# MASSACHUSETTS LOW-FLOW STATISTICS AT GAGED AND UNGAGED SITES

*Massachusetts Water Resources Commission Meeting*

*May 9, 2024*

*Gardner Bent*

*U.S. Geological Survey New England Water Science Center*

Executive Office of Energy and Environmental Affairs

dcr Massachusetts

USGS science for a changing world

# Low-Flow Statistics

- Used to determine wastewater discharges
- Used in MassDEP water-supply permits
- Used in Massachusetts Drought Management Plan
- 20+ years of additional streamflow data since Low-Flow Study by Ries and Friesz (2001)
- Updated and new GIS coverages available to test as explanatory variables
- No low-flow statistics exist for southeastern Massachusetts and Cape Cod

# Objectives

- Update selected streamflow statistics at selected USGS streamgages
- Analyses potential long-term trends in the annual 7-day low-flow at selected USGS streamgages
- Compute basin, land-use, and climatic characteristics for those selected USGS streamgages
- Develop regional regression equations for those selected streamflow statistics at ungaged sites
- Investigate and test potential methods for estimating these selected streamflow statistics for southeastern Massachusetts and Cape Cod

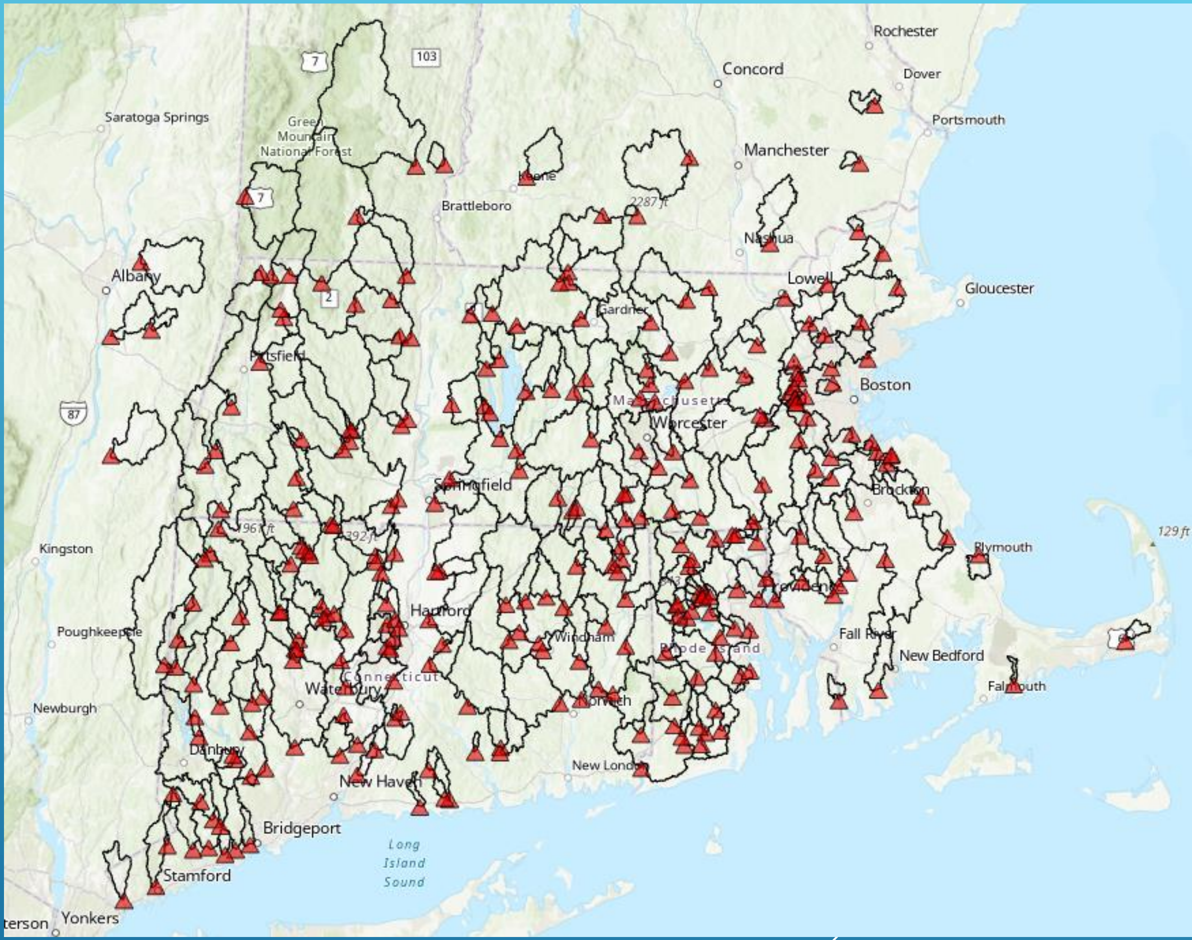
# Streamgages Regulated vs. Un-Regulated

- Statistics done for all unregulated and regulated streamgages in southern New England
- Regional regression equations will use "unregulated" gages
- Unregulated gages (i.e. little to no regulation) are based:
  - previous low-flow studies
  - water-use data
  - wastewater discharge data
  - Gages II information
  - local knowledge

USGS
science for a changing world

# Southern New England Streamgages

- About 300 streamgages
  - both regulated and little to no regulation) with 8+ years of record
- Streamgages with little to no regulation:
  - 169 with 8+ yrs of record
  - **149 with 10+ yrs of record**
  - 94 with 20+ yrs of record
  - 75 with 30+ yrs of record

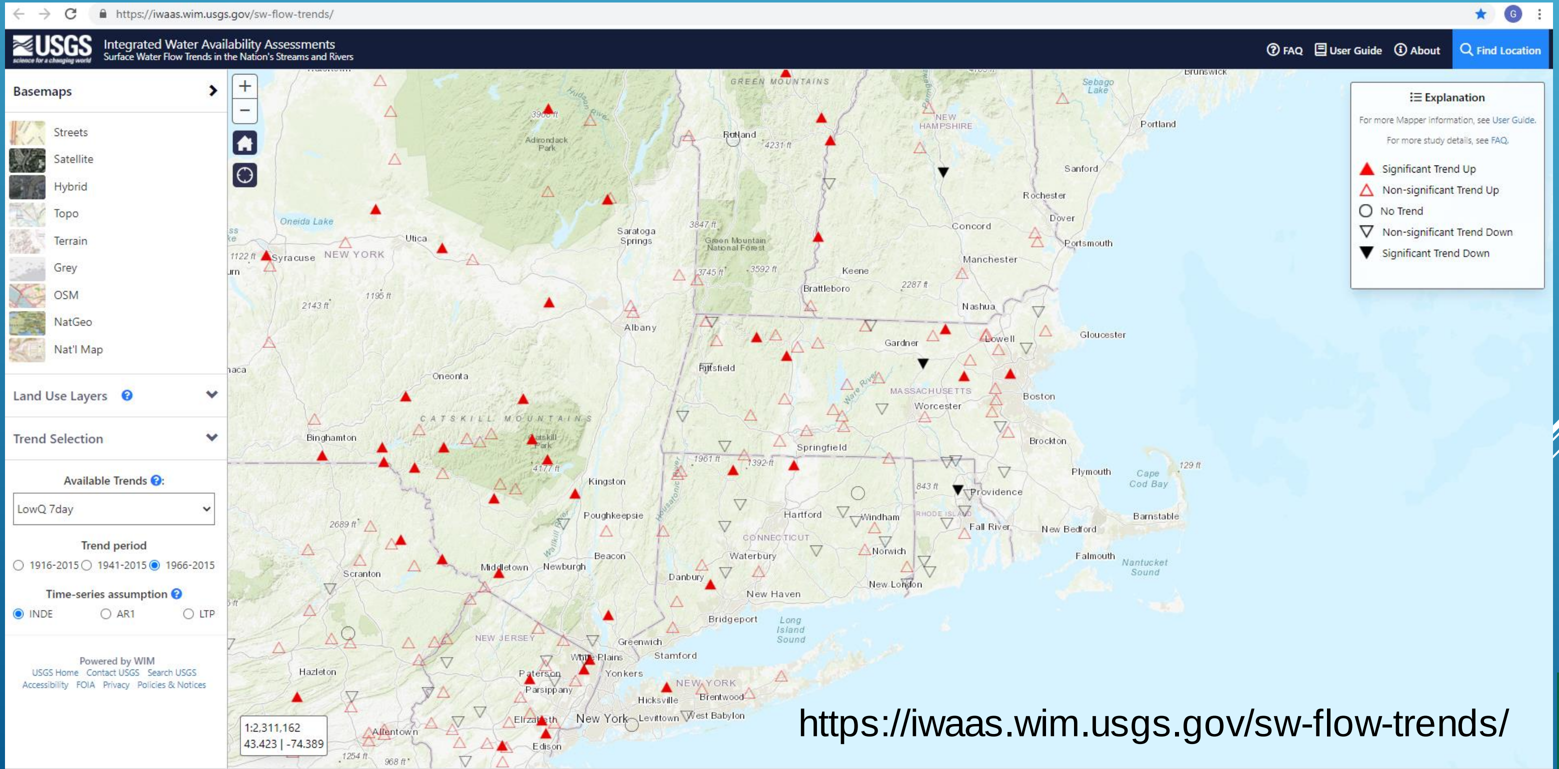



Of the 149 streamgages with 10+ yrs of record (52 – MA, 40 – CT, 26 – RI, 7 – southern NH, 4 – southern VT, and 15 eastern NY)

USGS
science for a changing world

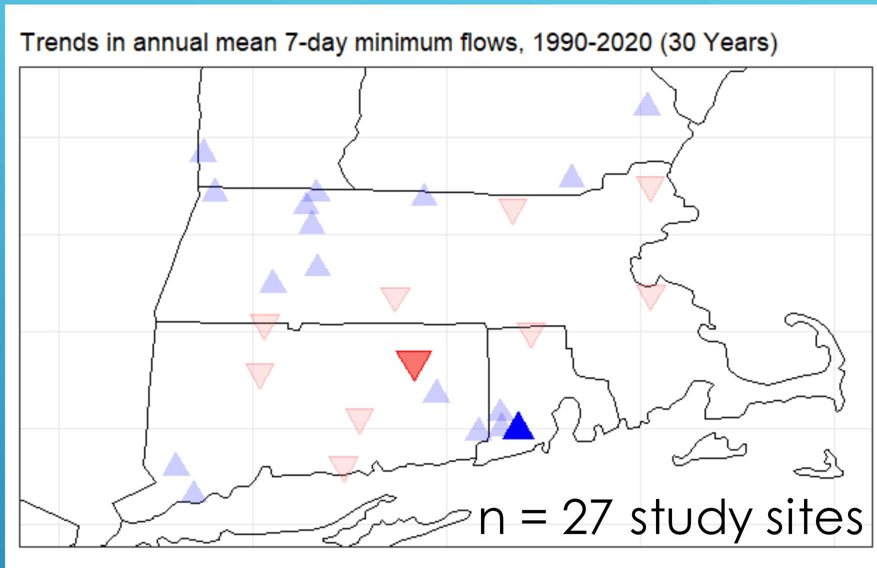
# Low-Flow Trends

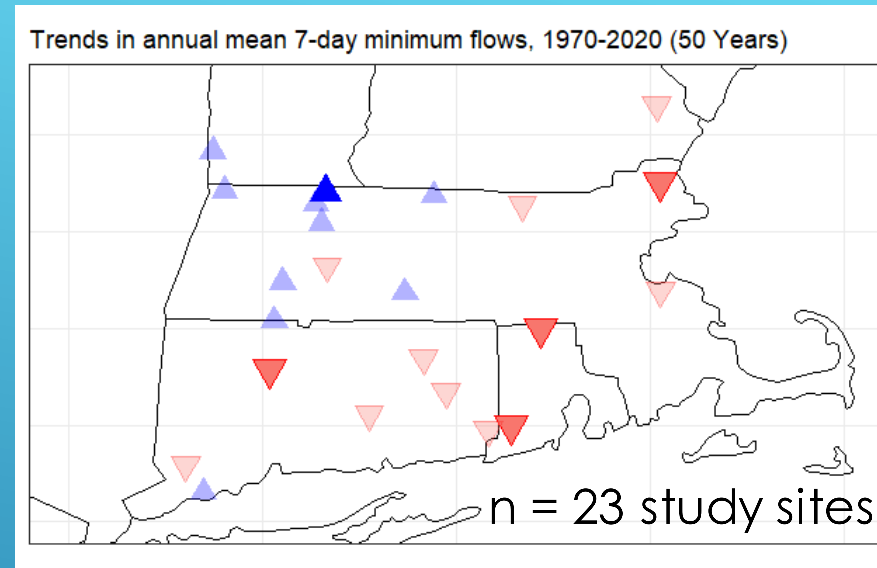
- Use set periods like national studies (last 30, 50, 70, and 90 years)
- Independence, Short-term persistence, Long-term persistence (methods follow Dudley and others, 2018)

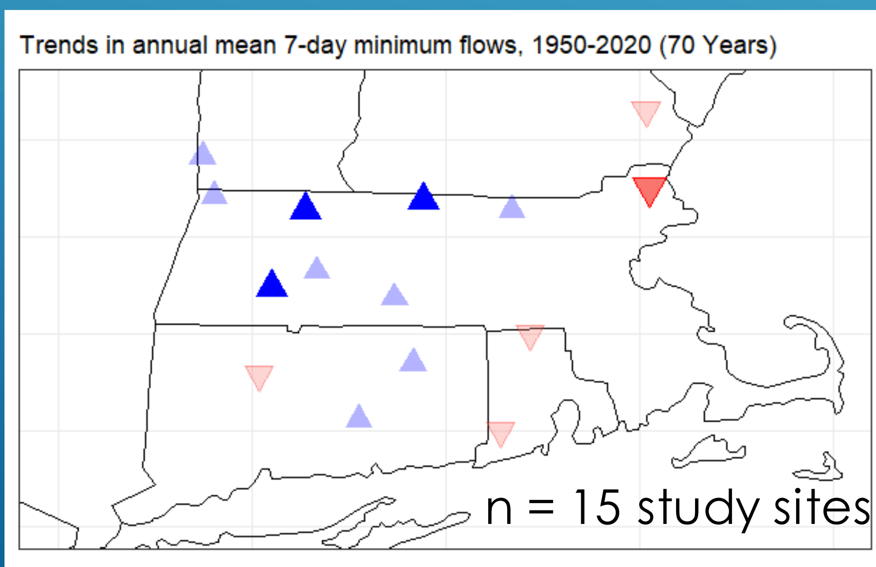


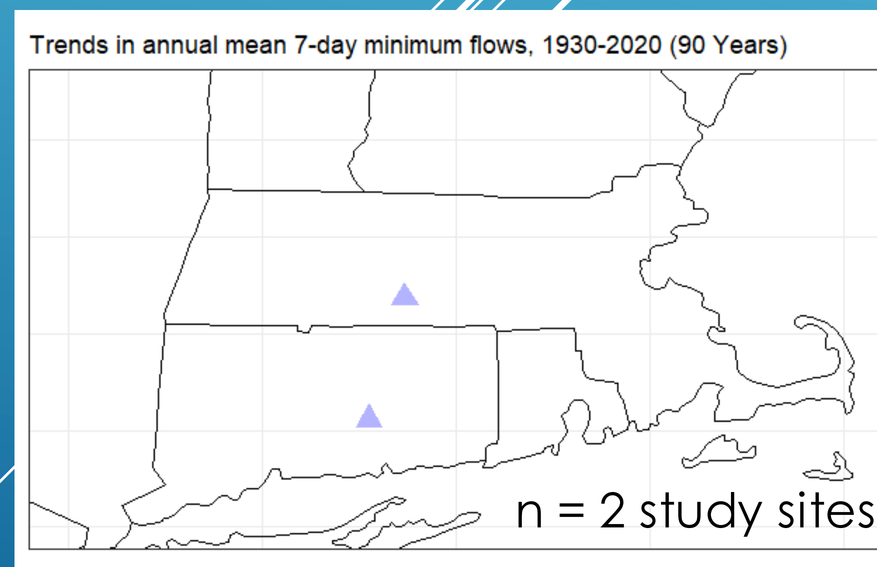

https://iwaas.wim.usgs.gov/sw-flow-trends/

# Low-Flow Trends



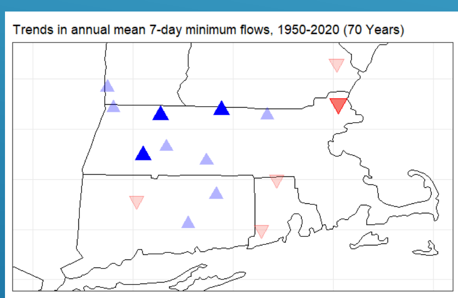



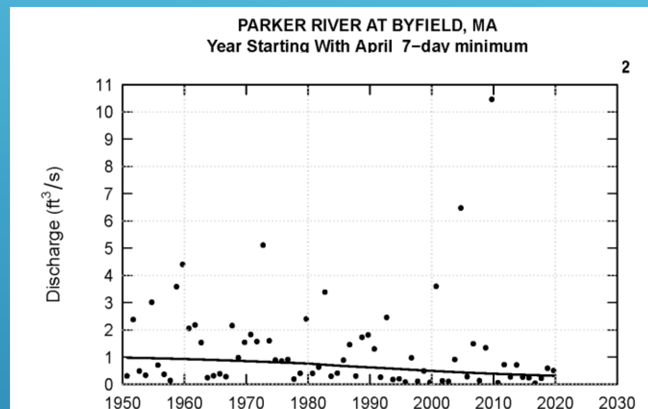

Clear decreasing or increasing trends are not apparent spatially or overtime

Provisional Data

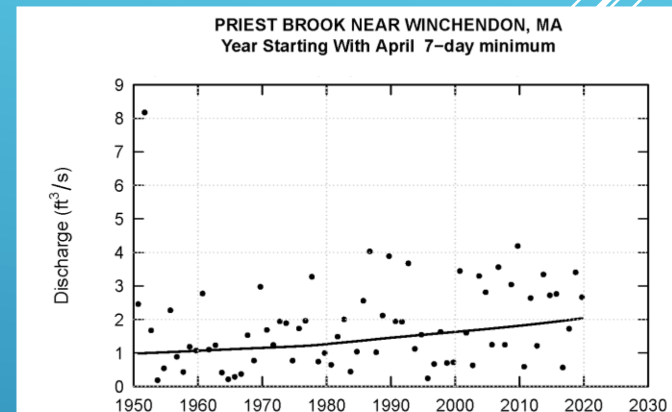
# Low-Flow Trends

Annual mean 7-day minimum flows for the four sites in MA with statistically significant trends in the 70-year record.

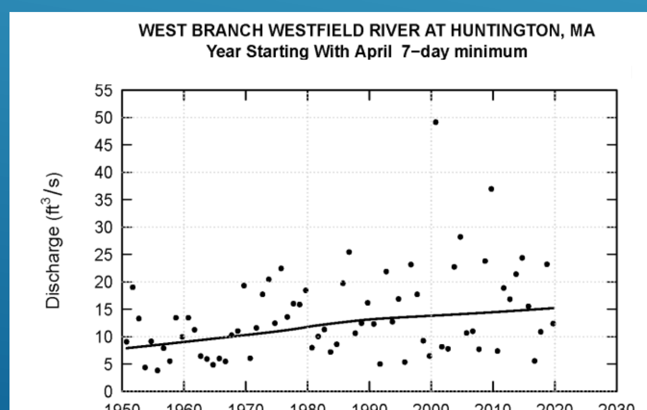


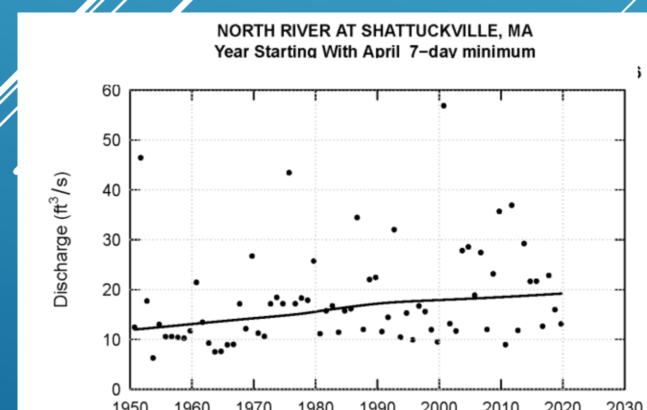

slope is -0.8%,
total change over 70 years is -0.5 cfs




slope is 1.6%,
total change over 70 years is 1.1 cfs




slope is 11%,
total change over 70 years is 7.8 cfs




slope is 9.9%,
total change over 70 years is 6.9 cfs

Provisional Data

USGS science for a changing world

# MA Streamflow Statistics Equations

Annual flow durations (10)

- 50-percent
- 60-percent
- 70-percent
- 75-percent
- 80-percent
- 85-percent
- 90-percent
- 95-percent
- 98-percent
- 99-percent

Frequency (5)

- 7Q2
- 7Q10
- Median of the annual minima (7-day LF)
- 30Q2
- 30Q10

Monthly 50- and 90-percentile (8)

- June
- July
- August
- September

Aquatic Base Flow (median of the monthly means) (3)

- February
- June
- August

Harmonic Mean (1)

Analyses through water year and climatic year 2022

USGS science for a changing world

# FLOW DURATION CURVE - EXAMPLE

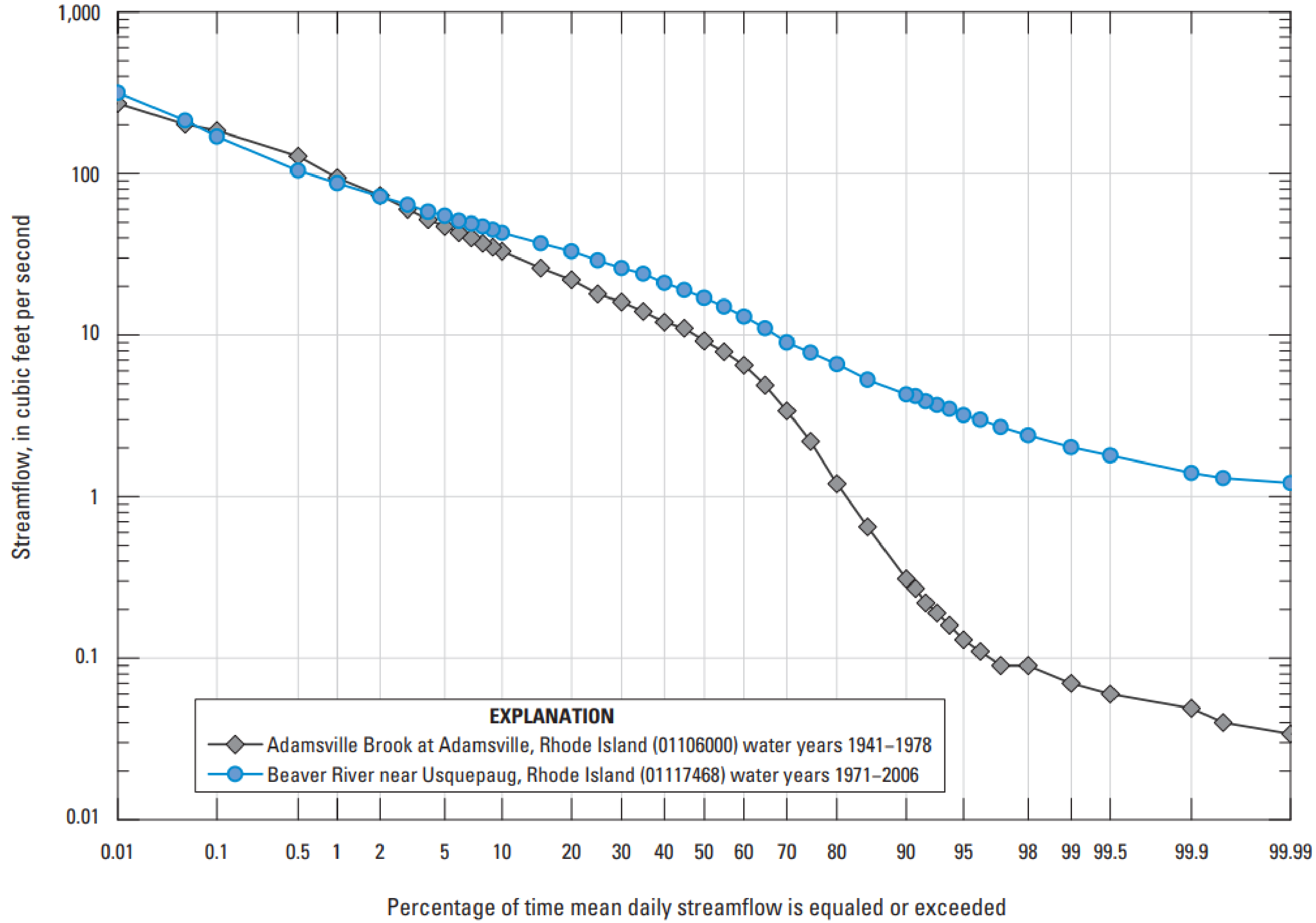
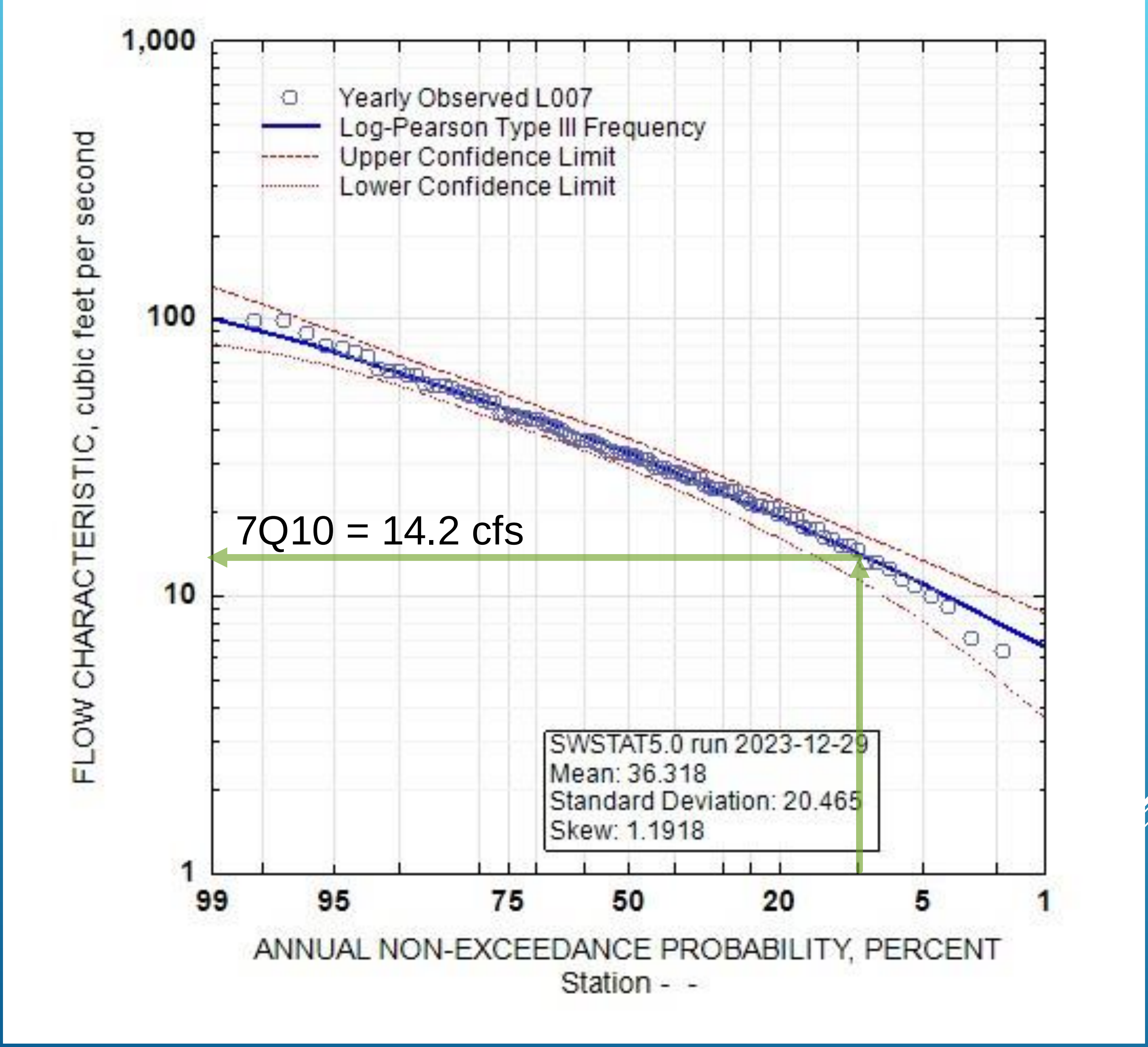



**Figure 6.** Flow-duration curves at the streamgages Adamsville Brook at Adamsville, R.I. (01106000), and Beaver River near Usquepaug, R.I. (01117468).

USGS science for a changing world

# LOW-FLOW FREQUENCY CURVE - EXAMPLE

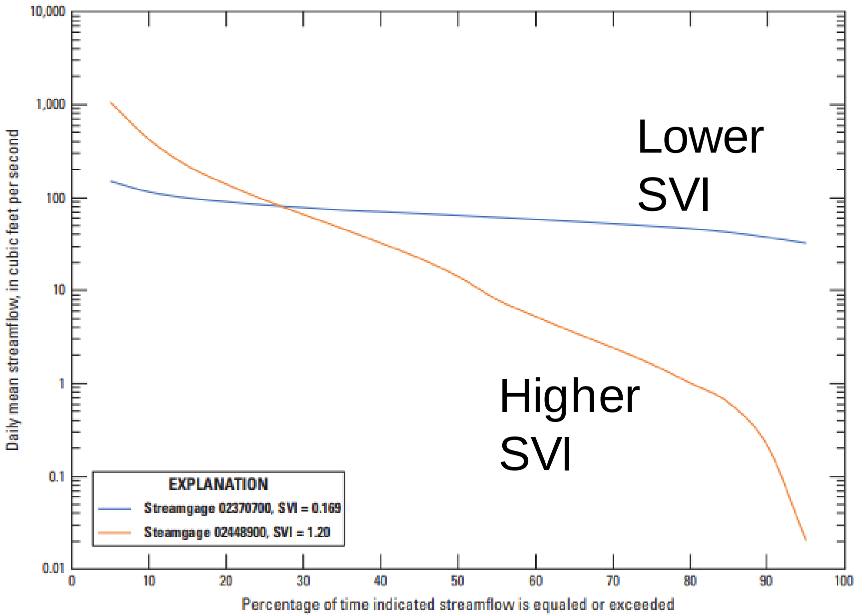


# Basin, Land-Use, Geology, and Climatic Characteristics

- Used common characteristics from other recent regional regression equations in the northeastern U.S.
- Basin Characteristics
  - Drainage area
  - Mean basin slope
  - Min., max, and mean basin elevation
  - Stream length
  - Drainage density
  - Basin X and Y centroid and outlet
  - Basin shape
  - Etc.
- Land-Use
  - National Land-Cover Dataset of 2016 (wetlands, water bodies, forest, urban, etc.)
- Geology
  - New surficial materials coverage for MA (1:24,000)
- Climatic
  - PRISM dataset for 1981-2010 (annual and monthly)

USGS science for a changing world

# STREAMFLOW VARIABILITY INDEX (SVI)




$$SVI\sqrt{\frac{\sum_{i=5,5}^{95}\left(\log_{10}(D_i)-\overline{\log_{10}(D)}\right)^2}{18}} \qquad (1)$$

where

| | | |
|---|---|---|
| $SVI$ | is | the streamflow-variability index, |
| $D_i$ | is | the $i$th percent duration streamflow ($i$=5, 10, 15, …95), and |
| $\overline{\log 10(D)}$ | is | the mean of the base 10 logarithms of the 19 streamflow values at 5-percent class intervals from 5 to 95 percent on the flow-duration curve of the daily mean flow. |

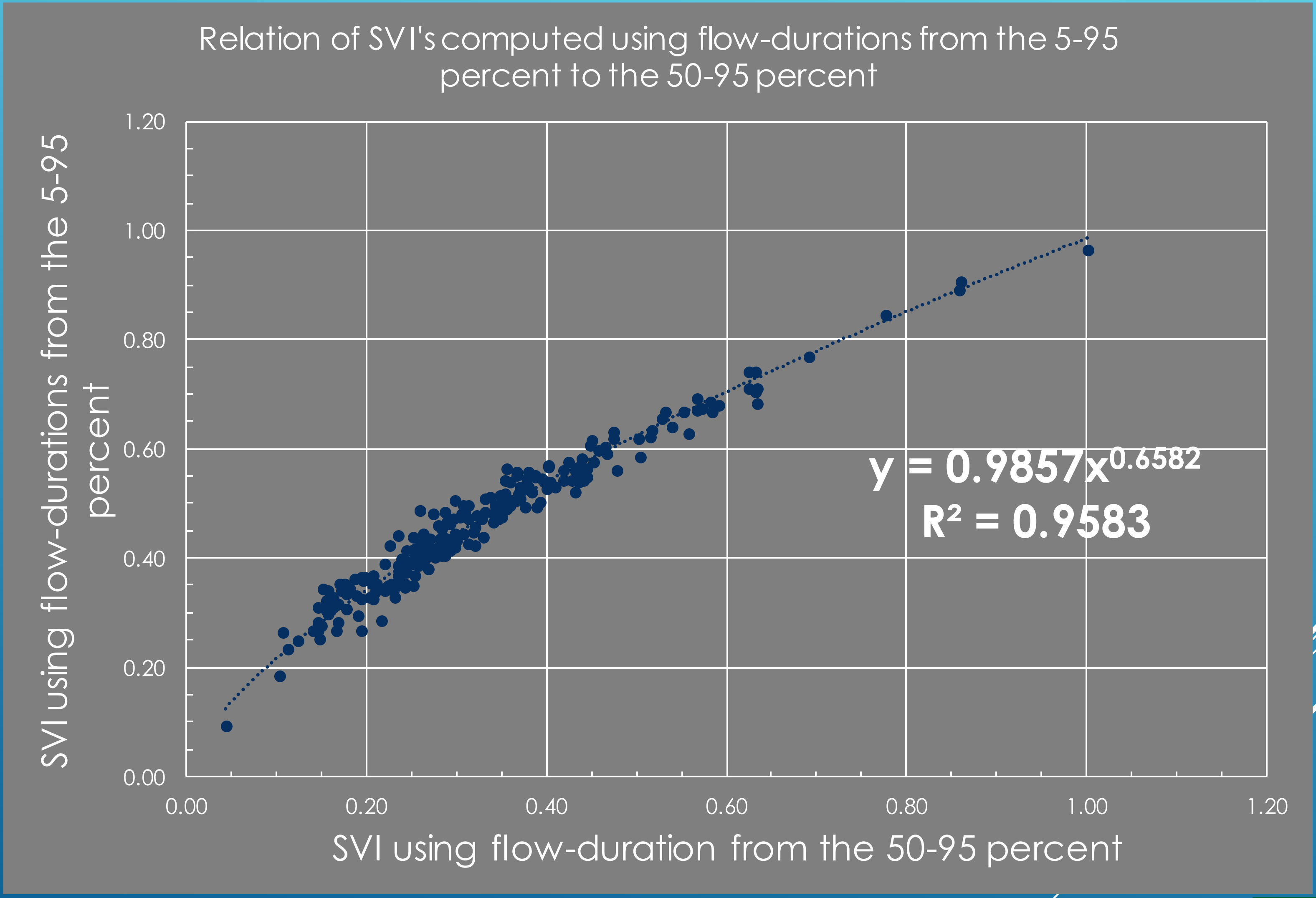
- SVI is a pseudo estimation of contributions of groundwater discharge and surface storage
- SVI used in some recent USGS low-flow studies

# SVI AT PARTIAL-RECORD STATIONS

- Related the SVI from the 5-95th flow durations to the lower half of the flow duration curve from the 50-95th percentiles
- Koltun and Whitehead (2012) and Martin and Arihood (2010) related the estimated 7Q10 at low-partial record sies to the SVI in Ohio and Kentucky, respectively
- Ries and Friesz (2001) estimated flow-durations for the 50-95th for over 100 low-flow partial-record stations
- Bent and others (2013) estimated flow durations for the 50-95th for over 50 low-flow partial-record stations in Rhode Island and nearby in CT and MA
- Thus, this allowed the inclusion of another 150+ sites in developing an SVI map for southern New England

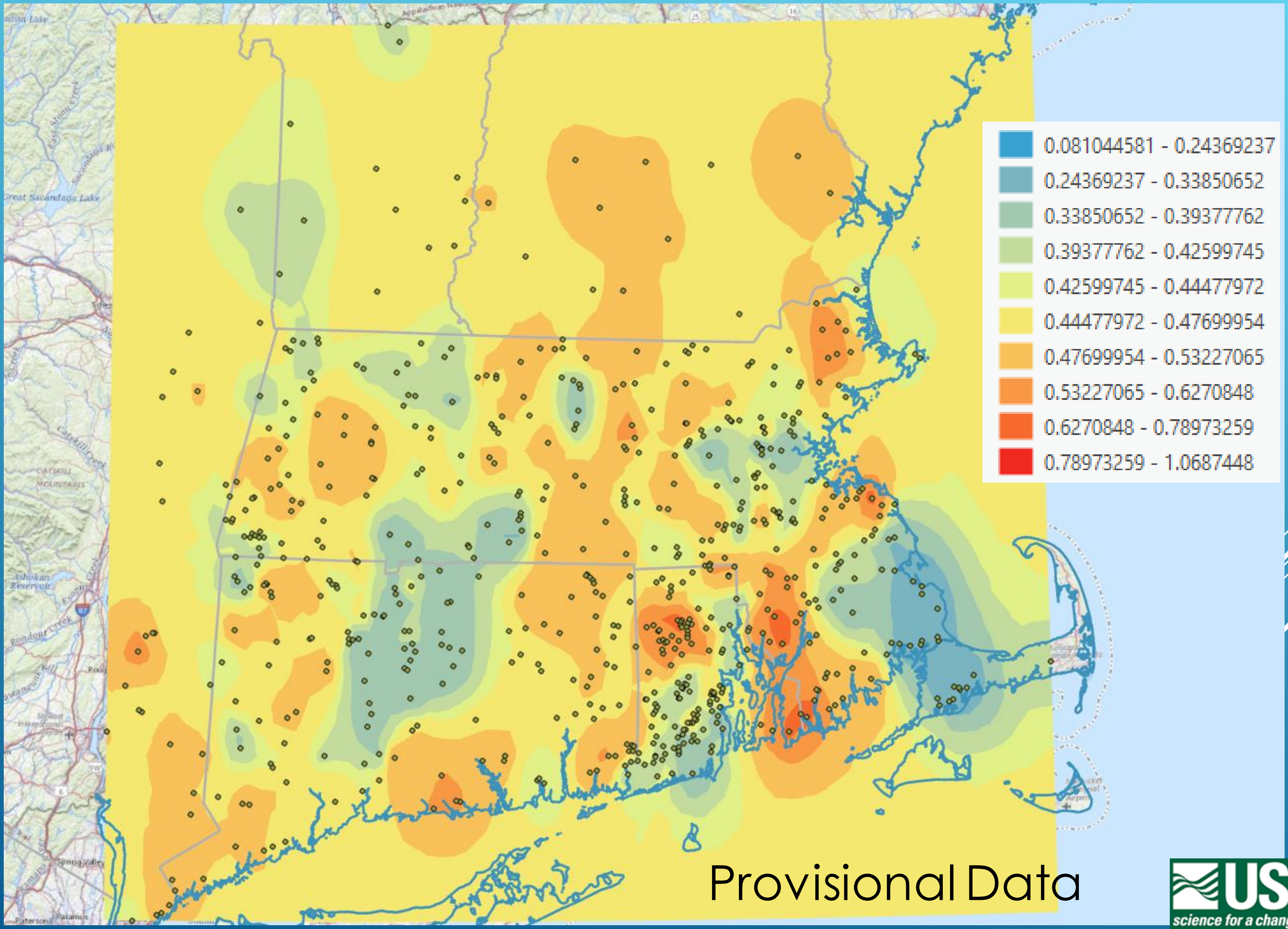
Provisional Data

# DETERMINING SVI AT PARTIAL-RECORD STATIONS



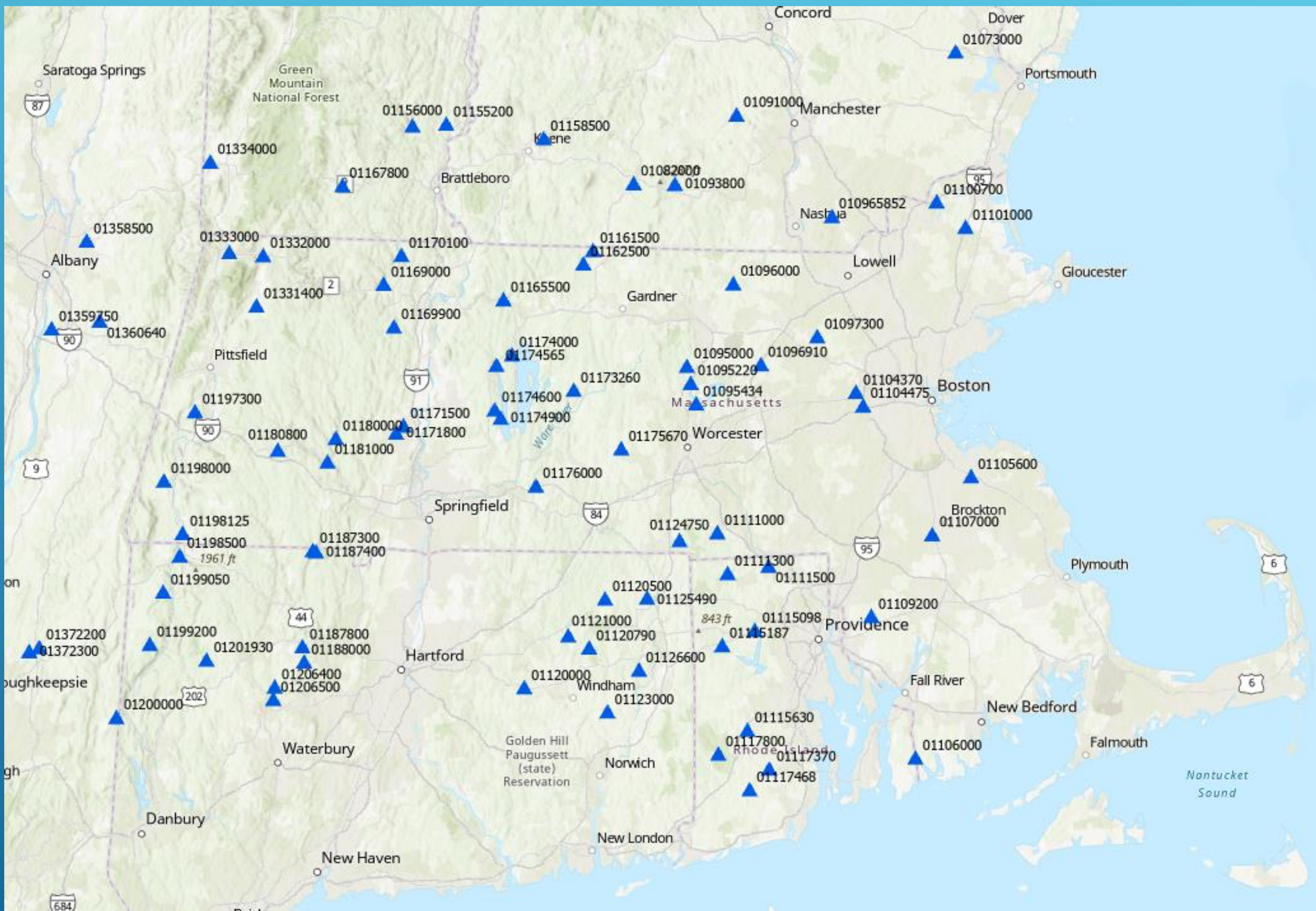

Provisional Data

# SVI MAP




USGS
science for a changing world

# MA STREAMGAGES PLUS THOSE 25 MILES OUTSIDE STATE BORDER (81 GAGES)




<u>81 streamgages:</u>
- 39 Massachusetts
- 18 Connecticut
- 6 New Hampshire
- 5 New York
- 9 Rhode Island
- 4 Vermont

Provisional Data

USGS
science for a changing world

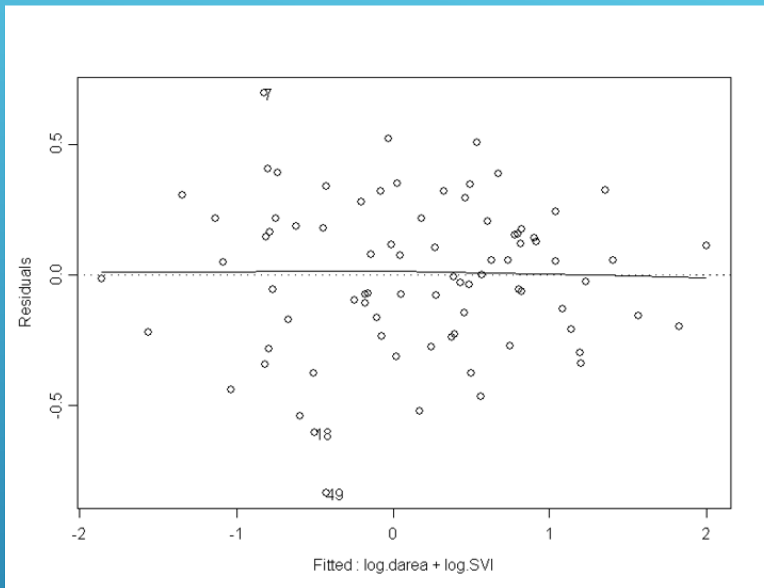
# REGRESSION ANALYSES

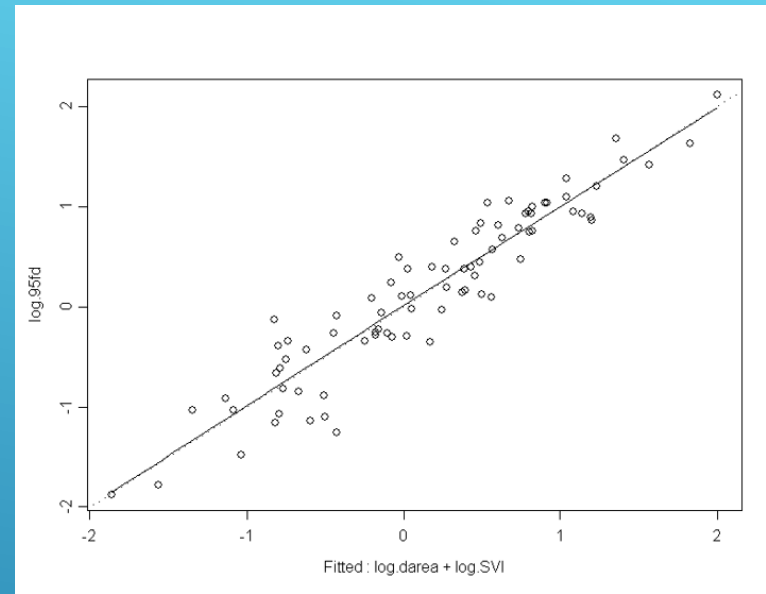
- Best subsets
- Stepwise regression
- Evaluating
  - Adjusted R-squared, p-values, residual std errors, and plots of residuals
- Weighted-multiple-linear REGression (WREG)
  - Weighting using record length
  - Plots of observed vs. predicted

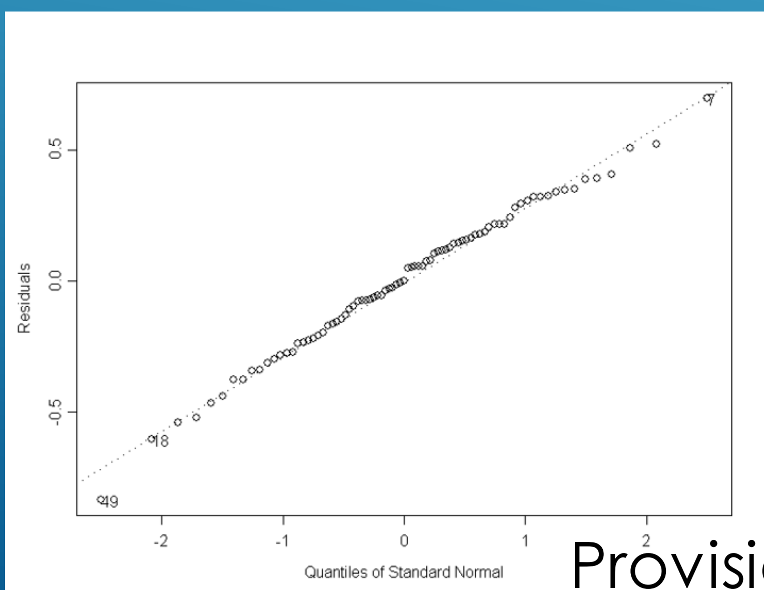
```
*** Linear Model ***

Call: lm(formula = log.95fd ~ log.darea + log.SVI, data = POR.FD.REGRESS
Residuals:
     Min       1Q   Median      3Q    Max
 -0.8332 -0.1978 0.001687 0.1844 0.6944

Coefficients:
               Value Std. Error  t value Pr(>|t|)
(Intercept)  -2.2140   0.2468    -8.9725   0.0000
  log.darea   1.2566   0.0529    23.7444   0.0000
    log.SVI  -2.6280   0.7545    -3.4830   0.0008

Residual standard error: 0.286 on 78 degrees of freedom
Multiple R-Squared: 0.8887      Adjusted R-squared: 0.8858
F-statistic: 311.3 on 2 and 78 degrees of freedom, the p-value is 0
```

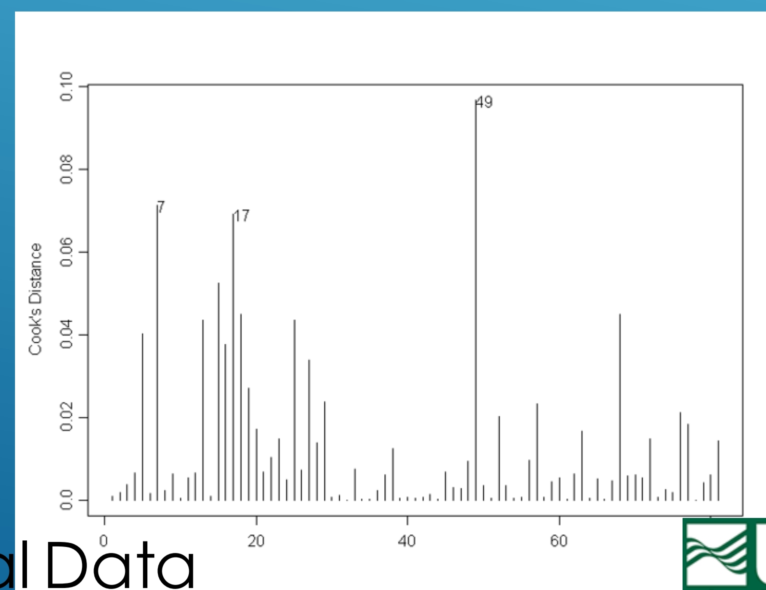
Provisional Data

# EXAMPLE EVALUATIONS OF REGRESSION ANALYSIS PLOTS



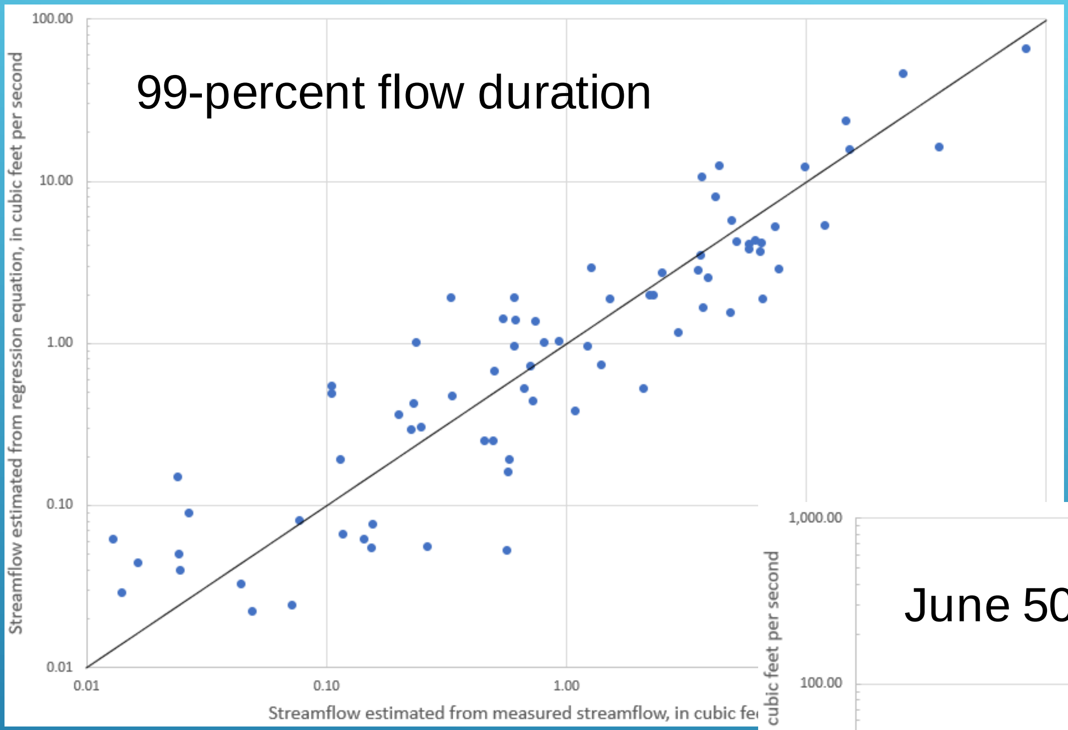

Provisional Data

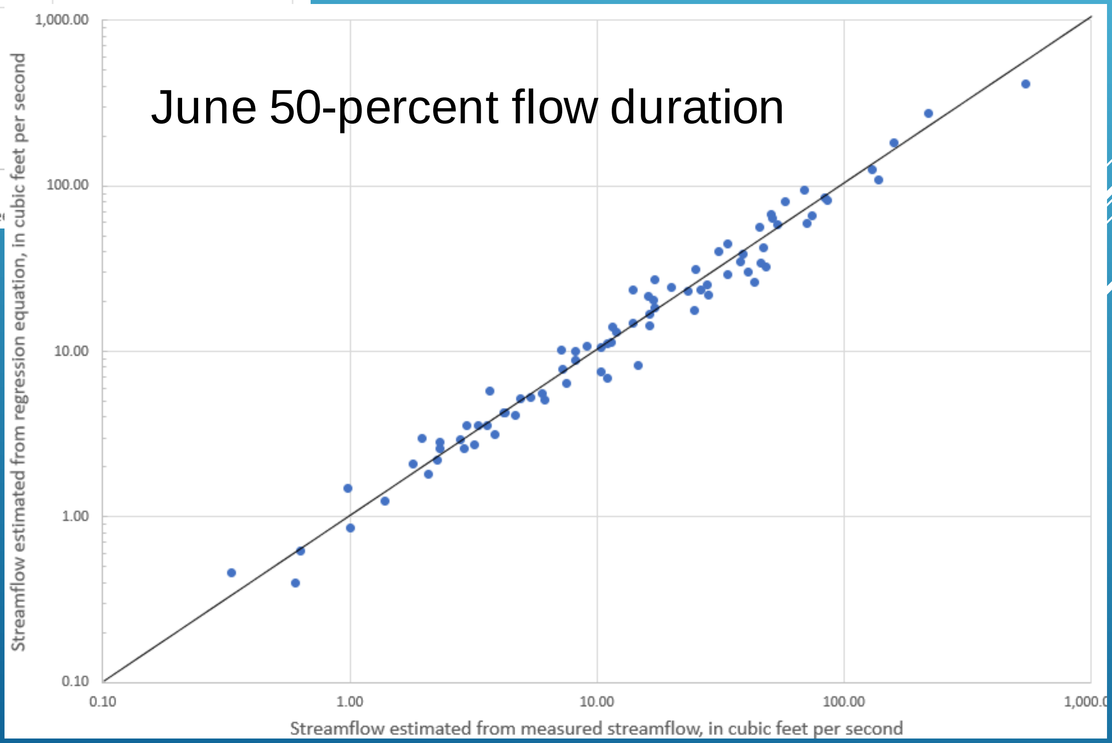
# Weighted-Multiple-Linear Regression (WREG) Results

| Flow Duration | SW drainage area (mi²) | SSURGO hydrologic soil types A and B (%) | Streamflow variability index (SVI) (unitless) | Intercept | Adj. $R^2$ | RMSE (%) |
|---|---|---|---|---|---|---|
| 50 | 1.0090 | 0.1306 | -- | -0.1688 | 0.9846 | 17.85 |
| 60 | 1.0248 | 0.1345 | -- | -0.3352 | 0.9808 | 20.35 |
| 70 | 1.0612 | 0.1424 | -- | -0.5718 | 0.9716 | 26.11 |
| 75 | 1.0668 | -- | -1.4915 | -0.9663 | 0.9675 | 31.70 |
| 80 | 1.0957 | -- | -1.8698 | -1.2460 | 0.9602 | 37.78 |
| 85 | 1.1285 | -- | -2.2595 | -1.5491 | 0.9479 | 46.03 |
| 90 | 1.1685 | -- | -2.7577 | -1.9153 | 0.9345 | 56.20 |
| 95 | 1.2276 | -- | -3.4435 | -2.4195 | 0.9078 | 75.45 |
| 98 | 1.2923 | -- | -4.1659 | -2.9471 | 0.8721 | 103.33 |
| 99 | 1.3474 | -- | -4.7437 | -3.3388 | 0.8462 | 130.70 |

Provisional Data

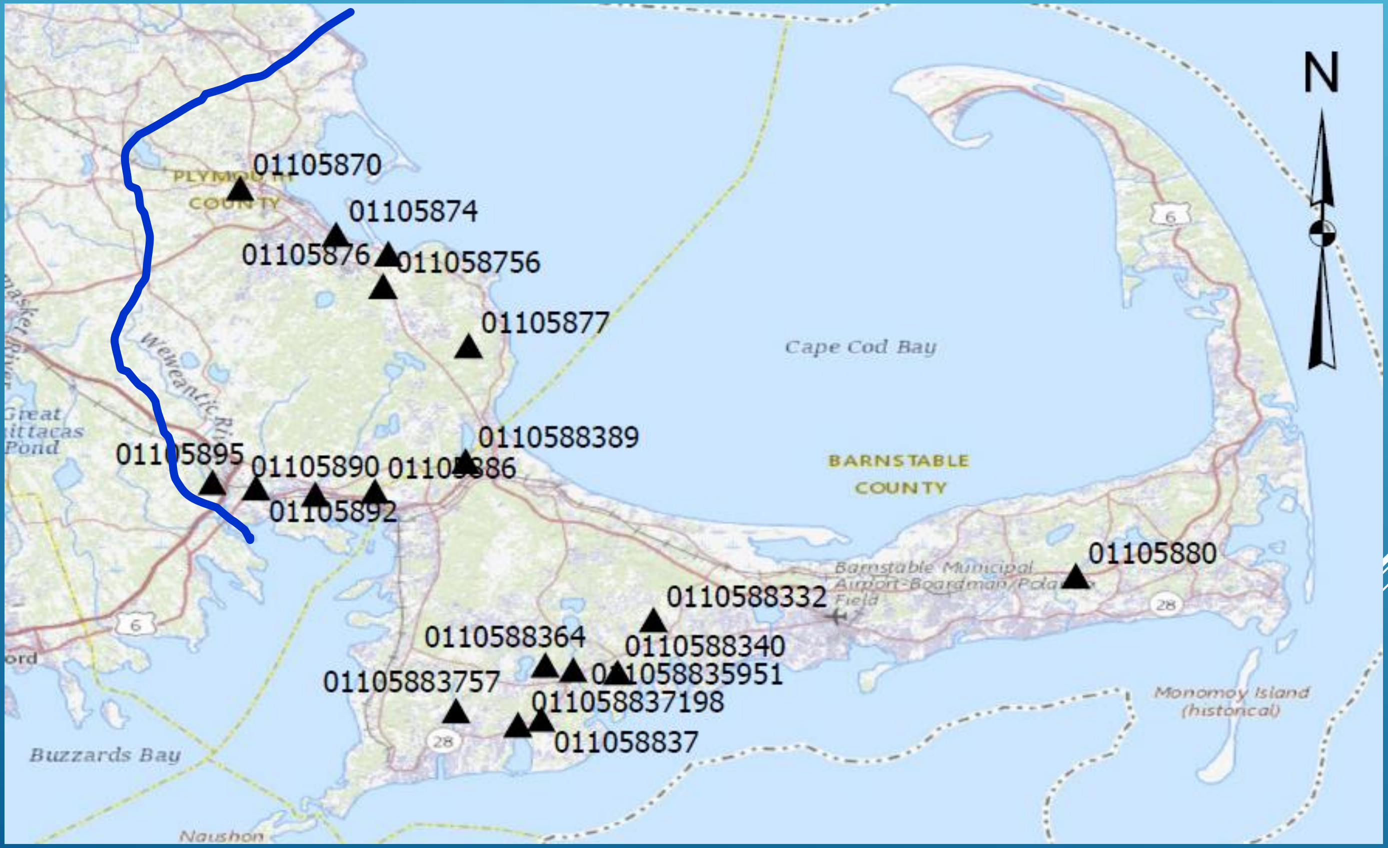
# Predicted versus Observed Streamflows



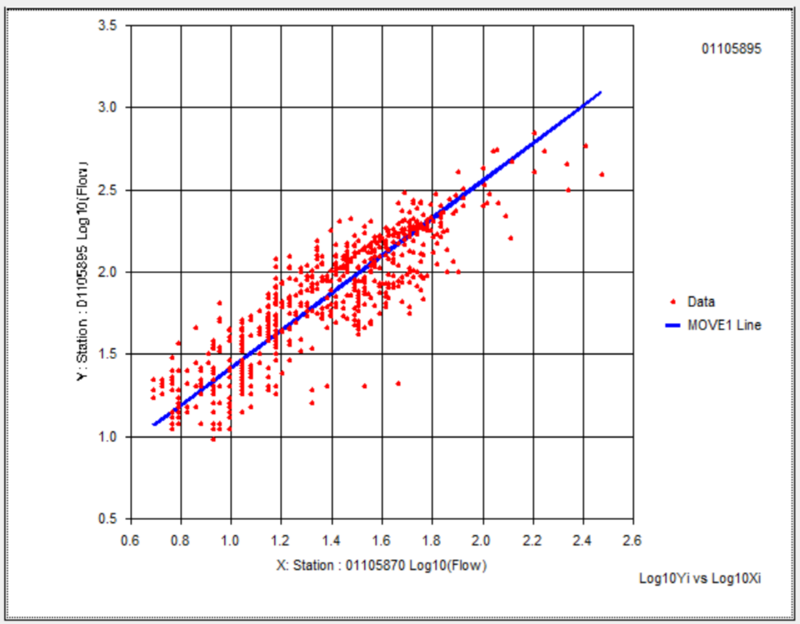
# Streamflow Data – SE Mass and Cape Cod

- 18 sites with sufficient streamflow data for determining flow statistics
  - 4 long-term streamgages (LTG) with > 10 yrs. of record
  - 3 short-term streamgages (STG) with <10 yrs. Of record
  - 11 partial-record stations (PRS) with miscellaneous QMs



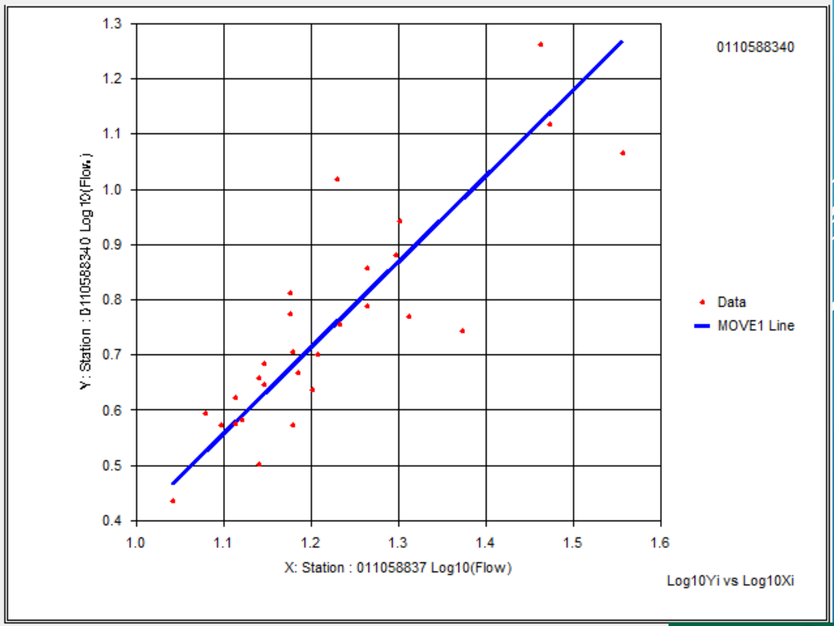
# Estimating Streamflow Data at STG and PRS – SE Mass and Cape Cod

- Correlations >0.80 between miscellaneous QMs at PRS and concurrent daily mean discharges at the LTG
- Correlations mainly >0.80 between concurrent daily mean discharges at STG and LTG
- MOVE.1 relation used to estimate long-term flow statistics at STG and PRS




Data and MOVE.1 Line for station: 01105895 by station: 01105870 R =0.881

MOVE.1 Eq.: Log10(Yi) = 0.279578098766389 + 1.1377237155265 Log10(Xi)




Data and MOVE.1 Line for station: 0110588340 by station: 011058837 R =0.861

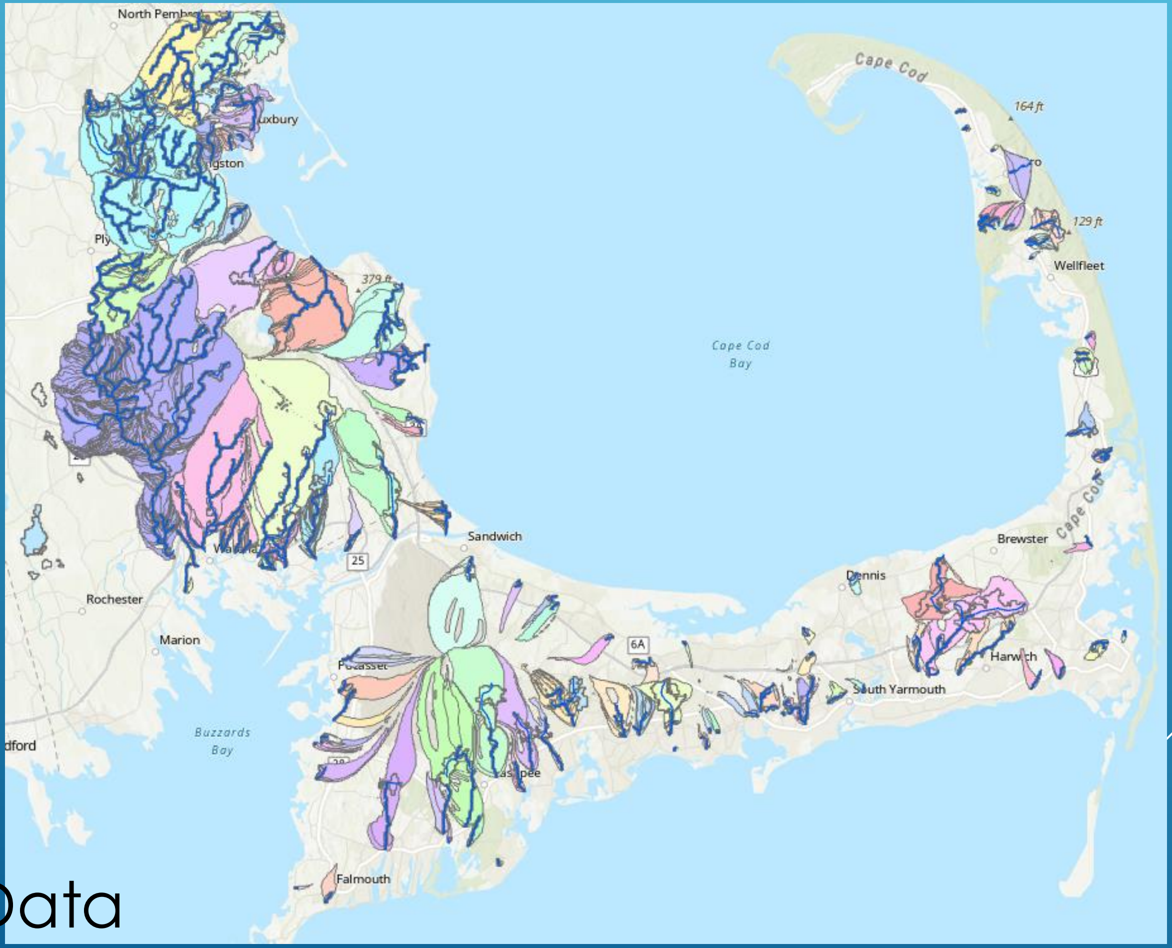
MOVE.1 Eq.: Log10(Yi) = -1.15566745130905 + 1.55797958407774 Log10(Xi)

Provisional Data

USGS science for a changing world

# GW Contributing Areas – SE Mass and Cape Cod

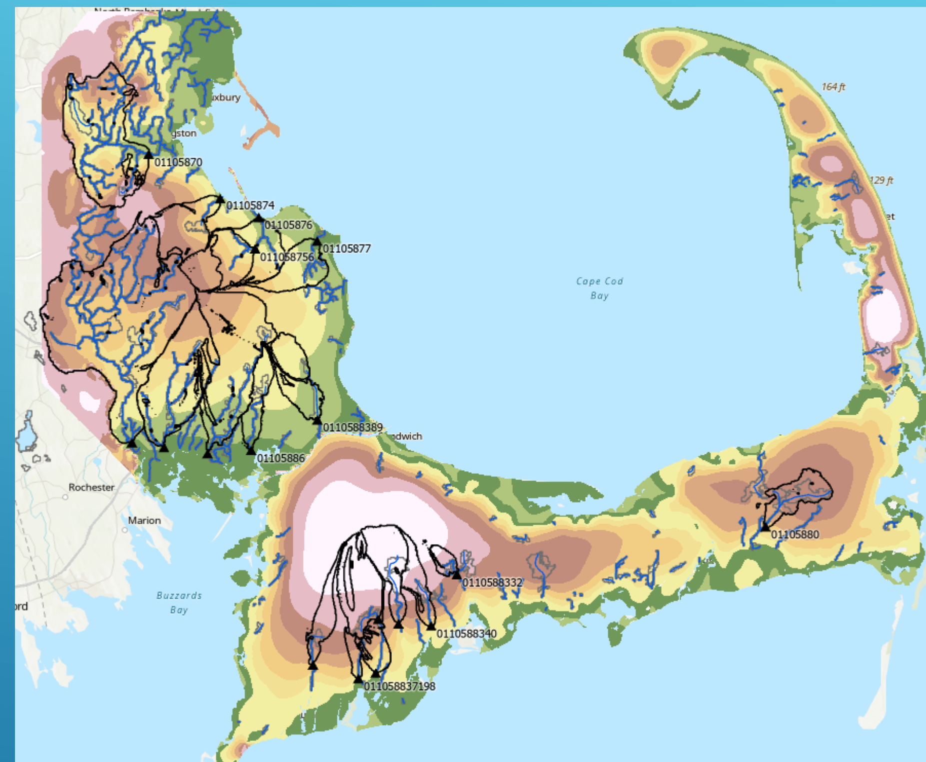
- Groundwater contributing area determined using GW models:
  - Plymouth-Carver-Kingston-Duxbury (Masterson and others, 2009)
  - Mid-Cape (LeBlanc and others, 2019)
  - Lower Cape (Masterson, 2004)




Provisional Data

# Basin Characteristics – SE Mass and Cape Cod

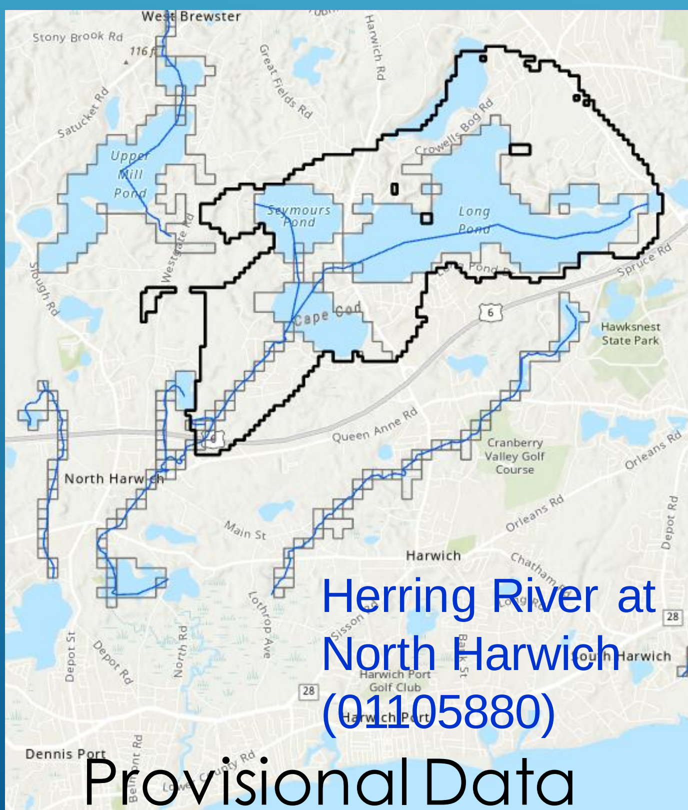
- Groundwater contributing area
- Maximum, minimum, and mean water-table elevations
- Mean water-table slope
- Mean aquifer saturated thickness
- Mean aquifer horizontal hydraulic conductivity
- Mean aquifer transmissivity
- Basin, land-use, geologic, and climatic characteristics tested in other part of state




Provisional Data

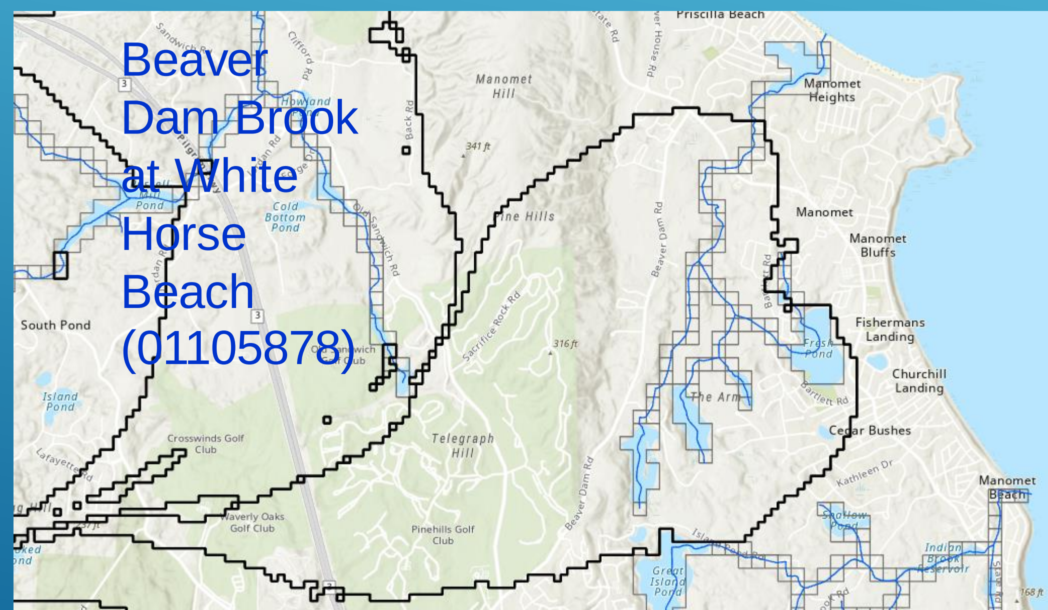
# Regression Analyses – SE Mass and Cape Cod

- Groundwater contributing area
- Storage (water bodies + wetlands)
- 2-variable equations which includes GW contributing area and strorage in all equations




Herring River at North Harwich (01105880)

Provisional Data




Beaver Dam Brook at White Horse Beach (01105878)

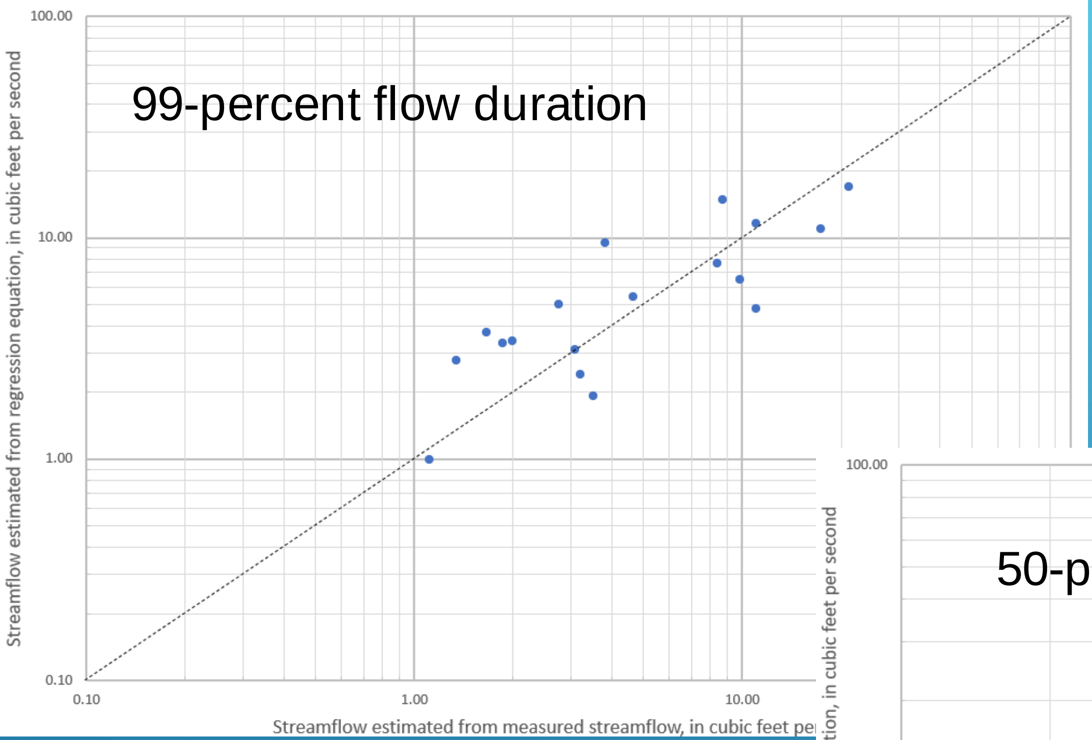
# Weighted-multiple-linear REGression (WREG) results – SE Mass and Cape Cod

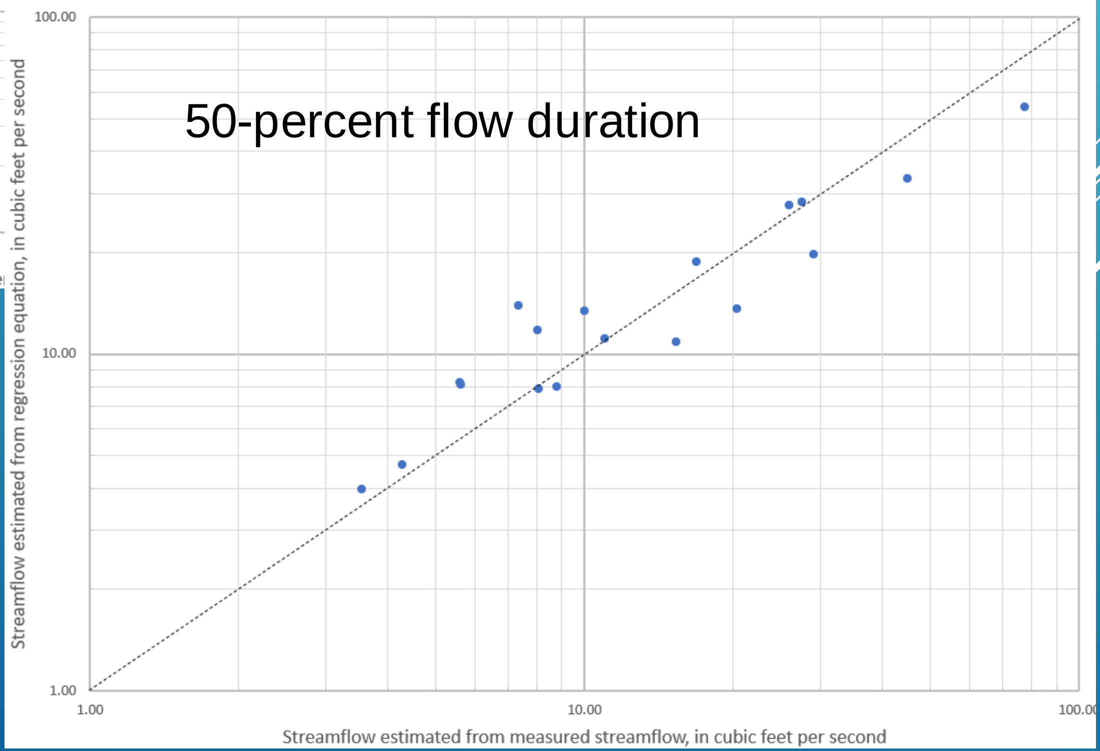
| Flow Duration | GW contributing area ($mi^2$) | Storage (water bodies + wetlands) NLCD16 (%) | Intercept | Adj. $R^2$ | RMSE (%) |
|---|---|---|---|---|---|
| 50 | 0.8088 | -0.2140 | 0.6652 | 0.8488 | 33.65 |
| 60 | 0.7985 | -0.2852 | 0.6952 | 0.8215 | 36.92 |
| 70 | 0.7669 | -0.3742 | 0.7703 | 0.7885 | 39.53 |
| 75 | 0.7830 | -0.4406 | 0.7961 | 0.7797 | 40.69 |
| 80 | 0.7771 | -0.5167 | 0.8590 | 0.7636 | 41.53 |
| 85 | 0.7924 | -0.6112 | 0.9042 | 0.7389 | 44.46 |
| 90 | 0.8058 | -0.7522 | 1.0083 | 0.7094 | 46.60 |
| 95 | 0.8434 | -0.9102 | 1.0805 | 0.6713 | 51.57 |
| 98 | 0.8800 | -1.0160 | 1.0875 | 0.6460 | 56.88 |
| 99 | 0.8478 | -1.0728 | 1.1261 | 0.5970 | 61.95 |

Provisional Data

USGS science for a changing world

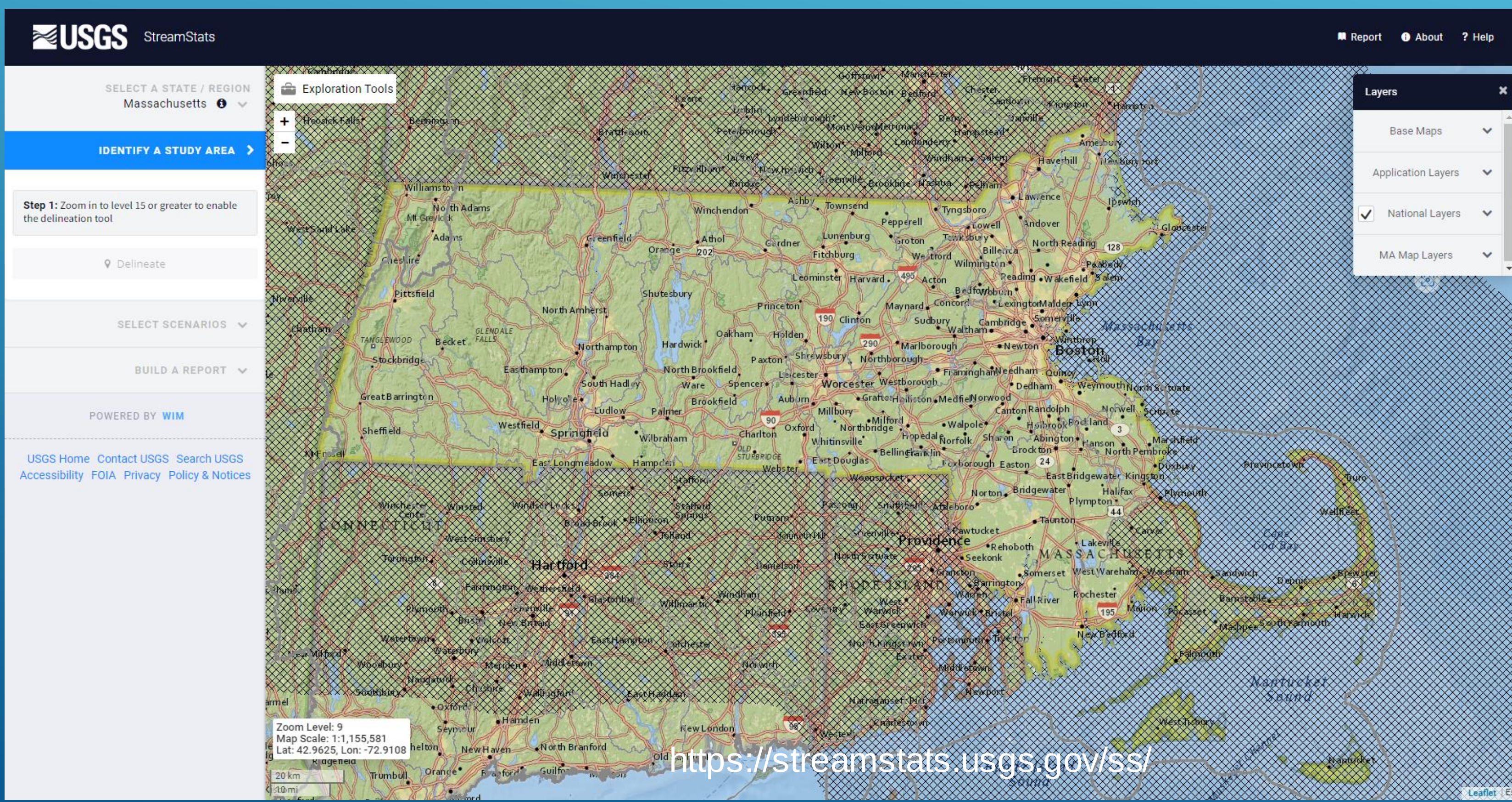
# Predicted versus Observed Streamflows – SE Mass and Cape Cod



# Products

- USGS Scientific Investigation Report
- USGS Data Releases
- USGS StreamStats



# Thanks to Viki Zoltay, Kate Bentsen, and Julie Butler who provided input throughout the project

<u>USGS Team:</u>

Liz Ahearn, Alex Butcher, Carl Carlson, Jenn Fair, Nina Labrie, Caroline Mazo, Tim McCobb, and Luke Sturtevant