New tools to estimate water availability at ungaged sites

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Technical Talk

Austin, TX

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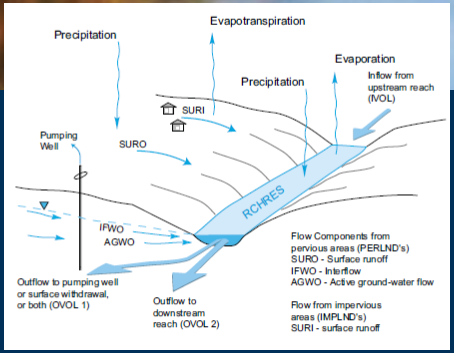
The Susquehanna River looking east, from City Island in Harrisburg, PA

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

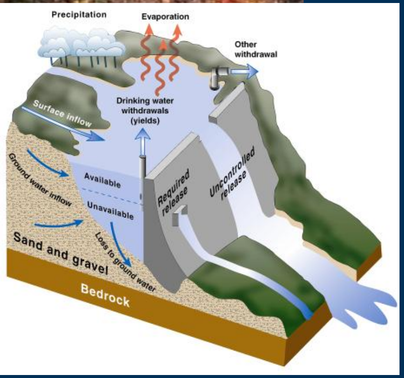
The need for streamflow time series

Streamflow time series are essential information for many types of analyses

Water quality monitoring and modeling



Water quantity modeling



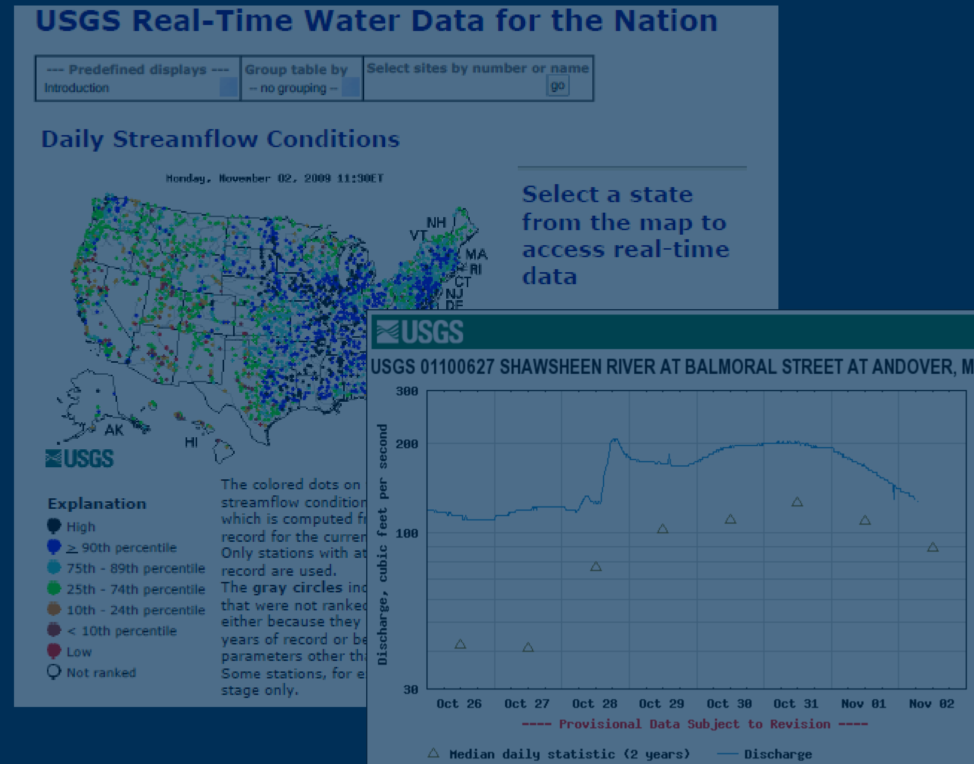
Water management decisions

USGS

Photographs from http://www.labsafety.com/Nalgene-Environmental-Sample-Bottles_24545938, Zarriello, P.J. and Reis, K.G., 2000, and Waldron and Archfield , 2006.

Obtaining streamflow information

http://waterdata.usgs.gov/nwis

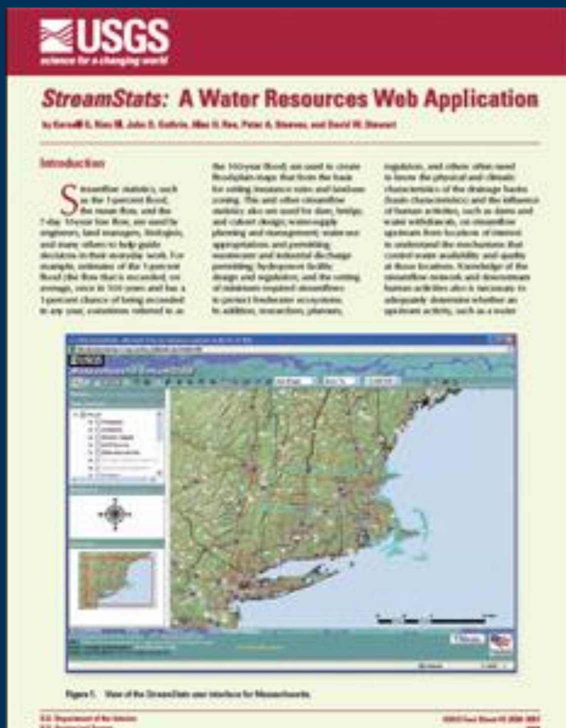


The need to estimate streamflow at ungaged catchments is so important that the International Association of Hydrological Sciences has undertaken a 10-year initiative (2003-2012) termed Predictions in Ungaged Basins (PUB) to develop new methods and insights into this issue.

(http://pub.iwmi.org/UI/Content/Default.aspx?PGID=0)

The USGS and flow estimation at ungaged catchments

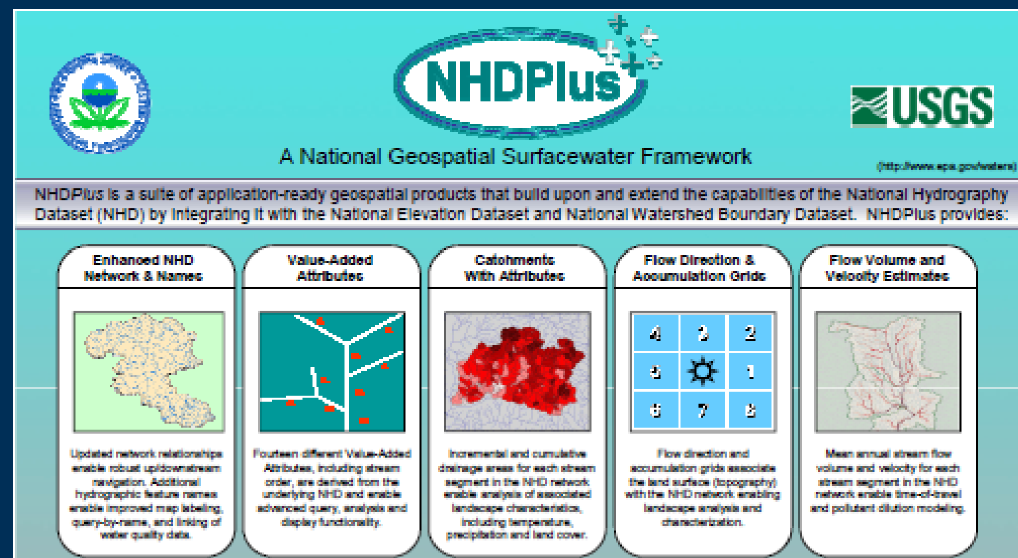
- The USGS is a leader in estimating and serving streamflow information at ungaged catchments across the United States


USGS

StreamStats: A Water Resources Web Application

Introduction

http://water.usgs.gov/osw/streamstats/ssonline.html



ftp://ftp.horizon-systems.com/NHDPlus/documentation/nhdplus_poster.pdf

Recent motivations for ***daily*** streamflow time series

The Natural Flow Regime

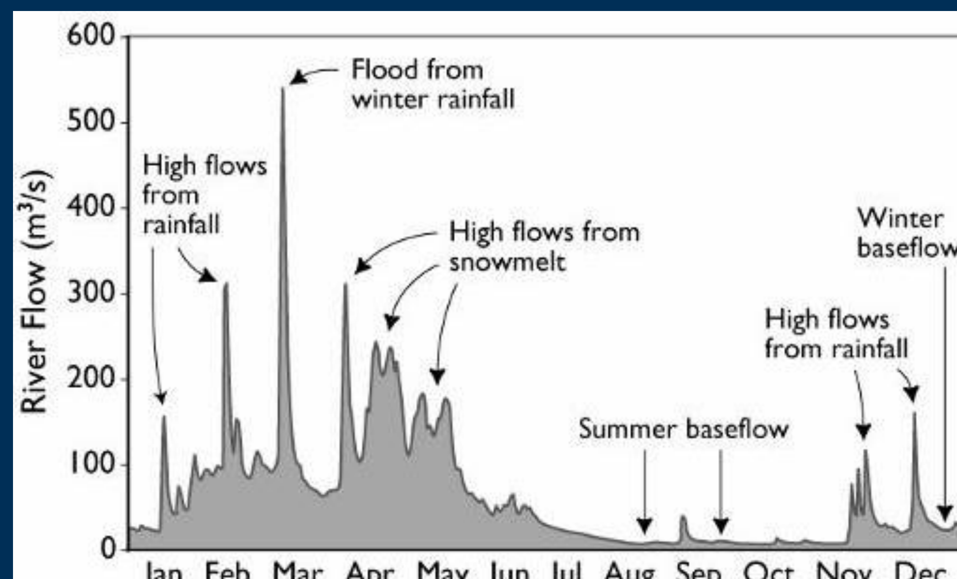
Published in: Bioscience, December 1997

A paradigm for river conservation and restoration

N. LeRoy Poff, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegaard, Brian D. Richter, Richard E. Sparks, and Julie C. Stromberg

The "Natural Flow Regime" is comprised of five characteristics:

1. Magnitude
2. Duration
3. Timing
4. Frequency
5. Rate of change

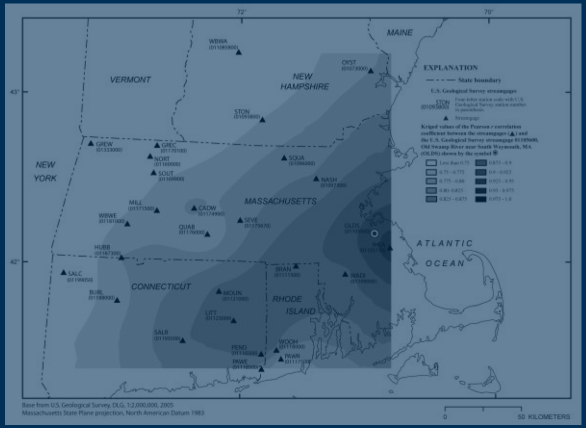


Richter et al. 1996, "A Method for Assessing Hydrologic Alteration Within Ecosystems." (Conservation Biology)

Topics for discussion

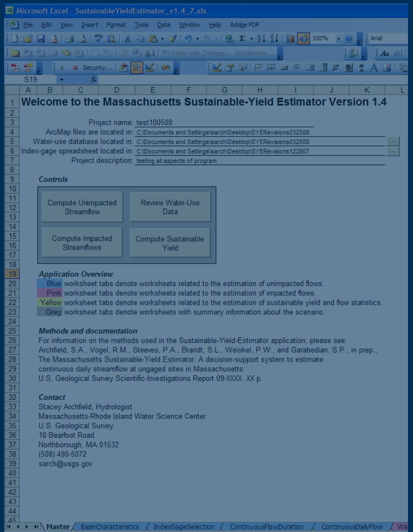
1. Existing methods to estimate daily streamflow time series at ungaged catchments

$$Qu_t = \frac{Au}{Ag} Qg_t$$



2. The Map Correlation method: An enhancement to existing methods

3. Integration with a water-availability decision-support tool and other applications



USGS

Existing methods to estimate streamflow time series using a reference catchment

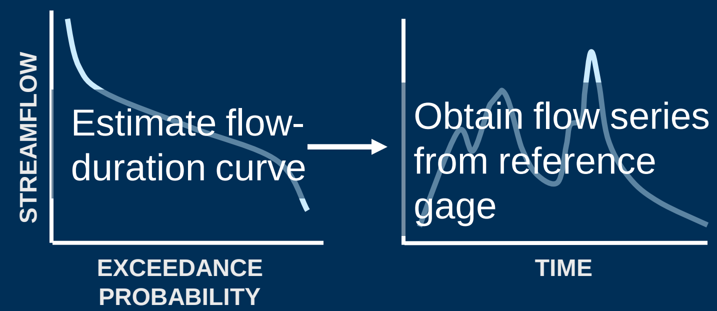
Drainage-area ratio

$$Qu_t = \frac{Au}{Ag} Qg_t$$

Scaling by the at-site mean and variance
(Hirsch, 1979)

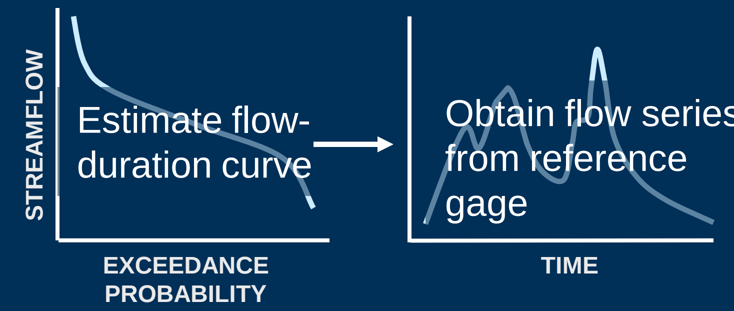
$$Qu_t = \hat{\mu}_u + \hat{\sigma}_u \left(\frac{Qg_t - \hat{\mu}_g}{\hat{\sigma}_g} \right)$$

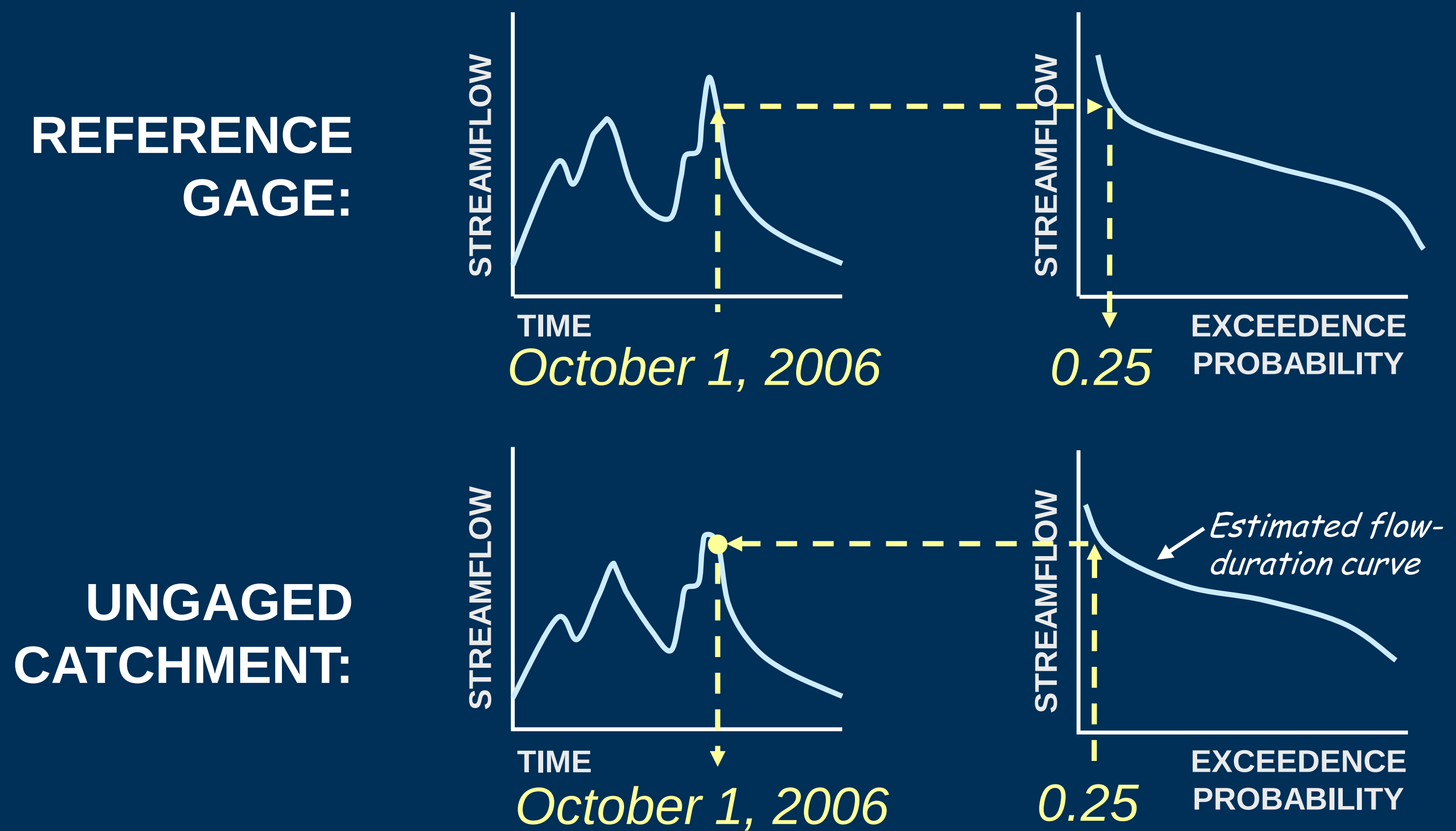
Non-linear spatial interpolation
(Fennessey, 1994; Smakhtin, 1999; Smakhtin et al. 1997, Mohamoud, 2008; Archfield and others, 2010)



USGS

Non-linear spatial interpolation method (*continued*)



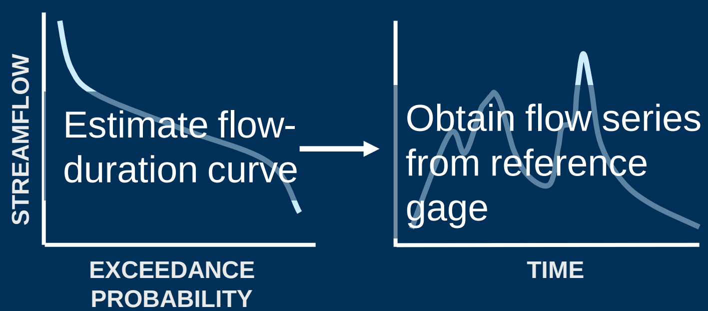


From Archfield and others, USGS SIR, 2010; adapted from Fennessey, 1994

Existing methods to estimate streamflow time series using a reference gage

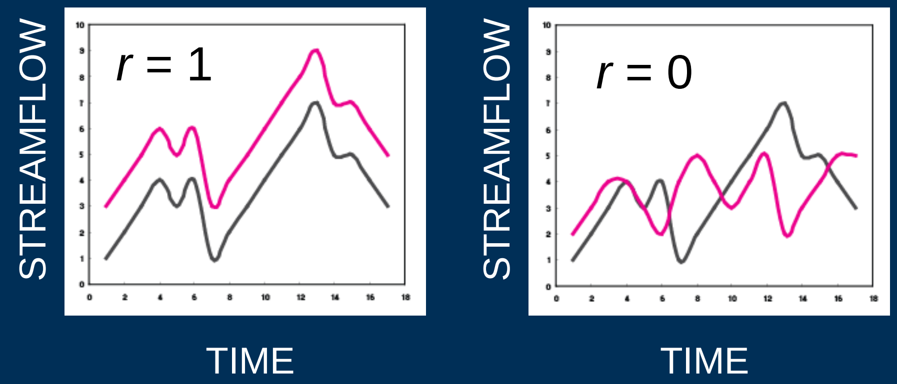
$$Qu_t = \frac{Au}{Ag} Qg_t$$

$$Qu_t = \hat{\mu}_u + \hat{\sigma}_u \left(\frac{Qg_t - \hat{\mu}_g}{\hat{\sigma}_u} \right)$$

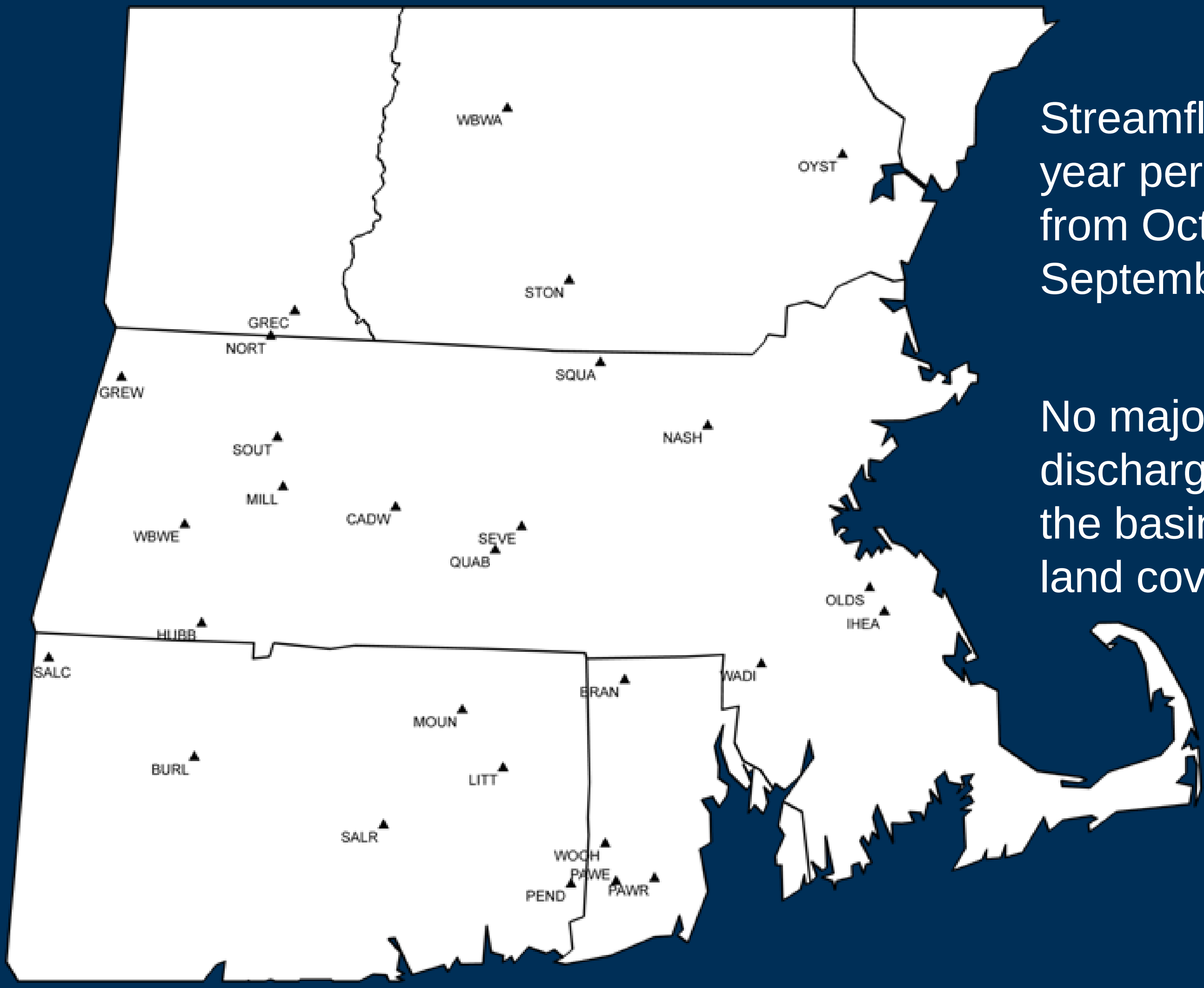


In practice, the nearest gage is used as the reference gage.

If even a few streamflow data points are known at the catchment of interest, one would use the correlation between the streamflow values.



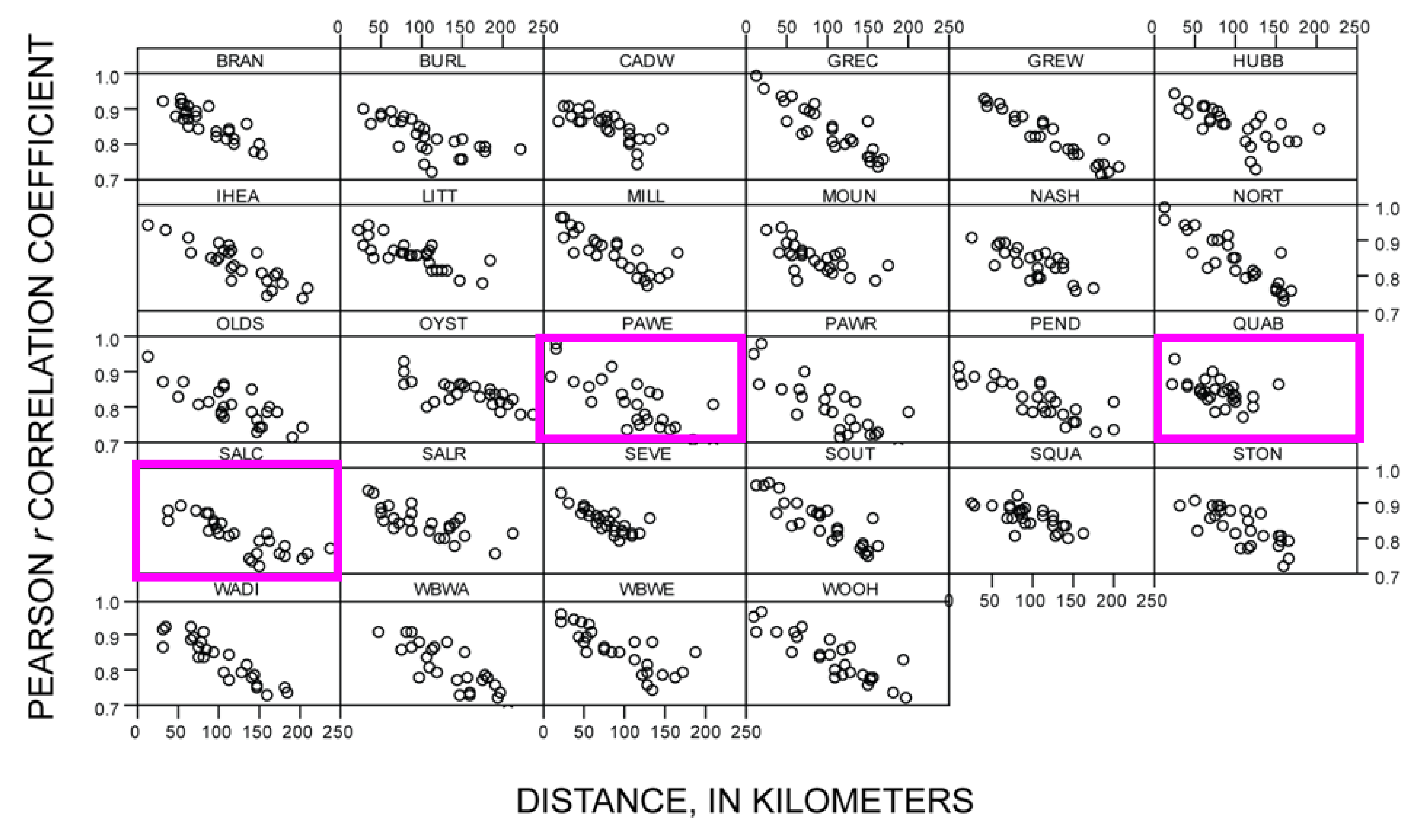
Relation between distance and correlation



Streamflow values have a 30-year period of record extending from October 1, 1967 through September 30, 1997.

No major water withdrawals, discharges or return flows in the basin and the predominant land cover is forest.

Relation between distance and correlation

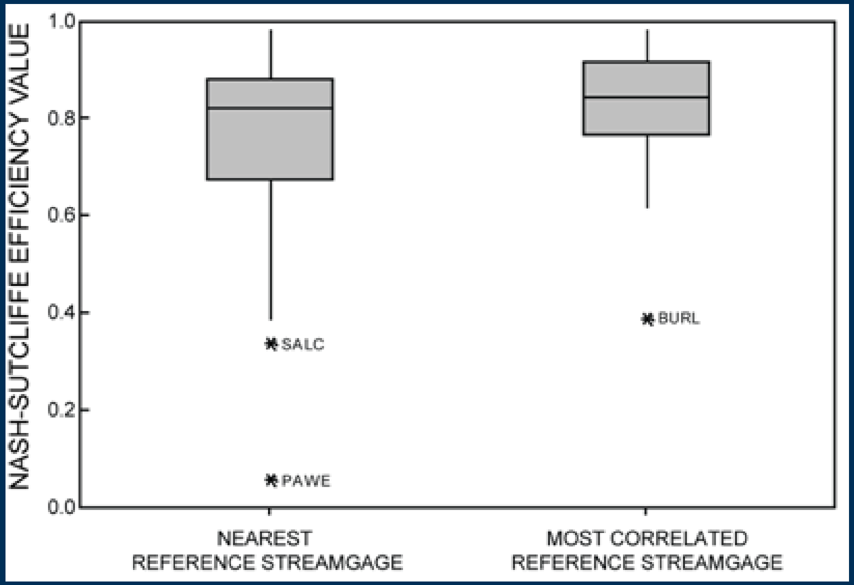


USGS

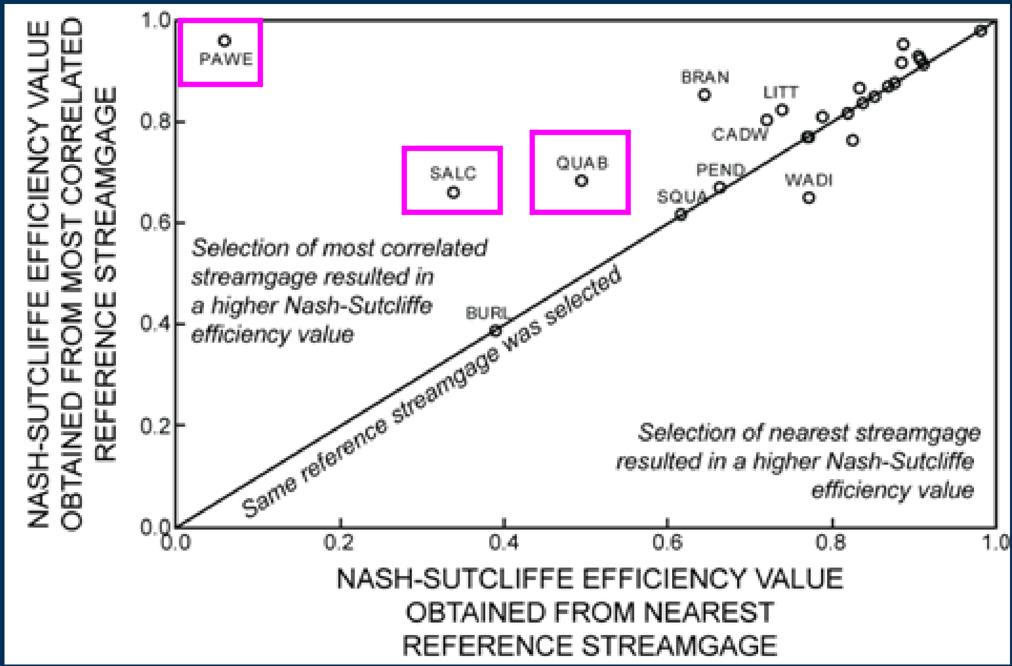
From Archfield and Vogel, Water Resources Research, 2010

Selecting a reference catchment: Distance versus correlation

$$Qu_t = \frac{Au}{Ag} Qg_t$$



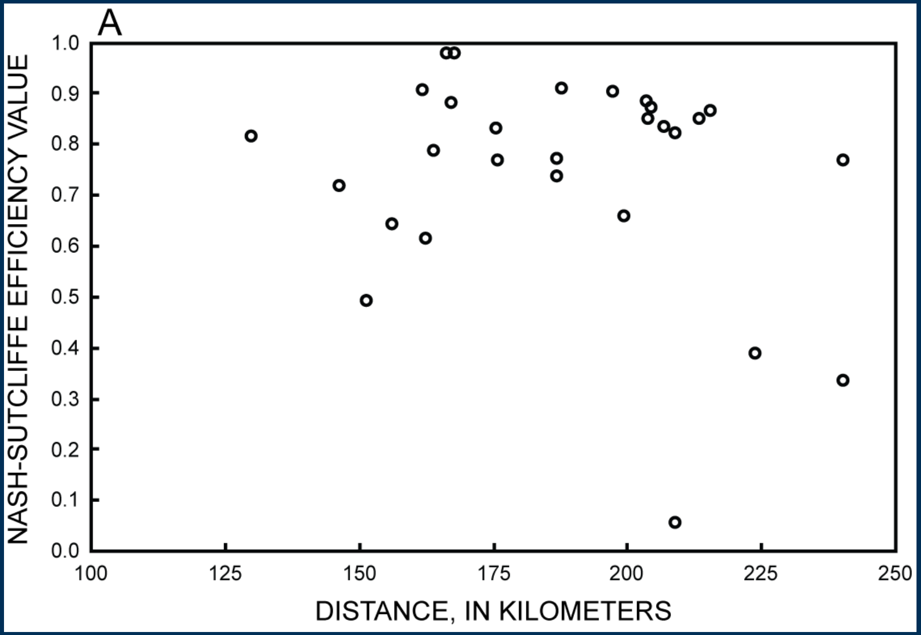
We applied the drainage-area ratio at each study streamgage using the nearest and most-correlated streamgage



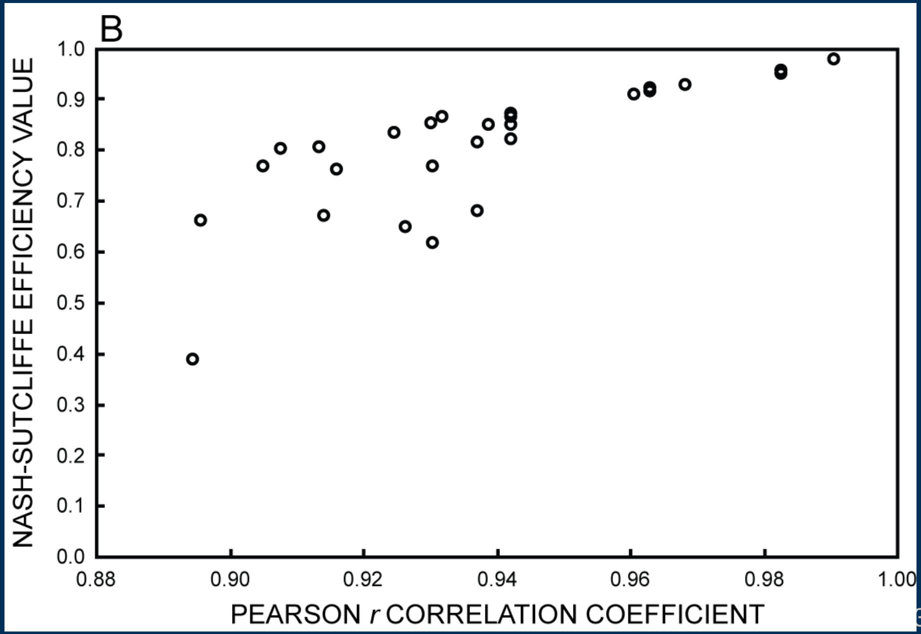
USGS

From Archfield and Vogel, Water Resources Research, 2010

Relation of goodness of fit to correlation



Correlation can also provide an uncertainty measure for the estimated streamflows; distance does not.



From Archfield and Vogel, Water Resources Research, 2010

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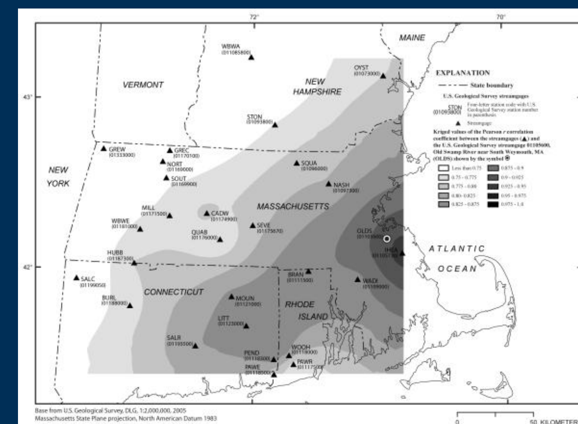
$$Qu_t = \frac{Au}{Ag} Qg_t$$

2. The Map Correlation method: An enhancement to existing methods



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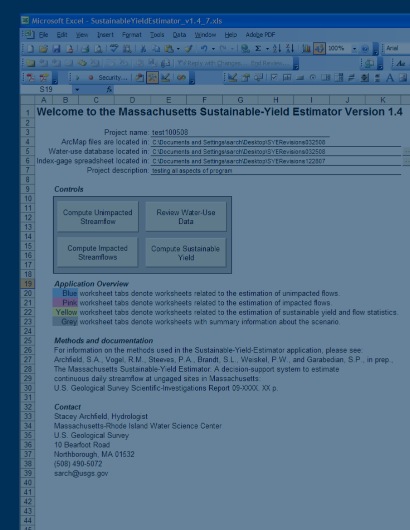

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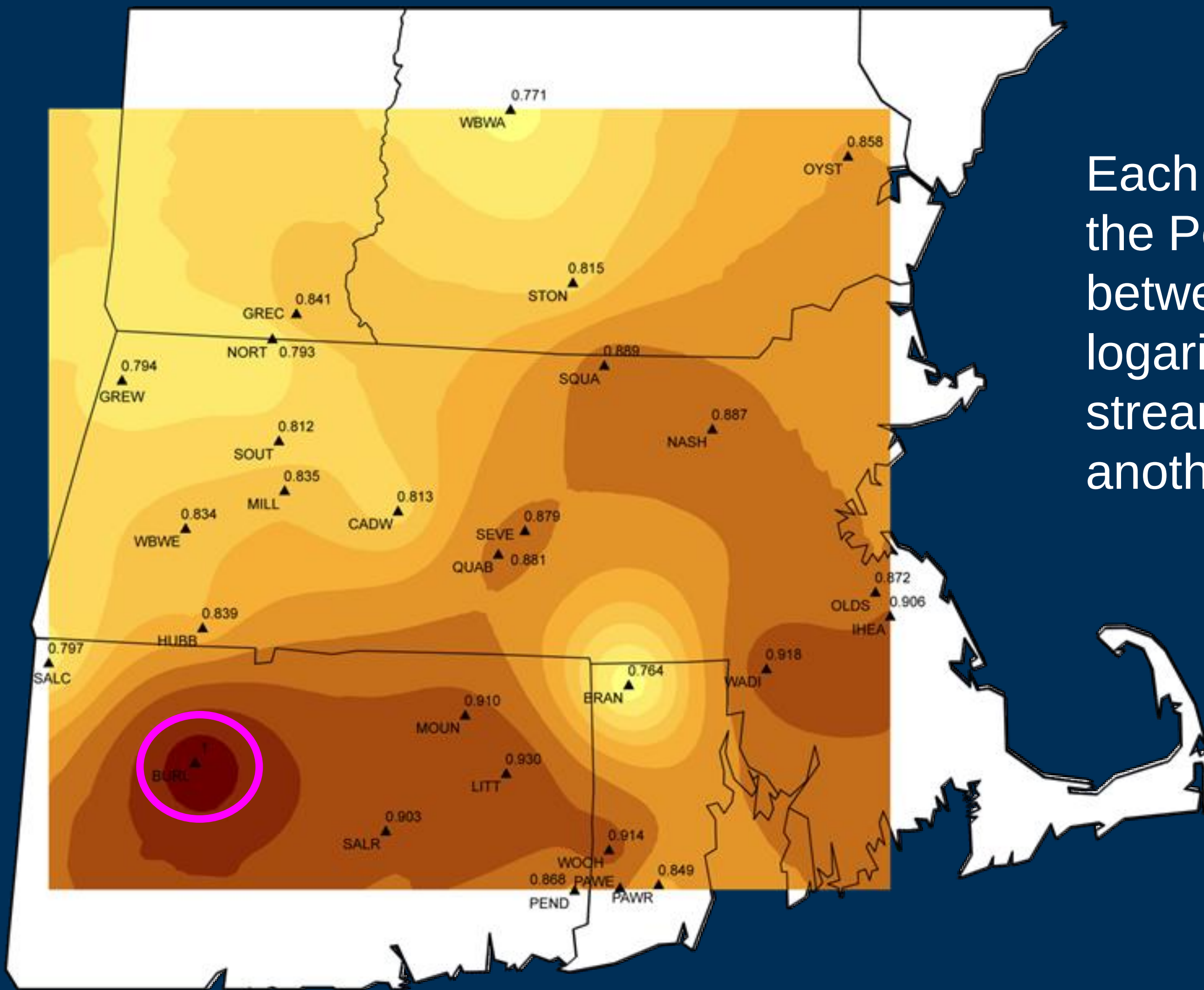
The Map-Correlation Method



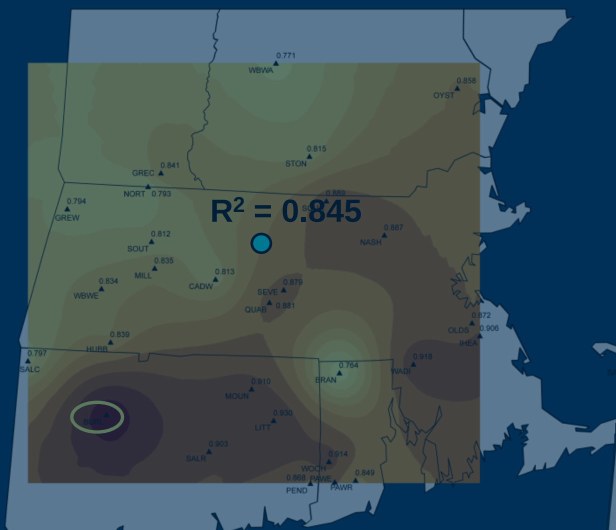
Each point on the map is the Pearson *r* correlation between the natural logarithms of the streamflows at BURL and another gage.

USGS

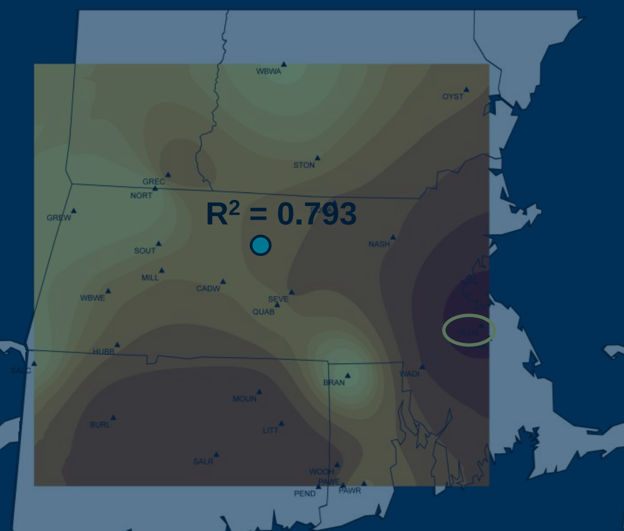
Selection of an index-streamflow gage -- *continued*

We can obtain estimates of correlation between our ungaged site and each of the index-streamflow gages in the study area.

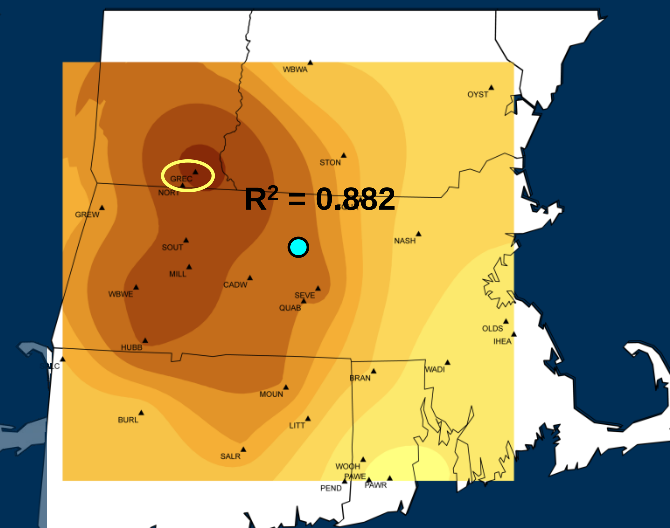
Estimated R^2 between ungaged site and the BURL gage = 0.845



Estimated R^2 between ungaged site and the OLDS gage = 0.793

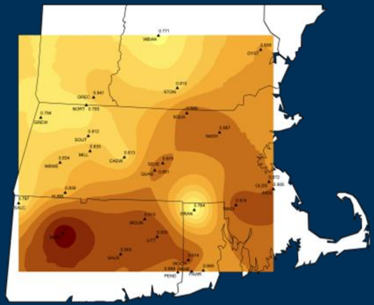


Estimated R^2 between ungaged site and the GREC gage = 0.882



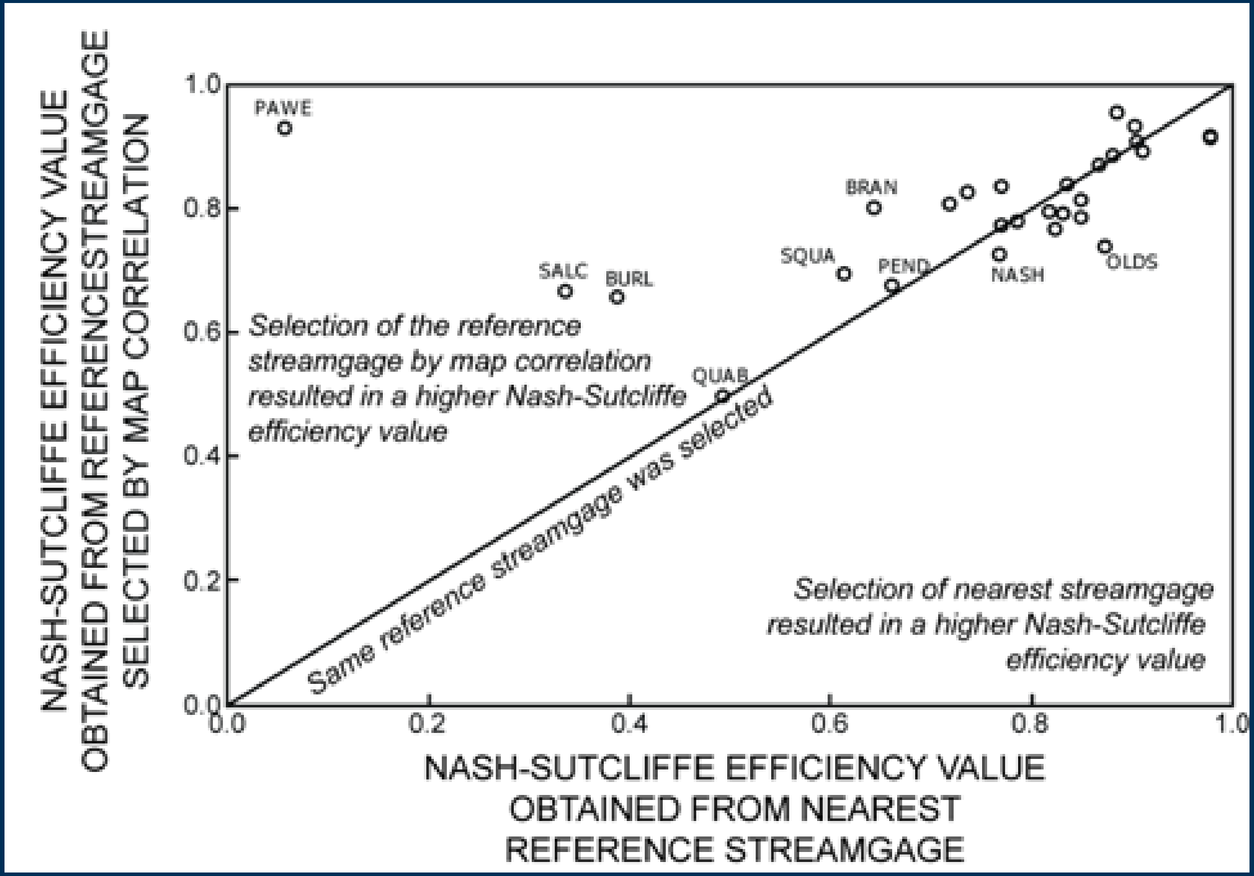
We will use the GREC gage to transform the flow-duration curve to a time series of flows.

How well does it work?



&

$$Qu_t = \frac{Au}{Ag} Qg_t$$



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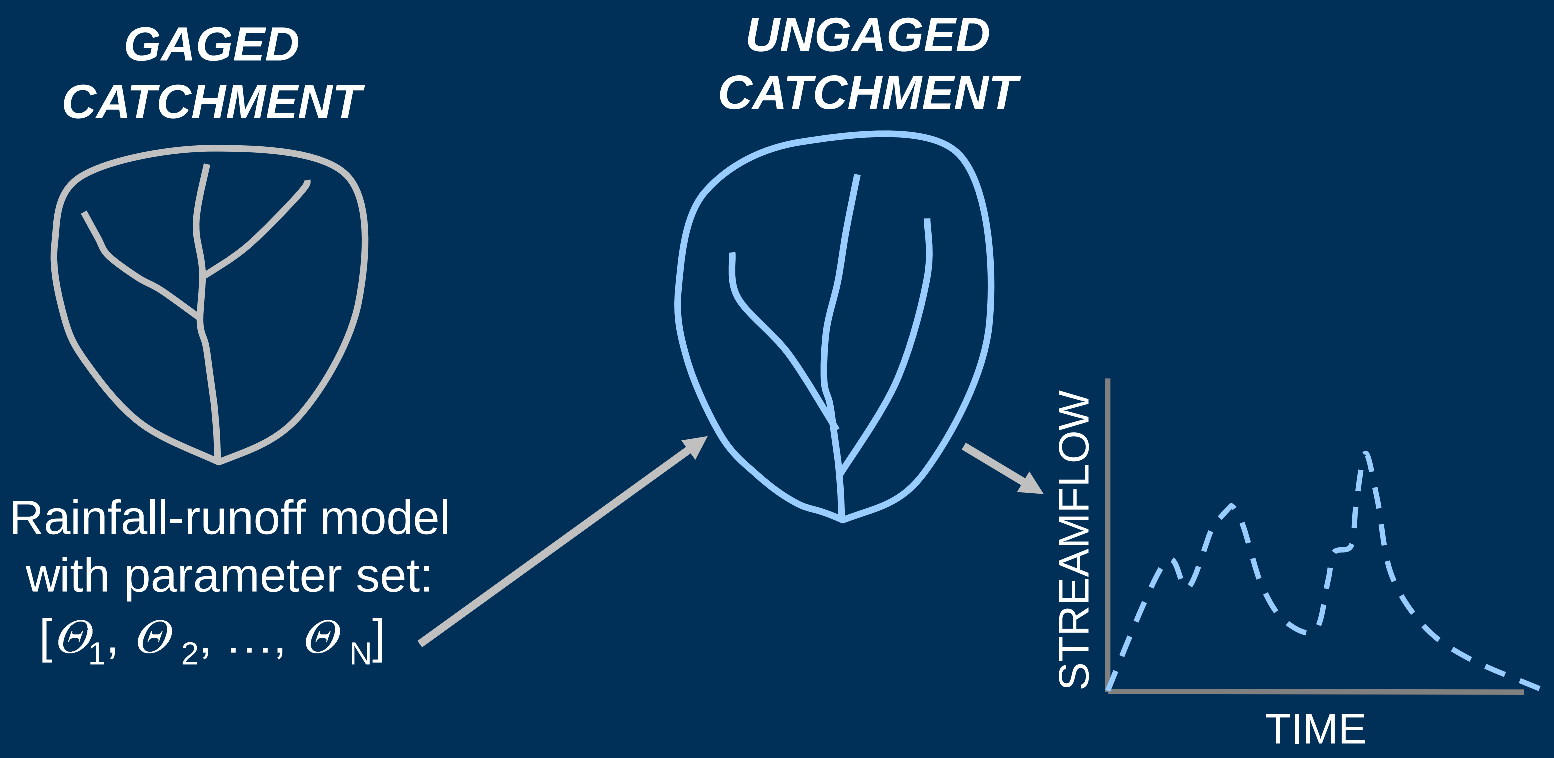
From Archfield and Vogel, Water Resources Research, 2010

Extension to other existing methods: Regionalization of model catchment parameters



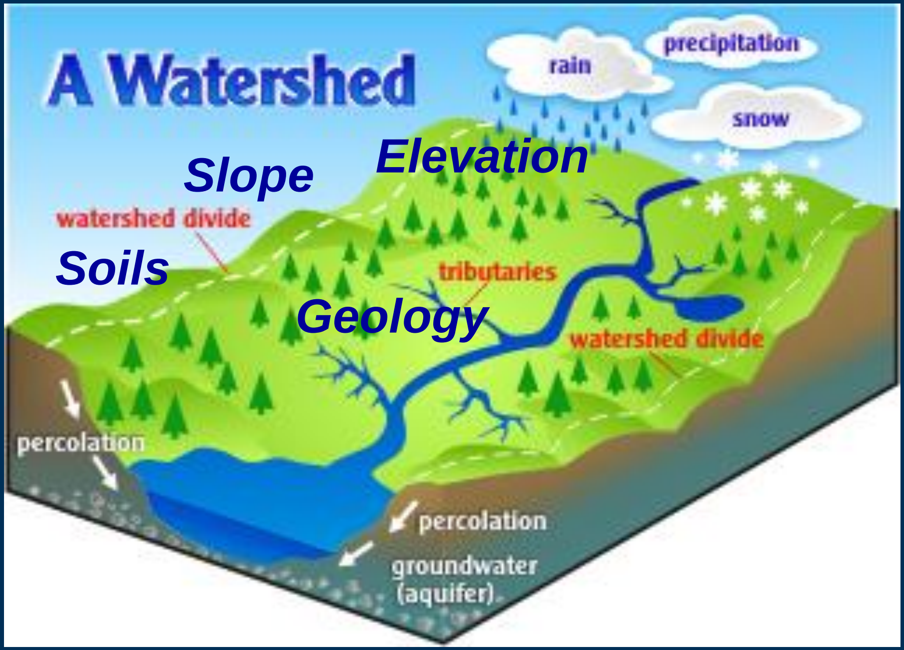
USGS

From Archfield, Singh, Wagener and Vogel, in review

In collaboration with: PENNSTATE Tufts UNIVERSITY

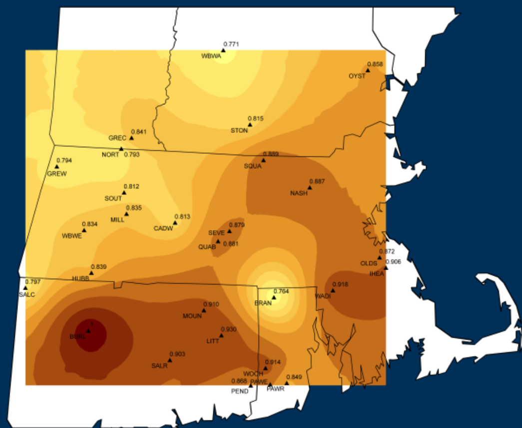
Hydrologic similarity

- As a proxy for hydrologic similarity, the literature has explored the use of the closest catchment or a catchment with similar physical properties (area, geology, etc.) as criteria to select the donor catchment
  - However, these approaches have been met with inconsistent success

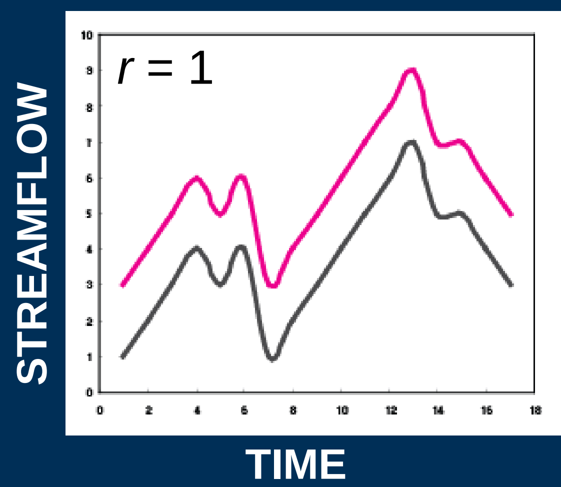


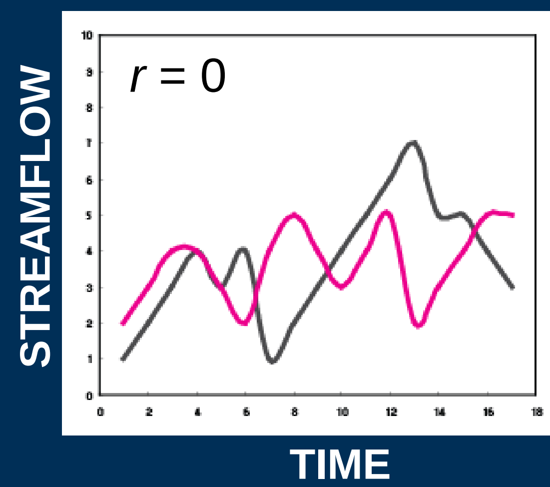
Watershed diagram from: http://www.depweb.state.pa.us/justforkids/lib/justforkids/watershed.jpg

Correlation as a criterion to select a donor catchment



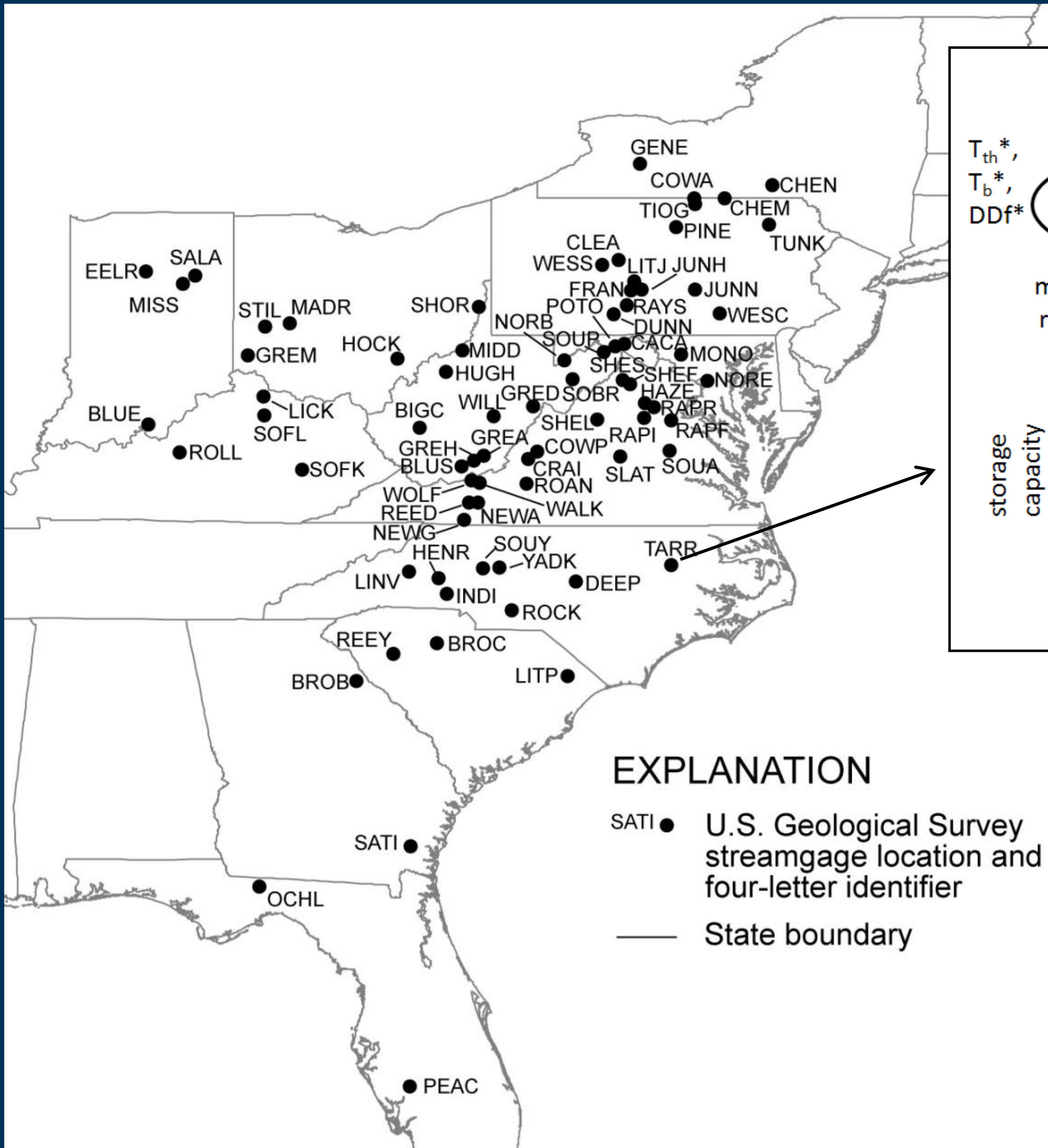
We hypothesize that the correlation in daily streamflow between two catchments would be an improved metric of hydrologic similarity

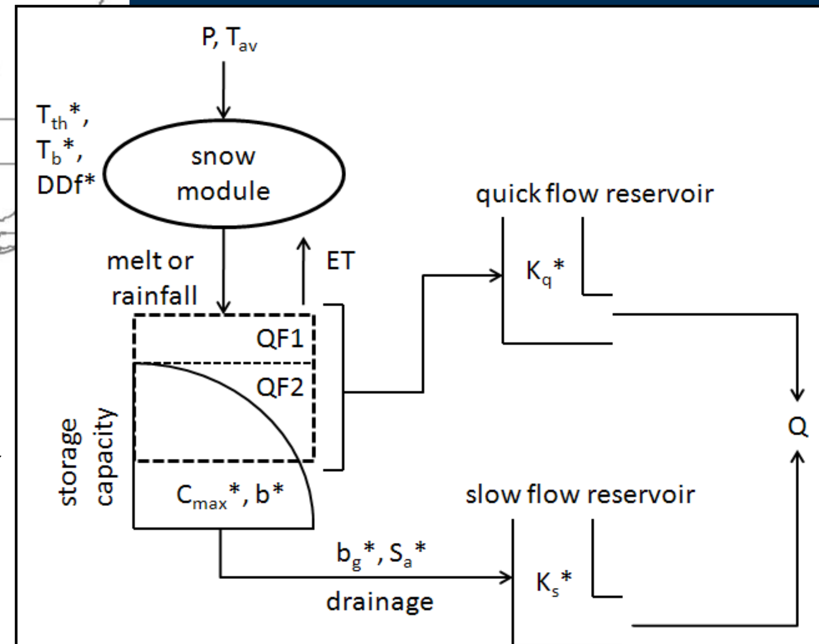




USGS

A case study in the mid-Atlantic U.S.

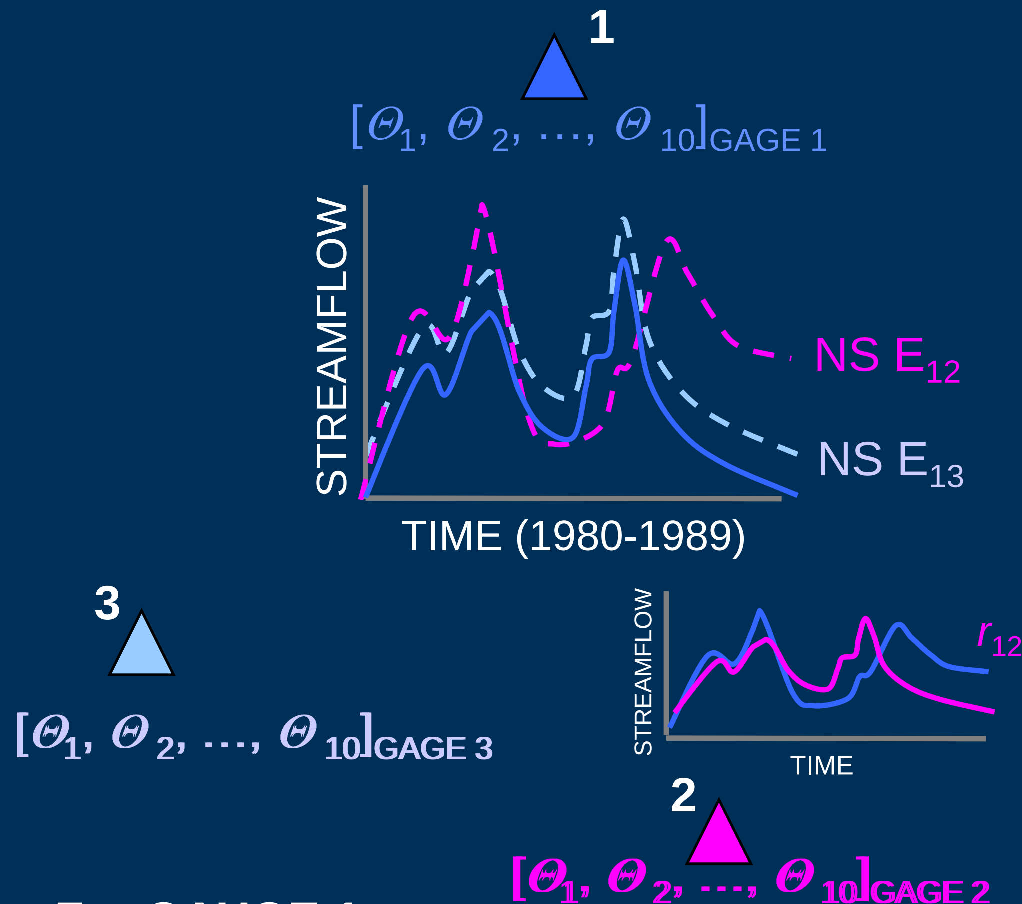




From Archfield, Singh, Wagener and Vogel, in review

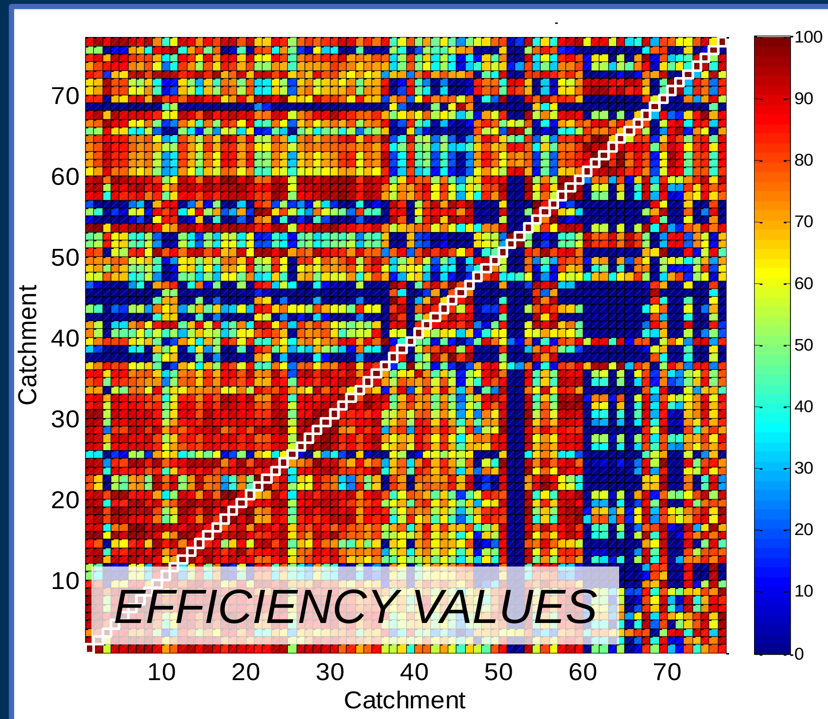
- Model has 10 parameters
- Calibrated using the SCE-UA Algorithm with fixed ranges on the parameters values
- Model simulates daily streamflow from 1980-1989

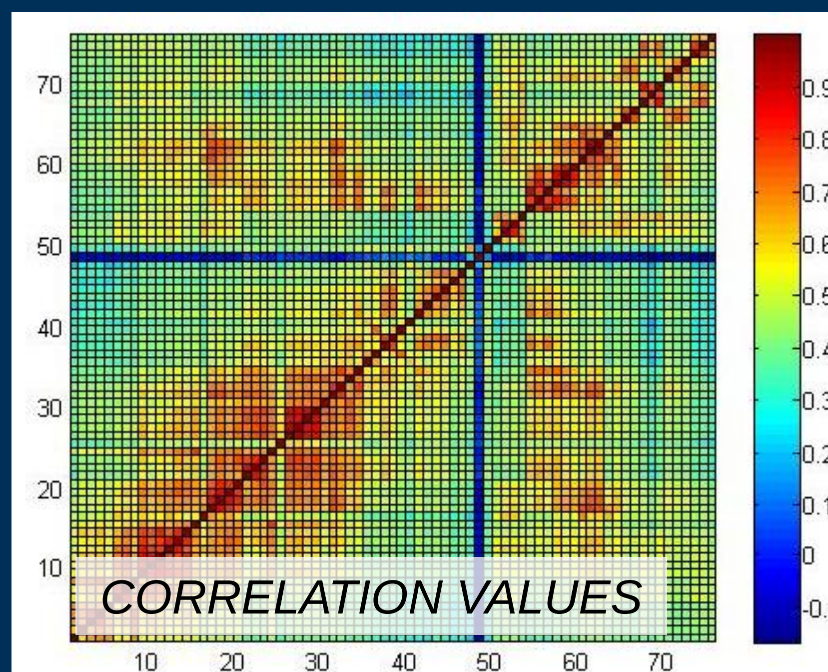
The experiment and results



For GAUGE 1:

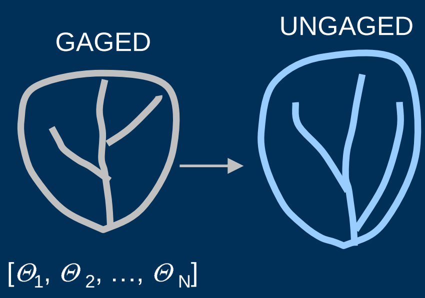
Donor gauge	Nash Sutcliffe Efficiency (NS E)	Correlation
2	NS E_{12}	r_{12}
3	NS E_{13}	r_{13}

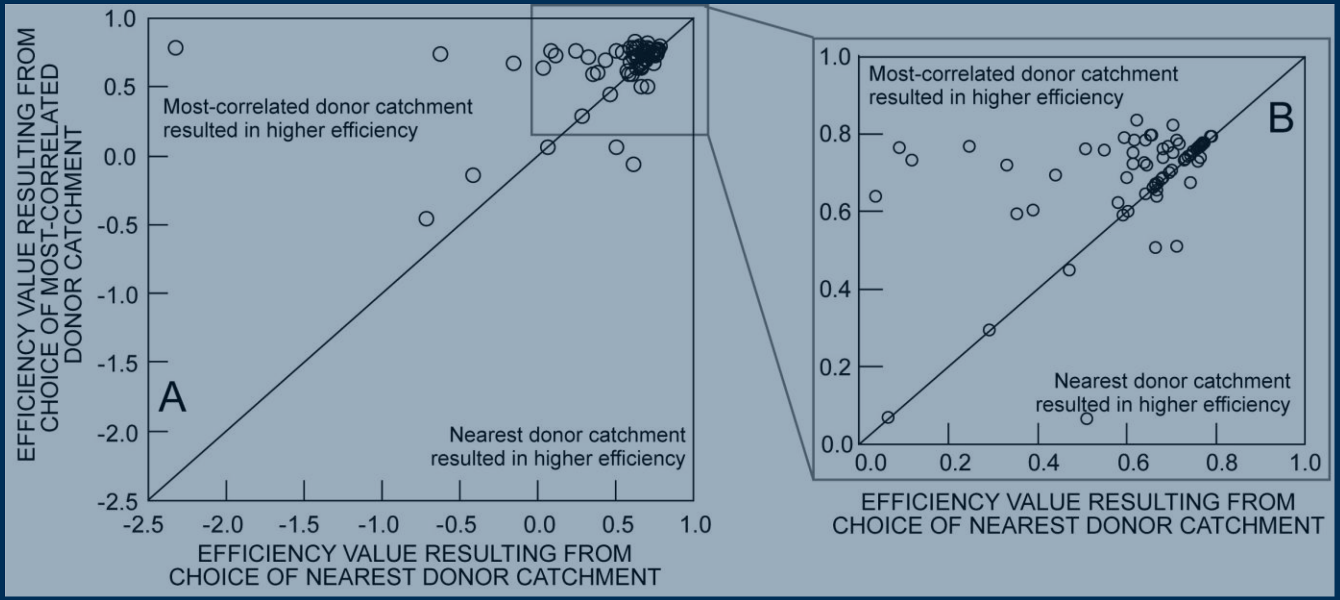




From Archfield, Singh, Wagener and Vogel, in review

Use of correlation for parameter transfer





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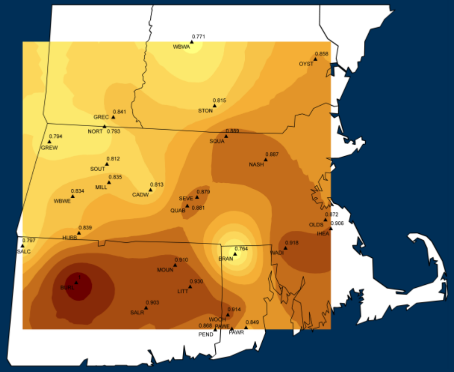

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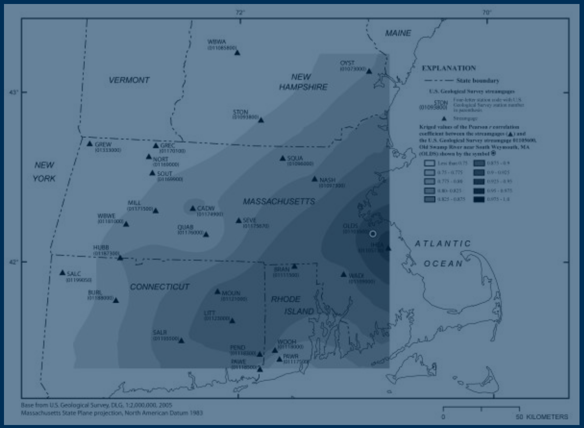

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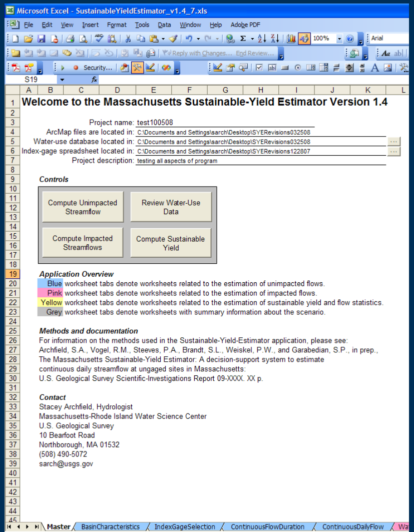
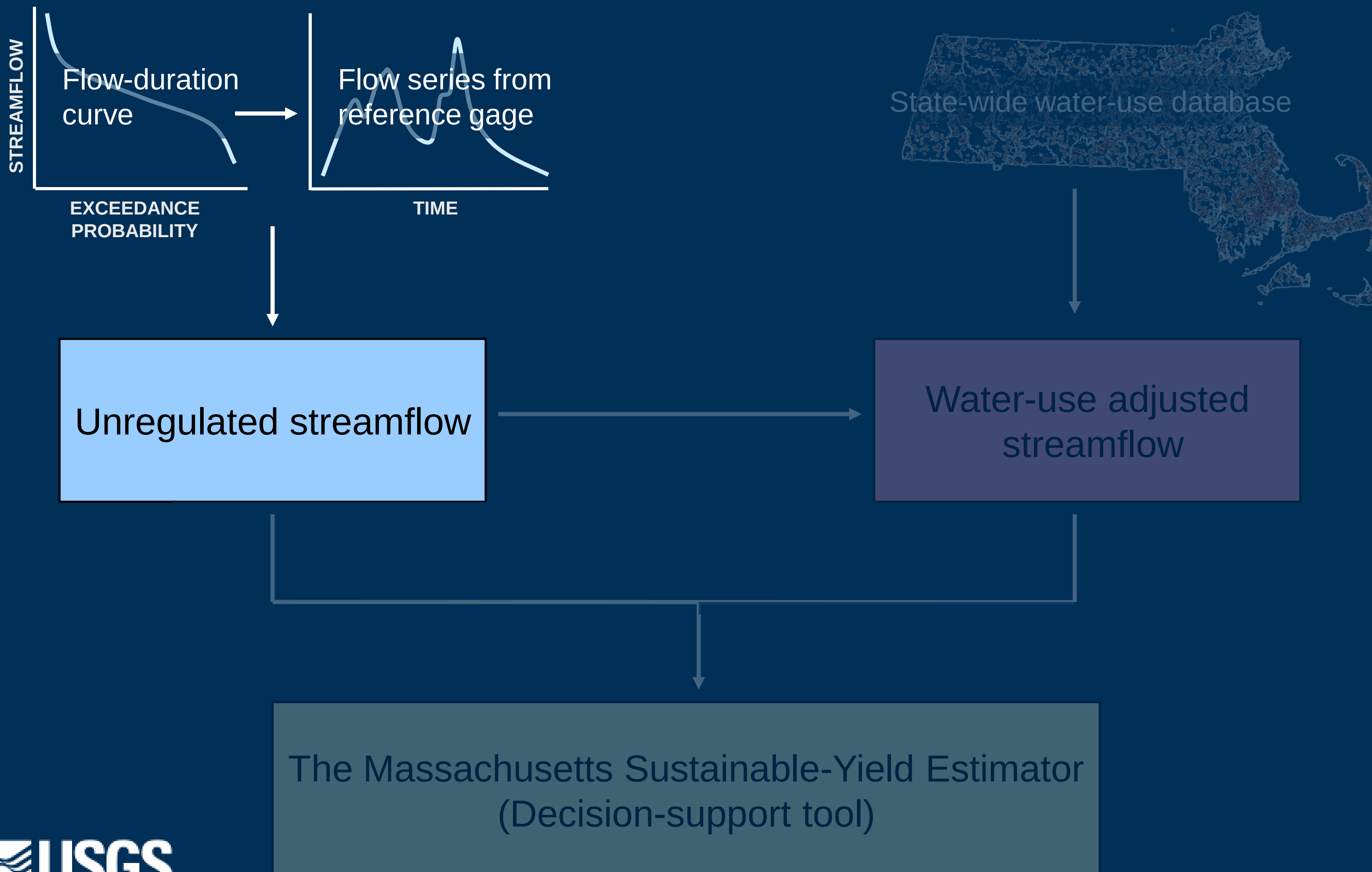


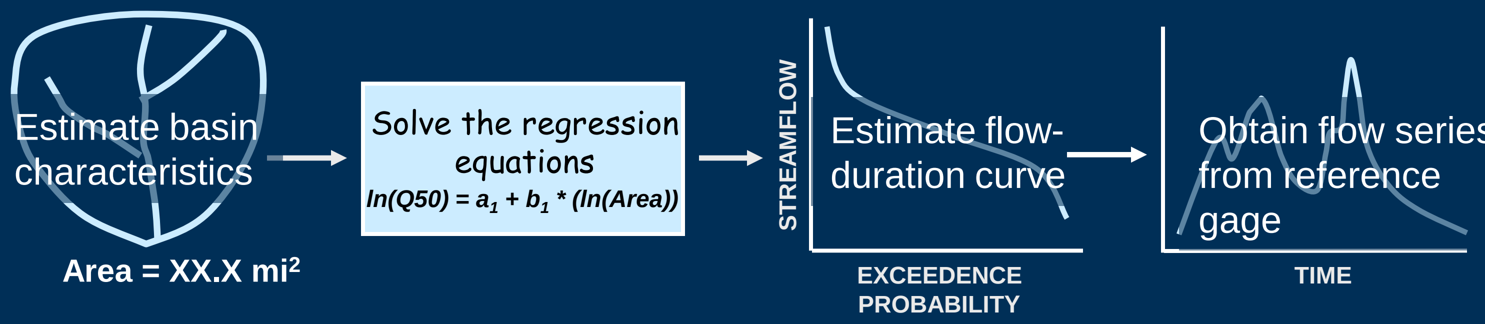
USGS

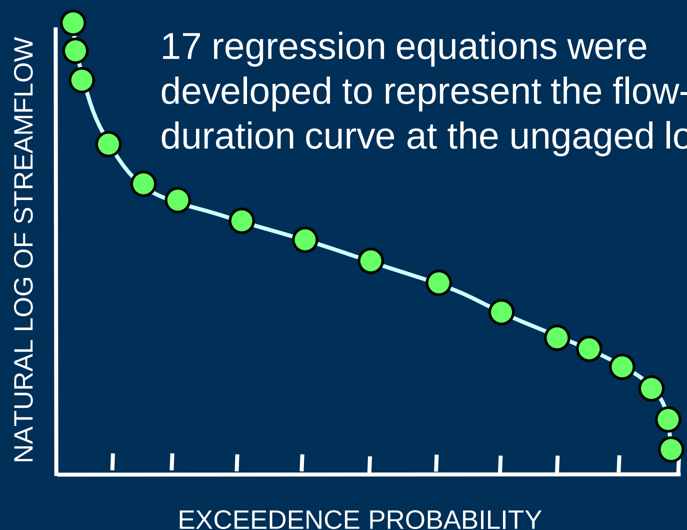
The Massachusetts Sustainable-Yield Estimator



USGS

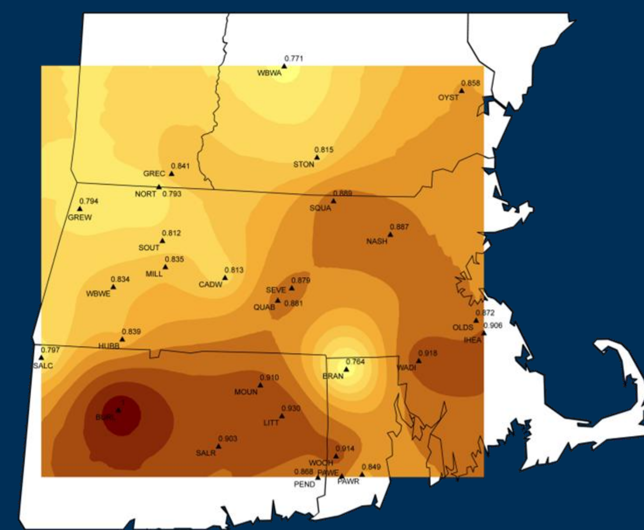
Estimating unregulated streamflow





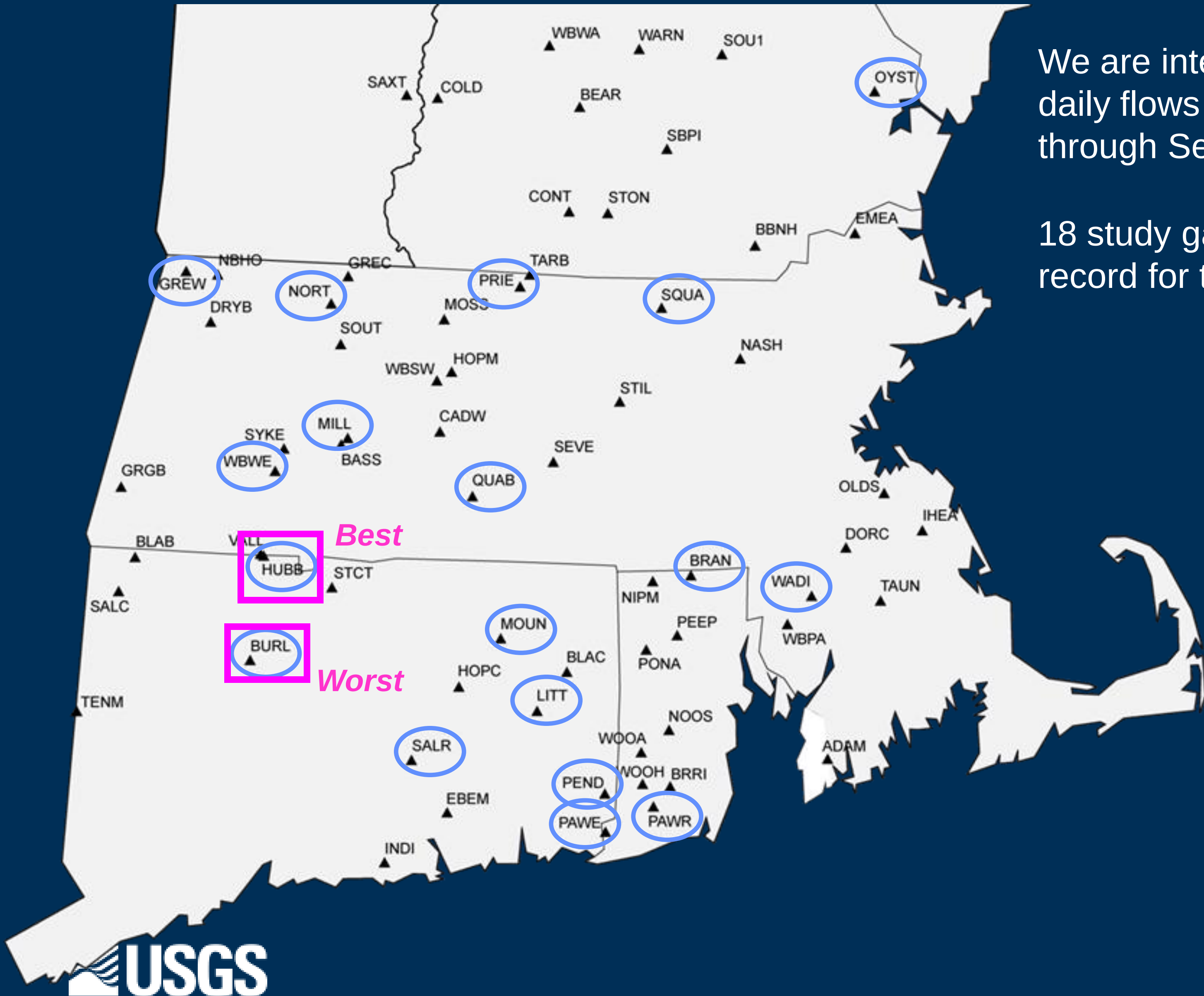
17 regression equations were developed to represent the flow-duration curve at the ungaged location

&



From Archfield and others (2010)

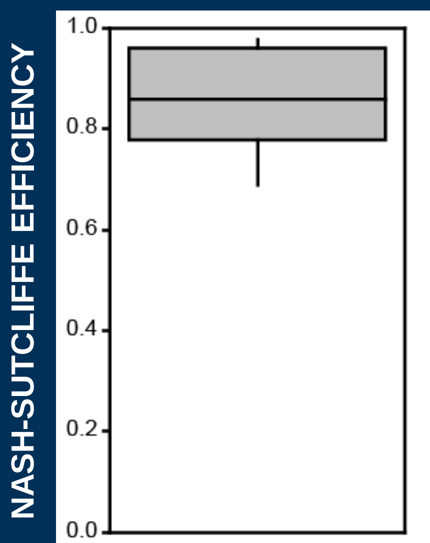
Cross-validation of results



We are interested in estimating daily flows from October 1,1960 through September 30, 2004.

18 study gages had observed record for this period.

ALL RESULTS

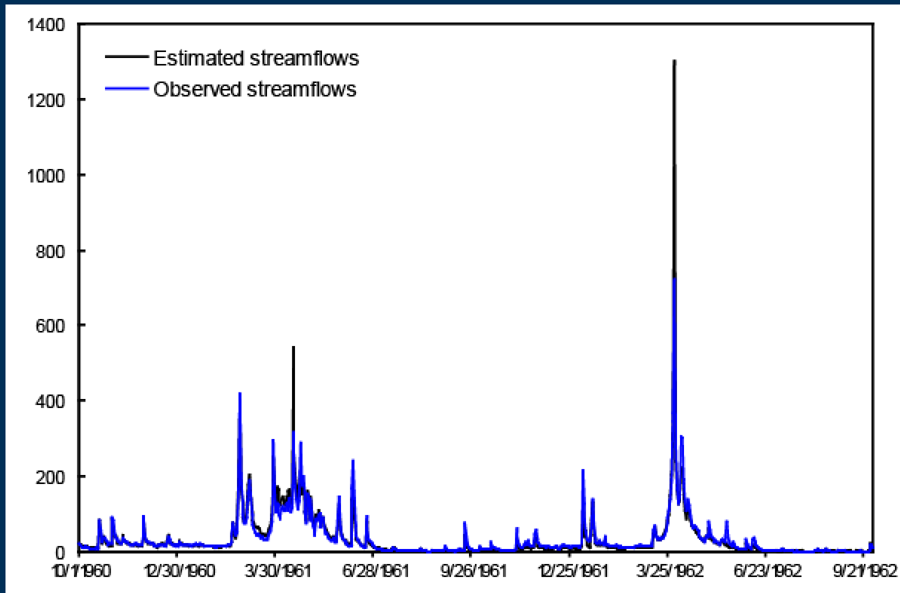


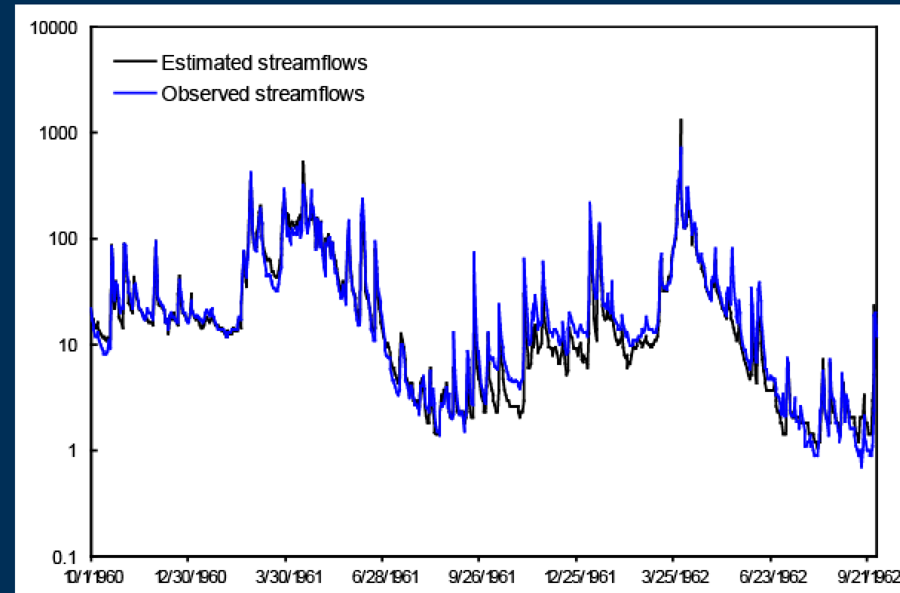
From Archfield and others (2010)

Observed and estimated streamflow (best and worst)

Hubbard River near West Hartland, CT (Best case)

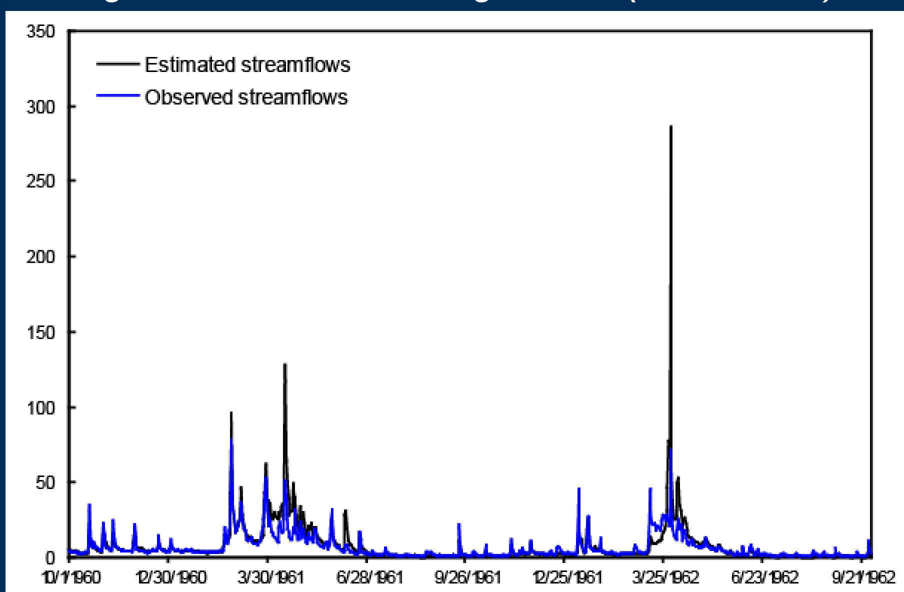
STREAMFLOW, IN CFS

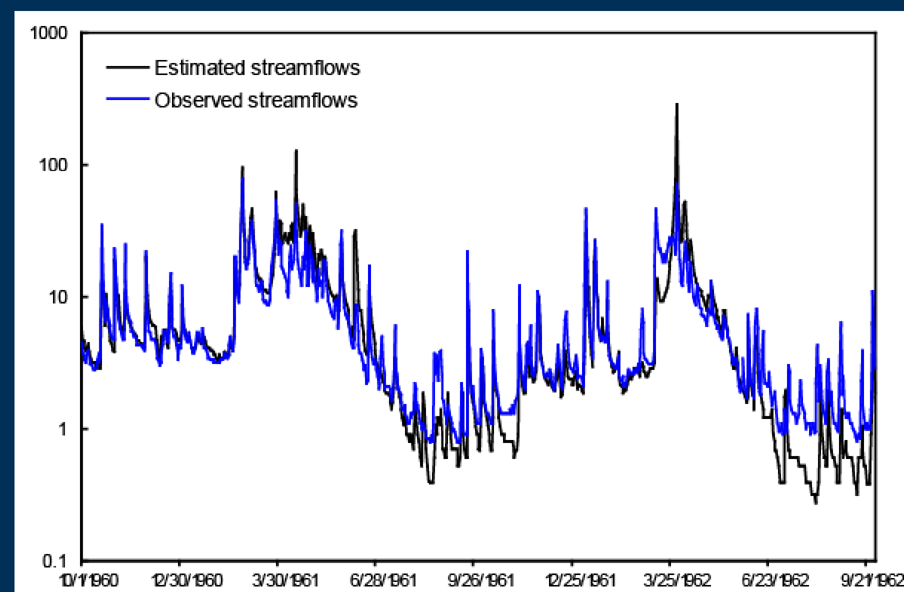




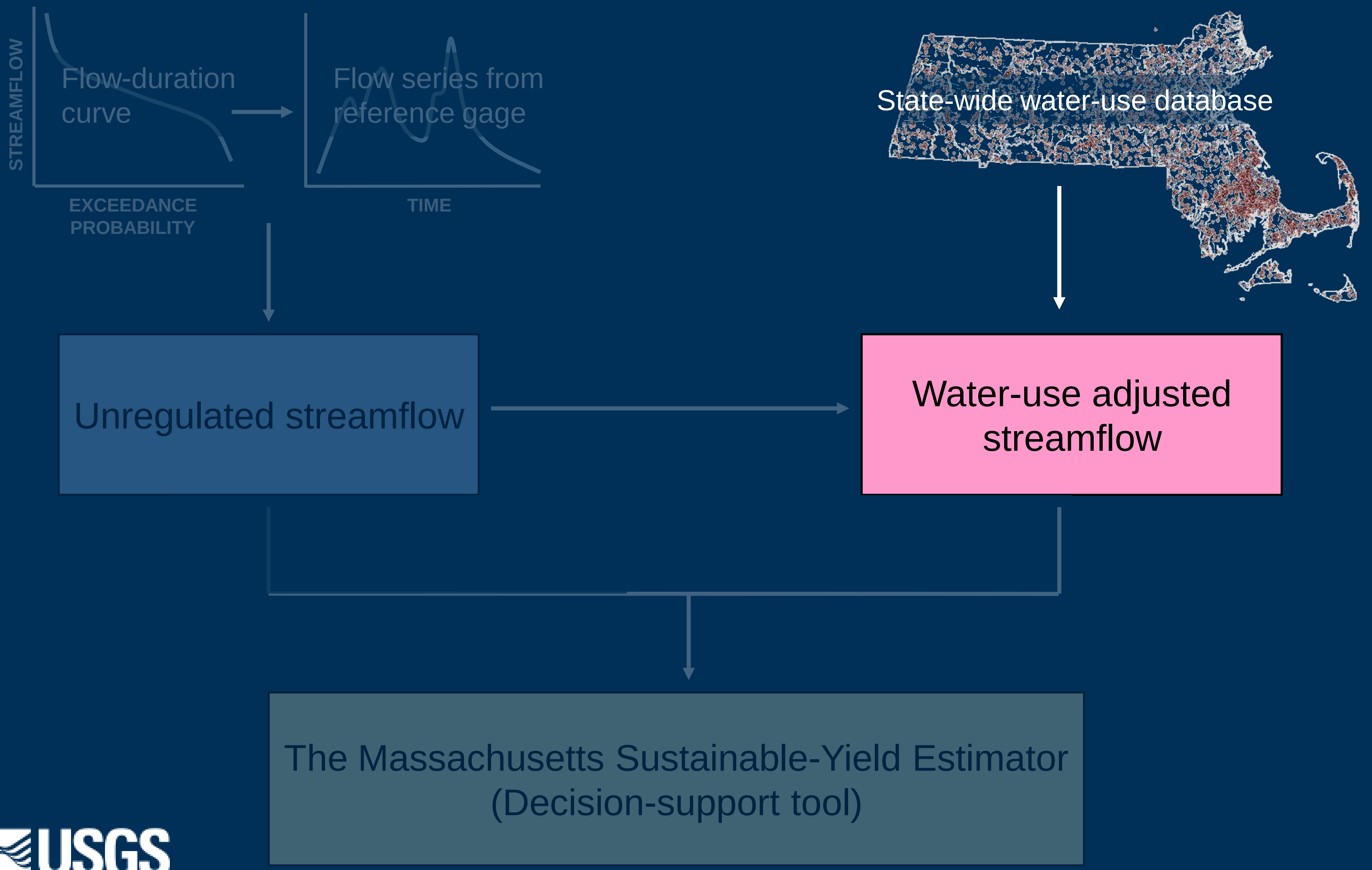
Burlington Brook near Burlington, CT (Worst case)

STREAMFLOW, IN CFS

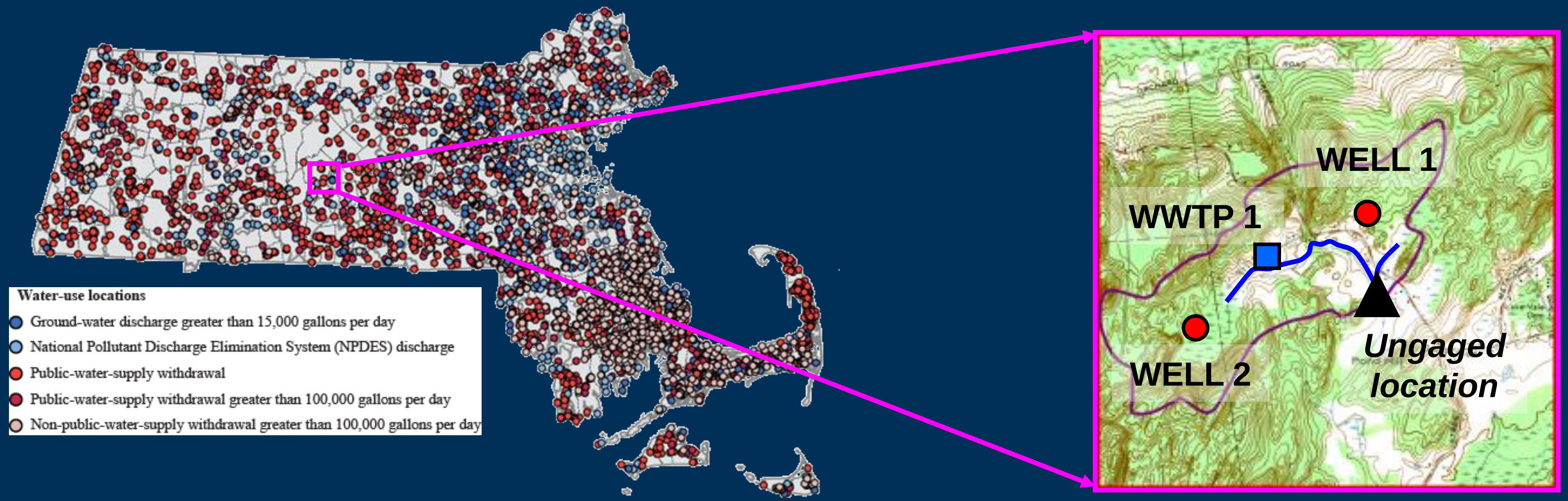




The Massachusetts Sustainable-Yield Estimator



Estimating regulated streamflow



$$
\begin{aligned}
\textit{Regulated streamflow}_t \;=\; & \textit{Unregulated streamflow}_t \\
& - \Sigma(\textit{Surface-water withdrawals}_t) \\
& - \Sigma(\textit{Ground-water withdrawals}_t) \\
& + \Sigma(\textit{Ground-water discharges}_t) \\
& + \Sigma(\textit{Return flows}_t)
\end{aligned}
$$

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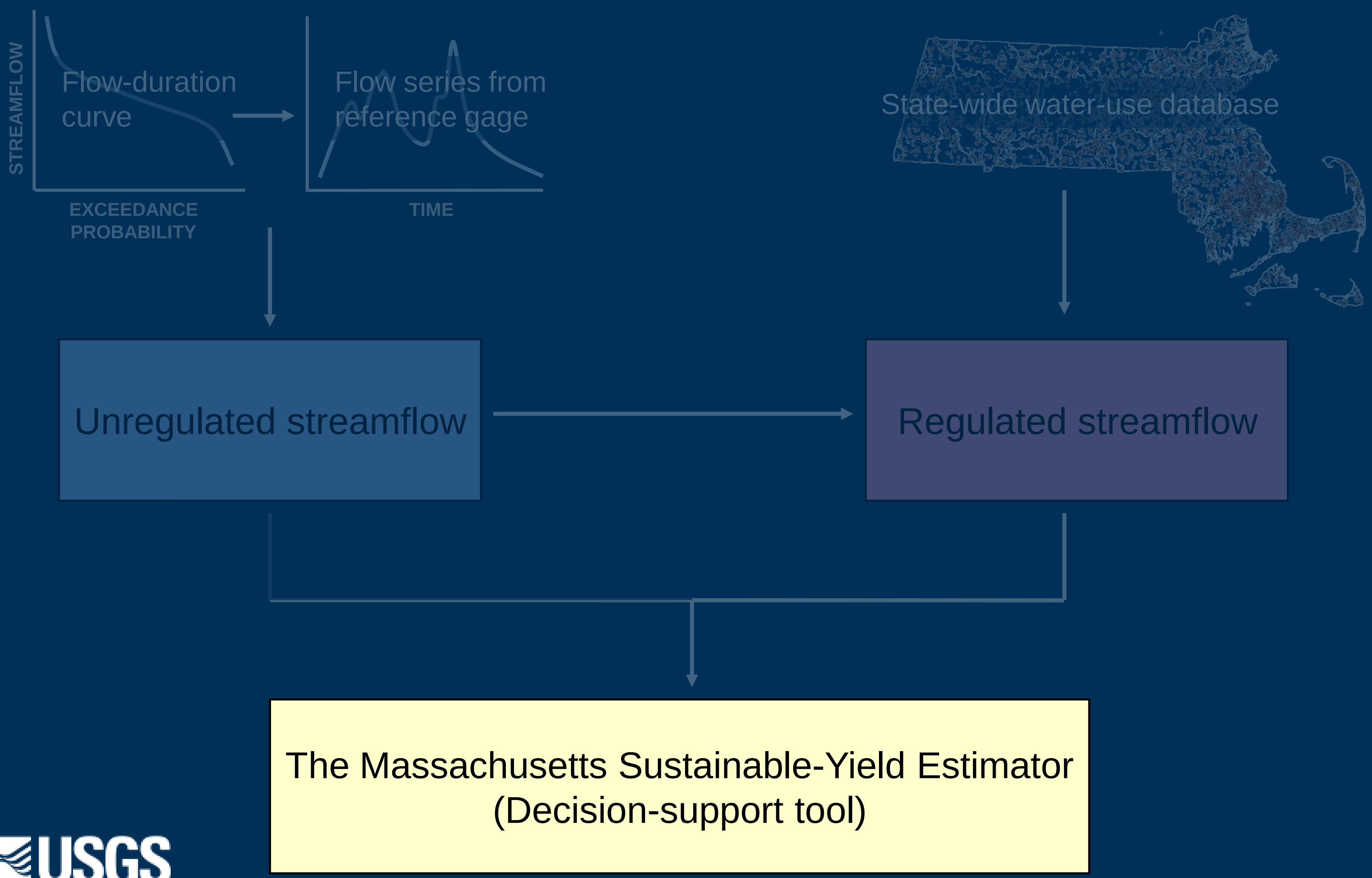
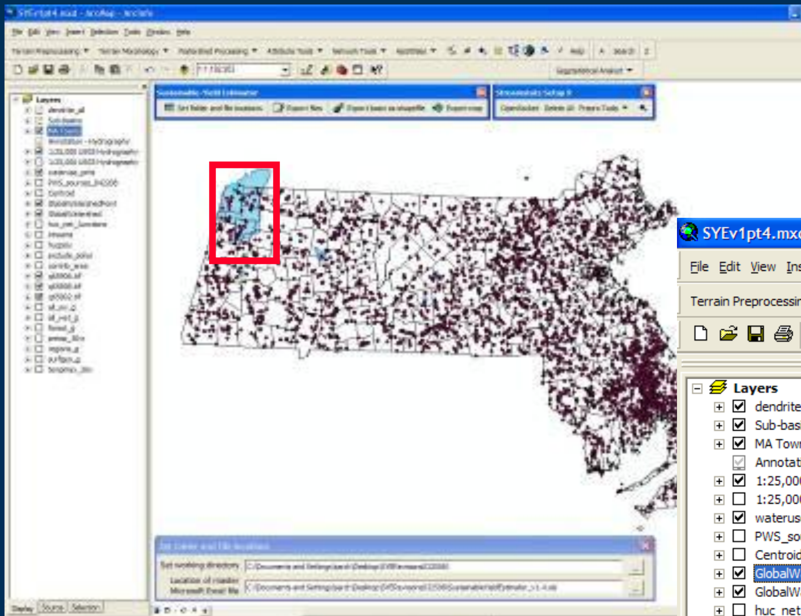
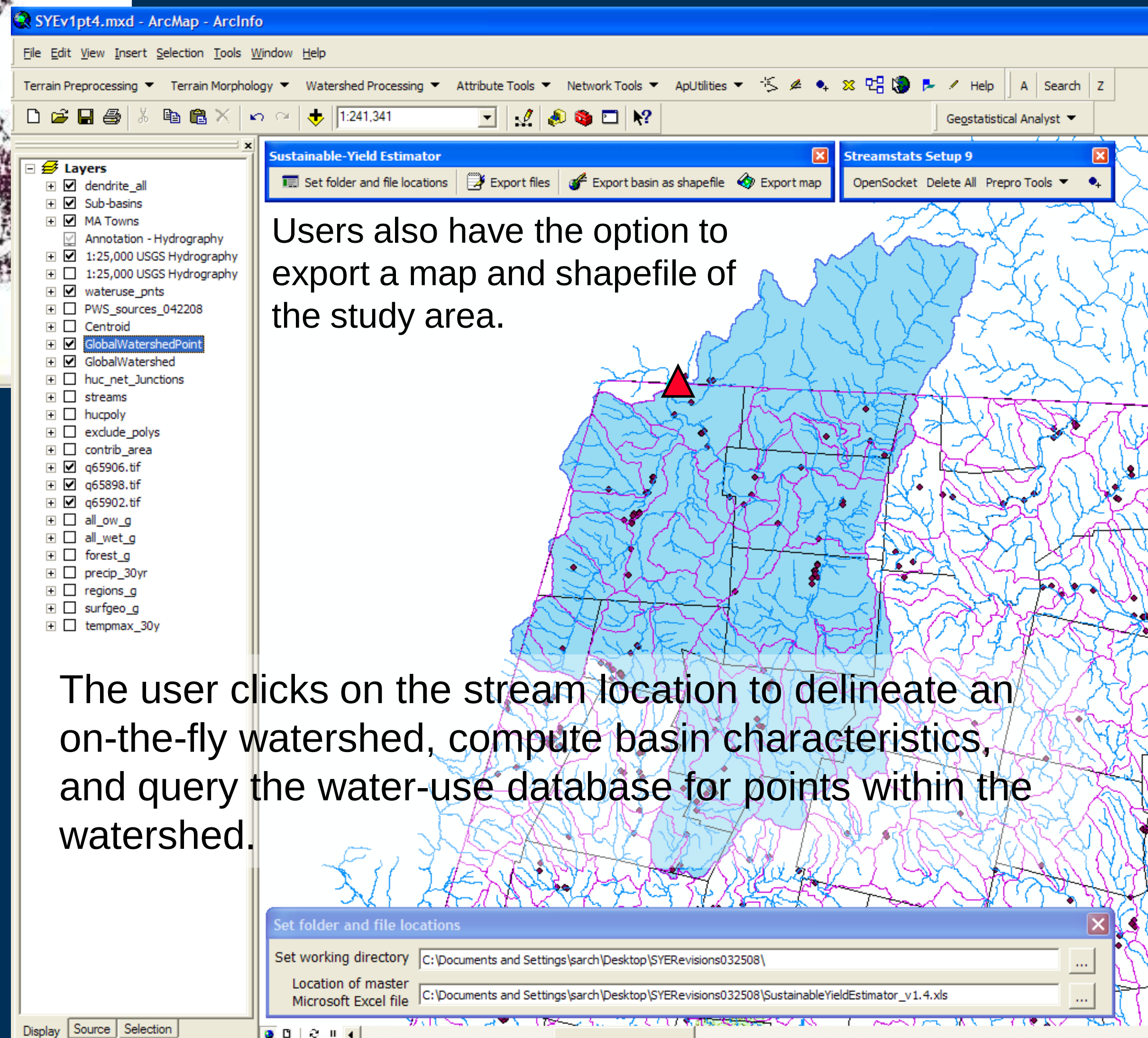


Point-and-click GIS user-interface



Users begin by opening an ESRI ArcMap document and locating the stream of interest.



Users also have the option to export a map and shapefile of the study area.

The user clicks on the stream location to delineate an on-the-fly watershed, compute basin characteristics, and query the water-use database for points within the watershed.

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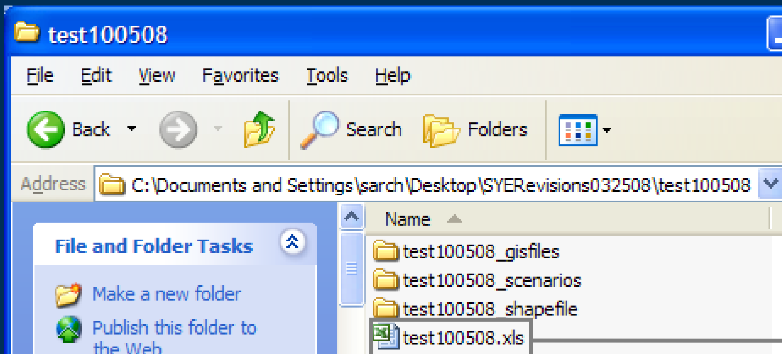
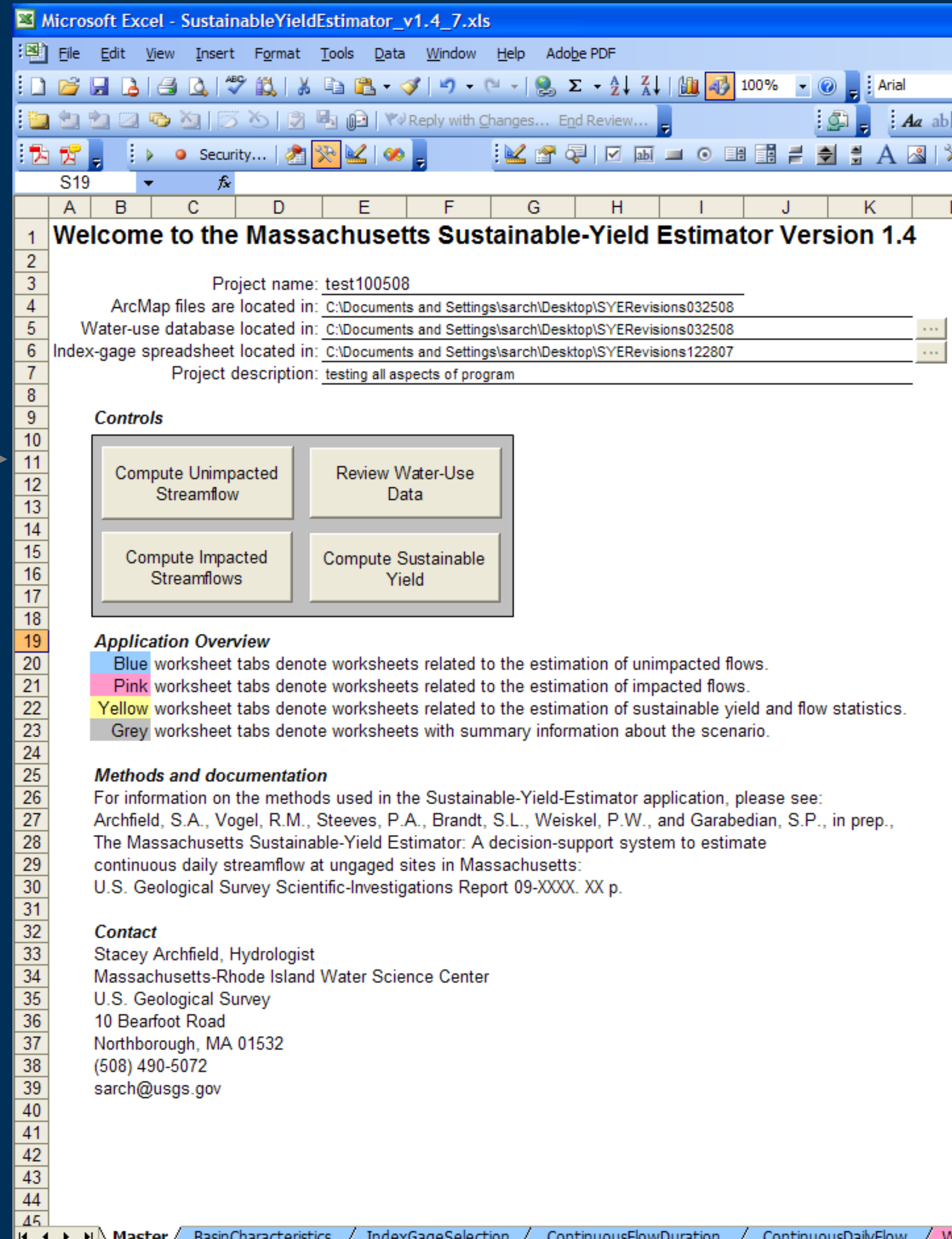
From Archfield and others (2010)

Navigating the tool



All relevant data is stored in a user-specified location and project folder.

A master Microsoft Excel file guides the user through the post-processing, graphing and reporting of the results.



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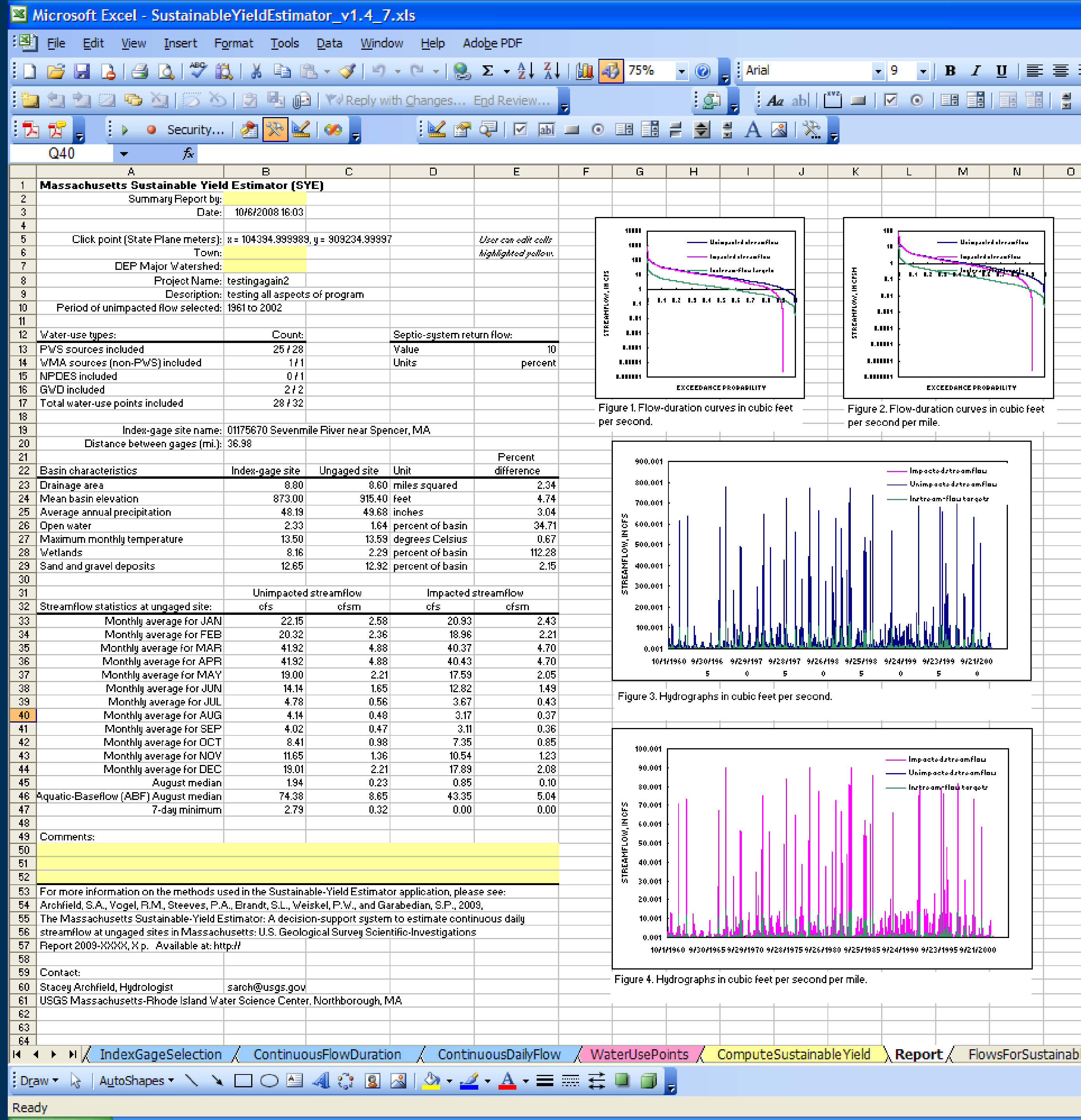
From Archfield and others (2010)

Results

Results are summarized for the user in a printable 2-page format.



Microsoft Excel - SustainableYieldEstimator_v1.4_7.xls

Massachusetts Sustainable Yield Estimator (SYE)				
Summary Report by:				
Date:	10/6/2008 16:03			
Click point (State Plane meters):	x = 104394.999989, y = 909234.99997			*User can edit cells highlighted yellow.*
Town:				
DEP Major Watershed:				
Project Name:	testingagain2			
Description:	testing all aspects of program			
Period of unimpacted flow selected:	1961 to 2002			
Water-use types:	Count:		Septic-system return flow:	
PWS sources included	25 / 28		Value	10
WMA sources (non-PWS) included	1 / 1		Units	percent
NPDES included	0 / 1			
GWD included	2 / 2			
Total water-use points included	28 / 32			
Index-gage site name:	01175670 Sevenmile River near Spencer, MA			
Distance between gages (mi.):	36.98			
Basin characteristics	Index-gage site	Ungaged site	Unit	Percent difference
Drainage area	8.80	8.60	miles squared	2.34
Mean basin elevation	873.00	915.40	feet	4.74
Average annual precipitation	48.19	49.68	inches	3.04
Open water	2.33	1.64	percent of basin	34.71
Maximum monthly temperature	13.50	13.59	degrees Celsius	0.67
Wetlands	8.16	2.29	percent of basin	112.28
Sand and gravel deposits	12.65	12.92	percent of basin	2.15
	Unimpacted streamflow		Impacted streamflow	
Streamflow statistics at ungaged site:	cfs	cfsm	cfs	cfsm
Monthly average for JAN	22.15	2.58	20.93	2.43
Monthly average for FEB	20.32	2.36	18.96	2.21
Monthly average for MAR	41.92	4.88	40.37	4.70
Monthly average for APR	41.92	4.88	40.43	4.70
Monthly average for MAY	19.00	2.21	17.59	2.05
Monthly average for JUN	14.14	1.65	12.82	1.49
Monthly average for JUL	4.78	0.56	3.67	0.43
Monthly average for AUG	4.14	0.48	3.17	0.37
Monthly average for SEP	4.02	0.47	3.11	0.36
Monthly average for OCT	8.41	0.98	7.35	0.85
Monthly average for NOV	11.65	1.36	10.54	1.23
Monthly average for DEC	19.01	2.21	17.89	2.08
August median	1.94	0.23	0.85	0.10
Aquatic-Baseflow (ABF) August median	74.38	8.65	43.35	5.04
7-day minimum	2.79	0.32	0.00	0.00

Comments:

For more information on the methods used in the Sustainable-Yield Estimator application, please see:
Archfield, S.A., Vogel, R.M., Steeves, P.A., Brandt, S.L., Weiskel, P.W., and Garabedian, S.P., 2009, The Massachusetts Sustainable-Yield Estimator: A decision-support system to estimate continuous daily streamflow at ungaged sites in Massachusetts: U.S. Geological Survey Scientific-Investigations Report 2009-XXXX, X p. Available at: http://

Contact:
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USGS Massachusetts-Rhode Island Water Science Center, Northborough, MA

Figure 1. Flow-duration curves in cubic feet per second.

Figure 2. Flow-duration curves in cubic feet per second per mile.

Figure 3. Hydrographs in cubic feet per second.

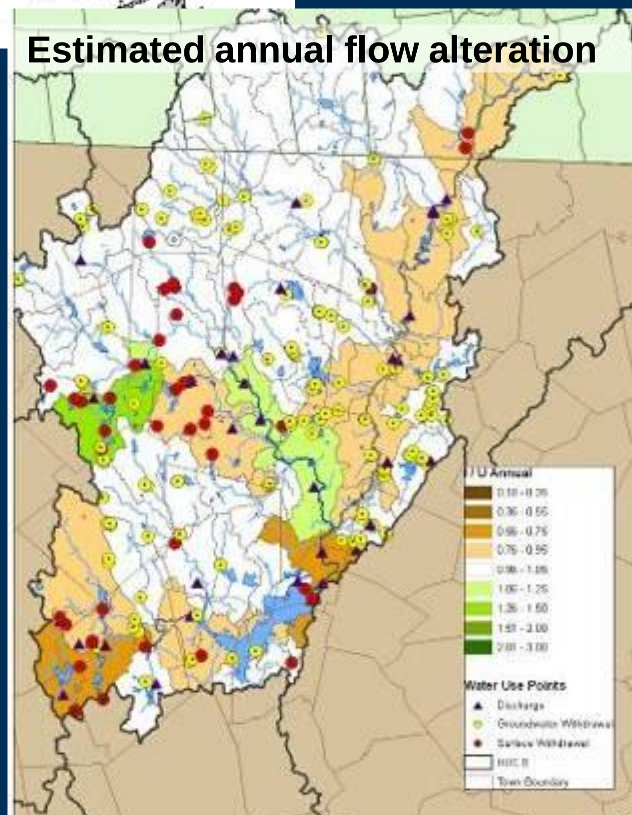
Figure 4. Hydrographs in cubic feet per second per mile.

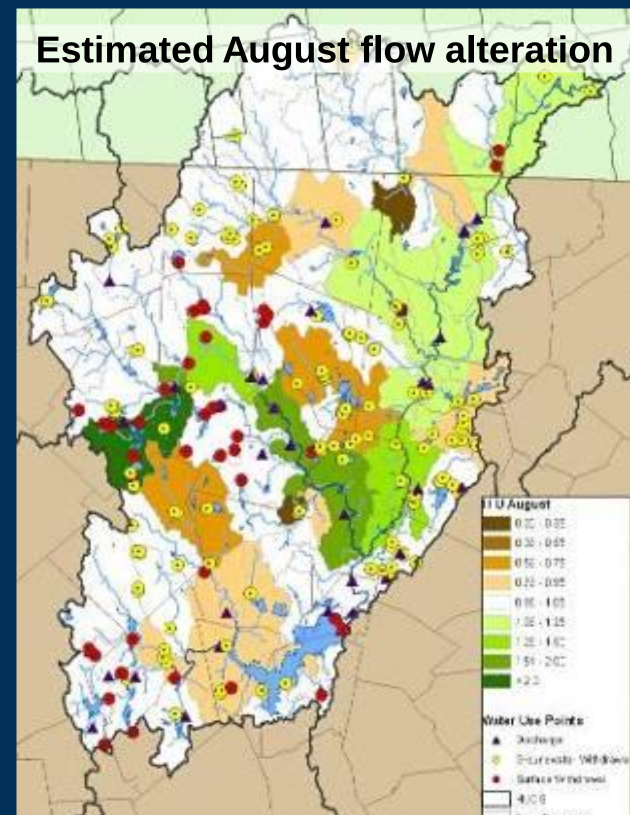
USGS

From Archfield and others (2010)

Application: *Mapping streamflow alteration and water availability*

Weiskel, P.K., Brandt, S.L., DeSimone, L.A., Ostiguy, L.J., and Archfield, S.A., 2010, Indicators of streamflow alteration, habitat fragmentation, impervious cover, and water quality for Massachusetts stream basins, USGS Scientific Investigations Report, 2009-5272





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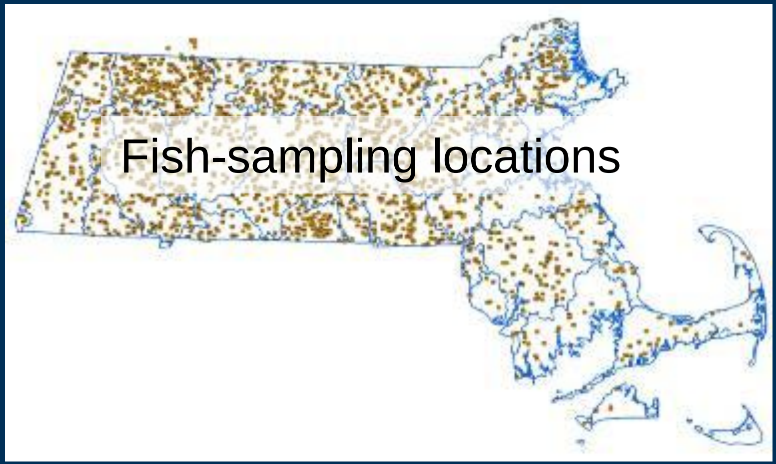
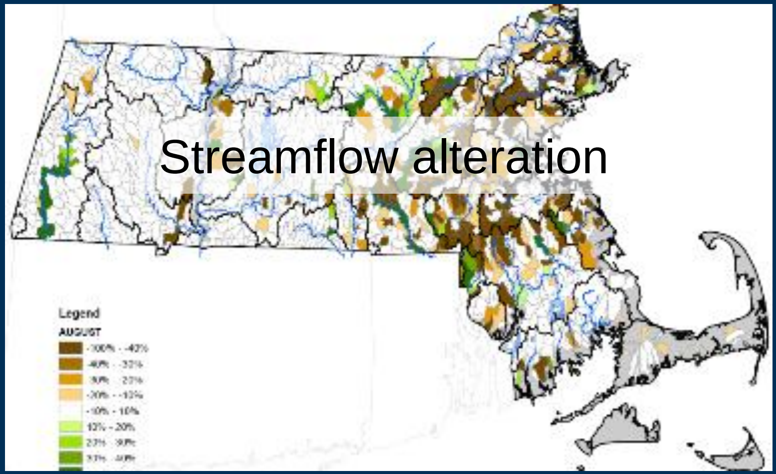
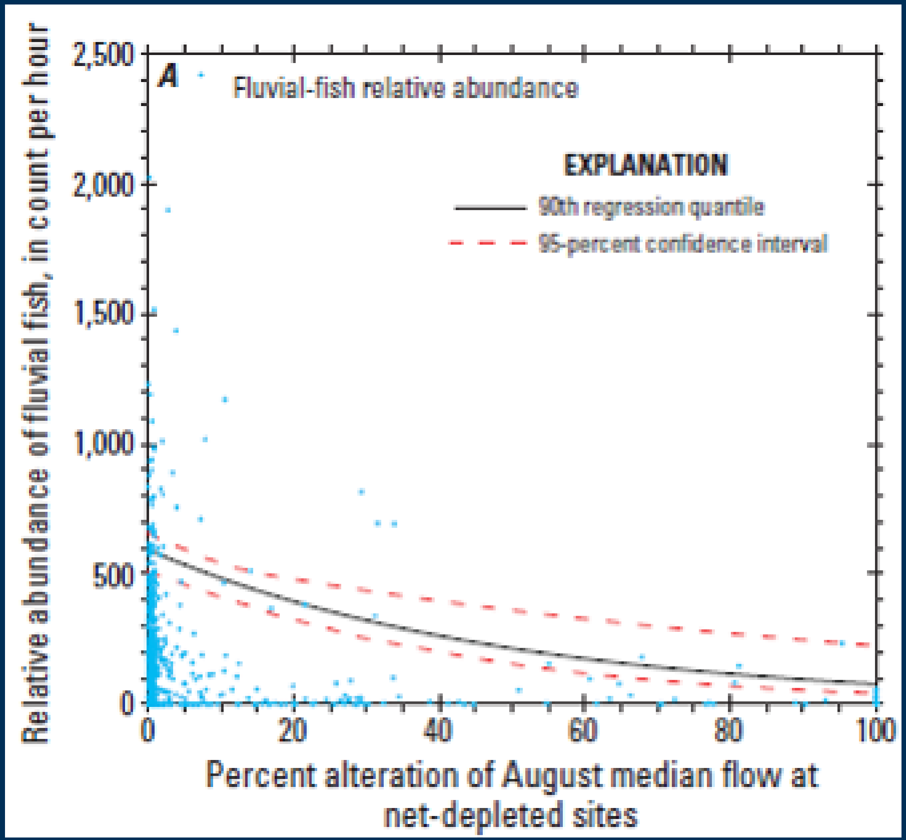
In cooperation with: Massachusetts Department of Conservation and Recreation

Application: *Relating streamflow alteration to fish data*

Armstrong, D.S., Richards, T.A., and Brandt, S.L., 2010, Preliminary assessment of factors influencing riverine fish communities in Massachusetts: U.S. Geological Survey Open-File Report 2010–1139, 43 p.







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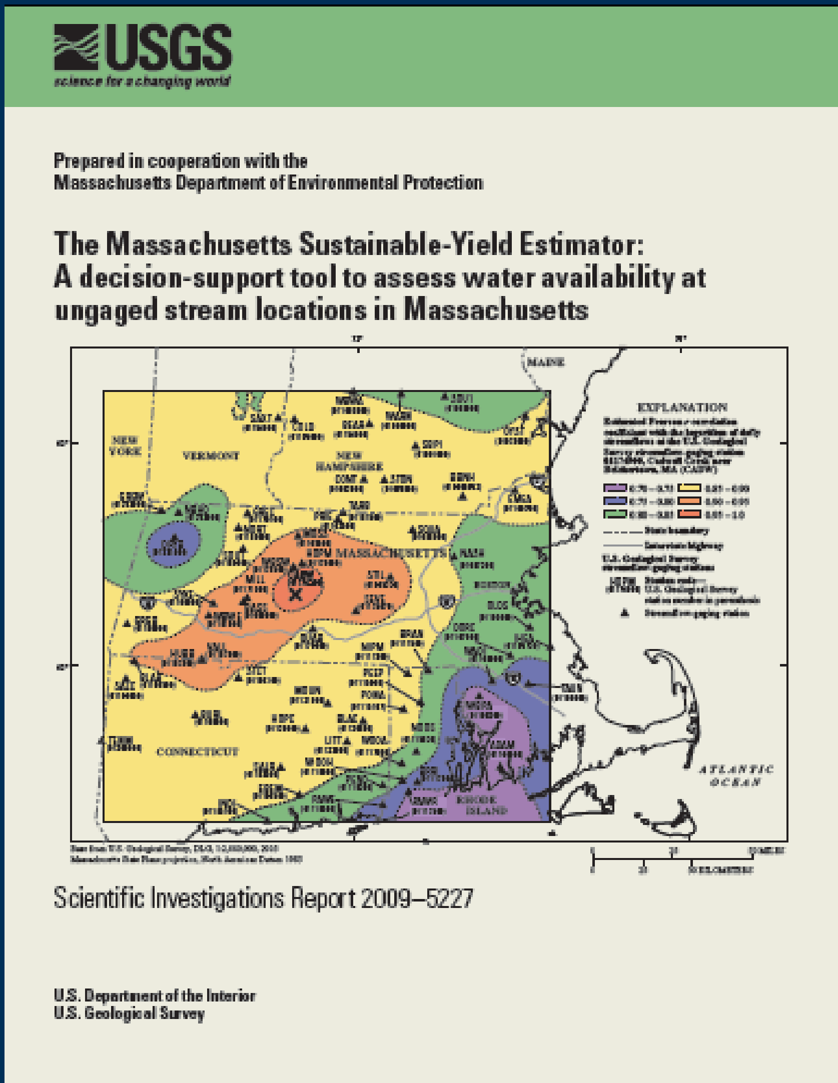
In cooperation with: Massachusetts Department of Conservation and Recreation, the Massachusetts Department of Environmental Protection, and the Massachusetts Department of Fish and Game

Application: *Regional daily, unregulated streamflows*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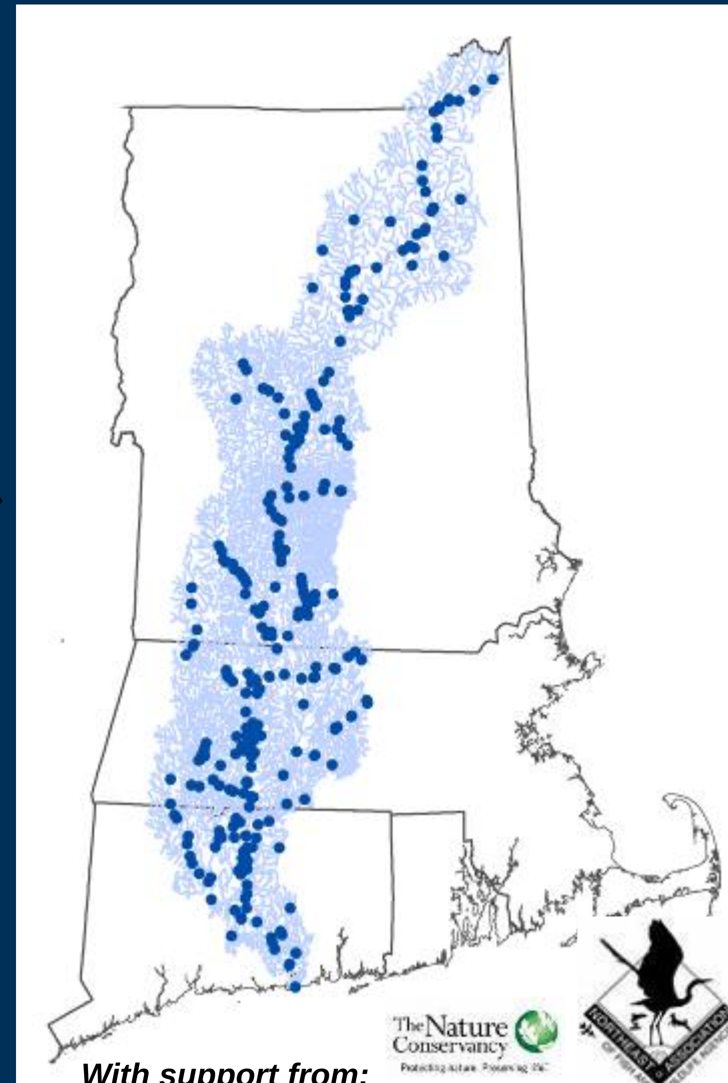
science for a changing world

Prepared in cooperation with the
Massachusetts Department of Environmental Protection

The Massachusetts Sustainable-Yield Estimator:
A decision-support tool to assess water availability at ungaged stream locations in Massachusetts

Scientific Investigations Report 2009–5227

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



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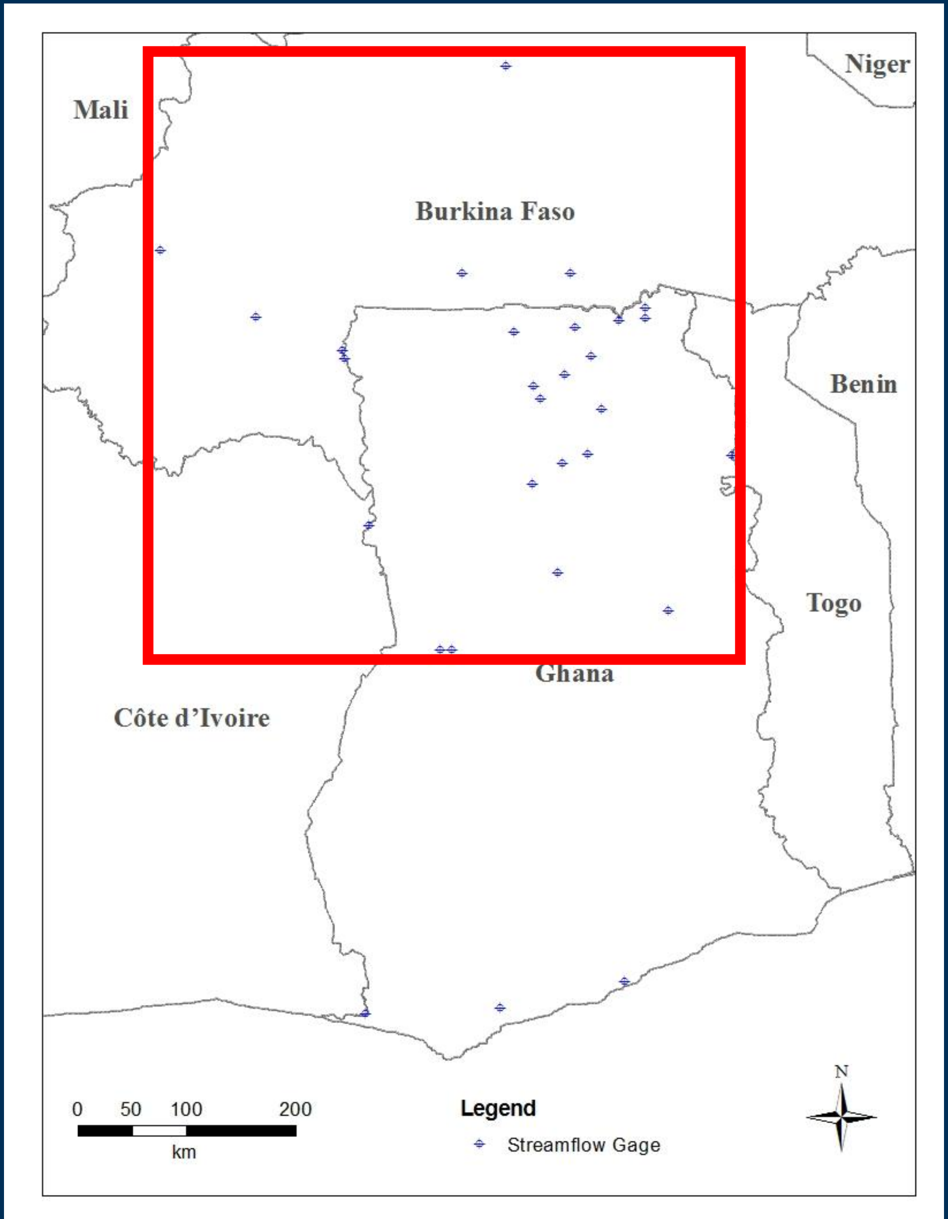
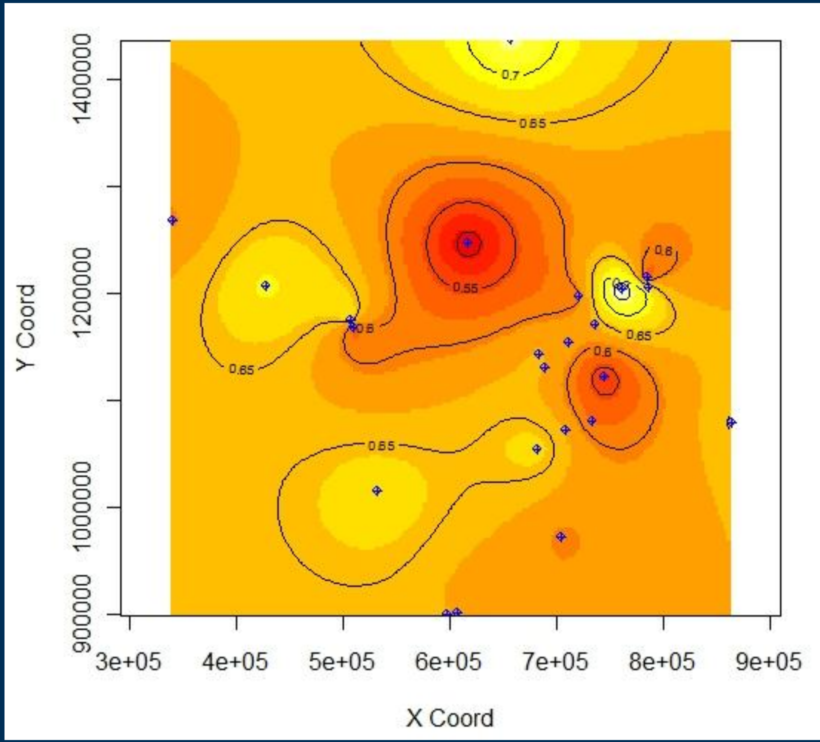
Application: *Use of map correlation in Ghana, West Africa*





Y. Gao, S. Archfield, and R. Vogel "Estimation of Daily Streamflow Series at Ungaged Sites in the Semi-arid Volta Basin of West Africa"

Map correlation: Limitations and future research

- The map-correlation method has potential application to many hydrologic problems, including: calibration of hydrologic models, evaluation of streamgage networks and catchment classification

- Correlation can also provide an uncertainty measure for the estimated streamflows; distance does not.

- The density of the streamgage network and period of record used to estimate correlation have not yet been evaluated, although in the limit (few streamgages with short non-coincident periods of record), this would surely pose a severe limit on the applicability of the method.

- The method has only been tested in a few study areas; future work is examining the utility of map correlation for other study areas

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