

Application of Sparse Sensing for Stream Nutrient Monitoring Programs

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Supplementary Information

The Supporting Information includes figures and tables to support the results described in the text. These figures and tables

10 were created using the methods described in the text.

Figure S1 to S4

Table S1 to S3

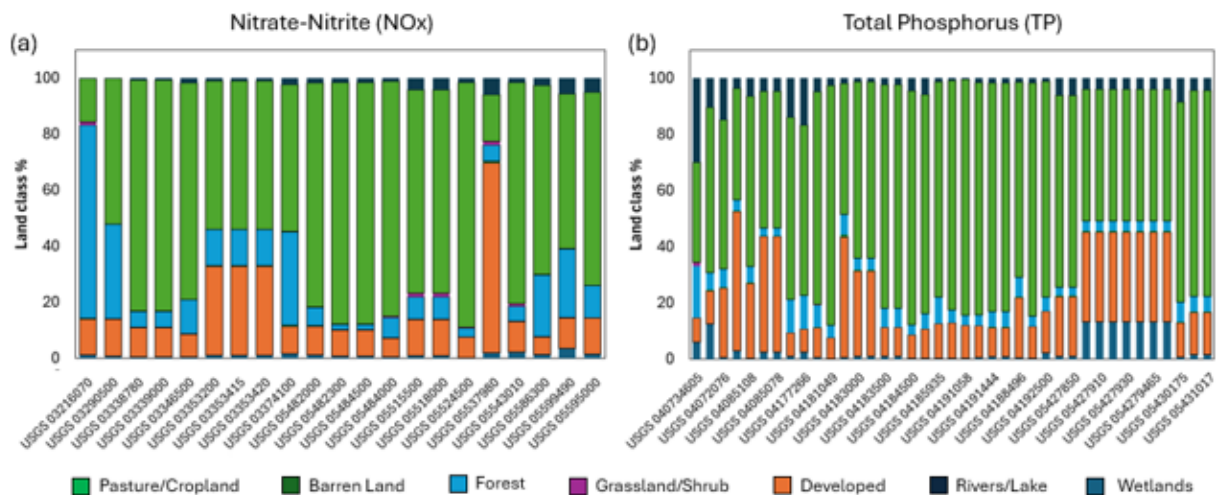
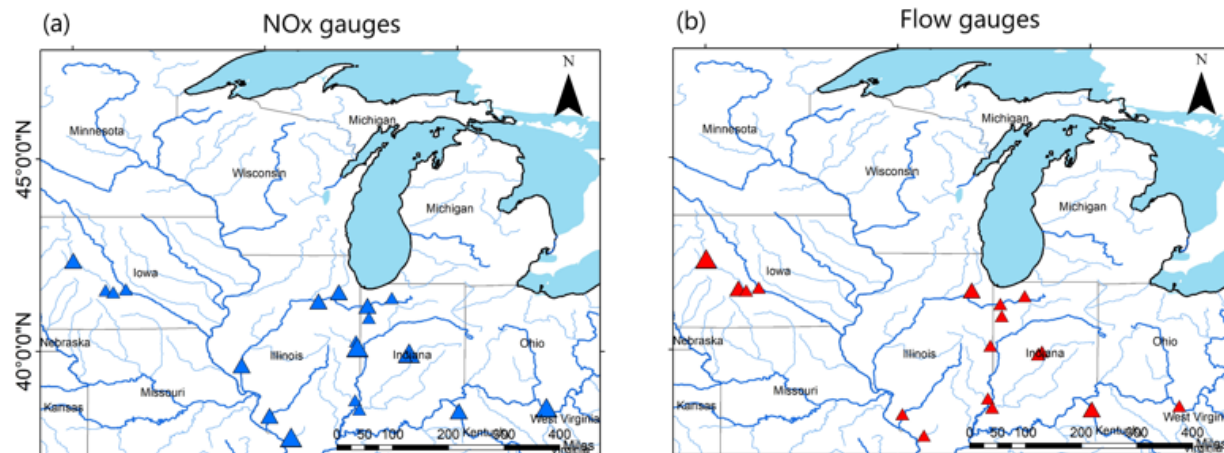
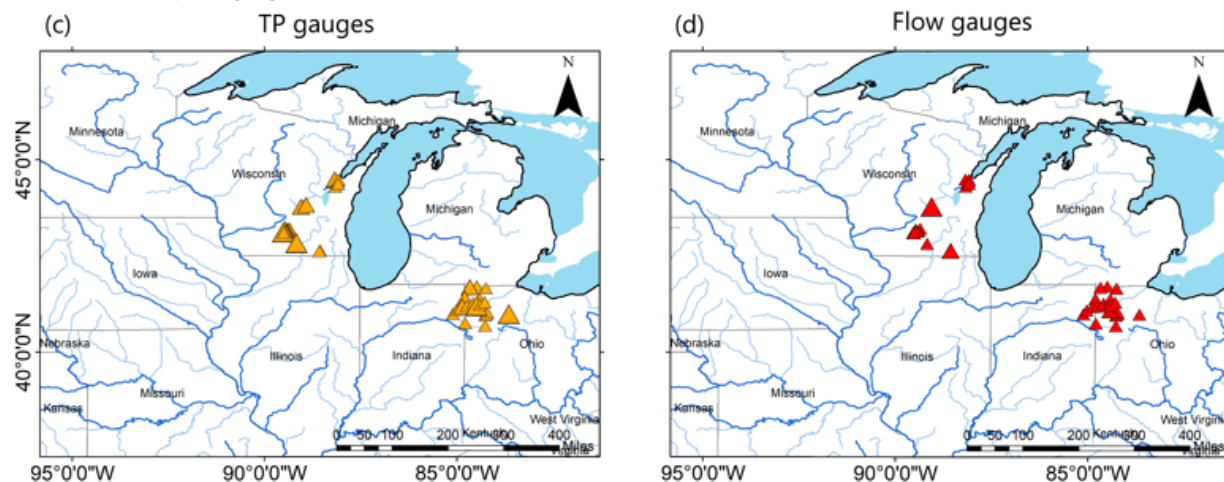


Figure S1: Land-use composition across basins associated with NO_x (a) and TP (b) monitoring gauges. For NO_x monitoring basins, the dominant land classes were pasture/cropland, developed, and forest, whereas for TP monitoring basins, the dominant land classes were pasture/cropland and developed. Land cover types that had an aerial extent of at least 10% in most of the basins were considered as dominant land classes.

Iroquois River, IN (NOx)



Sixmile Creek, WI (TP)



Monitoring gauges
 ▲ Nitrate-Nitrite (NOx)
 ▲ Streamflow (Q)

Ranks
 ▲ 1-5
 ▲ 6-15
 ▲ 16-39

Monitoring gauges
 ▲ Total Phosphorus (TP)
 ▲ Streamflow (Q)

Ranks
 ▲ 1-5
 ▲ 6-15
 ▲ 16-76

Figure S2: Spatial plots of informative sampling locations of flow and nutrient monitoring stations for reconstructing NOx time series (a, b) and TP time series (c, d). Top 15 informative gauges were distributed across the watersheds and were located mostly in watersheds dominated by pasture or croplands.

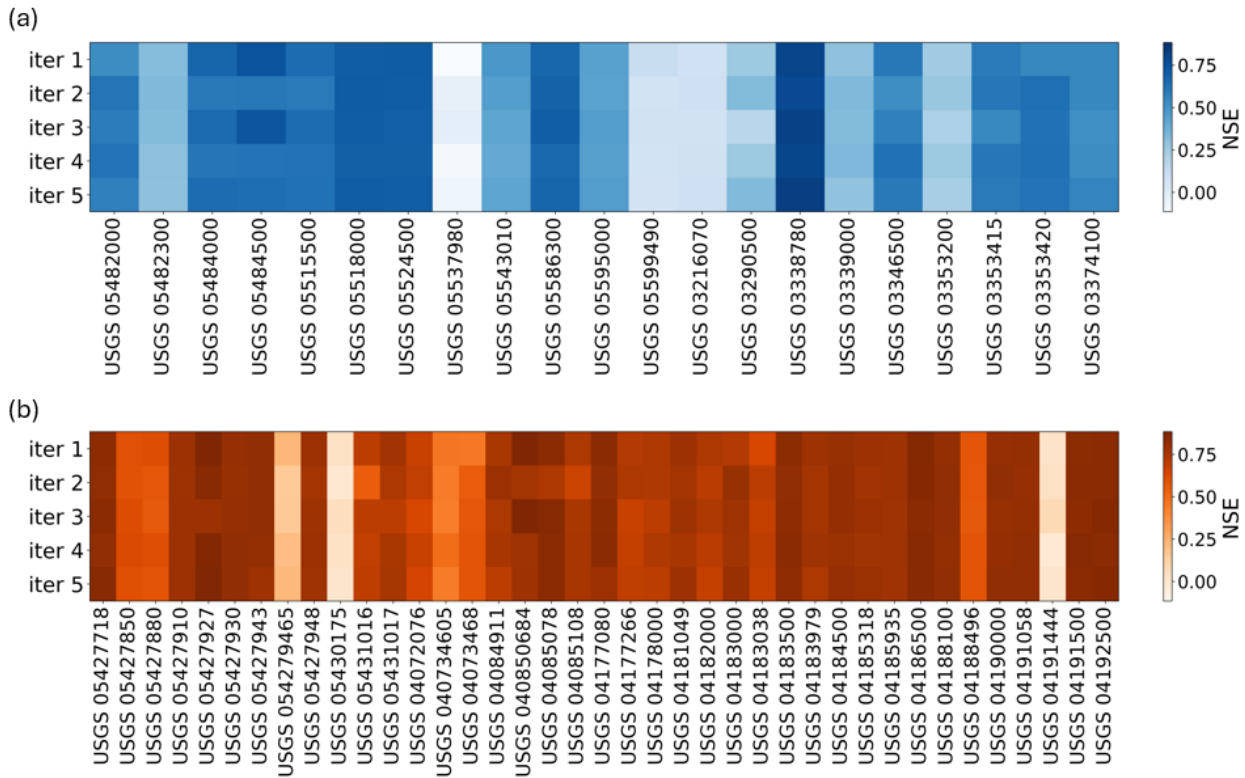
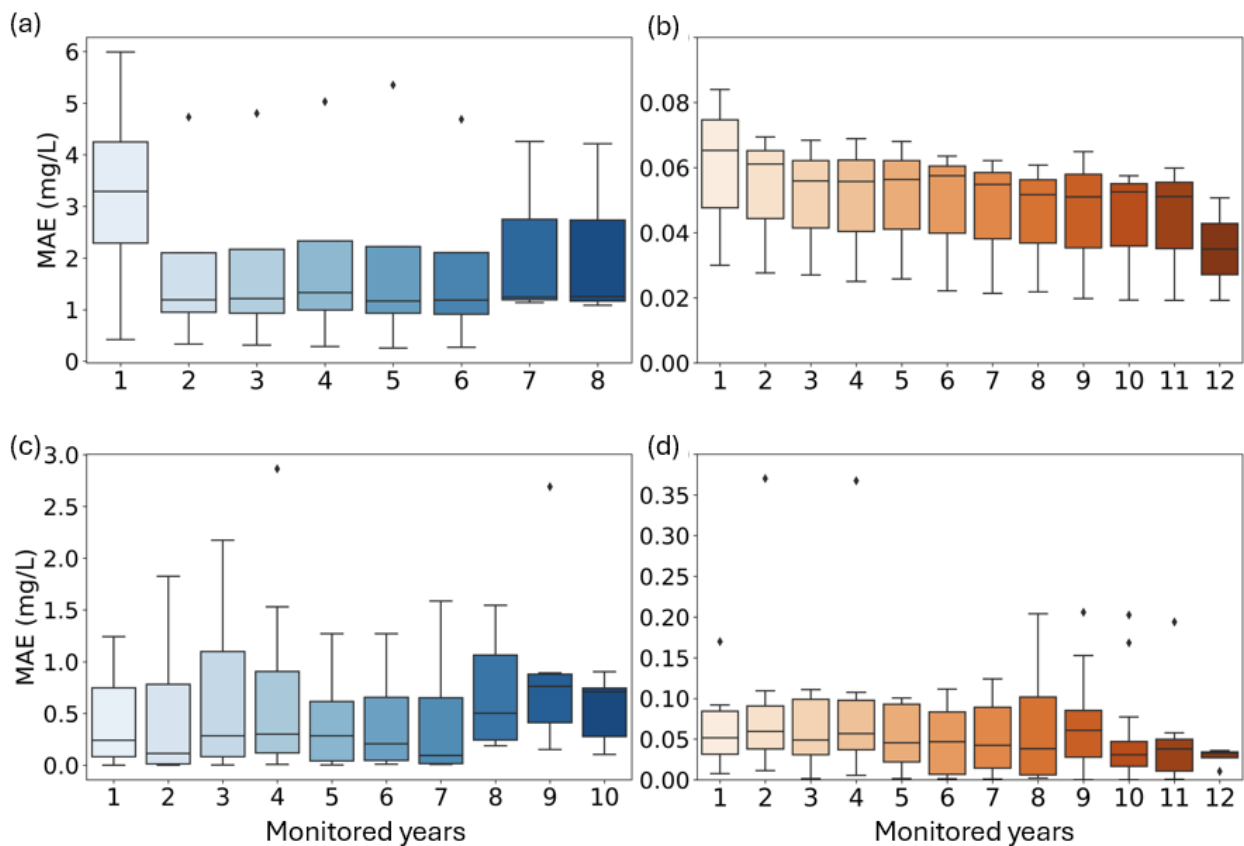


Figure S3: Model performance across the monitoring sites (in terms of NSE) for NO_x (a) and TP (b) reconstructions considering a training combination of flow and concentration. Each column represents USGS monitoring sites, whereas the rows represent results from 5 iterations. Color gradient reflects the variation in NSE values, with darker shades corresponding to better model performance. The results shown here are based on the model that used 50% of the total measurements.



35 **Figure S4: Model performance (in terms of MAE) for NO_x (a, c) and TP (b, d) reconstructions across different model configurations (different bars), i.e., variations in length of training data taken from either historic data (a, b) or regional data (c, d). The results shown here are based on the model that used 60 samples per year. The length of each bar/box represents the range of performance metrics among all the gauges. The red dashed line represents the threshold NSE value for the model to be satisfactory.**

Table S2: Summary of watershed properties of the nutrient monitoring gauges.

Station ID	Variable	Location	Observed Samples	% Missing Data	Mean Conc. (mg/L)	Mean Flow (m³/s)	Basin Area (sq.km)	Dominated LULC
USGS 05482000	NOx	Des Moines River at Des Moines, IA	1012	7.58	2.94	50.22	16174.49	Pasture/ Croplands
USGS 05482300	NOx	North Raccoon River near Sac City, IA	996	9.04	7.74	4.67	1812.99	Pasture/ Croplands
USGS 05484000	NOx	South Raccoon River at Redfield, IA	1083	1.10	2.68	6.69	2301.44	Pasture/ Croplands
USGS 05484500	NOx	Raccoon River at Van Meter, IA	1050	4.11	3.50	19.97	8912.16	Pasture/ Croplands
USGS 05515500	NOx	Kankakee River at Davis, IN	1077	1.64	1.57	14.26	1403.77	Pasture/ Croplands
USGS 05518000	NOx	Kankakee River at Shelby, IN	1081	1.28	1.71	48.40	4607.59	Pasture/ Croplands
USGS 05524500	NOx	Iroquois River near Foresman, IN	1047	4.38	5.26	9.37	1162.91	Pasture/ Croplands
USGS 05537980	NOx	Des Plaines River at Joliet, IN	1068	2.47	5.43	94.64	3890.16	Developed
USGS 05543010	NOx	Illinois River at Seneca, IL	1049	4.20	4.53	-	21276.77	Pasture/ Croplands
USGS 05586300	NOx	Illinois River at Florence, IL	1053	3.84	3.49	-	69593.03	Pasture/ Croplands, Forest
USGS 05595000	NOx	Kaskaskia River at New Athens, IL	1014	7.40	0.86	122.44	13439.46	Pasture/ Croplands, Forest
USGS 05599490	NOx	Big Muddy River at Murphysboro, IL	1045	4.57	0.68	53.82	5591.79	Pasture/ Croplands
USGS 03216070	NOx	Ohio River at Ironton, OH	1085	0.91	0.73	2271.55	-	Forest
USGS 03290500	NOx	Kentucky River at Lockport, KY	1000	8.68	0.73	219.98	16006.14	Pasture/ Croplands, Forest
USGS 03338780	NOx	North Fork Vermilion River near Bismarck, IL	1050	4.11	5.54	-	678.58	Pasture/ Croplands
USGS 03339000	NOx	Vermilion River near Danville, IL	988	9.77	5.29	30.80	3341.09	Pasture/ Croplands
USGS 03346500	NOx	Embarras River at Lawrenceville, IL	1086	0.82	2.15	61.76	6042.45	Pasture/ Croplands
USGS 03353200	NOx	Eagle Creek at Zionsville, IN	1000	8.68	1.73	3.16	274.54	Pasture/ Croplands, Developed
USGS 03353415	NOx	School Branch near Brownsburg, IN	998	8.86	2.03	0.07	8.78	Pasture/ Croplands, Developed
USGS 03353420	NOx	School Branch near Brownsburg, IN	990	9.59	2.24	0.16	12.17	Pasture/ Croplands, Developed
USGS 03374100	NOx	White River at Hazleton, IN	1059	3.29	1.34	369.91	29279.84	Pasture/ Croplands, Forest

Station ID	Variable	Location	Observed Samples	% Missing Data	Mean Conc. (mg/L)	Mean Flow (m ³ /s)	Basin Area (sq.km)	Dominated LULC
USGS 05427718	TP	Yahara River at Windsor, WI	1095	0	0.11	0.99	190.62	Pasture/ Croplands, Developed
USGS 05427850	TP	Yahara River at Madison, WI	1095	0	0.07	2.56	295.26	Pasture/ Croplands, Developed
USGS 05427880	TP	Sixmile Creek near Waunakee, WI	1095	0	0.21	0.50	64.23	Pasture/ Croplands, Developed
USGS 05427910	TP	Sixmile Creek near Waunakee, WI	1095	0	0.17	1.15	125.10	Pasture/ Croplands, Developed
USGS 05427927	TP	Dorn Creek at near Waunakee, WI	1095	0	0.17	0.22	25.77	Pasture/ Croplands, Developed
USGS 05427930	TP	Dorn Creek at near Waunakee, WI	1095	0	0.18	0.32	32.63	Pasture/ Croplands, Developed
USGS 05427943	TP	Pheasant Branch at Middleton, WI	1095	0	0.23	0.12	25.12	Pasture/ Croplands, Developed
USGS 054279465	TP	S. Fork Pheasant Branch at Middleton, WI	1095	0	0.27	0.06	15.85	Pasture/ Croplands, Developed
USGS 05427948	TP	Pheasant Branch at Middleton, WI	1095	0	0.14	0.28	47.40	Pasture/ Croplands, Developed
USGS 05430175	TP	Yahara River near Fulton, WI	1095	0	0.13	14.38	1341.61	Pasture/ Croplands
USGS 05431016	TP	Jackson Creek near Elkhorn, WI	1095	0	0.13	0.41	43.51	Pasture/ Croplands
USGS 05431017	TP	Delavan Lake Inlet at Lake Lawn, WI	1095	0	0.12	-	56.46	Pasture/ Croplands
USGS 04072076	TP	Silver Creek at Oneida, WI	1095	0	0.16	0.10	12.98	Pasture/ Croplands, Developed
USGS 040734605	TP	Green Lake Inlet near Green Lake, WI	1095	0	0.11	0.54	40.66	Pasture/ Croplands, Wetland
USGS 04073468	TP	Green Lake Inlet near Green Lake, WI	1095	0	0.07	-	138.56	Pasture/ Croplands
USGS 04084911	TP	Plum Creek near Wrightstown, WI	1095	0	0.28	0.54	54.91	Developed, Pasture/ Croplands
USGS 040850684	TP	Ashwaubenon Creek near West Depere, WI	1095	0	0.20	0.70	66.82	Pasture/ Croplands, Developed
USGS 04085078	TP	Duthomen Creek at Ashwaubenon, WI	1095	0	0.17	0.62	67.34	Pasture/ Croplands, Developed
USGS 04085108	TP	East River near GreenLeaf, WI	1095	0	0.31	1.04	116.03	Pasture/ Croplands, Developed
USGS 04177080	TP	St Joseph River near Waldron, MI	1095	0	0.09	2.18	183.37	Pasture/ Croplands
USGS 04177266	TP	St Joseph River near Nettle Lake,	1095	0	0.10	2.85	263.66	Pasture/ Croplands

OH

USGS 04178000	TP	St Joseph River near Newville, IN	1095	0	0.16	17.35	1579.89	Pasture/ Croplands
USGS 04181049	TP	St Marys River at Willshire, OH	1095	0	0.32	11.51	999.74	Pasture/ Croplands
USGS 04182000	TP	St Marys River at Fort Wayne, IN	1095	0	0.33	19.49	1973.57	Pasture/ Croplands, Developed
USGS 04183000	TP	Maumee River at New Haven, IN	1095	0	0.28	53.73	5094.51	Pasture/ Croplands, Developed
USGS 04183038	TP	Black Creek near Harlan, IN	1095	0	0.21	0.27	32.01	Pasture/ Croplands, Developed
USGS 04183500	TP	Maumee River at Antwerp, OH	1095	0	0.28	58.46	5514.09	Pasture/ Croplands
USGS 04183979	TP	Platter Creek near Sherwood, OH	1095	0	0.16	0.48	50.50	Pasture/ Croplands
USGS 04184500	TP	Bean Creek at Powers, OH	1095	0	0.12	6.01	533.54	Pasture/ Croplands
USGS 04185318	TP	Tiffin River near Evansport, OH	1095	0	0.18	15.07	1458.16	Pasture/ Croplands
USGS 04185935	TP	Auglaize River near Kossuth, OH	1095	0	0.19	5.60	520.59	Pasture/ Croplands
USGS 04186500	TP	Auglaize River near Fort Jennings, OH	1095	0	0.20	8.95	859.88	Pasture/ Croplands
USGS 04188100	TP	Ottawa River near Kalida, OH	1095	0	0.27	10.51	906.50	Pasture/ Croplands
USGS 04188496	TP	Eagle Creek above Findlay, OH	1095	0	0.21	1.49	132.09	Pasture/ Croplands, Developed
USGS 04190000	TP	Blanchard River near Dupont, OH	1095	0	0.27	17.91	1958.03	Pasture/ Croplands
USGS 04191058	TP	Little Auglaize River near Melrose, OH	1095	0	0.18	10.81	1038.59	Pasture/ Croplands
USGS 04191444	TP	Little Flatrock Creek near Junction, OH	1095	0	0.47	0.35	39.63	Pasture/ Croplands
USGS 04191500	TP	Auglaize River near Defiance OH	1095	0	0.25	56.05	6003.60	Pasture/ Croplands
USGS 04192500	TP	Maumee River near Defiance, OH	1095	0	0.25	141.65	14361.49	Pasture/ Croplands

Table S2: Distribution (frequency) of time-series rankings for Nitrate-Nitrite (NOx) reconstruction.

USGS ID	Station	Rank 1-5	Rank 6-10	Rank 11-15	Rank 16-39	Basin Properties		
Flow Time-series					Basin Area (km²)	Mean Daily Streamflow (m³/s)	Mean Concentration (mg/L)	
USGS 05482000		0	0	0	21	16174.49	50.22	
USGS 05482300		9	12	0	0	1812.99	4.67	
USGS 05484000		0	0	21	0	2301.44	6.69	
USGS 05484500		0	0	0	21	8912.16	19.97	
USGS 05515500		0	0	0	21	1403.77	14.26	
USGS 05518000		0	0	0	21	4607.59	48.40	
USGS 05524500		0	0	0	21	1162.91	9.37	
USGS 05537980		0	10	11	0	3890.16	94.64	
USGS 05595000		0	0	0	21	13439.46	122.44	
USGS 05599490		0	0	5	16	5591.79	53.82	
USGS 03216070		0	0	0	21	-	2271.55	
USGS 03290500		0	17	4	0	16006.14	219.98	
USGS 03339000		0	0	0	21	3341.09	30.80	
USGS 03346500		0	0	7	14	6042.45	61.76	
USGS 03353200		0	0	0	21	274.54	3.16	
USGS 03353415		0	0	0	21	8.78	0.07	
USGS 03353420		0	0	0	21	12.17	0.16	
USGS 03374100		0	0	0	21	29279.84	369.91	
NOx Time-series								
USGS 05482000		0	0	1	19	16174.49	50.22	2.94
USGS 05482300		0	1	15	4	1812.99	4.67	7.74
USGS 05484000		0	0	0	20	2301.44	6.69	2.68
USGS 05484500		0	0	0	20	8912.16	19.97	3.50
USGS 05515500		0	0	1	19	1403.77	14.26	1.57
USGS 05518000		0	0	0	20	4607.59	48.40	1.71
USGS 05524500		0	6	0	14	1162.91	9.37	5.26
USGS 05537980		0	20	0	0	3890.16	94.64	5.43
USGS 05543010		0	12	0	8	21276.77	-	4.53
USGS 05586300		0	10	0	10	69593.03	-	3.49
USGS 05595000		10	10	0	0	13439.46	122.44	0.86
USGS 05599490		20	0	0	0	5591.79	53.82	0.68

					-	2271.55	
USGS 03216070	18	2	0	0			0.73
USGS 03290500	6	1	0	13	16006.14	219.98	0.73
USGS 03338780	14	0	0	6	678.58	-	5.54
USGS 03339000	5	0	0	15	3341.09	30.80	5.29
USGS 03346500	16	0	0	4	6042.45	61.76	2.15
USGS 03353200	2	1	17	0	274.54	3.16	1.73
USGS 03353415	0	1	1	18	8.78	0.07	2.03
USGS 03353420	0	0	18	2	12.17	0.16	2.24
USGS 03374100	0	0	0	20	29279.84	369.91	1.34

50 **Table S3: Distribution (frequency) of time-series rankings for Total Phosphorous (TP) reconstruction.**

USGS station	Rank 1-5	Rank 6-10	Rank 11-15	Rank 16-76	Basin Properties		
Flow Time-series					Basin Area (km ²)	Mean Daily Streamflow (m ³ /s)	Mean Concentration (mg/L)
USGS 05427718	0	0	0	39	190.62	0.99	
USGS 05427850	0	0	0	39	295.26	2.56	
USGS 05427880	0	0	0	39	64.23	0.50	
USGS 05427910	0	0	0	39	125.10	1.15	
USGS 05427927	0	0	0	39	25.77	0.22	
USGS 05427930	0	0	0	39	32.63	0.32	
USGS 05427943	0	0	0	39	25.12	0.12	
USGS 054279465	0	0	0	39	15.85	0.06	
USGS 05427948	0	0	0	39	47.40	0.28	
USGS 05430175	0	0	0	39	1341.61	14.38	
USGS 05431016	1	38	0	0	43.51	0.41	
USGS 04072076	0	0	0	39	12.98	0.10	
USGS 040734605	31	8	0	0	40.66	0.54	
USGS 04084911	0	0	1	38	54.91	0.54	
USGS 040850684	0	0	0	39	66.82	0.70	
USGS 04085078	0	0	0	39	67.34	0.62	
USGS 04085108	0	0	0	39	116.03	1.04	
USGS 04177080	0	0	0	39	183.37	2.18	
USGS 04177266	0	0	0	39	263.66	2.85	
USGS 04178000	0	0	0	39	1579.89	17.35	
USGS 04181049	0	0	0	39	999.74	11.51	
USGS 04182000	0	0	0	39	1973.57	19.49	
USGS 04183000	0	0	0	39	5094.51	53.73	
USGS 04183038	0	0	0	39	32.01	0.27	
USGS 04183500	0	0	0	39	5514.09	58.46	
USGS 04183979	0	0	0	39	50.50	0.48	
USGS 04184500	0	0	0	39	533.54	6.01	
USGS 04185318	0	0	0	39	1458.16	15.07	
USGS 04185935	0	0	0	39	520.59	5.60	
USGS 04186500	0	0	0	39	859.88	8.95	
USGS 04188100	0	0	0	39	906.50	10.51	
USGS 04188496	0	0	0	39	132.09	1.49	

USGS 04190000	0	0	0	39	1958.03	17.91	
USGS 04191058	0	11	28	0	1038.59	10.81	
USGS 04191444	0	0	0	39	39.63	0.35	
USGS 04191500	0	0	0	39	6003.60	56.05	
USGS 04192500	0	0	0	39	14361.49	141.65	
TP Time-series							
USGS 05427718	0	0	0	38	190.62	0.99	0.11
USGS 05427850	0	32	6	0	295.26	2.56	0.07
USGS 05427880	8	28	0	2	64.23	0.50	0.21
USGS 05427910	0	0	2	36	125.10	1.15	0.17
USGS 05427927	0	0	0	38	25.77	0.22	0.17
USGS 05427930	0	0	1	37	32.63	0.32	0.18
USGS 05427943	6	0	0	32	25.12	0.12	0.23
USGS 054279465	31	0	2	5	15.85	0.06	0.27
USGS 05427948	8	0	0	38	47.40	0.28	0.14
USGS 05430175	29	0	0	9	1341.61	14.38	0.13
USGS 05431016	0	0	1	37	43.51	0.41	0.13
USGS 05431017	0	0	13	25	56.46	-	0.12
USGS 04072076	1	11	26	0	12.98	0.10	0.16
USGS 040734605	2	36	0	0	40.66	0.54	0.11
USGS 04073468	0	24	0	14	138.56	-	0.07
USGS 04084911	0	0	0	38	54.91	0.54	0.28
USGS 040850684	0	0	0	38	66.82	0.70	0.20
USGS 04085078	0	0	0	38	67.34	0.62	0.17
USGS 04085108	0	0	0	38	116.03	1.04	0.31
USGS 04177080	0	0	10	28	183.37	2.18	0.09
USGS 04177266	0	0	33	5	263.66	2.85	0.10
USGS 04178000	0	0	17	21	1579.89	17.35	0.16
USGS 04181049	0	0	0	38	999.74	11.51	0.32
USGS 04182000	0	0	1	37	1973.57	19.49	0.33
USGS 04183000	0	1	23	14	5094.51	53.73	0.28
USGS 04183038	0	1	12	25	32.01	0.27	0.21
USGS 04183500	0	0	0	38	5514.09	58.46	0.28
USGS 04183979	0	0	4	34	50.50	0.48	0.16
USGS 04184500	0	0	2	36	533.54	6.01	0.12
USGS 04185318	0	0	7	31	1458.16	15.07	0.18
USGS 04185935	0	0	2	36	520.59	5.60	0.19

USGS 04186500	0	0	0	38	859.88	8.95	0.20
USGS 04188100	32	0	0	6	906.50	10.51	0.27
USGS 04188496	5	0	0	33	132.09	1.49	0.21
USGS 04190000	0	0	0	38	1958.03	17.91	0.27
USGS 04191058	35	0	0	3	1038.59	10.81	0.18
USGS 04191444	2	0	0	36	39.63	0.35	0.47
USGS 04191500	0	0	0	38	6003.60	56.05	0.25
USGS 04192500	0	0	0	38	14361.49	141.65	0.25