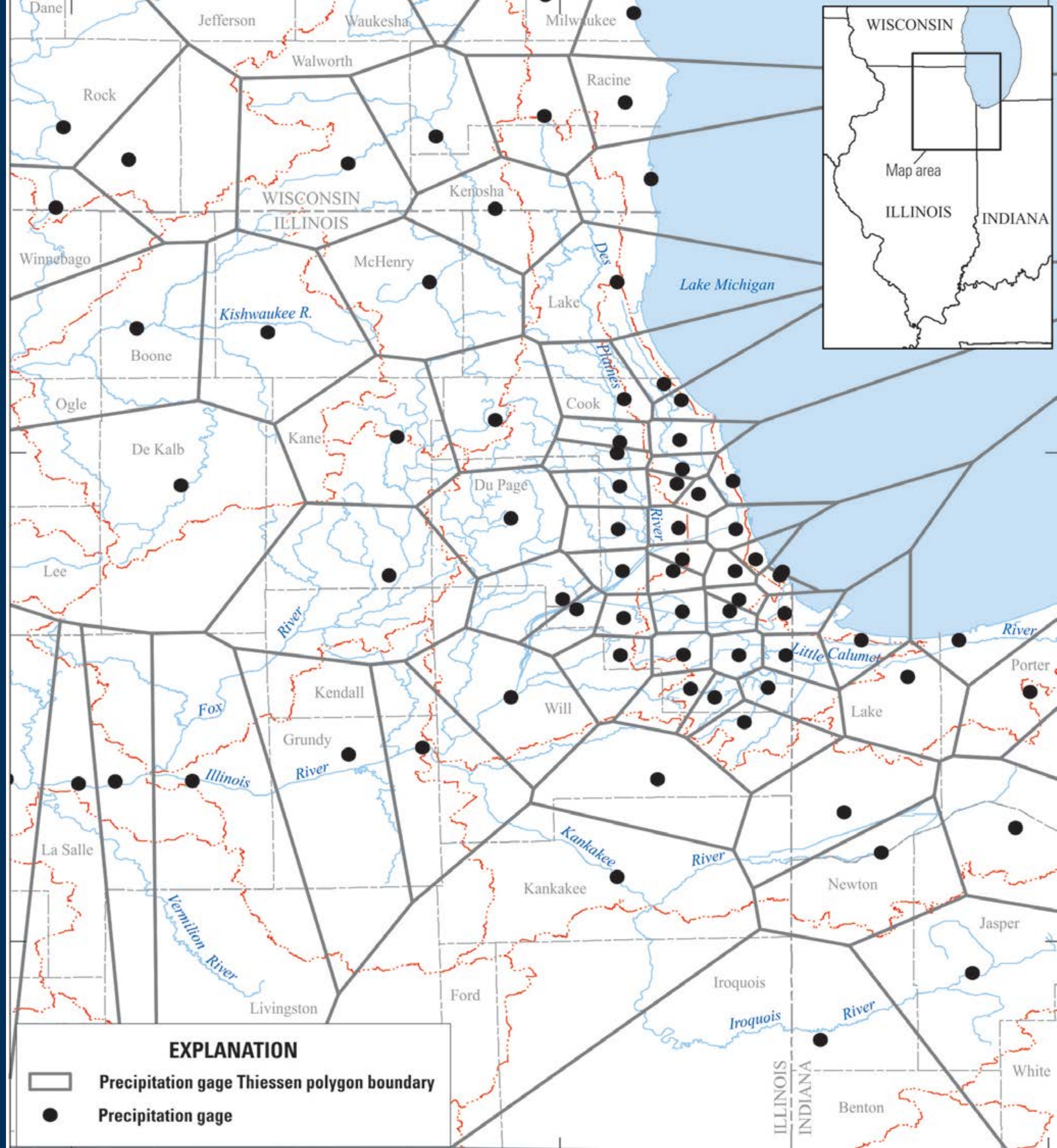
Selected streamflow stations



Adjustment step 1

Data used for adjustment:

Precipitation stations and Thiessen polygons

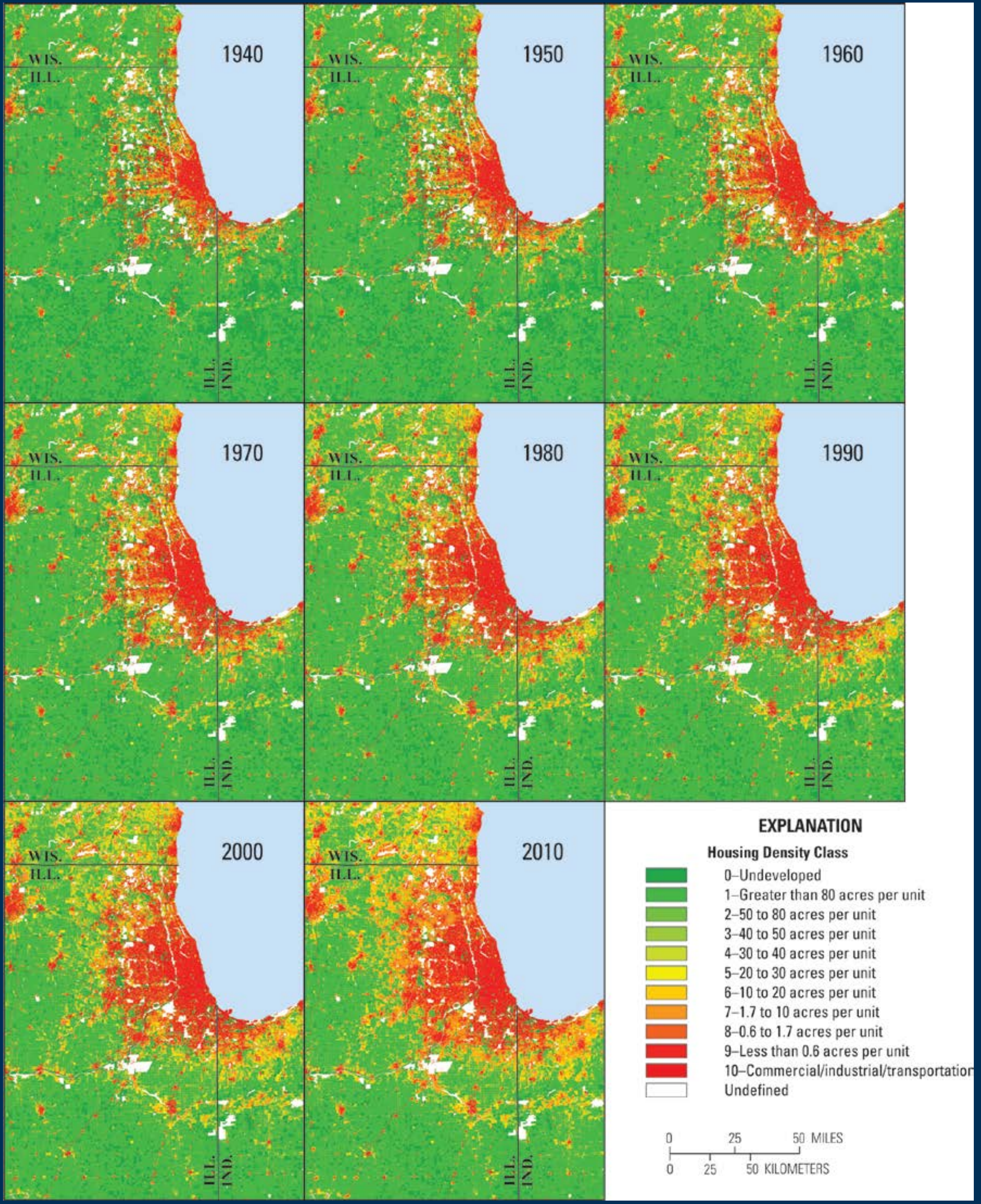


Adjustment step 1

Data used for adjustment

Historical urbanization data: **Decadal housing density product based on 2000 Census (Theobald, 2005)**

(2010 values are projected)



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Regression modeling

Two-step "fixed effects" quantile regression model (Canay, 2011):

Step 1: OLS "panel" regression: Determine fixed effects, which are intercepts of each station segment.

Step 2: Subtract fixed effects.

Step 3: Apply *quantile regression* to remainder to determine coefficients of *U* (urbanization) and *P* (precipitation) for each exceedance probability of interest.

Adjustment step 2

Regression step 1: Find intercepts $a(i)$ for each station segment i and common regional slopes b_U and b_P

For each segment i and year t,

$$y(i,t) = \log_{10}Q(i,t) = a(i) + b_U U(i,t) + b_P P(i,t) + e(i,t),$$

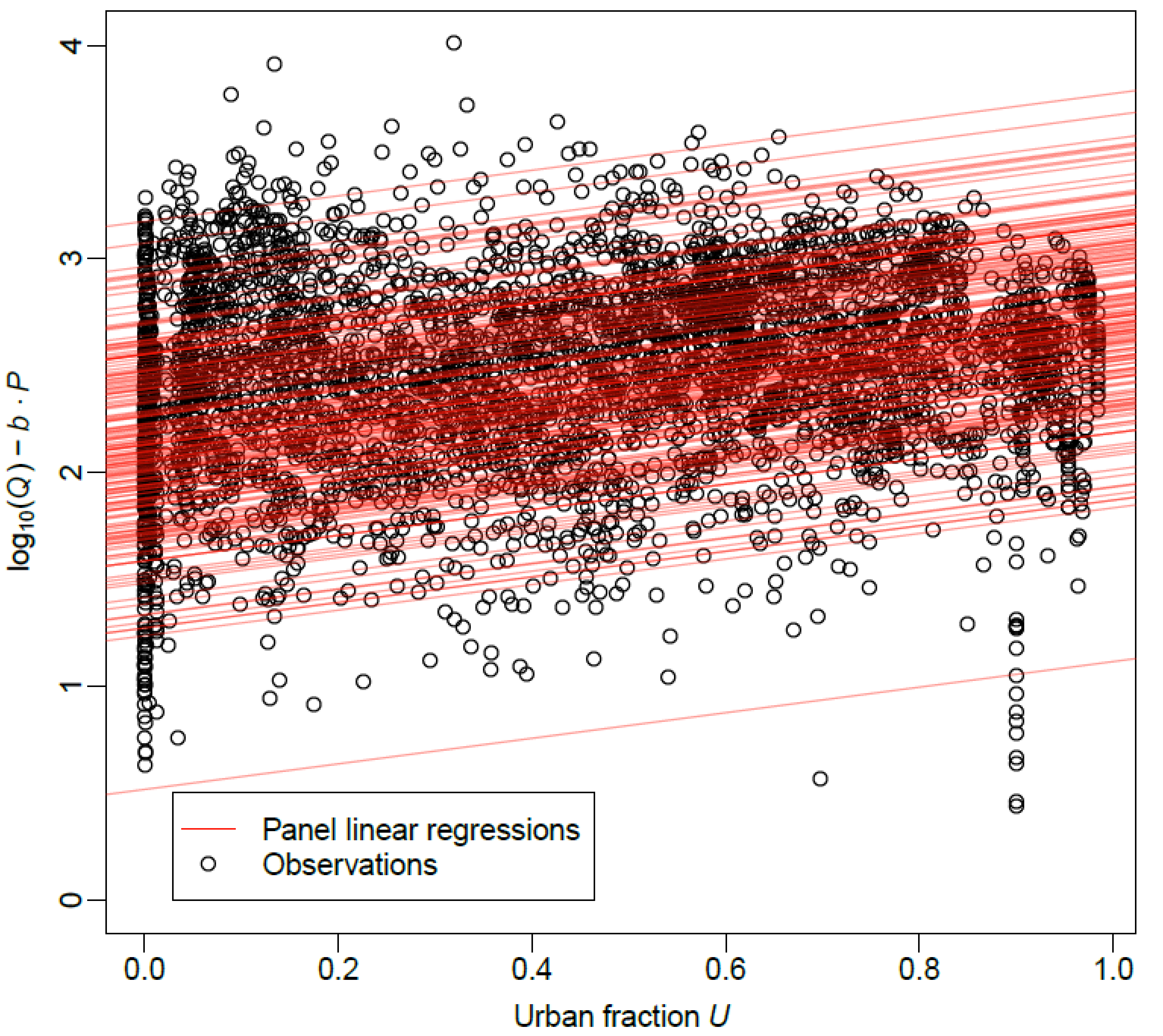
where

- Q = annual maximum flood peak
- $a(i)$ = intercept (fixed effect) of segment i
- b_U = regional urbanization coefficient = ~0.55
- U = urbanized fraction of watershed
- b_P = regional precipitation coefficient = ~0.10
- P = maximum daily precipitation
- e = error term

Adjustment step 2

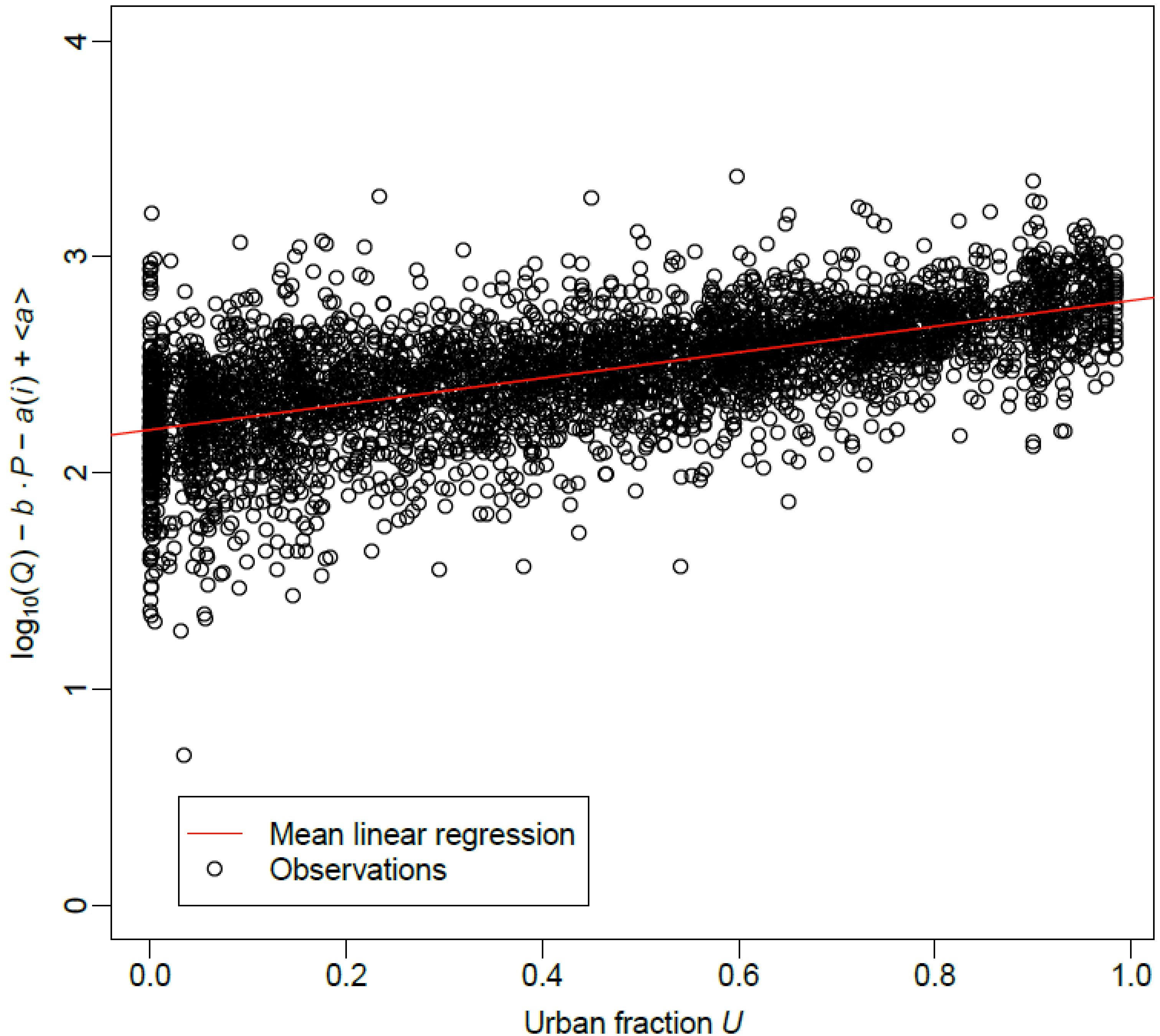
Regres-sion step 1

Plot shows urbanization dimension only



Adjustment step 2

Regression step 2: Subtract fixed effects (intercepts)



Data now assumed to be homogeneous between stations

Adjustment step 2

Regression model step 3: Find common regional slopes $\beta_U(p)$ and $\beta_P(p)$ depending on frequency p by *quantile regression*

For each exceedance probability (EP) p,

$$y'(i,t) = \log_{10}Q(i,t) - a(i) + \langle a \rangle =$$

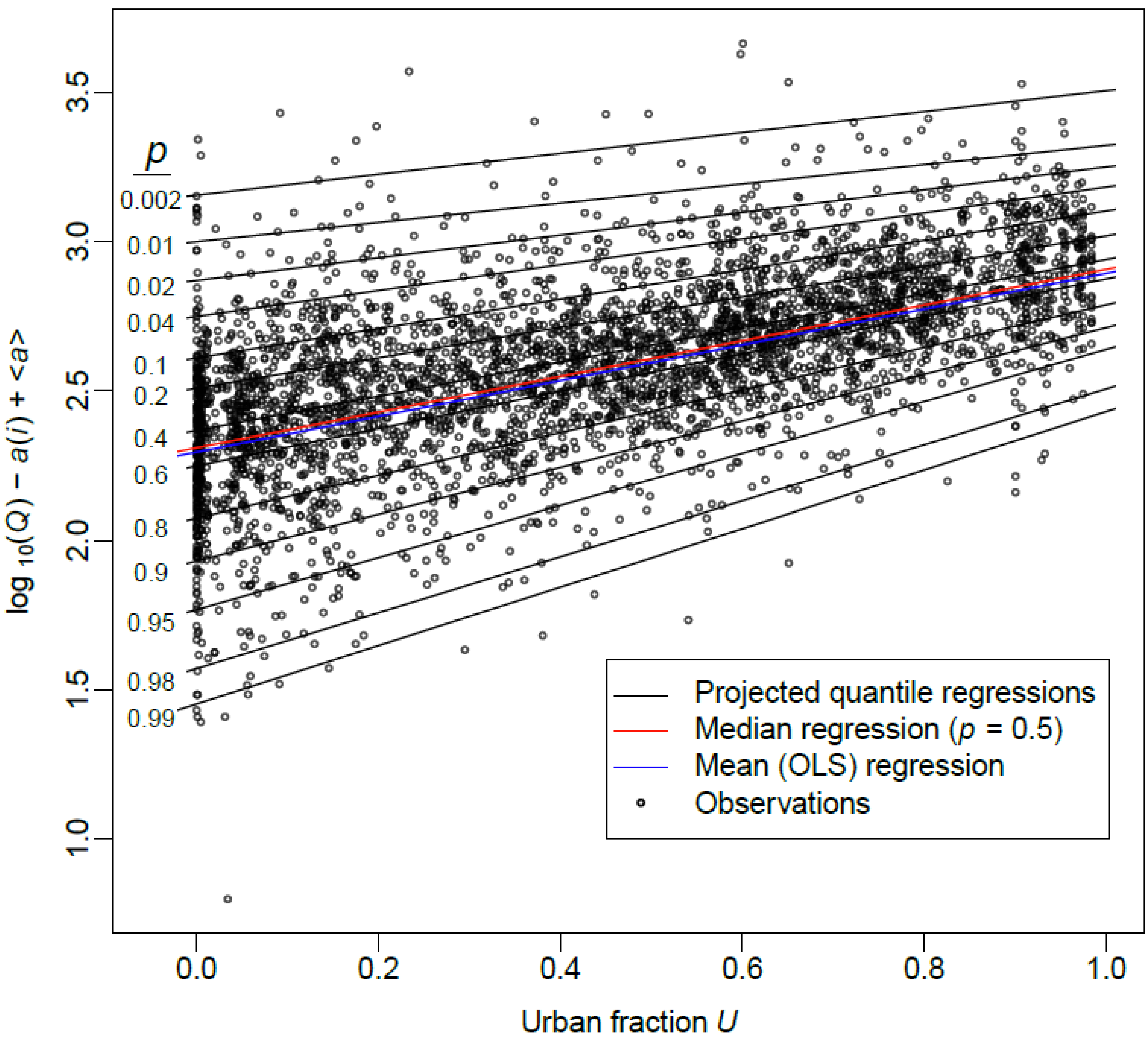
$$\alpha(p) + \beta_U(p)U(i,t) + \beta_P(p)P(i,t) + \varepsilon(i,t),$$

where

- Q = annual maximum flood peak
- $a(i)$ = intercept (fixed effect) of segment i
- $\beta_U(p)$ = regional urbanization coefficient for EP p = [.2-.9] (?)
- U = urbanized fraction of watershed
- $\beta_P(p)$ = regional precipitation coefficient for EP p = [.05-.15] (?)
- P = maximum daily precipitation
- e = error term

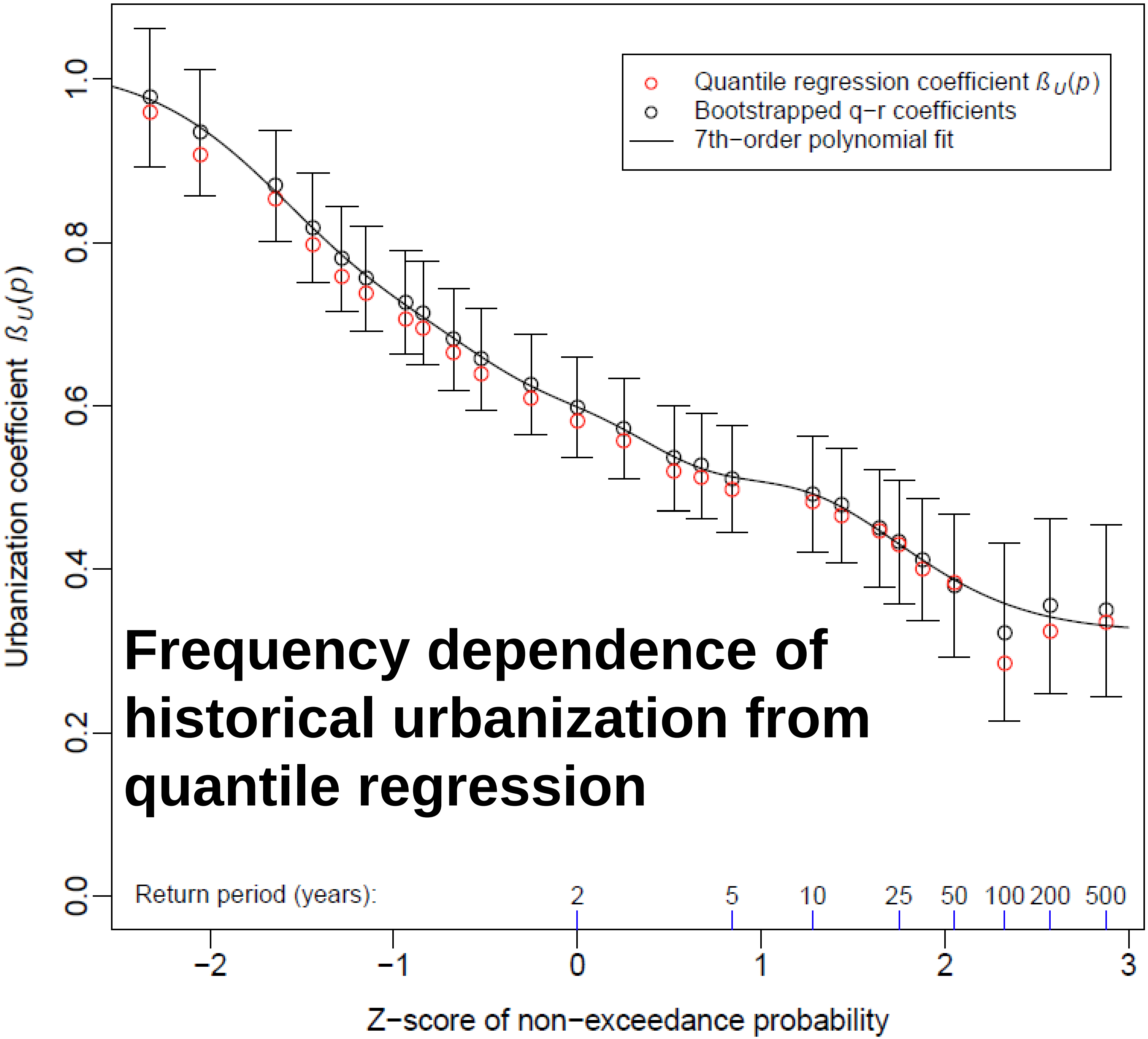
Adjustment step 2

Regression step 3: Quantile regression



Plot shows urbanization dimension only

Adjustment step 2



Frequency dependence of historical urbanization from quantile regression

Adjustment to 2010 urbanization:

Two steps:

1. Assign exceedance probability p to each observatoin by interpolation among quantile regression lines (planes)
2. Adjust by adding $\beta_U(p)[U(i,t) - U(i,2010)]$ for changing urbanizatoin between year t and 2010, that is:

$$\log_{10}Q_{2010}(i,t) = \log_{10}Q(i,t) + \beta_U(p)[U(i,t) - U(i,2010)]$$

where

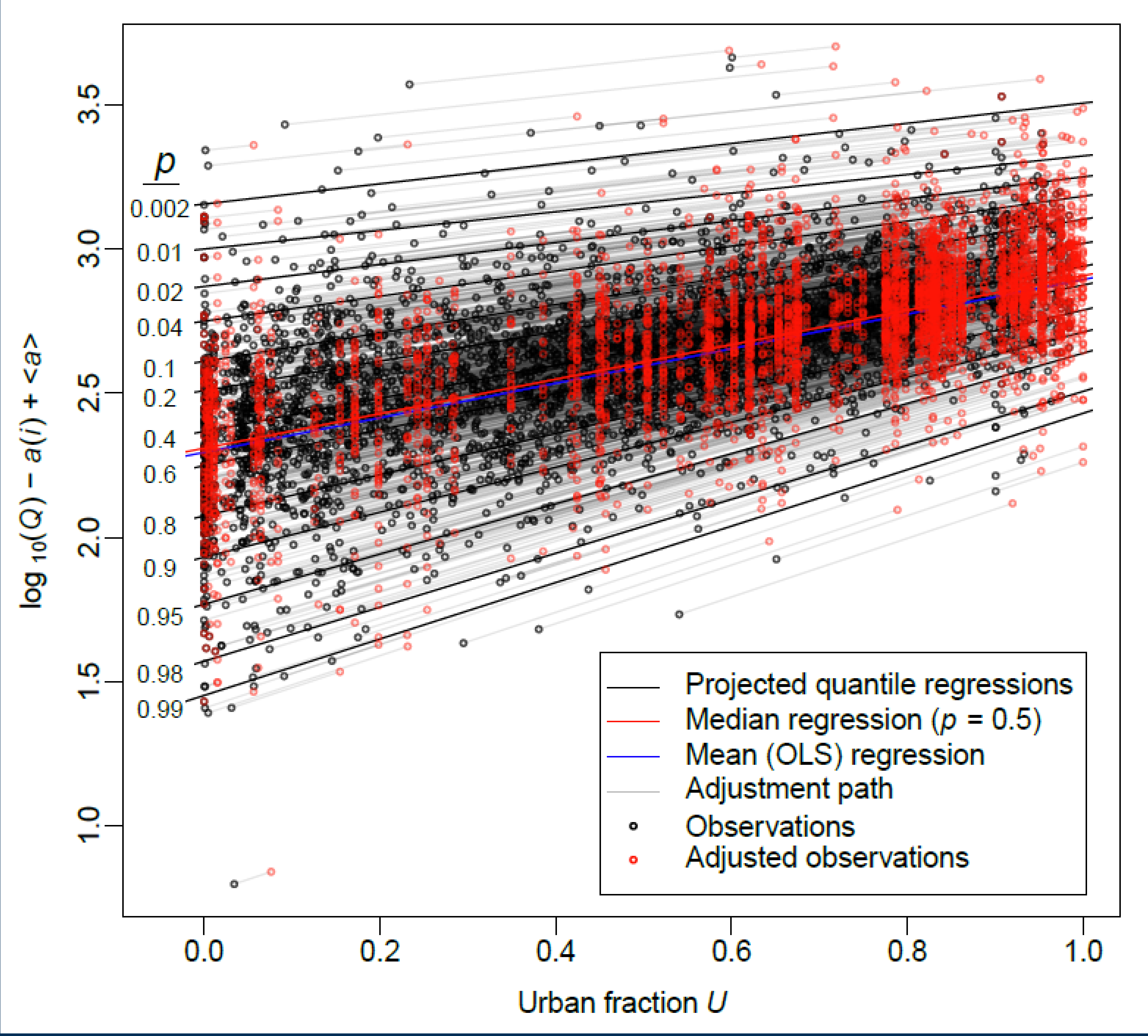
Q = annual maximum flood peak

$\beta_U(p)$ = regional urbanization coefficient for EP p

U = urbanized fraction of watershed

Adjustment step 3

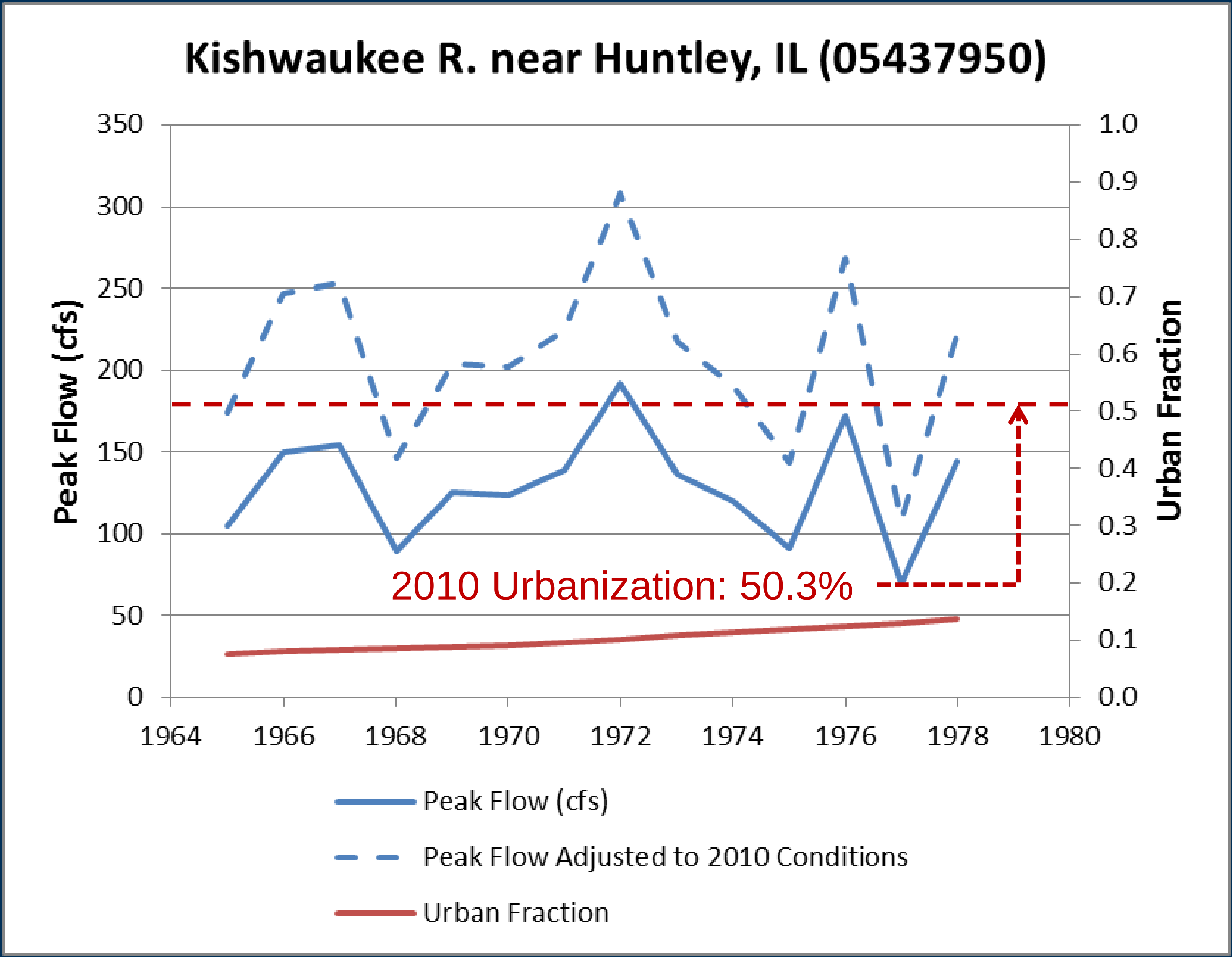
Original and adjusted peak flows



Example of Adjusted Record: Old Record

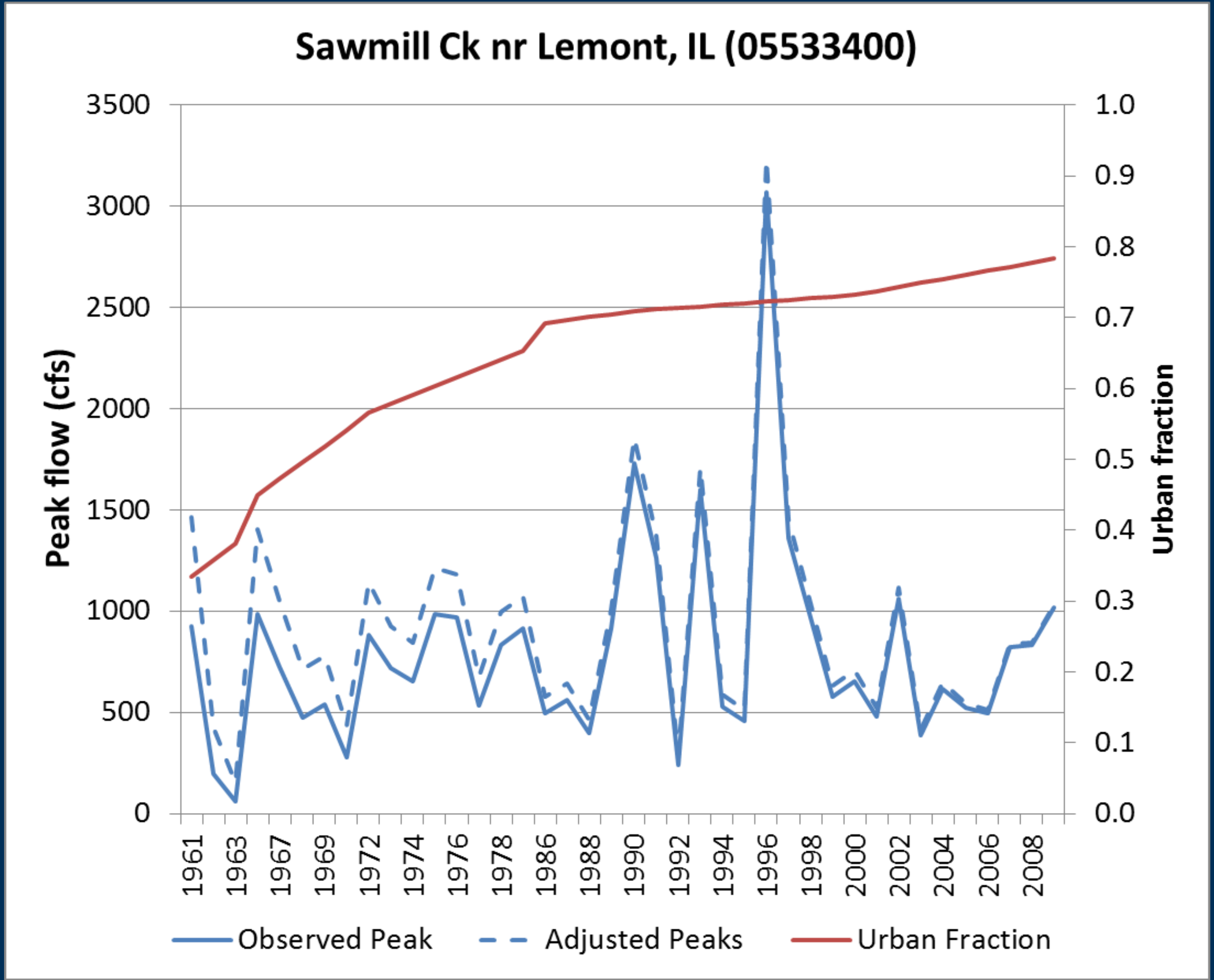
Adjustment step 3

Note: Assumes no major flood control works since end of record..



Adjustment step 3

Example of adjusted record: Urbanization trend



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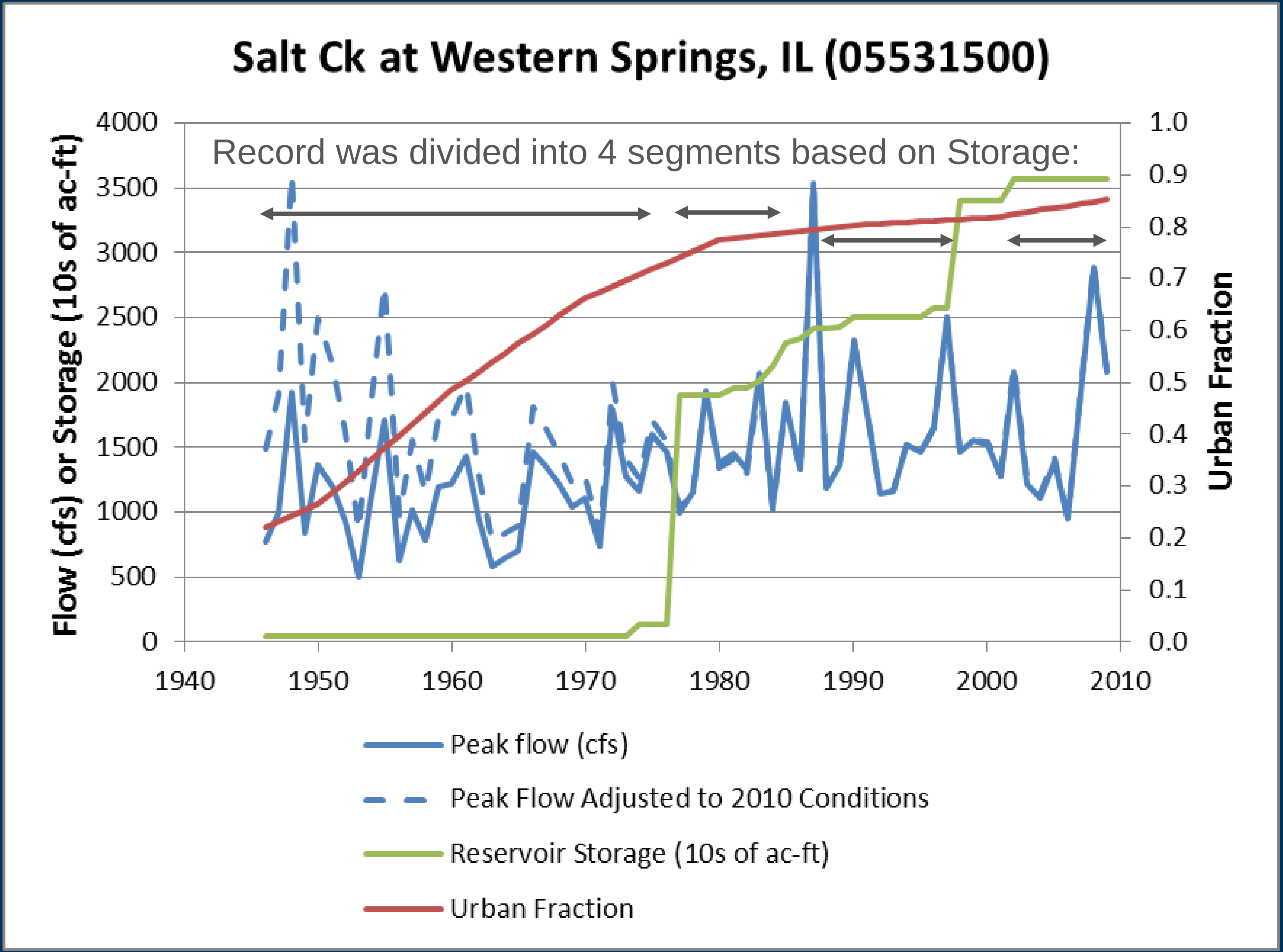
Example of adjusted record: segmented

Adjustment step 3



Conclusions

- Method developed to diagnose temporal effect of urbanization on peak flows.
- Found that temporal effect of urbanization decreased with increasing return period, agreeing with existing spatial equations.
- Allows adjustment of peak flow records to present conditions for use in spatial regression analysis
- Traditional spatial regression analysis is now underway.

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Questions?