



Analysis of Long-Term Hydrologic Records in the Chesapeake Bay Watershed

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Previous Research: Rice and Hirsch (2012)

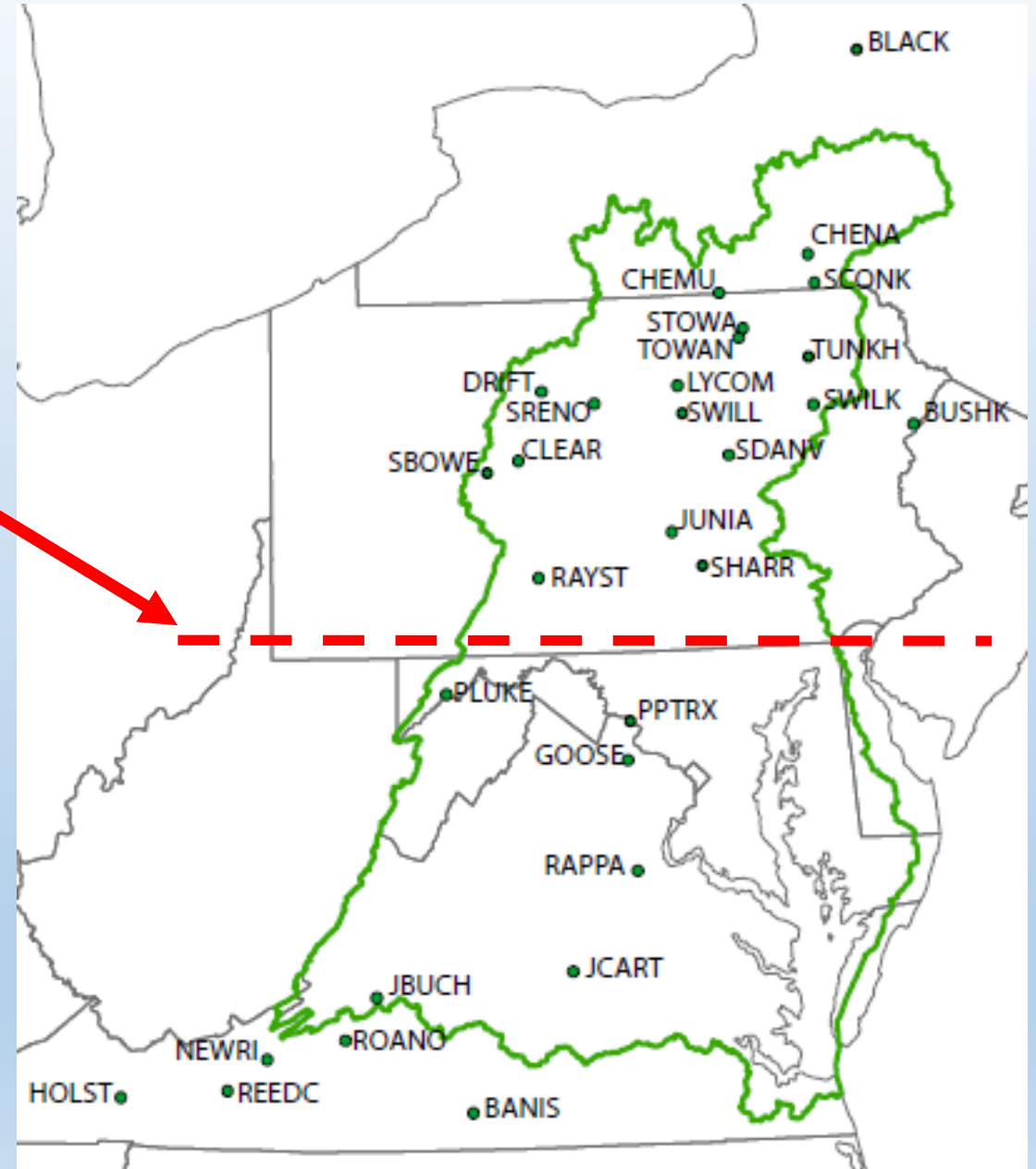
Discharge trends in the Chesapeake Bay watershed:
7-day low flow, mean flow, and
1-day high flow.

Spatial difference in some of these metrics between North and South in the Chesapeake Bay watershed.



Previous Research

Dividing line was approximately the Maryland/Pennsylvania border

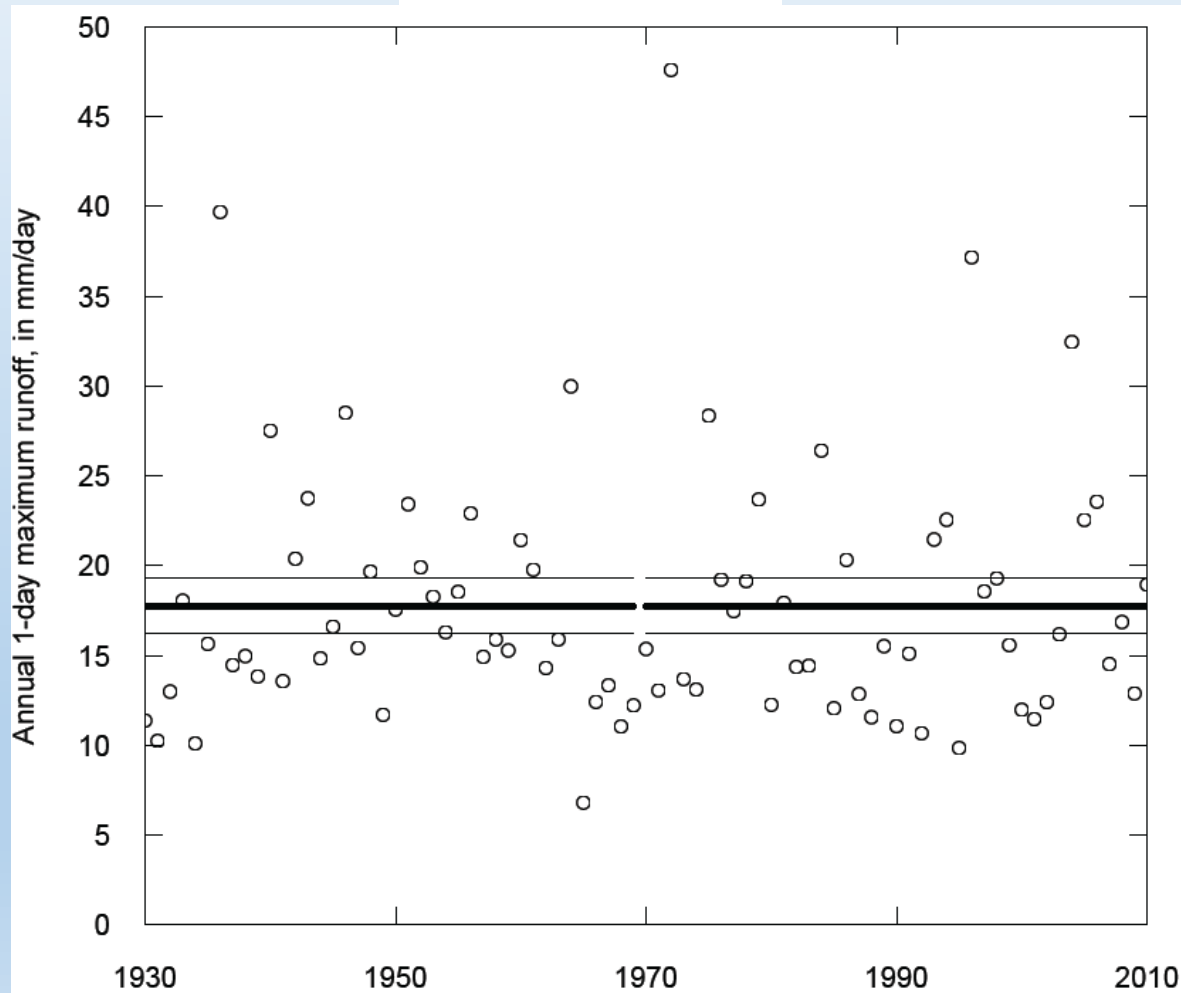


Prepared in Cooperation with the Virginia Department of Environmental Quality,
Office of Surface Water Investigations

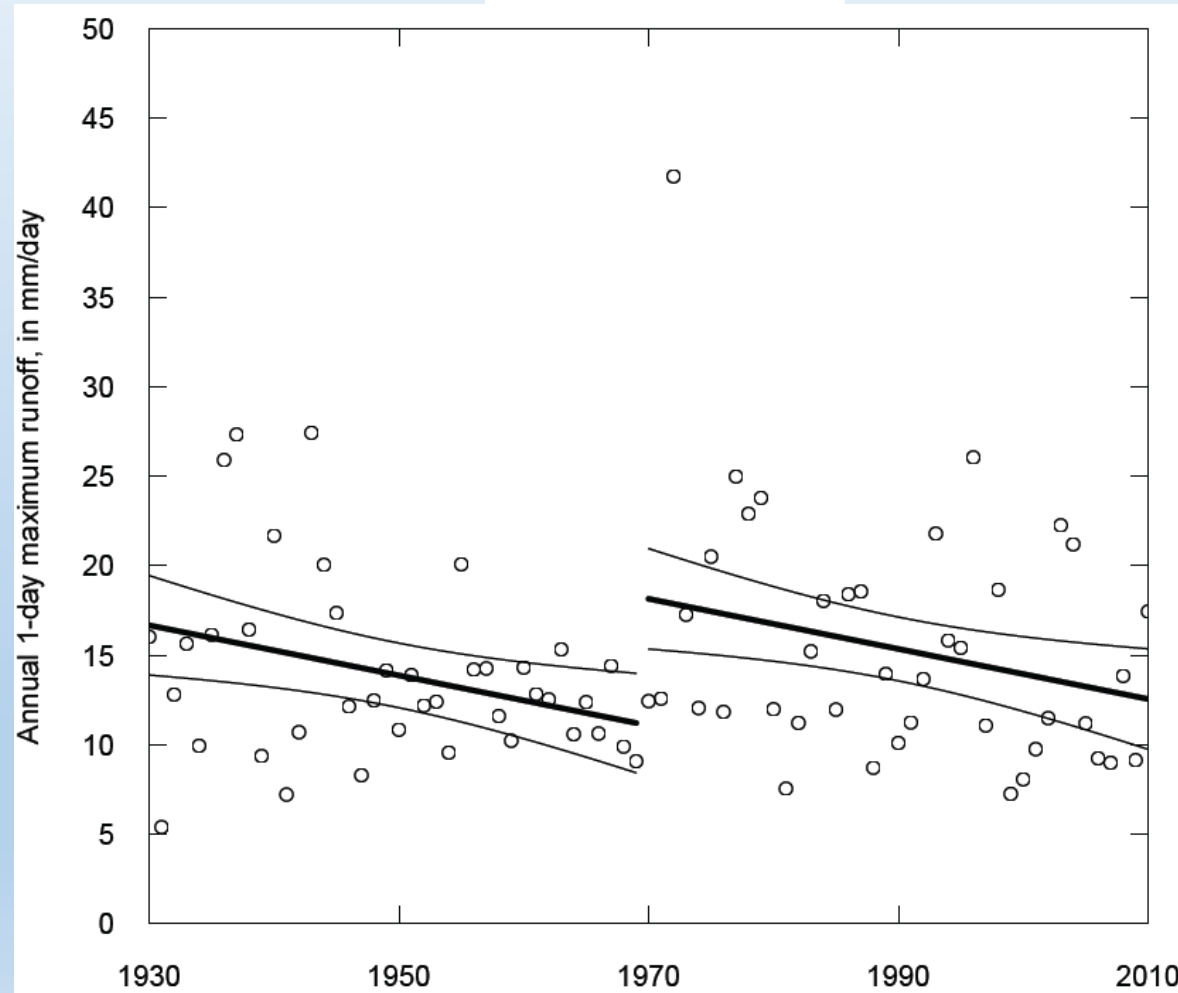
**Spatial and Temporal Trends in Runoff at Long-Term
Streamgages within and near the Chesapeake Bay
Watershed**

Mean 1-Day Maximum Runoff 1930-2010

North



South

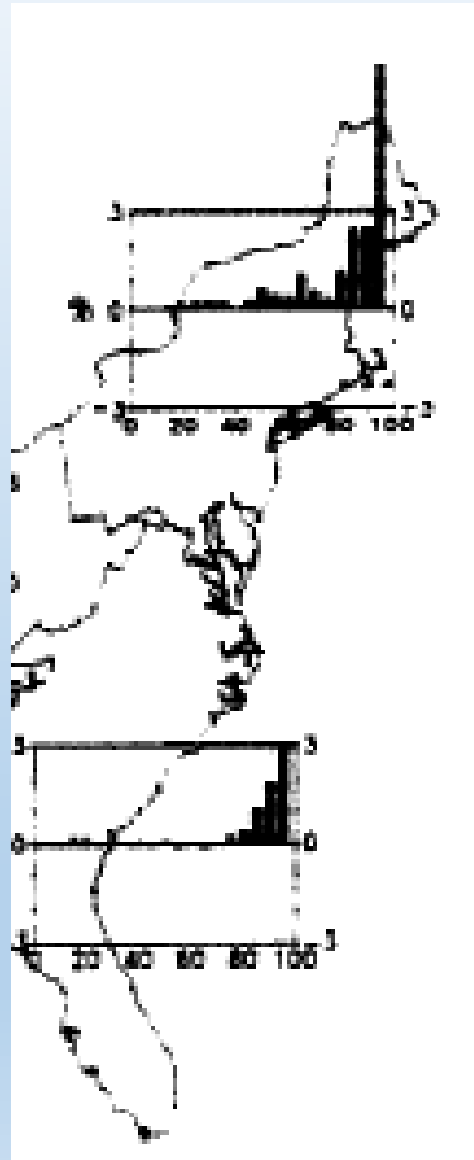


Secular Trends of Precipitation Amount, Frequency, and Intensity in the United States



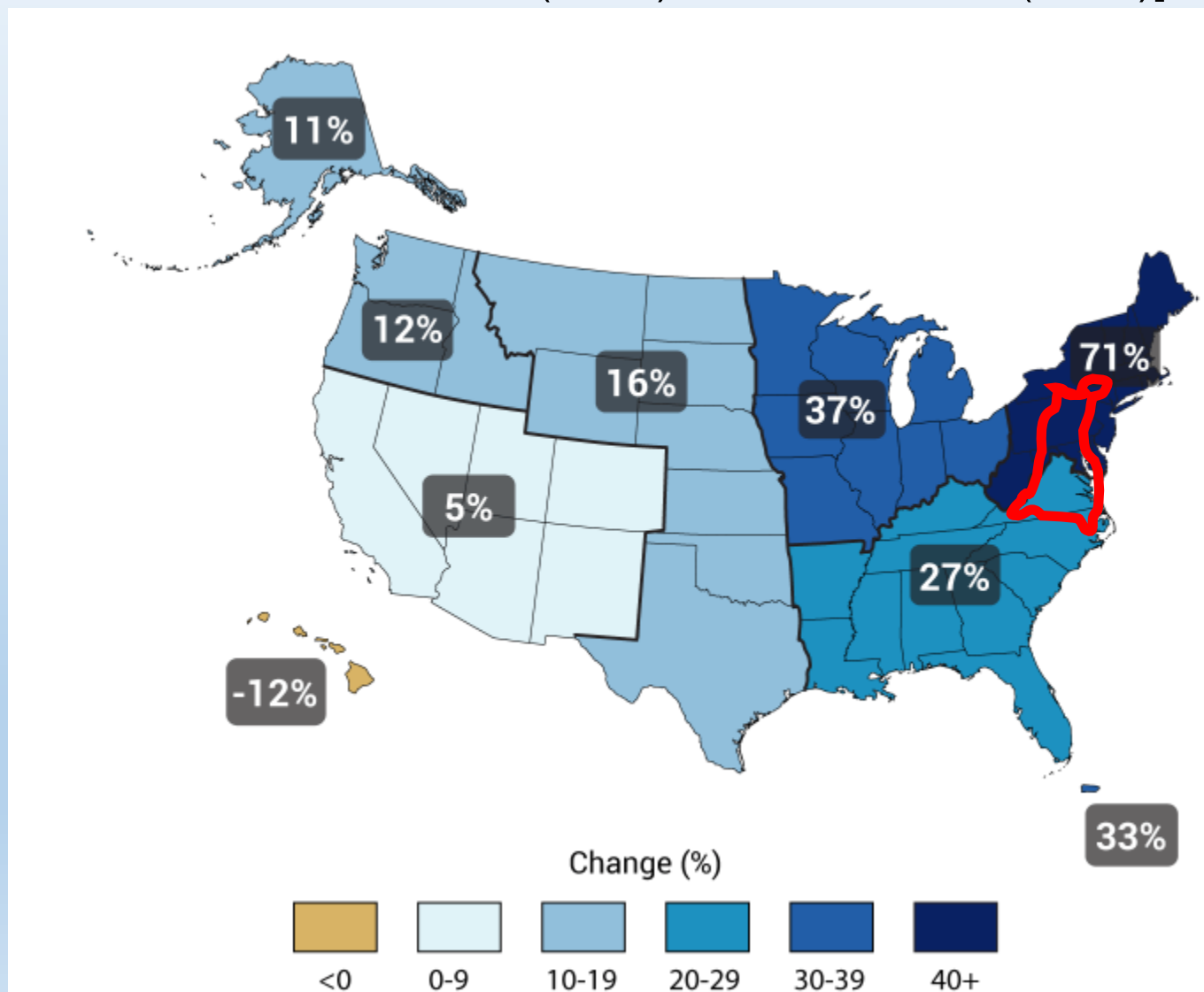
Thomas R. Karl and Richard W. Knight
NOAA/NESDIS/National Climatic Data Center, Asheville, North Carolina

Bulletin of the American Meteorological Society, 1998



Observed Change in Very Heavy Precipitation


Percent increase in heaviest 1% of all daily events from 1958 to 2012 [in U.S. Climate Assessment (2014), from Karl et al. (2009)]



Objective

Use Historical Records in Precipitation (P) and Discharge (Q) to Compare Trends in the Chesapeake Bay Watershed

How are changes in P being manifested in Q?



Linear Regression Trends
1927-2014
27 Watersheds

Precipitation: (PRISM data, monthly)

Discharge: (USGS gages, daily)

Precipitation

Site ID	Slope	t-ratio	p-value
04252500	0.0167	3.18	0.0015
01512500	0.0154	3.40	0.0007
01503000	0.0160	3.42	0.0007
01531000	0.0108	2.41	0.0162
01531500	0.0136	3.09	0.0021
01532000	0.0126	2.55	0.0110
01534000	0.0130	2.46	0.0141
01550000	0.0123	2.45	0.0146
01543000	0.0089	1.82	0.0684
01545500	0.0087	1.83	0.0682
01536500	0.0133	2.97	0.0031
01551500	0.0103	2.17	0.0305
01439500	0.0143	2.28	0.0229
01541500	0.0066	1.33	0.1836
01540500	0.0132	2.89	0.0039
01541000	0.0077	1.56	0.1187
01567000	0.0082	1.64	0.1007
01570500	0.0119	2.59	0.0098
01562000	0.0083	1.67	0.0955
01638500	0.0083	1.69	0.0908
01608500	0.0080	1.67	0.0953
01636500	0.0086	1.60	0.1097
01606500	0.0084	1.73	0.0835
01668000	0.0106	1.73	0.0841
02035000	0.0066	1.17	0.2428
02019500	0.0052	1.01	0.3131
03488000	0.0052	1.01	0.3108

NORTH



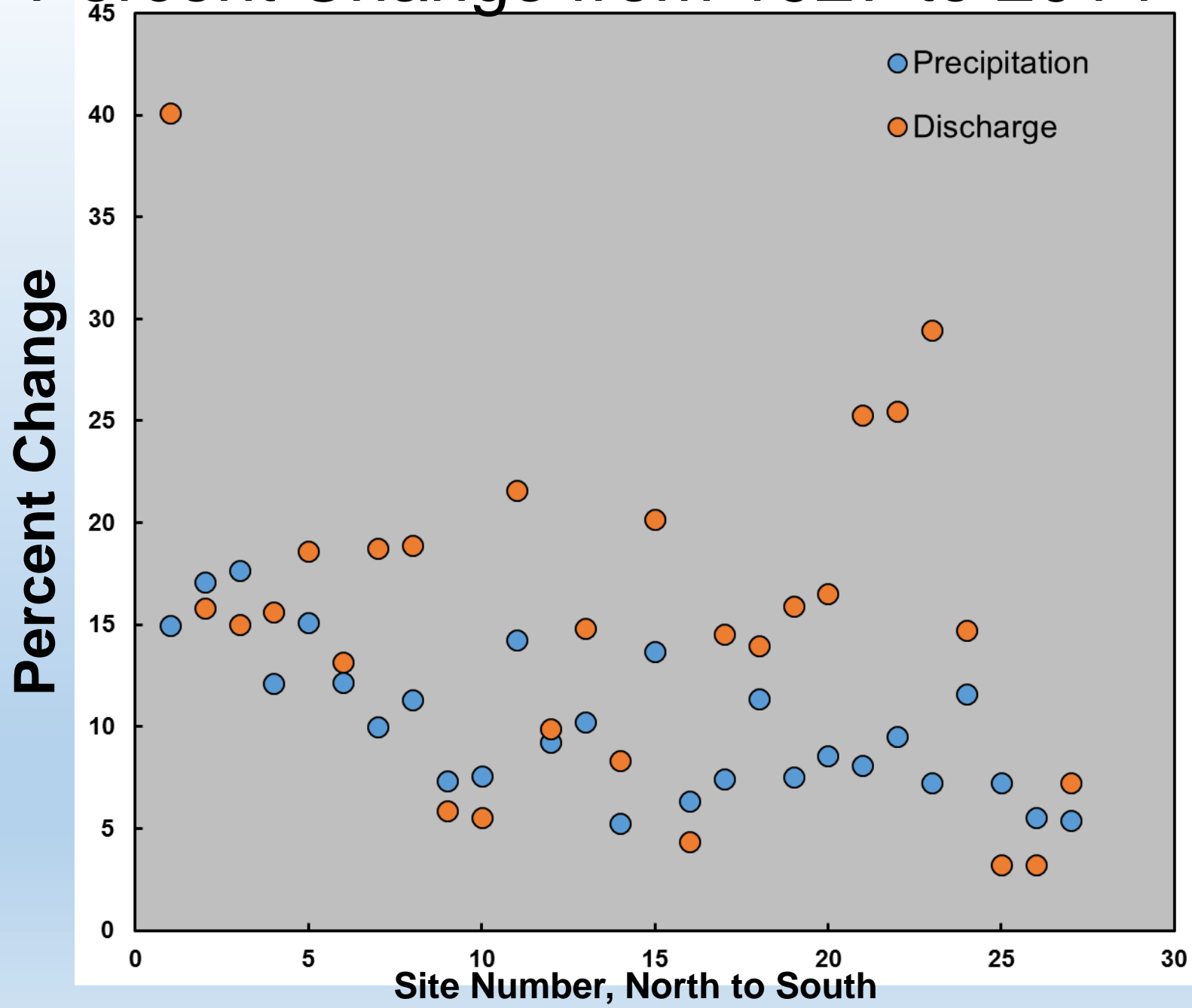
SOUTH

Discharge

Site ID	Slope	t-ratio	p-value
04252500	2.906	17.2	<0.0001
01512500	4.183	6.07	<0.0001
01503000	5.869	5.80	<0.0001
01531000	4.452	4.27	<0.0001
01531500	21.33	6.63	<0.0001
01532000	0.4106	2.83	0.0047
01534000	1.106	5.23	<0.0001
01550000	0.5808	5.35	<0.0001
01543000	0.2963	1.74	0.0821
01545500	3.079	2.13	0.0334
01536500	31.33	7.79	<0.0001
01551500	9.785	3.77	0.0002
01439500	0.3826	6.12	<0.0001
01541500	0.5346	2.94	0.0033
01540500	33.29	7.65	<0.0001
01541000	0.2716	1.49	0.1350
01567000	6.639	5.26	<0.0001
01570500	51.63	5.69	<0.0001
01562000	1.562	4.64	<0.0001
01638500	16.78	5.66	<0.0001
01608500	3.500	6.05	<0.0001
01636500	7.000	7.42	<0.0001
01606500	2.189	7.70	<0.0001
01668000	2.640	4.04	<0.0001
02035000	1.516	1.24	0.2155
02019500	0.8955	1.07	0.2859
03488000	0.2362	2.24	0.0249

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Percent Change from 1927 to 2014



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Specific Quantiles in P and Q

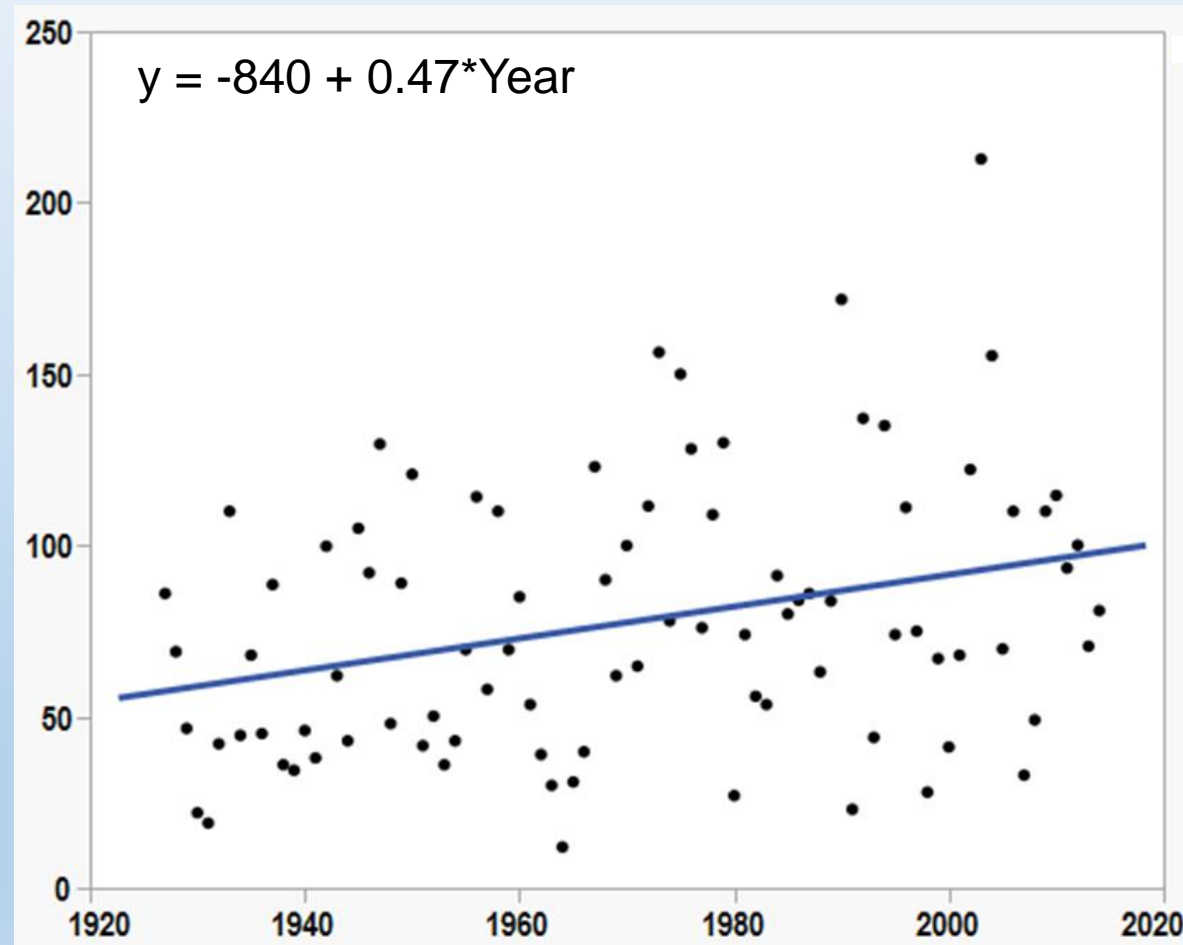


Methods


For each of the 27 watersheds:

1. Analyze annual distribution of:
 - monthly total precipitation
 - daily mean Q
2. Record P (cm) and Q (cfs) that corresponds to each decile (0th, 10th, 20th, ... 100th) for each year
3. Determine the slope of the linear regression line for the whole period for each decile

Q that corresponds to 30th decile for each year at site 01550000



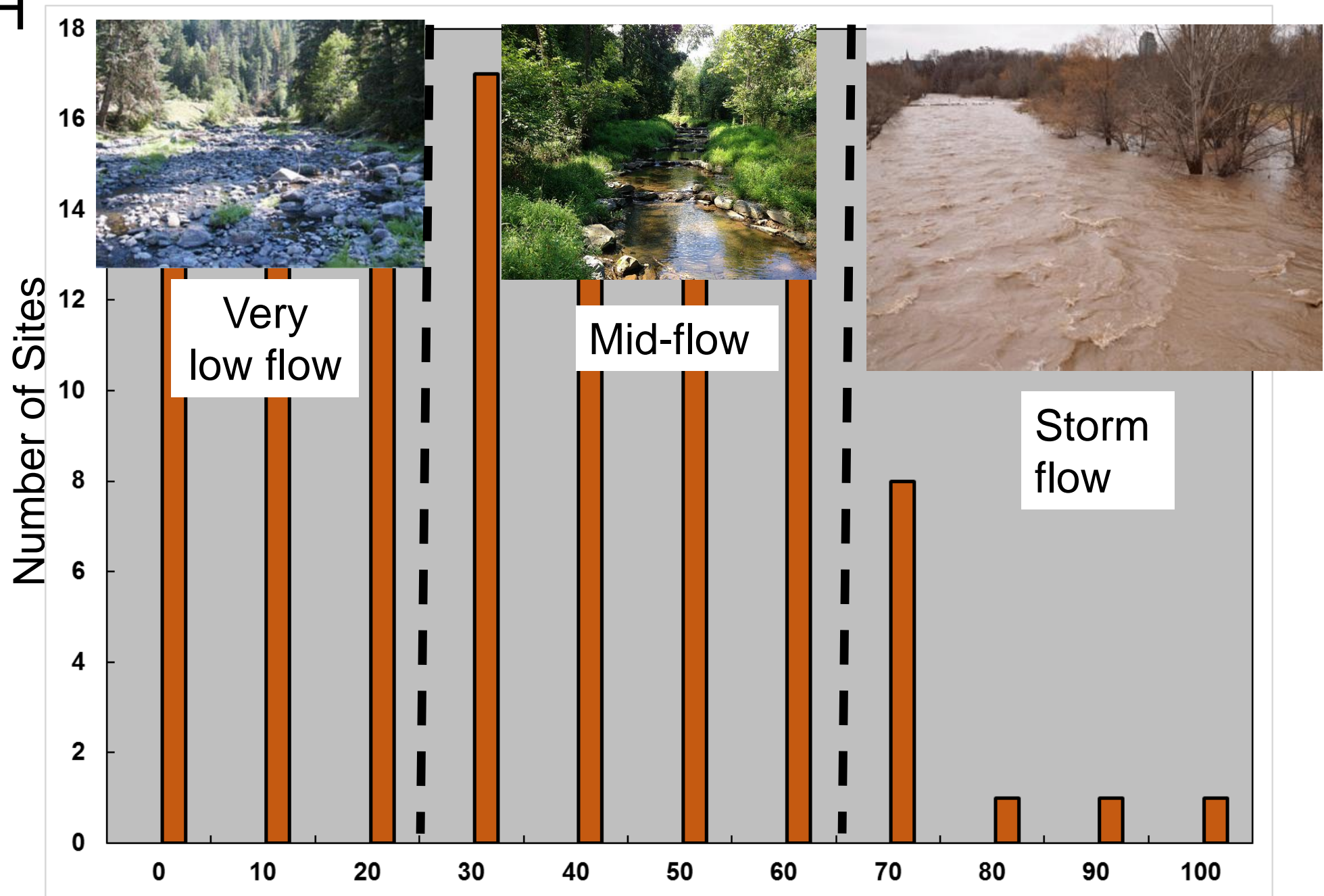
Slope = 0.4655; t-ratio = 2.98; p-value = 0.0038



Comparison of Trends in P and Q by Decile

Northern Sites first,
followed by Southern Sites

NORTH



Provisional

Northern Sites 1927-2014 Trends 0th decile

Precipitation

Site ID	Slope	t-ratio	p-value
04252500	0.0112	1.75	0.0833
01512500	0.0053	1.10	0.2759
01503000	0.0011	0.21	0.8346
01531000	0.0046	1.17	0.2465
01531500	0.0039	0.85	0.3970
01532000	0.0066	1.29	0.2021
01534000	0.0064	1.23	0.2212
01550000	0.0057	1.10	0.2758
01543000	0.0088	1.69	0.0945
01545500	0.0071	1.29	0.2017
01536500	0.0041	0.88	0.3828
01551500	0.0058	1.07	0.2874
01439500	0.0045	0.73	0.4704
01541500	0.0044	0.72	0.4708
01540500	0.0038	0.79	0.4316
01541000	0.0089	1.43	0.1552
01567000	0.0015	0.25	0.8038
01570500	0.0030	0.57	0.5735

Discharge

Site ID	Slope	t-ratio	p-value
04252500	0.7375	4.10	<0.0001
01512500	1.708	3.44	0.0009
01503000	1.960	2.82	0.0059
01531000	1.577	4.29	<0.0001
01531500	6.701	3.35	0.0012
01532000	0.0620	1.99	0.0501
01534000	0.2667	3.12	0.0024
01550000	0.0450	0.85	0.3954
01543000	0.0924	1.69	0.0956
01545500	3.627	3.81	0.0003
01536500	7.903	2.99	0.0036
01551500	6.907	3.61	0.0005
01439500	0.0094	0.14	0.8915
01541500	0.6058	5.83	<0.0001
01540500	10.63	3.49	0.0008
01541000	0.5839	6.37	<0.0001
01567000	4.099	4.47	<0.0001
01570500	27.83	3.66	0.0004

Provisional

Northern Sites 1927-2014 Trends 10th decile

Precipitation

Site ID	Slope	t-ratio	p-value
04252500	0.0112	1.84	0.0700
01512500	0.0057	1.29	0.2006
01503000	0.0023	0.49	0.6238
01531000	0.0045	1.15	0.2523
01531500	0.0041	0.96	0.3374
01532000	0.0060	1.28	0.2045
01534000	0.0059	1.21	0.2294
01550000	0.0048	0.99	0.3274
01543000	0.0074	1.58	0.1182
01545500	0.0058	1.17	0.2445
01536500	0.0041	0.95	0.3457
01551500	0.0042	0.85	0.3977
01439500	0.0034	0.59	0.5597
01541500	0.0034	0.61	0.5464
01540500	0.0040	0.80	0.3779
01541000	0.0081	1.44	0.1528
01567000	0.0025	0.47	0.6427
01570500	0.0028	0.57	0.5679

Discharge

Site ID	Slope	t-ratio	p-value
04252500	0.9837	3.82	0.0003
01512500	3.206	3.58	0.0006
01503000	3.823	2.78	0.0067
01531000	2.547	3.51	0.0007
01531500	12.96	3.43	0.0009
01532000	0.1358	1.99	0.0494
01534000	0.5160	2.83	0.0058
01550000	0.2251	2.38	0.0194
01543000	0.3379	2.67	0.0090
01545500	6.758	3.49	0.0008
01536500	16.28	3.24	0.0017
01551500	12.18	3.36	0.0012
01439500	0.1260	1.00	0.3205
01541500	0.8510	4.43	<0.0001
01540500	20.43	3.50	0.0007
01541000	0.7967	4.82	<0.0001
01567000	4.671	3.16	0.0021
01570500	43.16	3.18	0.0020

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Northern Sites 1927-2014 Trends 20th decile

Precipitation

Site ID	Slope	t-ratio	p-value
04252500	0.0098	1.73	0.0865
01512500	0.0108	2.51	0.0141
01503000	0.0087	1.84	0.0688
01531000	0.0050	1.20	0.2353
01531500	0.0073	1.69	0.0954
01532000	0.0058	1.22	0.2256
01534000	0.0056	1.08	0.2840
01550000	0.0035	0.69	0.4905
01543000	0.0043	0.93	0.3535
01545500	0.0031	0.61	0.5453
01536500	0.0070	1.58	0.1185
01551500	0.0025	0.49	0.6286
01439500	0.0014	0.24	0.8101
01541500	0.0008	0.15	0.8772
01540500	0.0067	1.53	0.1302
01541000	0.0042	0.79	0.4310
01567000	0.0023	0.45	0.6560
01570500	0.0047	0.96	0.3390

Discharge

Site ID	Slope	t-ratio	p-value
04252500	1.342	4.30	<0.0001
01512500	4.145	3.50	0.0007
01503000	4.914	2.64	0.0099
01531000	3.524	3.47	0.0008
01531500	16.75	3.30	0.0014
01532000	0.1876	1.97	0.0525
01534000	0.6493	2.66	0.0093
01550000	0.3480	2.71	0.0082
01543000	0.4929	2.61	0.0106
01545500	8.150	3.15	0.0022
01536500	20.43	3.22	0.0018
01551500	15.57	3.37	0.0011
01439500	0.0848	0.51	0.6119
01541500	1.084	4.17	<0.0001
01540500	24.59	3.40	0.0010
01541000	0.9546	4.18	<0.0001
01567000	5.292	2.60	0.0108
01570500	52.19	3.06	0.0030

Provisional

Northern Sites

1927-2014 Trends

30th decile

Precipitation

Site ID	Slope	t-ratio	p-value
04252500	0.0080	1.34	0.1842
01512500	0.0122	2.77	0.0069
01503000	0.0119	2.54	0.0129
01531000	0.0056	1.30	0.1971
01531500	0.0071	1.58	0.1171
01532000	0.0016	0.34	0.7366
01534000	0.0061	1.14	0.2594
01550000	0.0033	0.65	0.5172
01543000	0.0039	0.83	0.4065
01545500	0.0044	0.89	0.3751
01536500	0.0070	1.48	0.1439
01551500	0.0075	1.47	0.1447
01439500	0.0044	0.69	0.4930
01541500	0.0041	0.75	0.4548
01540500	0.0066	1.33	0.1860
01541000	0.0035	0.65	0.5183
01567000	0.0074	1.41	0.1619
01570500	0.0064	1.20	0.2349

Discharge

Site ID	Slope	t-ratio	p-value
04252500	1.645	4.88	<0.0001
01512500	4.819	3.30	0.0014
01503000	6.012	2.65	0.0095
01531000	4.477	3.39	0.0011
01531500	20.47	3.27	0.0016
01532000	0.2722	2.10	0.0389
01534000	0.8485	2.87	0.0052
01550000	0.4655	2.98	0.0038
01543000	0.6996	2.91	0.0047
01545500	9.822	3.05	0.0031
01536500	25.47	3.23	0.0018
01551500	19.58	3.50	0.0007
01439500	0.1708	0.87	0.3855
01541500	1.257	3.91	0.0002
01540500	30.44	3.33	0.0013
01541000	1.146	4.01	0.0001
01567000	6.140	2.32	0.0228
01570500	60.29	2.82	0.0059

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Northern Sites 1927-2014 Trends 40th decile

Precipitation

Site ID	Slope	t-ratio	p-value
04252500	0.010	1.76	0.0814
01512500	0.0100	1.99	0.0500
01503000	0.0115	2.26	0.0261
01531000	0.0091	2.23	0.0284
01531500	0.0116	2.46	0.0161
01532000	0.0101	2.12	0.0368
01534000	0.0077	1.49	0.1401
01550000	0.0102	2.00	0.0491
01543000	0.0028	0.54	0.5912
01545500	0.0044	0.88	0.3795
01536500	0.0111	2.30	0.0241
01551500	0.0070	1.40	0.1643
01439500	0.0093	1.39	0.1676
01541500	0.0049	0.90	0.3693
01540500	0.0108	2.21	0.0296
01541000	0.0058	1.07	0.2898
01567000	0.0072	1.29	0.2004
01570500	0.0098	1.99	0.0496

Discharge

Site ID	Slope	t-ratio	p-value
04252500	1.930	5.00	<0.0001
01512500	5.925	3.48	0.0008
01503000	8.058	3.01	0.0034
01531000	5.740	3.40	0.0010
01531500	27.24	3.65	0.0004
01532000	0.4254	2.53	0.0134
01534000	1.112	3.00	0.0036
01550000	0.5494	2.81	0.0061
01543000	0.8450	2.87	0.0052
01545500	10.61	2.77	0.0068
01536500	32.32	3.40	0.0010
01551500	21.80	3.17	0.0021
01439500	0.2375	1.08	0.2814
01541500	1.617	4.16	<0.0001
01540500	37.65	3.38	0.0011
01541000	1.325	3.77	0.0003
01567000	6.694	1.92	0.0578
01570500	71.87	2.73	0.0077

Provisional

Northern Sites 1927-2014 Trends 50th decile

Precipitation

Site ID	Slope	t-ratio	p-value
04252500	0.0144	2.33	0.0222
01512500	0.0107	1.98	0.0515
01503000	0.0111	1.99	0.0496
01531000	0.0095	2.18	0.0319
01531500	0.0102	2.09	0.0394
01532000	0.0124	2.47	0.0156
01534000	0.0078	1.42	0.1581
01550000	0.0120	2.34	0.0219
01543000	0.0070	1.34	0.1847
01545500	0.0072	1.35	0.1797
01536500	0.0099	2.00	0.0484
01551500	0.0087	1.63	0.1062
01439500	0.0107	1.47	0.1457
01541500	0.0092	1.69	0.0941
01540500	0.0099	1.98	0.0515
01541000	0.0095	1.68	0.0964
01567000	0.0064	1.02	0.3100
01570500	0.0121	2.53	0.0134

Discharge

Site ID	Slope	t-ratio	p-value
04252500	2.591	5.62	<0.0001
01512500	6.432	3.19	0.0020
01503000	8.671	2.66	0.0093
01531000	7.033	3.19	0.0020
01531500	29.28	3.27	0.0015
01532000	0.5190	2.31	0.0233
01534000	1.220	2.68	0.0088
01550000	0.7199	2.92	0.0044
01543000	0.8615	2.39	0.0191
01545500	10.73	2.28	0.0251
01536500	36.26	3.09	0.0027
01551500	21.74	2.59	0.0113
01439500	0.2385	0.99	0.3256
01541500	1.497	3.04	0.0031
01540500	43.08	3.19	0.0020
01541000	1.263	2.84	0.0056
01567000	6.389	1.51	0.1339
01570500	76.81	2.45	0.0163

Provisional

Northern Sites 1927-2014 Trends 60th decile

Precipitation

Site ID	Slope	t-ratio	p-value
04252500	0.0151	2.36	0.0204
01512500	0.0144	2.35	0.0212
01503000	0.0160	2.63	0.0100
01531000	0.1166	2.17	0.0331
01531500	0.0150	2.79	0.0065
01532000	0.0140	2.45	0.0163
01534000	0.0169	2.79	0.0064
01550000	0.0146	2.49	0.0149
01543000	0.0095	1.54	0.1275
01545500	0.0117	2.05	0.0433
01536500	0.0148	2.75	0.0073
01551500	0.0137	2.44	0.0167
01439500	0.0120	1.52	0.1324
01541500	0.0119	2.05	0.0438
01540500	0.0143	2.60	0.0110
01541000	0.0137	2.32	0.0229
01567000	0.0107	1.73	0.0867
01570500	0.02	2.65	0.0095

Discharge

Site ID	Slope	t-ratio	p-value
04252500	3.267	6.03	<0.0001
01512500	6.887	2.90	0.0048
01503000	10.04	2.59	0.0113
01531000	8.135	2.87	0.0052
01531500	33.58	2.94	0.0042
01532000	0.6273	2.15	0.0345
01534000	1.389	2.47	0.0155
01550000	0.8922	2.83	0.0057
01543000	0.9411	2.08	0.0400
01545500	11.53	2.12	0.0371
01536500	40.91	2.76	0.0070
01551500	23.19	2.32	0.0227
01439500	0.2337	0.85	0.3993
01541500	1.385	2.29	0.0245
01540500	50.21	3.04	0.0031
01541000	0.9228	1.77	0.0809
01567000	7.149	1.42	0.1592
01570500	94.50	2.60	0.0110

Provisional

Northern Sites

1927-2014 Trends

70th decile

Precipitation

Site ID	Slope	t-ratio	p-value
04252500	0.0209	2.84	0.0057
01512500	0.0156	2.41	0.0182
01503000	0.0231	3.50	0.0007
01531000	0.0152	2.33	0.0021
01531500	0.0184	2.96	0.0040
01532000	0.0175	2.54	0.0129
01534000	0.0153	2.06	0.0428
01550000	0.0196	2.85	0.0055
01543000	0.0110	1.62	0.1095
01545500	0.0140	2.28	0.0250
01536500	0.0178	2.80	0.0063
01551500	0.0154	2.49	0.0149
01439500	0.0203	2.18	0.0321
01541500	0.0157	2.57	0.0118
01540500	0.0187	2.83	0.0058
01541000	0.0160	2.63	0.0101
01567000	0.0128	1.82	0.0720
01570500	0.0182	2.69	0.0087

Discharge

Site ID	Slope	t-ratio	p-value
04252500	3.673	5.36	<0.0001
01512500	6.812	2.28	0.0252
01503000	10.11	2.12	0.0372
01531000	8.708	2.26	0.0262
01531500	31.46	2.16	0.0333
01532000	0.6101	1.57	0.1199
01534000	1.352	1.84	0.0690
01550000	0.8030	2.00	0.0483
01543000	0.7360	1.23	0.2213
01545500	5.783	0.93	0.3558
01536500	41.30	2.20	0.0304
01551500	15.42	1.26	0.2110
01439500	0.3182	0.95	0.3443
01541500	0.7363	0.98	0.3322
01540500	48.87	2.34	0.0215
01541000	0.3292	0.51	0.6124
01567000	8.356	1.36	0.1784
01570500	85.76	1.93	0.0574

Provisional

Northern Sites 1927-2014 Trends 80th decile

Precipitation

Site ID	Slope	t-ratio	p-value
04252500	0.0303	3.68	0.0004
01512500	0.0253	3.60	0.0005
01503000	0.0270	3.38	0.0011
01531000	0.0205	2.72	0.0008
01531500	0.0217	2.98	0.0037
01532000	0.0185	2.14	0.0352
01534000	0.0222	2.48	0.0150
01550000	0.0202	2.41	0.0183
01543000	0.0199	2.54	0.0130
01545500	0.0139	1.82	0.0721
01536500	0.0211	2.80	0.0063
01551500	0.0164	2.11	0.0380
01439500	0.0232	2.05	0.0437
01541500	0.0054	0.74	0.4629
01540500	0.0217	2.78	0.0066
01541000	0.0061	0.85	0.3996
01567000	0.0112	1.36	0.1780
01570500	0.0173	2.36	0.0205

Discharge

Site ID	Slope	t-ratio	p-value
04252500	4.006	4.42	<0.0001
01512500	6.307	1.48	0.1428
01503000	7.782	1.29	0.2003
01531000	6.973	1.36	0.1788
01531500	28.47	1.49	0.1398
01532000	0.6328	1.24	0.2172
01534000	1.375	1.37	0.1732
01550000	0.5289	1.04	0.3022
01543000	0.7675	1.01	0.3146
01545500	0.9157	0.12	0.9064
01536500	42.12	1.73	0.0871
01551500	1.482	0.10	0.9203
01439500	0.4427	1.05	0.2966
01541500	-0.0077	-0.01	0.9937
01540500	45.69	1.71	0.0901
01541000	-0.5069	-0.63	0.5318
01567000	6.300	0.78	0.4354
01570500	60.95	1.07	0.2857

Provisional

Northern Sites

1927-2014 Trends

90th decile

Precipitation

Site ID	Slope	t-ratio	p-value
04252500	0.0288	2.59	0.0114
01512500	0.0324	2.70	0.0083
01503000	0.0330	2.62	0.0103
01531000	0.0160	1.25	0.2137
01531500	0.0269	2.18	0.0323
01532000	0.0262	1.73	0.0866
01534000	0.0282	1.81	0.0744
01550000	0.0223	1.54	0.1268
01543000	0.0131	0.98	0.3292
01545500	0.0138	1.09	0.2774
01536500	0.0267	2.10	0.0387
01551500	0.0185	1.45	0.1506
01439500	0.0427	2.00	0.0483
01541500	0.0056	0.44	0.6630
01540500	0.0260	1.98	0.0507
01541000	0.0036	0.29	0.7763
01567000	0.0137	1.02	0.3097
01570500	0.0205	1.59	0.1148

Discharge

Site ID	Slope	t-ratio	p-value
04252500	4.532	3.14	0.0023
01512500	6.981	1.16	0.2493
01503000	4.855	0.55	0.5866
01531000	8.565	0.99	0.3254
01531500	22.55	0.80	0.4244
01532000	0.5006	0.60	0.5500
01534000	1.205	0.78	0.4401
01550000	0.0456	0.06	0.9528
01543000	0.1294	0.10	0.9186
01545500	-8.913	-0.77	0.4413
01536500	36.69	1.01	0.3175
01551500	-14.56	-0.68	0.4977
01439500	0.7636	1.31	0.1948
01541500	-0.5389	-0.36	0.7173
01540500	27.48	0.69	0.4896
01541000	-1.634	-1.30	0.1972
01567000	12.40	0.89	0.3767
01570500	-17.23	-0.19	0.8486

Provisional

Northern Sites

1927-2014 Trends

100th decile

Precipitation

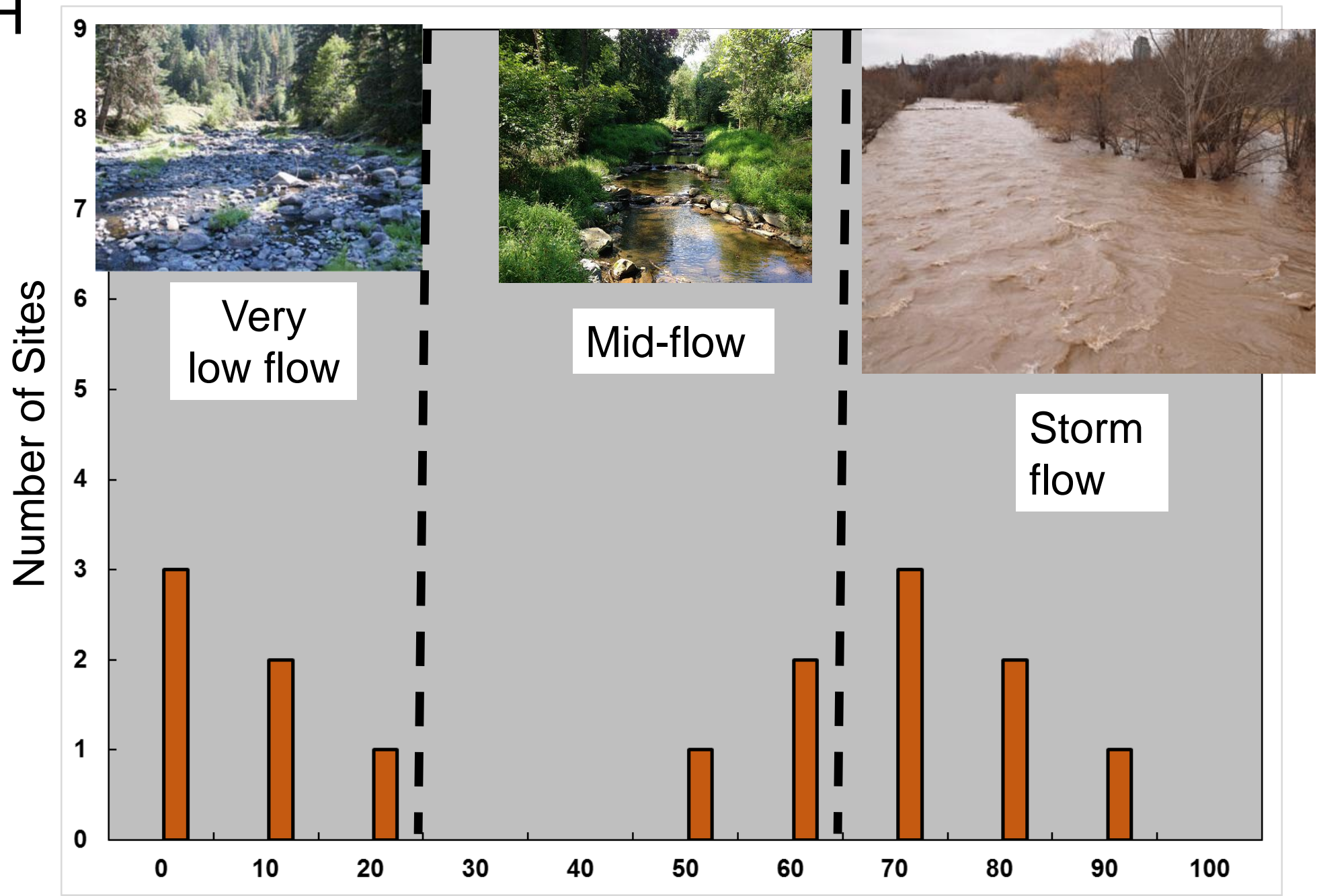
Site ID	Slope	t-ratio	p-value
04252500	0.0277	2.23	0.0284
01512500	0.0361	2.52	0.0138
01503000	0.0367	2.45	0.0162
01531000	0.0133	0.86	0.3917
01531500	0.0303	2.05	0.0439
01532000	0.0287	1.63	0.1079
01534000	0.0331	1.80	0.0747
01550000	0.0230	1.36	0.1789
01543000	0.0087	0.53	0.5962
01545500	0.0125	0.81	0.4212
01536500	0.0302	2.00	0.0487
01551500	0.0183	1.19	0.2374
01439500	0.0478	1.93	0.0575
01541500	0.0047	0.30	0.7649
01540500	0.0292	1.89	0.0628
01541000	0.0031	0.20	0.8409
01567000	0.0159	0.99	0.3264
01570500	0.0227	1.49	0.1406

Discharge

Site ID	Slope	t-ratio	p-value
04252500	21.36	2.92	0.0045
01512500	-46.26	-1.27	0.2075
01503000	-5.814	-0.12	0.9078
01531000	-188.6	-2.10	0.0388
01531500	-128.9	-0.70	0.4880
01532000	21.11	0.97	0.3343
01534000	6.785	0.31	0.7547
01550000	10.99	1.00	0.3224
01543000	-9.129	-0.59	0.5581
01545500	-245.3	-2.18	0.0317
01536500	-10.26	-0.05	0.9642
01551500	-167.3	-0.91	0.3650
01439500	2.936	0.50	0.6215
01541500	-21.03	-1.38	0.1701
01540500	-59.54	-0.26	0.7991
01541000	-5.0717	-0.31	0.7553
01567000	-80.54	-0.74	0.4617
01570500	-30.66	-0.06	0.9558

Provisional

SOUTH



Provisional

Southern Sites

1927-2014 Trends

0th decile

Precipitation

Site ID	Slope	t-ratio	p-value
01562000	0.0008	0.14	0.8903
01638500	-0.0017	-0.31	0.7553
01608500	-0.0069	-1.34	0.1823
01636500	-0.0030	-0.54	0.5910
01606500	-0.0045	-0.77	0.4427
01668000	0.0029	0.46	0.6436
02035000	-0.0053	-0.87	0.3863
02019500	-0.0059	-1.02	0.3103
03488000	0.0009	0.13	0.8960

Discharge

Site ID	Slope	t-ratio	p-value
01562000	0.1185	0.90	0.3728
01638500	5.285	2.47	0.0153
01608500	0.1397	0.57	0.5685
01636500	1.716	2.08	0.0409
01606500	0.1055	0.77	0.4428
01668000	-0.4425	-0.76	0.4486
02035000	-0.5791	-0.29	0.7744
02019500	2.061	4.46	<0.0001
03488000	0.0917	1.80	0.0760

Provisional

Southern Sites

1927-2014 Trends

10th decile

Precipitation

Site ID	Slope	t-ratio	p-value
01562000	0.0017	0.32	0.7481
01638500	-0.0007	-0.14	0.8914
01608500	-0.0036	-0.78	0.4365
01636500	-0.0014	-0.26	0.7922
01606500	-0.0019	-0.37	0.7095
01668000	0.0035	0.60	0.5500
02035000	-0.0019	-0.34	0.7323
02019500	-0.0031	-0.57	0.5693
03488000	0.0029	0.44	0.6591

Discharge

Site ID	Slope	t-ratio	p-value
01562000	0.3082	1.24	0.2176
01638500	8.491	2.16	0.0334
01608500	0.4845	1.12	0.2672
01636500	1.157	0.90	0.3709
01606500	0.2082	0.88	0.3813
01668000	-0.3830	-0.42	0.6762
02035000	-1.379	-0.46	0.6471
02019500	2.038	2.97	0.0039
03488000	0.0915	1.00	0.3194

Provisional

Southern Sites

1927-2014 Trends

20th decile

Precipitation

Site ID	Slope	t-ratio	p-value
01562000	0.0036	0.77	0.4416
01638500	0.0045	0.92	0.3585
01608500	0.0042	0.97	0.3347
01636500	0.0030	0.59	0.5557
01606500	0.0038	0.85	0.3059
01668000	0.0045	0.79	0.4305
02035000	0.0072	1.27	0.2089
02019500	0.0029	0.55	0.5860
03488000	0.0075	1.33	0.1883

Discharge

Site ID	Slope	t-ratio	p-value
01562000	0.5673	1.48	0.1437
01638500	8.143	1.62	0.1091
01608500	0.8373	1.41	0.1610
01636500	1.843	1.13	0.2626
01606500	0.3290	1.00	0.3206
01668000	-0.1545	-0.13	0.8955
02035000	-1.761	-0.45	0.6513
02019500	2.122	2.30	0.0237
03488000	0.1376	1.05	0.2976

Provisional

Southern Sites

1927-2014 Trends

30th decile

Precipitation

Site ID	Slope	t-ratio	p-value
01562000	0.0076	1.50	0.1361
01638500	0.0058	1.16	0.2498
01608500	0.0071	1.37	0.1747
01636500	0.0063	1.12	0.2651
01606500	0.0059	1.05	0.2956
01668000	0.0062	1.07	0.2865
02035000	0.0044	0.71	0.4818
02019500	0.0031	0.54	0.5887
03488000	0.0078	1.35	0.1795

Discharge

Site ID	Slope	t-ratio	p-value
01562000	0.7529	1.52	0.1322
01638500	9.463	1.42	0.1596
01608500	1.121	1.43	0.1564
01636500	2.859	1.41	0.1613
01606500	0.4286	0.99	0.3263
01668000	0.4196	0.30	0.7634
02035000	-0.0957	-0.02	0.9849
02019500	1.686	1.33	0.1879
03488000	0.1981	1.14	0.2567

Provisional

Southern Sites

1927-2014 Trends

40th decile

Precipitation

Site ID	Slope	t-ratio	p-value
01562000	0.0061	1.09	0.2791
01638500	0.0077	1.44	0.1524
01608500	0.0086	1.47	0.1462
01636500	0.0073	1.23	0.2240
01606500	0.0100	1.60	0.1137
01668000	0.0069	1.09	0.2810
02035000	0.0086	1.40	0.1648
02019500	0.0075	1.22	0.2275
03488000	0.0119	1.91	0.0600

Discharge

Site ID	Slope	t-ratio	p-value
01562000	1.144	1.78	0.0782
01638500	11.46	1.43	0.1552
01608500	1.821	1.84	0.0689
01636500	4.075	1.66	0.0996
01606500	0.7418	1.32	0.1890
01668000	0.8297	0.51	0.6108
02035000	0.3249	0.06	0.9558
02019500	1.290	0.75	0.4559
03488000	0.2359	1.12	0.2676

Provisional

Southern Sites

1927-2014 Trends

50th decile

Precipitation

Site ID	Slope	t-ratio	p-value
01562000	0.0073	1.14	0.2563
01638500	0.0101	1.76	0.0816
01608500	0.0137	2.34	0.0217
01636500	0.0099	1.57	0.1194
01606500	0.0146	2.38	0.0194
01668000	0.0113	1.73	0.0881
02035000	0.0060	0.88	0.3827
02019500	0.0074	1.16	0.2506
03488000	0.0095	1.44	0.1541

Discharge

Site ID	Slope	t-ratio	p-value
01562000	1.198	1.43	0.1572
01638500	14.63	1.52	0.1316
01608500	2.851	2.37	0.0200
01636500	4.809	1.69	0.0943
01606500	1.312	1.92	0.0581
01668000	1.402	0.78	0.4371
02035000	1.173	0.18	0.8598
02019500	0.5141	0.25	0.8038
03488000	0.3358	1.36	0.1786

Provisional

Southern Sites

1927-2014 Trends

60th decile

Precipitation

Site ID	Slope	t-ratio	p-value
01562000	0.0095	1.50	0.1372
01638500	0.0143	2.28	0.0253
01608500	0.0161	2.52	0.0137
01636500	0.0181	2.77	0.0069
01606500	0.0147	2.18	0.0322
01668000	0.0113	1.49	0.1407
02035000	0.0112	1.47	0.1451
02019500	0.0098	1.47	0.1459
03488000	0.0066	0.92	0.3589

Discharge

Site ID	Slope	t-ratio	p-value
01562000	1.307	1.20	0.2316
01638500	16.23	1.42	0.1580
01608500	3.670	2.49	0.0147
01636500	5.981	1.81	0.0735
01606500	1.785	2.15	0.0348
01668000	2.178	1.09	0.2798
02035000	2.946	0.40	0.6902
02019500	0.2670	0.11	0.9110
03488000	0.4252	1.63	0.1072

Provisional

Southern Sites

1927-2014 Trends

70th decile

Precipitation

Site ID	Slope	t-ratio	p-value
01562000	0.0112	1.54	0.1278
01638500	0.02	1.91	0.0592
01608500	0.0172	2.22	0.0290
01636500	0.0151	1.89	0.0624
01606500	0.0144	1.86	0.0660
01668000	0.0191	2.15	0.0347
02035000	0.0088	1.05	0.2960
02019500	0.0129	1.76	0.0826
03488000	0.0046	0.59	0.5559

Discharge

Site ID	Slope	t-ratio	p-value
01562000	1.439	1.06	0.2921
01638500	21.30	1.48	0.1427
01608500	4.357	2.23	0.0281
01636500	8.706	2.01	0.0472
01606500	2.470	2.23	0.0281
01668000	2.996	1.23	0.2239
02035000	5.437	0.58	0.5649
02019500	1.637	0.53	0.5971
03488000	0.5302	1.69	0.0953

Provisional

Southern Sites

1927-2014 Trends

80th decile

Precipitation

Site ID	Slope	t-ratio	p-value
01562000	0.0124	1.53	0.1287
01638500	0.0091	1.07	0.2884
01608500	0.0086	0.99	0.3264
01636500	0.0083	0.92	0.3581
01606500	0.0087	1.04	0.3036
01668000	0.0182	1.80	0.0754
02035000	0.0094	0.94	0.3480
02019500	0.0056	0.63	0.5308
03488000	0.0010	0.11	0.9124

Discharge

Site ID	Slope	t-ratio	p-value
01562000	1.685	0.92	0.3618
01638500	25.35	1.28	0.2033
01608500	5.129	1.82	0.0716
01636500	11.66	2.01	0.0481
01606500	3.235	2.10	0.0384
01668000	4.360	1.35	0.1806
02035000	9.142	0.71	0.4819
02019500	1.673	0.39	0.7004
03488000	0.6266	1.48	0.1420

Provisional

Southern Sites

1927-2014 Trends

90th decile

Precipitation

Site ID	Slope	t-ratio	p-value
01562000	0.0153	1.21	0.2297
01638500	0.0101	0.82	0.4169
01608500	0.0030	0.26	0.7963
01636500	0.0127	0.83	0.4113
01606500	0.0074	0.61	0.5431
01668000	0.0146	0.82	0.4152
02035000	0.0062	0.39	0.7004
02019500	0.0028	0.21	0.8360
03488000	-0.0036	-0.31	0.7598

Discharge

Site ID	Slope	t-ratio	p-value
01562000	3.588	1.22	0.2275
01638500	33.83	1.13	0.2622
01608500	6.446	1.46	0.1484
01636500	15.76	1.73	0.0868
01606500	5.124	2.21	0.0300
01668000	6.205	1.20	0.2334
02035000	15.30	0.77	0.4449
02019500	0.3301	0.04	0.9659
03488000	0.0303	0.04	0.9690

Provisional

Southern Sites 1927-2014 Trends 100th decile

Precipitation

Site ID	Slope	t-ratio	p-value
01562000	0.0176	1.13	0.2637
01638500	0.0115	0.77	0.4440
01608500	0.0000	0.00	0.9998
01636500	0.0161	0.86	0.3937
01606500	0.0051	0.36	0.7186
01668000	0.0143	0.64	0.5247
02035000	0.0032	0.17	0.8684
02019500	0.0013	0.08	0.9375
03488000	-0.0040	-0.30	0.7665

Discharge

Site ID	Slope	t-ratio	p-value
01562000	15.81	0.45	0.6551
01638500	-212.9	-0.74	0.4590
01608500	50.28	0.57	0.5723
01636500	-30.77	-0.24	0.8112
01606500	56.05	1.47	0.1454
01668000	21.61	0.28	0.7836
02035000	-76.76	-0.42	0.6735
02019500	18.31	0.26	0.7977
03488000	8.648	0.93	0.3570

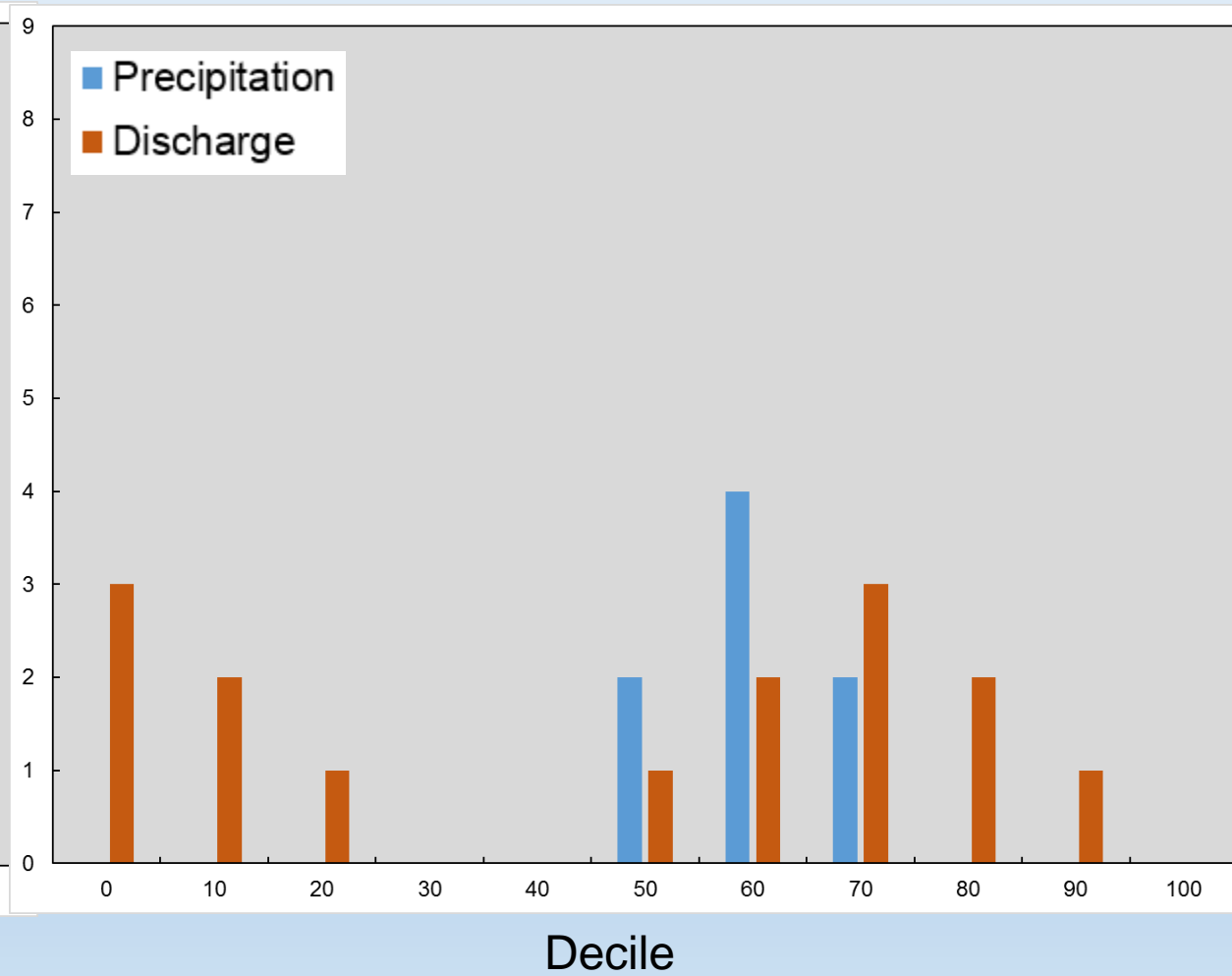
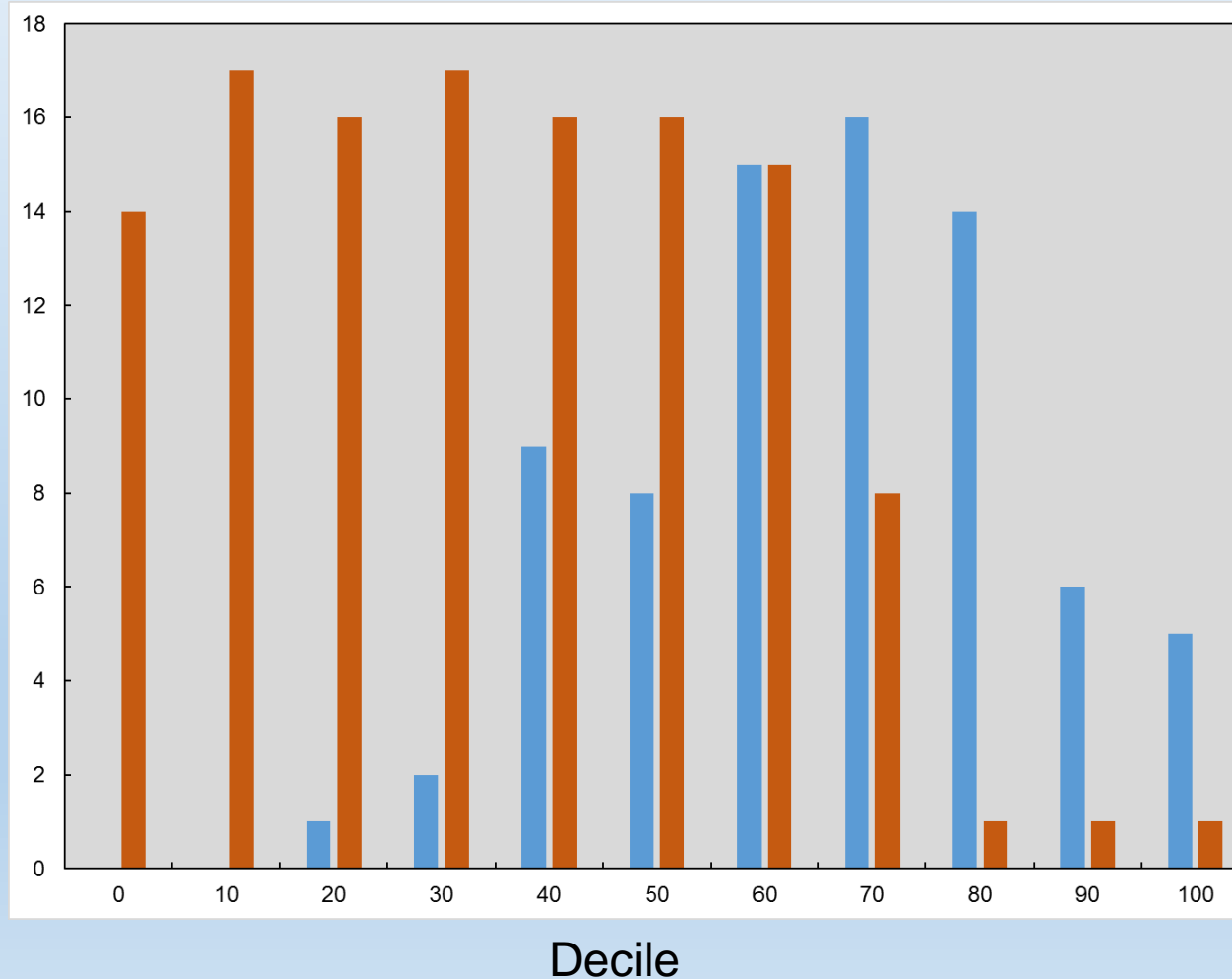
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Number of Significant Positive Trends in each Decile

Provisional

North

South





From North to South:

- Linkage in P & Q decreases
- Trends in P have lower slopes
- Fewer significant P & Q trends
- Significance of trends decreases
- Fewer significant trends in P&Q deciles

Provisional



Watershed Storage

- Sponge like:
Lag times, travel times
- Land use:
Urban, Ag, Forest
Wetlands
Dams
Withdrawals
- Snow pack and timing of snowmelt
- Antecedent conditions & ET

$$P \neq Q$$

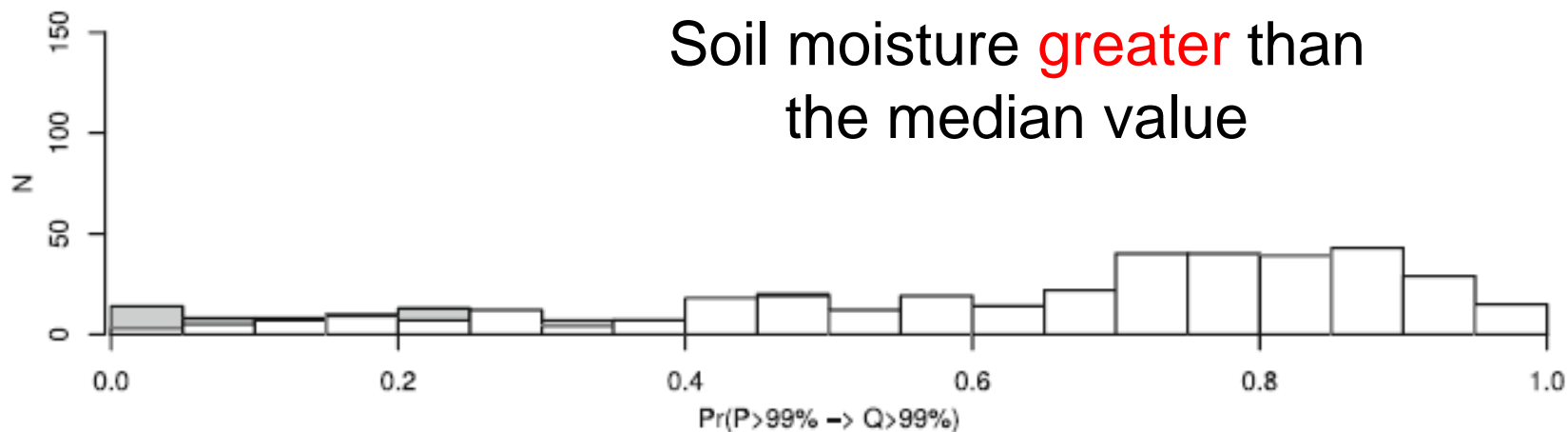
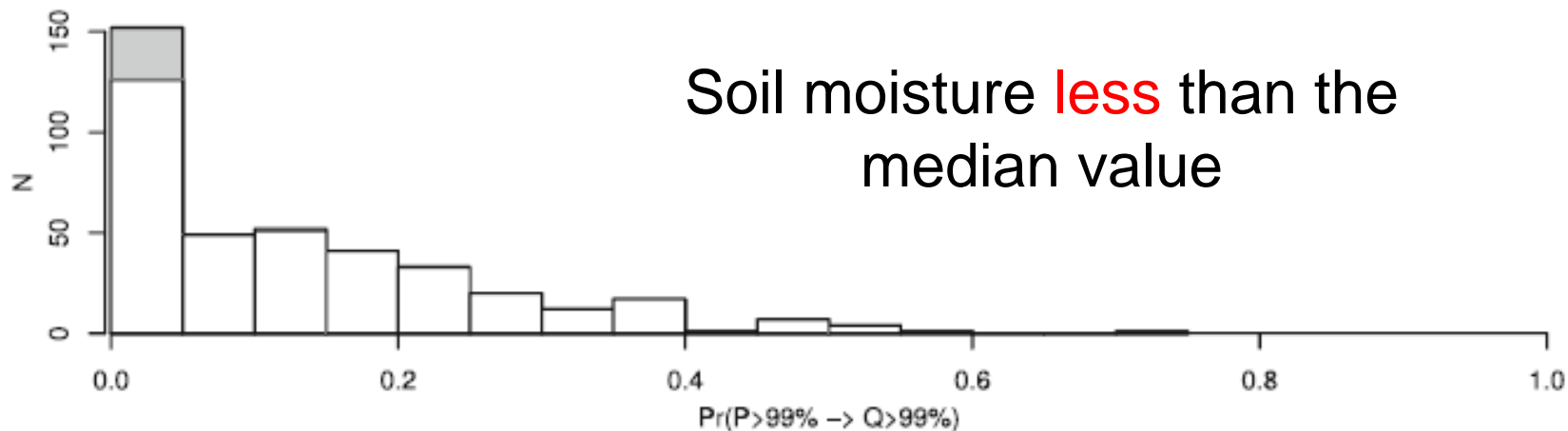


Examining why trends in very heavy precipitation should not be mistaken for trends in very high river discharge

Timothy J. Ivancic¹ • Stephen B. Shaw¹

Number of sites with the probability that a 99th percentile precipitation event results in a 99th percentile discharge event

P ≠ Q



Trends in Runoff Ratio (Q/P) 1927-2014

North


Site ID	Slope	t-ratio	p-value
04252500	0.0019	3.17	0.0021
01512500	-0.0002	-0.62	0.5363
01503000	-0.0002	-0.53	0.5980
01531000	-0.0001	-0.27	0.7904
01531500	0.0002	0.44	0.6618
01532000	-0.0001	-0.17	0.8673
01534000	0.0004	0.96	0.3387
01550000	0.0004	0.77	0.4412
01543000	-0.0002	-0.51	0.6108
01545500	-0.0002	-0.61	0.5461
01536500	0.0003	0.97	0.3353
01551500	-0.0001	-0.24	0.8084
01439500	0.0004	0.76	0.4496
01541500	0.0000	-0.08	0.9400
01540500	0.0003	0.92	0.3585
01541000	-0.0004	-0.79	0.4301
01567000	0.0001	0.32	0.7482
01570500	0.0001	0.26	0.7935

South

Site ID	Slope	t-ratio	p-value
01562000	0.0002	0.39	0.6957
01638500	0.0002	0.47	0.6392
01608500	0.0006	1.30	0.1955
01636500	0.0004	0.93	0.3529
01606500	0.0009	2.11	0.0377
01668000	0.0002	0.05	0.9619
02035000	-0.0004	-1.00	0.3208
02019500	-0.0003	-0.70	0.4862
03488000	0.0000	0.09	0.9323

P ≠ Q

Provisional



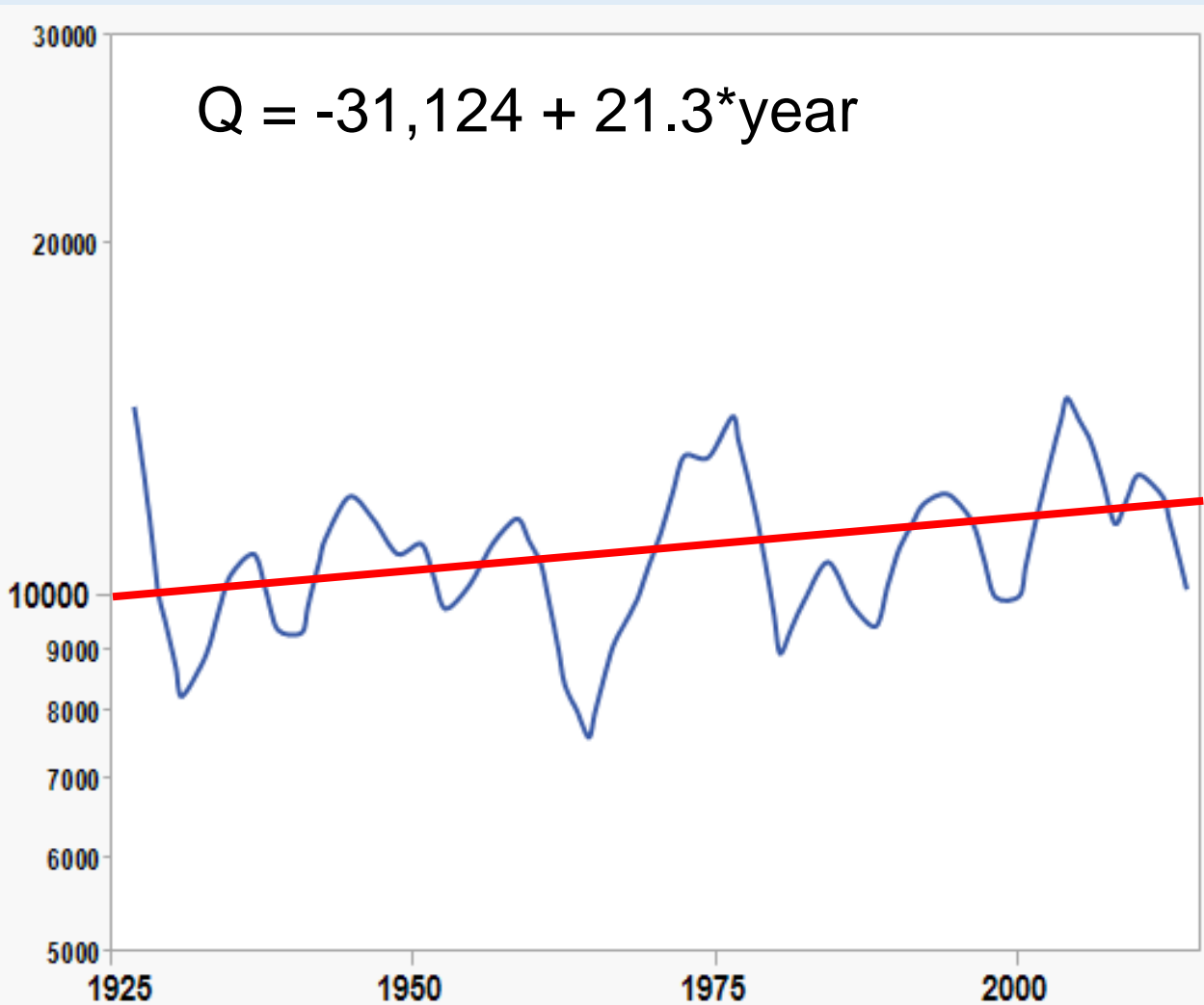
What about the period
specific to the WSM?

1985-2014

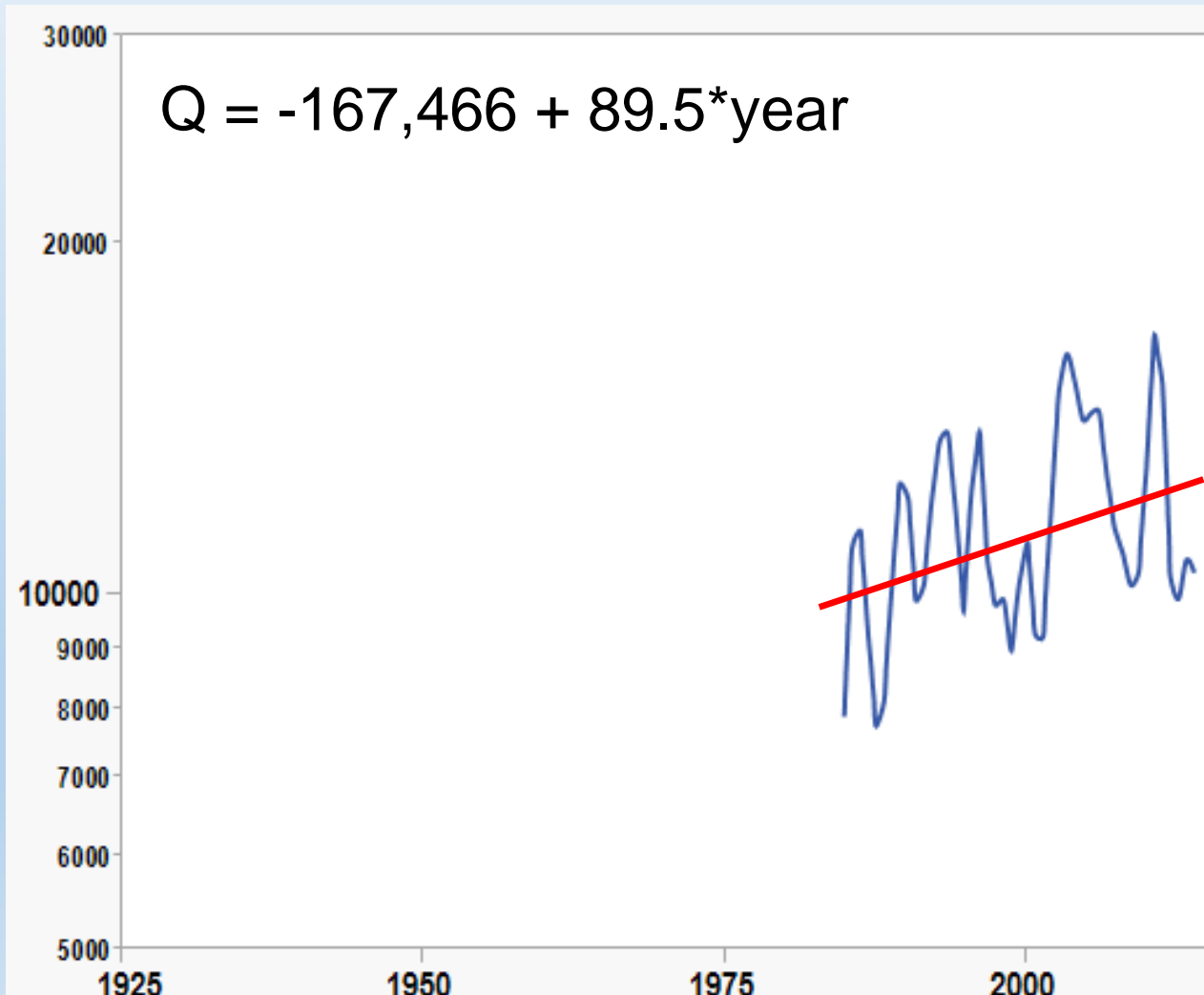


Daily Mean Discharge: Site 01531500

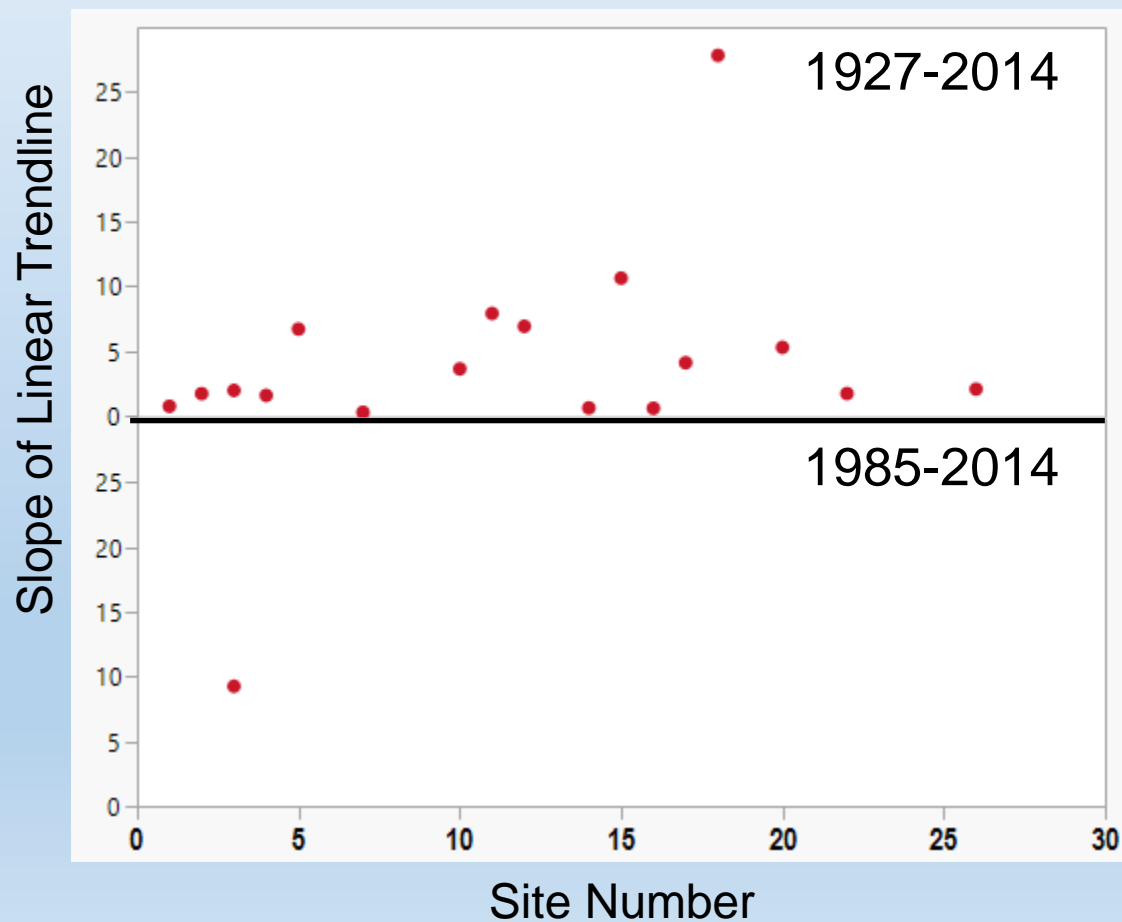
1927-2014



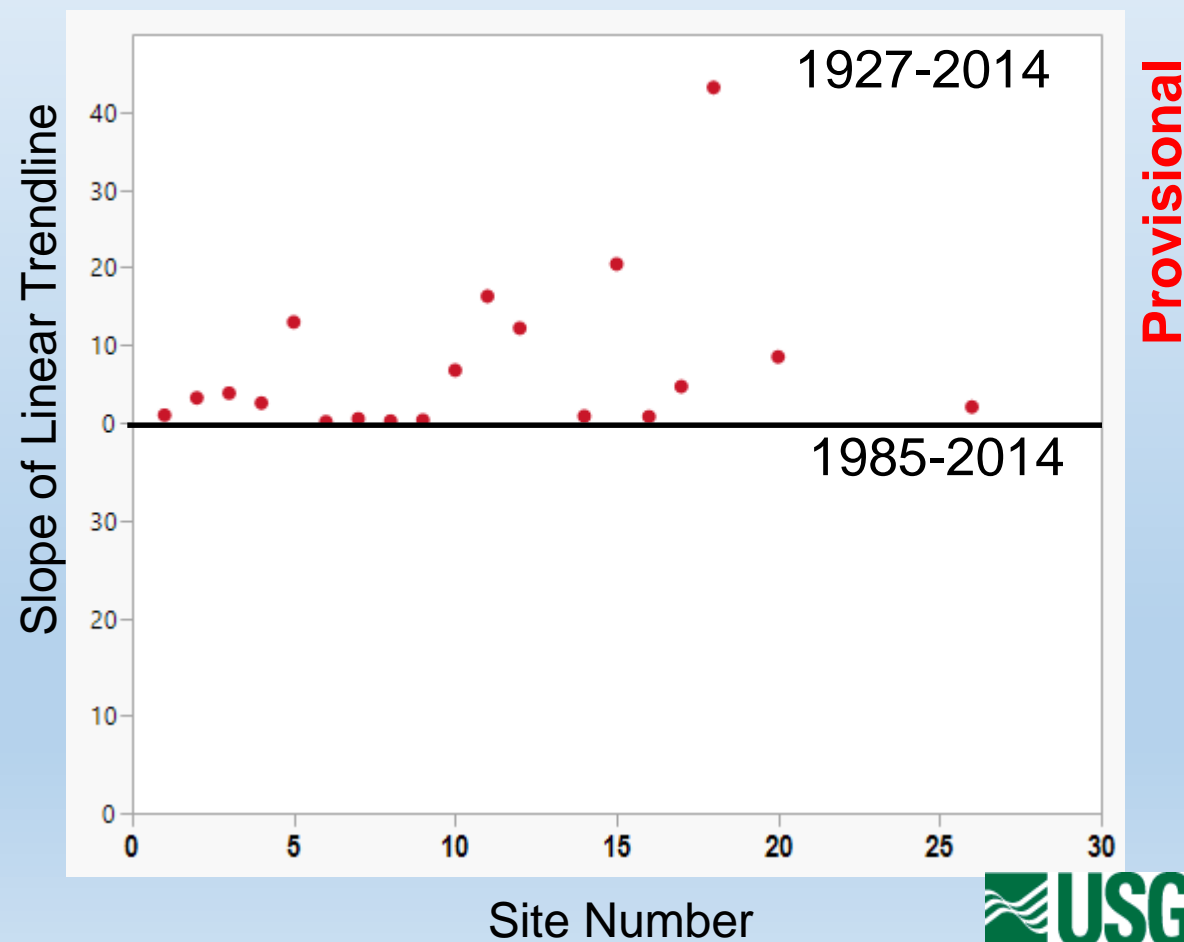
1985-2014



Significant slopes at 0th decile

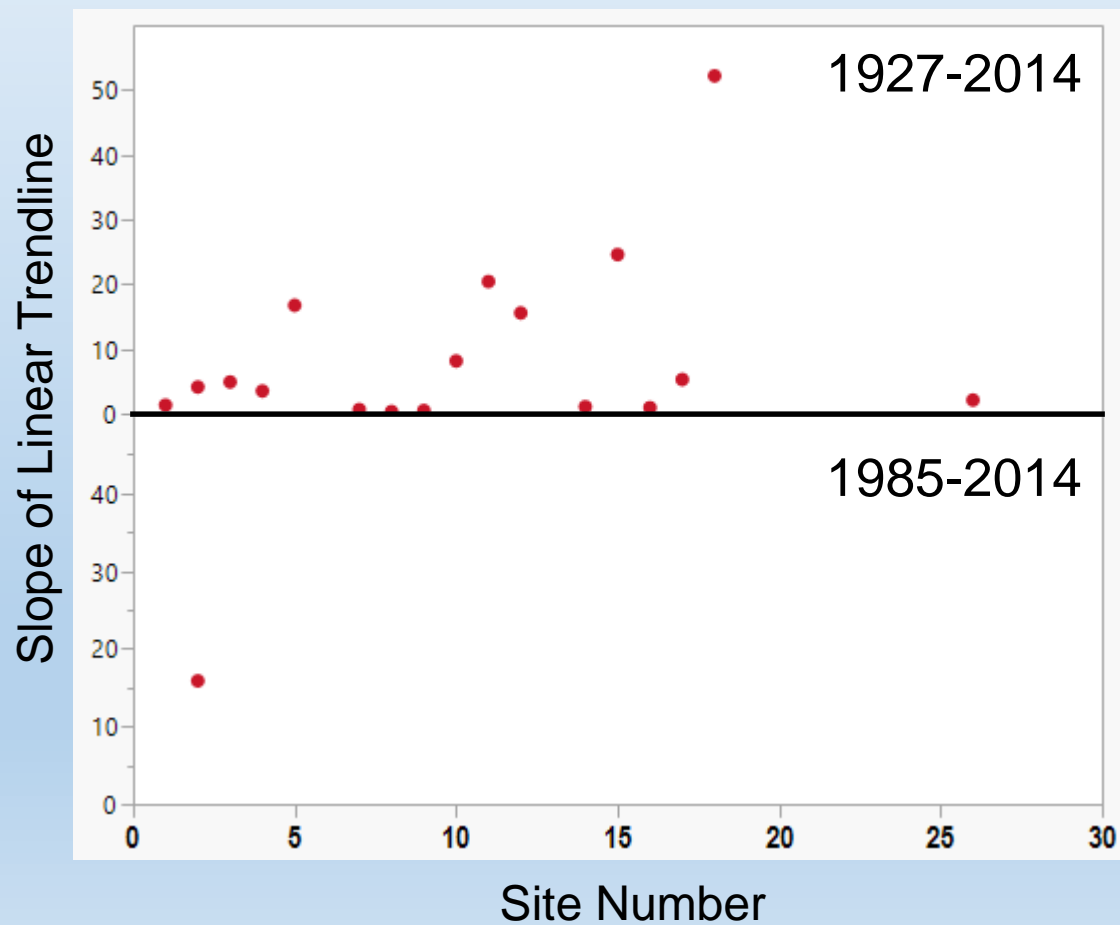


Significant slopes at 10th decile

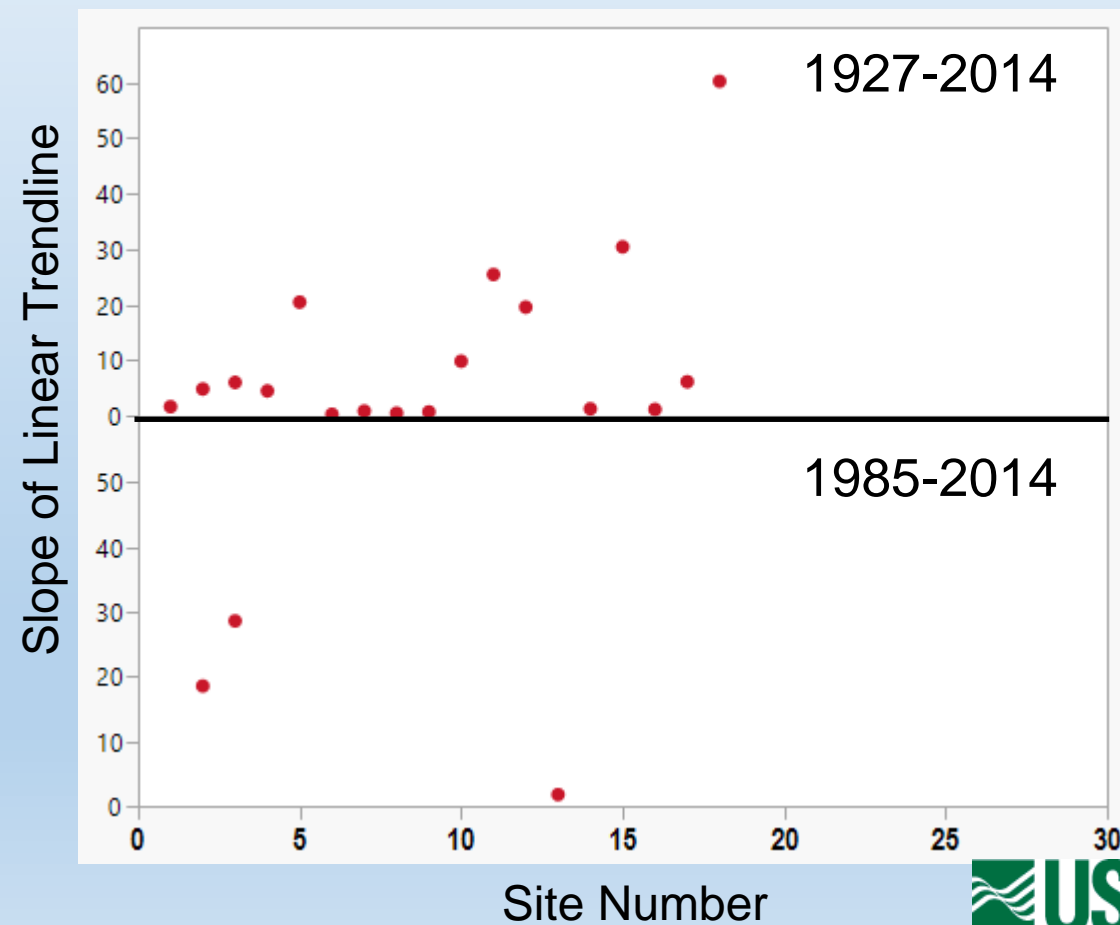


Provisional

Significant slopes at 20th decile

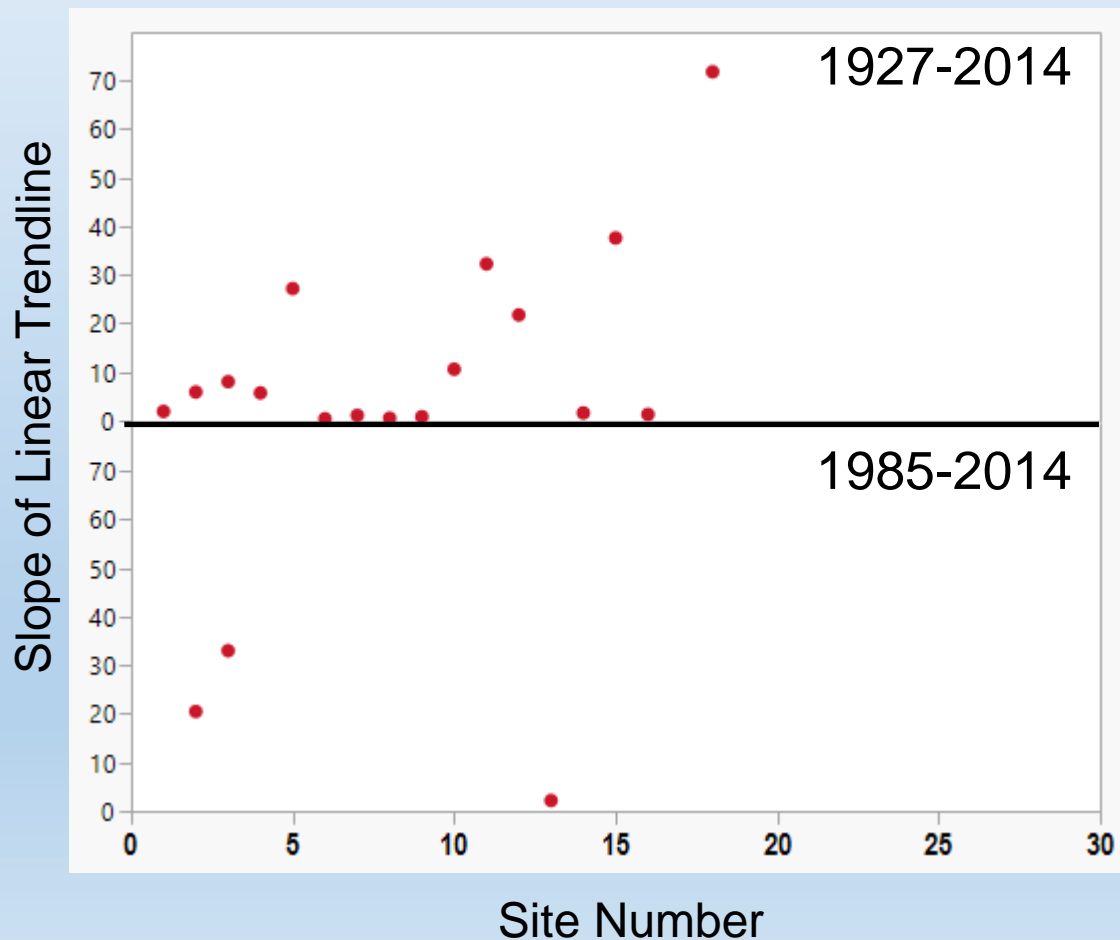


Significant slopes at 30th decile

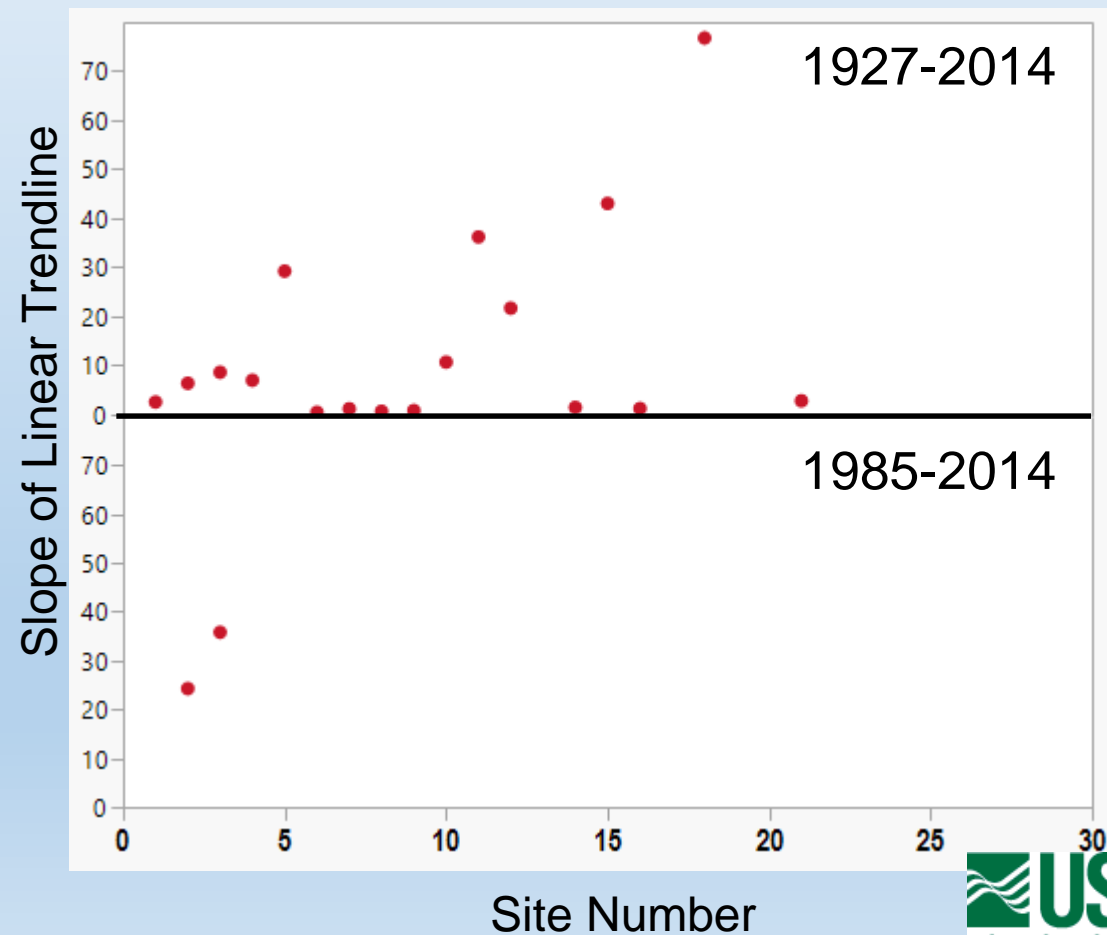


Provisional

Significant slopes at 40th decile

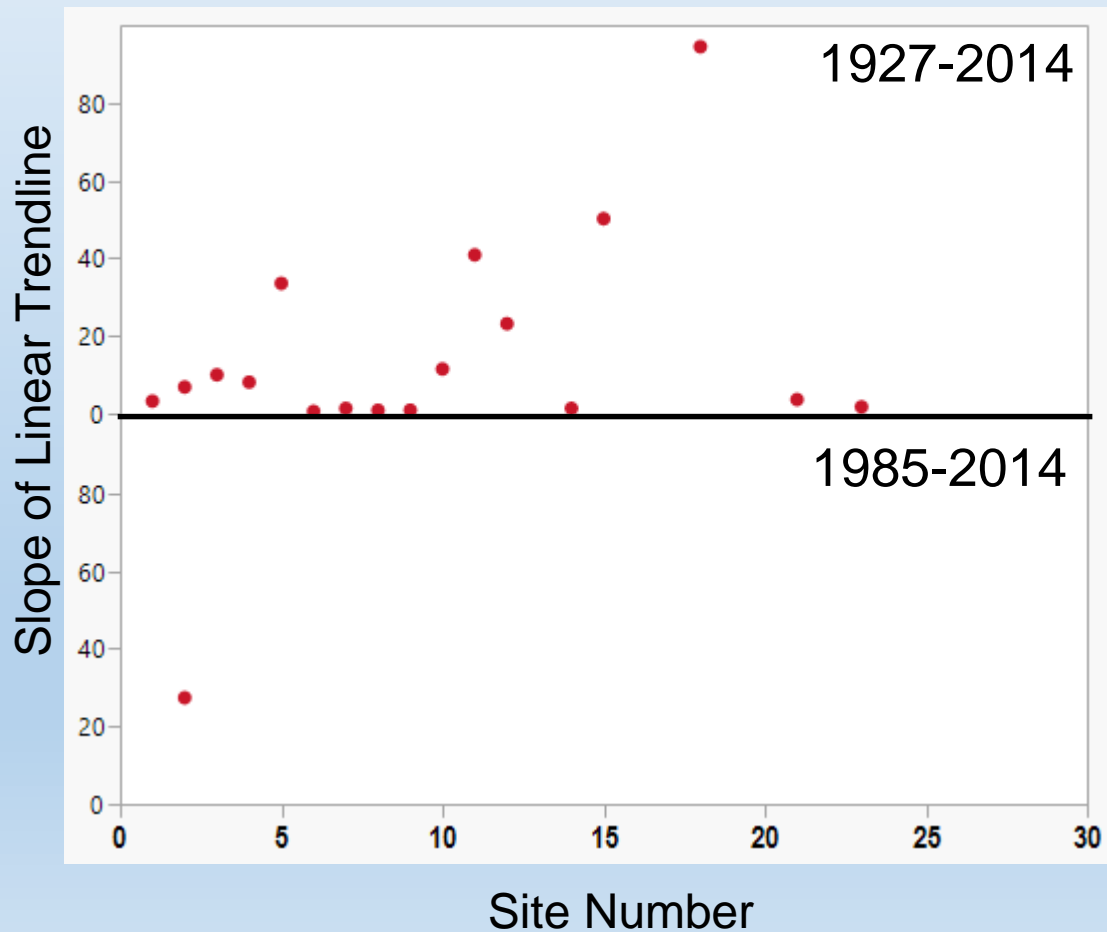


Significant slopes at 50th decile

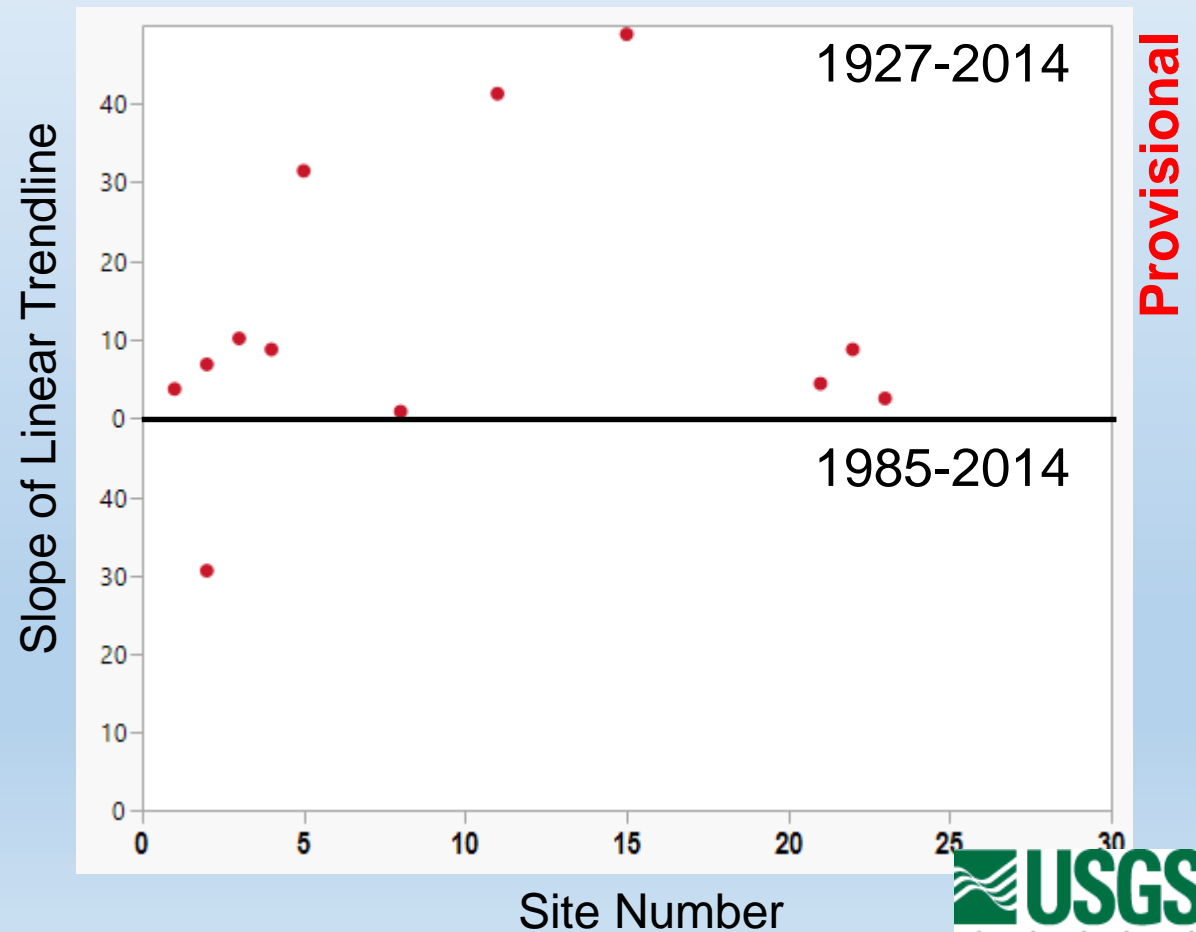


Provisional

Significant slopes at 60th decile

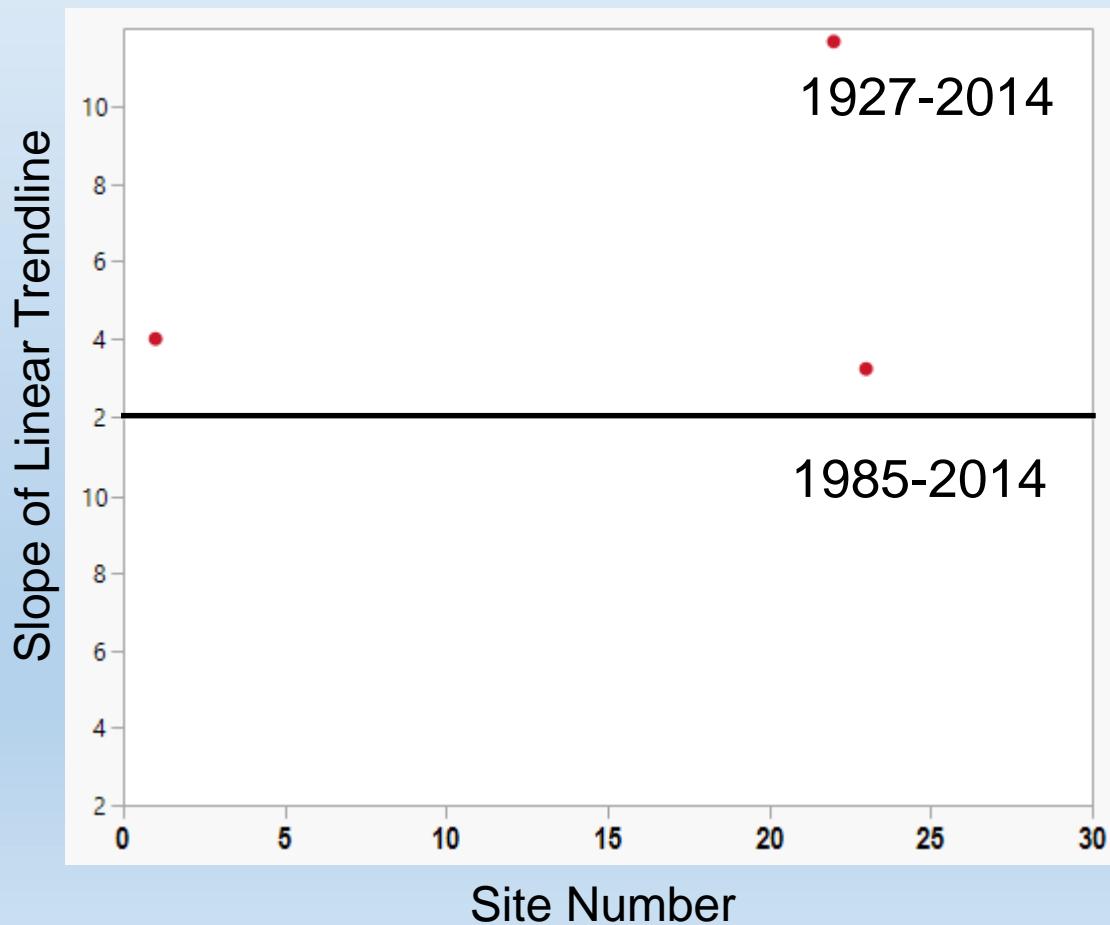


Significant slopes at 70th decile

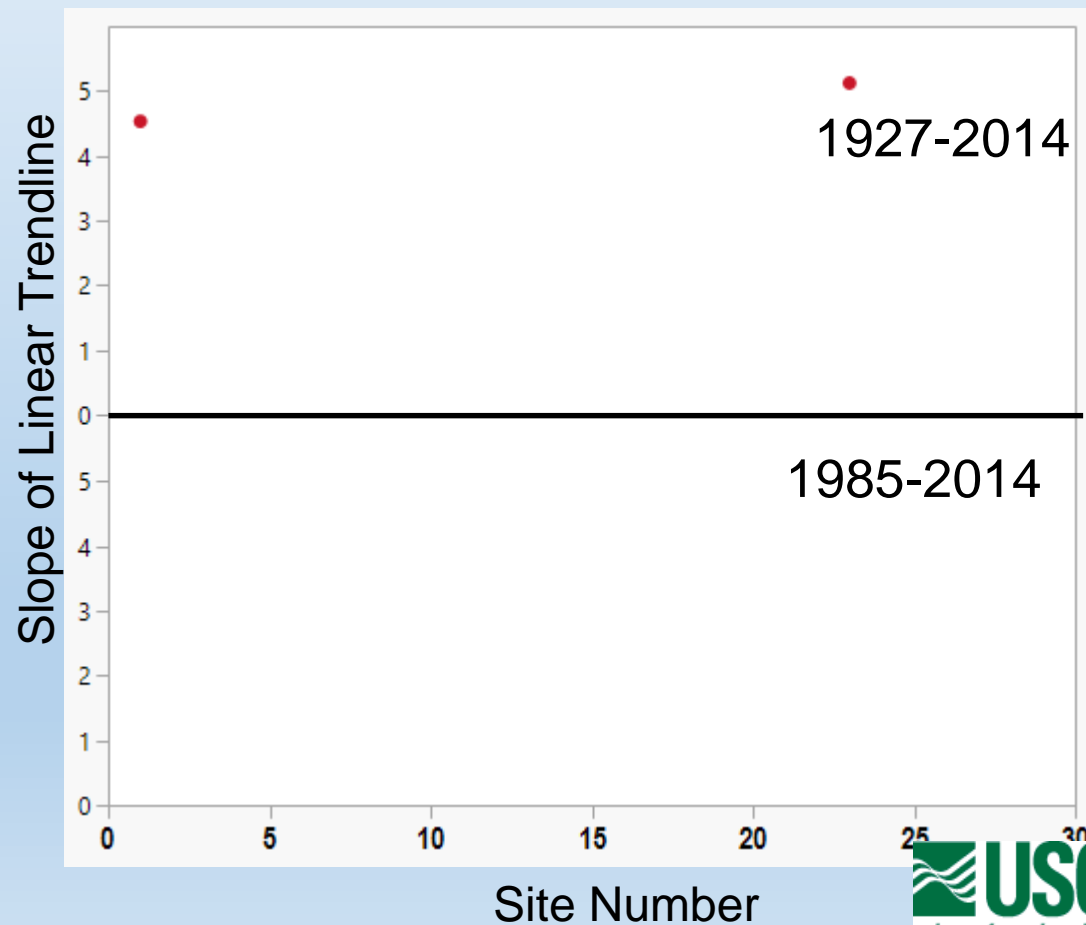


Provisional

Significant slopes at 80th decile

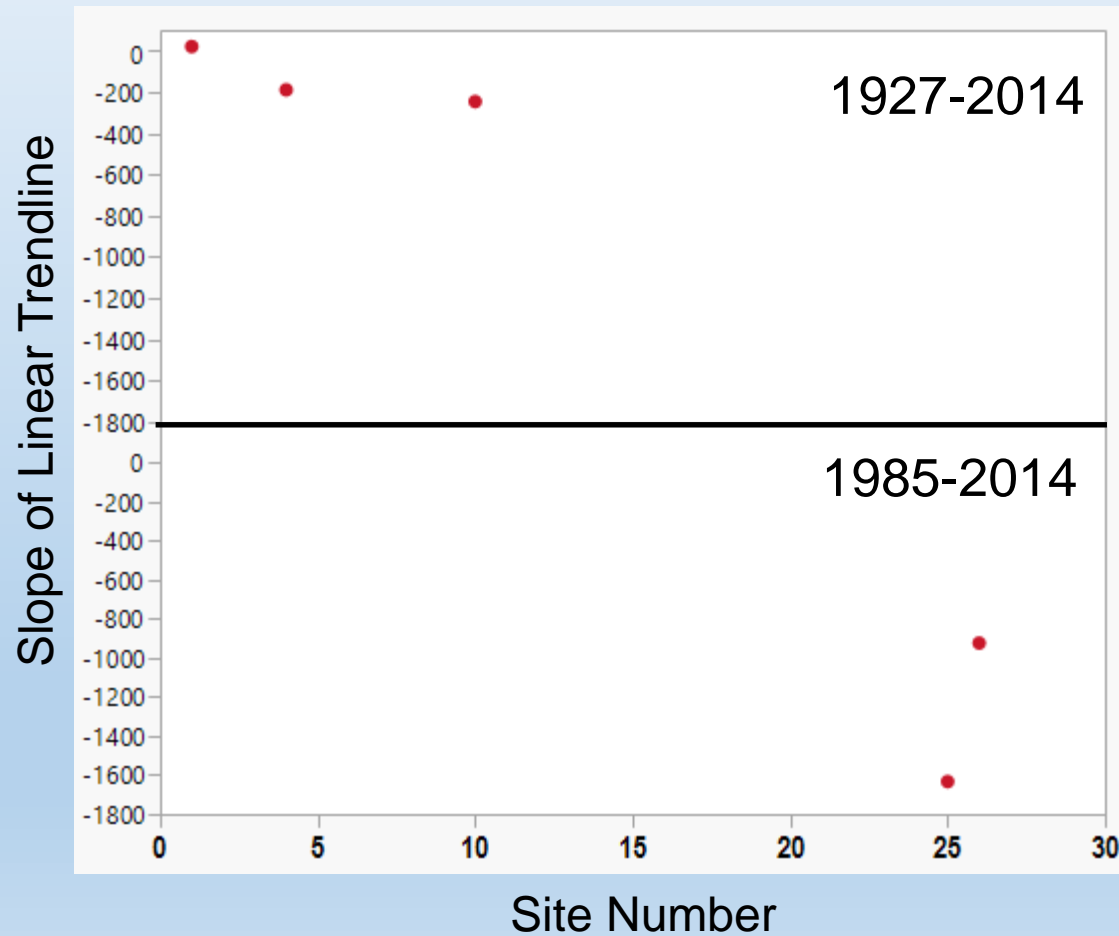


Significant slopes at 90th decile




Provisional

Significant slopes at 100th decile



Provisional



Why is the number of
significant slopes
different between
1927-2014 and 1985-2014?

139 (47%)	14 (4.7%)
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Definition of the quantitative power of a linear trend test:

$$Power = f(b/s * n^{1.5}),$$

where b is the trend slope, s is the standard deviation of the error, and **n is the number of observations.**

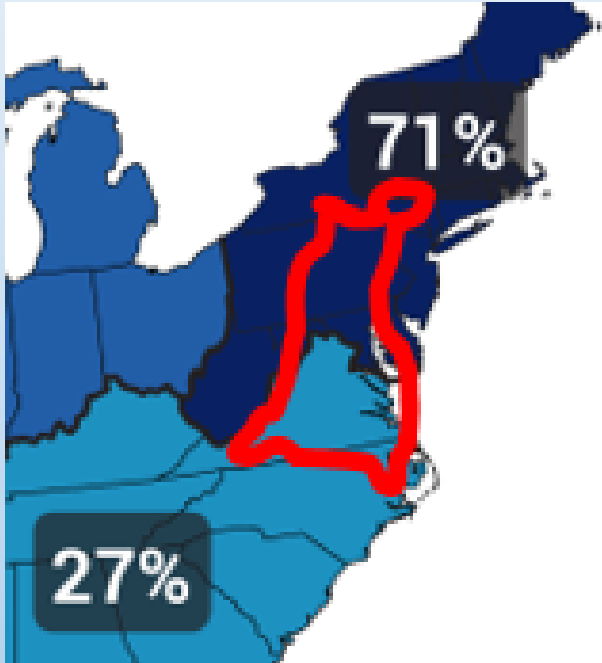


Long-Term Observations Necessary

“In a nonstationary world, continuity of observations is critical.” (Milly et al., 2008, *Science*)

“The idea here is that we must use **long-term hydrologic observations** to help us evaluate, on an ongoing basis, how the changing atmosphere is changing hydrologic processes.” (Milly et al., 2015, *Water Resour. Res.*)

Diverse Watershed



Complicating Factors:

- Land Use
- Wetlands
- Dams
- Withdrawals
- Hurricanes
- Atmospheric Forcings

Summary

- 1) $P \neq Q$
- 2) North \neq South
- 3) Trends in
1985-2014 \neq 1927-2014

Analyses have not been reviewed or approved by
USGS; please do not cite or quote