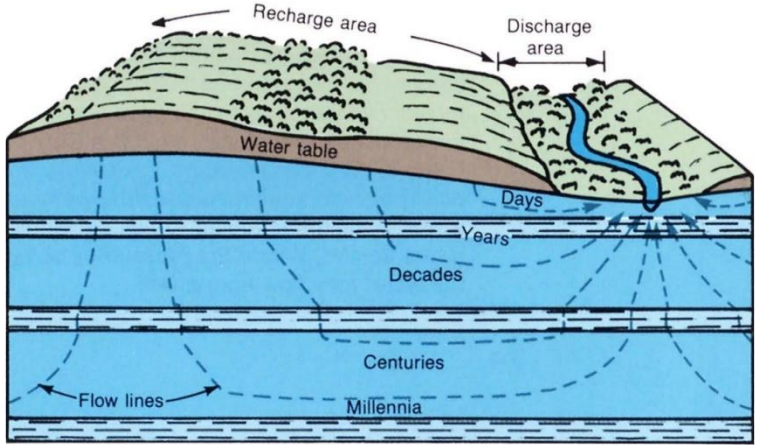








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Beneath the Basin: Advances in Groundwater Availability Modeling for the Delaware River Basin

Michael Thompson, P.E.

November 11, 2026

AWRA 2026 Annual Water Resources Conference

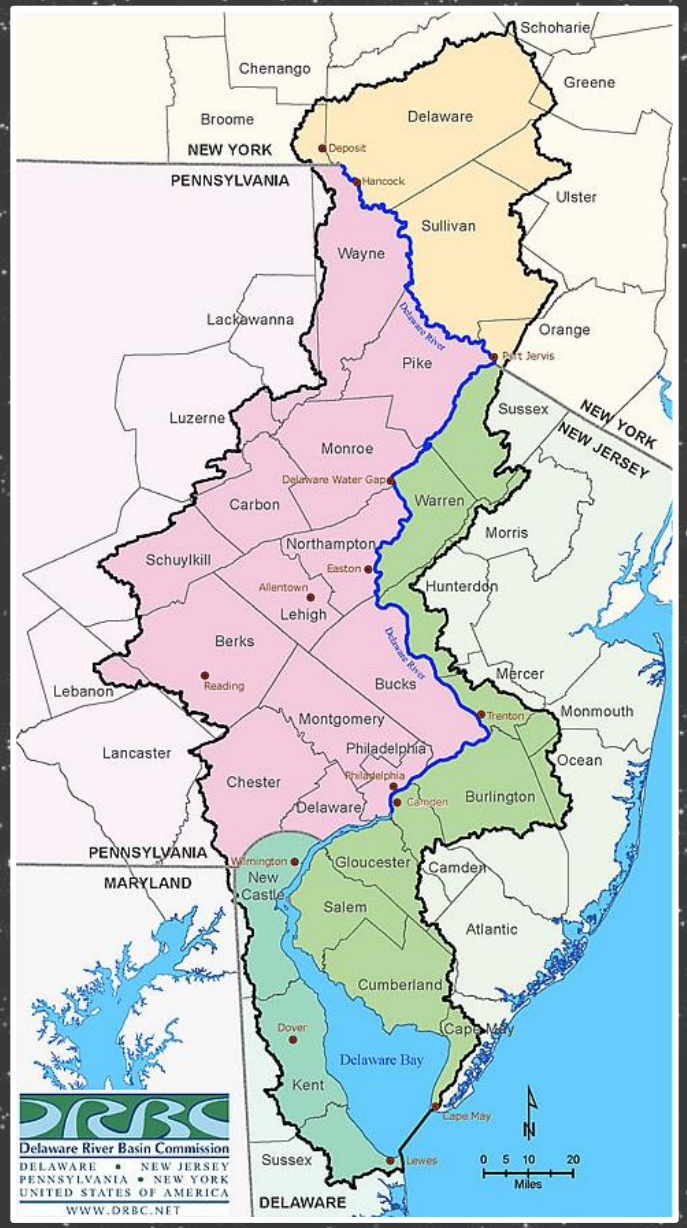
About the speaker



Michael Thompson is a Senior Water Resource Engineer at the Delaware River Basin Commission (DRBC). He joined the Commission in 2018 and has led numerous research projects and authored publications which provide key insight into the region's water resource management. His work is focused on sustainable water use planning for the Basin, which includes but is not limited to hydrology, groundwater and surface water availability modelling, withdrawal data analysis, as well as water audits and water loss conservation. He received a B.S. in Civil Engineering from Lafayette College, an M.S.C.E. from the University of Notre Dame, and is a licensed professional engineer in Pennsylvania.

Delaware River Basin

- 330 miles long
- interstate boundary
- un-dammed
- 13,539 square miles
- 8.6 million people live here (2020)
- ½ of New York City's water supply
- 6.2 billion gal/day withdrawn (2024)
- Cools 102 TWh of energy (2024)



Delaware River Basin
13,500 square miles
8.6 million people



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What is the Delaware River Basin Commission?



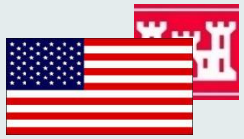
Established by interstate compact in 1961, a regional body with the force of law to oversee a unified approach to managing a river system without regard to political boundaries.


Delaware


New Jersey


New York


Pennsylvania


Federal Gov't (USACE)



"provide trusted, effective and coordinated management of our Basin's shared water resources."

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Groundwater availability (concepts)



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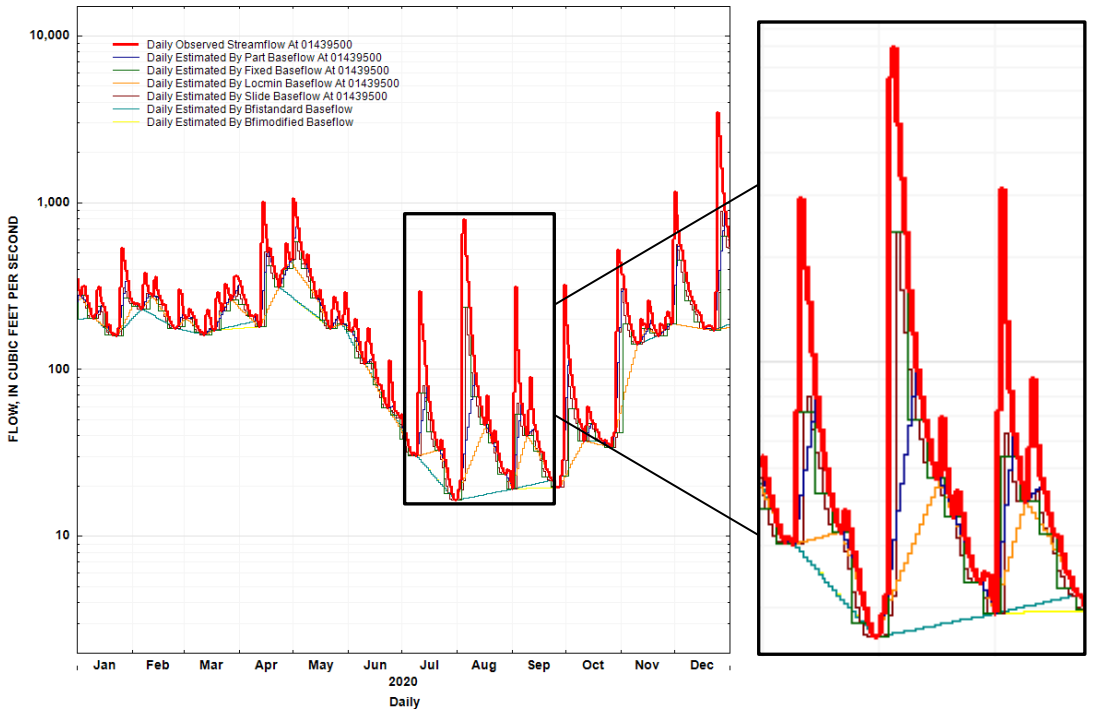
Groundwater baseflow

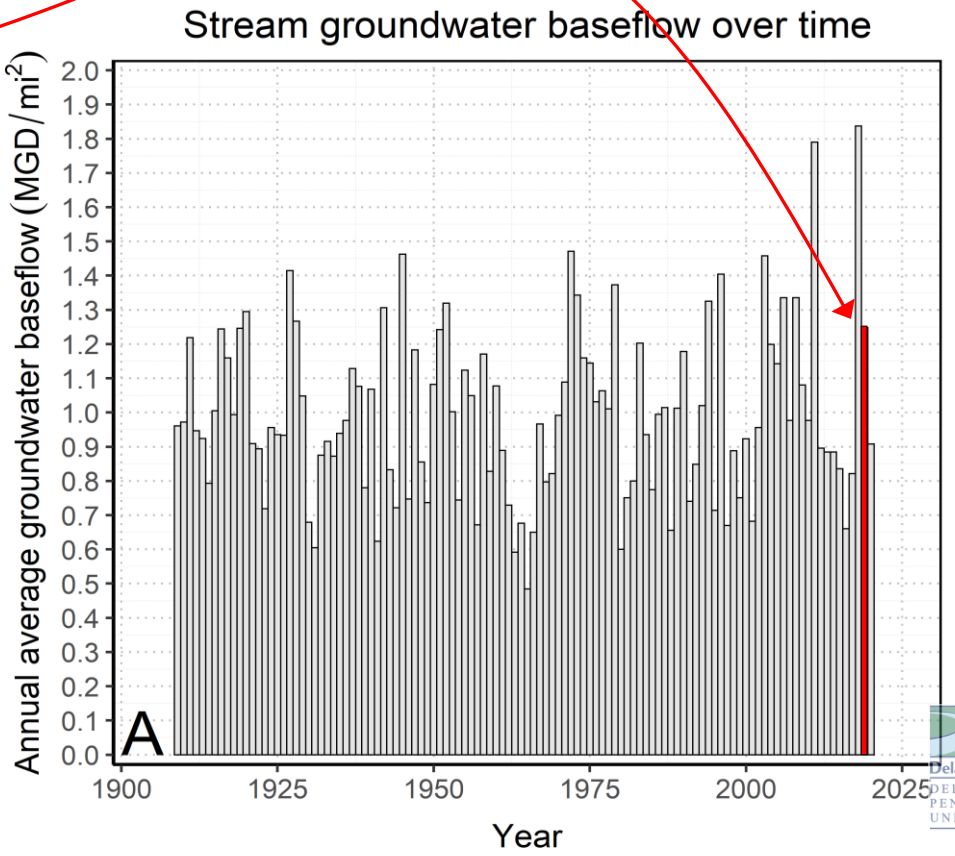
Baseflow Separation

Bush Kill at Shoemakers, PA

CY2020

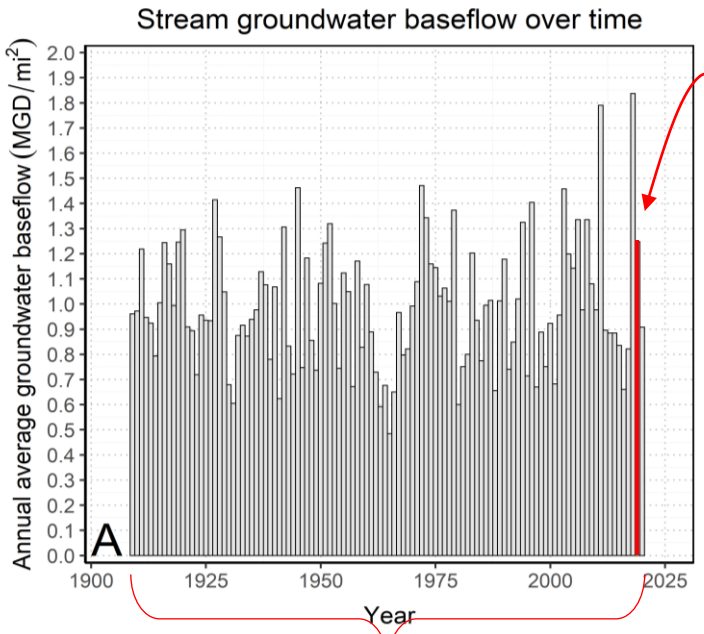
Average = 0.909 MGD/mi^2





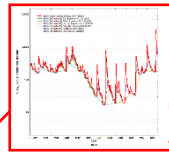
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Recurrence interval



n = 112 data points

Recall



Baseflow Separation
Bush Kill at Shoemakers, PA
CY2020
Average = 0.909 MGD/mi²

0.909 MGD/mi² is the 44th lowest

Weibull plotting position: $P_i = \frac{i}{n+1}$

Where is P_i is the calculated probability for the i^{th} ranked observation, given n total observations.

$$P_i = \frac{44}{112+1} = 0.389$$

Recurrence interval: $T = \frac{1}{P}$

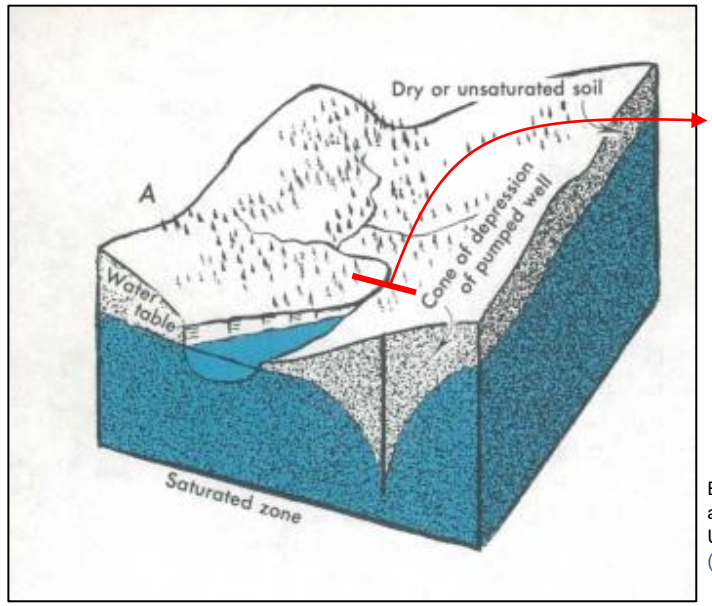
Where T is the recurrence interval (in years) for a specific baseflow, and P is the probability that this baseflow value will not be exceeded in a given year.

$$T = \frac{1}{0.389} = 2.57\ years$$

Annual Groundwater availability = **Annual net GW withdrawal (MG)** / **Annual baseflow (MG) (at 25-year and 50-year RI)**

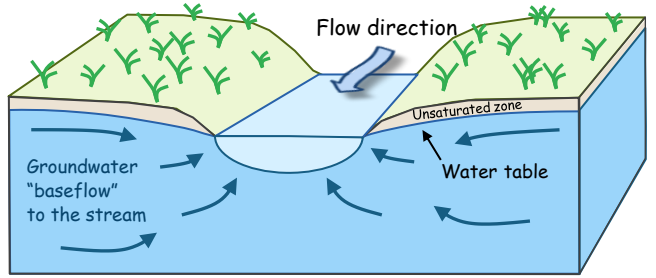
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Groundwater availability

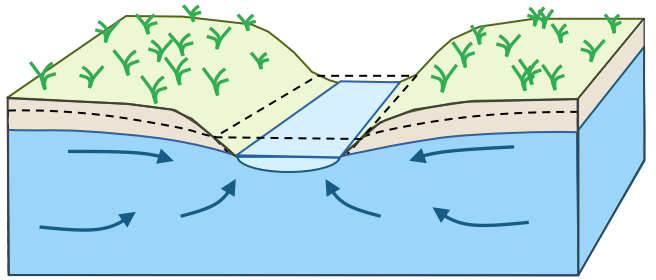


Look at a cross-section

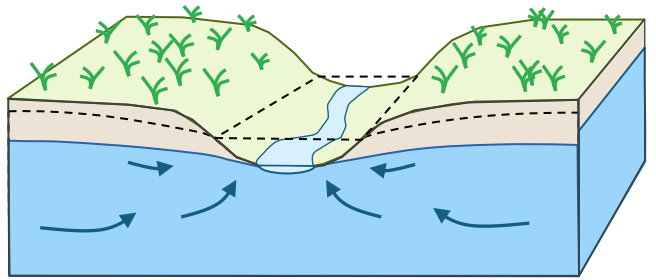
Effect on local water table of pumping a well. Adopted from the 1960 USGS report "*A Primer on Water*". (Leopold & Langbein, 1960)



"Regular" groundwater flow
(e.g. every other year)
"Normal" groundwater levels
2-year recurrence interval



"Dry" conditions
(e.g. once every 25 years)
Lower groundwater
25-year recurrence interval



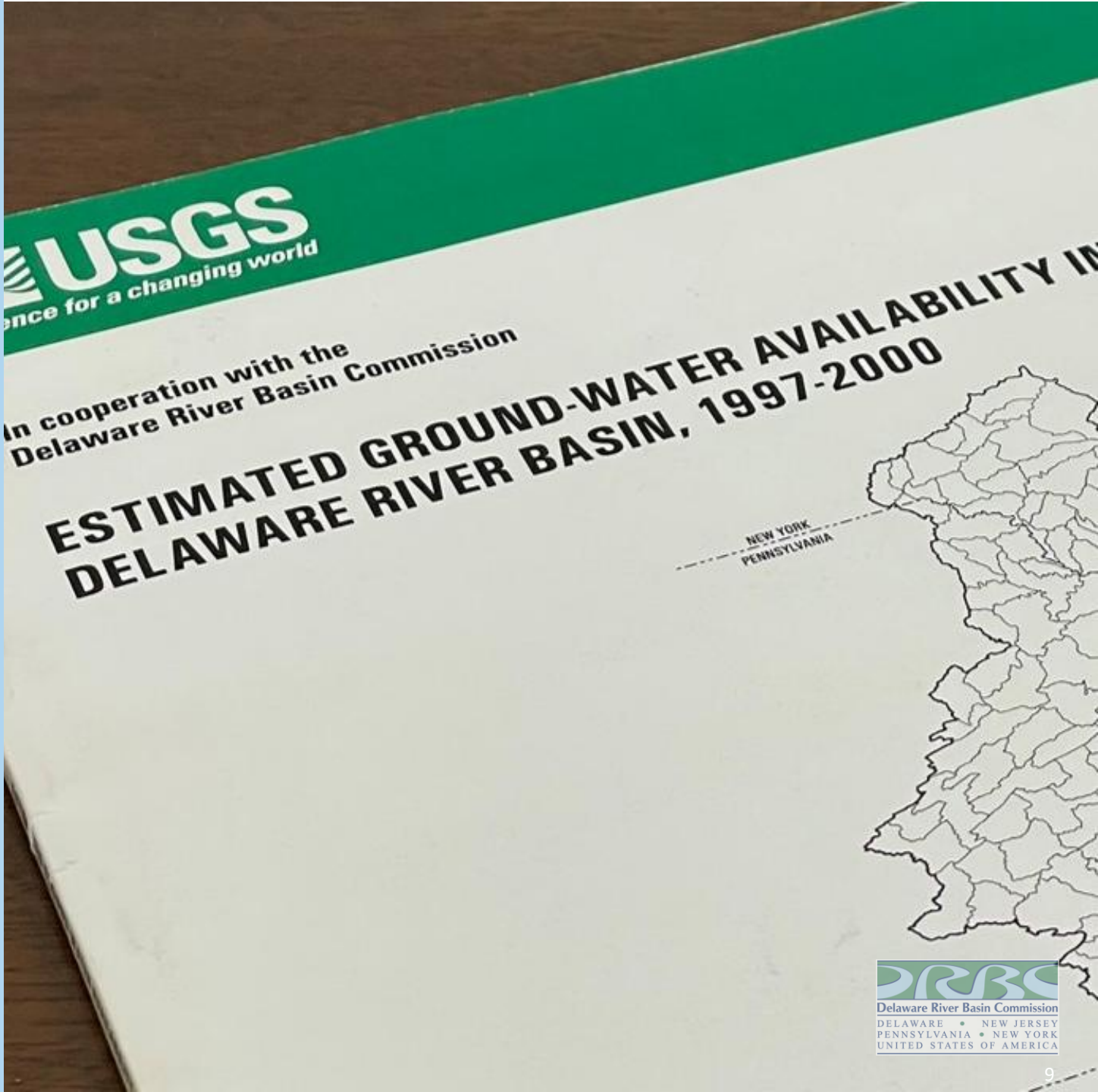
"Very Dry" conditions
(e.g. once every 50 years)
Even lower groundwater
50-year recurrence interval

$$\text{Annual Groundwater availability} = \frac{\text{Annual net GW withdrawal (MG)}}{\text{Annual baseflow (MG) (at 25-year and 50-year RI)}}$$

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Sloto & Buxton, 2006

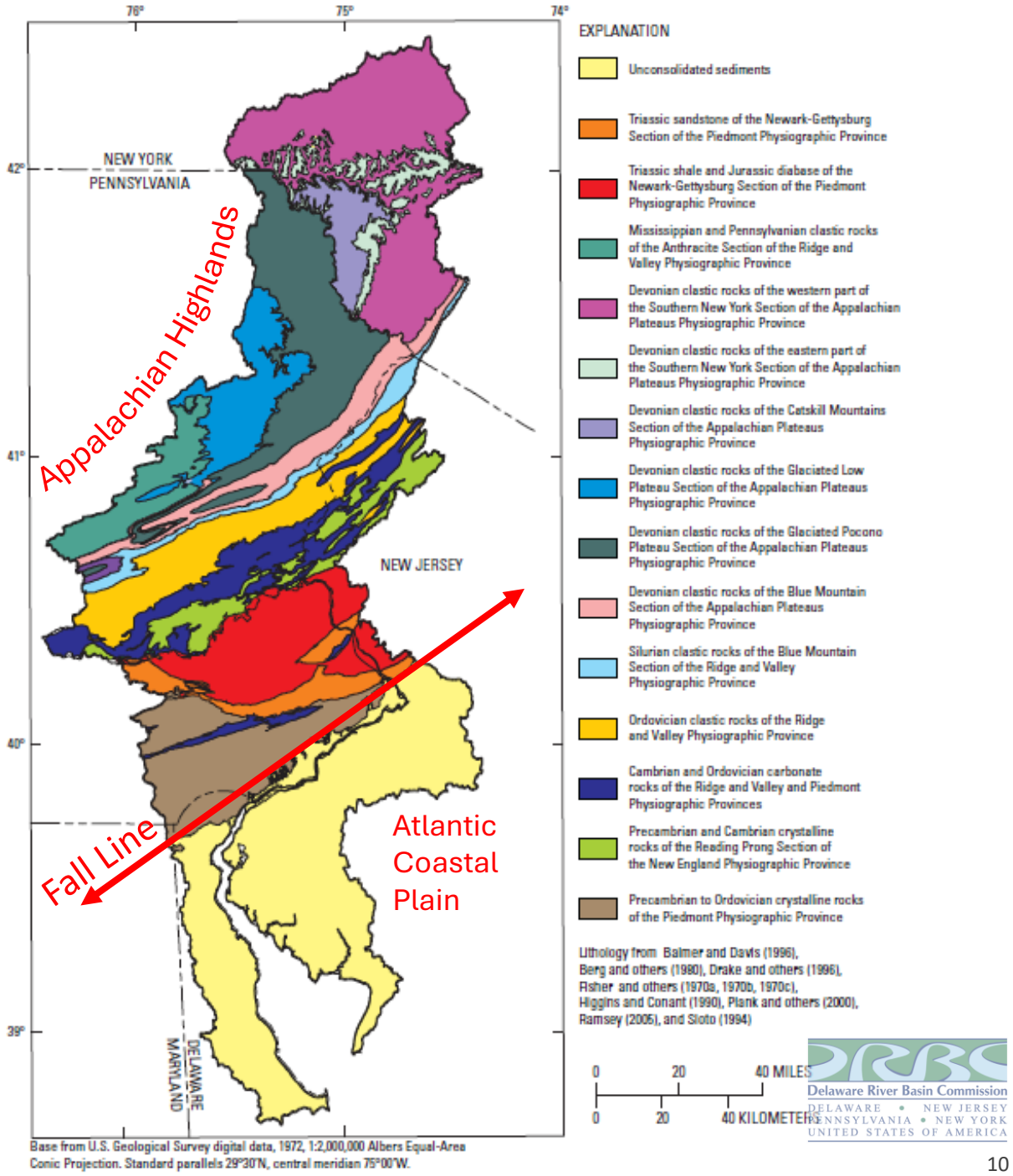
(Estimated Groundwater Availability in the Delaware River Basin, 1997-2000)



Estimation Methods

- **APPALACHIAN HIGHLANDS** (method #1)
  - Sloto & Buxton, 2006 grouped fractured rock into 14 generalized groups
  - Empirically calculate baseflow recurrence intervals for each rock type
  - Estimate baseflow recurrence intervals for watersheds based on "weighted geologic index"

- **ATLANTIC COASTAL PLAIN** (method #2)
  - Reference surficial geology & land use
  - Empirically calculate baseflow recurrence intervals for each combination
  - Estimate baseflow recurrence intervals for watersheds based on weighted average of classification



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Example baseflow estimation

Table 3. Potential index streamflow-gaging stations draining fractured rocks in the Delaware River Basin.

[USGS, U.S. Geological Survey]

USGS station number	Station name	Drainage area (square miles)	Period of record
01479000	White Clay Creek near Newark, Del.	89.1	1932-35, 1944-56, 1960-2001
01480000	Red Clay Creek at Wooddale, Del.	47.0	1944-2001
01480300	West Branch Brandywine Creek near Honey Brook, Pa.	18.7	1961-2001

Streamflow data through 2001

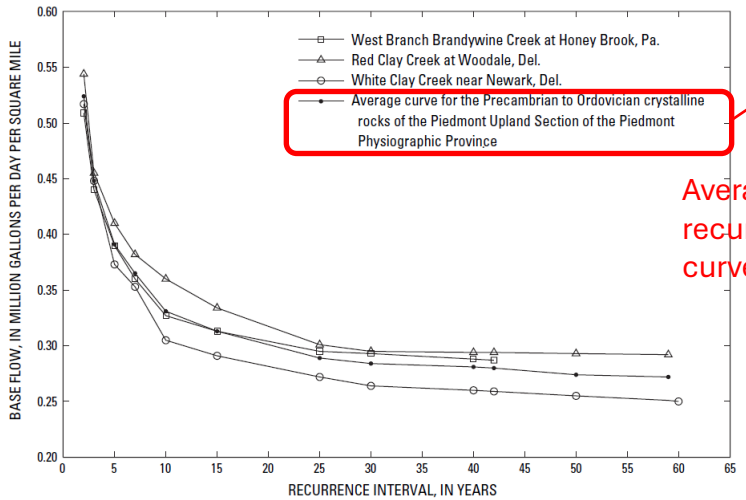
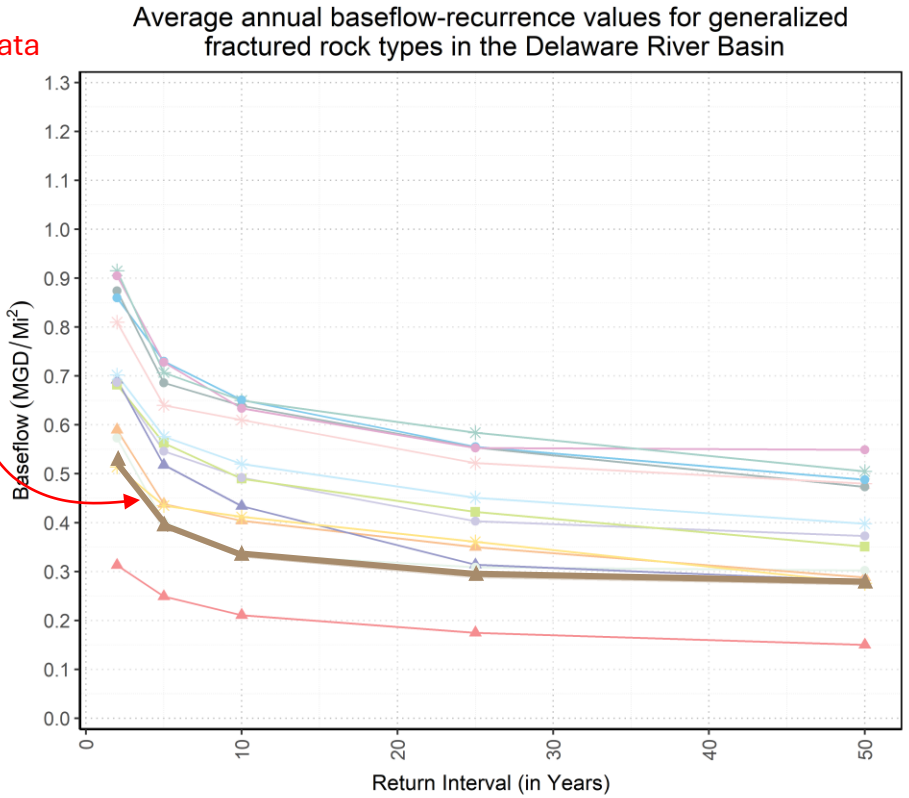
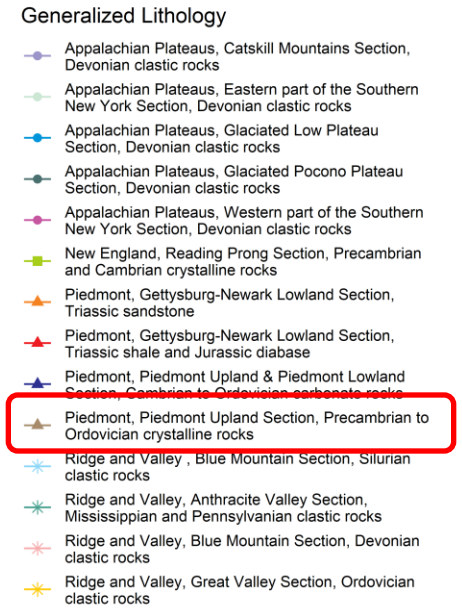


Figure 7. Base-flow-frequency curves for streamflow-gaging stations in the Precambrian to Ordivician crystalline rocks of the Piedmont Upland Section of the Piedmont Physiographic Province.

Average becomes recurrence interval curve



14 categories



1. Use streamflow data from these gages
2. Separate baseflow (HYSEP Loc-min method)
3. calculate recurrence intervals to represent this rock type

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Results

- Calculated 2-, 5-, 10-, 25-, and 50-year recurrence interval baseflow values for 147 sub-watersheds in the Basin
- Quarry dewatering was tricky in terms of “net” withdrawal, as much goes back into stream
- Withdrawal from confined aquifers should not be considered in availability screening tool

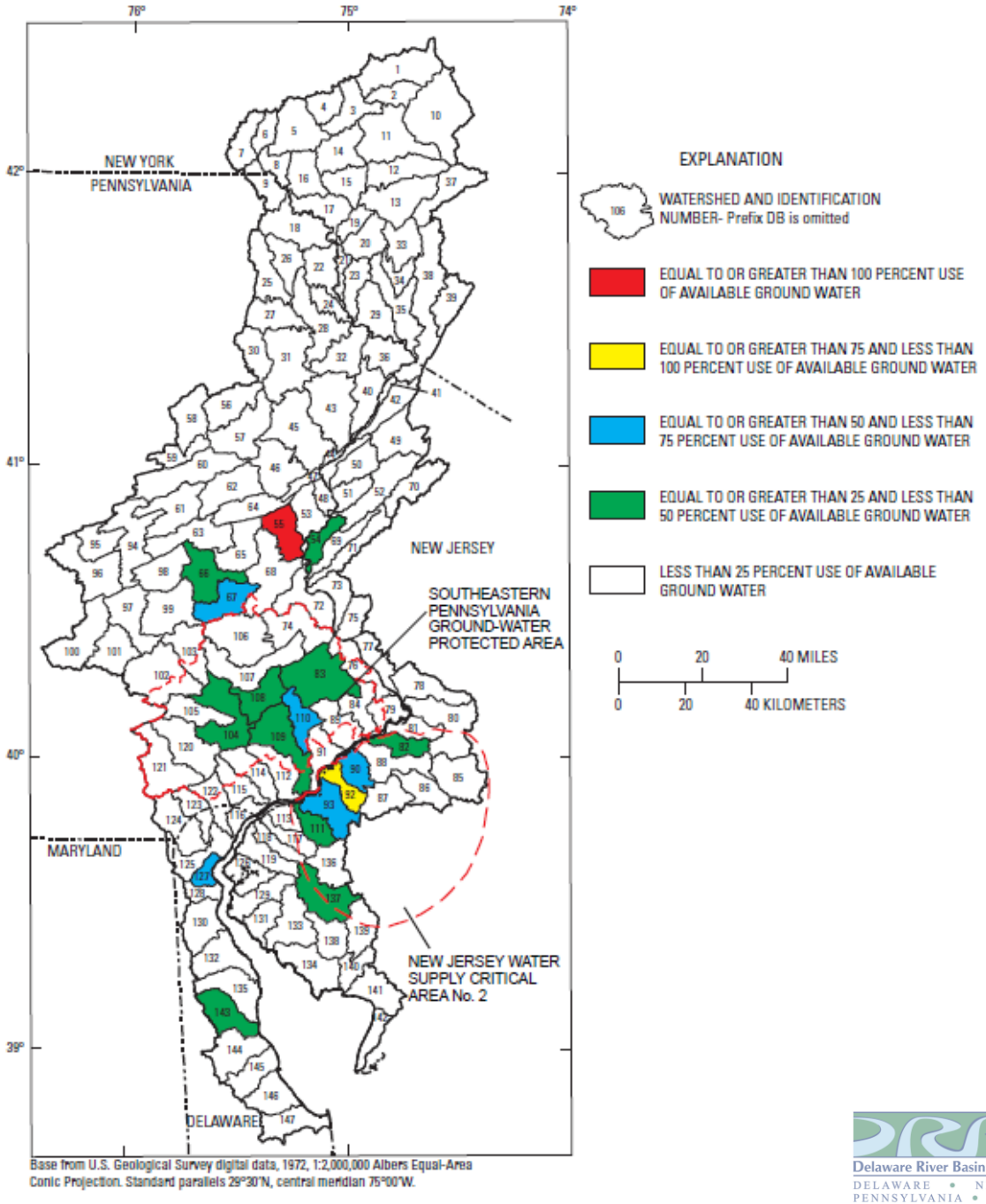
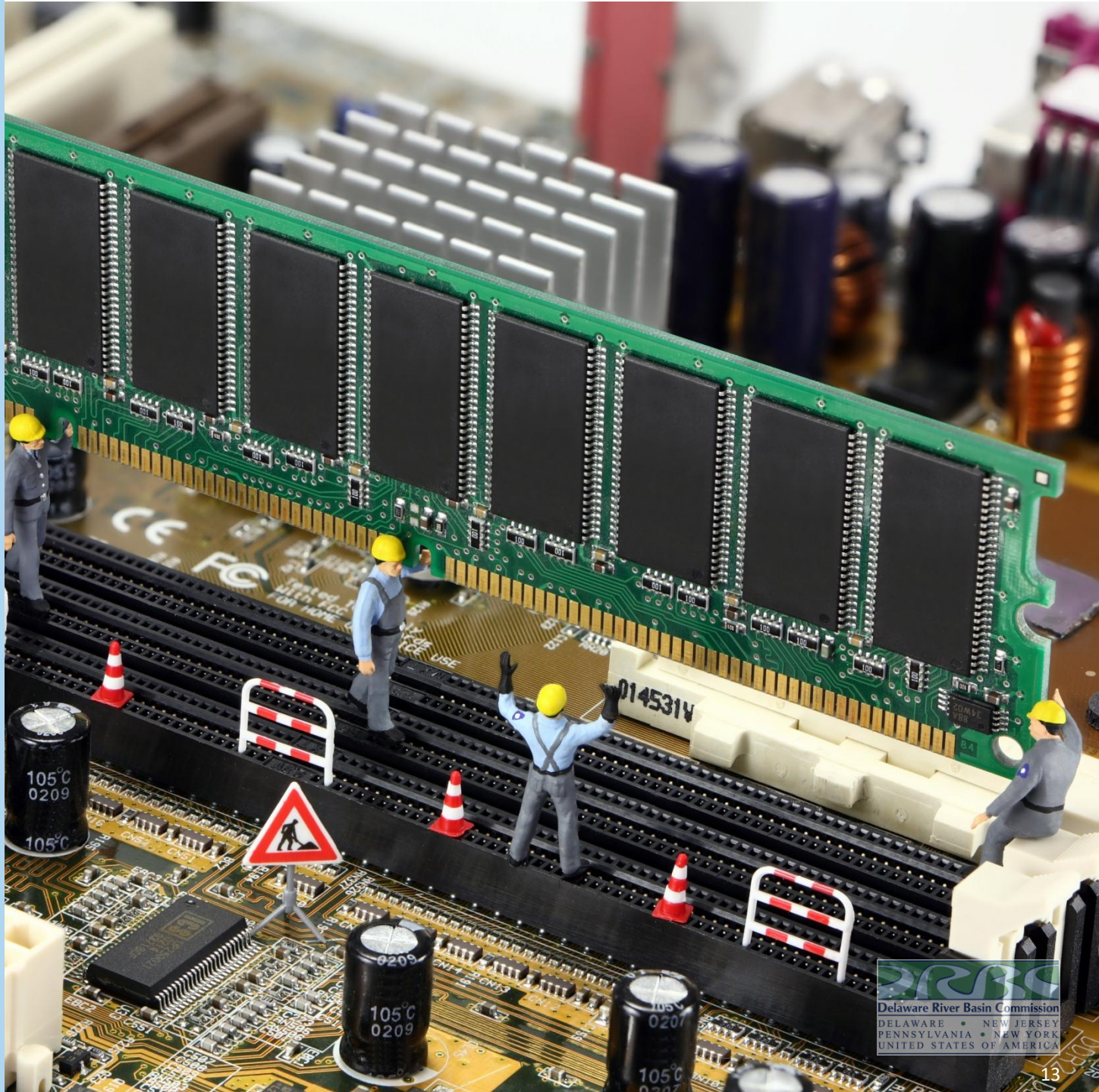


Figure 37. Percent of ground-water use for 50-year annual base-flow recurrence.

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Updates to methodology



This project aims to…



re-assess the groundwater baseflow recurrence intervals with up to 20 years of additional hydrologic data



assess temporal resolution (i.e. seasonality)



use an ensemble of baseflow separation algorithms for hydrograph analysis (e.g., USGS GW-Toolbox)



assess additional geographic scales



use an alternative method to correlate groundwater baseflow recurrence intervals to un-gaged subwatersheds

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+20 years of data

(Sloto & Buxton, 2006) Reference Gages					Calculated values in this study using verified methods (same data as SB2006)					Calculated values in this study using verified methods (including 20+ years of additional streamflow data)							% Change						
Ref No	Site No.	Name	Area (mi²)	yr_sta	yr_end	RI-2	RI-5	RI-10	RI-25	RI-50	yr_end	Δn	RI-2	RI-5	RI-10	RI-25	RI-50	RI-2	RI-5	RI-10	RI-25	RI-50	RockType	Include
1	01413500	East Branch Delaware River at Margaretville, N.Y.	163	1938	2001	0.739	0.584	0.505	0.471	0.453	2024	23	0.755	0.599	0.522	0.476	0.458	2.1%	2.5%	3.4%	1.1%	1.1%		TRUE
2	01414000	Platte Kill at Dunraven, N.Y.	34.9	1942	2001	0.673	0.526	0.491	0.378	--	2023	22	0.729	0.613	0.516	0.479	--	8.2%	16.5%	5.0%	26.8%	--	CSHL	TRUE
3	01414500	Mill Brook near Dunraven, N.Y.	25.2	1938	2001	0.887	0.735	0.689	0.574	0.550	2023	22	0.935	0.750	0.703	0.576	0.559	5.4%	2.1%	2.0%	0.4%	1.7%		TRUE
4	01415000	Tremper Kill near Andes, N.Y.	33.2	1938	2001	0.649	0.535	0.455	0.416	0.370	2023	22	0.671	0.557	0.460	0.430	0.382	3.4%	4.2%	1.2%	3.5%	3.3%	CSHL	TRUE
9	01420500	Beaver Kill at Cooks Falls, N.Y.	241	1915	2001	0.897	0.721	0.628	0.548	0.544	2024	23	0.913	0.799	0.654	0.563	0.547	1.7%	10.7%	4.1%	2.7%	0.5%	CAT4	TRUE
10	01421900	West Branch Delaware River upstream From Delhi, N.Y.	134	1938	2001	0.665	0.497	0.469	0.373	--	2024	23	0.694	0.574	0.486	0.430	0.342	4.4%	15.5%	3.6%	15.3%	--	CSHL	TRUE
12	01422500	Little Delaware River near Delhi, N.Y.	49.8	1938	2001	0.654	0.527	0.467	0.412	--	2024	23	0.701	0.558	0.472	0.427	0.408	7.2%	5.9%	1.1%	3.7%	--	CSHL	TRUE
13	0142400103	Trout Creek near Trout Creek, N.Y.	20.2	1953	2001	0.584	0.437	0.411	--	--	2024	23	0.697	0.565	0.438	0.408	--	19.5%	29.3%	6.4%	--	--		TRUE
18	01437500	Neversink River at Godeffroy, N.Y.	307	1938	2001	0.577	0.469	0.418	0.381	0.316	2024	23	0.635	0.492	0.428	0.397	0.336	10.0%	4.9%	2.4%	4.4%	6.4%		TRUE
19	01439500	Bush Kill at Shoemakers, Pa.	117	1909	2001	0.878	0.680	0.634	0.552	0.470	2024	23	0.891	0.692	0.640	0.575	0.491	1.4%	1.7%	1.0%	4.2%	4.4%	CAT1	TRUE
20	01440000	Flat Brook near Flatbrookville, N.J.	64	1924	2001	0.696	0.571	0.516	0.447	0.395	2024	23	0.731	0.578	0.518	0.467	0.424	5.1%	1.3%	0.5%	4.5%	7.3%	SILR	TRUE
21	01440400	Brodhead Creek near Analomink, Pa.	65.9	1958	2001	0.789	0.670	0.648	0.504	--	2023	22	0.833	0.691	0.654	0.559	0.497	5.7%	3.1%	1.0%	11.0%	--		TRUE
23	01442500	Brodhead Creek at Minisink Hills, Pa.	259	1951	2001	0.822	0.645	0.571	0.555	0.482	2023	22	0.837	0.657	0.596	0.554	0.521	1.7%	1.9%	4.4%	0.0%	8.1%		TRUE
24	01445500	Pequest River at Pequest, N.J.	106	1922	2001	0.668	0.553	0.461	0.414	0.290	2024	23	0.700	0.557	0.461	0.394	0.322	4.8%	0.8%	0.1%	-4.8%	11.1%	XLNR	TRUE
26	01447500	Lehigh River at Stoddartsville, Pa.	91.7	1944	2001	0.852	0.724	0.644	0.550	0.484	2023	22	0.881	0.729	0.650	0.575	0.516	3.4%	0.8%	0.9%	4.5%	6.5%	CAT2	TRUE
27	01447720	Tobyhanna Creek near Blakeslee, Pa.	118	1962	2001	0.871	0.714	0.682	0.587	--	2023	22	0.895	0.767	0.686	0.591	0.573	2.7%	7.4%	0.6%	0.8%	--		TRUE
29	01449360	Pohopoco Creek at Kresgeville, Pa.	49.9	1967	2001	0.889	0.755	0.681	0.657	--	2024	23	0.937	0.800	0.683	0.668	0.649	5.4%	5.9%	0.2%	1.7%	--		TRUE
31	01450500	Aquashicola Creek at Palmerton, Pa.	76.7	1940	2001	0.804	0.635	0.605	0.529	0.477	2024	23	0.815	0.665	0.616	0.550	0.494	1.4%	4.8%	1.9%	3.8%	3.5%	CAT3	TRUE
32	01451500	Little Lehigh Creek near Allentown, Pa.	80.8	1946	2001	0.619	0.464	0.388	0.281	0.252	2024	23	0.675	0.479	0.395	0.332	0.256	9.1%	3.2%	1.8%	18.0%	1.7%	CARB	TRUE
33	01451800	Jordan				0.510	0.431	0.408	0.358	--	2024	23	0.586	0.446	0.421	0.394	0.333	15.0%	3.3%	3.3%	10.1%	--	MART	TRUE
34	01452500	Mo					0.432	0.371	0.225	0.188	2024	23	0.647	0.441	0.382	0.290	0.200	12.4%	2.2%	3.0%	28.7%	6.4%		TRUE
36	01457000	M					0.643	0.566	0.488	0.406	2024	23	0.821	0.646	0.569	0.484	0.433	2.8%	0.5%	0.5%	-0.9%	6.5%	XLNR	TRUE
41	01468500	S					0.730	0.702	0.650	--	2024	23	0.901	0.767	0.713	0.678	0.636	-8.5%	5.0%	1.6%	4.3%	--	ANTH	TRUE
43	01470779	T					0.616	0.549	0.436	--	2024	23	0.827	0.649	0.602	0.467	0.408	6.0%	5.2%	9.6%	7.3%	--		TRUE
46	01472157	F					0.459	0.393	0.279	--	2023	22	0.574	0.471	0.395	0.295	0.270	2.2%	2.5%	0.4%	5.6%	--		TRUE
47	01472198	P					0.482	0.457	--	--	2024	23	0.623	0.479	0.453	0.409	--	9.2%	-0.5%	-0.9%	--	--		TRUE
48	01472199	W					0.515	0.469	--	--	2024	23	0.651	0.512	0.472	0.440	--	6.0%	-0.6%	0.7%	--	--		TRUE
52	01475850	C					0.471	0.418	--	--	2022	21	0.609	0.475	0.417	0.344	--	8.4%	0.8%	-0.1%	--	--		TRUE
53	01479000	W					0.370	0.302	0.269	0.253	2022	21	0.530	0.390	0.315	0.277	0.259	3.3%	5.5%	4.1%	3.0%	2.4%	XLNP	TRUE
54	01480000	R					0.407	0.357	0.299	0.291	2023	22	0.576	0.427	0.361	0.300	0.292	7.0%	4.9%	1.1%	0.5%	0.4%	XLNP	TRUE
55	01480300	W					0.387	0.325	0.293	--	2023	22	0.520	0.392	0.348	0.291	0.282	2.9%	1.4%	7.1%	-0.5%	--	XLNP	TRUE
5	01415500	T					0.617	0.561	0.424	--	1961	0											CSHL	
6	01418500	B					0.715	0.670	0.602	--	1969	0												
7	01419500	W					0.704	0.653	0.495	--	2024	6												
8	01420000	U					0.669	0.526	0.479	0.466	1980	0												
11	01422000	Wes						0.469	0.449	0.407	--	1969	0											
14	01424500	Trout Creek at Cannonsville, N.Y.			962				0.414	--	--	1962	0											
15	01426000	Oquaga Creek at Deposit, N.Y.			72				376	0.275	--	1972	0											
16	01427500	Callicoon Creek at Callicoon, N.Y.							37	0.306	--	2023	5										HNDL	
17	01428000	Tenmile River at Tusten, N.Y.			1972				8	0.289	--	2024	6											
22	01441000	McMichaels Creek at Stroudsburg, Pa.							9	0.465	--	1937	0											
25	01446000	Beaver Brook near Belvidere, N.J.							7	0.390	--	2022	19											
28	01448000	Lehigh River at Tannery, Pa.							09	0.536	--	1958	0											
30	01450000	Pohopoco Creek near Parryville, Pa.							0.484	0.428	--	1969	0											
35	01456000	Musconetcong River near Hackettstown, N.J.							0.482	0.436	0.311	1972	0											
37	01459500	Tohickon Creek near Pipersville, Pa.							0.187	0.160	--	2024	52											
38	01460000	Tohickon Creek at Point Pleasant, Pa.			94					0.188	--	1913	0											
39	01465000	Neshaminy Creek at Rushland, Pa.			1885					247	--	1933	0										TRSS	
40	01467500	Schuylkill River at Pottsville, Pa.								43	--	1968	0										ANTH	
42	01470756	Maiden Creek at Virginville, Pa.									--	1994	0											
44	01471000	Tulpehocken Creek near Reading, Pa.									--	2024	46											
45	01471980	Manatawny Creek near Pottstown, Pa.									--	2003	2										XLNR	
49	01472500	Perkiomen Creek near Frederick, Pa.									--	1913	0											
50	01473000	Perkiomen Creek at Graterford, Pa.					0				--	2024	68											
51	01473120	Skippack Creek near Collegeville, Pa.			93	0					--	1993	0										TRSH	
56	01481000	Brandywine Creek at Chadds Ford, Pa.			71	0				9	0.307	2023	52											
57	01481500	Brandywine Creek at Wilmington, Del.			71	0				4	--	2024	53											

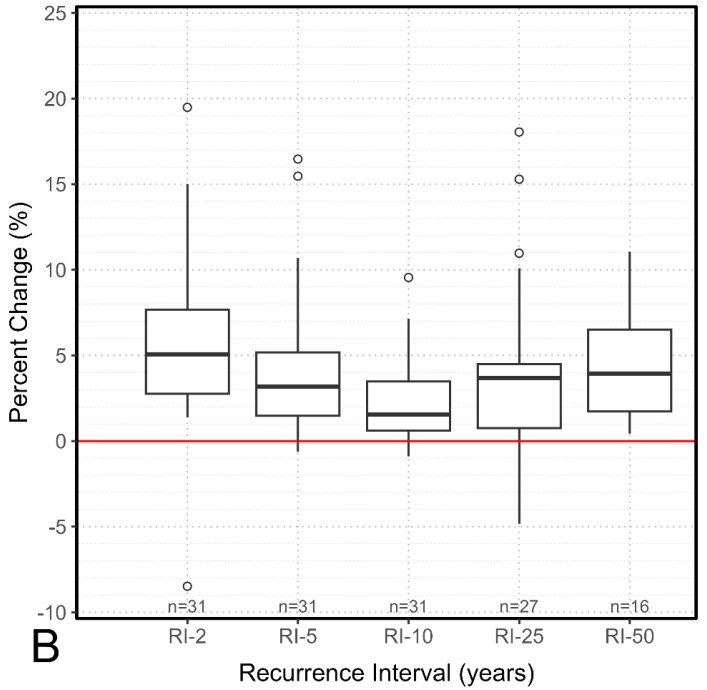


57 reference gages used in SB2006

31 had new data

Comparison against (Sloto & Buxton, 2006)

Baseflow Separation Method:	HYSEP Local Minimum
RI Calc. Method:	Emperical
Timescale:	Annual
Data Start:	(Sloto & Buxton, 2006)
Data End:	2024



Only some were used to define rock type recurrence interval baseflows

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+20 years of data

Original Values

+20 years of data

Rock Type	Number of gages (total)	Number of gages with new dat	Calculated values in this study using verified methods (same data as SB2006)					Calculated values in this study using verified methods (including 20+ years of additional streamflow data)					% Change				
			2-ye	5-ye	10-ye	25-ye	50-ye	2-ye	5-ye	10-ye	25-ye	50-ye	2-ye	5-ye	10-ye	25-ye	50-ye
ANTH	2	1	0.905	0.701	0.645	0.546	--	0.863	0.719	0.650	0.560	0.636	-4.61%	2.62%	0.85%	2.55%	--
CARB	1	1	0.685	0.513	0.430	0.312	0.278	0.747	0.530	0.437	0.368	0.283	9.10%	3.21%	1.78%	18.05%	1.72%
CAT1	1	1	0.878	0.680	0.634	0.552	0.470	0.891	0.692	0.640	0.575	0.491	1.44%	1.66%	0.96%	4.18%	4.37%
CAT2	1	1	0.852	0.724	0.644	0.550	0.484	0.881	0.729	0.650	0.575	0.516	3.42%	0.79%	0.92%	4.49%	6.55%
CAT3	1	1	0.804	0.635	0.605	0.529	0.477	0.815	0.665	0.616	0.550	0.494	1.39%	4.77%	1.92%	3.84%	3.52%
CAT4	1	1	0.897	0.721	0.628	0.548	0.544	0.913	0.799	0.654	0.563	0.547	1.75%	10.70%	4.11%	2.71%	0.46%
CSHL	5	4	0.681	0.540	0.489	0.401	0.370	0.712	0.584	0.499	0.438	0.378	4.51%	8.03%	2.13%	9.39%	2.02%
HNDL	1	0	0.568	0.397	0.337	0.306	--	0.568	0.397	0.337	0.306	--	0.00%	0.00%	0.00%	0.00%	--
MART	1	1	0.510	0.431	0.408	0.358	--	0.586	0.446	0.421	0.394	0.333	15.00%	3.30%	3.29%	10.09%	--
SILR	1	1	0.696	0.571	0.516	0.447	0.395	0.731	0.578	0.518	0.467	0.424	5.07%	1.27%	0.46%	4.50%	7.27%
TRSH	1	0	0.310	0.246	0.208	0.174	--	0.310	0.246	0.208	0.174	--	0.00%	0.00%	0.00%	0.00%	--
TRSS	1	0	0.588	0.437	0.402	0.350	--	0.588	0.437	0.402	0.350	--	0.00%	0.00%	0.00%	0.00%	--
XLNP	3	3	0.519	0.388	0.328	0.287	0.272	0.542	0.403	0.341	0.290	0.278	4.44%	3.95%	4.04%	0.92%	2.12%
XLNR	3	2	0.676	0.558	0.486	0.418	0.348	0.694	0.560	0.487	0.410	0.377	2.67%	0.44%	0.22%	-1.96%	8.40%

Can have drastic effects if a rock type were defined by a single gaging station

14 rock types

Not all gaging stations used to define a rock type had new data

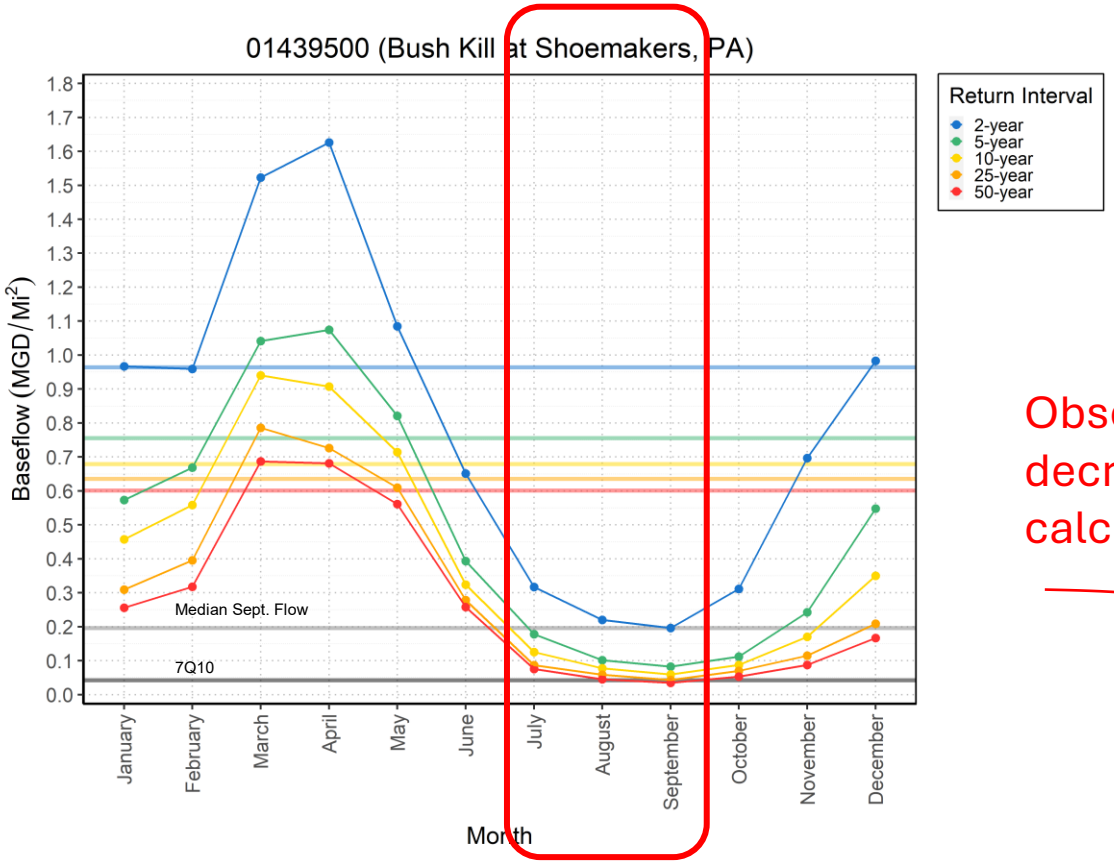
Percent change in recurrence interval baseflow based on adding new data

Conclusions:

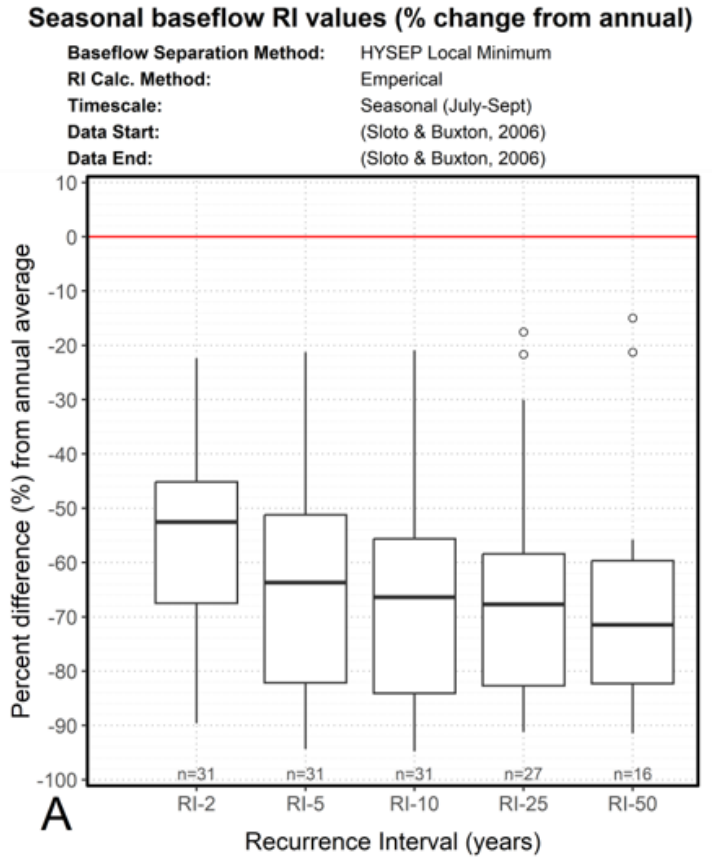
Adding new data results in significant change in baseflow estimates at all recurrence intervals

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Assess baseflows “seasonally”



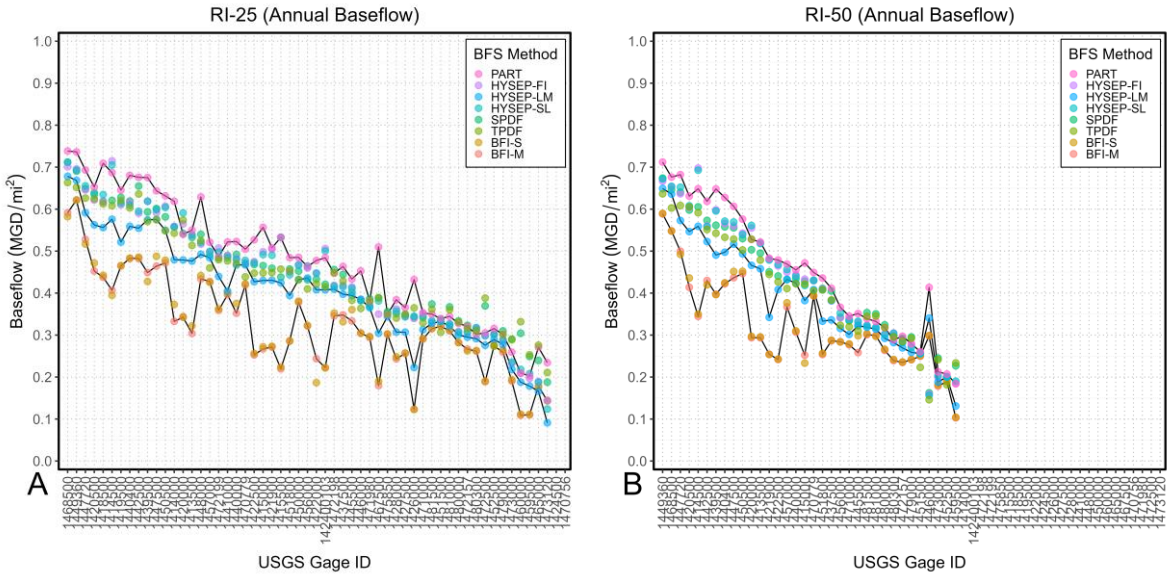
Observed expected decrease in calculated baseflows

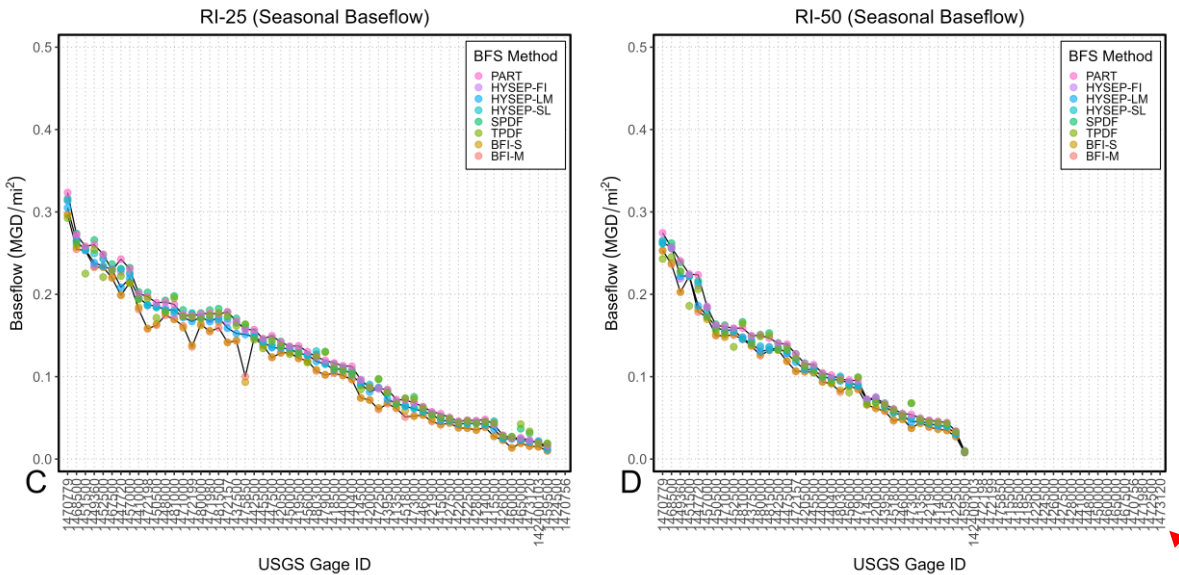


Rerun the analyses restricting input streamflow to “low-flow season” (Q3)

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Use an ensemble of HYSEP algorithms





Hydrograph separation algorithm	Mean of all gage baseflows (MGD/mi²)				Decrease (% of annual)	
	Annual		Seasonal			
	RI-25	RI-50	RI-25	RI-50	RI-25	RI-50
PART	0.477	0.451	0.130	0.121	73%	73%
HYSEP-FI	0.445	0.426	0.126	0.116	72%	73%
HYSEP-LM	0.405	0.390	0.123	0.114	70%	71%
HYSEP-SL	0.446	0.426	0.126	0.116	72%	73%
SPDF	0.450	0.423	0.131	0.121	71%	71%
TPDF	0.440	0.409	0.125	0.114	71%	72%
BFI-S	0.328	0.323	0.114	0.108	65%	67%
BFI-M	0.326	0.320	0.113	0.108	65%	66%
Variation $\left(\frac{max - min}{max}\right)$	32%	29%	14%	11%	--	--

Gage order doesn't matter, each just ordered by decreasing median

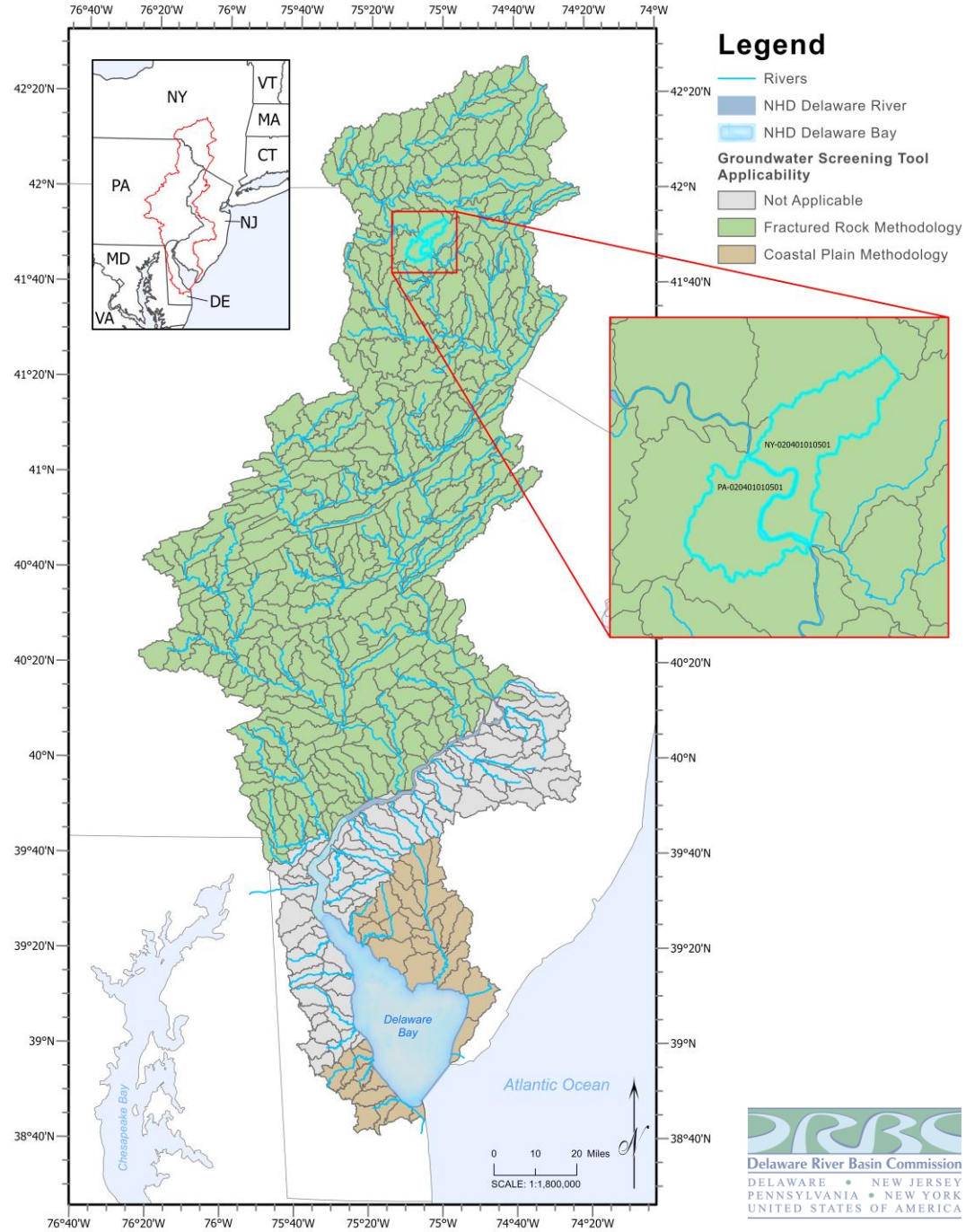
Conclusion:

- There is more variation between methods using annual data, than with using seasonal data
- The updated method uses seasonal data, and will therefore continue to use HYSEP-LM

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HUC-12 (modified)

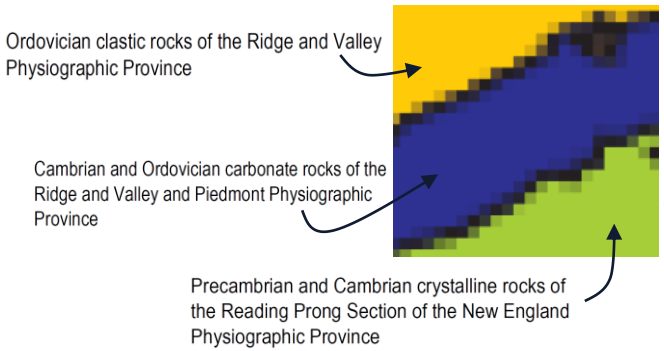
- DRB-147 (87.4 mi^2) → HUC-12 (28.3 mi^2)
- HUC-12 spanning the Delaware River were divided into components
- Delaware River mainstem = 27 polygons (portions of each split HUC-12)
- HUC-12 “to-from” flow metadata update
- Delaware Bay boundary incorporated from NHD dataset ∴ HUC-12 boundaries adjusted



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New methodology

Instead of....



$$\text{Watershed } RI_{25} = 0.3\,RI_{25} + 0.4\,RI_{25} + 0.3\,RI_{25}$$

A "geologic index" approach with discrete estimates for each return interval

We will try...

Multi-variate regression to model Log-Pearson-III distribution parameters



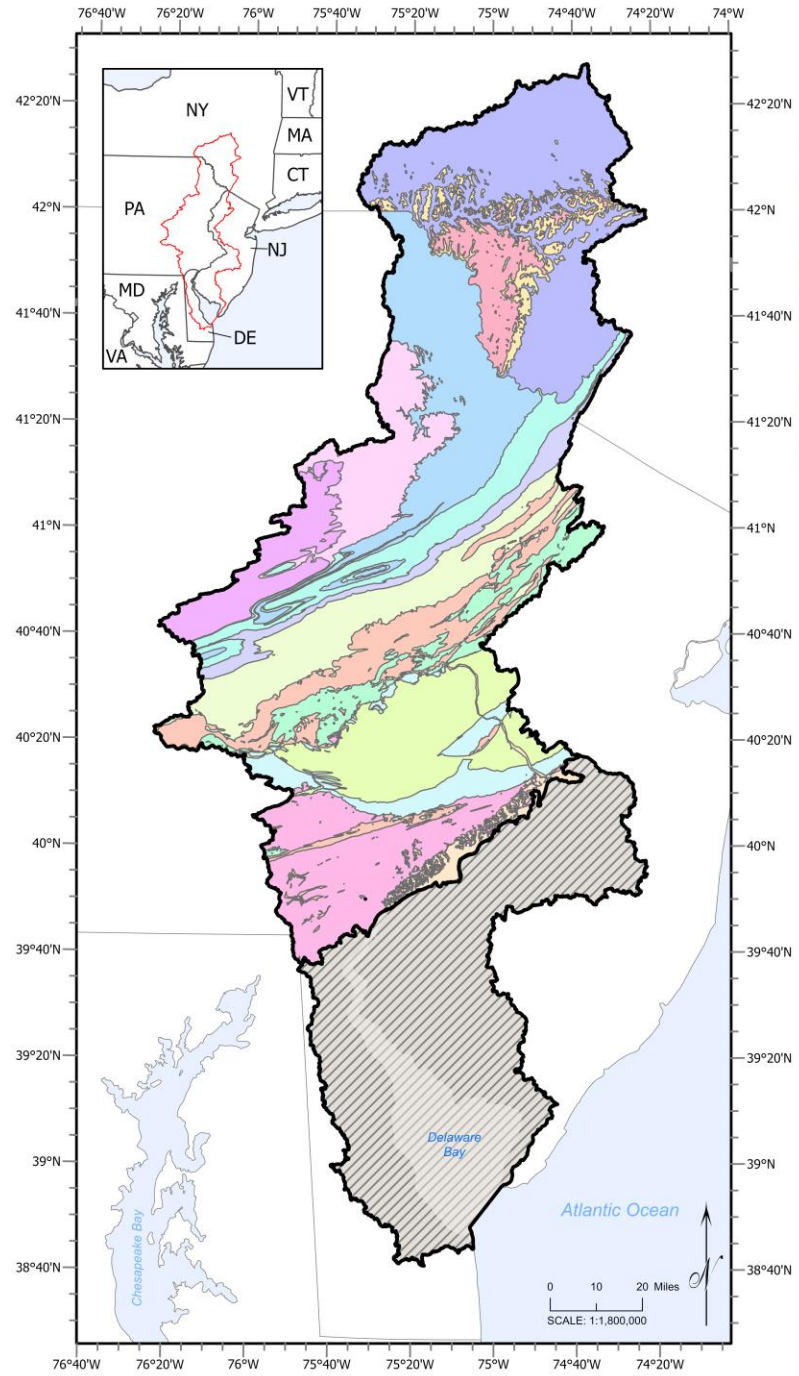


LOTS of data has been gathered and we will continue to work on it...

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New methodology

- Document grouping 241 geologic codes into 14 generalized rock types
- Regenerate GIS files such that there are **no gaps** with new boundaries
- Re-perform geologic-indexing



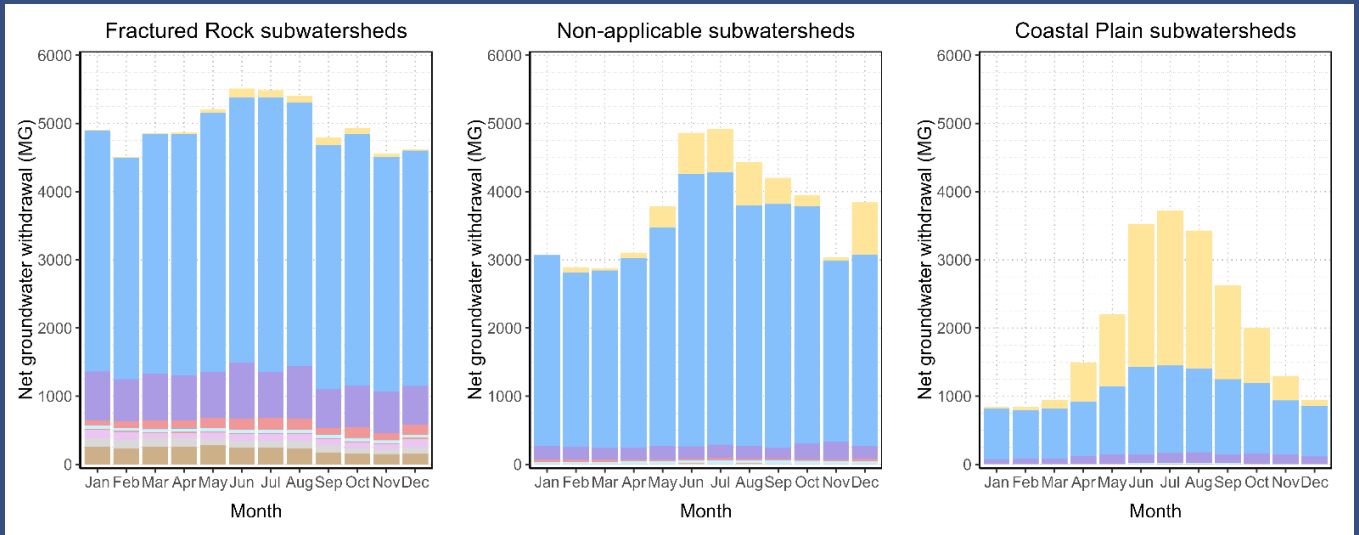
Example:

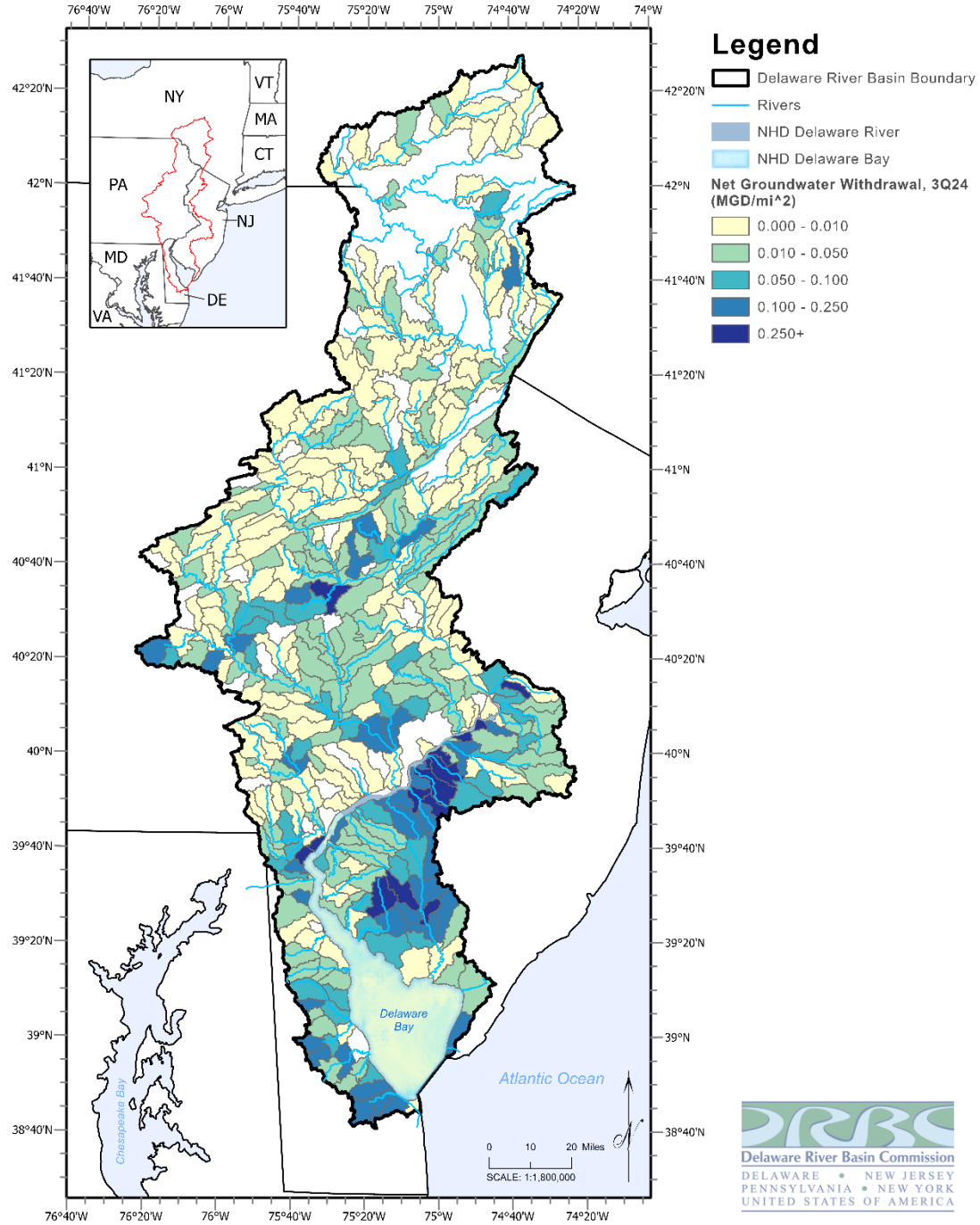
A	B	C
STA	GEO_CO	ROCK_TY
PA	Pp	ANTH
PA	Pl	ANTH
PA	Mp	ANTH
PA	Mmc	ANTH
PA	MDsk	ANTH
NJ	Yf	CARB
PA	Xc	CARB
PA	Os	CARB
PA	Ori	CARB
PA	Oo	CARB
NJ	Ojw	CARB
PA	Ojk	CARB
NJ	Oj	CARB

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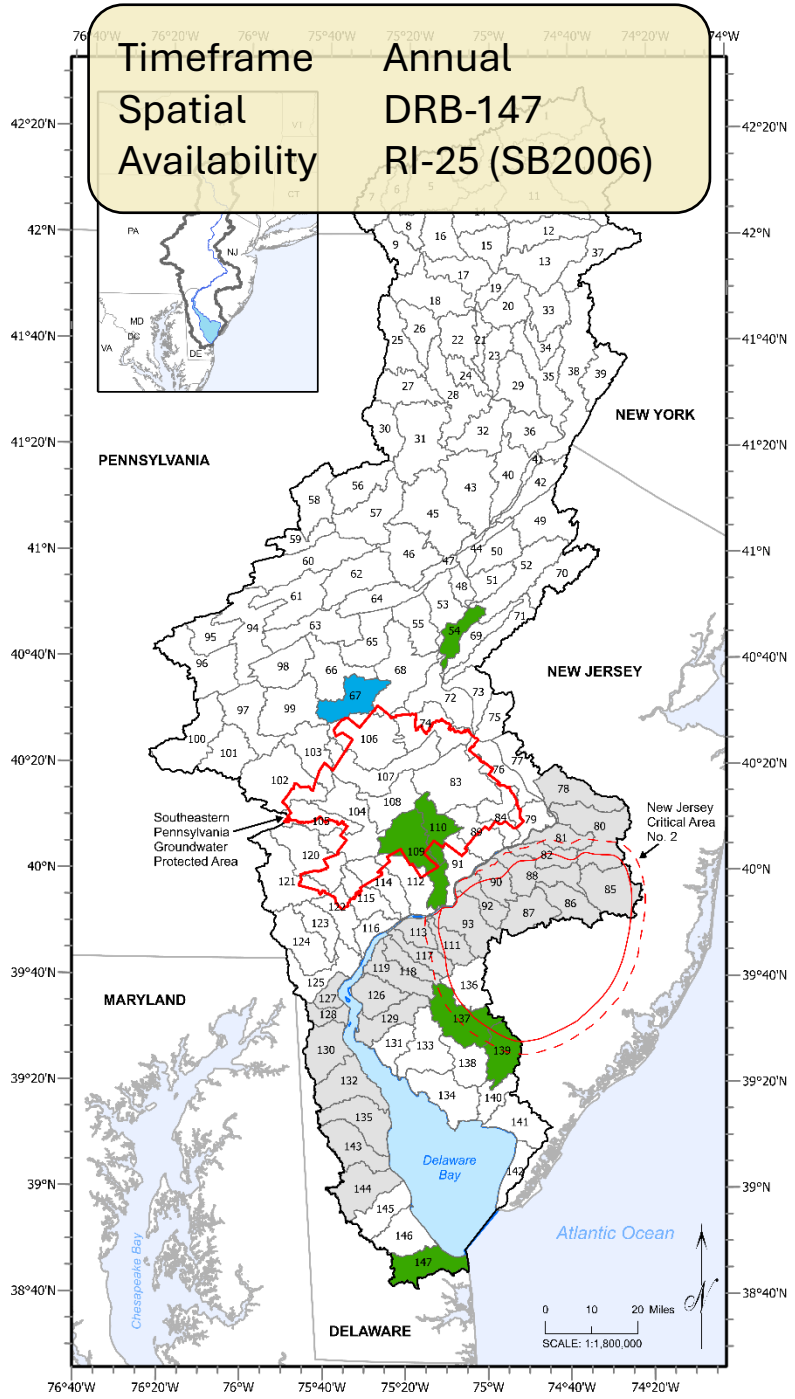
New methodology

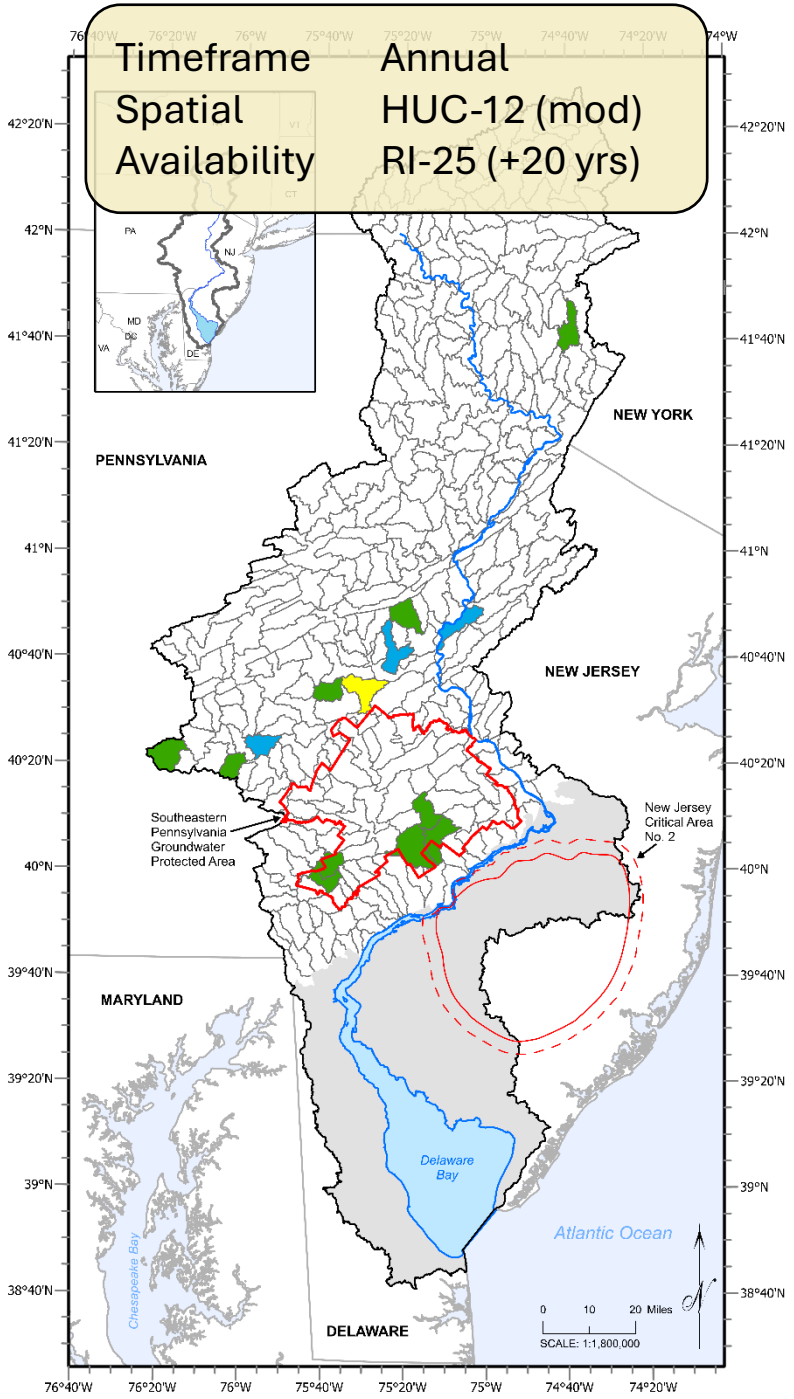
- Characterize **net** groundwater withdrawals
- Seasonal signal compounds with water availability signal





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EQUAL TO OR GREATER THAN 100 PERCENT USE OF AVAILABLE GROUNDWATER

EQUAL TO OR GREATER THAN 75 AND LESS THAN 100 PERCENT USE OF AVAILABLE GROUNDWATER

EQUAL TO OR GREATER THAN 50 AND LESS THAN 75 PERCENT USE OF AVAILABLE GROUNDWATER

EQUAL TO OR GREATER THAN 25 AND LESS THAN 50 PERCENT USE OF AVAILABLE GROUNDWATER

LESS THAN 25 PERCENT USE OF AVAILABLE GROUNDWATER

SCREENING TOOL NOT APPLIED

98 WATERSHED AND IDENTIFICATION NUMBER - Prefix DB is omitted

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We never know the Worth of Water, till the Well is dry.



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