Flow-Normalized Nutrient Loads in Kentucky

2006 – 2023

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Contents

Tables

Figures

Introduction

The Division of Water (DOW) conducts ongoing water quality monitoring across the Commonwealth which provides the opportunity to analyze water quality trends, including insight into nutrient contributions to the Gulf of Mexico, and plays a key role in Kentucky's Nutrient Reduction Strategy. Analyzing loads at these and other monitoring stations measures progress towards meeting goals and identifies areas that may need more attention.

Key goals for this study are to:

- align with current U.S. Geological Survey (USGS) methodology
- make direct comparisons to regional and national data
- track progress towards the Hypoxia Task Force interim goal of 20% reduction of nitrogen and phosphorus loads, and
- assess results for next steps

This study seeks to align with methodology adopted by the USGS to track nutrient trends at the Gulf of Mexico. Specifically, this study transitions from the Load Estimator (LOADEST) (Runkel, 2004) methodology used in the *Nutrient Loads and Yields in Kentucky: 2005-2017* (Chan C., 2019) to the *Weighted Regressions on Time, Discharge, and Season (WRTDS)* (Lee, Murphy, Crawford, & Deacon, 2017) methodology. The latter methodology accounts for the effects of interannual flow variability on load delivery, thereby reducing discrepancies from natural discharge and making loading trends easier to identify.

Analyses were reduced to 16 monitoring stations from 57 in the 2021 Loads & Yields Study to provide non-overlapping statewide coverage of Kentucky's nutrient contribution, despite a significant portion of load originating outside of the state. Totals from these 16 stations are then compared to flow-normalized loading trends from the Ohio River and the Mississippi & Atchafalaya River Basin. The combination of these data points provides context for changes in the size of the Gulf of Mexico Hypoxic Zone.

The primary goal of this study is to compare flow-normalized load trends for Kentucky against trends of loads delivered to the Gulf of Mexico from the Mississippi River & Atchafalaya Basin (MARB). This study models individual station changes, aggregates trends, and explores contributing geographic and chemical factors.

Methods

Data Sources

Data sources and acceptance criteria were the same as the previous nutrient loads studies (Chan C., 2019; Chan & Frey, 2021). Only a subset of stations was analyzed for this update, focusing on larger basins with no overlap. Figure 1 shows these non-overlapping Kentucky basins and monitoring stations that cover approximately 82% of the state, while Table 1 contains station and discharge details. Dam discharge data were obtained from the Tennessee Valley Authority or the U.S. Army Corps of Engineers, depending on dam ownership. The modeled parameters included Total Phosphorus (TP), Total Nitrogen (TN) and Ammonia. Total Nitrogen was calculated by adding the analytes Nitrate & Nitrite as N and Total Kjeldhal Nitrogen as N.

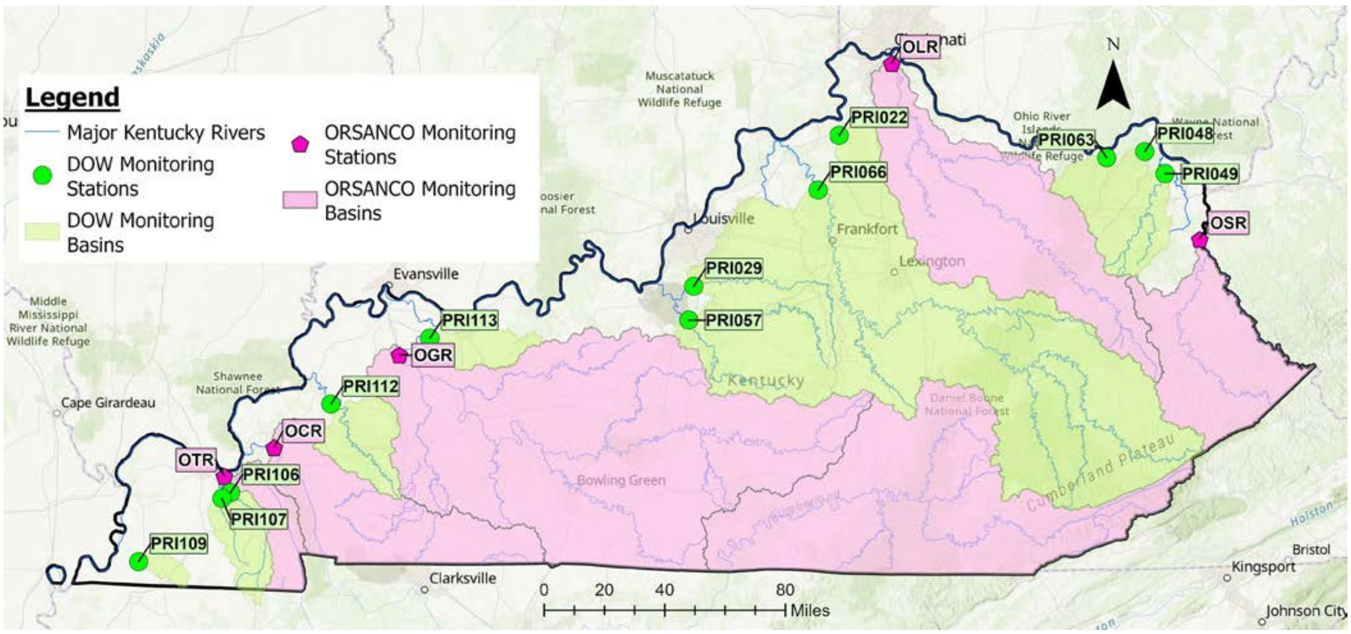


Figure 1. Monitoring stations with the Kentucky portion of their contributing basins.

Of the 16 stations used in this study, 11 are sampled bi-monthly by DOW, and 5 are sampled bi-monthly by the Ohio River Valley Sanitation Commission (ORSANCO). The study period are water years 2006 through 2023 with two exceptions: data for OGR was only available through water year 2022, and PRI113 sampling data begins with water year 2012. Delineation of contributing catchments is outlined in the DOW 2021 Update to Nutrient Loads &Yields in Kentucky study (Chan & Frey, 2021).

The MARB comparison data was obtained from the USGS National Water Quality Network (NWQN) and is the sum of loads from two stations: the Mississippi River near St. Francisville, LA and the Atchafalaya River at Melville, LA representing the total load of nutrients entering the Gulf of Mexico from the MARB (U.S. Geologic Survey, 2023). Regional comparison data for the Ohio River at Olmsted, IL also comes from a USGS NWQN dataset (USGS, Ohio River at Olmsted, 2024).

Table 1. Monitoring station identification and source of discharge data.

Station ID	Station Name	USGS stream-gaging stations used for discharge	Drainage Area (mi²)	Latitude	Longitude
ORSANCO Stations					
OSR	Big Sandy R @ Louisa	03212500 03214500	3894	38.17111	-82.63472
OLR	Licking R @ Covington	03254520 03253500	3702	39.05139	-84.495
OGR	Green R @ Sebree	03320000 03316500	8638	37.64415	-87.49797
OCR	Cumberland R @ Pinkneyville	Barkley Dam discharge	17,833	37.18556	-88.23944
OTR	Tennessee R @Paducah	Kentucky Dam discharge	40388	37.04028	-88.53389
Kentucky Division of Water Ambient Monitoring Stations					
PRI022	Eagle Cr @ Glenco	03291500	1,278	37.83759	-82.40971
PRI029	Salt R @ Shepherdsville	03298500	1,197	37.98517	-85.71720
PRI048	Tygarts Cr nr Lynn	03217000	275	38.59981	-82.95265
PRI049	Little Sandy @ Argilite	03216500	539	38.49038	-82.83428
PRI057	Rolling Fk nr Lebanon Junction	03310500	1,374	37.82267	-85.74787
PRI066	Kentucky R nr Lockport	03290500	4,588	37.82009	-84.70509
PRI106	Clarks R nr Sharpe	03610200	310	36.96133	-88.49321
PRI107-1	W Fk Clarks R nr Symsonia	03610200	186	36.93245	-88.54396
PRI109	Bayou de Chien nr Cayce	07024000	103	36.61530	-89.03025
PRI112	Tradewater R nr Piney	03384100 03383000	605	37.39678	-87.84486
PRI113	Panther Cr nr W Louisville	03321350	372	37.72497	-87.31513

Statistical Analysis

Analyses used the Weighted Regressions on Time, Discharge, and Season (WRTDS) statistical method using the R packages Exploration and Graphics for RivEr Trends (EGRET; Hirsch & De Cicco, 2015) and EGRETci (Hirsch, Archfield, & De Cicco, 2015) to generate statistics and graphics, and to be comparable to other USGS studies.

Data frames were constructed according to the EGRET User Guide, using the default period of analysis (the water year, with period start representing October and for 12 months). Flow history and residual analyses evaluated consistency of both flow and residuals across the study period, and the flux bias statistic was calculated to evaluate model fit. Confidence Intervals around trends were generated using the bootstrap method in the EGRETci package. Two time periods - 2006 to 2023 and 2013 to 2023 – were assessed for trends.

Results

Flow-normalized models of individual basins in Kentucky's monitoring network reveal similarities and differences between nitrogen and phosphorus trends (see Figure 7 & Figure 8). For nitrogen, 9 of 16 stations show a downward trend, 4 show no trend, and 3 are increasing. For phosphorus, 9 show no trend, 4 trend down, and 3 trend up. For both parameters, only smaller basins have an increasing trend. Two stations on the Clarks River (PRI106 & PRI107-1) had a flux bias statistic for phosphorus just outside of the recommended 90% range (0.11 and 0.142, respectively), suggesting slight bias in the phosphorus models for those stations (see Appendix 1: Flow-Normalized (Flux) Nitrogen and Phosphorus Trends). Basins larger than 1,400 square miles (Table 1) demonstrated either no trend or a declining trend in flow-normalized nitrogen and phosphorus loads compared to smaller basins. Graphs depicting nitrogen and phosphorus trends for individual stations are available in Appendix 2: Flow-Normalized Nitrogen Flux at Kentucky Stations and Appendix 3: Flow-Normalized Phosphorus Flux for Kentucky Stations.

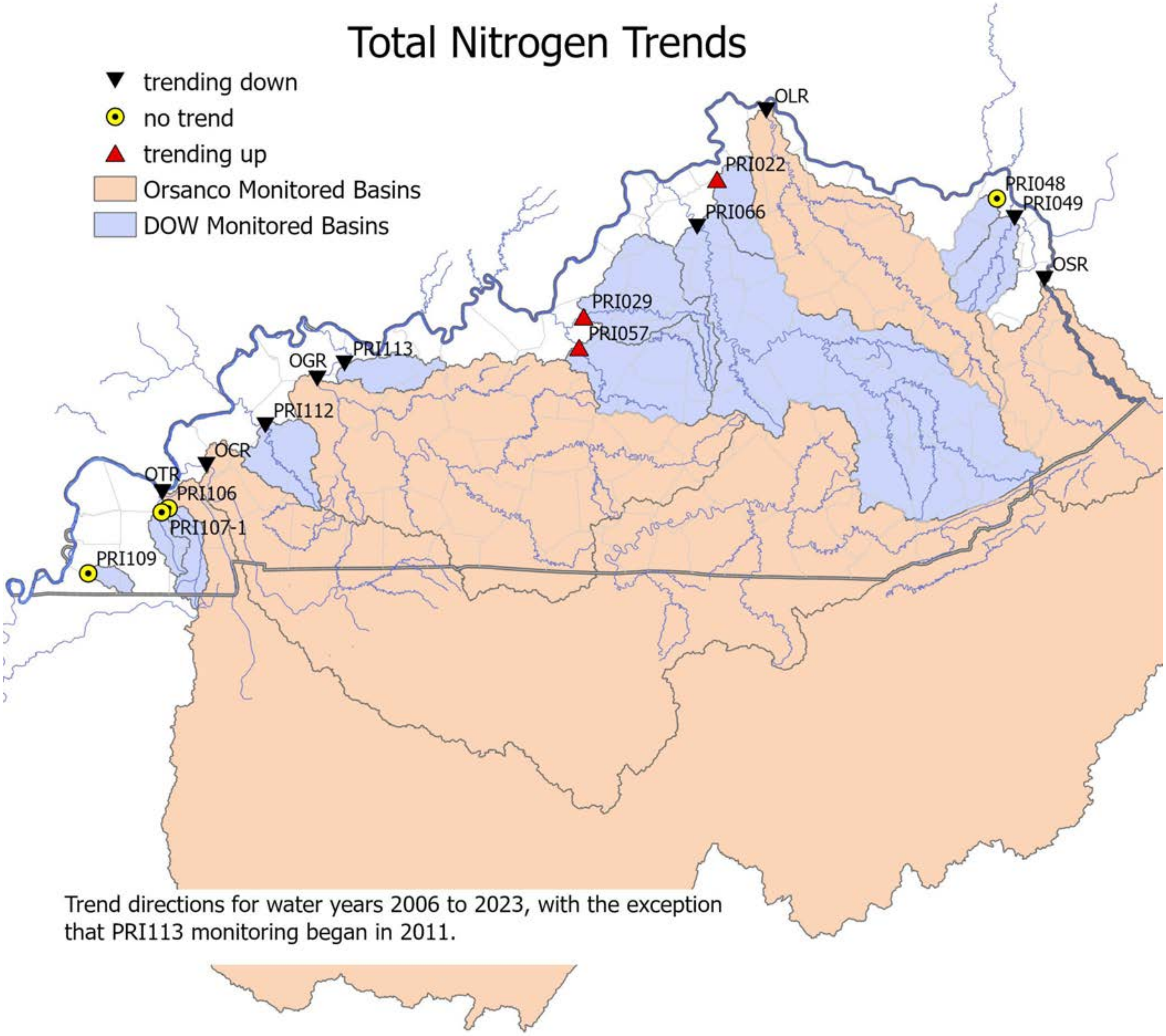


Figure 2. Total Nitrogen Trends

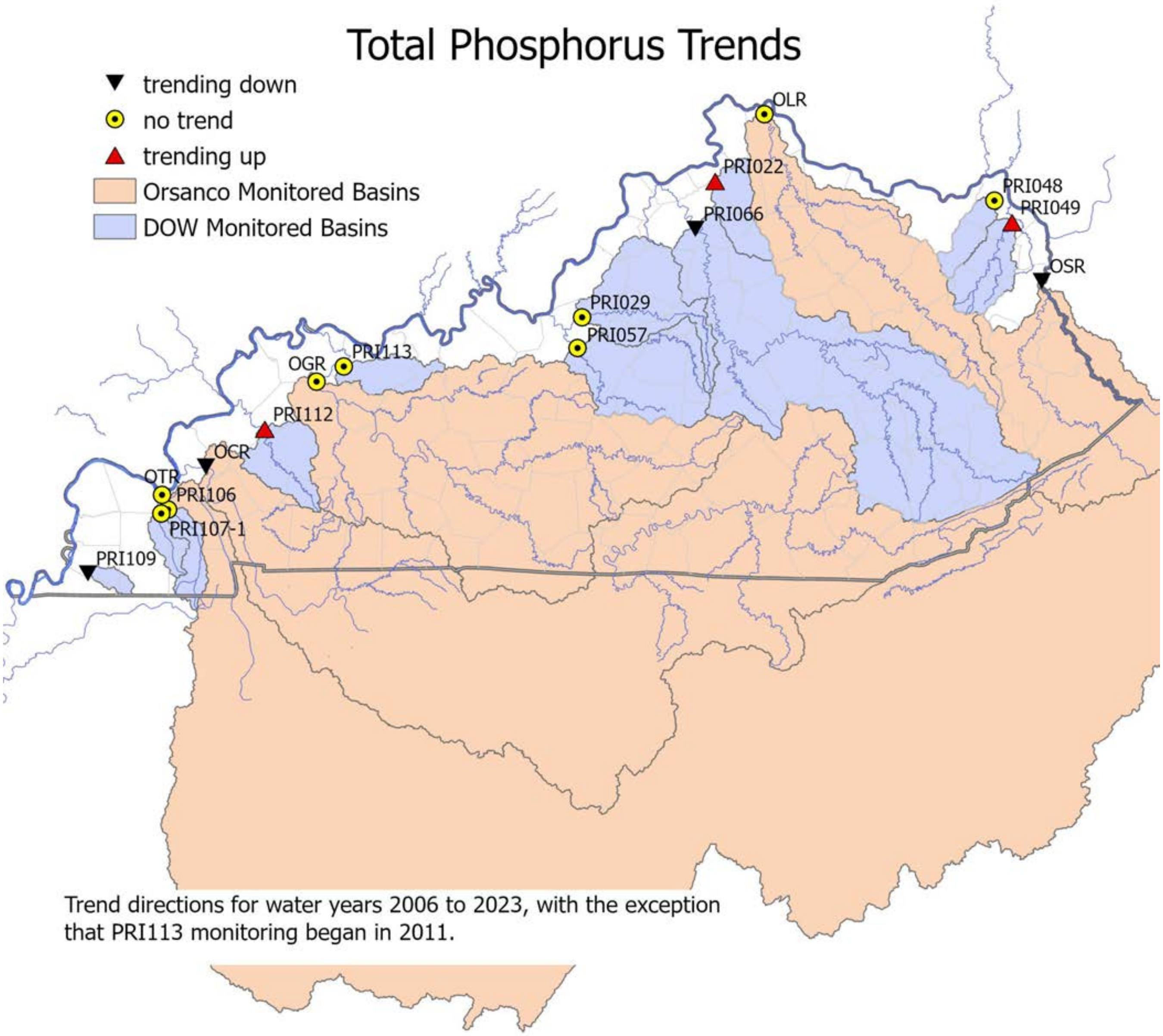


Figure 3. Total Phosphorus Trends.

Discussion

Kentucky's contribution to nutrient loading

The selected monitoring stations for this study cover 82% of Kentucky's statewide drainage area, but they cover basins with significant portions outside the Commonwealth of Kentucky. Only 1% of the Tennessee River drainage area is located in Kentucky, while 40% of the Cumberland River and 50% of the Big Sandy basins are within state boundaries. A more representative analysis of flow-normalized trends within Kentucky is achieved by removing the contributions from basins with a majority of drainage originating from outside the state (see Figure 4 & Figure 5). Without nutrient contributions from the Tennessee and Cumberland Rivers, Kentucky's total nitrogen flow-normalized load decreases 56% (2023), while flow-normalized phosphorus loading decreases by 49% (2023).

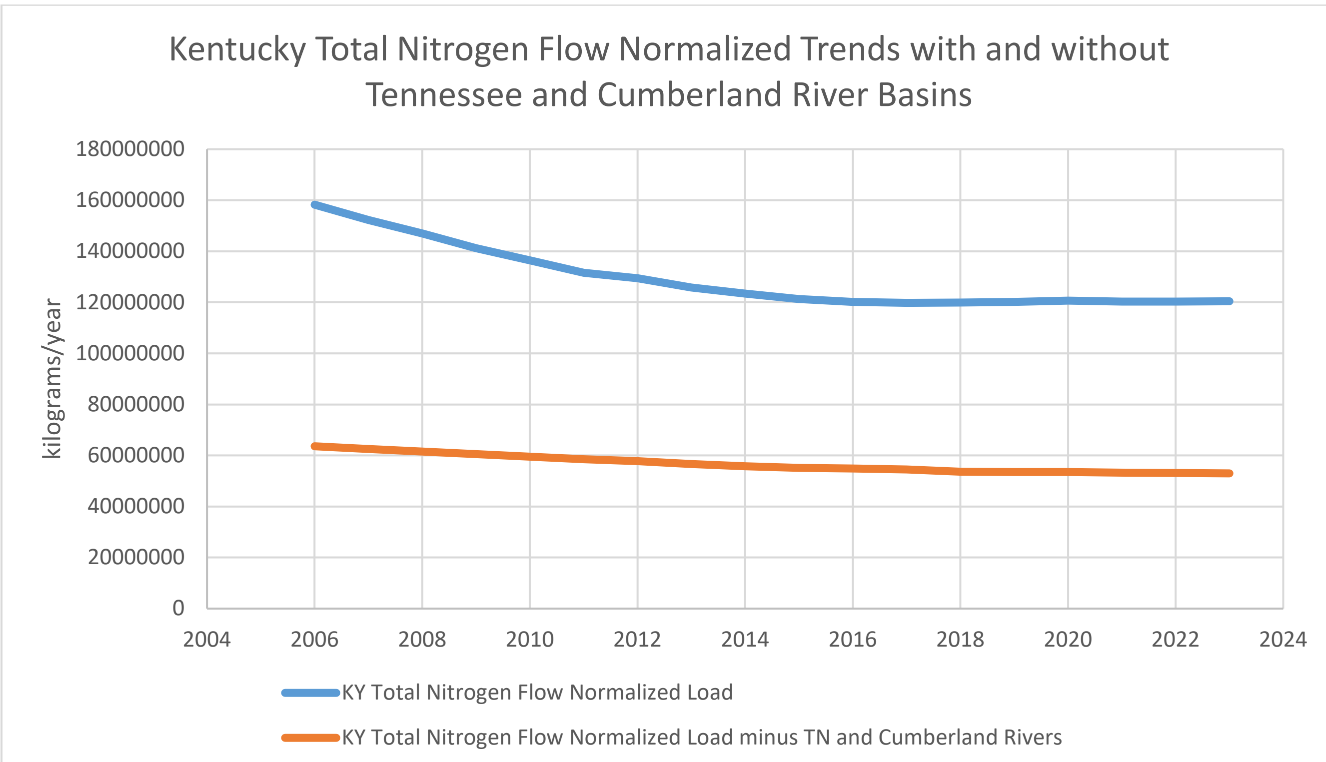


Figure 4. Nitrogen Trends without Cumberland and Tennessee Rivers.

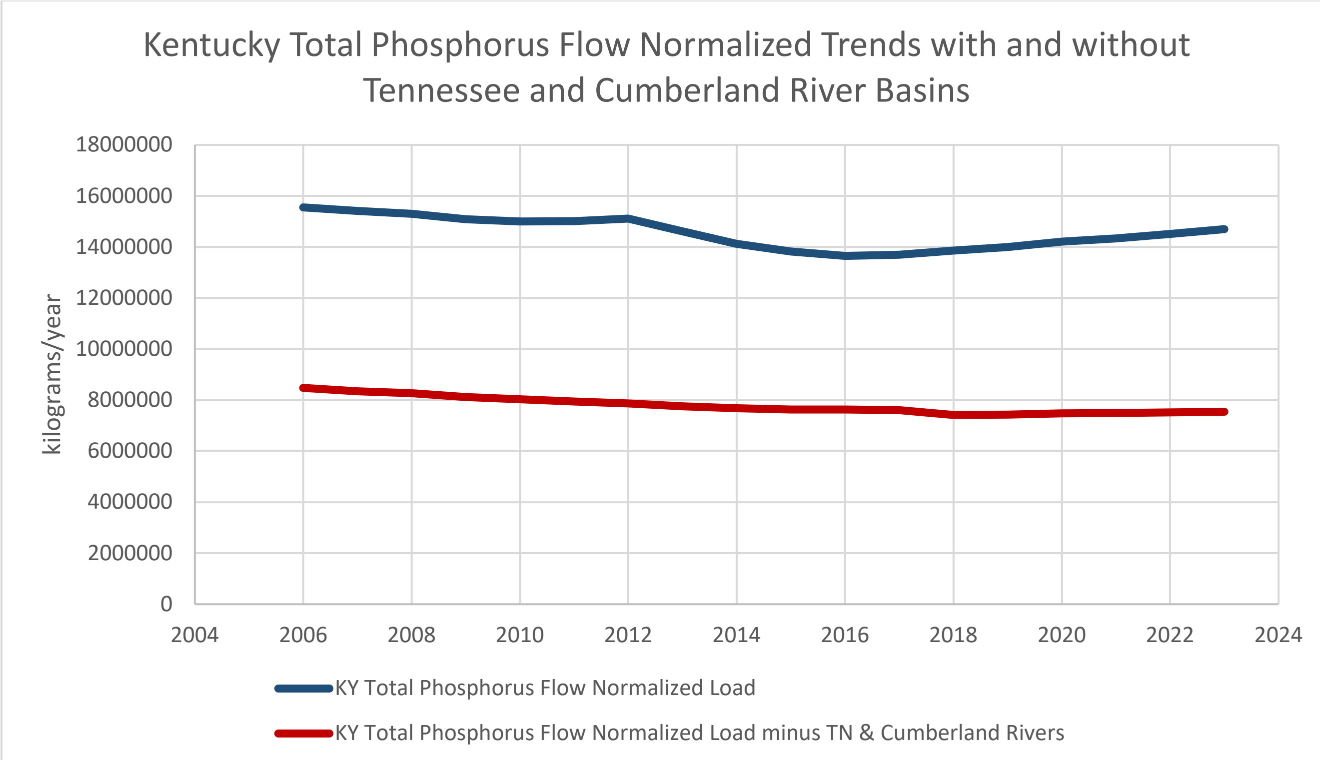


Figure 5. Phosphorus Trends without Cumberland and Tennessee Rivers.

When all monitored basins are included in Kentucky's statewide flow-normalized loading, there is a decrease of 31.6% in nitrogen loading and decrease of 7.2% in phosphorus loading from 2006-2023. Compared with the 16.7% decline in nitrogen loading and 11% decline in phosphorus loading when the Tennessee and Cumberland Rivers are excluded, this suggests unique dynamics between out-of-state contributing catchments and in-state contributing catchments. To better understand these dynamics, a comparison of Kentucky's statewide flow-normalized loading, including the Tennessee and Cumberland Rivers, with regional data is important.

Regional context for declining Kentucky flow-normalized loads is provided by the USGS Station on the Ohio River at Olmsted, IL *(USGS, Ohio River at Olmsted, 2024)* and the combined stations at the Mississippi River near St. Francisville, LA and Atchafalaya River at Melville, LA representing the MARB (*see Figure 6*). While Kentucky's statewide monitored basins includes most of Tennessee and parts of Alabama, Georgia, North Carolina and Virginia, the Ohio River station at Olmsted, IL captures a larger area that includes all of the Kentucky monitored area, most of Indiana, Ohio, and West Virginia, and parts of Illinois, Pennsylvania, Virginia and New York. At a more expansive scale, the MARB stations captures the Mississippi and Atchafalaya River Basin which drains 41% of the continental United States and covers portions of 31 states *(EPA, n.d.)*.

Figure 6. Spatial Comparison of Kentucky Monitored Basins and Regional Monitoring Locations

Comparing these three drainage areas reveals distinct similarities and differences in trend, magnitude, and variability. Kentucky's statewide flow-normalized nitrogen load, and both the Ohio and MARB show declining trends. Notably different between the three is the decrease in nitrogen loading since the early 1980s to the MARB. The less dramatic nitrogen load reduction from the Ohio River suggests considerable influence by other basins to the MARB. Phosphorus loading across each basin is more variable, with a noticeable plateau and moderate recent decline in Kentucky's monitored basins and the Ohio River, while phosphorus in the MARB appears to be in a hastening decline after decades of variability.

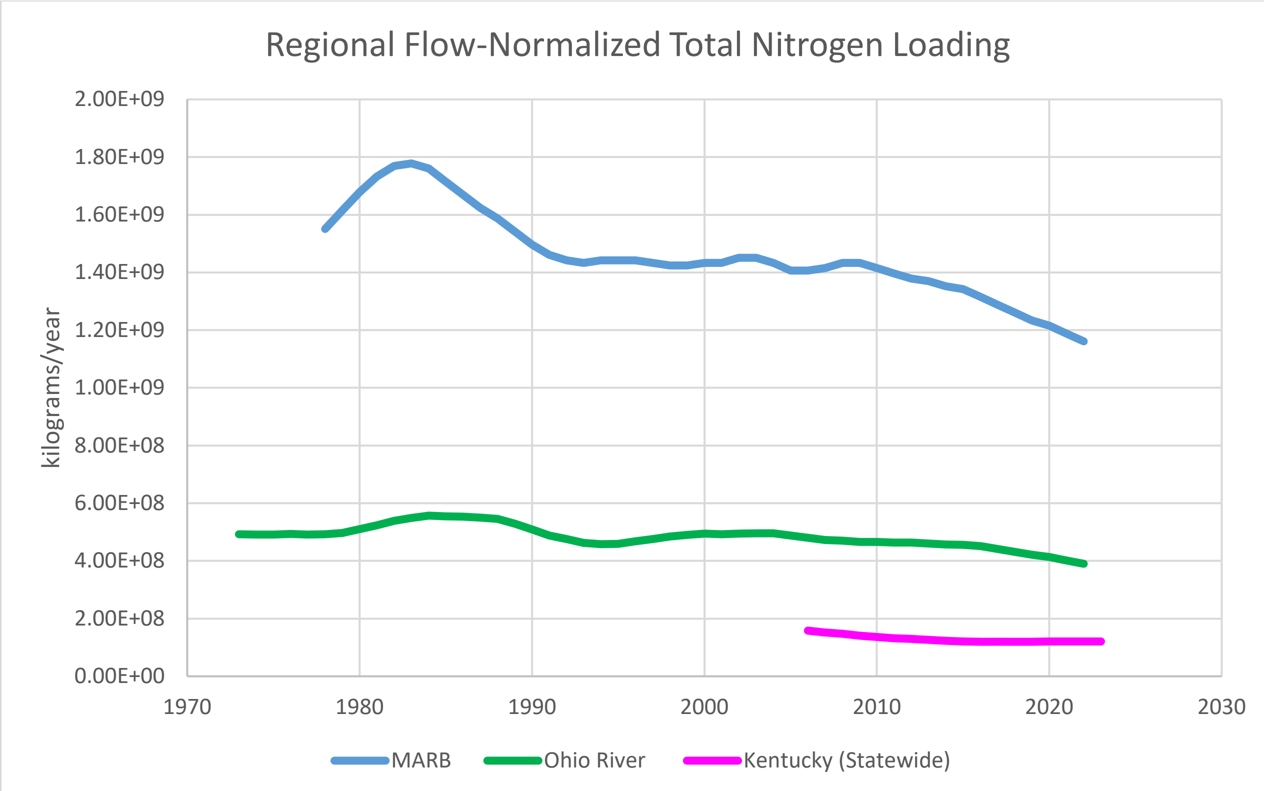


Figure 7. Kentucky and Regional Monitoring Locations Trends in Flow-Normalized Nitrogen Loading

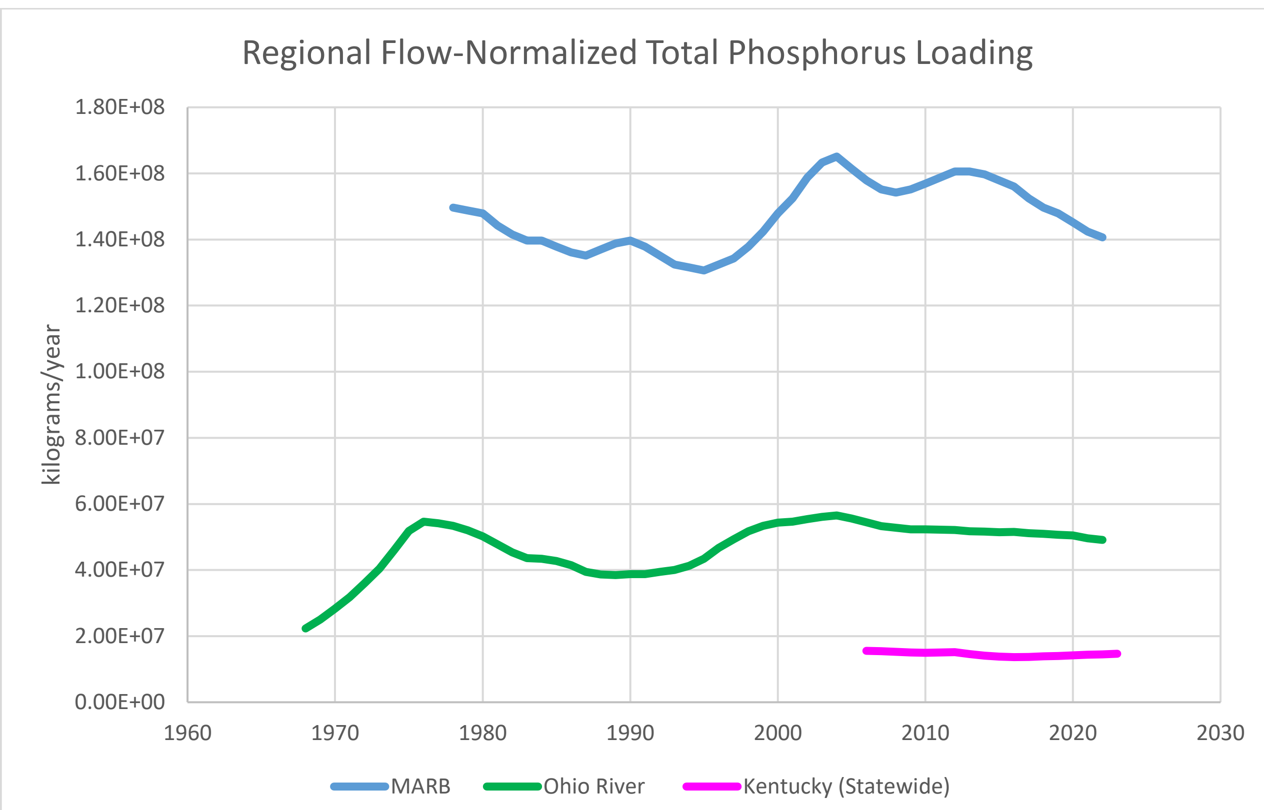


Figure 8. Kentucky and Regional Monitoring Locations Trends in Flow-Normalized Phosphorus Loading

DOW sought to understand potential drivers behind nitrogen load changes by comparing ammonia and nitrate-nitrite loading between Kentucky, the Ohio River, and the MARB reference locations (see Figure 9). Initial analysis of ammonia loading reveals a sharp decline from the Ohio River basin and MARB that began in the 1980s and leveled out in the 2000s. Kentucky's ammonia loading steadily declined from 2006 to the late 2010s, and slightly increased after 2020. Overall ammonia loading from Kentucky, the Ohio River and the MARB in the 2000s, along with the proclivity of ammonia to rapidly nitrify in aquatic systems (Edwards, et al., 2023), suggests improvements in localized management rather than basin-wide inputs.

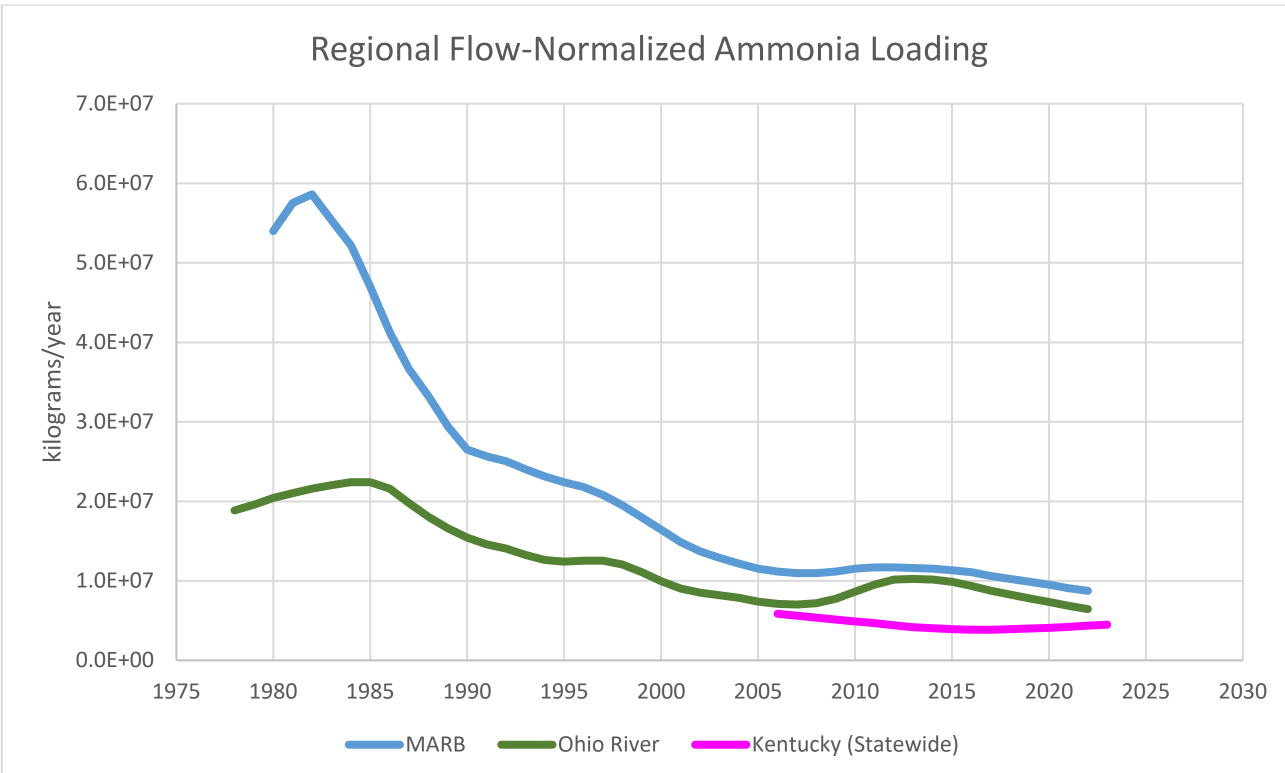


Figure 9. Flow-Normalized Ammonia Trends between Regional Monitoring Locations

Ammonia trends need to be compared to nitrate-nitrite trends on a larger scale to understand the significance of Kentucky's statewide ammonia data. MARB nitrate-nitrite data provides context for smaller basin ammonia trends given the proclivity of localized ammonia to nitrify into a more stable form of nitrogen (nitrate-nitrite) that is delivered to the Gulf of Mexico (Edwards, et al., 2023). Flow normalized nitrate-nitrite trends in the MARB (see Figure 10) show a sharp decline in the 1980s, followed by a leveling period and another noticeable decline after 2015. The scale of nitrate-nitrite loading compared to ammonia loading in the MARB reveals the disparity between these Total Nitrogen constituents to the Gulf of Mexico. Both ammonia and nitrate-nitrite loading trends show accelerated flow-normalized nitrogen reduction after 2015, which could have implications for nutrient reduction efforts (EPA, 2023).

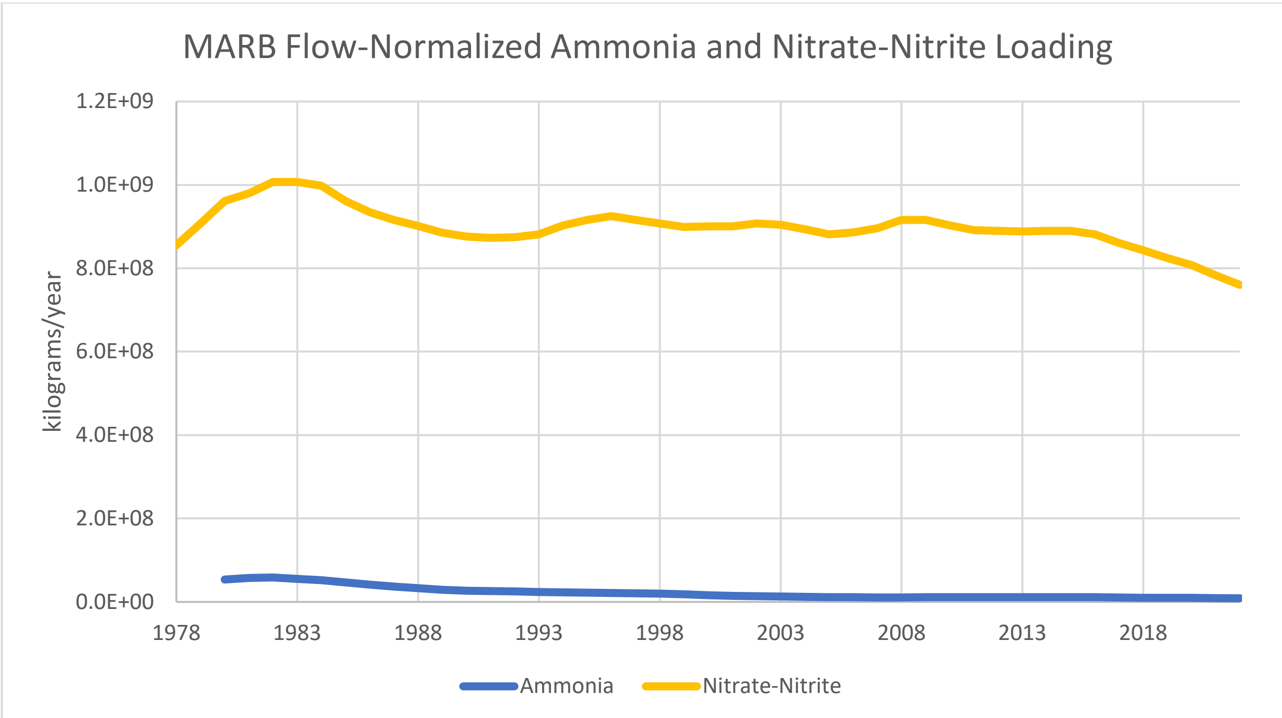


Figure 10. Flow-Normalized Nitrogen Constituents at the MARB.

Declining ammonia loading trends from Kentucky's monitored basins, and at the Ohio River and MARB reference locations, are significant because of the unusual relationship with ammonia atmospheric deposition trends. Atmospheric deposition of nitrogen represents the largest modeled source of nitrogen to the aquatic environment for Kentucky (Robertson, 2019). However, atmospheric deposition trends for nitrogen constituents demonstrate diverging trends.

Figure 11 shows ammonia and nitrate deposition trends based on data from Kentucky stations in the National Trends Network (National Atmospheric Deposition Program, 2024). These data indicate that nitrate deposition decreased from a peak of over 16 kilograms/hectare in 1998, to a low of approximately 7 kilograms/hectare in 2019. Alternatively, ammonia deposition increased from a low of just under 2 kg/ha in 1988, to a high of over 5 kg/ha in 2011. Kentucky's air monitors in the National Trends Network reveal declining nitrate deposition while ammonia deposition is increasing over time. Potential sources and causes of these trends merit further investigation and may provide insight into management effects on excess nutrient loading to the aquatic environment.

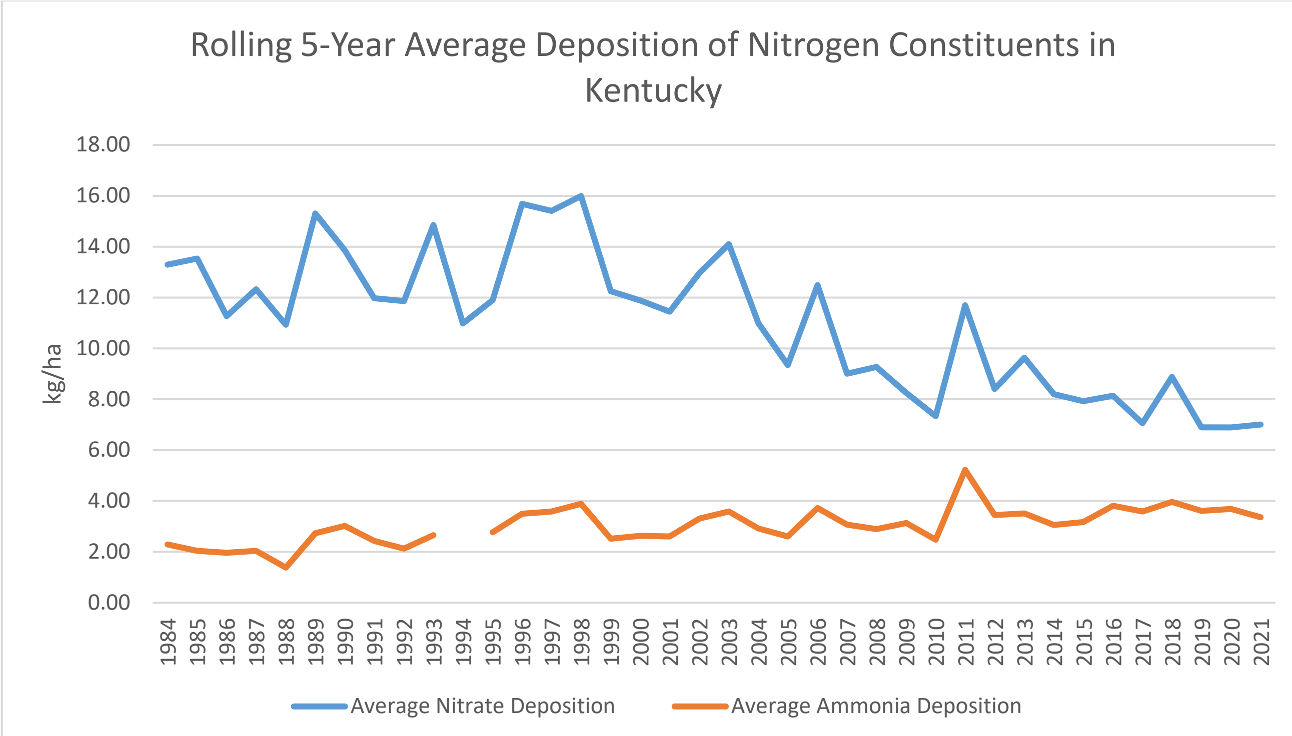
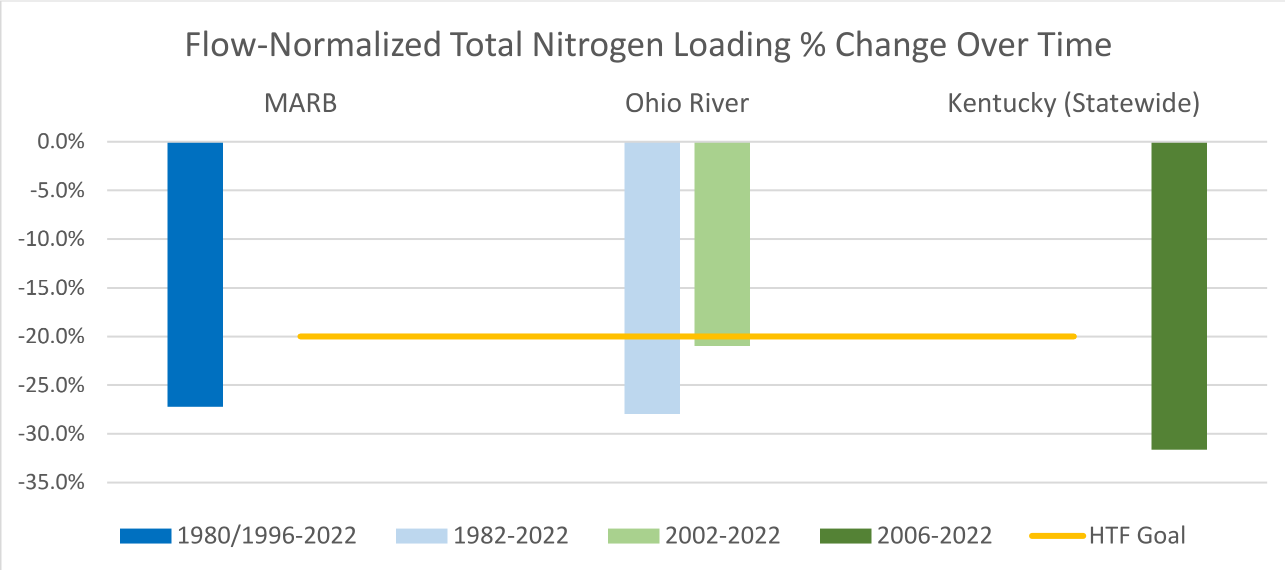


Figure 11. Atmospheric Deposition of Nitrogen Constituents in Kentucky

The Hypoxia Task Force set goals for nutrient reduction and hypoxic zone size between 2001 and 2015 (EPA, 2023), with a specific interim goal of 20% reduction of nitrogen and phosphorus by 2025. Flow-normalized loading data from the MARB suggests the interim nitrogen goal for the Gulf of Mexico was met by 2022 in relation to a 1980-1996 baseline (see Figure 12).

From 1982 to 2022, the flow-normalized average nitrogen load at the Ohio River decreased by 28%, which is similar to the MARB's 27.2% decrease from 1980/1996 to 2022. Using a later time period (2002-2022) for the Ohio River may provide a better comparison for Kentucky's 2006-2023 analysis; the Ohio River demonstrated a 21% decrease in this later period, compared to Kentucky's 31.6% decrease. This comparison suggests Kentucky statewide monitored basins may have realized a long-term flow-normalized nitrogen load reduction on par with the 27.2% and 28% reductions of the MARB and Ohio Rivers, respectively.

Compared to long-term nitrogen trends, the phosphorus trends for all three reference points are mixed. From 1980/1996 to 2022, flow-normalized phosphorus loading to the MARB increased by 2%, while Ohio River loading increased by 8% from 1982 to 2022 (see Figure 12). However, flow-normalized phosphorus loading appears to peak in the early 2000s (Figure 8), followed by an 11% decrease from the Ohio River and a 7.2% decrease from Kentucky's monitored basins. This recent declining trend in phosphorus loads compared to historic variability supports the need for further evaluation of contributing factors that is beyond the scope of this study.



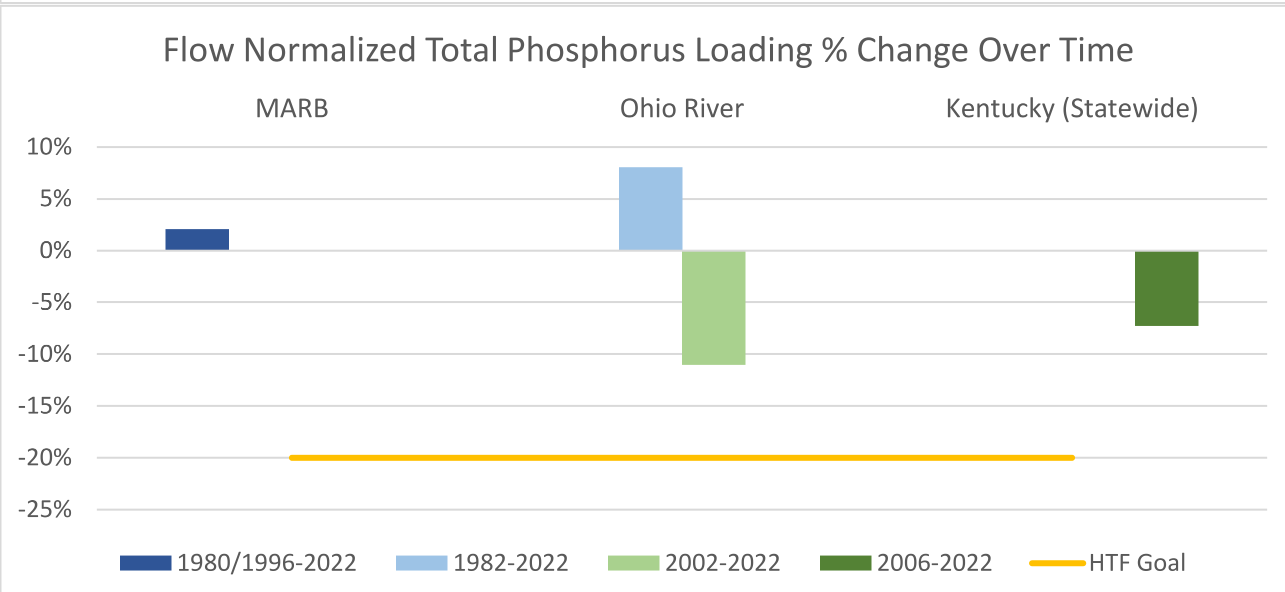


Figure 12. Flow-Normalized Nutrient Loading Change Over Time

The Hypoxia Task Force's interim nutrient load reduction goals ultimately serve the larger objective of reducing the 5-year rolling average size of the Gulf of Mexico Hypoxic Zone to 5,000 square kilometers. Since 1985, the Hypoxic Zone size has only been below or at 5,000 square kilometers twice, in 2000 and 2016 (Figure 13). However, the 5-year rolling average size of the Hypoxic Zone has shown significant reduction since 1994, when five years of continuous data was first available. Specifically, the Hypoxic Zone decreased in size by 16.5% between 1994 and 2022, with notable acceleration after 2002 when the average size decreased by 29.6% (see Figure 14). While more work is needed to meet the established goal, this trend suggests that progress is being made.

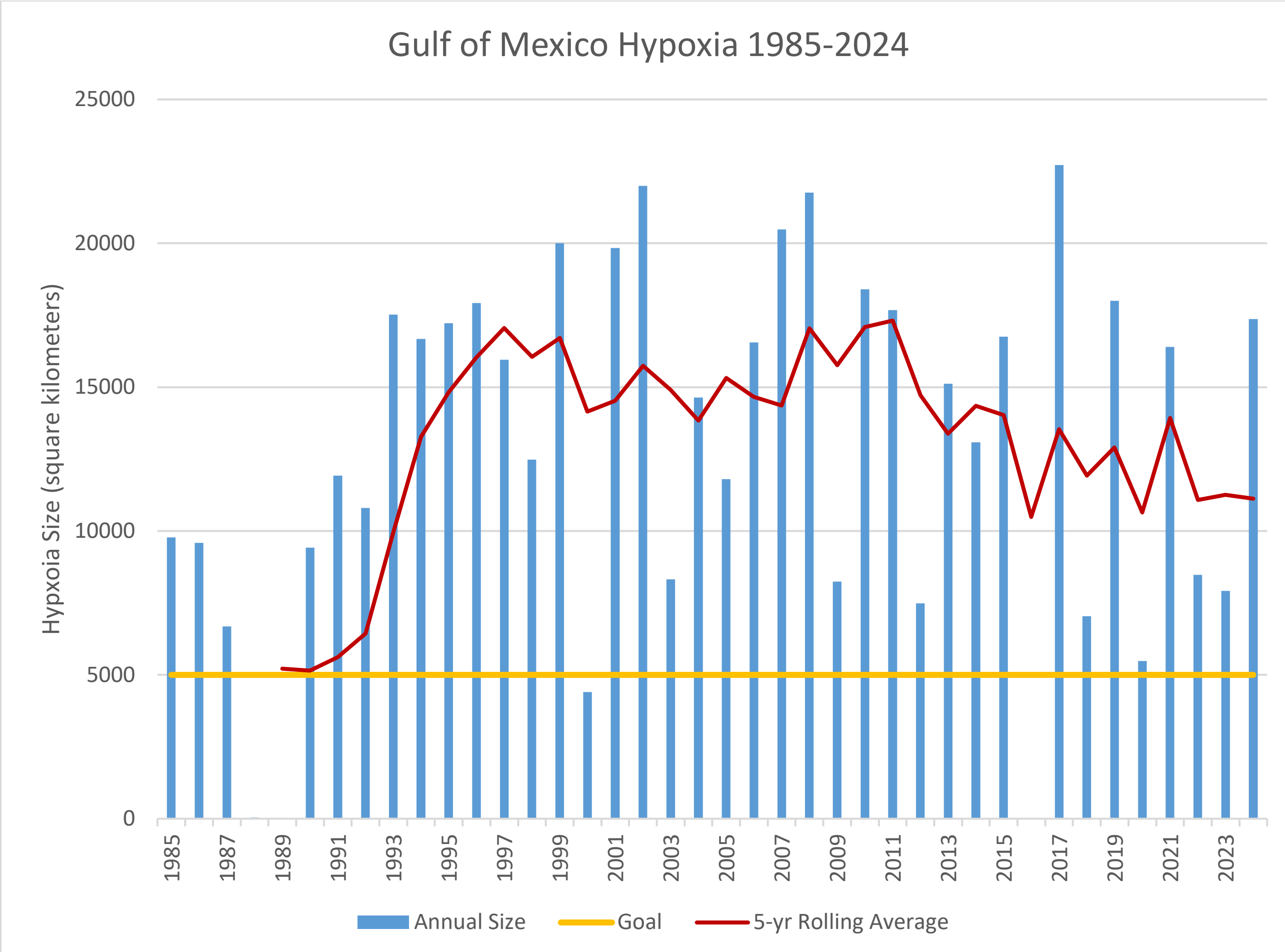


Figure 13. Gulf of Mexico Hypoxia Zone Size (NOAA, 2024).

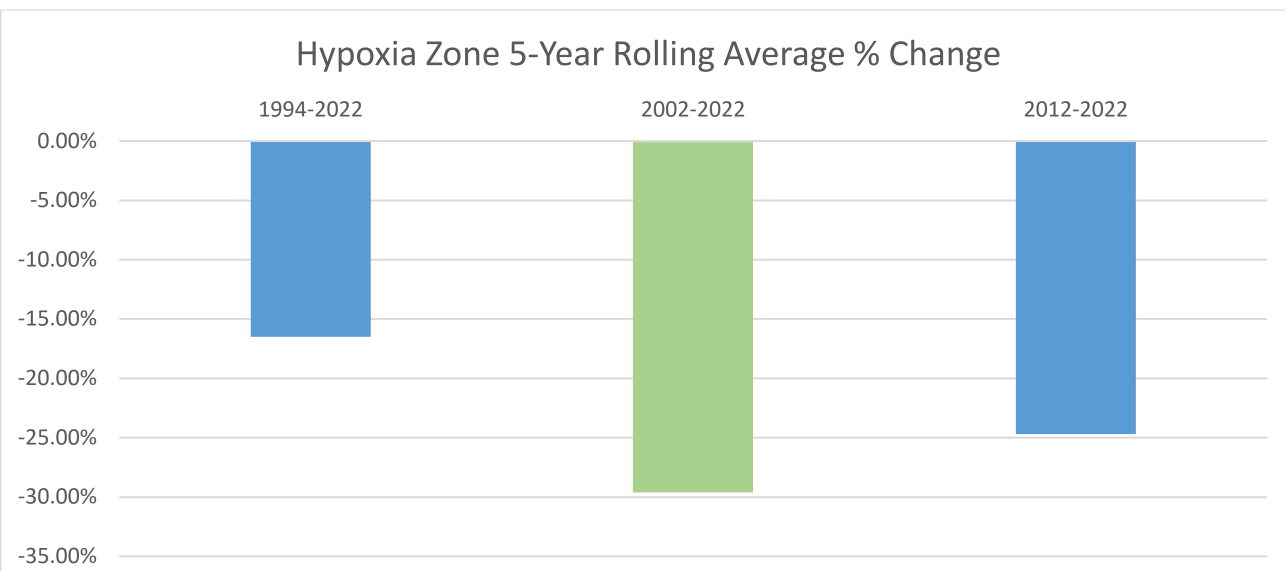


Figure 14. Hypoxia Zone 5-year Rolling Average Change Over Time.

Comparison with the MARB

DOW aggregated the annual flow-normalized load for 16 stations from 2006 until 2023 to identify trends and then compared them to the flow-normalized loads to the Gulf of Mexico as identified by the National Water Quality Network (NWQN) run by USGS (U.S. Geologic Survey, 2023). DOW extrapolated flow-normalized loading to the MARB (indicated by the blue highlighted line in Figure 15) with Kentucky's loading trends. The resulting comparison is identified in Figure 16 and reveals decreases in both outgoing Kentucky statewide loads and MARB loading. This suggests a steady decline in nitrogen loading to the Gulf since at least 1983, and steady reductions from Kentucky monitored basins during the study period (2006-2023).

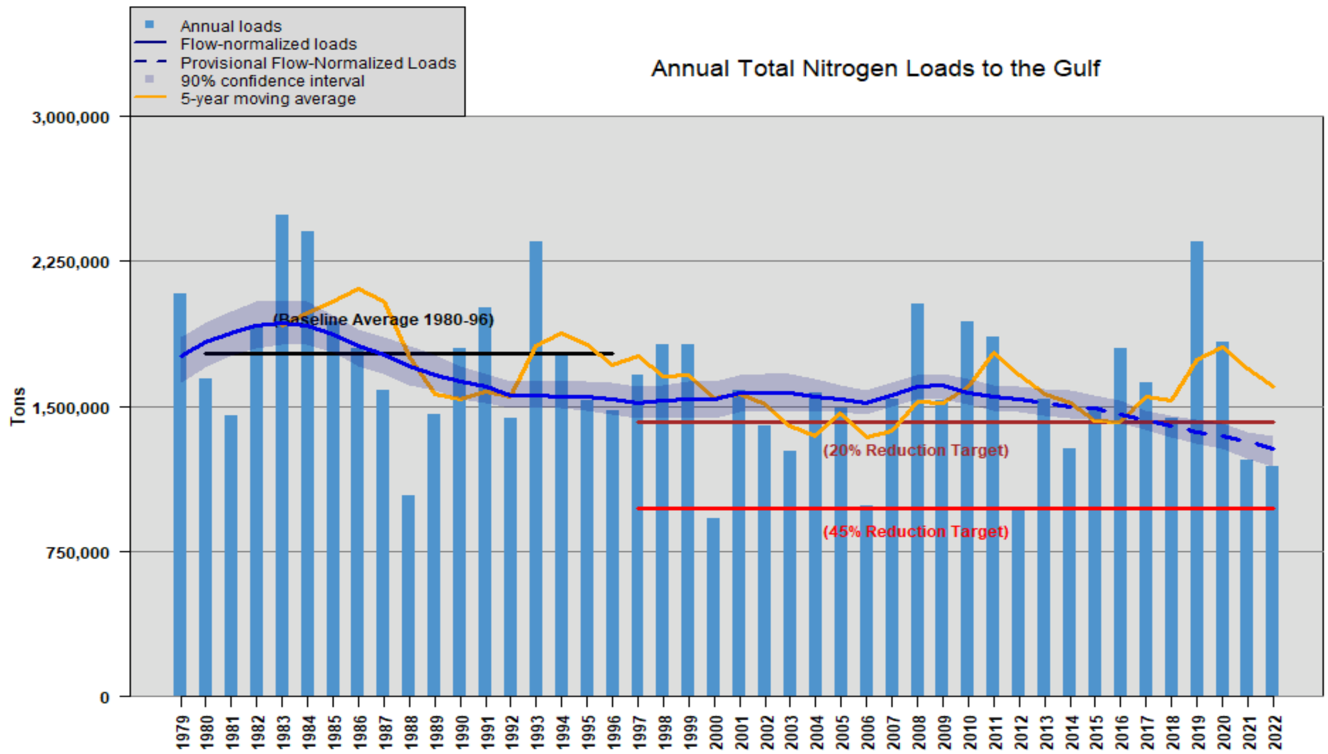


Figure 15. USGS Annual Total Nitrogen Loads to the Gulf of Mexico (U.S. Geologic Survey, 2023)

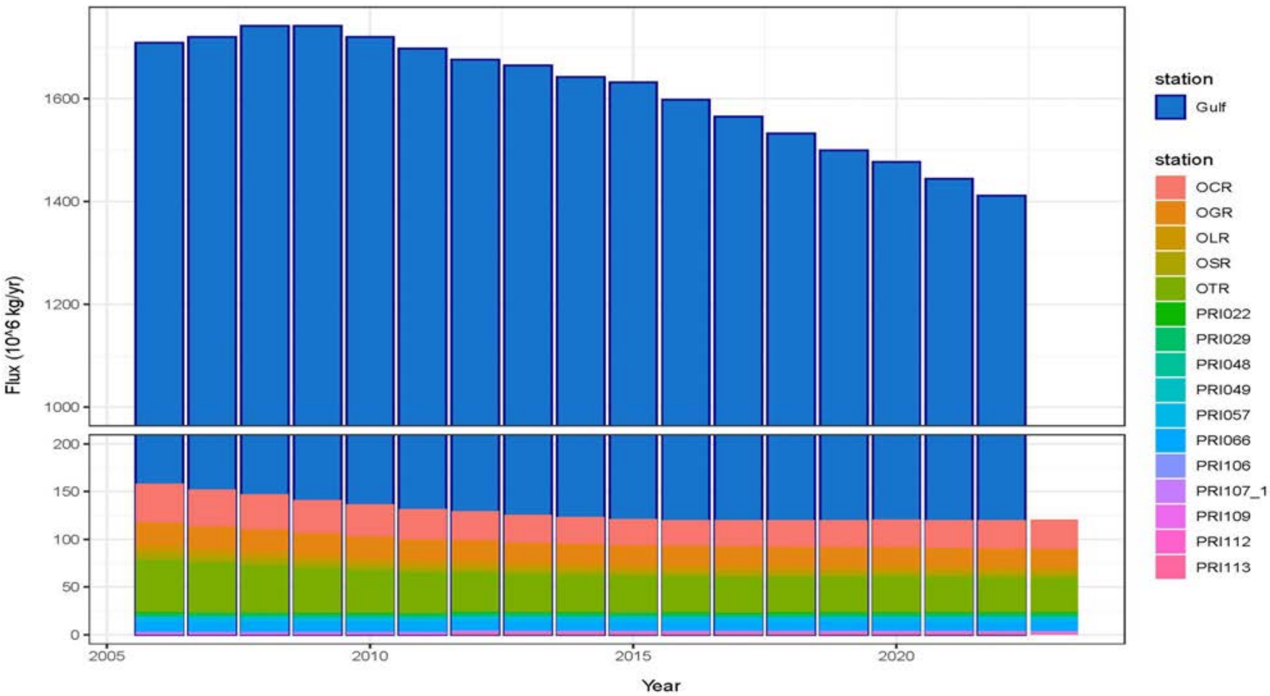


Figure 16. Kentucky & Gulf of Mexico Flow-Normalized Nitrogen Loads

Phosphorus loading in Kentucky and the region present a different trend, albeit on a dramatically different scale. The annual baseline (U.S. Geologic Survey, 2023) of phosphorus loading to the Gulf is 151,588 tons, while the baseline average nitrogen loading is 1,751,764 tons, or ~11 times the phosphorus baseline. While the Hypoxia Task Force goal of 20% nitrogen reduction by 2025 appears within reach, phosphorus shows a more muted trend consistent with historic analyses. While there is agreement that nitrate loading doubled or tripled since the early 1900s until the 1980-1996 baseline, phosphorus trends prior to the 1980-1996 baseline (Rabialis, 1996) are disputed. Flow-normalized phosphorus loading to the Gulf appeared to peak in 2003 (see Figure 4), with notable declines since 2012/2013. Stacking individual Kentucky stations (see Figure 5) allows a visual analysis of how various-sized basins influence total loading. Kentucky's flow-normalized phosphorus trend is more muted than the Gulf, but appears to have been under a slow decline from 2006-2012, followed by a slight dip and leveling off.

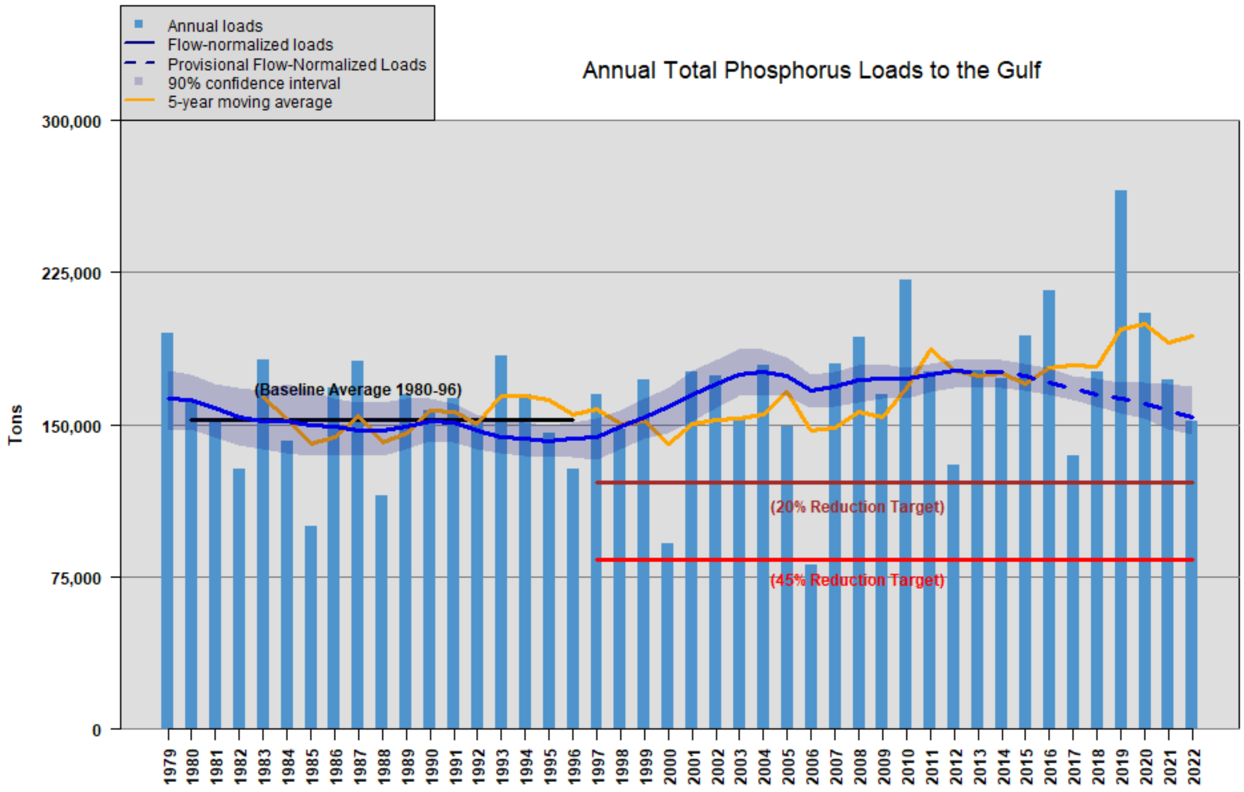


Figure 17. USGS Annual Total Phosphorus Loads to the Gulf of Mexico (U.S. Geologic Survey, 2023)

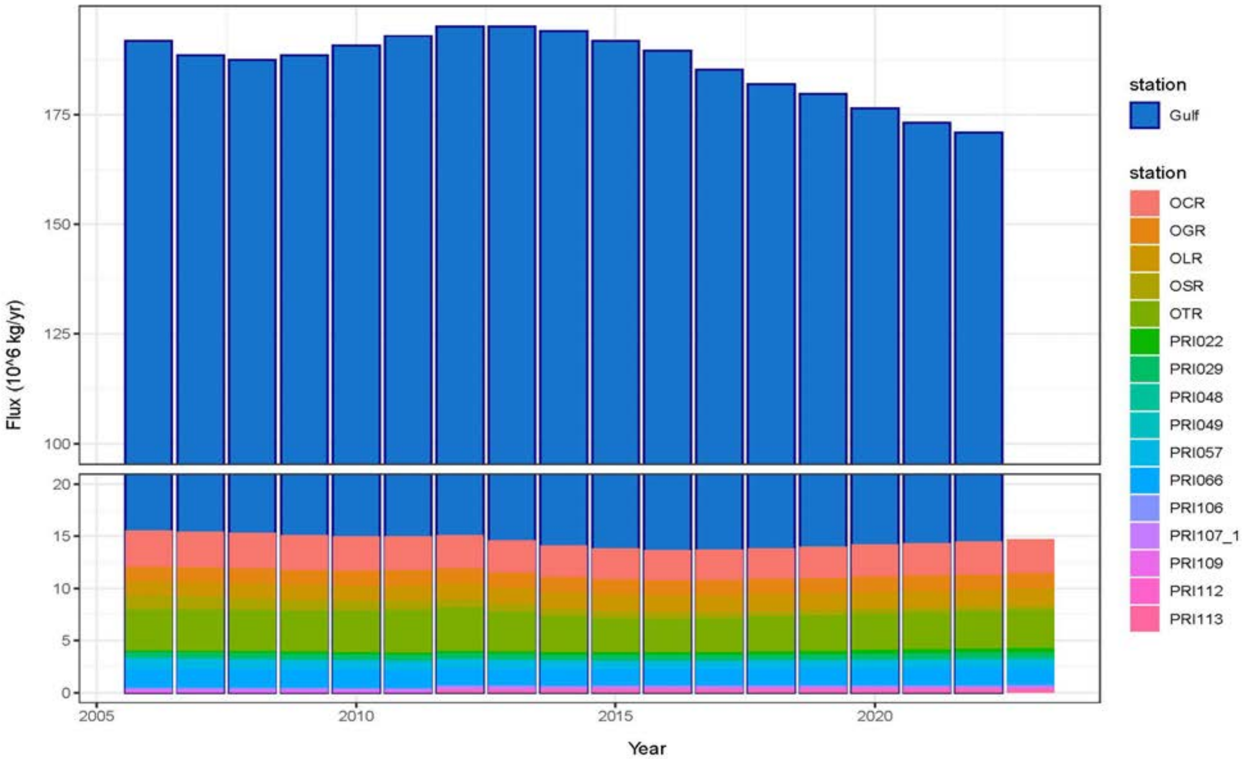


Figure 18. Kentucky & Gulf of Mexico Flow-Normalized Phosphorus Loads

Conclusions

This study provides a comparison of Kentucky's nutrient loads with regional and national watersheds using a unified methodology that offers insights for Hypoxia Task Force goal tracking. Kentucky's monitored basins are on a similar trajectory as Gulf of Mexico nitrogen loading that met the Hypoxia Task Force's interim goal of a 20% reduction, but more work is needed to meet a 20% phosphorus reduction. Flow-normalized nitrogen reductions from Kentucky and regional reference basins (i.e. Ohio River, MARB) coincide with a declining 5-year rolling average size of the Gulf of Mexico Hypoxic Zone.

Future studies may evaluate data from new monitoring stations in Western Kentucky that will fill nutrient coverage gaps. Additional study is needed to understand Kentucky's nutrient dynamics, particularly how complex atmospheric, terrestrial, and aquatic trends influence long-term loading.

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Appendix 1: Flow-Normalized (Flux) Nitrogen and Phosphorus Trends

Table 2. Change estimates for water years 2006 to 2023.

Site	Analyte	Concentration (mg/L)				Flux (kg/yr)				Trend	
		est change	95% CI		p-value	est change	95% CI		p-value	Conc	Flux
OCR Cumberland R @ Pinkneyville	Phosphorus	-0.028	-0.069	0.099	0.25	-2.33E+05	-1.275	2.211	0.84		
	Nitrogen	-0.222	-0.449	0.067	0.18	-1.06E+07	-18.160	-2.890	0.02		
OGR* Green R @ Sebree	Phosphorus	-0.010	-0.039	0.047	0.86	-7.22E+04	-0.693	0.849	0.94		
	Nitrogen	-0.250	-0.470	-0.019	0.078	-4.23E+06	-7.260	-1.020	0.03		
OLR Licking R @ Covington	Phosphorus	-0.006	-0.113	0.085	0.96	1.83E+05	-1.291	1.274	0.61		
	Nitrogen	-0.488	-1.027	-0.143	0.02	-1.46E+06	-4.478	1.072	0.20		
OSR Big Sandy R @ Louisa	Phosphorus	-0.073	-0.146	0.006	0.06	-9.19E+05	-1.863	0.044	0.06		
	Nitrogen	-0.331	-0.546	-0.094	0.02	-2.87E+06	-5.316	-0.634	0.02		
OTR Tennessee R @ Paducah	Phosphorus	-0.005	-0.019	0.040	0.98	-1.80E+05	-1.246	2.640	0.84		
	Nitrogen	-0.382	-0.618	-0.228	0.05	-1.91E+07	-40.360	-9.310	0.02		
PRI066 Kentucky R nr Lockport	Phosphorus	-0.015	-0.057	0.036	0.6	-1.03E+05	-0.815	0.747	0.99		
	Nitrogen	-0.174	-0.454	0.174	0.31	-1.38E+06	-4.057	2.897	0.55		
PRI022 Eagle Cr @ Glenco	Phosphorus	0.101	-0.055	0.234	0.12	1.79E+05	-0.071	0.444	0.13		
	Nitrogen	0.325	-0.348	0.896	0.18	5.05E+05	-0.295	1.260	0.12		
PRI029 Salt R @ Shepherdsville	Phosphorus	0.020	-0.019	0.069	0.23	5.50E+04	-0.127	0.289	0.60		
	Nitrogen	0.178	-0.103	0.603	0.12	1.41E+05	-0.710	0.991	0.60		
PRI048 Tygarts Cr nr Lynn	Phosphorus	0.004	-0.006	0.027	0.33	-5.36E+02	-0.010	0.022	0.85		
	Nitrogen	0.096	-0.156	0.356	0.39	3.36E+04	-0.118	0.167	0.53		
PRI049 Little Sandy @ Argilite	Phosphorus	0.020	0.007	0.034	0.02	2.56E+04	0.004	0.049	0.02		
	Nitrogen	-0.176	-0.385	0.072	0.12	-4.36E+04	-0.211	0.134	0.72		
PRI057 Rolling Fk nr Lebanon Junction	Phosphorus	0.012	-0.057	0.128	0.65	-1.63E+05	-0.569	0.651	0.41		
	Nitrogen	0.345	-0.055	0.773	0.072	4.25E+05	-0.531	1.434	0.33		
PRI106 Clarks R nr Sharpe	Phosphorus	0.016	-0.041	0.069	0.51	1.80E+04	-0.027	0.060	0.45		
	Nitrogen	0.154	-0.223	0.476	0.39	3.87E+03	-0.140	0.158	0.77		
PRI107-1 W Fk Clarks R nr Symsonia	Phosphorus	0.027	-0.062	0.125	0.63	-7.08E+03	-0.067	0.049	0.81		
	Nitrogen	-0.072	-0.720	0.382	0.75	-1.41E+05	-0.381	0.089	0.24		
PRI109 Bayou de Chien nr Cayce	Phosphorus	-0.054	-0.145	0.020	0.19	-7.32E+04	-0.130	0.008	0.07		
	Nitrogen	-0.231	-0.912	0.159	0.28	-3.11E+05	-0.645	0.023	0.07		
PRI112 Tradewater nr Piney	Phosphorus	0.006	-0.023	0.027	0.76	1.57E+04	-0.004	0.032	0.18		
	Nitrogen	-0.221	-0.459	0.271	0.14	-4.09E+04	-0.331	0.323	0.71		
PRI113** Panther Cr nr W Louisville	Phosphorus	0.024	-0.094	0.177	0.630	1.20E+05	-0.104	0.344	0.210		
	Nitrogen	-0.625	-0.913	-0.250	0.220	-1.71E+05	-0.765	0.443	0.650		

**OGR is for water years 2006 to 2022.*

***PRI113 is for water years 2012 to 2023.*

LEGEND	highly likely	very likely	likely	as likely as not
trending up				
trending down				

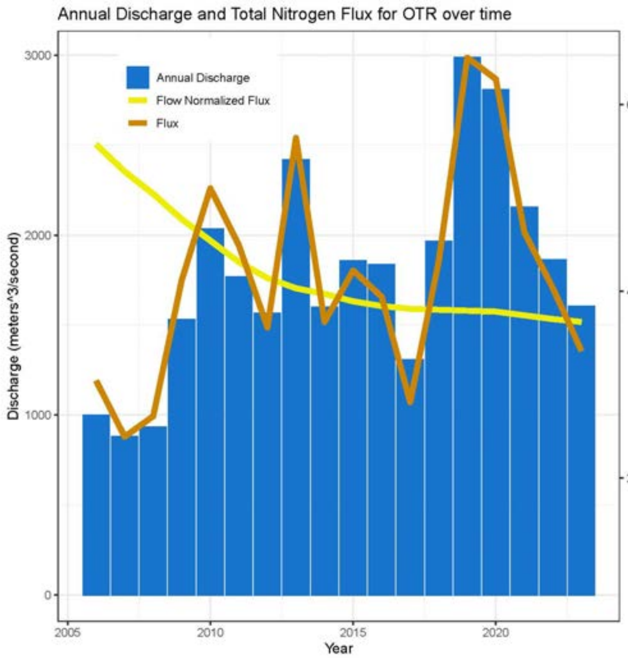
Table 3. Trends in loads by both amount and percent change. Two time periods are shown for trends, the difference between 2006 and 2023, and 2013 and 2023.

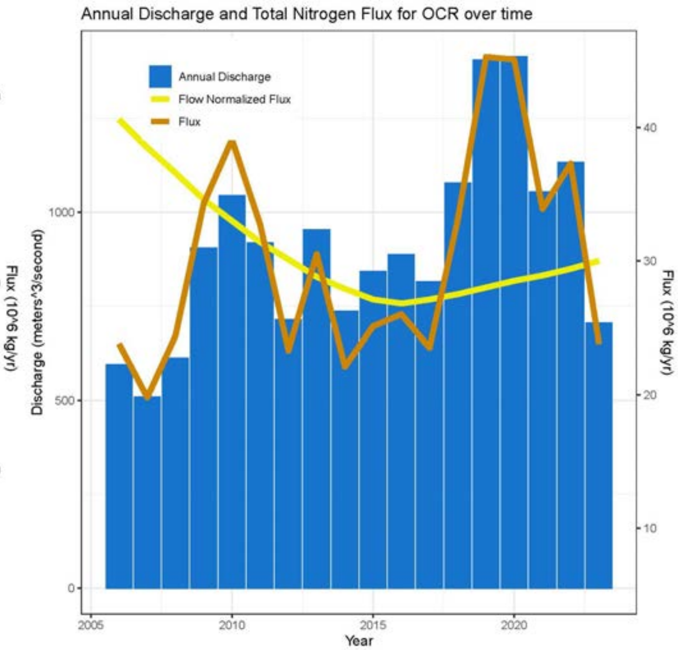
Station		Total Phosphorus		Total Nitrogen	
	Start Year	10^6 kg/yr	pct change	10^6 kg/yr	pct change
OGR	2006*	0.0769	5.01%	-2.44	-10.20%
Green R @ Sebree	2013*	0.0206	1.37%	-2.03	-9.60%
OLR	2006	0.346	24.80%	-0.92	-12.61%
Licking R @ Covington	2013	0.0312	2.03%	-0.0481	-0.81%
OCR	2006	0.244	7.47%	-6.41	-16.54%
Cumberland R @ Pinkneyville	2013	0.451	14.69%	3.48	12.05%
OSR	2006	-0.0733	-65.80%	-2.22	-34.68%
Big Sandy R @ Louisa	2013	-0.296	-42.38%	-0.556	-11.73%
OTR	2006	0.388	10.34%	-12.2	-22.80%
Tennessee R @ Paducah	2013	0.352	9.29%	0.549	1.35%
PRI022	2006	0.179	89.28%	0.505	61.41%
Eagle Cr @ Glenco	2013	0.141	57.82%	0.376	39.18%
PRI029	2006	0.055	9.54%	0.141	3.69%
Salt R @ Shepherdsville	2013	0.0748	13.43%	0.247	6.63%
PRI048	2006	-0.000536	-2.85%	0.0336	14.79%
Tygarts Cr nr Lynn	2013	0.00122	7.57%	0.0297	13.16%
PRI049	2006	0.0256	73.49%	-0.0436	-9.26%
Little Sandy @ Argilite	2013	0.0222	58.35%	0.0156	3.79%
PRI057	2006	-0.163	-18.71%	0.425	12.01%
Rolling Fk nr Lebanon Junction	2013	-0.0532	-6.99%	0.185	4.89%
PRI066	2006	0.129	6.68%	-0.221	-1.90%
Kentucky R nr Lockport	2013	0.128	7.38%	-0.223	-2.09%
PRI106	2006	0.018	19.52%	0.00387	62.00%
Clarks R nr Sharpe	2013	0.0164	17.44%	0.0286	4.74%
PRI107-1	2006	-0.00708	-7.16%	-0.141	-22.54%
W Fk Clarks R nr Symsonia	2013	0.0033	3.73%	-0.026	-5.08%
PRI109	2006	-0.0732	-37.25%	-0.311	-36.83%
Bayou de Chien nr Cayce	2013	-0.036	-22.59%	-0.156	-22.65%
PRI119	2006	0.0154	28.60%	-0.0409	-5.58%
Tradewater R nr Piney	2013	0.0118	20.64%	-0.0796	-10.33%
PRI113	2006**				
Panther Cr nr W Louisville	2013	0.112	45.60%	-0.149	-11.51%

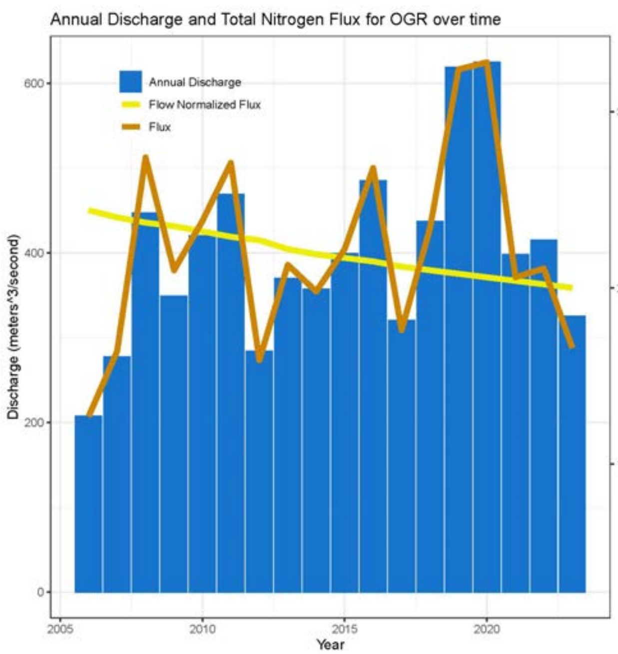
*End year is 2022

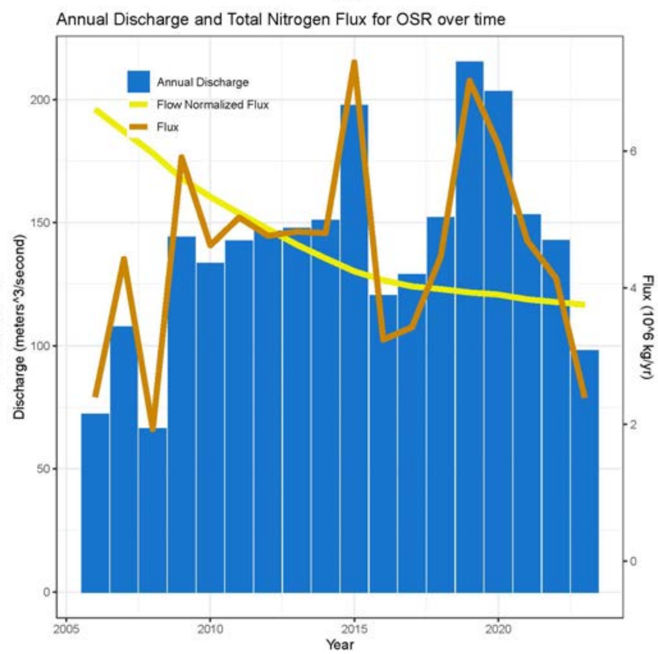
**Monitoring began in water year 2012

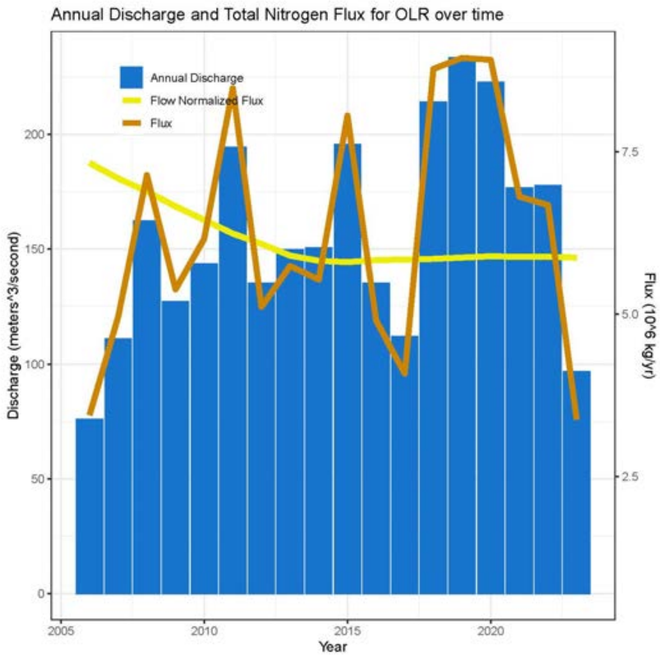
Appendix 2: Flow-Normalized Nitrogen Flux at Kentucky Stations

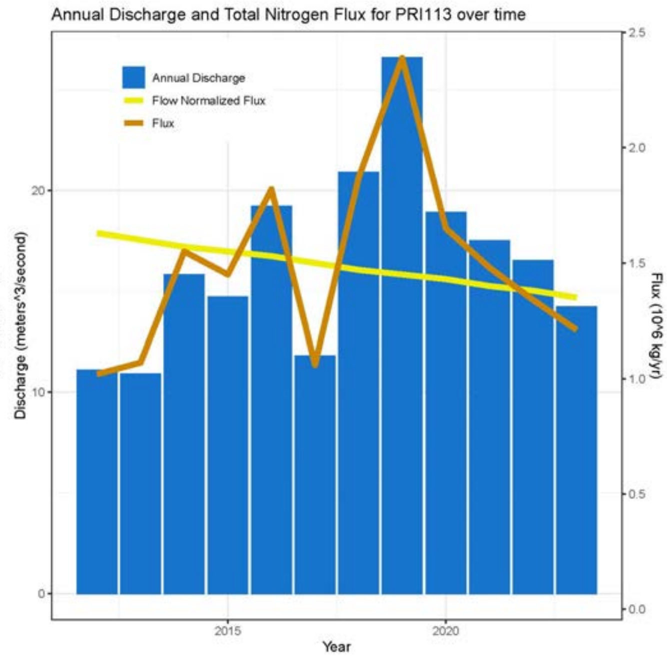


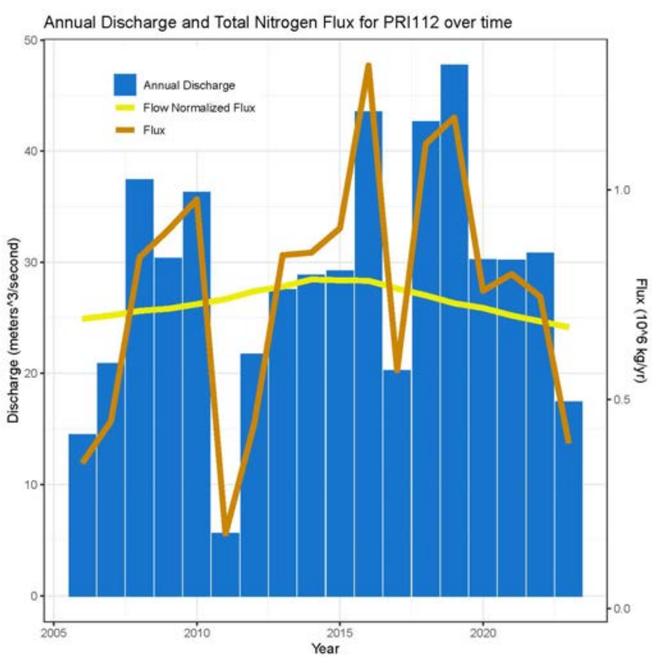


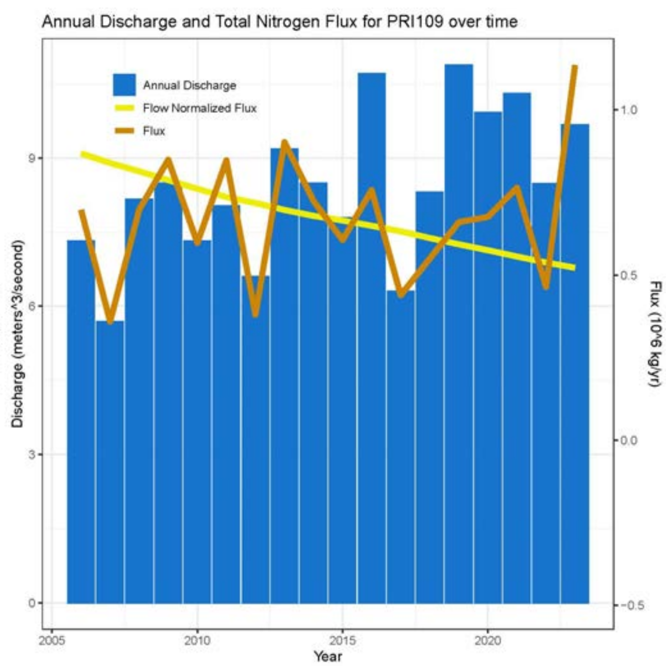




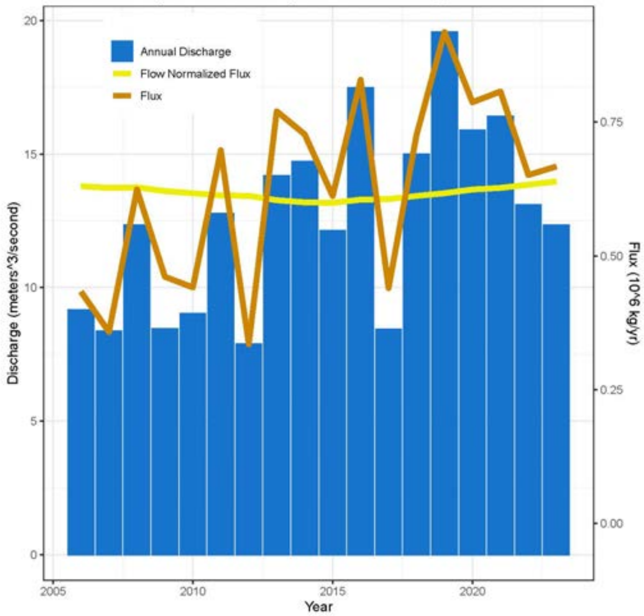

Annual Discharge and Total Nitrogen Flux for OLR over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year


Annual Discharge and Total Nitrogen Flux for PRI113 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

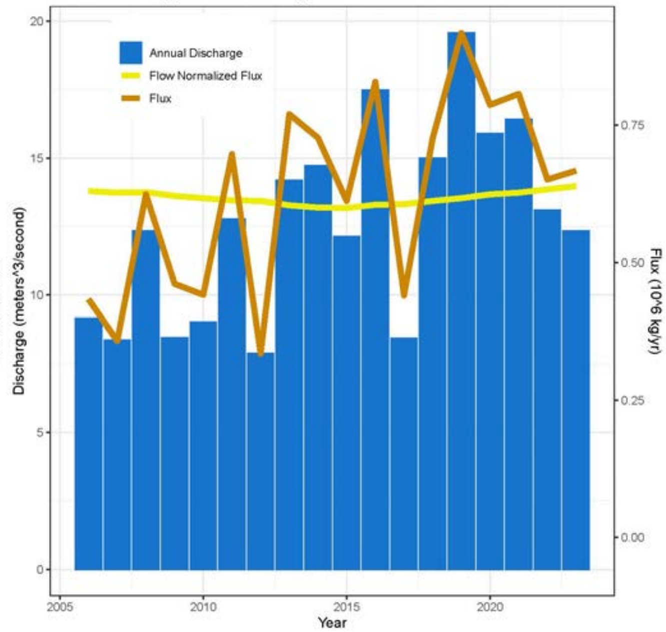

Annual Discharge and Total Nitrogen Flux for PRI112 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year


Annual Discharge and Total Nitrogen Flux for PRI109 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

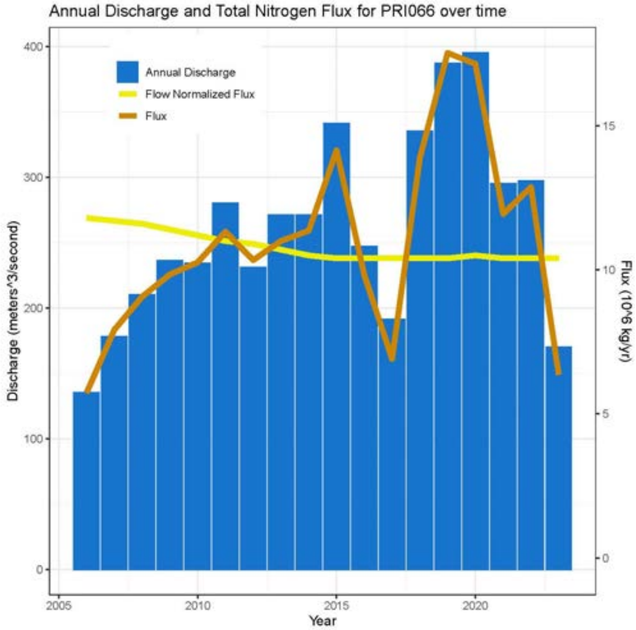
Annual Discharge and Total Nitrogen Flux for PRI107_1 over time



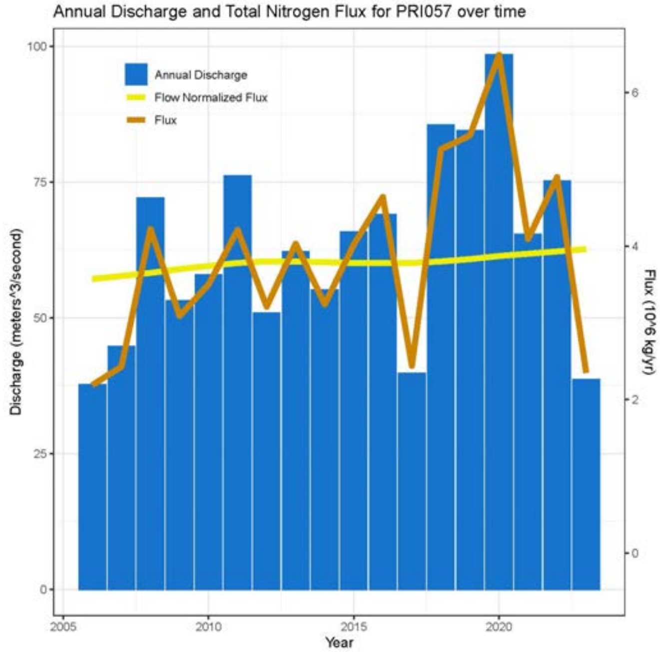
Annual Discharge and Total Nitrogen Flux for PRI106 over time

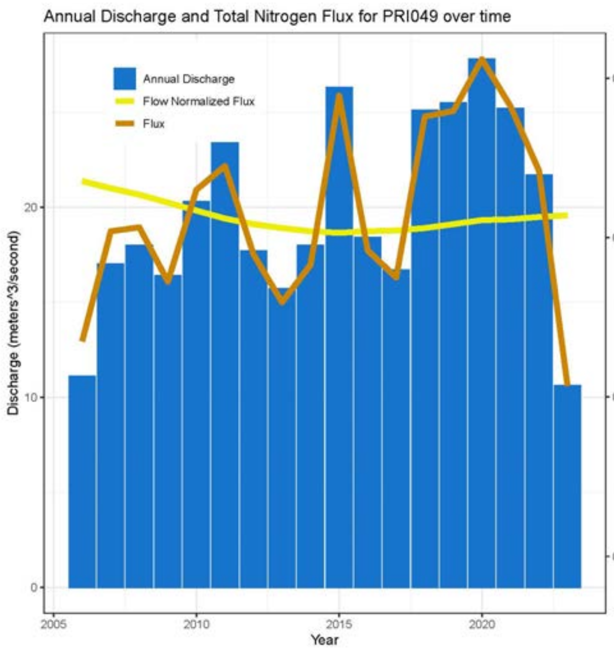


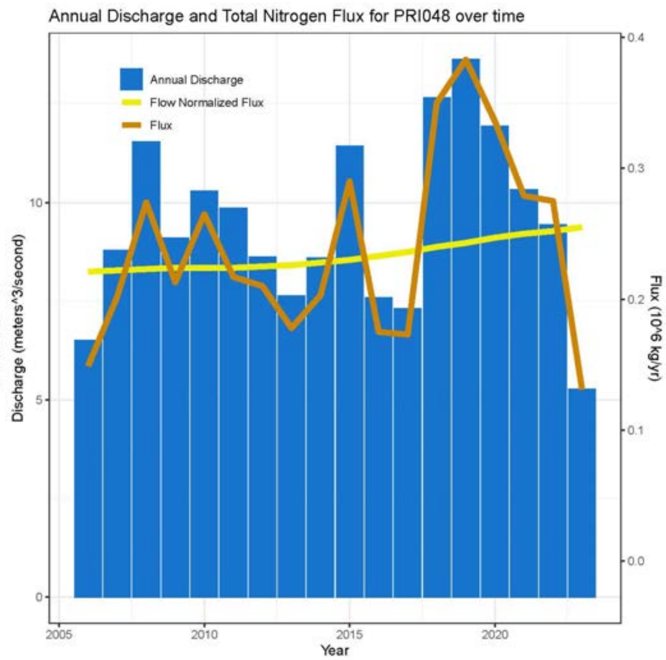
Annual Discharge and Total Nitrogen Flux for PRI066 over time

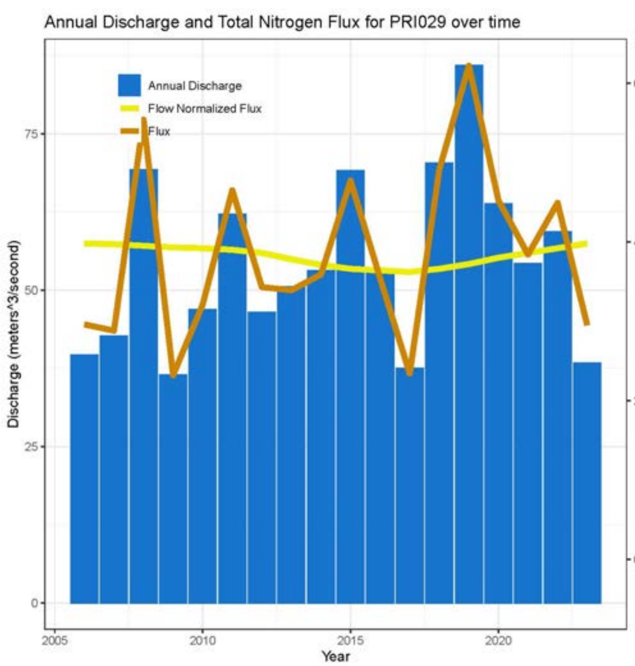


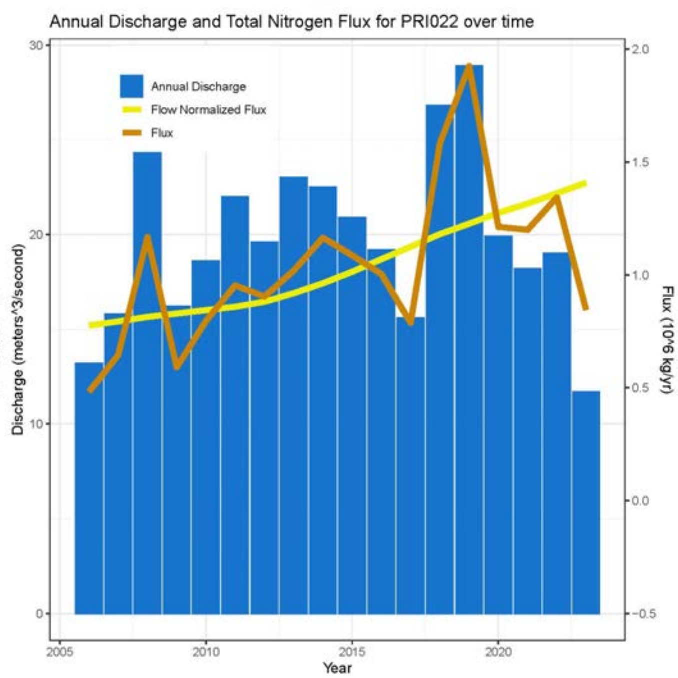
Annual Discharge and Total Nitrogen Flux for PRI057 over time



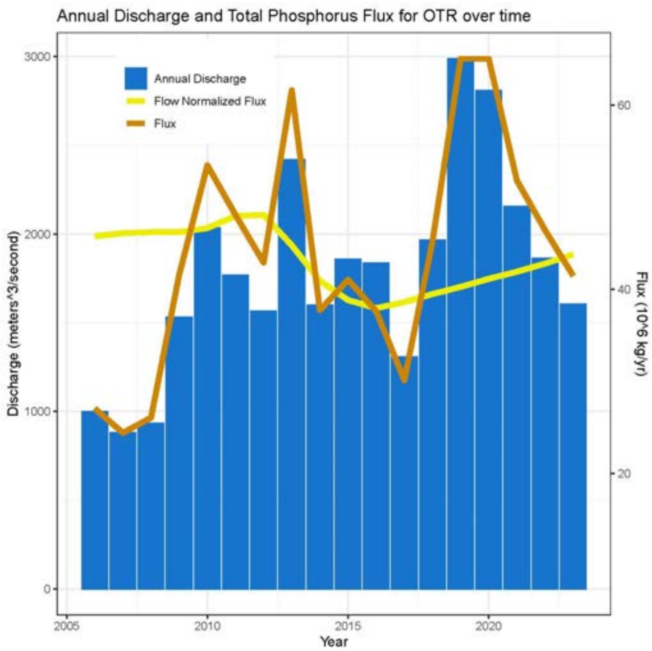

Annual Discharge and Total Nitrogen Flux for PRI049 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

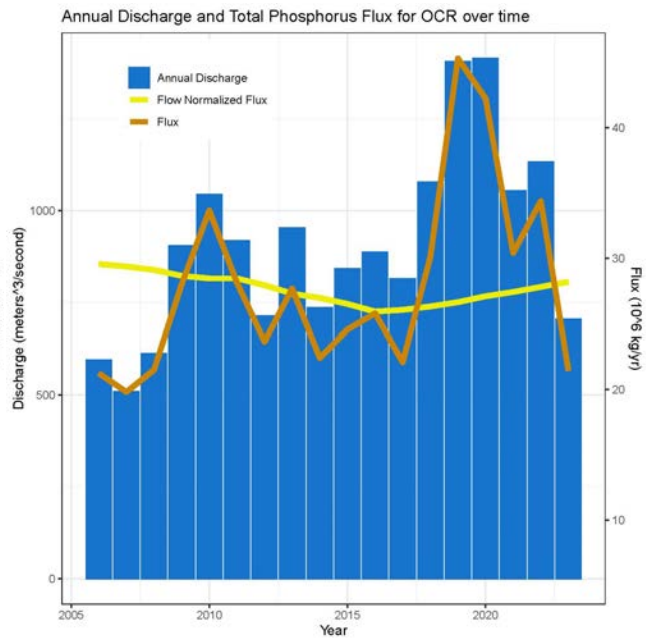

Annual Discharge and Total Nitrogen Flux for PRI048 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

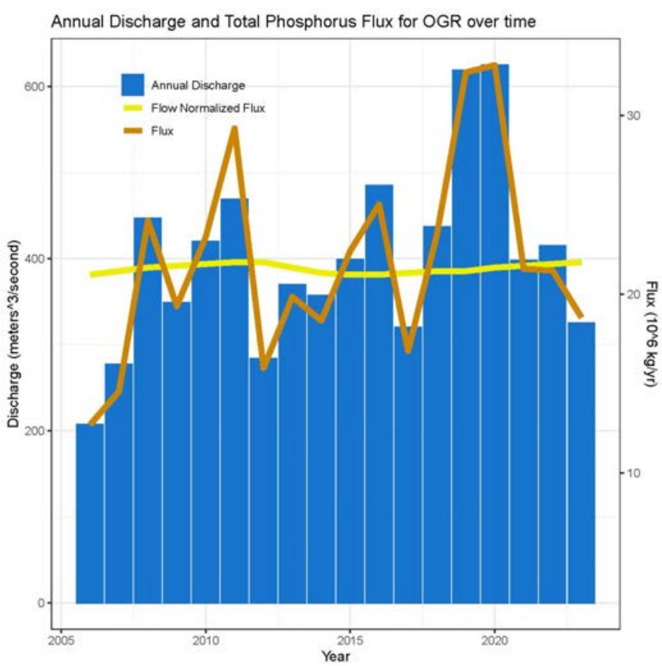

Annual Discharge and Total Nitrogen Flux for PRI029 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

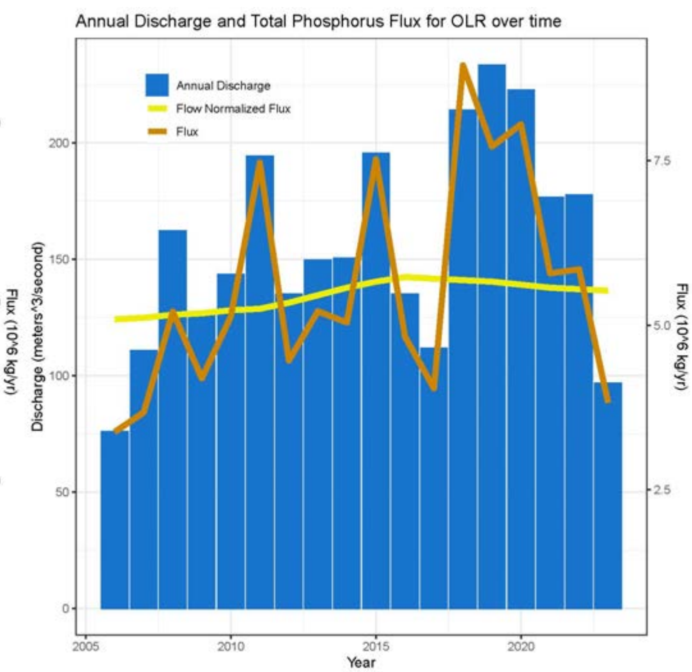

Annual Discharge and Total Nitrogen Flux for PRI022 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

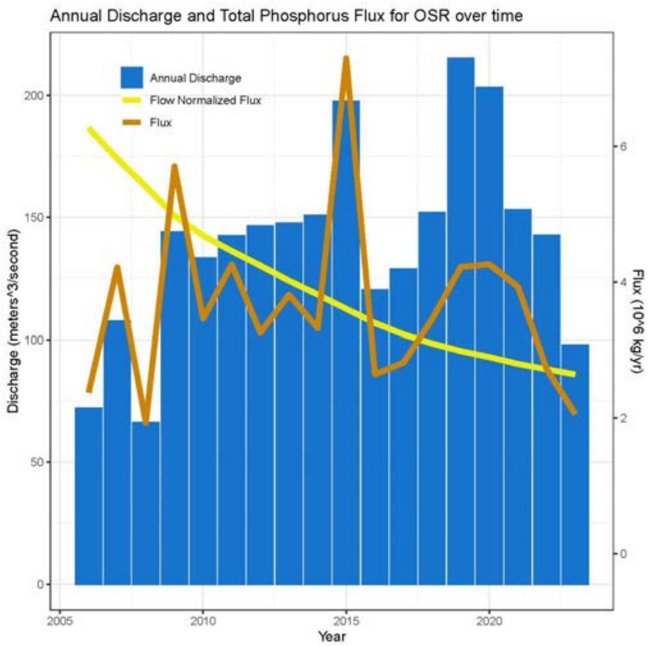
Appendix 3: Flow-Normalized Phosphorus Flux at Kentucky Stations

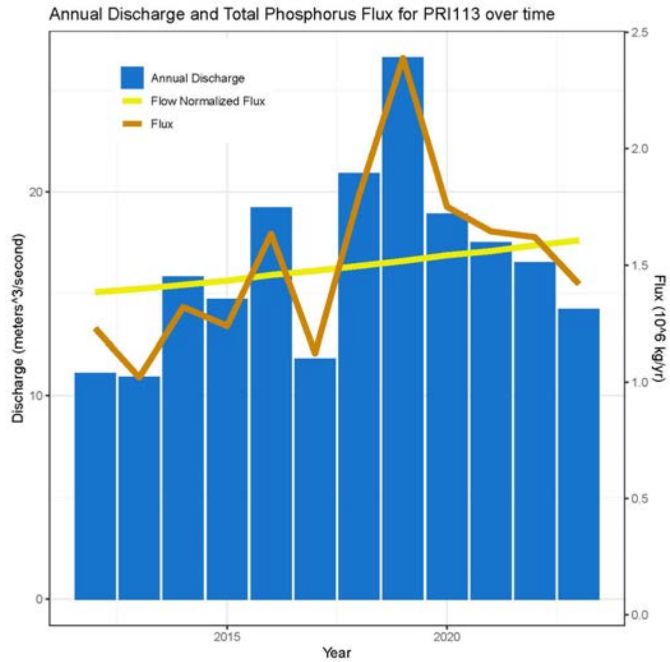


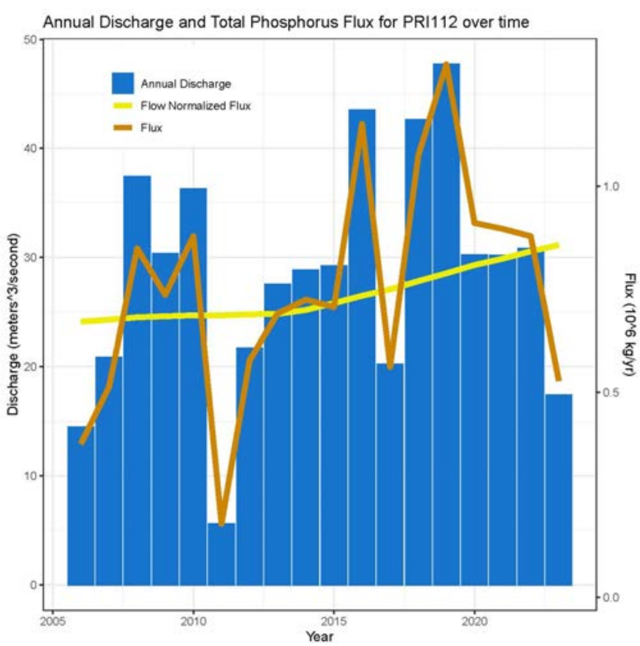


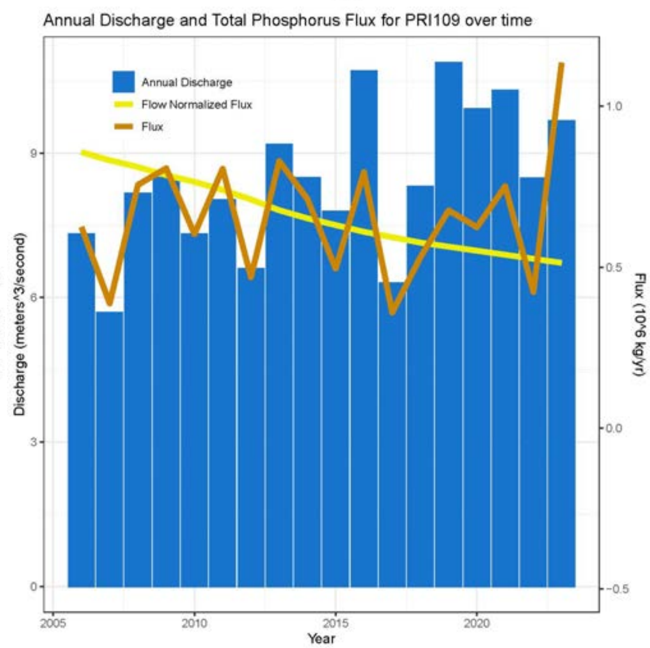


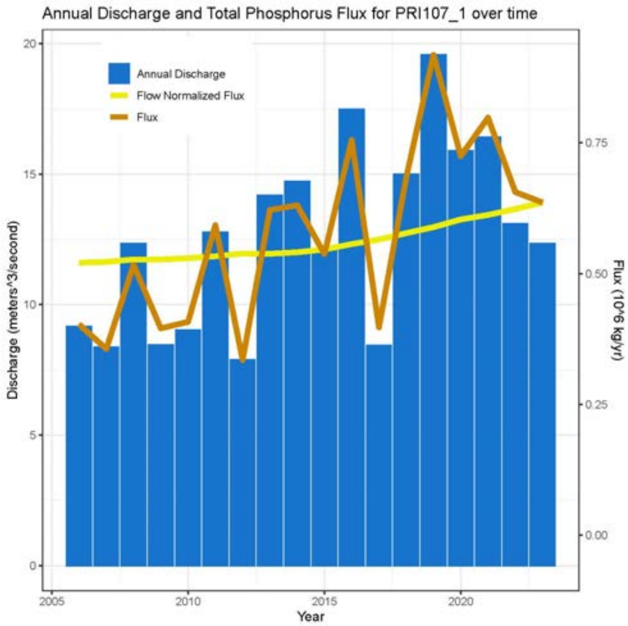


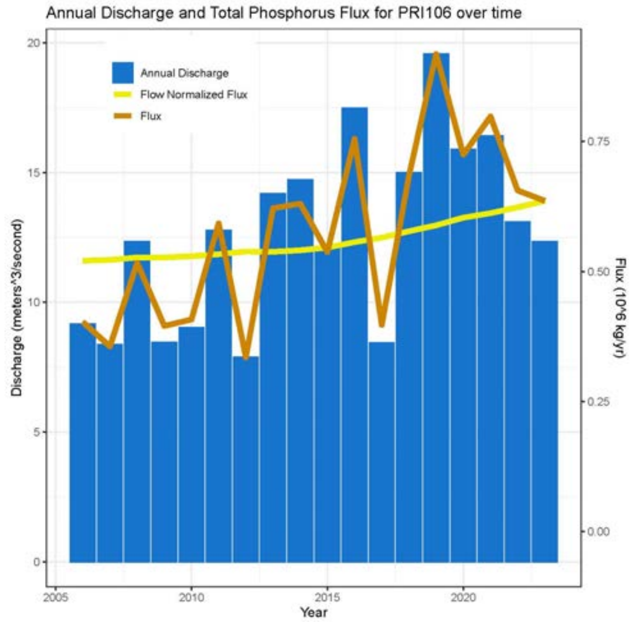

Annual Discharge and Total Phosphorus Flux for OSR over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

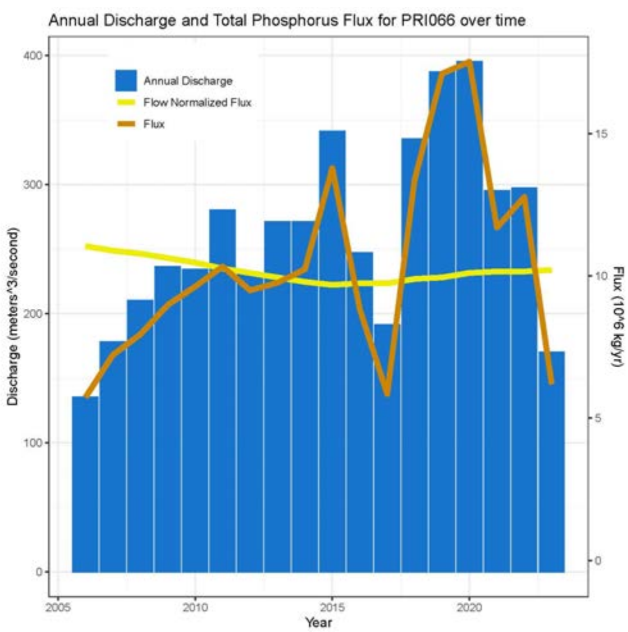

Annual Discharge and Total Phosphorus Flux for PRI113 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

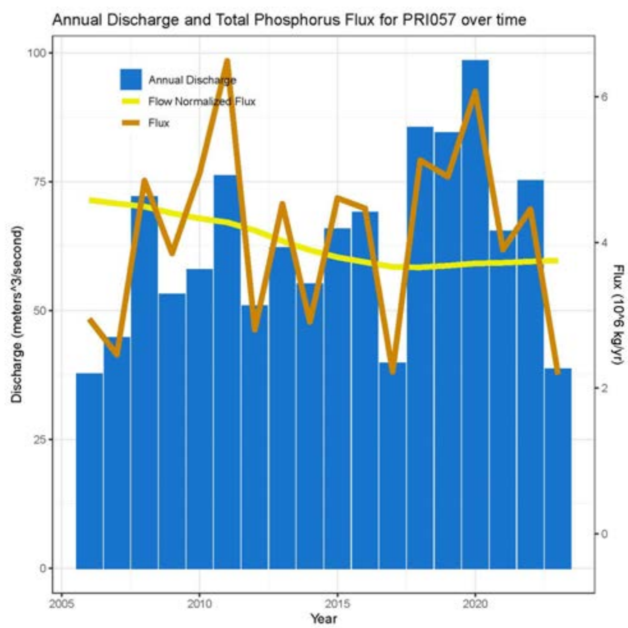

Annual Discharge and Total Phosphorus Flux for PRI112 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

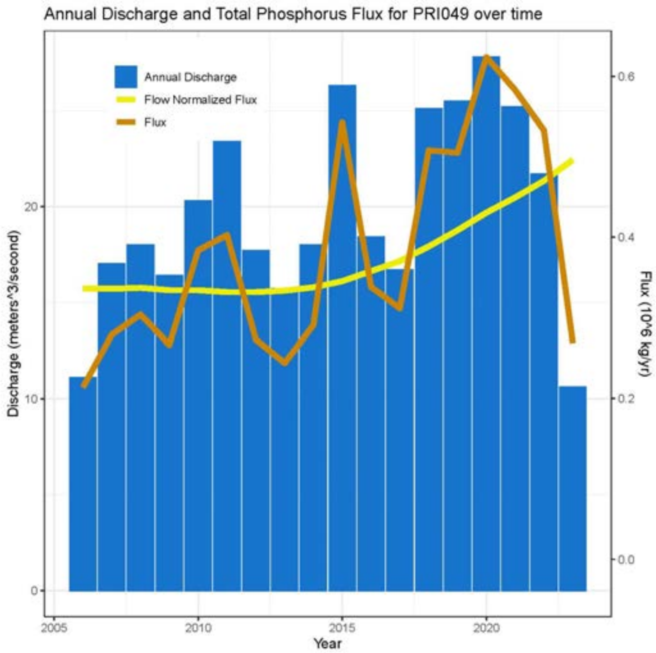

Annual Discharge and Total Phosphorus Flux for PRI109 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

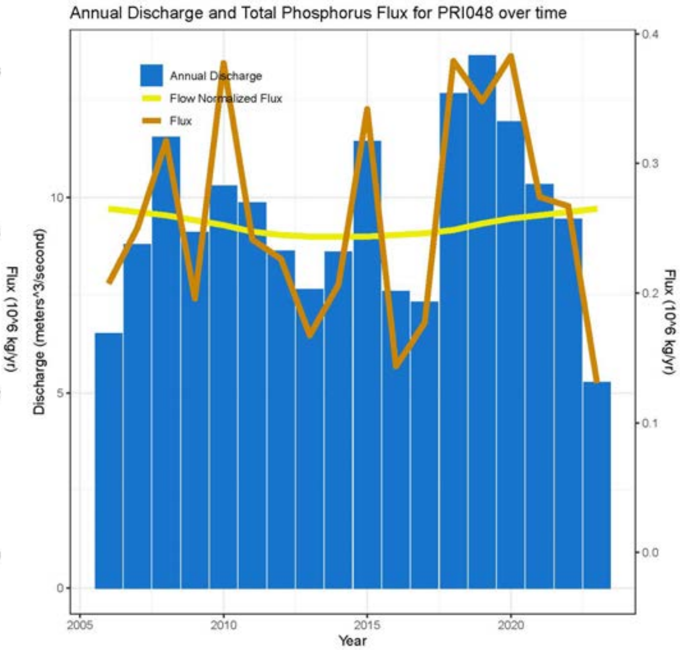

Annual Discharge and Total Phosphorus Flux for PRI107_1 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

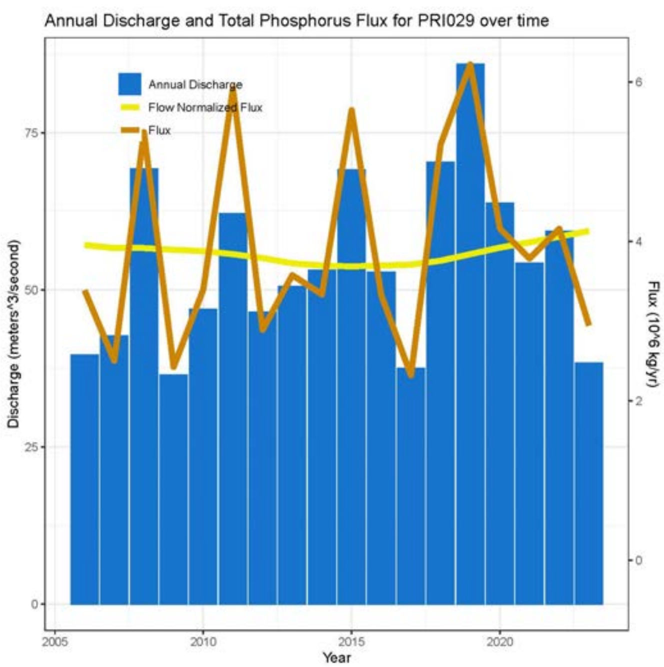

Annual Discharge and Total Phosphorus Flux for PRI106 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year

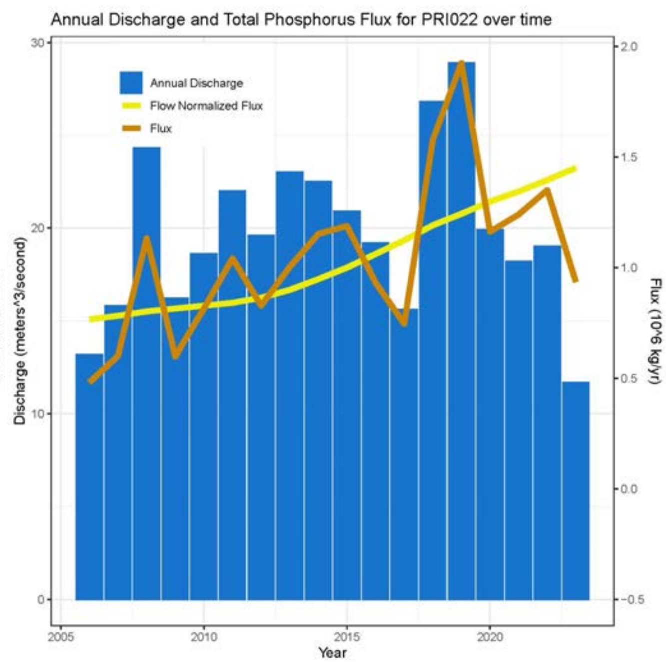

Annual Discharge and Total Phosphorus Flux for PRI066 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year


Annual Discharge and Total Phosphorus Flux for PRI057 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year


Annual Discharge and Total Phosphorus Flux for PRI049 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year


Annual Discharge and Total Phosphorus Flux for PRI048 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year


Annual Discharge and Total Phosphorus Flux for PRI029 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year


Annual Discharge and Total Phosphorus Flux for PRI022 over time
Annual Discharge
Flow Normalized Flux
Flux
Discharge (meters^3/second)
Flux (10^6 kg/yr)
Year