Upgrades to the USGS-Massachusetts Long-term Observation-Well Network:

Conversion of selected wells to real time reporting

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Massachusetts
Water Resources Commission
October 12, 2017

Observation well upgrades:

- In 2017, USGS and MassDEP funded the upgrade of 11 wells to real time, to increase the MA total to 42. (MassDCR and USGS are funding long-term operations, maintenance, and data management.)

- 10 of the 11 wells have been completed, the 11th well (Hardwick 1) will be re-drilled before upgrade.

Why upgrade wells to real-time?

1. To improve basic understanding of how:

- Climate variations and trends (P, ET)
- Geologic conditions (till vs. sand & gravel)
- Hydrologic position (upland vs. lowland)

affect groundwater levels, aquifer recharge rates, and summer baseflows in streams.

Why upgrade wells to real-time?

2. Support timely decision-making. Examples:

- Drought management (local and State)
- Projecting likely high groundwater levels
  (Title 5 and the Frimpter Method)
- Projecting likely low groundwater levels
  (New developments in dug-well design)

Lakeville 14

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Lakeville 14 instrumentation (older technology)

West Brookfield 2

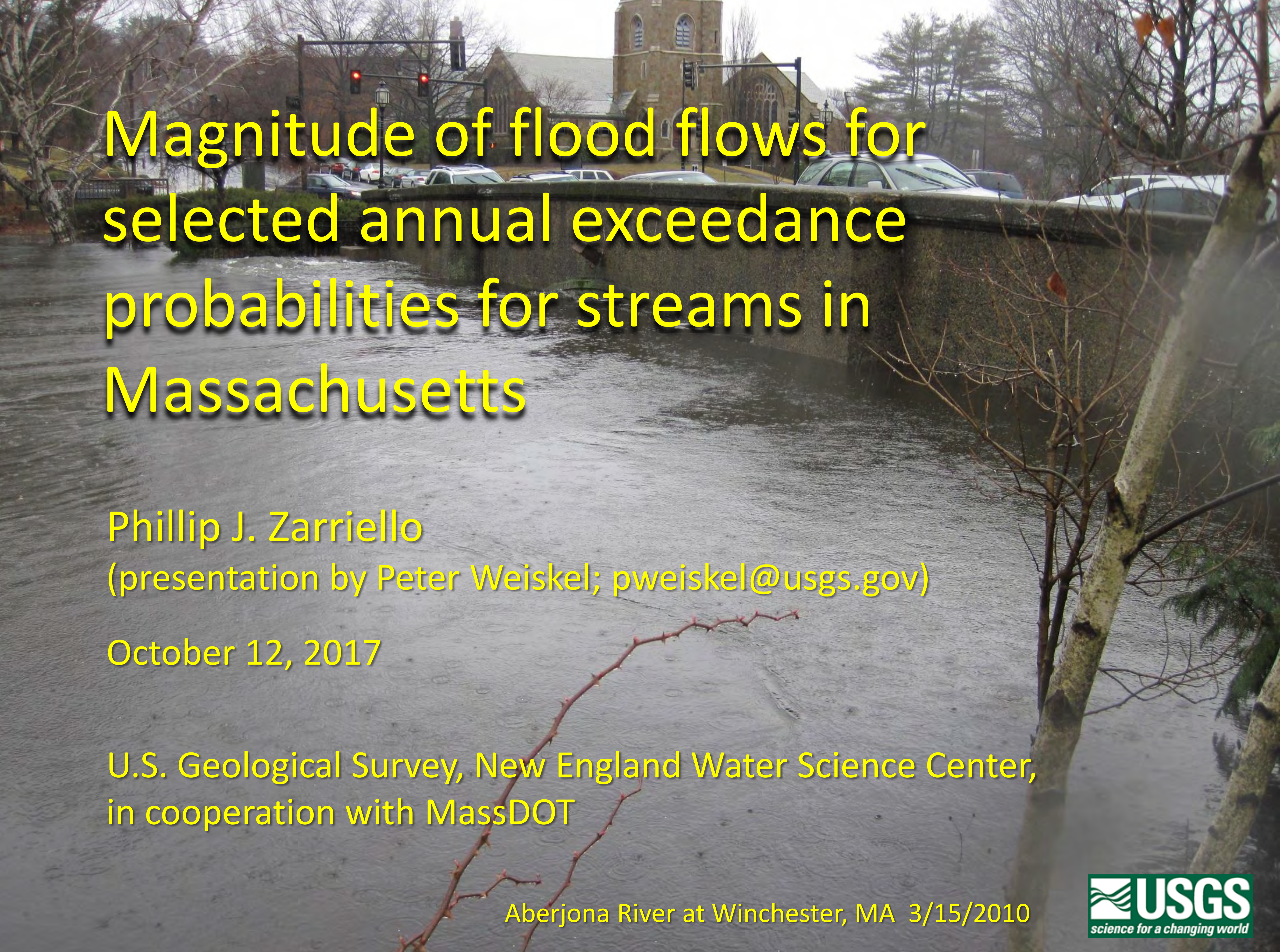
West Brookfield 2 Instrumentation (new technology)

Magnitude of flood flows for selected annual exceedance probabilities for streams in Massachusetts

Phillip J. Zarriello
(presentation by Peter Weiskel; pweiskel@usgs.gov)

October 12, 2017

U.S. Geological Survey, New England Water Science Center,
in cooperation with MassDOT



Aberjona River at Winchester, MA 3/15/2010

Objectives:

- Update at-site flood flow information for MA streamgages
- Develop new regional equations for estimating flood flows at ungaged locations in MA.
- Make information and equations accessible through the USGS StreamStats application.

Why Update Flood Flow Anlaysis?

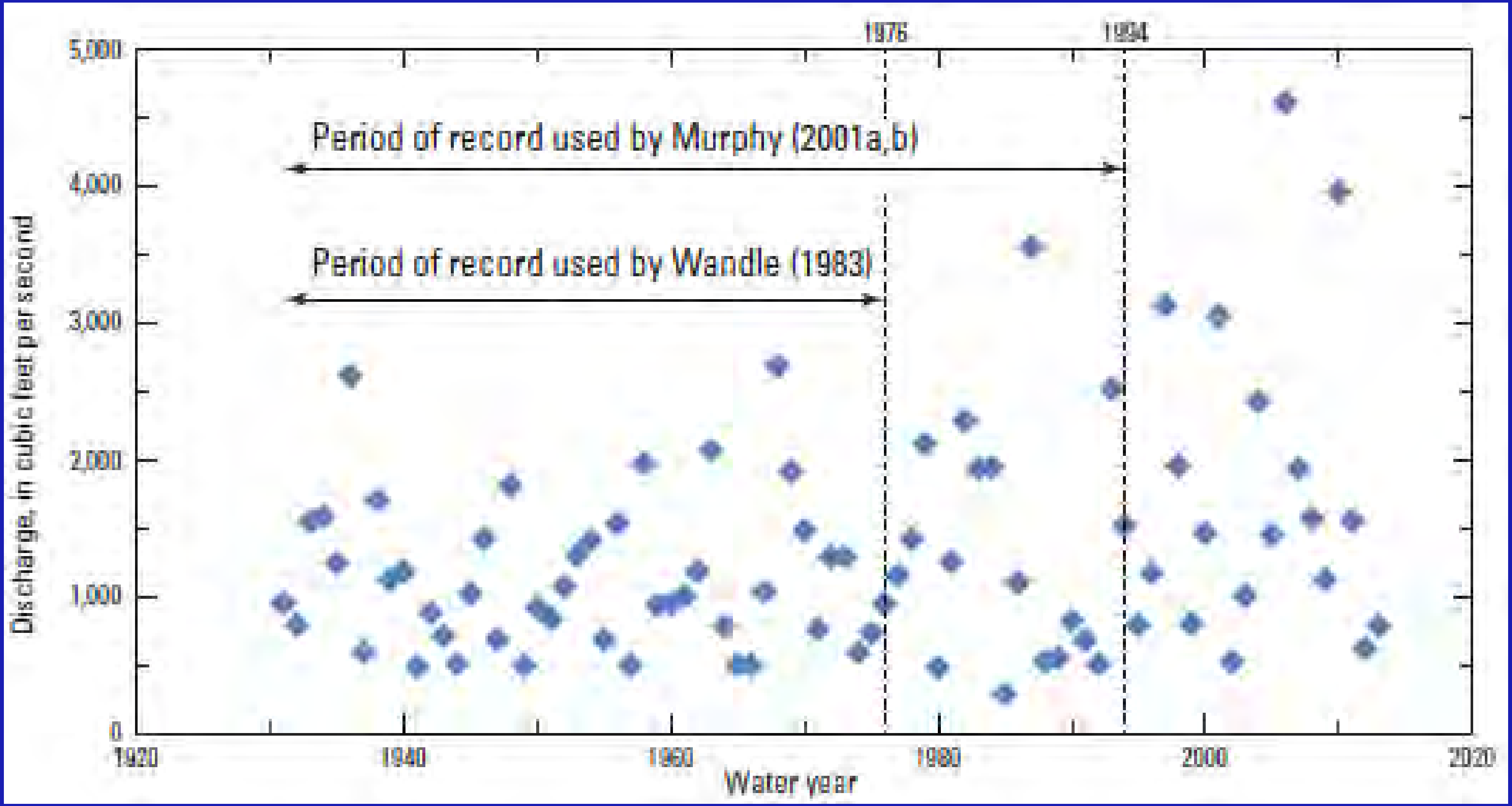
- Critical for infrastructure design, hazard mitigation, and climate-change adaptation.

- Existing MA regional equations were out of date.
  Wandle (1983)— used data through 1976 at 95 sites, for 2-, 5-, 10-, 25-, 50-, and 100-year floods; Murphy (2001) developed equations for mixed population floods; data up to 1993 at only 30 sites.

- More robust statistical methods, and new streamflow and landscape data are now available

The period of record matters…

Annual peak flows, Ipswich River at Ipswich, MA:



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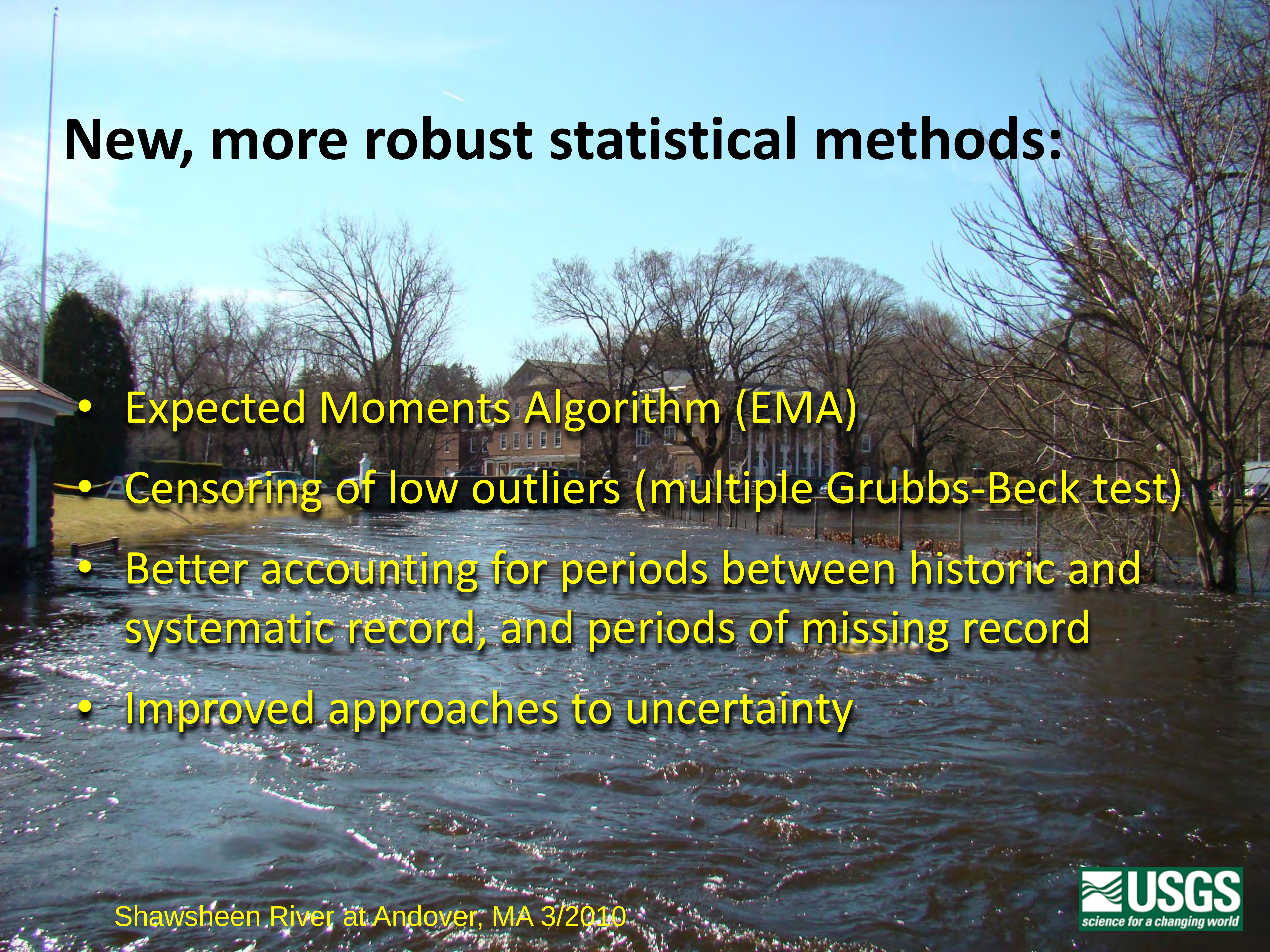
New, more robust statistical methods:

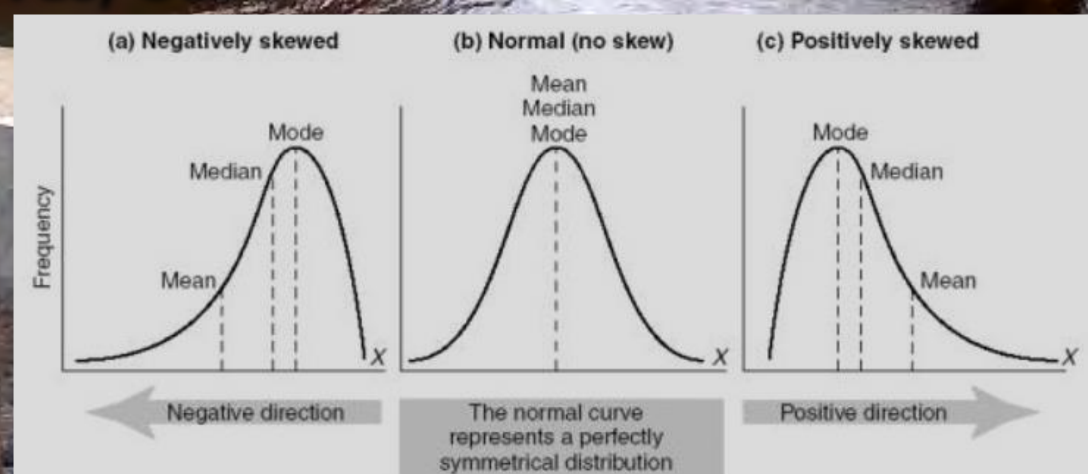
- Expected Moments Algorithm (EMA)
- Censoring of low outliers (multiple Grubbs-Beck test)
- Better accounting for periods between historic and systematic record, and periods of missing record
- Improved approaches to uncertainty



Shawsheen River at Andover, MA 3/2010

Estimation of regional skew coefficient

- Flood analysis is based on 3 statistics of annual peak flows– mean (μ), standard deviation (σ), and skew
- Skew determines shape of a probability function; sensitive to extreme events, and more variable than μ and σ
- Methods for determining skew have improved recently – Bayesian WLS/GLS



Matapoisett River 3/31/2010

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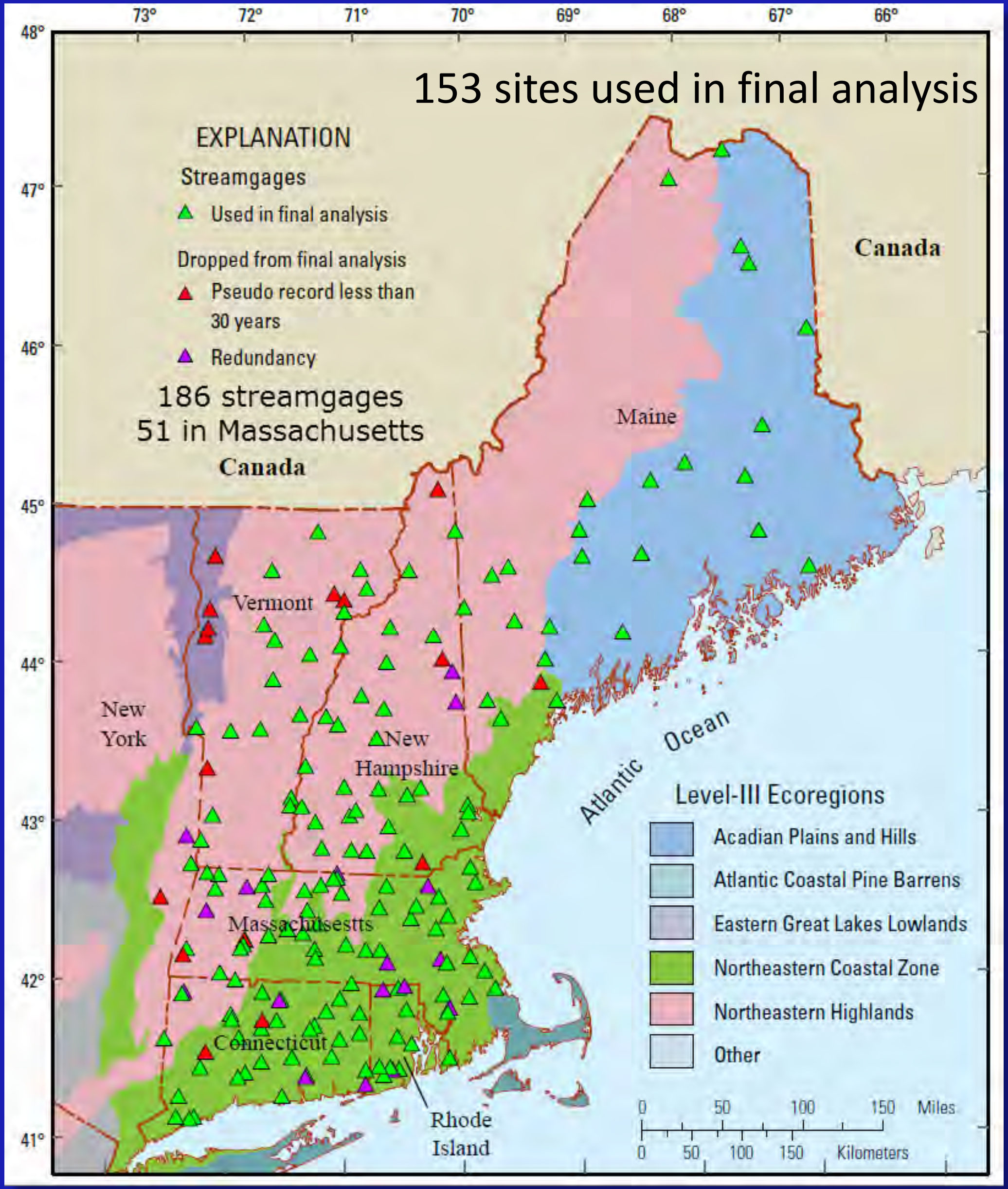
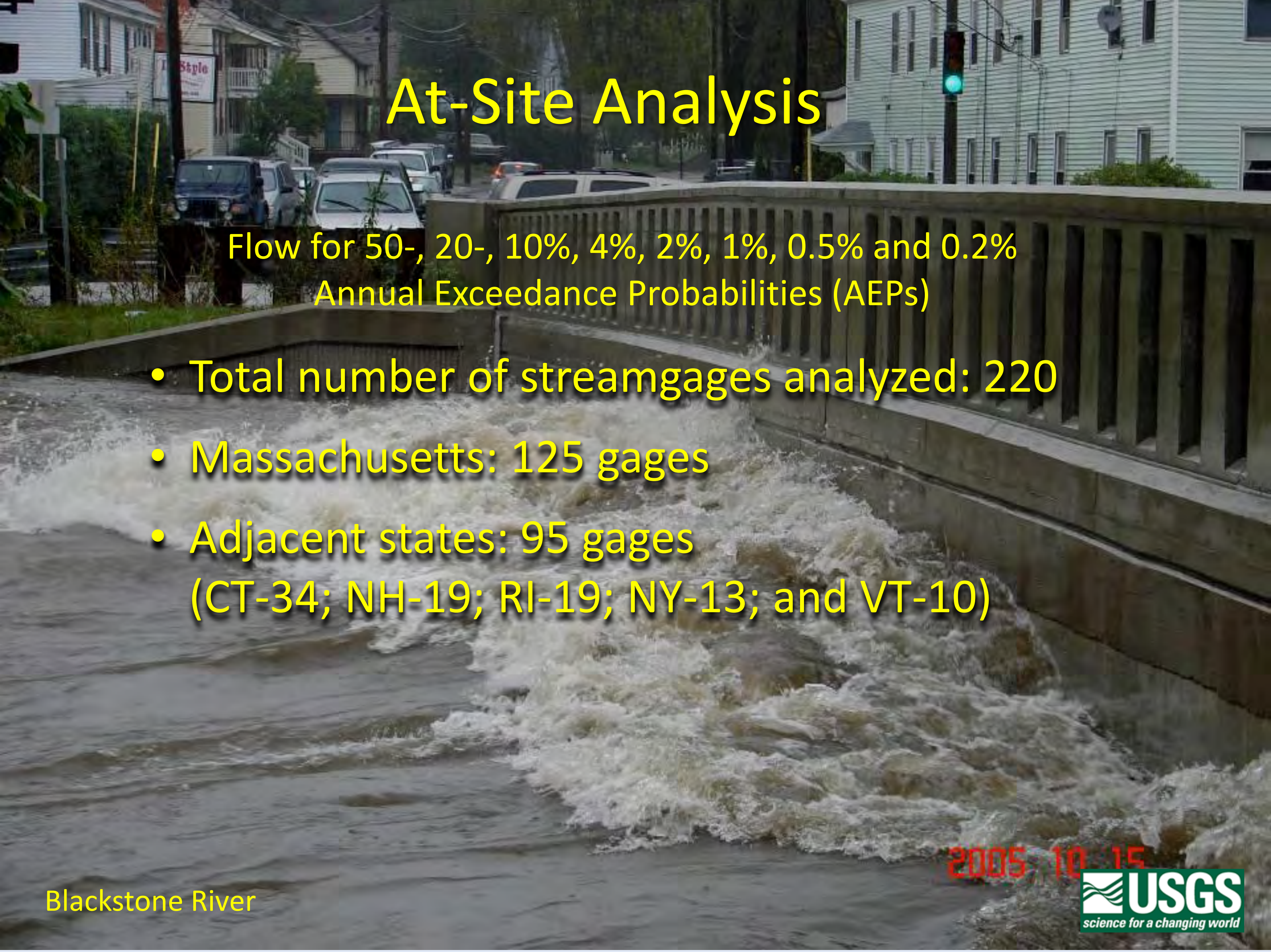


Veilleux and others, 2017

USGS has completed new skew analysis for New England

No significant spatial trends were found in skew.

Single Skew of 0.37 was determined to be optimal for New England



At-Site Analysis

Flow for 50-, 20-, 10%, 4%, 2%, 1%, 0.5% and 0.2%
Annual Exceedance Probabilities (AEPs)

- Total number of streamgages analyzed: 220
- Massachusetts: 125 gages
- Adjacent states: 95 gages
  (CT-34; NH-19; RI-19; NY-13; and VT-10)

Blackstone River

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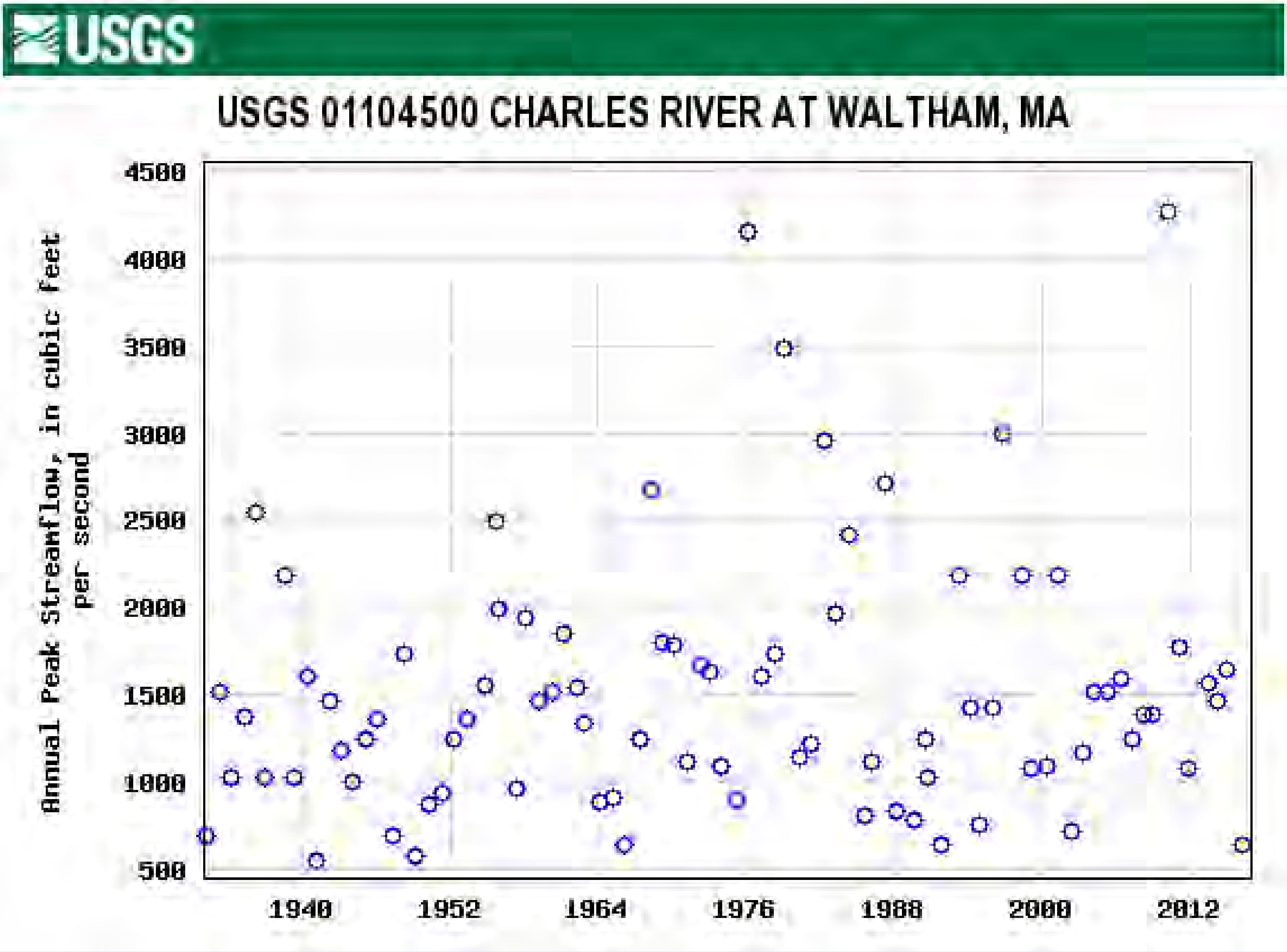
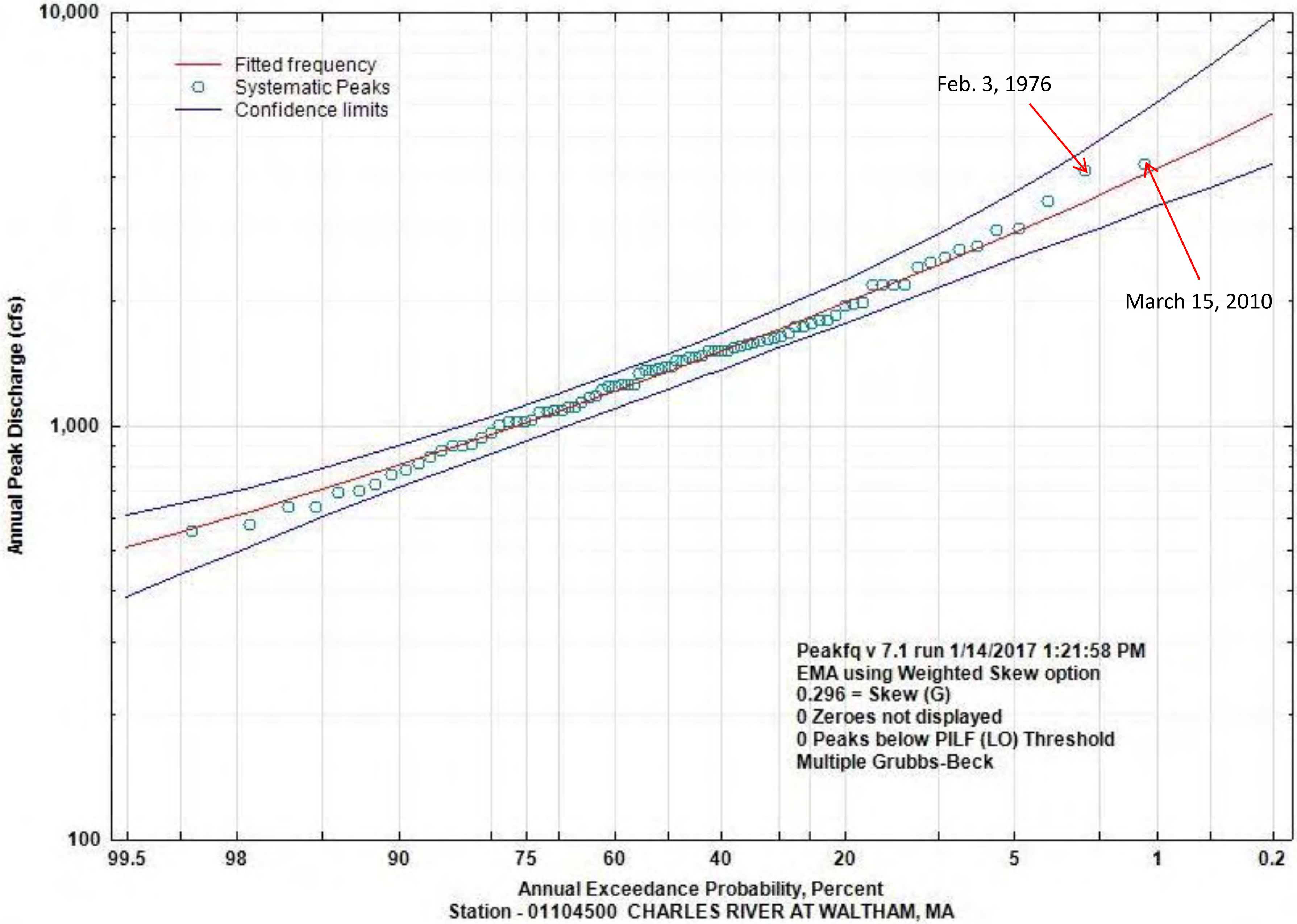

USGS
USGS 01104500 CHARLES RIVER AT WALTHAM, MA
Annual Peak Streamflow, in cubic feet per second
4500
4000
3500
3000
2500
2000
1500
1000
500
1940
1952
1964
1976
1988
2000
2012



10,000
1,000
100
Annual Peak Discharge (cfs)
Fitted frequency
Systematic Peaks
Confidence limits
Feb. 3, 1976
March 15, 2010
Peakfq v 7.1 run 1/14/2017 1:21:58 PM
EMA using Weighted Skew option
0.296 = Skew (G)
0 Zeroes not displayed
0 Peaks below PILF (LO) Threshold
Multiple Grubbs-Beck
99.5
98
90
75
60
40
20
5
1
0.2
Annual Exceedance Probability, Percent
Station - 01104500 CHARLES RIVER AT WALTHAM, MA

Regional Analysis

- Included 199 streamgages – 105 in Mass. (did not use highly regulated and redundant sites)
- Compiled 60 basin characteristics associated with each gage, for potential use as explanatory variables in regional flood-flow equations
- Exploratory regression analysis used to determine the best basin characteristics and subsets of data

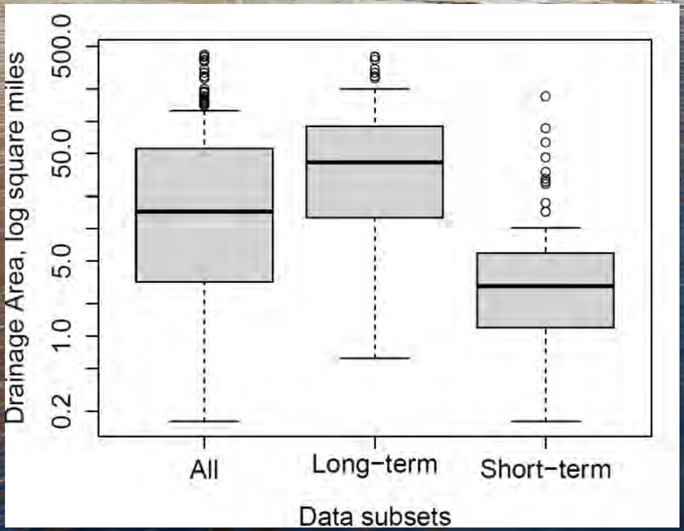
Hurricane Irene - Deerfield River at
Bridge of Flowers, Shelburne Falls, MA
Photo by Jeff Brown

Explanatory Basin Characteristics

- Basin size and shape
- Land cover (2006 NLCD): impervious cover, wetlands, open water, etc.
- National Hydrography Dataset & NWI
- Topography (10-meter DEM)
- Infiltration (NRCS soils & USGS surficial geology)
- Climate (mean annual precip & temp, and 24-hr precip: 10-, 100-, and 500-yr)

Hurricane Irene, Deerfield River at Conway Street in Buckland, MA
Photo by Jeff Brown

Include streamgages with short record?



Yes… allows for small basins

- Most long-term basins > 20 sq mi
- Most short-term (<20 yrs) basins < 10 sq mi
- Uncertainty analysis accounts for shorter record lengths.

Shawsheen River at Andover, MA 3/15/2010

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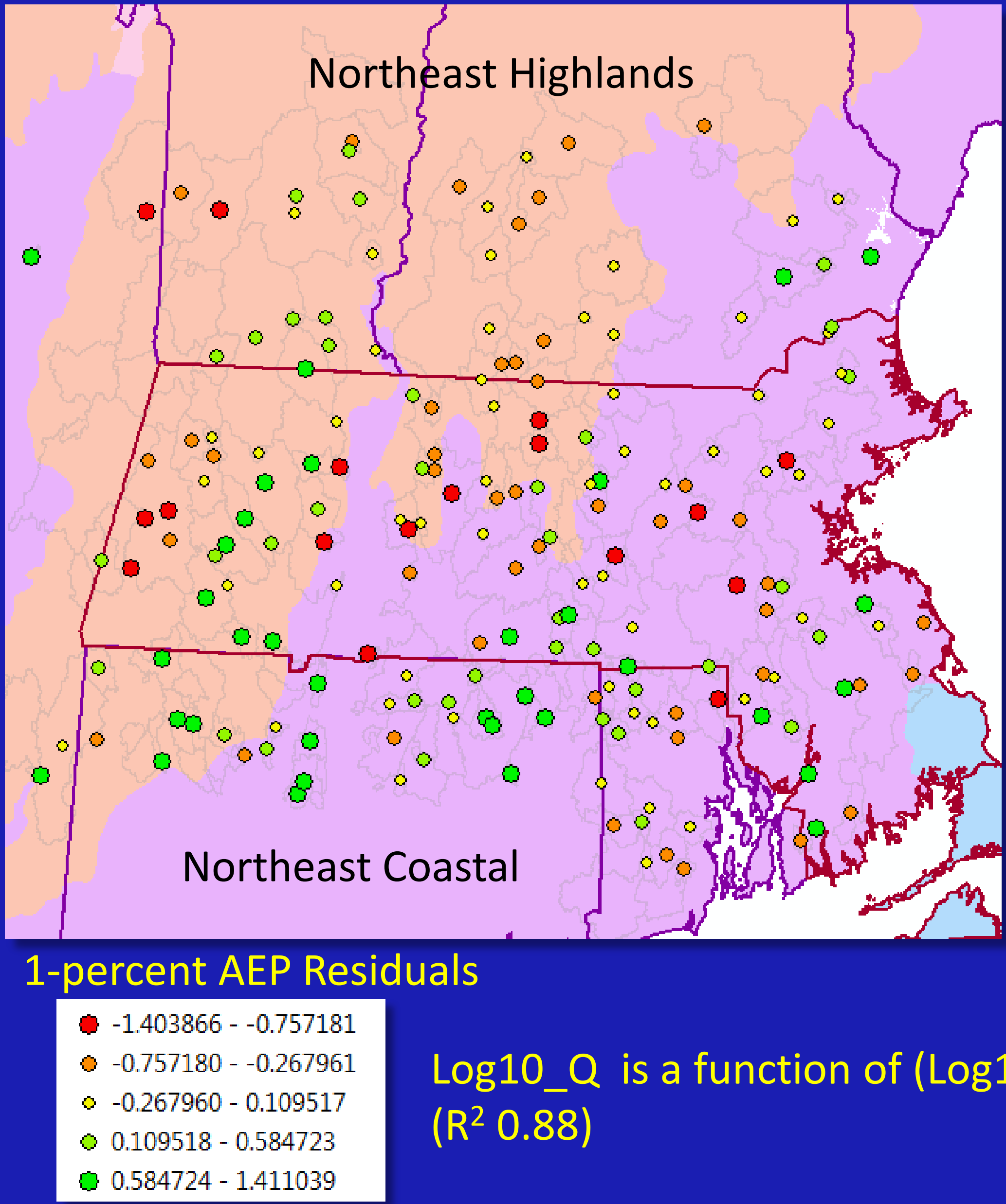


Use Sub-Regions?

EPA Ecoregion Level III
OLS regression residuals

All data (199 Obs): R^2 0.88

***NE Highlands* model** (108 Obs) was slightly better: (R^2 0.90)

NE Coastal model (91 Obs) was slightly worse: (R^2 0.87)

Residuals ***do not*** show a spatial pattern that merits subregions;

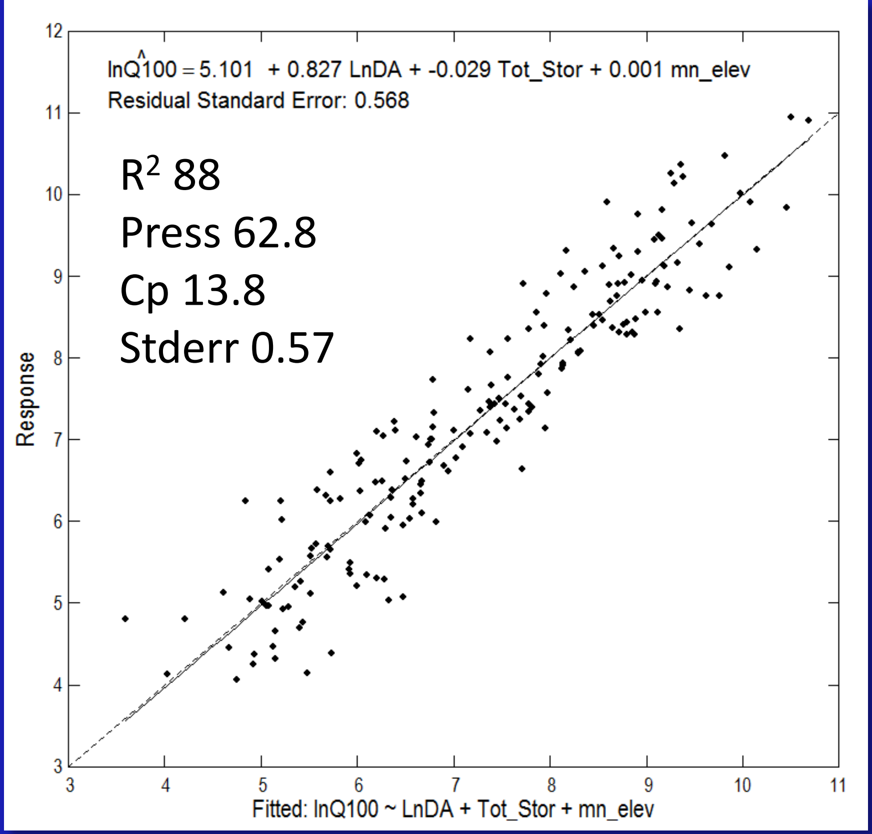
Therefore, Sub-Regions were not used.

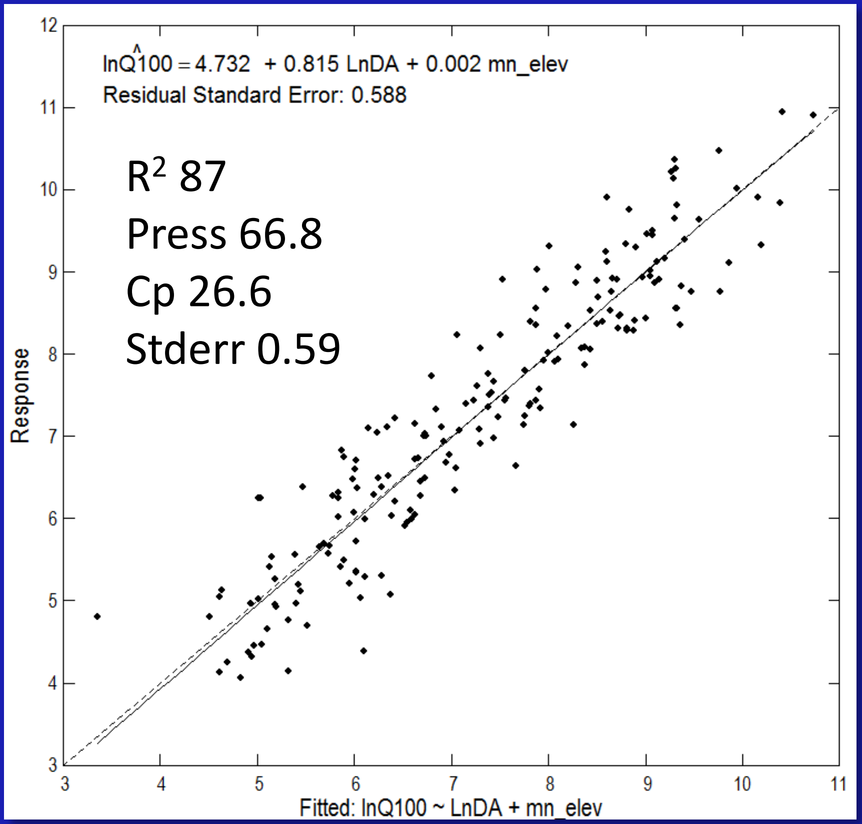
Log10_Q is a function of (Log10_DA, mean elev, and total storage) (R^2 0.88)

Ordinary Least-Squares (OLS) Regression Models

3-Variable model
DA, TotStor, mn_elev

2-Variable model
DA, mn_elev





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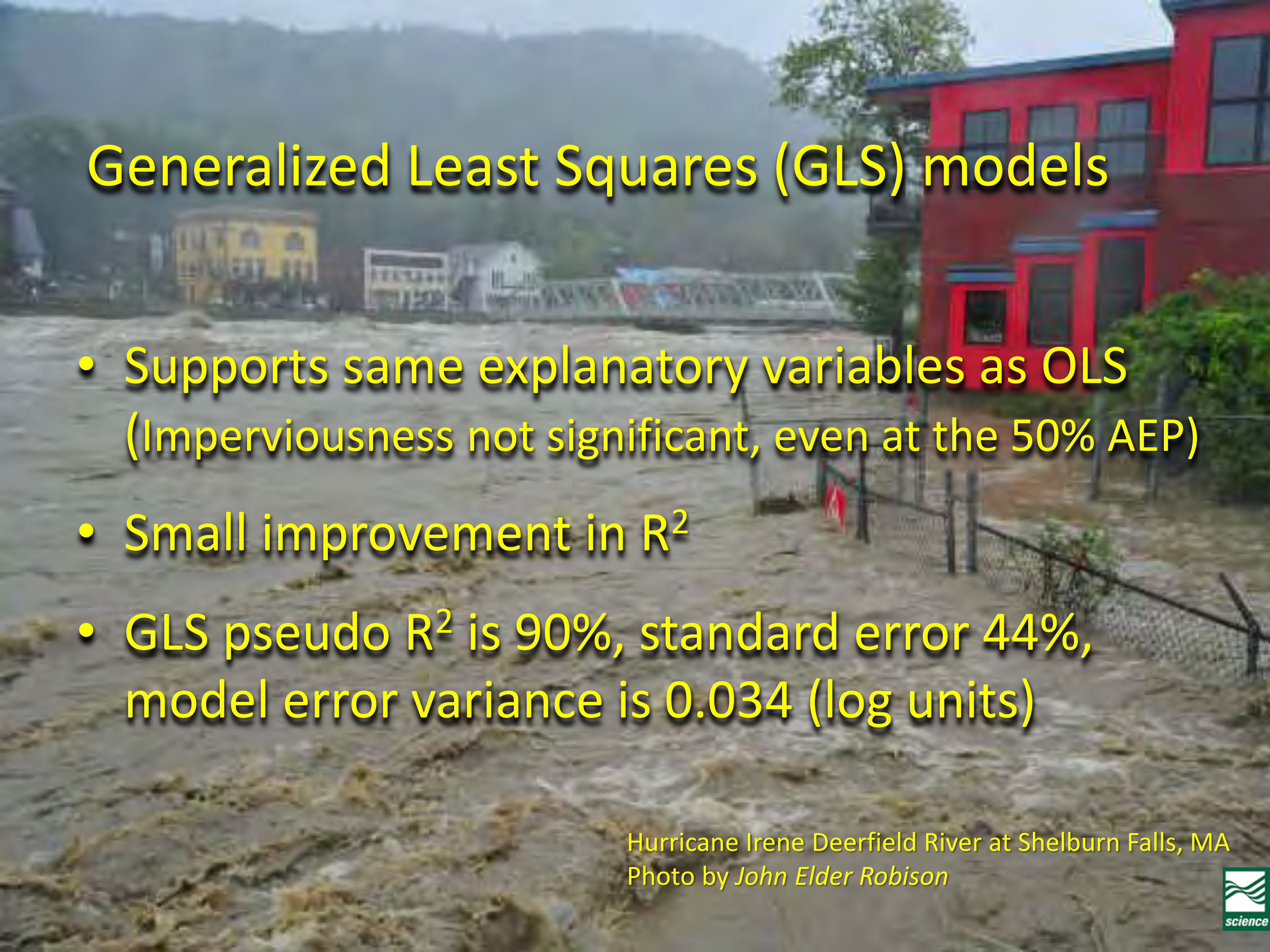
Generalized Least Squares (GLS) models

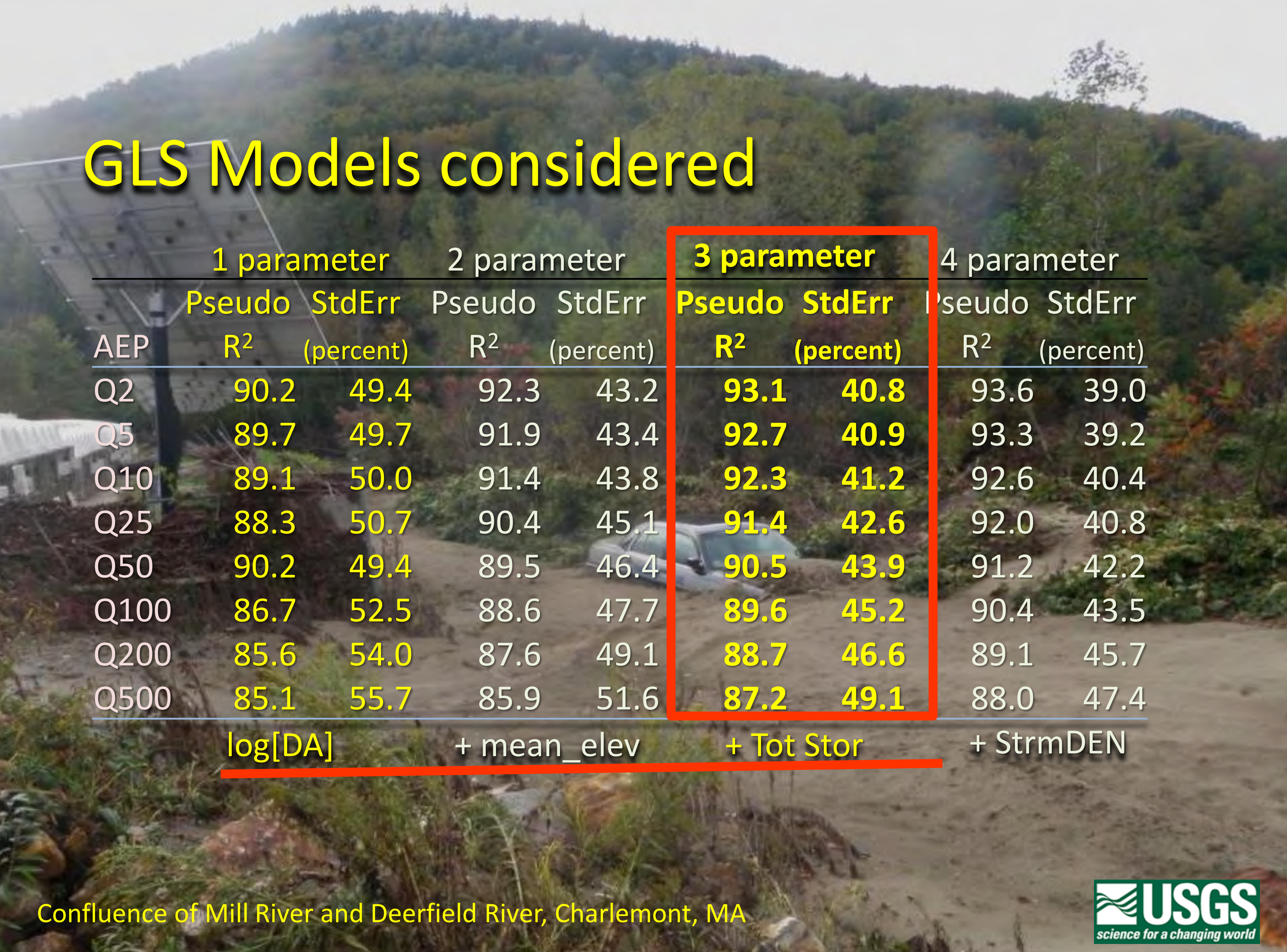
- Supports same explanatory variables as OLS (Imperviousness not significant, even at the 50% AEP)
- Small improvement in R^2
- GLS pseudo R^2 is 90%, standard error 44%, model error variance is 0.034 (log units)



Hurricane Irene Deerfield River at Shelburn Falls, MA
Photo by *John Elder Robison*

GLS Models considered

	1 parameter		2 parameter		3 parameter		4 parameter	
AEP	Pseudo R^2	StdErr (percent)	Pseudo R^2	StdErr (percent)	**Pseudo R^2**	**StdErr (percent)**	Pseudo R^2	StdErr (percent)
Q2	90.2	49.4	92.3	43.2	**93.1**	**40.8**	93.6	39.0
Q5	89.7	49.7	91.9	43.4	**92.7**	**40.9**	93.3	39.2
Q10	89.1	50.0	91.4	43.8	**92.3**	**41.2**	92.6	40.4
Q25	88.3	50.7	90.4	45.1	**91.4**	**42.6**	92.0	40.8
Q50	90.2	49.4	89.5	46.4	**90.5**	**43.9**	91.2	42.2
Q100	86.7	52.5	88.6	47.7	**89.6**	**45.2**	90.4	43.5
Q200	85.6	54.0	87.6	49.1	**88.7**	**46.6**	89.1	45.7
Q500	85.1	55.7	85.9	51.6	**87.2**	**49.1**	88.0	47.4
	log[DA]		+ mean_elev		+ Tot Stor		+ StrmDEN	



Confluence of Mill River and Deerfield River, Charlemont, MA

Final GLS Models

Models with 3 explanatory variables were chosen.

Flood-flow equations for 50-, 20-, 10-, 4-, 2-, 1-, 0.5- and 0.2% Annual Exceedance Probabilities (AEPs) are functions of---

-- log [basin drainage area (mi^2)]
-- mean basin elevation (ft)
-- total storage (% open water + wetlands)

Final GLS Models

Example: the 1% AEP (100-yr flood) equation:

$$Q_1 = 10^{\left[2.256+0.767\times\log_{10}(DRNAREA)+0.790\times0.001\times\left(\frac{ELEV}{3.28084}\right)-1.137\times0.01\times(LC06STOR)\right]},$$

Flood flows:

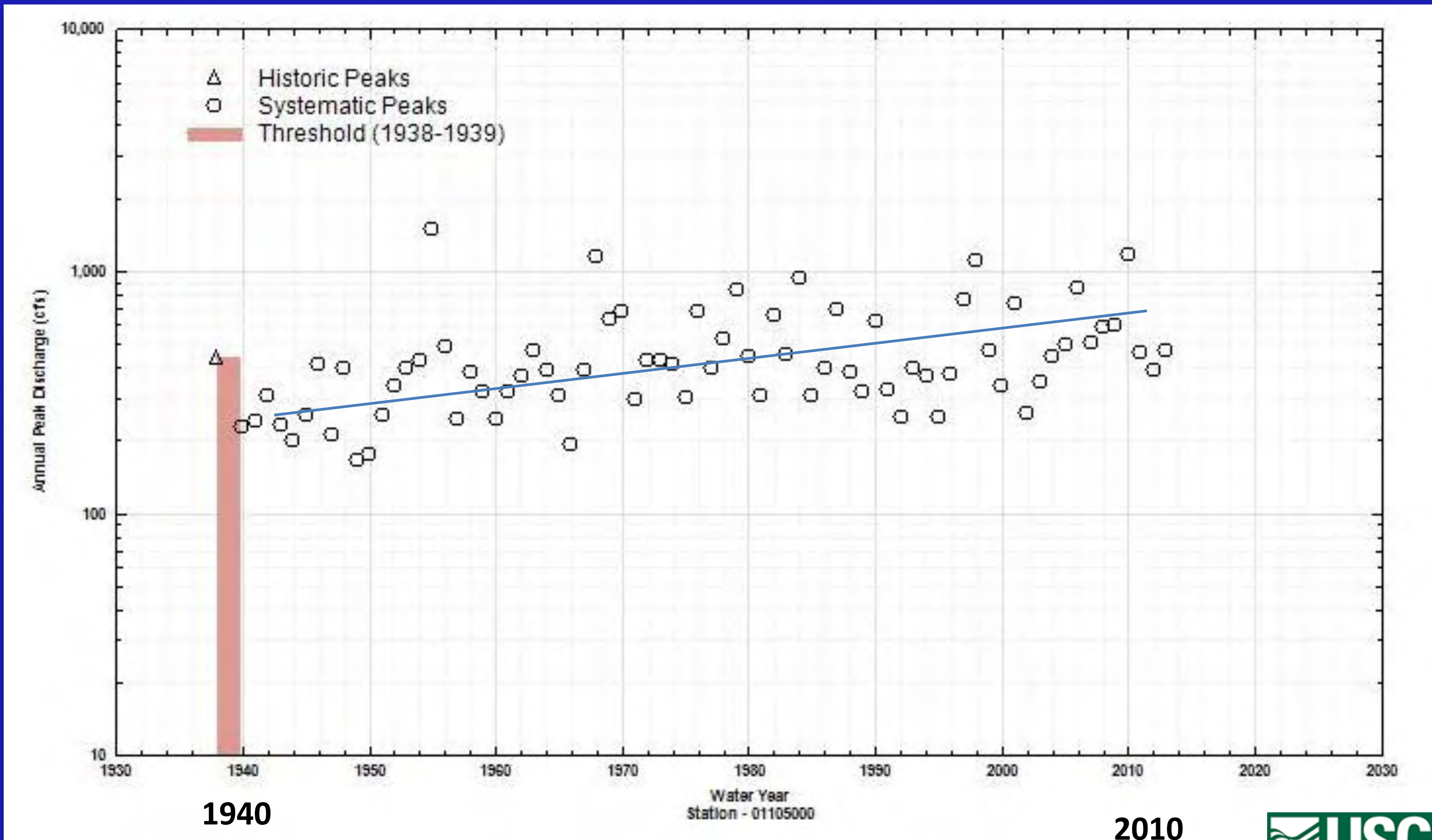
increase with increasing drainage area
increase with mean basin elevation
decrease with increasing basin storage
(% open water + wetlands).

Are provided: 90-percent prediction interval equations

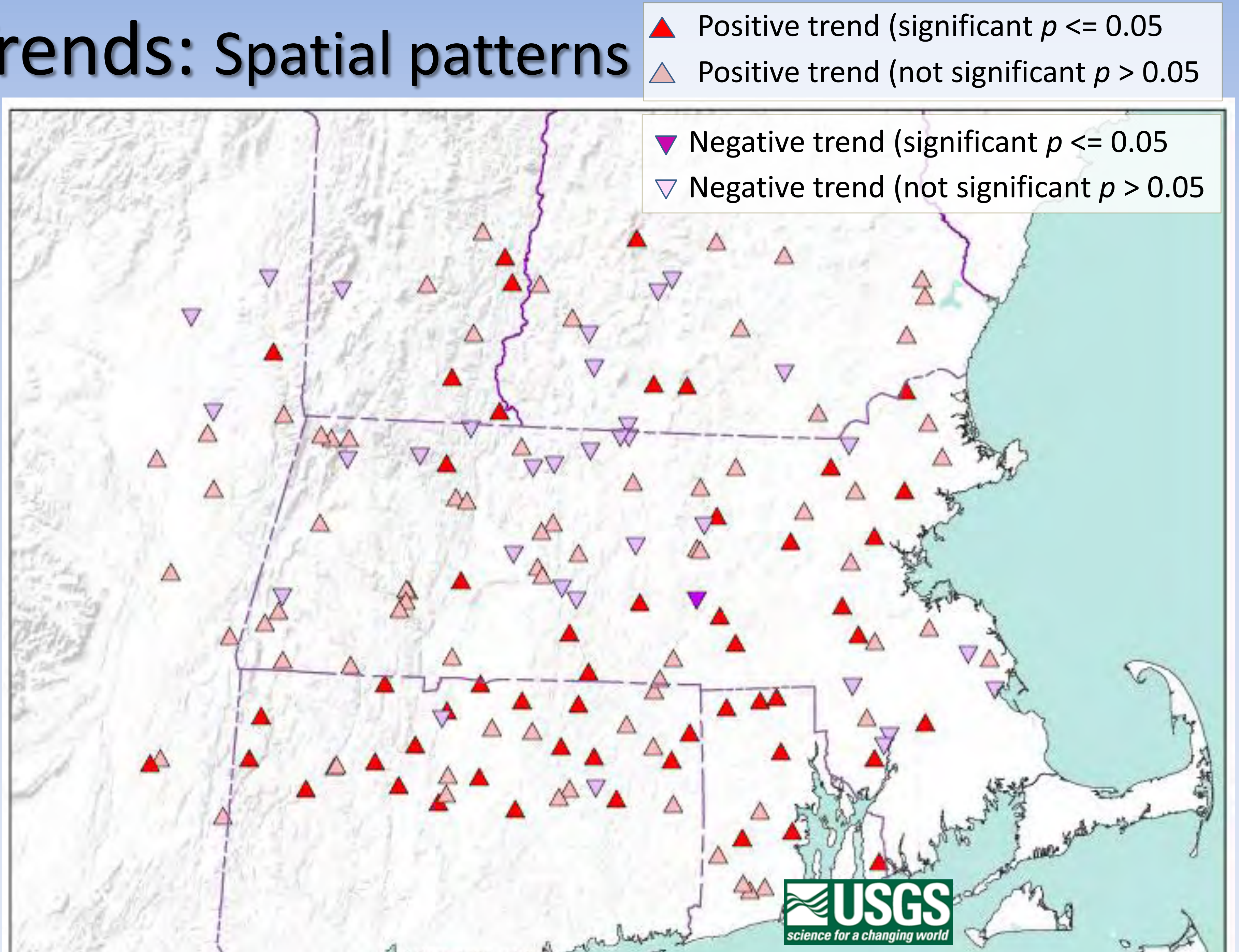
Trends in annual peak flows

Example of a ***significant*** trend – 01105000 Neponset River at Norwood, MA

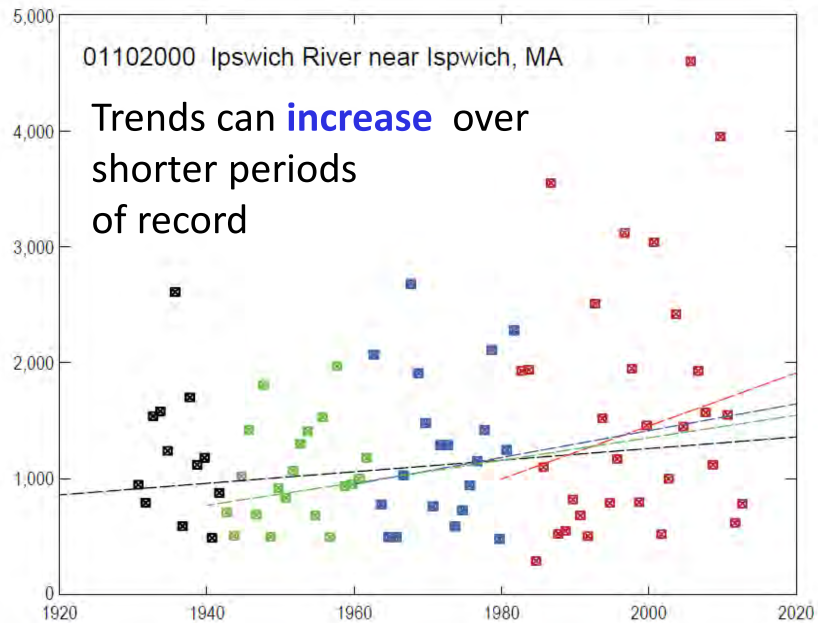
TAU: 0.32; *p*-value: 0.000041 slope: 3.31

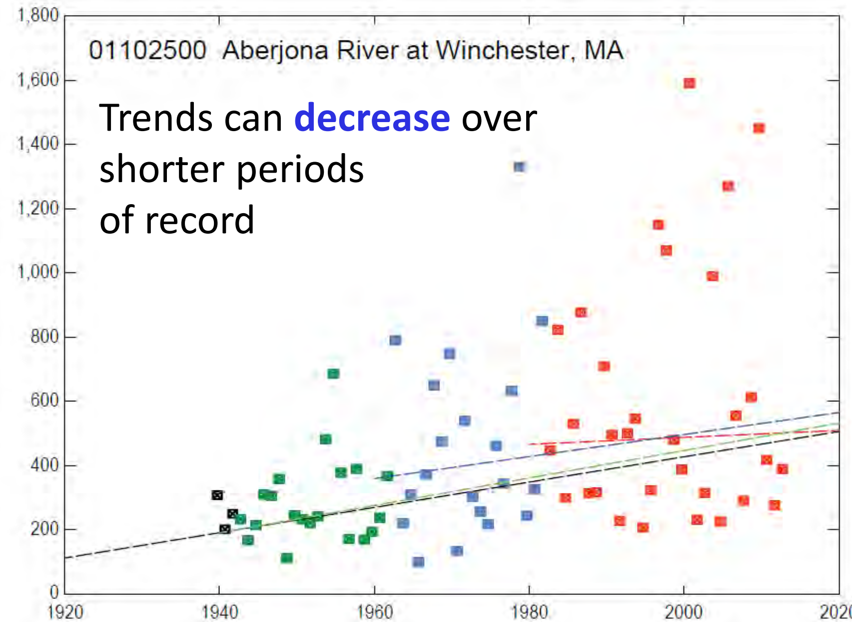


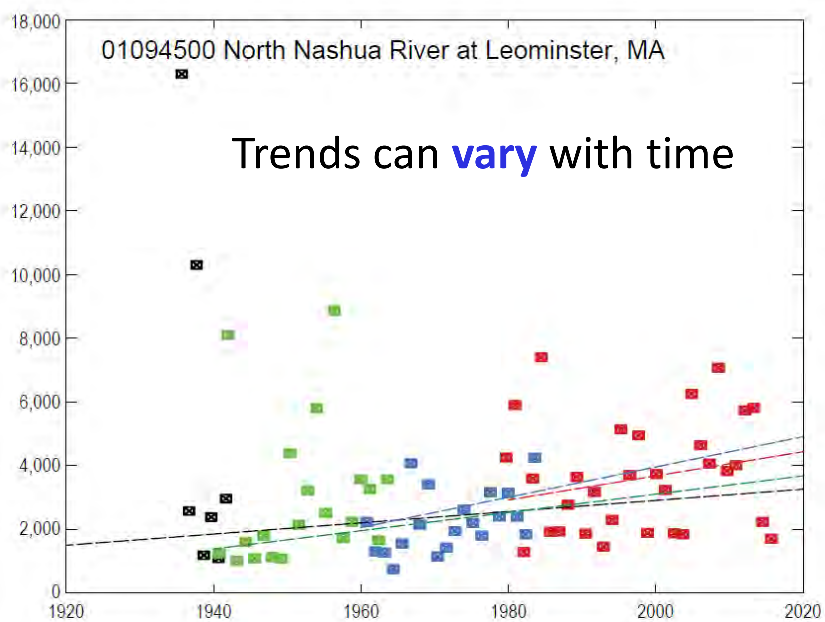
Trends: Spatial patterns

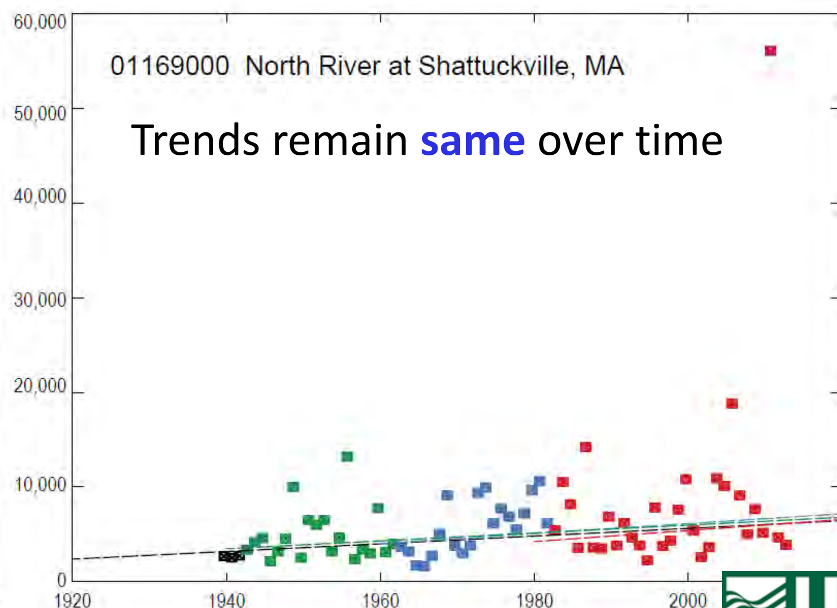


Trend Variability, at p <= 0.05









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Trends: Summary of Findings

	MA + Neighbor states		MA Only	
	count	% total	count	% total
Total no sites	148		64	
***P* <= 0.05**	52	35 %	17	27 %
***p* <= 0.1**	64	43 %	22	34 %
not significant	84	57 %	42	66 %
Years of record				
Average	52		63	
Minimum	20		20	
Maximum	103		101	

All *significant* trends were *upward*

(except 1 site in MA with abbreviated record, ending in 1978)

Dealing with Trends

- No "cookbook" methods exist; none of the existing methods have wide acceptance.
  Possible approaches:

- De-trend the data and rerun the analysis
  (assume stationarity)

- Modify the probability distribution moments: mean (μ), standard deviation (σ), and skew (k)

- Determine a flood magnification factor based on the trend and the planning horizon of interest
  (one way to address non-stationarity)

Photo NOAA, Taunton River, 2010 flood

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USGS StreamStats:

- An interactive web application for obtaining basin and streamflow statistics at both USGS streamgages and ungaged sites.
- Provides easy access to relevant flood and low-flow statistics for thousands of USGS gages nationally.
- Prediction intervals (error bars) are provided for all flow estimates at ungaged sites.

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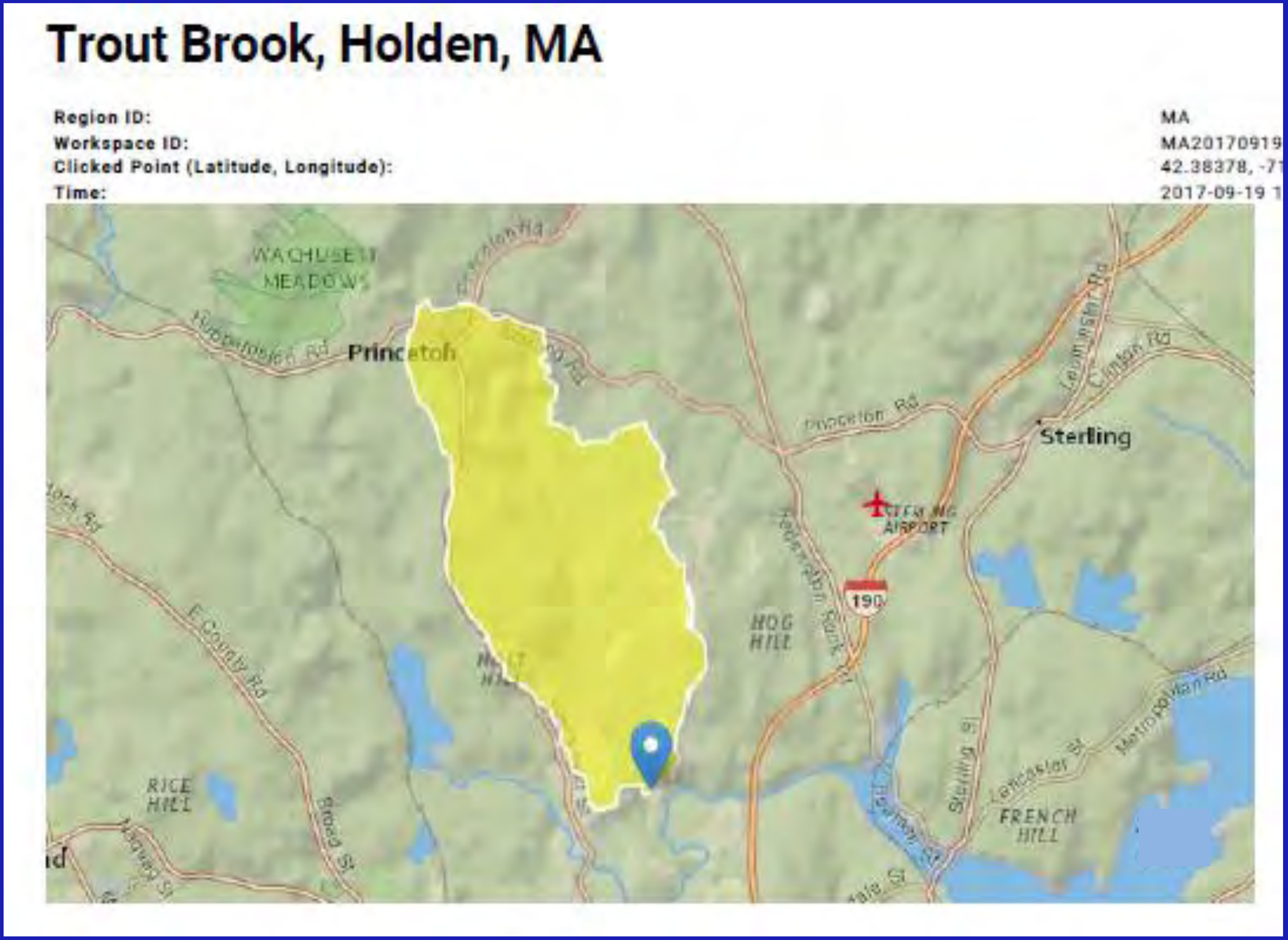
StreamStats: Example basin 1

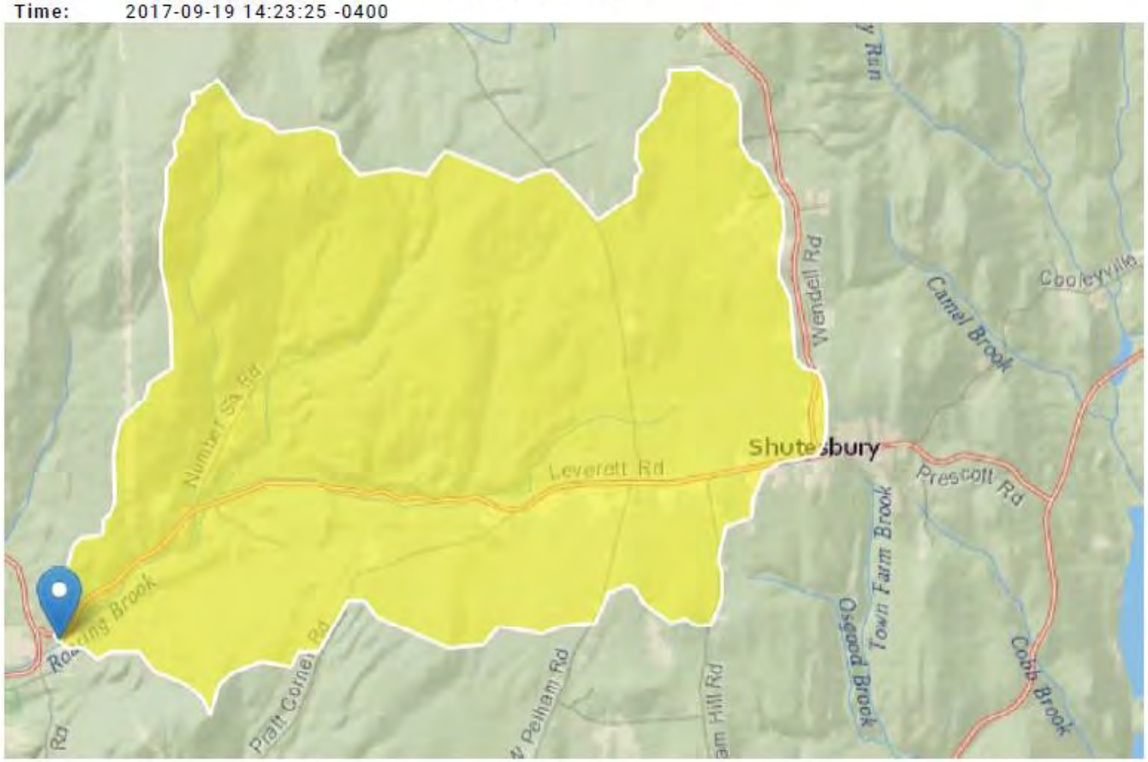


StreamStats: Example basin 2

Roaring Brook, Leverett, MA

Region ID: MA

Workspace ID: MA20170919182305680000
Clicked Point (Latitude, Longitude): 42.43942, -72.48089
Time: 2017-09-19 14:23:25 -0400



Comparison: Trout and Roaring Brooks

	DA (mi2)	Mean Elev (ft)	Storage (% ponds, wetlands)	1% AEP Flood (cfs)
Trout Brook, Holden	8.34	811	14.3	989
Roaring Brook, Leverett	7.26	987	4.8	1,260
Difference	-13%	+22%	-66%	**+27%**

Roaring Brook has a smaller drainage area, but its other basin characteristics override its smaller size.

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Benefits of the study

- Improved understanding of Massachusetts flood flows, probabilities of exceedance, uncertainties, and trends— leading to:

- More accurate floodplain maps (DFIRM's)

- Better infrastructure design & resiliency

- More effective emergency preparedness and response.

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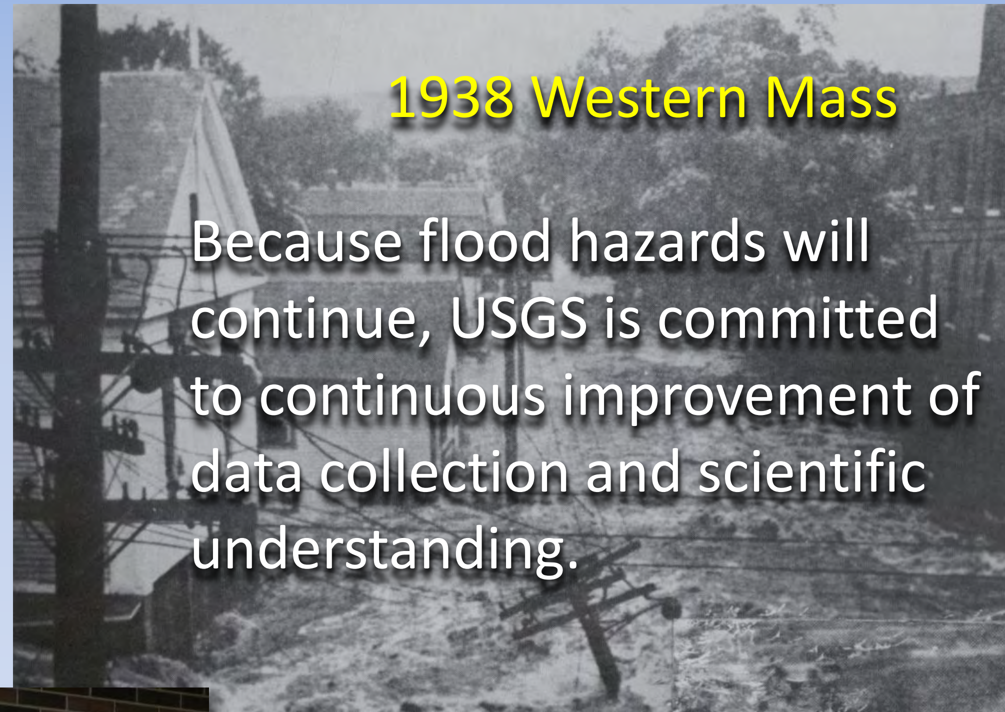

Because flood hazards will continue, USGS is committed to continuous improvement of data collection and scientific understanding.

Greenfield WWTP

Tropical Storm Irene

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Many thanks to the Commonwealth for the partnering with USGS on this project…

USGS Report: https://pubs.er.usgs.gov/publication/sir20165156
StreamStats: https://streamstats.usgs.gov/ss/

Questions?

Shelburne Falls, Tropical Storm Irene
Photo Courtesy of John Elder Robison

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