Nutrient Loads and Yields in Kentucky 2005-2017

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KENTUCKY DIVISION OF WATER Watershed Management Branch

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Introduction

Nutrient loads from the greater Mississippi River basin have created a hypoxic zone in the Gulf of Mexico, which measured a record 8,776 square miles in 2017. States within the basin determined in *The Gulf Hypoxia Action Plan 2008* (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2008) to develop strategies to reduce nutrient loads and develop reasonable and appropriate watershed-specific plans to further manage nutrients. The Division of Water, with its partners, is updating the Kentucky Nutrient Reduction Strategy to assist in this state and federal initiative to reduce nutrient loading to the basin and the size of the hypoxic zone.

To determine if implemented strategies are effective, baseline measures of loads and yields must be known. The Division has regularly sampled stations in the primary ambient monitoring network for water quality and other parameters for decades. While station changes occasionally occur for safety or other reasons, this network can be used to characterize and track changes to the Commonwealth's water quality over the long term. A United States Geological Survey (USGS) report, *Concentrations, and estimated loads and yields of total nitrogen and total phosphorus at selected stations in Kentucky, 1979-2004* (Crain, 2009) used these stations to evaluate nutrients. This study provides a broad baseline of nutrient loads and yields throughout the Commonwealth, but is not based on current data.

To build a nutrient reduction strategy, current information is needed. The goal of this study was to replicate the USGS study using data from 2005 – 2017. An effort was made to use the same monitoring stations and methods so that results can provide current nutrient load and yield information, but also be compared directly to the previous study results.

Nutrient loads and yields from this study provided similar results to the USGS study, with higher nutrient loads coming from basins with greater proportions of agricultural land uses. Individual stations, however, showed considerable differences. One explanation for variation was a four-fold increase in the detection limit for Total Kjeldahl Nitrogen (TKN), used in calculating total nitrogen (TN). In addition, the area of some contributing basins substantially differed, reflecting inconsistencies with the determination of whether a station was at the mouth of a tributary or on the main stem of a stream.

With the overall goal of building an effective nutrient reduction strategy, baseline values and measures of change over time must be consistent. To that end, an additional step was undertaken for this study: rolling 5-year mean annual loads were determined. Five-year terms both mitigates the variability found in weather cycles but also allows the detection of changes over time. Statewide, total nitrogen was found to be increasing, while no trend was found for total phosphorus (TP).

Data Collection

Station selections and data screening

Because this study was designed as an update of the 2009 USGS study, the 55 stations used in the USGS study were initially selected to be used in this study. Data for each station were reviewed to determine if the available data met inclusion criteria – mainly ongoing water quality measurements and the availability of discharge data from nearby USGS stream gages. Since site PRI024 was discontinued from the ambient monitoring program in 2007 and had only 13 samples available, this site was dropped from the study. The western part of the state was under-represented in comparison with the rest of the state, so 3 stations were added: PRI107, PRI112, and PRI113. With the additional stations, 57 total stations were used for this study. Discharge data were taken from co-located USGS gage stations, if available. Otherwise, nearby stations were used to estimate discharge based on drainage-area-ratio adjustment. Site PRI007 is located downstream from Wolf Creek Dam, the pool of which is regulated by the United States Army Corps of Engineers (USACE) – Nashville. No USGS gage was located downstream from the dam so the drainage-area-ratio adjustment was not feasible. Instead, dam discharge was obtained from the USACE – Nashville and used in place of flow.

Data were examined for outliers and laboratory flags. For outliers, original laboratory sheets were examined to determine if there was a quality assurance or other qualifying issue with the data, and retained and used or kept and discarded based on these findings. For flagged data, determinations to use or discard were based on the individual flag.

Contributing basins were derived using the StreamStats (USGS, 2017) web application and are shown in Figure 1. Three stations, PRI002, PRI003 and PRI064, could not be delineated using the application because part of their contributing area was in West Virginia where the StreamStats application has not yet been developed. Of these, two were located at the pour points of HUC12 basins and were delineated by selecting all of the HUC12 basins that drained to them. The third was delineated by selecting the full HUC12 basins that drained to that point, and editing the polygon to follow the topography of the partial basin to outline all of the contributing watershed. Delineated basins were used to determine area for the yield calculations as well as land use and cover. Table 1 provides basic station information, including the monitoring station location and drainage area. For detailed information on land cover and use for each station see Appendix 1: Land Cover and Use.

Figure 1. Stations used in this study with the delineated contributing basin. Stations are identified by the numeric portion of their Station ID, "PRIxxx".

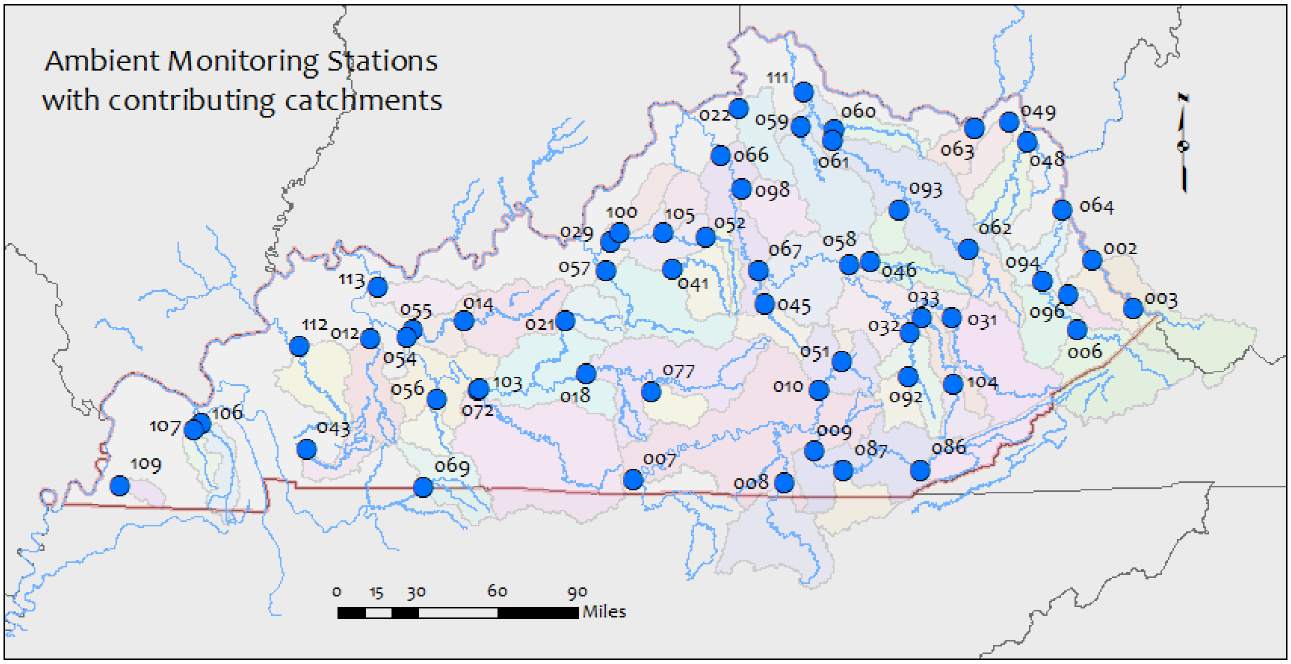


Table 1. Basic monitoring station identification.

DOW station	DOW Station Name	USGS stream-gaging station used for discharge	Drainage Area (mi^2)	Latitude	Longitude
Big and Little Sandy, Tygarts					
PRI002	Tug Fork at Kermit, WV	03214500	1278	37.837594	-82.409706
PRI003	Tug Fork at Freeburn	03213700	781	37.566047	-82.143753
PRI006	Levisa Fork near Pikeville	03209500	1230	37.464424	-82.525984
PRI048	Tygarts Creek near Lynn	03217000	275	38.599805	-82.952652
PRI049	Little Sandy River at Argillite	03216500	539	38.490378	-82.834278
PRI064	Levisa Fork near Louisa	multiple stations	2323	38.115921	-82.600416
PRI094	Levisa Fork at Auxier	multiple stations	1723	37.729083	-82.754389
PRI096	Johns Creek at McCombs	03210000	121	37.65529	-82.587115
Four Rivers, Upper & Lower Cumberland					
PRI007	Cumberland River near Burkesville	Wolf Creek Dam	6245	36.688769	-85.567046
PRI008	Big South Fork Cumberland River at Blue Heron	03410500	964	36.670258	-84.548881
PRI009	Cumberland River at Cumberland Falls	multiple stations	1976	36.83565	-84.340219
PRI010	Rockcastle River at Billows	multiple stations	604	37.171358	-84.296759
PRI043	Little River near Cadiz	03438000	268	36.841044	-87.777291
PRI051	Rockcastle River near Lamero	multiple stations	62	37.320076	-84.138434
PRI069	Red River near Keysburg	multiple stations	550	36.640657	-86.979607
PRI086	Cumberland River at Calvin	multiple stations	519	36.722422	-83.625354
PRI087	Clear Fork near Williamsburg	multiple stations	370	36.726148	-84.142205
PRI106	Clarks River near Sharpe	03610200	310	36.961331	-88.49321
PRI107	West Fork Clarks River nr Symsonia	03610200	186	36.932447	-88.54396
PRI109	Bayou de Chien near Cayce	07024000	103	36.615302	-89.030247

DOW station	DOW Station Name	USGS stream-gaging station used for discharge	Drainage Area (mi^2)	Latitude	Longitude
		Kentucky River			
PRI022	Eagle Creek at Glenco	03291500	437	38.70629	-84.825055
PRI031	North Fork Kentucky River at Jackson	multiple stations	1101	37.551209	-83.384647
PRI032	Middle Fork Kentucky River at Tallega	03280000	536	37.554949	-83.593835
PRI033	South Fork Kentucky River at Booneville	03281500	692	37.475123	-83.670814
PRI045	Dix River near Danville	03285000	317	37.641763	-84.661148
PRI046	Red River Clay City	03283500	362	37.864708	-83.9332
PRI058	Kentucky River near Trapp	multiple stations	3235	37.846751	-84.081753
PRI066	Kentucky River near Lockport	03290500	6178	38.445126	-84.957282
PRI067	Kentucky River at High Bridge	multiple stations	4588	37.820085	-84.705092
PRI092	Goose Creek near Oneida	multiple stations	251	37.23254	-83.690969
PRI098	Elkhorn Creek near Peaks Mill	03289500	473	38.268559	-84.814284
PRI104	Middle Fork Kentucky River near Dryhill	multiple stations	227	37.182647	-83.382449

DOW station	DOW Station Name	USGS stream-gaging station used for discharge	Drainage Area (mi²)	Latitude	Longitude
		Salt, Licking			
PRI029	Salt River at Shepherdsville	03298500	1197	37.985173	-85.717199
PRI041	Beech Fork near Maud	03300400	436	37.832578	-85.296143
PRI052	Salt River at Glensboro	03295400	173	38.002316	-85.060223
PRI057	Rolling Fork near Lebanon Jct.	03310500	1374	37.822668	-85.74787
PRI059	South Fork Licking River at Morgan	03252500	838	38.603337	-84.400595
PRI060	North Fork Licking River near Milford	03251200	287	38.581237	-84.165948
PRI061	Licking River at Claysville	03250500	1966	38.520583	-84.183072
PRI062	Licking River at West Liberty	multiple stations	334	37.914694	-83.261704
PRI063	Kinniconick Creek near Tannery	multiple stations	229	38.574634	-83.188072
PRI093	Slate Creek near Owingsville	multiple stations	185	38.141506	-83.728511
PRI100	Floyds Fork near Shepherdsville	03298200	259	38.034488	-85.659494
PRI105	Brashears Creek at Taylorsville	03295890	262	38.030373	-85.35173
PRI111	Licking River at Butler	multiple stations	3375	38.789636	-84.36761
		Tradewater, Green			
PRI012	Pond River near Sacramento	03320500	578	37.441809	-87.352767
PRI014	Rough River near Dundee	03319000	757	37.547175	-86.721467
PRI018	Green River at Munfordville	03308500	1680	37.268591	-85.88532
PRI021	Nolin River at White Mills	03310300	351	37.555346	-86.031721
PRI054	Rough River near Livermore	03319000	1067	37.49934	-87.06574
PRI055	Green River at Livermore	multiple stations	6423	37.452963	-87.104537
PRI056	Mud River near Gus	multiple stations	268	37.123233	-86.900437
PRI072	Barren River near Woodbury	03314500	2264	37.170705	-86.620494
PRI077	Russell Creek near Bramlett	03307000	262	37.170126	-85.435343
PRI103	Green River near Woodbury	03316500	3136	37.182442	-86.610402
PRI112	Tradewater River nr Piney	multiple stations	605	37.396781	-87.844859
PRI113	Panther Creek nr West Louisville	03321350	372	37.724966	-87.315129

Analytes

Total nitrogen and total phosphorus were examined in this study. Total nitrogen is not a laboratory reported measure, but a calculated value taken from adding TKN and Nitrate/Nitrite (as N). A considerable difference between this study and the 2009 USGS study and an important consideration in how this study progressed is that the method detection limit for TKN increased from 0.05 to 0.2. This four-fold increase results in a considerable increase in the number of censored measures in this more recent study period. The censored values used in this study and the 2009 USGS study are shown in Table 2. Rules to calculate total nitrogen were the same as those in the previous study as shown in Table 3.

Table 2. Censored values of nutrients.

Nutrient	Reporting units	Censored value	
		this study	2009 study
TKN	mg/L as N	0.2	0.05
Nitrate/Nitrite	mg/L as N	0.01	0.01
Phosphorus, total	mg/L as P	0.01	0.01

Table 3. Rules for the calculation of total nitrogen.

Scenario	Calculation
TKN and Nitrate/Nitrite > detection limit	TN = TKN + Nitrate/Nitrite
TKN > detection limit and Nitrate/Nitrite < detection limit	TN = TKN + detection limit of Nitrate/Nitrite
TKN < detection limit and Nitrate/Nitrite > detection limit	TN = detection limit of TKN + Nitrate/Nitrite
TKN < detection limit and Nitrate/Nitrite < detection limit	TN = Missing
TKN or Nitrate/Nitrite missing	TN = Missing

Estimates of daily discharge

Nineteen monitoring stations were co-located with USGS gaging stations providing daily discharge. For monitoring stations without co-located gages or with incomplete records, drainage area ratio adjustment was used when there were one or more gages on that body of water. Regression and drainage area ratio adjustment was used when there were no gages on a stream and data from gages on other streams with similar characteristic were used. The Maintenance of Variance Extension Type 1 (MOVE .1) method (Hirsch, 1982) was used to fill larger gaps. Monitoring station PRI007 was downstream from Wolf Creek Dam, which is managed by the USACE – Nashville. No gage was located along that segment of the Cumberland River but daily discharge was available from USACE – Nashville and used in its place. For small gaps (<10 consecutive missing values), discharge was estimated by filling in values that fit between the last available discharge with the next available value. For larger gaps, estimation methods were used from other stations. Table 4 indicates which gaging stations were used for ambient monitoring stations that did not have a co-located gaging station or had an incomplete record.

To avoid a divide by zero error with the model, any discharge value of 0 was changed to 0.01 cfs with the exception of station PRI007. For short periods of time, zero discharge was reported. The dam has a minimum discharge greater than zero and in addition, Wolf Creek National Fish Hatchery has persistent discharge just below the dam, therefore the minimum discharge value (50 cfs) was used instead of 0.01 cfs.

Table 4. USGS gaging stations used for estimating discharge for ambient monitoring stations without a co-located gage or complete record.

Ambient Monitoring Station	Monitoring Station Name	USGS Stream Gaging Station Number(s)	USGS Stream Gaging Station name(s)
Big and Little Sandy, Tygarts			
PRI003	Tug Fork at Freeburn, WV	03213700	Tug Fork at Williamson, WV
PRI048	Tygarts Creek near Lynn	03217000	Tygarts Creek near Greenup
PRI049	Little Sandy at Argilite	03216500	Little Sandy River at Grayson
PRI064	Levisa Fork near Louisa	03212500	Levisa Fork at Paintsville
		03209500	Levisa Fork at Pikeville
PRI094	Levisa Fork at Auxier	03212500	Levisa Fork at Paintsville
		03209500	Levisa Fork at Pikeville
PRI096	Johns Creek at McCombs	03210000	Johns Creek near Meta
Four Rivers, Upper & Lower Cumberland			
PRI007	Cumberland River near Burkesville	USACE	Wolf Creek Dam discharge record
PRI008	South Fork Cumberland River at Blue Heron	03410500	South Fork Cumberland River at Leatherwood Ford, TN
PRI009	Cumberland River at Cumberland Falls	03404000	Cumberland River at Williamsburg
		03404500	Cumberland River at Cumberland Falls
PRI051	Rockcastle River near Lamero	03404900	Lynn Camp Creek at Corbin
		03413200	Beaver Creek near Monticello
		03407500	Buck Creek near Shopville
		03307000	Russell Creek near Columbia
PRI069	Red River near Keysburg	03435305	Red River below Hwy 161 near Barren Plain, TN
		03436100	Red River at Port Royal, TN
		03314000	Drakes Creek near Alvaton
		03438000	Little River near Cadiz
PRI086	Cumberland River at Calvin	03402900	Cumberland River at Pineville
		03404000	Cumberland River at Williamsburg
		03401000	Cumberland River near Harlan
PRI087	Clear Fork near Williamburg	03403910	Clear Fork at Saxton
		03307000	Russell Creek near Columbia
		03406500	Rockcastle River at Billows
PRI106	Clarks River near Sharpe	03610200	Clarks River at Almo
PRI107	West Fork Clarks River near Symsonia	03610200	Clarks River at Almo
PRI109	Bayou de Chien near Cayce	07024000	Bayou De Chien near Clinton

Ambient Monitoring Station	Monitoring Station Name	USGS Stream Gaging Station Number(s)	USGS Stream Gaging Station name(s)
Kentucky River			
PRI033	South Fork Kentucky River at Booneville	03281500	South Fork Kentucky River at Booneville
PRI058	Kentucky River near Trapp	03284000	Kentucky River near Winchester
		03283500	Red River at Clay City
		03282290	Kentucky River near College Hill
PRI092	Goose Creek near Oneida	03281100	Goose Creek at Manchester
		03280700	Cutshin Creek at Wooton
PRI104	Middle Fork Kentucky River at Dryhill	03280600	Middle Fork Kentucky River at Hyden
		03280700	Cutshin Creek at Wooton
		03281100	Goose Creek at Manchester
		03281500	South Fork Kentucky River at Booneville
Salt, Licking			
PRI059	South Fork Licking River at Morgan	03252500	South Fork Licking River at Hayes
PRI060	North Fork Licking River near Milford	03251200	North Fork Licking River near Mt Olivet
PRI061	Licking River at Claysville	03250500	Licking River at Blue Springs
PRI062	Licking River at West Liberty	03248300	Licking River nr Salyersville
		03283500	Red River at Clay City
PRI063	Kinniconick Creek near Tannery	03217000	Tygarts Creek near Greenup
		03248300	Licking River near Slayersville
		03252300	Hinkston Creek nr Carlisle
PRI093	Slate Creek near Owingsville	03250190	Slate Creek at Mt Sterling
		03288100	North Elkhorn Creek at Georgetown
PRI100	Floyds Fork near Shepherdsville	03298200	Floyds Fork near Mt Washington
PRI105	Brashears Creek at Taylorsville	03295890	Brashears Creek at Taylorsville
PRI111	Licking River at Butler	03253500	Licking River at Catawba
		03251500	Licking River at McKinneysburg

Ambient Monitoring Station	Monitoring Station Name	USGS Stream Gaging Station Number(s)	USGS Stream Gaging Station name(s)
Tradewater, Green			
PRI012	Pond River near Sacramento	03320500	Pond River near Apex
		03383000	Tradewater River at Olney
PRI054	Rough River near Livermore	03319000	Rough River near Dundee
PRI055	Green River at Livermore	03316500	Green River at Paradise
		03320000	Green River at Calhoun
PRI056	Mud River near Gus	03320500	Pond River near Apex
		03316275	Mud River near Huntsville
		03383000	Tradewater River at Olney
		03314000	Drakes Creek near Alvaton
PRI072	Barren River at Woodbury	03314500	Barren River at Bowling Green
		03313700	West Fork Drakes Creek near Franklin
PRI077	Russell Creak near Bramlett	03307000	Russell Creek near Columbia
PRI103	Green River near Woodbury	03316500	Green River at Paradise
PRI112	Tradewater River nr Piney	03384100	Tradewater River near Providence
		03383000	Tradewater River at Olney
PRI113	Panther Creek near West Louisville	03321350	South Fork Panther Creek near Whitesville

Load and yield estimation

Loads were estimated with the USGS program, LOADEST (Runkel, 2004). LOADEST uses analyte measures and streamflow to develop a rating curve. It then uses daily streamflow data to generate the estimated load (See Figure 2 for a rating curve example). Nine pre-defined models are generated. The program allows the user to select the model, or to allow the program to select the model with the best fit as determined by the lowest Akaike Information Criterion (AIC). The AIC is a statistical method that compares models for best fit.

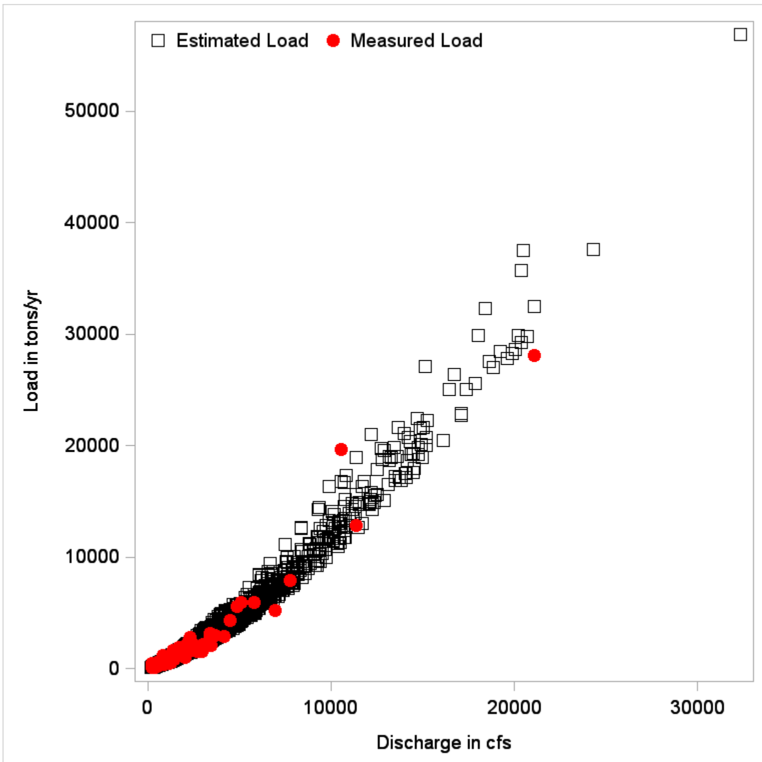
LOADEST can produce three estimation methods: Maximum Likelihood Estimation (MLE), Adjusted Maximum Likelihood Estimation (AMLE), and Least Absolute Deviation (LAD). The characteristics of the data determine which is most appropriate. The AMLE method is most commonly used when some of the data are below the detection limit. AMLE[1] produces the least biased model coefficients when left-censored data are present and residuals follow a normal distribution with constant variance. Data in this study were left-censored and residuals were normally distributed with constant variance. Thus, the AMLE method was chosen. Appendix 2: Model Equations lists the chosen equations for each station and analyte. Bias diagnostics were calculated by the program, and the recommended threshold of ±25% was adopted for

[1] The MLE produces best results when there is no censoring of data (no data below the detection limit), the residuals are normally distributed with constant variance. LAD produces the best fit models for data do not have normally distributed residuals with constant variance.

model acceptability. The assumption of normality was also examined by creating residual plots as well as examining the Probability Plot Correlation Coefficient (PPCC) produced by LOADEST.

Yield was calculated from load by dividing the mean annual load by the area, in square miles, of the contributing watershed.

Figure 2. An example (station PRI094) of the measured loads, used to develop the rating curve, with the estimated loads derived from the rating curve.



Concentrations, and Estimated Loads and Yields of Nutrients

Discharge and Concentrations

Unacceptable load bias was found for phosphorus load estimations at three stations: PRI045, PRI063, and PRI100. While these estimated loads are reported, the values are flagged to indicate highly uncertain results.

Residuals were examined at all stations to determine if the station met the assumption of normality (data not shown). Tests for normality of model residuals found that the assumption was met.

Output from the program includes the distributions for streamflow and analyte concentrations created by the rating curve (Table 5).

Table 5. Distribution of discharge and concentrations for each station.

Station	Period of record	Streamflow (ft^3/s)						Total nitrogen (mg/l)						Total phosphorus (mg/l)					
		Mean	Min	25th	Median	75th	Max	Samples (<DL)	Min	25th	Median	75th	Max	Samples (<DL)	Min	25th	Median	75th	Max
Big and Little Sandy, Tygarts																			
PRI002	2005-2017	1503	109	438	919	1870	46900	87(0)	0.42	0.70	0.82	0.95	2.07	92(21)	0.004	0.017	0.025	0.035	0.231
PRI003	2005-2017	940	63	290	571	1128	29158	89(0)	0.25	0.48	0.59	0.74	2.67	94(31)	0.003	0.013	0.020	0.028	0.278
PRI006	2005-2017	1462	136	433	876	1688	28136	88(0)	0.46	0.60	0.68	0.78	1.29	93(36)	0.005	0.014	0.019	0.023	0.074
PRI048	2005-2017	312	0	27	116	332	17200	85(0)	0.06	0.48	0.59	0.68	1.12	91(33)	0.006	0.013	0.016	0.021	0.171
PRI049	2005-2017	646	17	82	252	732	14486	84(0)	0.47	0.59	0.67	0.80	1.65	87(14)	0.011	0.017	0.022	0.031	0.268
PRI064	2005-2017	2722	228	754	1519	3165	41117	83(0)	0.52	0.65	0.74	0.84	1.33	86(11)	0.007	0.022	0.029	0.040	0.227
PRI094	2005-2017	2026	199	578	1182	2370	32333	83(0)	0.47	0.67	0.74	0.83	1.86	85(11)	0.010	0.022	0.030	0.039	0.261
PRI096	2005-2017	193	5	46	95	218	11959	85(0)	0.11	0.70	0.82	0.97	1.32	89(23)	0.006	0.017	0.023	0.033	0.311
Four Rivers, Upper & Lower Cumberland																			
PRI007	2005-2017	8447	2	2682	5978	12578	29880	85(0)	0.49	0.59	0.63	0.7	0.99	83(70)	0.01	0.01	0.02	0.02	0.03
PRI008	2005-2017	1820	9	226	811	1953	54802	81(0)	0.23	0.32	0.36	0.40	0.54	94(55)	0.004	0.008	0.011	0.015	0.137
PRI009	2005-2017	3248	81	643	1710	3760	42800	83(0)	0.22	0.42	0.51	0.65	2.26	91(30)	0.007	0.013	0.018	0.028	0.542
PRI010	2005-2017	928	2	91	391	994	28900	76(0)	0.15	0.46	0.53	0.62	1.11	84(42)	0.004	0.011	0.017	0.022	0.051
PRI043	2005-2017	403	9	75	221	467	9920	91(0)	2.00	4.00	4.00	5.00	5.00	90(0)	0.066	0.100	0.128	0.165	1.196
PRI051	2005-2017	89	1	12	37	91	4231	72(0)	0.34	0.37	0.39	0.40	0.46	90(51)	0.007	0.009	0.010	0.012	0.014
PRI069	2005-2016	794	26	175	443	894	42280	77(0)	3.00	5.00	6.00	6.00	6.00	81(3)	0.018	0.040	0.054	0.072	4.161
PRI086	2005-2017	1473	51	364	911	1865	31134	78(0)	0.25	0.47	0.57	0.70	2.22	81(34)	0.003	0.011	0.017	0.025	3.495
PRI087	2005-2017	577	2	60	249	613	23106	77(0)	0.27	0.43	0.46	0.47	0.48	82(32)	0.007	0.014	0.018	0.023	0.087
PRI106	2005-2017	394	3	41	97	221	26628	89(0)	0.41	1.00	1.37	1.82	2.30	87(0)	0.023	0.105	0.144	0.185	0.362
PRI107	2005-2017	234	2	24	57	132	15824	81(0)	0.08	0.82	1.28	1.79	4.46	87(0)	0.023	0.084	0.114	0.159	1.755
PRI109	2005-2017	273	34	62	96	175	8835	83(0)	0.30	0.68	1.10	1.80	3.83	83(0)	0.100	0.150	0.180	0.250	2.040

Station	Period of record	Streamflow (ft³/s)						Total nitrogen (mg/l)						Total phosphorus (mg/l)					
		Mean	Min	25th	Median	75th	Max	Samples (<DL)	Min	25th	Median	75th	Max	Samples (<DL)	Min	25th	Median	75th	Max
Kentucky River																			
PRI022	2005-2017	676	0	28	156	471	20800	74(0)	0.48	0.68	0.77	0.91	2.16	80(1)	0.033	0.063	0.080	0.117	1.069
PRI031	2005-2017	1368	40	326	735	1560	32400	78(0)	0.33	0.56	0.70	0.86	1.94	87(16)	0.006	0.016	0.022	0.033	2.803
PRI032	2005-2017	786	30	141	378	990	12200	79(0)	0.33	0.44	0.49	0.55	0.74	91(22)	0.007	0.013	0.016	0.022	0.177
PRI033	2005-2017	1004	0	111	445	1060	23100	79(0)	0.34	0.41	0.45	0.52	36.06	92(27)	0.010	0.015	0.018	0.023	29.904
PRI045	2005-2017	437	0	30	153	450	35200	82(0)	0.16	1.05	1.54	1.99	5.51	82(0)	0.035	0.076	0.086	0.099	0.180
PRI046	2006-2017	493	3	70	215	577	14100	80(0)	0.46	0.52	0.56	0.60	0.81	83(10)	0.017	0.030	0.037	0.046	0.145
PRI058	2005-2017	4233	45	764	2148	5261	49814	74(0)	0.36	0.46	0.51	0.57	0.79	79(20)	0.002	0.015	0.021	0.033	0.666
PRI066	2005-2017	8294	114	1503	4580	10500	105000	72(0)	0.53	0.91	1.08	1.29	2.23	74(0)	0.033	0.087	0.115	0.156	0.695
PRI067	2005-2016	6517	8	1135	3490	8048	99000	72(0)	0.29	0.63	0.82	0.99	4.05	73(0)	0.012	0.042	0.059	0.079	0.459
PRI092	2006-2017	392	0	36	158	420	11672	75(0)	0.47	0.50	0.57	0.65	0.70	79(14)	0.009	0.018	0.024	0.033	0.078
PRI098	2005-2017	716	17	116	308	779	24400	82(0)	3.00	3.00	4.00	4.00	6.00	82(0)	0.400	0.410	0.450	0.570	2.640
PRI104	2005-2017	379	13	66	181	495	5100	72(0)	0.36	0.43	0.49	0.55	0.84	77(26)	0.007	0.015	0.021	0.030	0.055
Salt, Licking																			
PRI029	2005-2017	1781	26	172	692	2670	40100	54(0)	1.00	1.00	2.00	2.00	5.00	54(0)	0.089	0.154	0.202	0.236	1.797
PRI041	2005-2017	641	0	24	161	506	31700	78(0)	0.50	0.78	0.97	1.28	5.59	86(0)	0.083	0.140	0.166	0.211	1.229
PRI052	2005-2017	233	0	19	66	204	11500	79(0)	0.55	1.53	1.95	2.42	5.24	79(0)	0.170	0.250	0.300	0.350	1.860
PRI057	2005-2017	1823	0	108	595	1733	48268	77(0)	1.00	1.00	2.00	2.00	3.00	78(1)	0.049	0.120	0.162	0.217	1.010
PRI059	2013-2017	1085	3	91	391	1091	18614	32(0)	0.57	1.31	1.86	2.37	4.64	32(0)	0.066	0.129	0.162	0.258	3.733
PRI060	2005-2017	419	0	12	98	366	11780	73(0)	0.67	1.04	1.51	2.05	6.63	77(0)	0.034	0.090	0.120	0.192	3.294
PRI061	2005-2017	2620	49	386	1150	4262	37180	75(0)	0.45	0.63	0.74	1.02	3.11	78(2)	0.024	0.055	0.077	0.106	1.000
PRI062	2005-2017	429	2	75	202	500	12166	79(0)	0.38	0.46	0.49	0.54	0.67	85(23)	0.013	0.019	0.024	0.029	0.047
PRI063	2005-2017	223	0	24	89	238	9215	80(0)	0.25	0.37	0.47	0.59	0.80	89(64)	0.002	0.005	0.008	0.012	0.097
PRI093	2005-2017	316	0	25	91	272	12847	83(0)	0.40	0.94	1.07	1.20	1.79	86(0)	0.036	0.057	0.076	0.103	0.244
PRI100	2005-2017	423	5	52	150	354	24806	75(0)	1.00	2.00	2.00	3.00	5.00	76(0)	0.046	0.087	0.122	0.168	4.500
PRI105	2005-2017	417	0	23	139	381	20333	76(0)	0.48	0.80	1.37	1.99	14.12	79(1)	0.058	0.150	0.190	0.249	1.382
PRI111	2005-2017	4306	53	511	1969	5816	63187	60(0)	0.54	0.77	1.08	1.55	5.08	61(1)	0.030	0.072	0.095	0.172	2.980

Station	Period of record	Streamflow (ft^3/s)						Total nitrogen (mg/l)						Total phosphorus (mg/l)					
		Mean	Min	25th	Median	75th	Max	Samples (<DL)	Min	25th	Median	75th	Max	Samples (<DL)	Min	25th	Median	75th	Max
Tradewater, Green																			
PRI012	2005-2017	947	0	38	212	766	34238	88(0)	0.66	1.12	1.26	1.47	2.37	94(0)	0.063	0.083	0.087	0.091	0.101
PRI014	2014-2017	1325	73	173	812	1776	8692	25(0)	0.66	0.95	1.19	1.48	2.03	22(2)	0.012	0.040	0.061	0.089	0.227
PRI018	2005-2017	2760	112	481	1205	4010	54400	82(0)	0.58	1.04	1.36	1.56	1.82	82(11)	0.010	0.023	0.036	0.059	0.348
PRI021	2005-2017	543	21	118	292	606	13800	83(0)	2.00	3.00	4.00	4.00	4.00	84(1)	0.052	0.096	0.131	0.194	1.391
PRI054	2014-2017	1869	103	244	1145	2506	12262	25(0)	1.00	1.00	1.00	1.00	2.00	22(2)	0.014	0.045	0.066	0.105	0.276
PRI055	2005-2017	9759	150	2582	6032	13955	62568	85(0)	0.97	1.47	1.72	2.04	2.90	86(1)	0.023	0.042	0.055	0.075	0.230
PRI056	2009-2017	467	5	46	163	463	19941	58(0)	0.84	1.02	1.25	1.47	1.84	59(1)	0.026	0.048	0.058	0.073	0.222
PRI072	2005-2017	2509	20	568	1746	3927	53750	74(0)	1.00	2.00	2.00	3.00	4.00	71(1)	0.037	0.060	0.070	0.085	0.138
PRI077	2005-2017	442	2	57	186	453	28593	95(0)	0.14	1.00	1.60	2.11	3.37	95(8)	0.011	0.031	0.046	0.063	2.489
PRI103	2005-2017	8249	118	2159	5012	11865	53839	69(0)	0.98	1.29	1.51	1.73	2.20	71(7)	0.012	0.030	0.043	0.064	0.157
PRI112	2005-2017	913	0	32	299	1230	13600	86(0)	0.25	0.76	0.94	1.25	1.7	91(0)	0.032	0.061	0.07	0.081	0.103
PRI113	2011-2017	486	0	10	89	393	16746	46(0)	0.77	1.71	2.42	3.16	5.14	44(0)	0.028	0.12	0.164	0.206	0.514

Estimated Mean Annual Loads and Mean Yields

As expected, loads were greater at stations with larger drainage areas (Table 6) while yields did not follow this pattern. The highest total nitrogen yields were in the Tradewater, Green and Salt, Licking River basins. The highest total phosphorus yields were in the Salt, Licking and Four Rivers, Upper & Lower Cumberland basins. The Big and Little Sandy, Tygarts basins had the lowest yields of both nitrogen and phosphorus.

Table 6. Estimated loads and yields.

Station	Period of record	Drainage Area (mi^2)	Estimated mean annual load		Estimated mean annual yield		Prediction error	
			TN	TP	TN	TP	TN	TP
			(ton/yr)(+/-SEP)		(ton/yr)/mi^2		(percent)	
Big and Little Sandy, Tygarts								
PRI002	2005-2017	1278	1507(102)	69(15)	1.18	0.05	7	21
PRI003	2005-2017	781	861(58)	37(11)	1.10	0.05	7	30
PRI006	2005-2017	1230	1197(58)	40(7)	0.97	0.03	5	18
PRI048	2005-2017	275	219(26)	29(3)	0.80	0.11	12	10
PRI049	2005-2017	539	427(37)	37(7)	0.79	0.07	9	20
PRI064	2005-2017	2323	2464(128)	157(22)	1.06	0.07	5	14
PRI094	2005-2017	1723	1898(120)	113(15)	1.10	0.07	6	13
PRI096	2005-2017	121	153(11)	0(5)	1.27	0.00	7	–
Four Rivers, Upper & Lower Cumberland								
PRI007	2005-2017	6245	5606(208)	150(11)	0.90	0.02	4	7
PRI008	2005-2017	964	756(55)	55(18)	0.78	0.06	7	33
PRI009	2005-2017	1976	2832(321)	245(62)	1.43	0.12	11	25
PRI010	2005-2017	604	551(51)	26(7)	0.91	0.04	9	29
PRI043	2005-2017	268	1701(55)	73(11)	6.34	0.27	3	15
PRI051	2005-2017	62	37(4)	3(0)	0.59	0.04	10	4
PRI069	2005-2016	534	4490(150)	186(80)	8.41	0.34	3	43
PRI086	2005-2017	519	1179(77)	164(91)	2.27	0.32	7	56
PRI087	2005-2017	370	263(18)	29(3)	0.71	0.08	7	9
PRI106	2005-2017	310	635(80)	91(11)	2.05	0.29	13	12
PRI107	2005-2017	186	500(73)	113(22)	2.69	0.61	15	19
PRI109	2005-2017	103	577(106)	183(33)	5.59	1.77	18	18

Station	Period of record	Drainage Area (mi²)	Estimated mean annual load		Estimated mean annual yield		Prediction error	
			TN	TP	TN	TP	TN	TP
			(ton/yr)(+/-SEP)		(ton/yr)/mi²		(percent)	
Kentucky River								
PRI022	2005-2017	437	796(88)	183(29)	1.82	0.42	11	16
PRI031	2005-2017	1101	1215(102)	153(47)	1.10	0.14	8	31
PRI032	2005-2017	536	416(22)	33(3)	0.78	0.06	5	8
PRI033	2005-2017	692	668(84)	40(11)	0.97	0.06	13	27
PRI045	2005-2017	317	1139(99)	47(4)*	3.59	0.15*	9	8
PRI046	2006-2017	362	288(22)	15(4)	0.80	0.04	8	27
PRI058	2005-2017	3235	2438(164)	347(120)	0.75	0.11	7	35
PRI066	2005-2017	6178	10844(642)	1464(128)	1.76	0.24	6	9
PRI067	2005-2016	4588	6048(631)	664(99)	1.32	0.14	10	15
PRI092	2006-2017	251	208(15)	4(1)	0.83	0.01	7	31
PRI098	2005-2017	473	2774(193)	449(55)	5.87	0.95	7	12
PRI104	2005-2017	227	201(11)	29(1)	0.89	0.13	5	3
Salt, Licking								
PRI029	2005-2017	1197	4106(332)	621(69)	3.43	0.52	8	11
PRI041	2005-2017	436	1449(204)	237(33)	3.33	0.54	14	14
PRI052	2005-2017	173	741(66)	117(15)	4.29	0.68	9	13
PRI057	2005-2017	1374	3676(493)	515(88)	2.68	0.37	13	17
PRI059	2013-2017	838	3300(299)	741(197)	3.94	0.88	9	27
PRI060	2005-2017	287	1340(157)	230(37)	4.66	0.80	12	16
PRI061	2005-2017	1966	3110(270)	431(80)	1.58	0.22	9	19
PRI062	2005-2017	334	230(11)	26(2)	0.69	0.08	5	7
PRI063	2005-2017	229	135(11)	0(1)*	0.59	0.00	8	*
PRI093	2005-2017	185	434(37)	26(5)	2.35	0.14	8	19
PRI100	2005-2017	259	971(183)	197(91)*	3.74	0.76*	19	46
PRI105	2005-2017	262	1803(318)	164(29)	6.88	0.63	18	18
PRI111	2005-2017	3384	8833(1E3)	1818(398)	2.62	0.54	11	22

Station	Period of record	Drainage Area (mi^2)	Estimated mean annual load		Estimated mean annual yield		Prediction error	
			TN	TP	TN	TP	TN	TP
			(ton/yr)(+/-SEP)		(ton/yr)/mi^2		(percent)	
Tradewater, Green								
PRI012	2005-2017	578	1380(142)	88(7)	2.39	0.15	10	8
PRI014	2014-2017	757	1792(226)	113(26)	2.37	0.15	13	23
PRI018	2005-2017	1680	4227(219)	219(29)	2.52	0.13	5	13
PRI021	2005-2017	351	1748(62)	110(26)	4.98	0.31	4	23
PRI054	2014-2017	1067	2730(266)	190(44)	2.56	0.18	10	23
PRI055	2005-2017	6423	19684(763)	814(55)	3.06	0.13	4	7
PRI056	2009-2017	268	690(55)	47(7)	2.57	0.18	8	15
PRI072	2005-2017	2264	6001(347)	197(15)	2.65	0.09	6	7
PRI077	2005-2017	262	1106(164)	99(51)	4.23	0.38	15	52
PRI103	2005-2017	3136	13852(690)	537(73)	4.42	0.17	5	14
PRI112	2005-2017	605	697(47)	58(4)	1.15	0.1	7	6
PRI113	2011-2017	372	1737(237)	139(22)	4.68	0.37	14	16

*Bp (load bias in percent) > ±25%, indicating load estimation is highly uncertain.

Figure 3. Loads and yields by basin management unit.

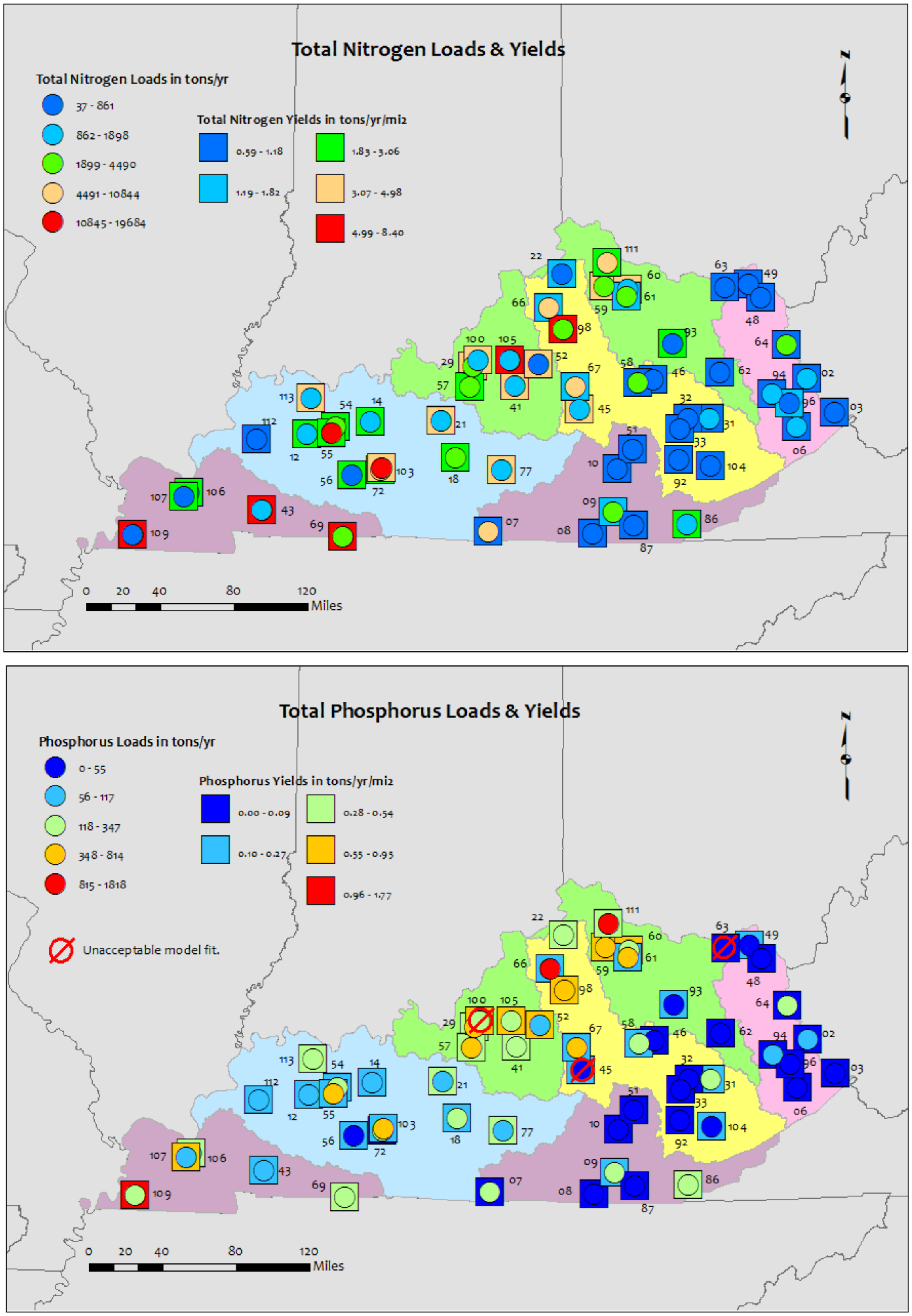
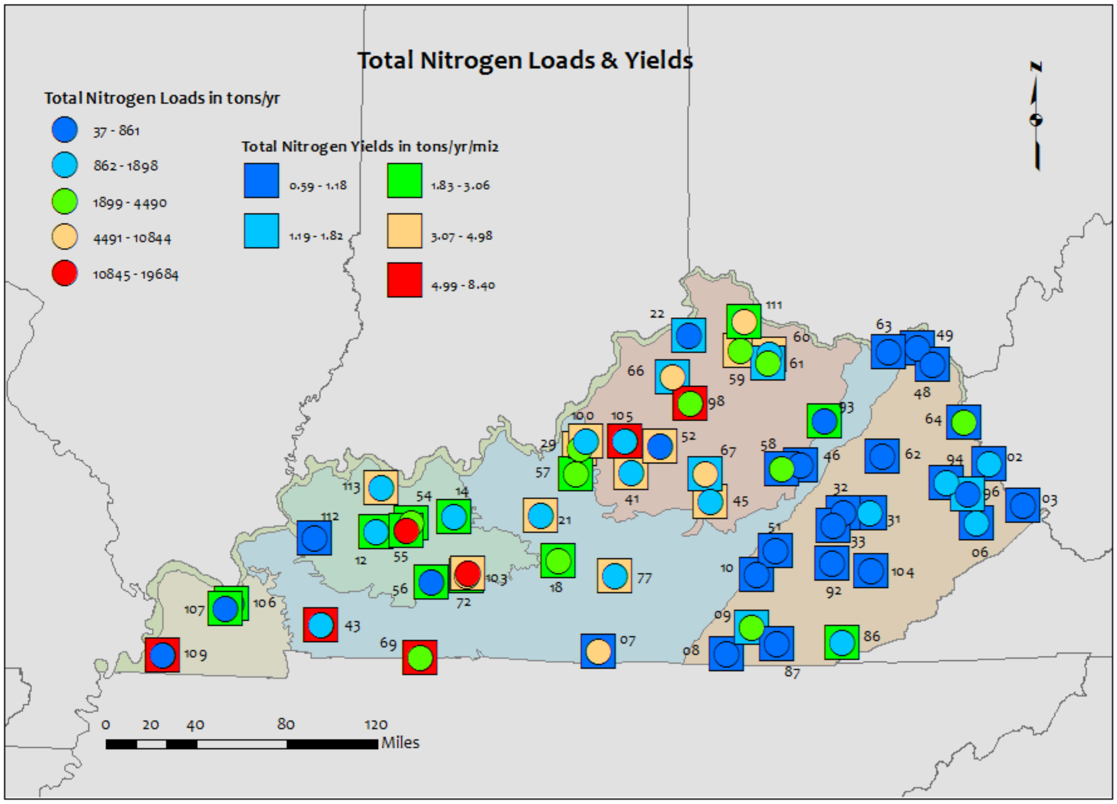
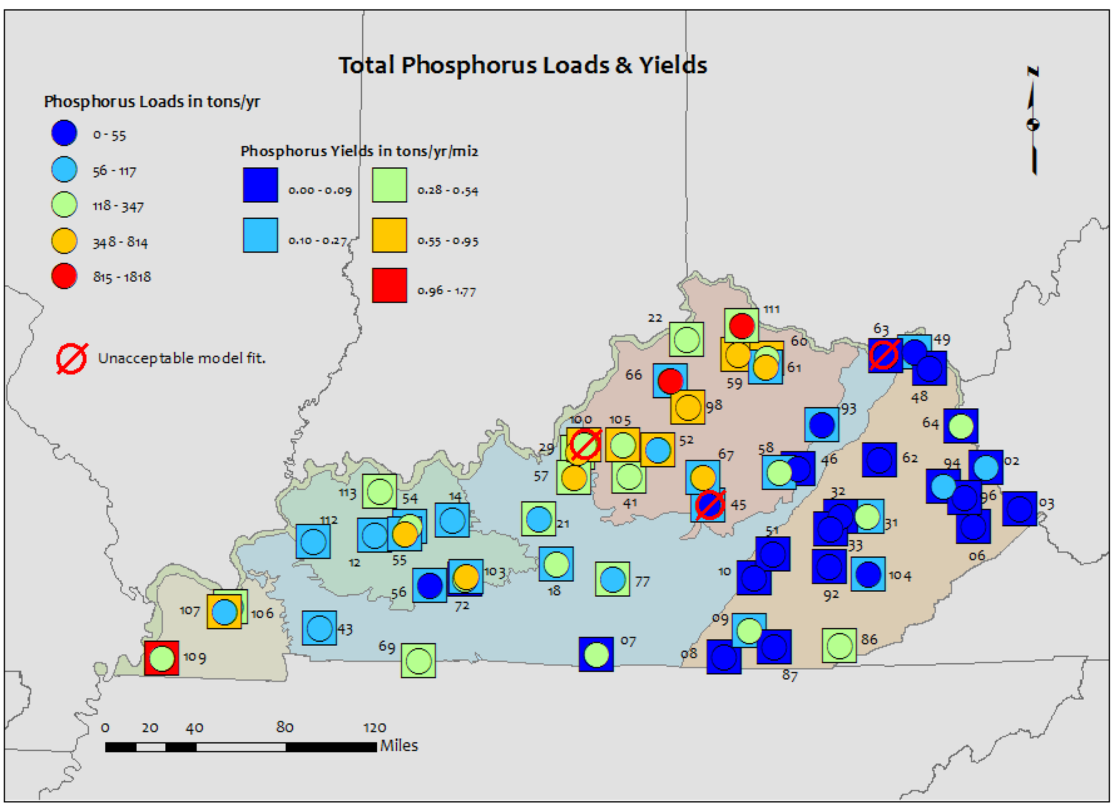


Figure 4. Loads and yields by simplified physiographic region.





Land use and yield

An examination of yield on a map (Figure 3) illustrates that nutrient yields are highest in two areas; in the far western part of the state and in some parts of the Bluegrass. When comparing maps by river basin and physiographic region, it is apparent that yields are better characterized by physiographic region than basin. Each physiographic region has a unique geology leading to differences in land use and antecedent soil conditions, particularly with regard to phosphorus. The Jackson Purchase, in the far west, is flat and has rich soils. Row crops are a prevalent land use in this region. In the Bluegrass, limestone is naturally high in phosphorus and has benefits for livestock. Equine and cattle agriculture are more predominant than row crop acreage in this region. Appendix 1: Land Cover and Use gives the percentages of contributing watersheds in row crops, pasture, forest, and developed. Close examination shows that monitoring stations in the Four Rivers Basin Management Unit (far west) with the highest yields also have the highest percentages of row crop. Conversely, stations in the Bluegrass with the highest yield have the highest percentages of pasture.

The relationship between land use and total nitrogen and phosphorus yields was examined via regression analyses (Figure 5 and Figure 6). The relationships between agricultural land use and natural land cover show strong relationships. As expected, the greater the portion of the contributing watershed in agricultural use, the higher the yield of both total nitrogen and phosphorus. The relationship is stronger for nitrogen than phosphorus. The inverse is true for natural land cover. Higher yields are associated with lower natural cover. For developed land, while still significant, the relationships between percent developed land use and yield are weaker. While the data span a wide range of watershed coverage for agriculture and natural land use classes, most developed land uses fall below 10% coverage for the studied watersheds, with only two contributing basins reaching about 20% developed land use.

Figure 5. Regression showing the yield of total nitrogen versus the percent of land cover: agriculture, natural, or developed.

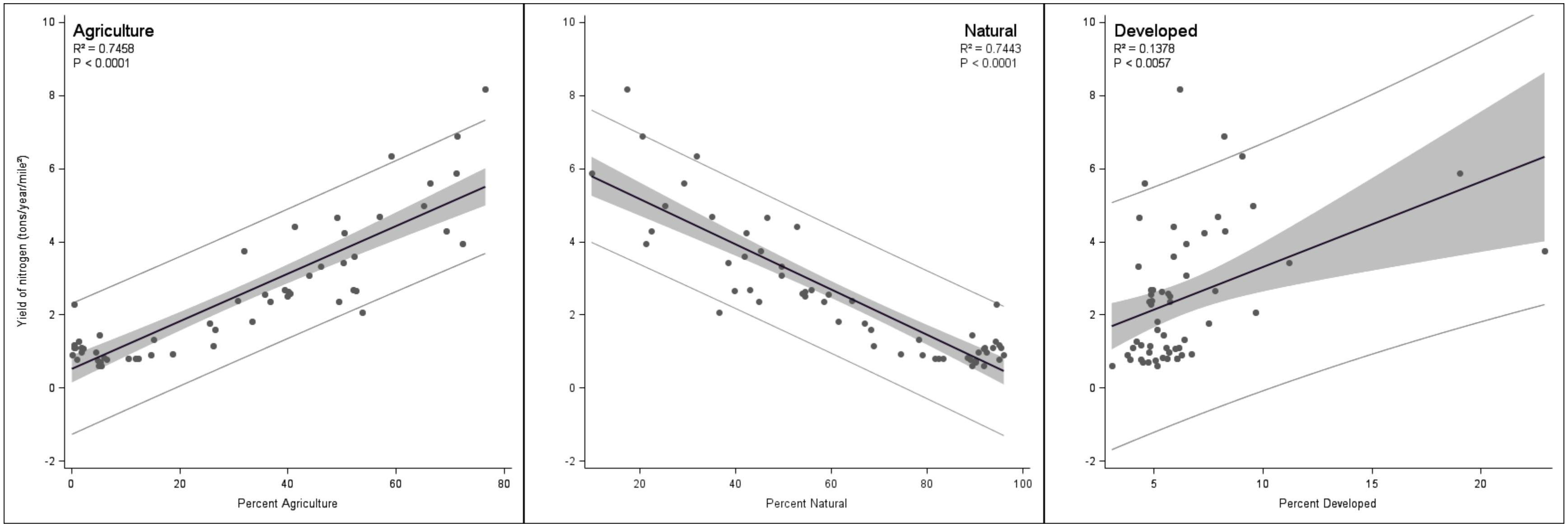


Figure 6. Regression showing the yield of total phosphorus versus the percent of land cover: agriculture, natural, or developed.

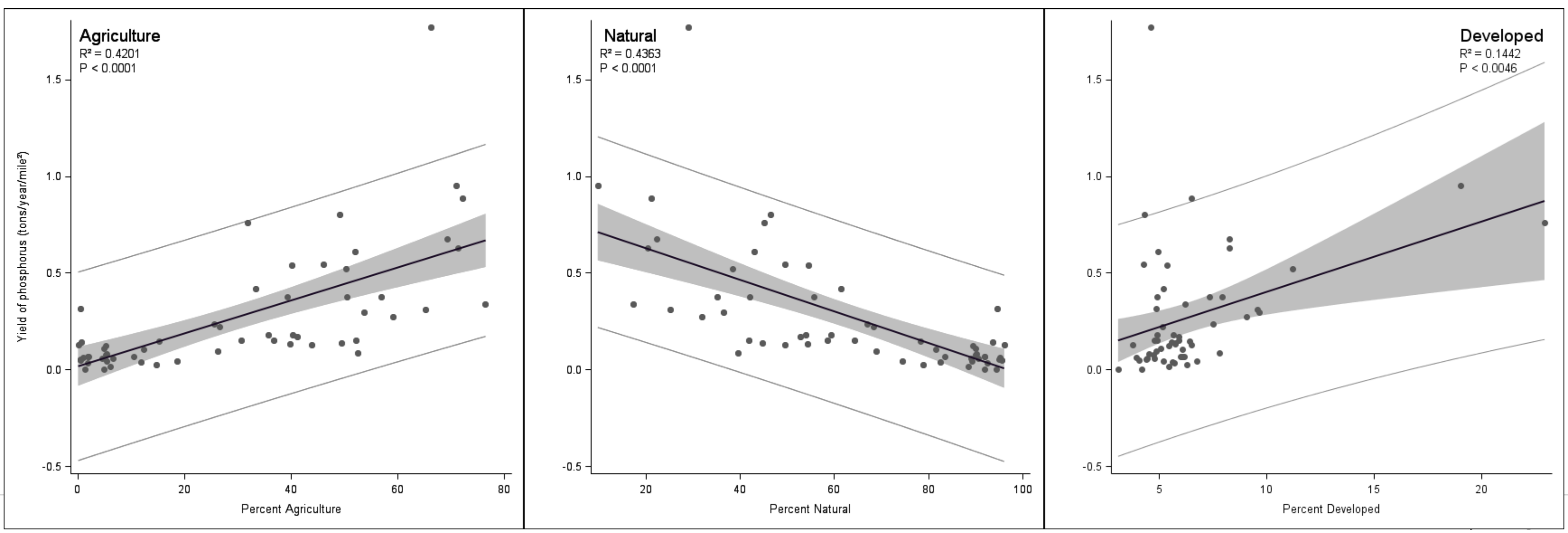


Figure 7 and Figure 8 exhibit the same information with the 95% confidence interval for each station. These plots illustrate the greater variability in yield at stations with higher percentages of agriculture in the contributing watershed or lower natural land coverage. This variability may result from the seasonality of fertilizer application on agricultural lands. Increased rates of nutrient application may result in higher concentrations in runoff during the growing season resulting in higher variability in the calibration file from samples taken at different times of the year. Because this study did not include seasonality as a factor, stations with a higher percentage of agricultural lands in the area of contribution, and consequently lower natural land acreages, would be expected to have greater variability in the calibration dataset and less certainty (larger confidence intervals) in the output. No clear pattern of uncertainty is perceived for developed land use. None of the stations in this study are predominated by developed land use in their contributing watersheds; yields more likely reflect impacts from the predominant land use or class in the contributing watershed.

Figure 7. Mean total nitrogen yield and 95% confidence interval for percent land use of contributing watershed.

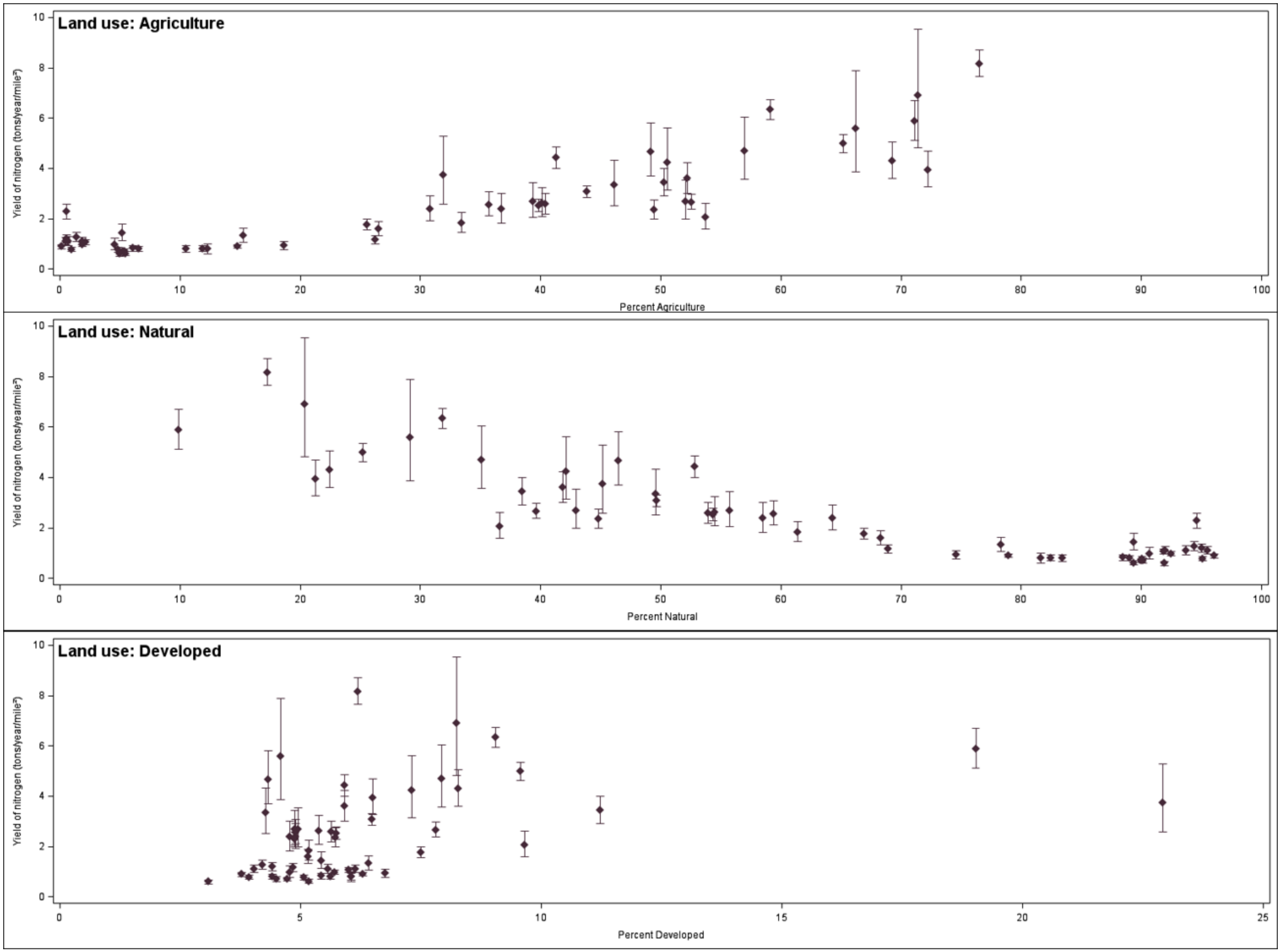


Figure 8. Mean total phosphorus yield and 95% confidence interval for percent land use of contributing watershed.

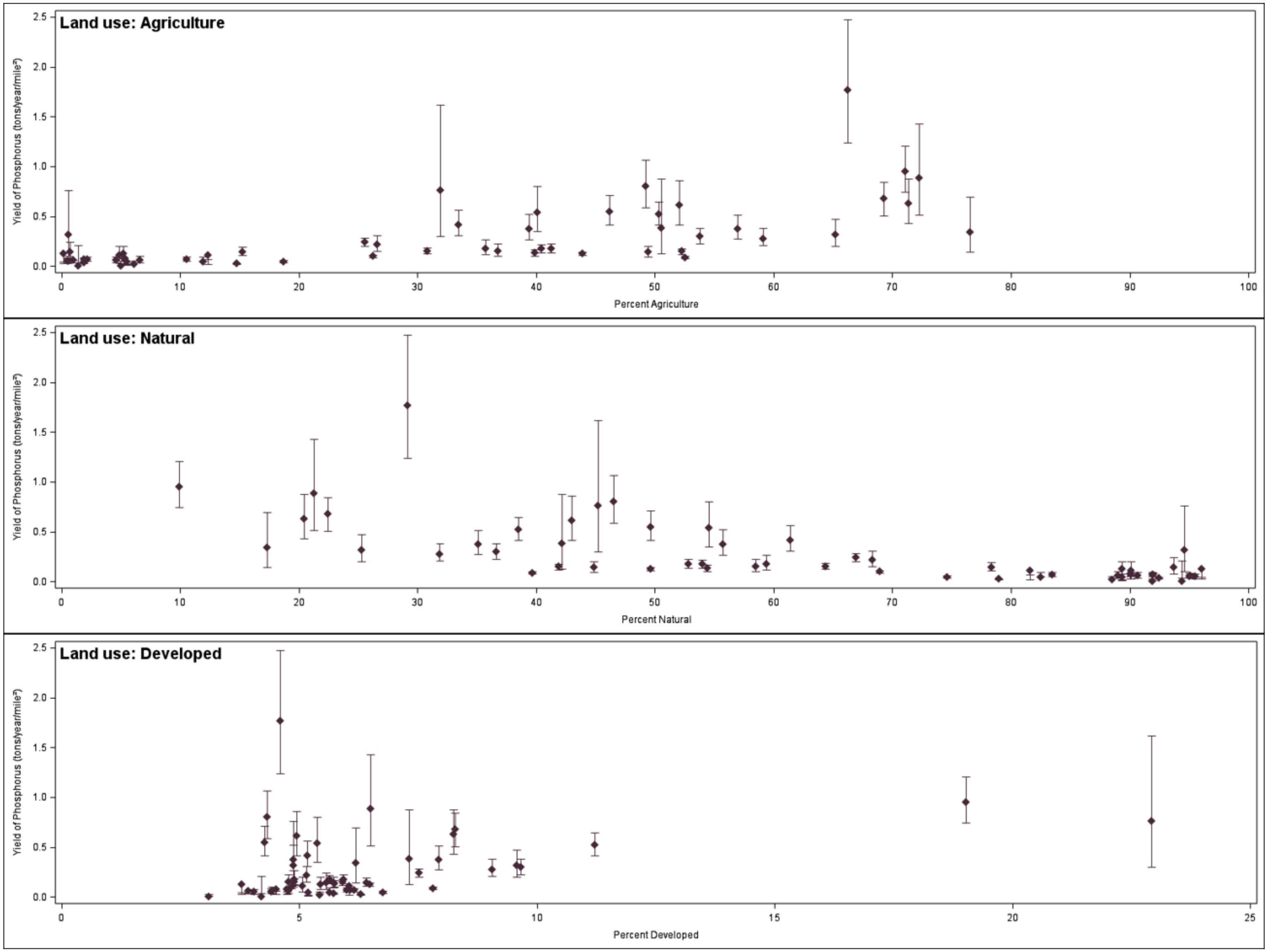
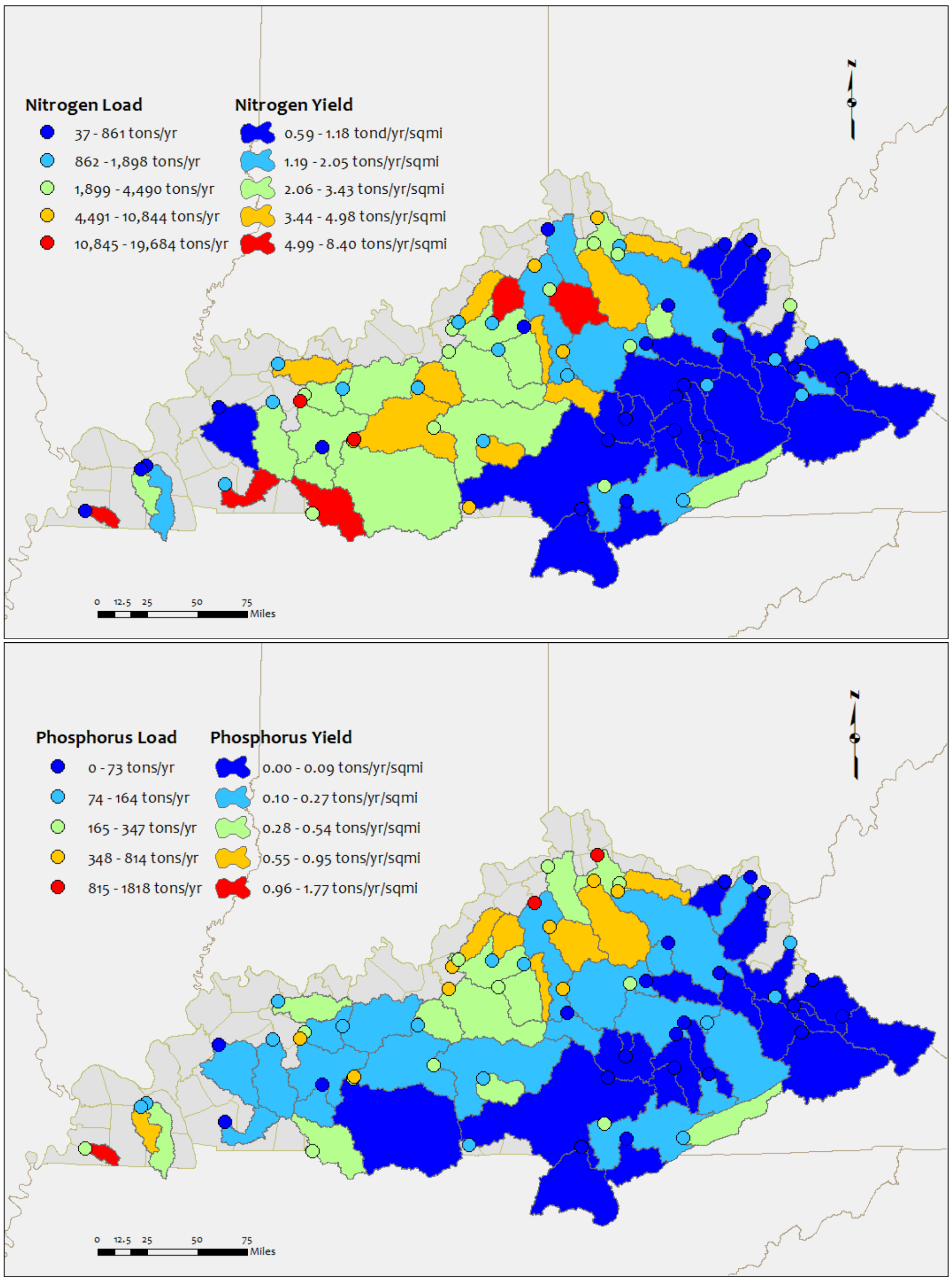


Figure 9 more clearly illustrates loads and yields by showing the loads as point values and the yields by the contributing basin. Results are as anticipated, reflecting the highest total nitrogen yields in the areas of the state with the most agriculture. Phosphorus yields similarly reflect higher levels where agriculture is present, but also reflect increased yields in the Bluegrass physiographic region where geology contributes to naturally higher concentrations of the nutrient. Loads, shown as points, reflect not only the amount of the nutrient, but also the size of the contributing basin.

Figure 9. Nutrient loads and yields. Loads show the amount of nutrient at one point. Yields reflect the amount per area. Note that some of the contributing basins overlap, with the smaller basins drawn on top of the larger basins.



Comparison to 1979-2004 results

An objective of this study was to compare the results of this study with the earlier USGS study. A puzzling finding was that differences in yield were quite variable as shown in Table 7. As noted earlier, the substantial increase in the detection limit for TKN was expected to influence the comparability for total nitrogen, which may account for the great differences at stations PRI043 and PRI069. However, the variability found between the studies for total phosphorus was also mutable. One potential source of error was that for some stations, the drainage area was found to be substantially different than the 2009 study. The USGS study did not indicate how contributing watershed area was determined. One possibility for this large difference may be confusion as to whether a monitoring station was on the main stem of a river or at the mouth of the tributary. These differences could result in much different yields, but would not be expected to influence loads. In fact, this pattern can be seen for the stations with the greatest difference in areas, as shown in Table 8.

Table 7. Percent change between current study and 1979-2004 USGS study.

Station	Percent change					
	Concen-tration	Load	Yield	Concen-tration	Load	Yield
	Nitrogen			Phosphorus		
Big and Little Sandy, Tygarts						
PRI002	4%	0%	-2%	-17%	-5%	-10%
PRI003	31%	13%	-61%	100%	-48%	-82%
PRI006	10%	-82%	-82%	-5%	-86%	-85%
PRI048	-7%	-81%	-83%	60%	-50%	-56%
PRI049	-14%	-18%	-21%	10%	-22%	-25%
PRI064	9%	17%	18%	45%	.	.
PRI094	25%	19%	18%	50%	33%	31%
PRI096	-4%	-38%	-15%	15%	-100%	-100%
Four Rivers, Upper & Lower Cumberland						
PRI007	12%	-3%	-6%	60%	3%	20%
PRI008	-72%	-31%	-29%	10%	-50%	-53%
PRI009	-2%	8%	-67%	-10%	-21%	-77%
PRI010	-7%	-32%	-30%	70%	-51%	-53%
PRI043	18%	27%	15%	1180%	-45%	-50%
PRI051	-90%	156%	107%	26%	30%	32%
PRI069	30%	17%	9%	440%	343%	336%
PRI086	33%	22%	-31%	70%	.	.
PRI087	48%	17%	17%	-64%	265%	295%
PRI106	-14%	5%	8%	11%	19%	18%
PRI109	18%	-4%	64%	20%	105%	254%

Station	Percent change					
	Concen-tration	Load	Yield	Concen-tration	Load	Yield
	Nitrogen			Phosphorus		
Kentucky River						
PRI022	-18%	-30%	-30%	14%	-31%	-30%
PRI031	3%	-7%	-8%	10%	-36%	-37%
PRI032	20%	1%	1%	60%	-41%	-81%
PRI033	7%	-3%	1%	80%	-74%	-72%
PRI045	10%	-2%	0%	43%	-44%	87%
PRI046	8%	-27%	-28%	85%	-81%	-81%
PRI058	-6%	-13%	-13%	110%	.	.
PRI066	-10%	-13%	-12%	64%	22%	25%
PRI067	8%	27%	39%	18%	4%	11%
PRI092	12%	17%	17%	20%	-39%	-27%
PRI098	5%	-18%	-18%	15%	-34%	-32%
PRI104	29%	35%	92%	110%	317%	544%
Salt, Licking						
PRI029	18%	3%	4%	-4%	-35%	116%
PRI041	-12%	-11%	-10%	19%	-33%	148%
PRI052	-11%	-24%	-25%	7%	-27%	-27%
PRI057	54%	-1%	-1%	25%	-54%	-54%
PRI059	9%	-29%	-28%	8%	16%	16%
PRI060	8%	8%	8%	33%	65%	67%
PRI061	-1%	178%	182%	93%	373%	338%
PRI062	-4%	-22%	-24%	20%	-74%	-75%
PRI063	-11%	-48%	-61%	-20%	-91%	-92%
PRI093	-3%	-13%	2245%	52%	-31%	-14%
PRI100	18%	7%	7%	-6%	-43%	-42%
PRI105	-14%	-40%	-37%	-10%	-53%	-52%
PRI111	23%	13%	13%	58%	136%	134%
Tradewater, Green						
PRI012	64%	144%	117%	74%	137%	116%
PRI014	8%	30%	32%	53%	35%	36%
PRI018	24%	1%	1%	-10%	1%	161%
PRI021	29%	15%	16%	19%	0%	1%
PRI054	-9%	52%	51%	32%	49%	48%
PRI055	23%	30%	28%	38%	6%	6%
PRI056	14%	37%	35%	-3%	53%	47%
PRI072	0%	-14%	-24%	40%	-23%	-33%
PRI077	23%	20%	32%	53%	135%	151%
PRI103	-11%	-39%	5%	7%	326%	755%

Table 8. Monitoring stations with the largest differences in drainage areas between the two studies frequently have correspondingly large differences in yield.

Station	Drainage area (mi²) this study	Drainage area (mi²) USGS study	Difference in area	Difference in Yield	
				Nitrogen	Phosphorus
PRI003	781	271	65%	-61%	-82%
PRI009	1976	562	72%	-77%	-67%
PRI086	519	770	-48%	-	-31%
PRI103	3137	5404	-72%	5%	755%
PRI104	227	324	-43%	92%	544%
PRI109	103	178	-73%	254%	64%

Rolling 5-year averages

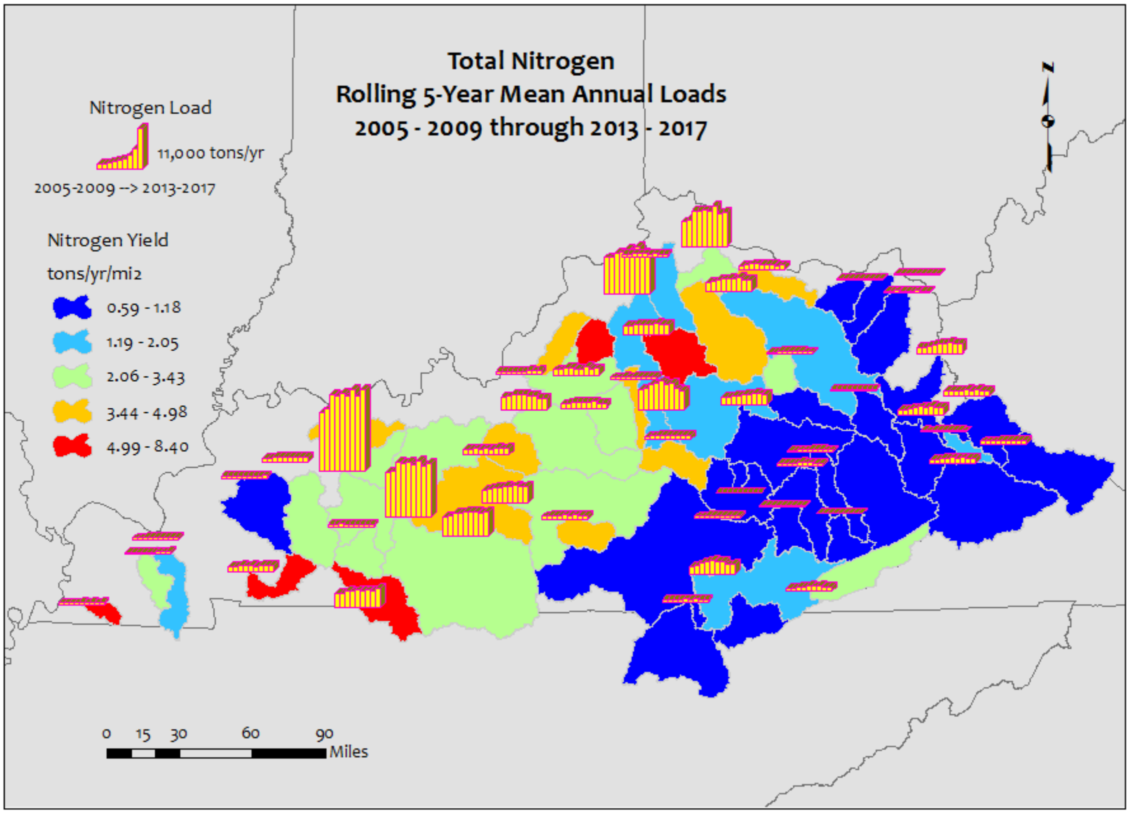
Because of the inconsistencies found between the original USGS study and the current study, using the USGS study as the baseline for loading does not appear prudent. Because of the continuous record available for these stations, a rolling 5-year average loading appeared to be a method that would work to detect changes over time while mitigating the variability of weather cycles. For the 2005 through 2017 time period, nine 5-year mean loads and yields were calculated. Figure 10, below, depicts the loads for each 5-year period, starting with 2005-2011 and ending with 2013-2017. The yields for the contributing area to each station depict the mean annual yield for the entire 2005-2017 time period. Appendix 3 depicts loads for each station over time.

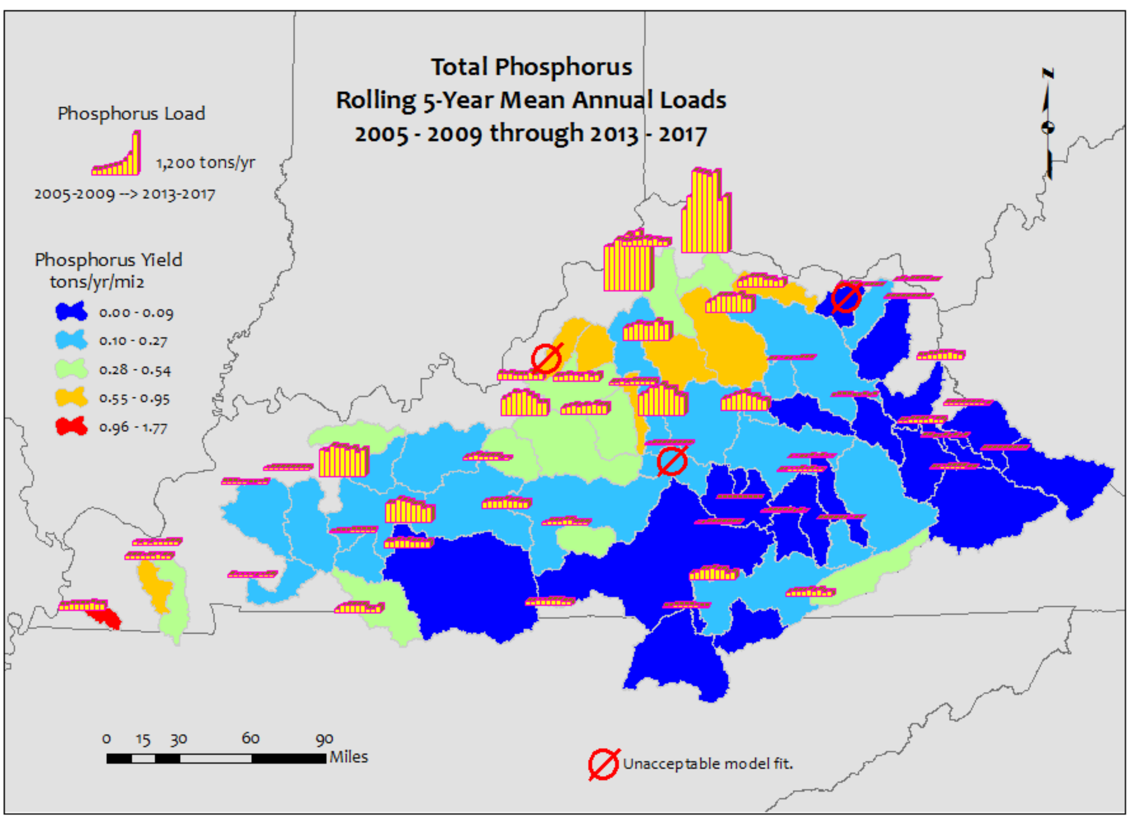
Examining regressions of yields over time (Table 9), the mean slopes with 95% confidence interval show an increasing trend for total nitrogen and no trend for total phosphorus. As more years and 5-year means are added to this dataset, any trends will become apparent.

Table 9. Mean and confidence interval of regression parameters for yields at all ambient monitoring stations, statewide.

Regression parameter	lower 95% CI	mean	upper 95% CI
Total Nitrogen			
slope	0.043	0.064	0.085
intercept	-168.4	-125.8	-83.2
R^2	0.37	0.44	0.52
Total Phosphorus			
slope	-0.001	0.003	0.006
intercept	-11.6	-5.1	1.4
R^2	0.21	0.28	0.35

Figure 10. Rolling 5-year mean annual loads along with the 2005-2017 annual yields for each ambient monitoring station.





Conclusions

Nutrient loads reflect both nutrient concentrations and contributing basin size. Yields are a better measure of where reduction strategies might be most effective.

Yields, as anticipated, are greater in areas with more agriculture. The western part of the state, particularly the Jackson Purchase physiographic region/Four Rivers basin, has the greatest concentration of row crops. This region of the state has the highest total nitrogen yields. Total agriculture land use, with larger percentages of pasture/hay, are found in the Salt, Licking and Tradewater Green river basins as well as individual contributing watersheds in the Kentucky River Basin. These watersheds are reflected with moderate to high yields of nitrogen and phosphorus in these areas. The limestone in the Bluegrass contributes to naturally higher levels of phosphorus in the water, and this certainly contributes to the phosphorus yield in this part of the state. The eastern part of state has the lowest rates of agricultural land uses, and this is reflected by the lowest calculated loads and yields for both nitrogen and phosphorus.

Because the comparison between the 2009 USGS study and the current study showed unexplained inconsistencies, the calculation of 5-year rolling means for loads and yields was undertaken. This provides a consistent baseline for evaluating implemented reduction strategies while mitigating the effects of extreme weather years and provides a means for continuing assessments as additional sample years accrue. These rolling means found a slight, but significant, increasing trend for total nitrogen, while no trend was found for total phosphorus.

The western part of state is still under-represented in this study despite the addition of three more stations. To be included in this study, both a primary ambient monitoring station and a nearby gage that can be used to estimate daily discharge must be present. The presence of controls on discharge (dams) must also be taken into account. A closer look at monitoring stations and gages should be undertaken to determine if additional stations can be added to this ongoing assessment of loading, or if additional monitoring and/or gaging stations are needed.

The results of this study provides the basis for updating the Kentucky Nutrient Reduction Strategy and the means of evaluating the effectiveness of the implemented strategy. This study can inform decisions for where mitigation efforts can best achieve goals.

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Appendix 1: Land Cover and Use

Table 10. Percent land cover and use of watersheds draining to each station.

Station ID	Station Name	Drainage Area (mi²)	Percent land cover in 2016						
			Pasture /Hay	Row Crop	Total Ag	Forested	Wetlands	Natural	Developed
Big and Little Sandy, Tygarts									
PRI002	Tug Fork at Kermit, WV	1278	0.6	0.0	0.6	86	0.00	95	4.4
PRI003	Tug Fork at Freeburn	781	0.5	0.0	0.5	89	0.00	95	4.0
PRI006	Levisa Fork near Pikeville	1230	1.8	0.0	1.8	84	0.01	92	5.7
PRI048	Tygarts Creek near Lynn	275	12.2	0.1	12.3	77	0.03	82	6.1
PRI049	Little Sandy River at Argillite	539	10.3	0.2	10.5	81	0.02	83	6.1
PRI064	Levisa Fork near Louisa	2323	2.1	0.0	2.1	85	0.01	92	6.0
PRI094	Levisa Fork at Auxier	1723	1.9	0.0	1.9	84	0.01	92	6.1
PRI096	Johns Creek at McCombs	121	1.4	0.0	1.4	85	0.00	94	4.2
Four Rivers, Upper & Lower Cumberland									
PRI007	Cumberland River near Burkesville	6245	13.5	1.3	14.8	73	0.09	79	6.3
PRI008	Big South Fork Cumberland River at Blue Heron	964	6.5	0.1	6.6	83	0.03	89	4.4
PRI009	Cumberland River at Cumberland Falls	1976	5.2	0.0	5.2	82	0.08	89	5.4
PRI010	Rockcastle River at Billows	604	18.4	0.3	18.7	72	0.02	75	6.8
PRI043	Little River near Cadiz	268	17.2	41.9	59.1	30	0.34	32	9.0
PRI051	Rockcastle River near Lamero	62	5.5	0.0	5.5	88	0.00	89	5.2
PRI069	Red River near Keysburg	534	55.1	0.4	76.5	16	0.45	17	6.2
PRI086	Cumberland River at Calvin	519	0.5	0.0	0.5	87	0.02	95	4.9
PRI087	Clear Fork near Williamsburg	370	5.3	0.0	5.4	82	0.16	90	4.5
PRI106	Clarks River near Sharpe	310	15.3	38.4	53.8	30	5.39	37	9.7
PRI109	Bayou de Chien near Cayce	103	11.1	55.1	66.3	22	6.87	29	4.6

Station ID	Station Name	Drainage Area (mi^2)	Percent land cover in 2016						
			Pasture /Hay	Row Crop	Total Ag	Forested	Wetlands	Natural	Developed
	Kentucky River								
PRI022	Eagle Creek at Glenco	437	33.2	0.3	33.4	60	0.03	61	5.2
PRI031	North Fork Kentucky River at Jackson	1101	0.7	0.0	0.7	82	0.00	94	5.6
PRI032	Middle Fork Kentucky River at Tallega	536	1.0	0.0	1.0	88	0.01	95	3.9
PRI033	South Fork Kentucky River at Booneville	692	4.5	0.0	4.5	88	0.01	91	4.8
PRI045	Dix River near Danville	317	47.3	4.9	52.2	40	0.06	42	5.9
PRI046	Red River Clay City	362	10.8	1.1	11.9	80	0.05	82	5.6
PRI058	Kentucky River near Trapp	3235	4.7	0.1	4.9	83	0.02	90	5.1
PRI066	Kentucky River near Lockport	6178	24.2	1.3	25.6	62	0.05	67	7.5
PRI067	Kentucky River at High Bridge	4588	14.8	0.4	15.2	73	0.03	78	6.4
PRI092	Goose Creek near Oneida	251	6.1	0.0	6.1	85	0.01	88	5.4
PRI098	Elkhorn Creek near Peaks Mill	473	66.7	4.4	71.1	9	0.11	10	19.0
PRI104	Middle Fork Kentucky River near Dryhill	227	0.1	0.0	0.1	87	0.00	96	3.8
	Salt, Licking								
PRI029	Salt River at Shepherdsville	1197	39.7	10.6	50.3	36	0.11	38	11.2
PRI041	Beech Fork near Maud	436	42.6	3.6	46.1	48	0.01	50	4.3
PRI052	Salt River at Glensboro	173	62.9	6.4	69.3	21	0.01	22	8.3
PRI057	Rolling Fork near Lebanon Jct.	1374	31.6	7.8	39.4	54	0.23	56	4.9
PRI059	South Fork Licking River at Morgan	838	68.9	3.3	72.3	20	0.06	21	6.5
PRI060	North Fork Licking River near Milford	287	43.2	6.0	49.2	45	0.00	46	4.3
PRI061	Licking River at Claysville	1966	25.2	1.4	26.6	66	0.05	68	5.2
PRI062	Licking River at West Liberty	334	5.2	0.0	5.3	86	0.01	90	4.7
PRI063	Kinniconick Creek near Tannery	229	4.8	0.2	5.0	90	0.03	92	3.1
PRI093	Slate Creek near Owingsville	185	48.9	0.6	49.4	44	0.06	45	5.7
PRI100	Floyds Fork near Shephердsville	259	27.0	4.9	31.9	43	0.06	45	22.9
PRI105	Brashears Creek at Taylorsville	262	48.8	22.5	71.4	19	0.03	20	8.2
PRI111	Licking River at Butler	3384	37.9	2.2	40.1	52	0.05	55	5.4

Station ID	Station Name	Drainage Area (mi^2)	Percent land cover in 2016						
			Pasture /Hay	Row Crop	Total Ag	Forested	Wetlands	Natural	Developed
Tradewater, Green									
PRI012	Pond River near Sacramento	578	13.1	17.7	30.8	54	6.36	64	4.9
PRI014	Rough River near Dundee	757	25.6	11.1	36.7	56	0.14	59	4.8
PRI018	Green River at Munfordville	1680	33.4	6.4	39.9	52	0.16	54	5.7
PRI021	Nolin River at White Mills	351	31.0	34.2	65.2	24	0.18	25	9.6
PRI054	Rough River near Livermore	1067	22.1	13.6	35.7	56	0.93	59	4.9
PRI055	Green River at Livermore	6423	31.5	12.3	43.8	46	0.61	50	6.4
PRI056	Mud River near Gus	268	26.3	14.1	40.4	51	1.05	54	5.6
PRI072	Barren River near Woodbury	2264	13.2	0.1	52.5	37	0.16	40	7.8
PRI077	Russell Creek near Bramlett	262	44.0	6.5	50.5	41	0.01	42	7.3
PRI103	Green River near Woodbury	3136	31.0	10.2	41.3	50	0.19	53	5.9

Appendix 2: Model Equations

Table 11. Model equations and fit for total nitrogen load.

Station	Total nitrogen regression equations	R2 (percent)	Estimated residual variance
	Big and Little Sandy, Tygarts		
PRI002	$7.33 + 1.26\ \text{Ln}(Q) - 0.01\ \text{Sin}(2\pi dt) + 0.18\ \text{Cos}(2\pi dt) - 0.04dt$	91	0.138
PRI003	$6.6 + 1.44\ \text{Ln}(Q) - 0.06\ \text{Sin}(2\pi dt) + 0.2\ \text{Cos}(2\pi dt) - 0.03dt$	94	0.111
PRI006	$7.58 + 1.18\ \text{Ln}(Q) - 0.02dt$	94	0.096
PRI048	$4.04 + 1.13\ \text{Ln}(Q) - 0.01\ \text{Ln}(Q)^2 + 0.17\ \text{Sin}(2\pi dt) + 0.03\ \text{Cos}(2\pi dt) + 0(dt) + 0.01(dt)^2$	96	0.164
PRI049	$5.75 + 0.86\ \text{Ln}(Q) + 0.07\ \text{Ln}(Q)^2 + 0.1\ \text{Sin}(2\pi dt) - 0.06\ \text{Cos}(2\pi dt) - 0.02(dt) + 0(dt)^2$	95	0.082
PRI064	$8.08 + 1.18\ \text{Ln}(Q)$	95	0.095
PRI094	$7.82 + 1.23\ \text{Ln}(Q) + 0.04\ \text{Ln}(Q)^2 - 0.11\ \text{Sin}(2\pi dt) + 0.17\ \text{Cos}(2\pi dt) - 0.02(dt)$	93	0.106
PRI096	$5.2 + 1.19\ \text{Ln}(Q) - 0.12\ \text{Ln}(Q)^2 - 0.05dt$	94	0.114
	Four Rivers, Upper & Lower Cumberland		
PRI007	$7.04 + 1.01\ \text{Ln}(Q) + 0.02\ \text{Ln}(Q)^2 + 0.09\ \text{Sin}(2\pi dt) + 0.01\ \text{Cos}(2\pi dt) + 0.02(dt) + 0.01(dt)^2$	97	0.012
PRI008	$5.81 + 1.09\ \text{Ln}(Q) - 0.02dt$	96	0.121
PRI009	$7.15 + 1.34\ \text{Ln}(Q) + 0.05\ \text{Ln}(Q)^2 + 0.31\ \text{Sin}(2\pi dt) - 0.06\ \text{Cos}(2\pi dt) - 0.03(dt)$	95	0.115
PRI010	$5.3 + 1.19\ \text{Ln}(Q) - 0.03\ \text{Ln}(Q)^2 - 0.11\ \text{Sin}(2\pi dt) + 0.18\ \text{Cos}(2\pi dt) - 0.04(dt) + 0.01(dt)^2$	97	0.100
PRI043	$7.43 + 1.09\ \text{Ln}(Q) - 0.04\ \text{Ln}(Q)^2 - 0.05\ \text{Sin}(2\pi dt) + 0.07\ \text{Cos}(2\pi dt)$	99	0.024
PRI051	$2.89 + 1.04\ \text{Ln}(Q)$	95	0.111
PRI069	$8.58 + 1.13\ \text{Ln}(Q) - 0.05\ \text{Ln}(Q)^2 + 0.01dt$	99	0.024
PRI086	$7.11 + 1.36\ \text{Ln}(Q) - 0.01\ \text{Sin}(2\pi dt) + 0.26\ \text{Cos}(2\pi dt)$	94	0.127
PRI087	$5.06 + 1.05\ \text{Ln}(Q) - 0.02\ \text{Ln}(Q)^2$	97	0.095
PRI106	$6.6 + 1.09\ \text{Ln}(Q) - 0.03\ \text{Ln}(Q)^2 - 0.25\ \text{Sin}(2\pi dt) + 0.24\ \text{Cos}(2\pi dt)$	94	0.189
PRI107	$6.22 + 1.33\ \text{Ln}(Q) - 0.07\ \text{Ln}(Q)^2 + 0.14\ \text{Sin}(2\pi dt) + 0.14\ \text{Cos}(2\pi dt) - 0.02(dt) + 0.01(dt)^2$	94	0.225
PRI109	$6.89 + 1.54\ \text{Ln}(Q) - 0.19\ \text{Ln}(Q)^2 - 0.19\ \text{Sin}(2\pi dt) + 0.2\ \text{Cos}(2\pi dt)$	89	0.273
	Kentucky River		
PRI022	$4.07 + 1.08\ \text{Ln}(Q) + 0.01\ \text{Ln}(Q)^2 - 0.02\ \text{Sin}(2\pi dt) - 0.16\ \text{Cos}(2\pi dt) - 0.01(dt) - 0.01(dt)^2$	98	0.137
PRI031	$7 + 1.2\ \text{Ln}(Q) - 0.06dt$	91	0.189
PRI032	$5.91 + 1.07\ \text{Ln}(Q) - 0.04dt$	95	0.113
PRI033	$4.46 + 0.96\ \text{Ln}(Q) + 0.05\ \text{Ln}(Q)^2 - 0.02dt$	95	0.194
PRI045	$5.09 + 1.24\ \text{Ln}(Q)$	97	0.185
PRI046	$5.05 + 1.08\ \text{Ln}(Q) + 0.03\ \text{Sin}(2\pi dt) - 0.16\ \text{Cos}(2\pi dt)$	94	0.146
PRI058	$7.41 + 1.11\ \text{Ln}(Q) + 0.14\ \text{Sin}(2\pi dt) - 0.07\ \text{Cos}(2\pi dt)$	94	0.101
PRI066	$8.71 + 1.16\ \text{Ln}(Q) + 0.2\ \text{Sin}(2\pi dt) - 0.13\ \text{Cos}(2\pi dt) - 0.03dt$	96	0.084
PRI067	$8.11 + 1.05\ \text{Ln}(Q) + 0.06\ \text{Ln}(Q)^2 + 0.04\ \text{Sin}(2\pi dt) + 0.22\ \text{Cos}(2\pi dt) - 0.05(dt) - 0.01(dt)^2$	93	0.120
PRI092	$4.2 + 1.01\ \text{Ln}(Q) - 0.04\ \text{Sin}(2\pi dt) - 0.19\ \text{Cos}(2\pi dt)$	96	0.117
PRI098	$8.1 + 0.93\ \text{Ln}(Q) + 0.03\ \text{Ln}(Q)^2 - 0.17\ \text{Sin}(2\pi dt) - 0.24\ \text{Cos}(2\pi dt)$	93	0.130
PRI104	$5.19 + 1.04\ \text{Ln}(Q) + 0.03\ \text{Ln}(Q)^2 - 0.04dt$	96	0.079

Station	Total nitrogen regression equations	R2 (percent)	Estimated residual variance
	Salt, Licking		
PRI029	$7.7 + 1.08 \ln(Q) + 0.06 \ln(Q)^2 + 0.06 \sin(2\pi dt) - 0.05 \cos(2\pi dt) - 0.01(dt) + 0(dt)^2$	96	0.092
PRI041	$3.68 + 1.13 \ln(Q) + 0.02 \ln(Q)^2 + 0.13 \sin(2\pi dt) - 0.09 \cos(2\pi dt) + 0(dt) - 0.01(dt)^2$	98	0.162
PRI052	$5.5 + 1.19 \ln(Q)$	96	0.173
PRI057	$3.13 + 1 \ln(Q) + 0.01 \ln(Q)^2 + 0.14 \sin(2\pi dt) - 0.12 \cos(2\pi dt)$	97	0.219
PRI059	$6.74 + 1.24 \ln(Q)$	98	0.086
PRI060	$3.67 + 1.16 \ln(Q) + 0.02 \ln(Q)^2 + 0.02dt$	98	0.188
PRI061	$7.49 + 1.26 \ln(Q) + 0.05 \ln(Q)^2 + 0.21 \sin(2\pi dt) + 0.1 \cos(2\pi dt)$	94	0.177
PRI062	$5.23 + 1.06 \ln(Q) - 0.02dt$	96	0.010
PRI063	$3.96 + 1.08 \ln(Q) - 0.22 \sin(2\pi dt) - 0.04 \cos(2\pi dt)$	95	0.095
PRI093	$3.34 + 1.1 \ln(Q)$	96	0.136
PRI100	$6.64 + 0.96 \ln(Q) + 0.04 \ln(Q)^2 + 0.22 \sin(2\pi dt) - 0.16 \cos(2\pi dt) + 0.03(dt)$	88	0.159
PRI105	$3.77 + 1.25 \ln(Q) + 0.03 \ln(Q)^2$	96	0.242
PRI111	$8.16 + 1.28 \ln(Q) + 0.05 \ln(Q)^2 + 0.03dt$	95	0.194
	Tradewater, Green		
PRI012	$3.88 + 1.06 \ln(Q) + 0.04 \sin(2\pi dt) + 0.22 \cos(2\pi dt) + 0.03dt$	96	0.304
PRI014	$7.28 + 1.09 \ln(Q) - 0.26dt$	93	0.167
PRI018	$8.42 + 1.17 \ln(Q) - 0.05 \ln(Q)^2 - 0.14 \sin(2\pi dt) - 0.01 \cos(2\pi dt)$	97	0.069
PRI021	$7.93 + 0.98 \ln(Q) - 0.04 \ln(Q)^2 + 0.01dt$	97	0.032
PRI054	$7.68 + 1.11 \ln(Q)$	95	0.110
PRI055	$9.72 + 1.14 \ln(Q) - 0.17 \sin(2\pi dt) + 0.11 \cos(2\pi dt) + 0.01dt$	97	0.055
PRI056	$6.21 + 1.06 \ln(Q) + 0.18 \sin(2\pi dt) - 0.06 \cos(2\pi dt)$	95	0.130
PRI072	$8.26 + 1.06 \ln(Q) - 0.23 \sin(2\pi dt) - 0.3 \cos(2\pi dt)$	95	0.090
PRI077	$5.82 + 1.38 \ln(Q) - 0.04 \ln(Q)^2$	96	0.142
PRI103	$9.34 + 1.09 \ln(Q) - 0.17 \sin(2\pi dt) - 0.01 \cos(2\pi dt)$	95	0.061
PRI112	$5.69 + 0.96 \ln(Q) - 0.02 \ln(Q)^2 - 0.11 \sin(2\pi dt) + 0.31 \cos(2\pi dt) - 0.01(dt) - 0.01(dt)^2$	97	0.164
PRI113	$4.33 + 1.1 \ln(Q) - 0.19 \sin(2\pi dt) - 0.19 \cos(2\pi dt)$	97	0.252

Table 12. Regression equations and model fit for phosphorus loads.

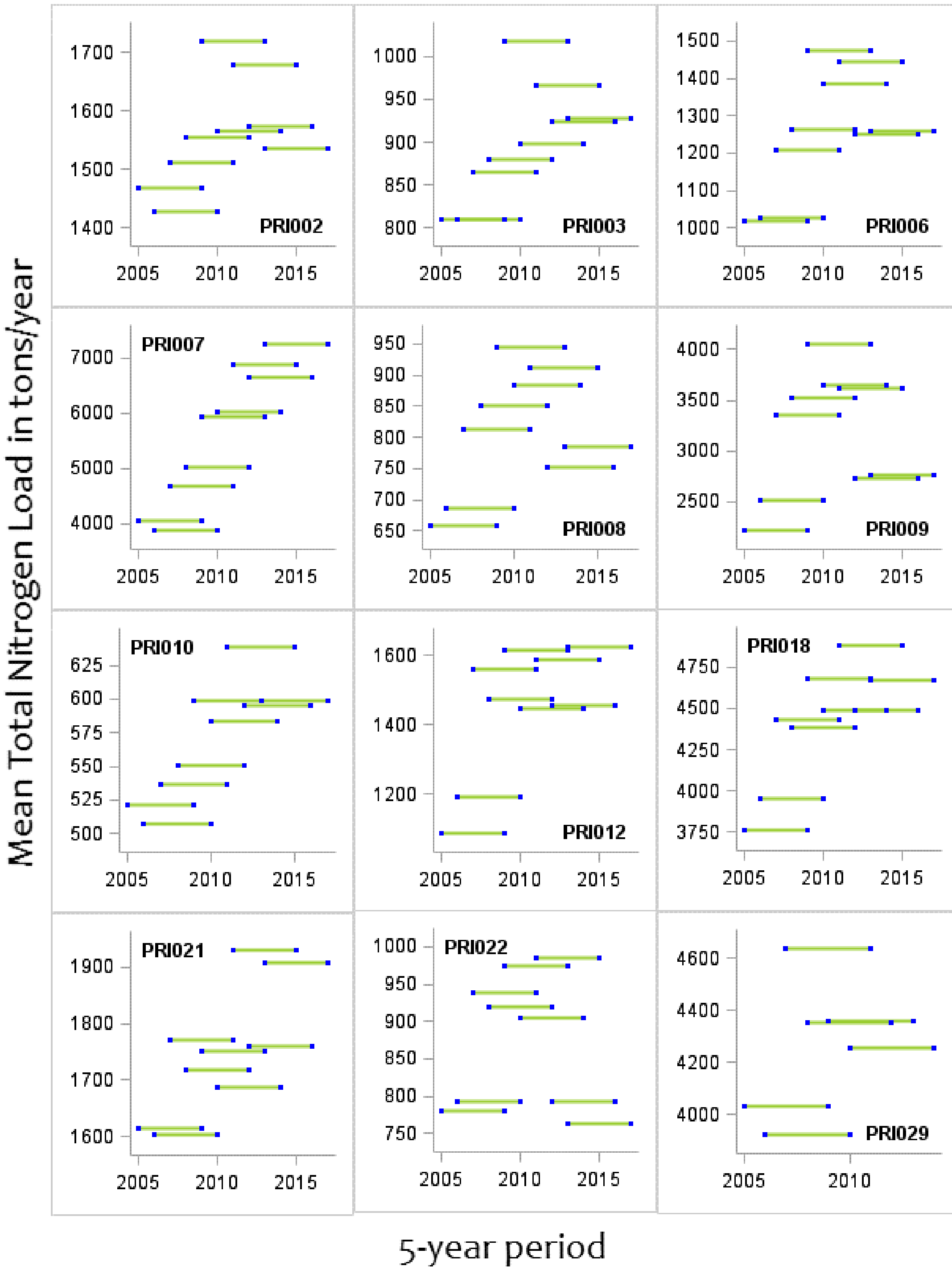
Station	Total phosphorus regression equations	R2 (percent)	Estimated residual variance
	Big and Little Sandy, Tygarts		
PRI002	$3.78 + 1.5\ Ln(Q) + 0.05\ Ln(Q)^2 - 0.11\ Sin(2\pi dt) + 0.35\ Cos(2\pi dt) - 0.08(dt) - 0.01(dt)^2$	84	0.427
PRI003	$3.01 + 1.43\ Ln(Q) + 0.09\ Ln(Q)^2 - 0.4\ Sin(2\pi dt) + 0.25\ Cos(2\pi dt) - 0.08(dt) - 0.01(dt)^2$	79	0.542
PRI006	$3.93 + 1.27\ Ln(Q) + 0.08\ Ln(Q)^2 - 0.07\ Sin(2\pi dt) + 0\ Cos(2\pi dt) - 0.06(dt) - 0.02(dt)^2$	74	0.675
PRI048	$0.2 + 1.18\ Ln(Q) + 0.05\ Ln(Q)^2 - 0.1\ Sin(2\pi dt) + 0.48\ Cos(2\pi dt) - 0.05(dt)$	90	0.383
PRI049	$2.34 + 1.37\ Ln(Q) + 0.07\ Ln(Q)^2 + 0.04\ Sin(2\pi dt) + 0.3\ Cos(2\pi dt) - 0.02(dt) + 0.01(dt)^2$	94	0.204
PRI064	$4.93 + 1.56\ Ln(Q) + 0.05\ Ln(Q)^2 + 0.31\ Sin(2\pi dt) + 0.24\ Cos(2\pi dt) - 0.04(dt) - 0.01(dt)^2$	88	0.345
PRI094	$4.5 + 1.51\ Ln(Q) + 0.12\ Ln(Q)^2 + 0.27\ Sin(2\pi dt) + 0.52\ Cos(2\pi dt) - 0.03(dt)$	86	0.313
PRI096	$1.46 + 1.45\ Ln(Q) + 0.06\ Ln(Q)^2 - 0.17\ Sin(2\pi dt) + 0.25\ Cos(2\pi dt) - 0.03(dt) - 0.01(dt)^2$	82	0.523
	Four Rivers, Upper & Lower Cumberland		
PRI007	$3.23 + 1.07\ Ln(Q) - 0.05dt$	88	0.541
PRI008	$1.97 + 1.23\ Ln(Q) + 0.09\ Ln(Q)^2 - 0.07dt$	86	0.541
PRI009	$3.36 + 1.57\ Ln(Q) + 0.16\ Ln(Q)^2 - 0.12\ Sin(2\pi dt) - 0.57\ Cos(2\pi dt) - 0.06(dt) + 0.01(dt)^2$	89	0.330
PRI010	$1.39 + 1.27\ Ln(Q)$	85	0.714
PRI043	$3.67 + 1.08\ Ln(Q) + 0.1\ Ln(Q)^2 + 0.23\ Sin(2\pi dt) - 0.32\ Cos(2\pi dt) + 0(dt) + 0.01(dt)^2$	86	0.250
PRI051	$-0.74 + 0.96\ Ln(Q) - 0.03(dt)$	83	0.339
PRI069	$3.59 + 1.45\ Ln(Q) + 0.14\ Ln(Q)^2 - 0.01\ Sin(2\pi dt) + 0.62\ Cos(2\pi dt) - 0.03(dt) + 0.01(dt)^2$	89	0.290
PRI086	$2.92 + 1.84\ Ln(Q) + 0.24\ Ln(Q)^2 + 0.63\ Sin(2\pi dt) + 0.72\ Cos(2\pi dt) - 0.07(dt)$	81	0.719
PRI087	$1.62 + 1.26\ Ln(Q) + 0.37\ Sin(2\pi dt) + 0.06\ Cos(2\pi dt) - 0.08(dt)$	85	0.641
PRI106	$4.51 + 1.27\ Ln(Q) - 0.05\ Ln(Q)^2 + 0.05\ Sin(2\pi dt) + 0.14\ Cos(2\pi dt) - 0.03(dt)$	96	0.149
PRI107	$3.76 + 1.44\ Ln(Q) + 0.28\ Sin(2\pi dt) + 0.14\ Cos(2\pi dt) - 0.03dt$	93	0.302
PRI109	$5.01 + 1.56\ Ln(Q) + 0.22\ Sin(2\pi dt) + 0.19\ Cos(2\pi dt)$	89	0.204
	Kentucky River		
PRI022	$1.71 + 1.24\ Ln(Q) + 0.02\ Ln(Q)^2 - 0.28\ Sin(2\pi dt) - 0.37\ Cos(2\pi dt) - 0.01(dt) - 0.01(dt)^2$	97	0.201
PRI031	$3.31 + 1.48\ Ln(Q) + 0.21\ Ln(Q)^2 - 0.41\ Sin(2\pi dt) + 0.25\ Cos(2\pi dt) - 0.09(dt)$	90	0.275
PRI032	$2.39 + 1.32\ Ln(Q) + 0.1\ Ln(Q)^2 + 0.15\ Sin(2\pi dt) + 0.14\ Cos(2\pi dt) - 0.05(dt)$	93	0.244
PRI033	$1.01 + 0.99\ Ln(Q) + 0.1\ Ln(Q)^2 + 0.3\ Sin(2\pi dt) + 0.16\ Cos(2\pi dt)$	87	0.451
PRI045	$2.23 + 1.12\ Ln(Q) + 0.28\ Sin(2\pi dt) + -0.04\ Cos(2\pi dt)$	95	0.278
PRI046	$2.08 + 1.27\ Ln(Q) + 0.01\ Sin(2\pi dt) - 0.46\ Cos(2\pi dt) - 0.05(dt)$	83	0.552
PRI058	$3.97 + 1.51\ Ln(Q) + 0.16\ Ln(Q)^2 + 0.5\ Sin(2\pi dt) + 0.03\ Cos(2\pi dt) - 0.11(dt) - 0.02(dt)^2$	83	0.493
PRI066	$6.39 + 1.42\ Ln(Q) + 0.56\ Sin(2\pi dt) - 0.04\ Cos(2\pi dt) - 0.03(dt)$	94	0.155
PRI067	$5.4 + 1.31\ Ln(Q) + 0.08\ Ln(Q)^2 + 0.21\ Sin(2\pi dt) + 0.52\ Cos(2\pi dt) - 0.07(dt) - 0.01(dt)^2$	92	0.178
PRI092	$0.89 + 1.14\ Ln(Q) + 0.17\ Sin(2\pi dt) - 0.67\ Cos(2\pi dt) - 0.06(dt)$	91	0.266
PRI098	$5.89 + 0.96\ Ln(Q) + 0.13\ Ln(Q)^2$	89	0.207
PRI104	$1.82 + 1.04\ Ln(Q) + 0.56\ Sin(2\pi dt) + 0.18\ Cos(2\pi dt) - 0.07(dt)$	65	0.724

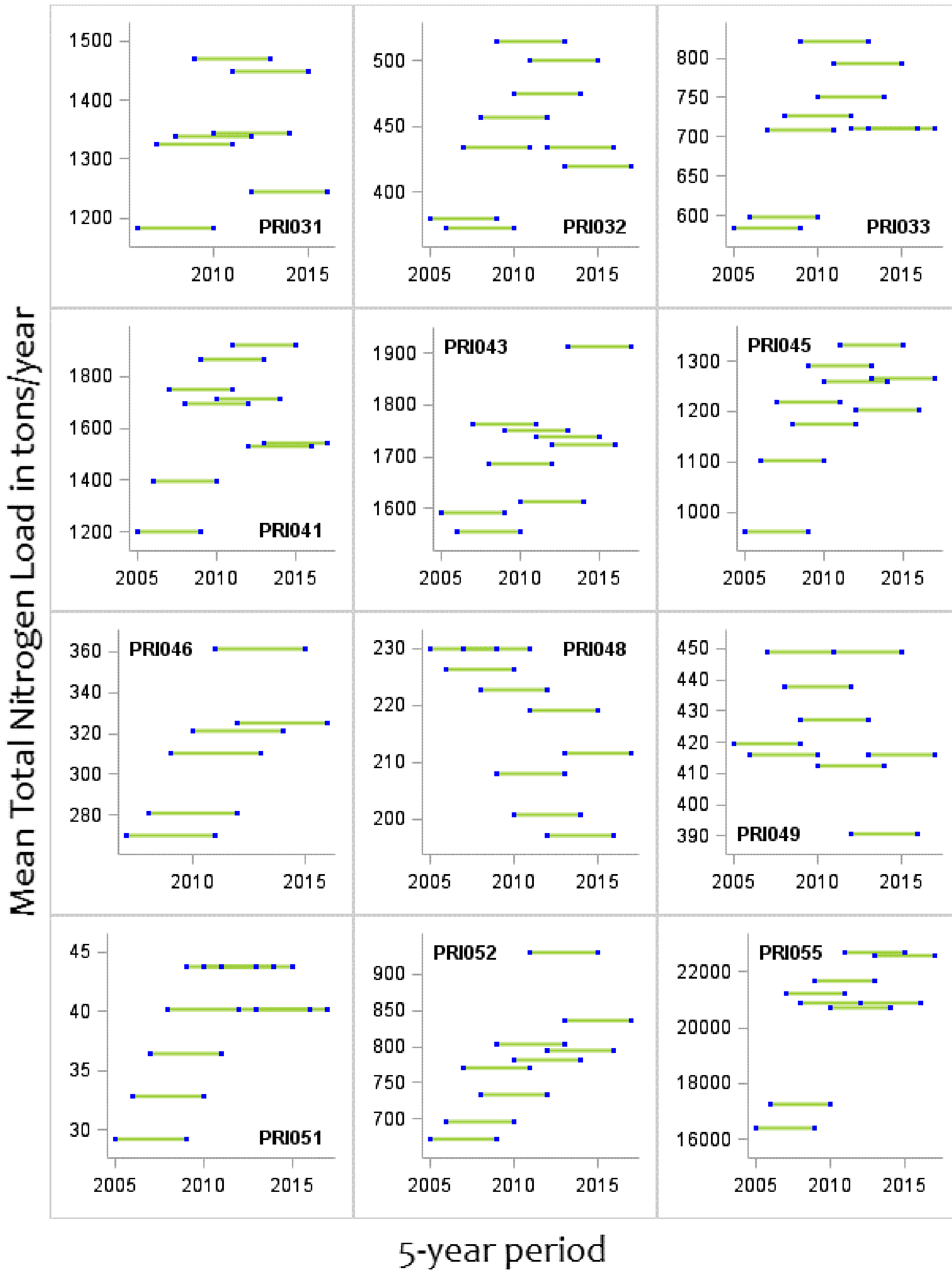
Station	Total phosphorus regression equations	R2 (percent)	Estimated residual variance
	Salt, Licking		
PRI029	$5.38 + 1.19\ Ln(Q) + 0.09\ Ln(Q)^2 + 0.22\ Sin(2\pi dt) + 0.4\ Cos(2\pi dt)$	95	0.120
PRI041	$1.8 + 1.14\ Ln(Q) + 0.02\ Ln(Q)^2 + 0.46\ Sin(2\pi dt) - 0.14\ Cos(2\pi dt)$	97	0.176
PRI052	$3.61 + 1.15\ Ln(Q) + 0.03\ Ln(Q)^2 - 0.11\ Sin(2\pi dt) - 0.37\ Cos(2\pi dt)$	96	0.141
PRI057	$0.62 + 1.03\ Ln(Q) + 0.03\ Ln(Q)^2 + 0.49\ Sin(2\pi dt) + 0.33\ Cos(2\pi dt) - 0.04(dt) - 0.01(dt)^2$	97	0.293
PRI059	$3.89 + 1.35\ Ln(Q) + 0.07\ Ln(Q)^2 + 0.45\ Sin(2\pi dt) + 0.27\ Cos(2\pi dt)$	97	0.222
PRI060	$0.95 + 1.21\ Ln(Q) + 0.05\ Ln(Q)^2 + 0.57\ Sin(2\pi dt) - 0.03\ Cos(2\pi dt) + 0.02(dt)$	98	0.210
PRI061	$4.89 + 1.4\ Ln(Q) + 0.11\ Ln(Q)^2 + 0.47\ Sin(2\pi dt) + 0.39\ Cos(2\pi dt)$	86	0.517
PRI062	$1.86 + 1.09\ Ln(Q) - 0.07(dt)$	79	0.677
PRI063	$-0.58 + 1.41\ Ln(Q) + 0.76\ Sin(2\pi dt) - 0.15\ Cos(2\pi dt) - 0.1(dt)$	75	1.017
PRI093	$0.57 + 1.08\ Ln(Q) + 0\ Ln(Q)^2 + 0.6\ Sin(2\pi dt) - 0.02\ Cos(2\pi dt) - 0.01(dt) + 0.01(dt)^2$	91	0.264
PRI100	$3.63 + 1.21\ Ln(Q) + 0.11\ Ln(Q)^2 + 0.36\ Sin(2\pi dt) + 0.44\ Cos(2\pi dt) - 0.03(dt)$	86	0.306
PRI105	$1.96 + 1.22\ Ln(Q) + 0.01\ Ln(Q)^2 + 0.48\ Sin(2\pi dt) + 0.03\ Cos(2\pi dt)$	95	0.290
PRI111	$5.59 + 1.52\ Ln(Q) + 0.13\ Ln(Q)^2 + 0.54\ Sin(2\pi dt) - 0.03\ Cos(2\pi dt)$	92	0.398
	Tradewater, Green		
PRI012	$1.38 + 1.03\ Ln(Q)$	95	0.331
PRI014	$4.45 + 1.3\ Ln(Q) + 0.42\ Sin(2\pi dt) - 0.21\ Cos(2\pi dt) - 0.38(dt)$	86	0.422
PRI018	$4.73 + 1.59\ Ln(Q) + 0.32\ Sin(2\pi dt) + 0.45\ Cos(2\pi dt) - 0.04(dt)$	89	0.374
PRI021	$4.43 + 0.98\ Ln(Q) + 0.19\ Ln(Q)^2 + 0.27\ Sin(2\pi dt) + 0.3\ Cos(2\pi dt) - 0.04(dt) - 0.01(dt)^2$	81	0.241
PRI054	$4.58 + 1.26\ Ln(Q) + 0.44\ Sin(2\pi dt) + 0.36\ Cos(2\pi dt) - 0.36(dt)$	88	0.395
PRI055	$6.05 + 1.37\ Ln(Q) + 0.05\ Ln(Q)^2 + 0.17\ Sin(2\pi dt) + 0.21\ Cos(2\pi dt) - 0.03(dt) + 0.01(dt)^2$	96	0.106
PRI056	$3.34 + 1.22\ Ln(Q) + 0.03\ Ln(Q)^2 - 0.19\ Sin(2\pi dt) - 0.03\ Cos(2\pi dt) + 0(dt) - 0.04(dt)^2$	97	0.117
PRI072	$4.82 + 1.12\ Ln(Q) - 0.06\ Sin(2\pi dt) + 0.19\ Cos(2\pi dt) - 0.05(dt)$	90	0.169
PRI077	$2.06 + 1.37\ Ln(Q) + 0.09\ Ln(Q)^2 + 0.37\ Sin(2\pi dt) + 0.68\ Cos(2\pi dt)$	89	0.374
PRI103	$5.55 + 1.33\ Ln(Q) - 0.22\ Sin(2\pi dt) + 0.3\ Cos(2\pi dt) - 0.07(dt)$	83	0.365
PRI112	$2.16 + 1.01\ Ln(Q) + -0.01\ Ln(Q)^2 + 0.04\ Sin(2\pi dt) + 0.21\ Cos(2\pi dt) - 0.02(dt)$	97	0.178
PRI113	$1.44 + 1.22\ Ln(Q) + -0.12\ Sin(2\pi dt) + 0.3\ Cos(2\pi dt)$	97	0.318

Load bias estimate exceeds threshold, do not use model.

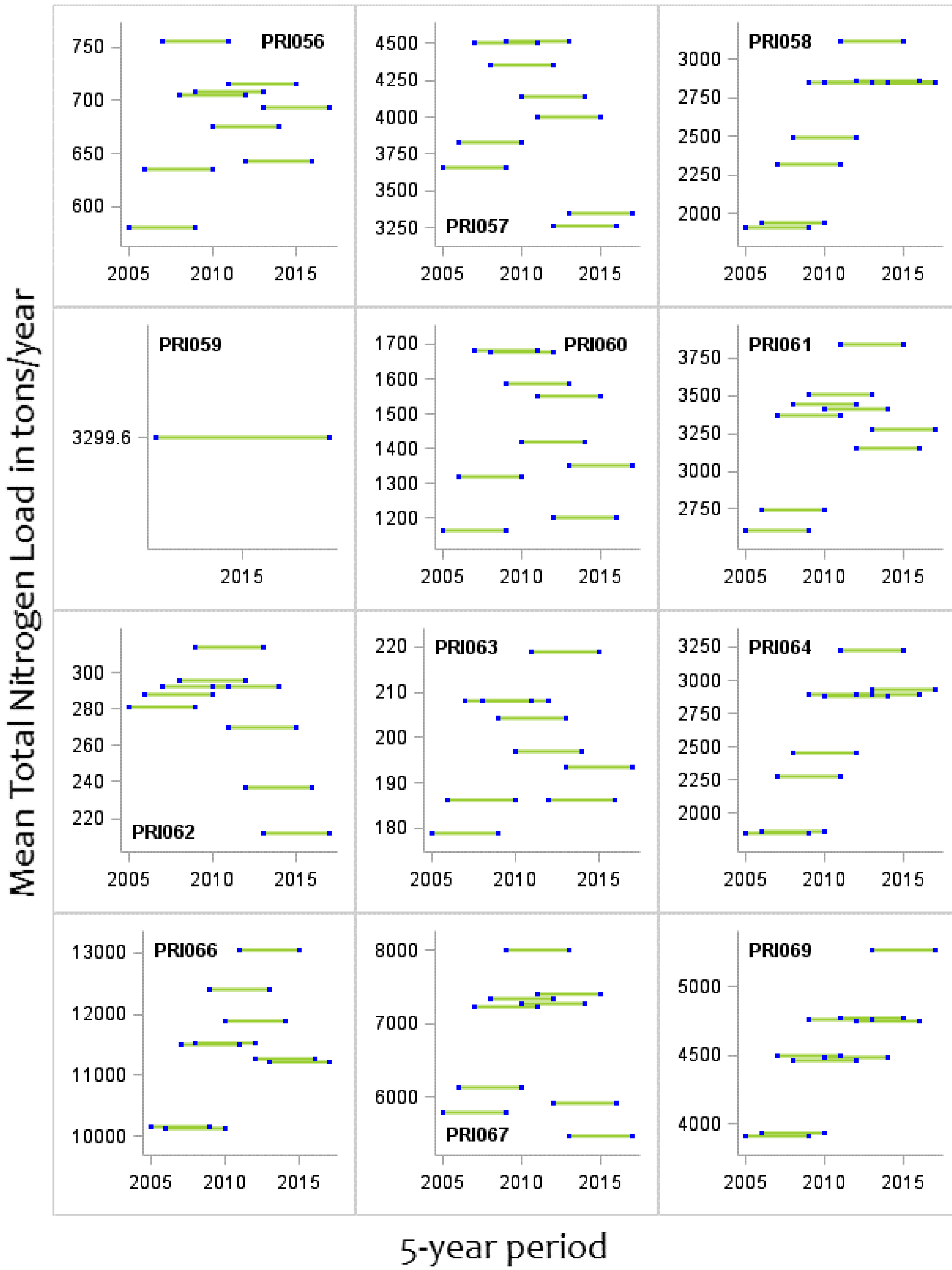
Appendix 3: Rolling 5-Year Average Loads and Yields

Figure 11. Mean 5-year averages for total nitrogen averages at each monitoring station.

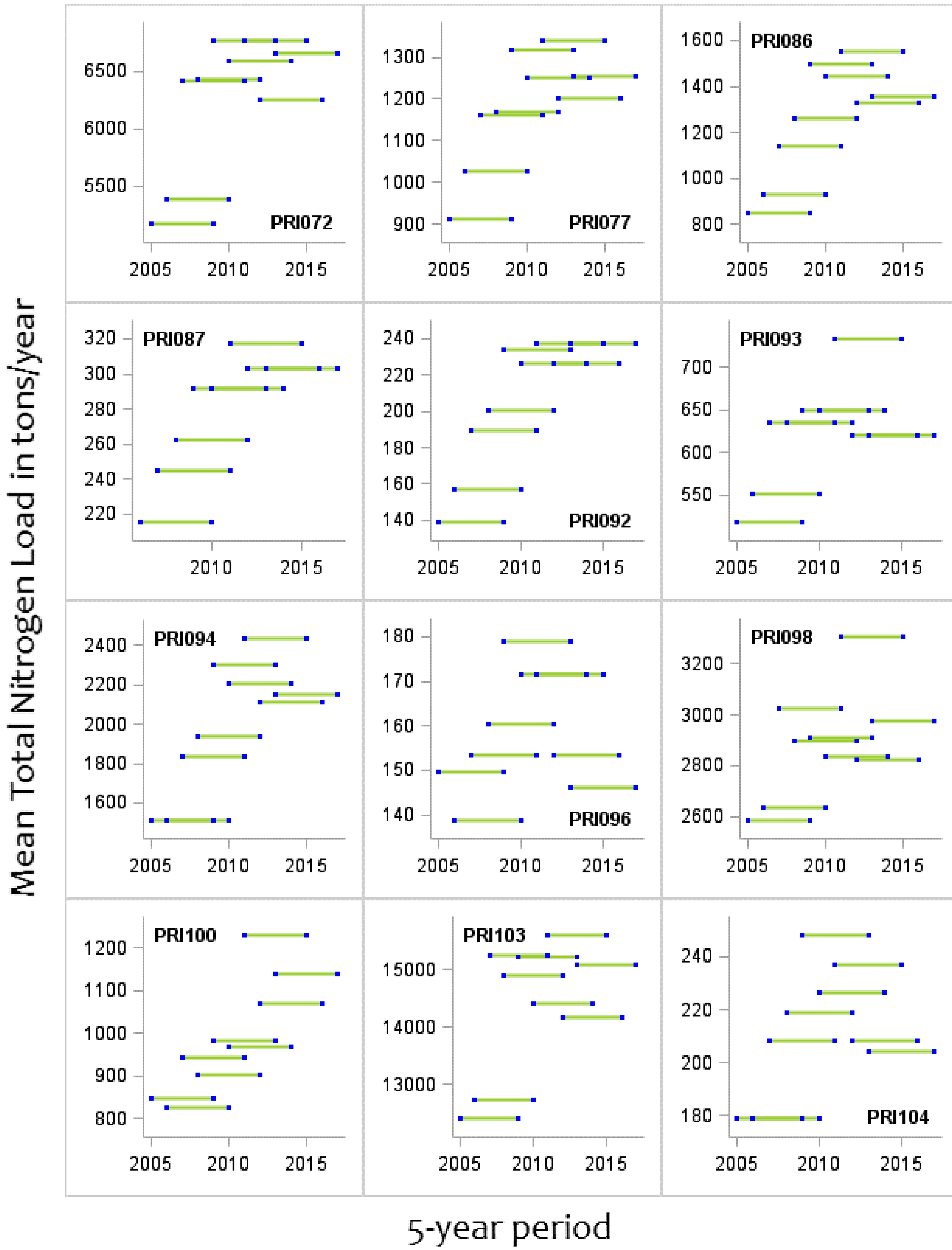




Mean Total Nitrogen Load in tons/year
PRI031
PRI032
PRI033
PRI041
PRI043
PRI045
PRI046
PRI048
PRI049
PRI051
PRI052
PRI055
5-year period



Mean Total Nitrogen Load in tons/year
PRI056
750
700
650
600
2005
2010
2015
PRI057
4500
4250
4000
3750
3500
3250
PRI058
3000
2750
2500
2250
2000
PRI059
3299.6
PRI060
1700
1600
1500
1400
1300
1200
PRI061
3750
3500
3250
3000
2750
PRI062
300
280
260
240
220
PRI063
220
210
200
190
180
PRI064
3250
3000
2750
2500
2250
2000
PRI066
13000
12000
11000
10000
PRI067
8000
7000
6000
PRI069
5000
4500
4000
5-year period


Mean Total Nitrogen Load in tons/year
PRI072
PRI077
PRI086
PRI087
PRI092
PRI093
PRI094
PRI096
PRI098
PRI100
PRI103
PRI104
5-year period

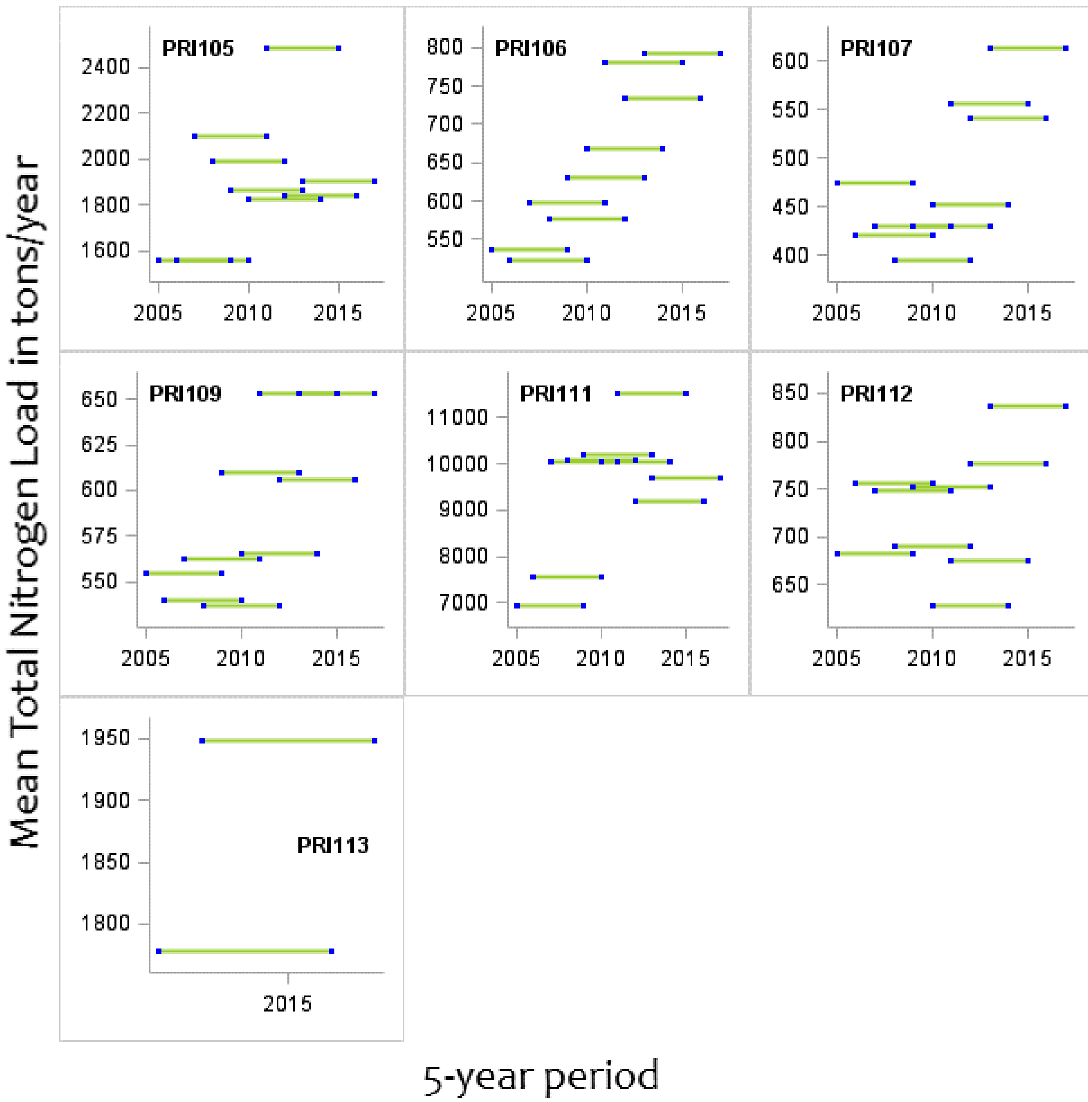
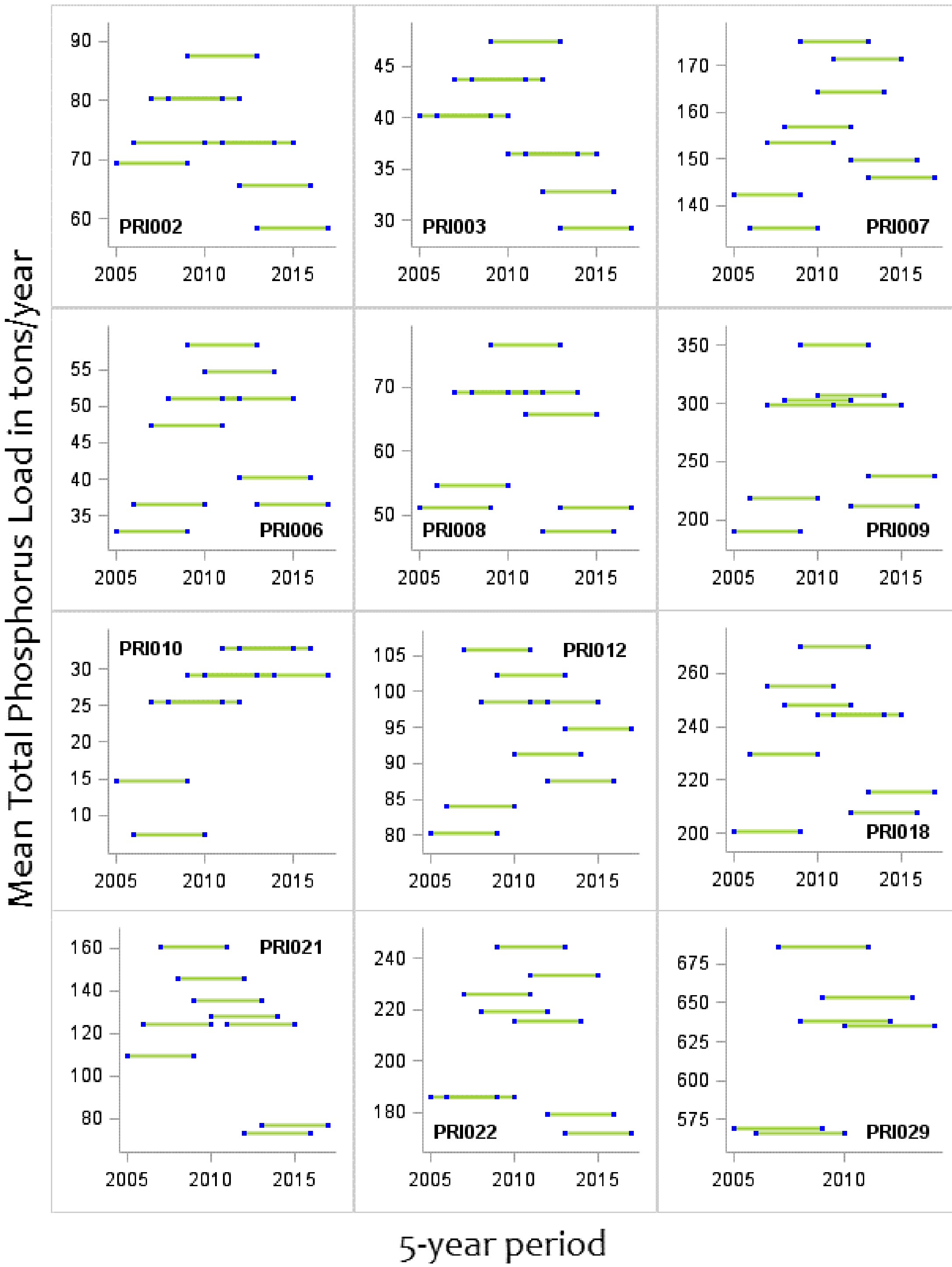
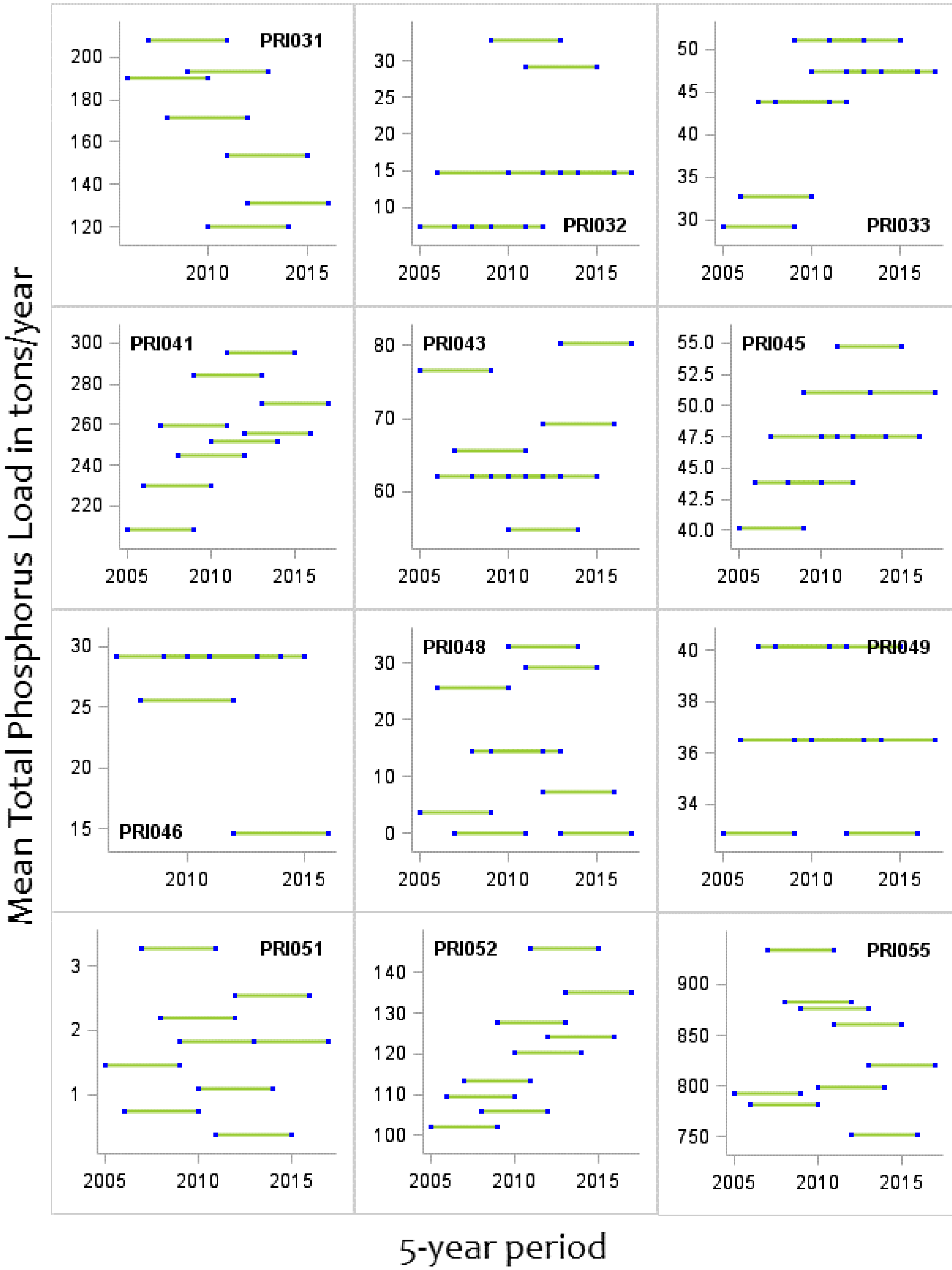
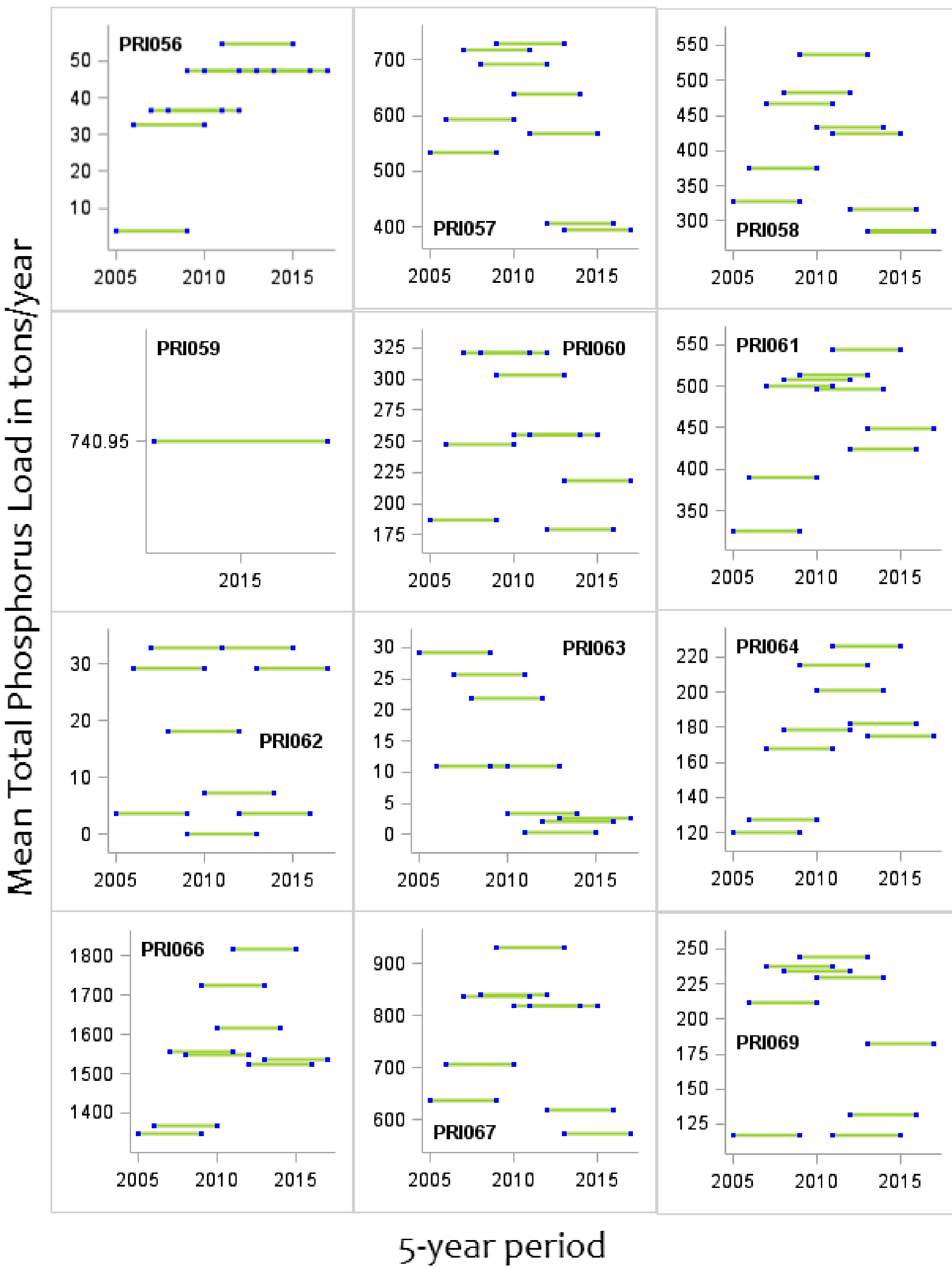

Mean Total Nitrogen Load in tons/year
PRI105
PRI106
PRI107
PRI109
PRI111
PRI112
PRI113
5-year period

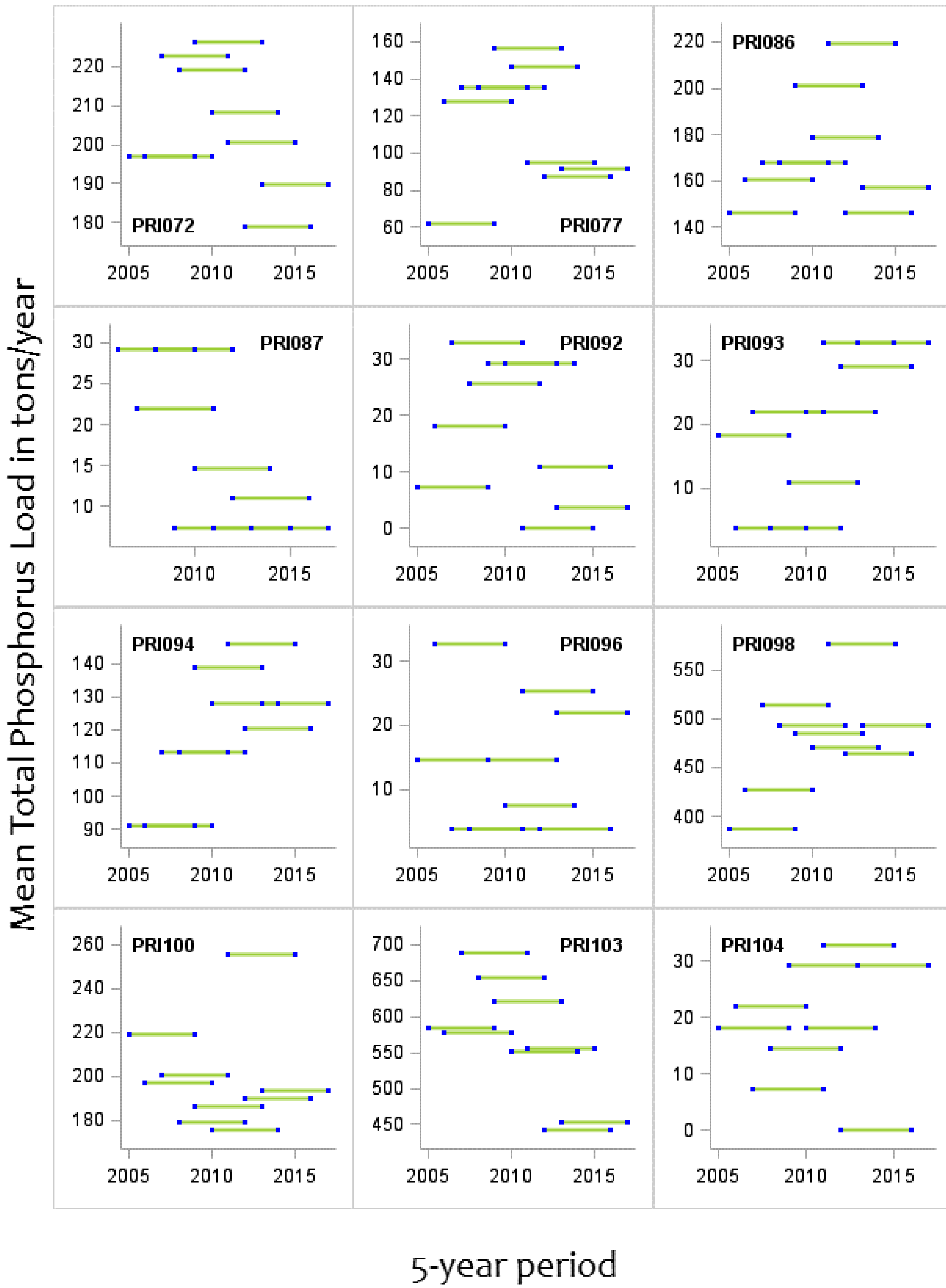
Figure 12. Mean 5-year averages for total phosphorus averages at each monitoring station.

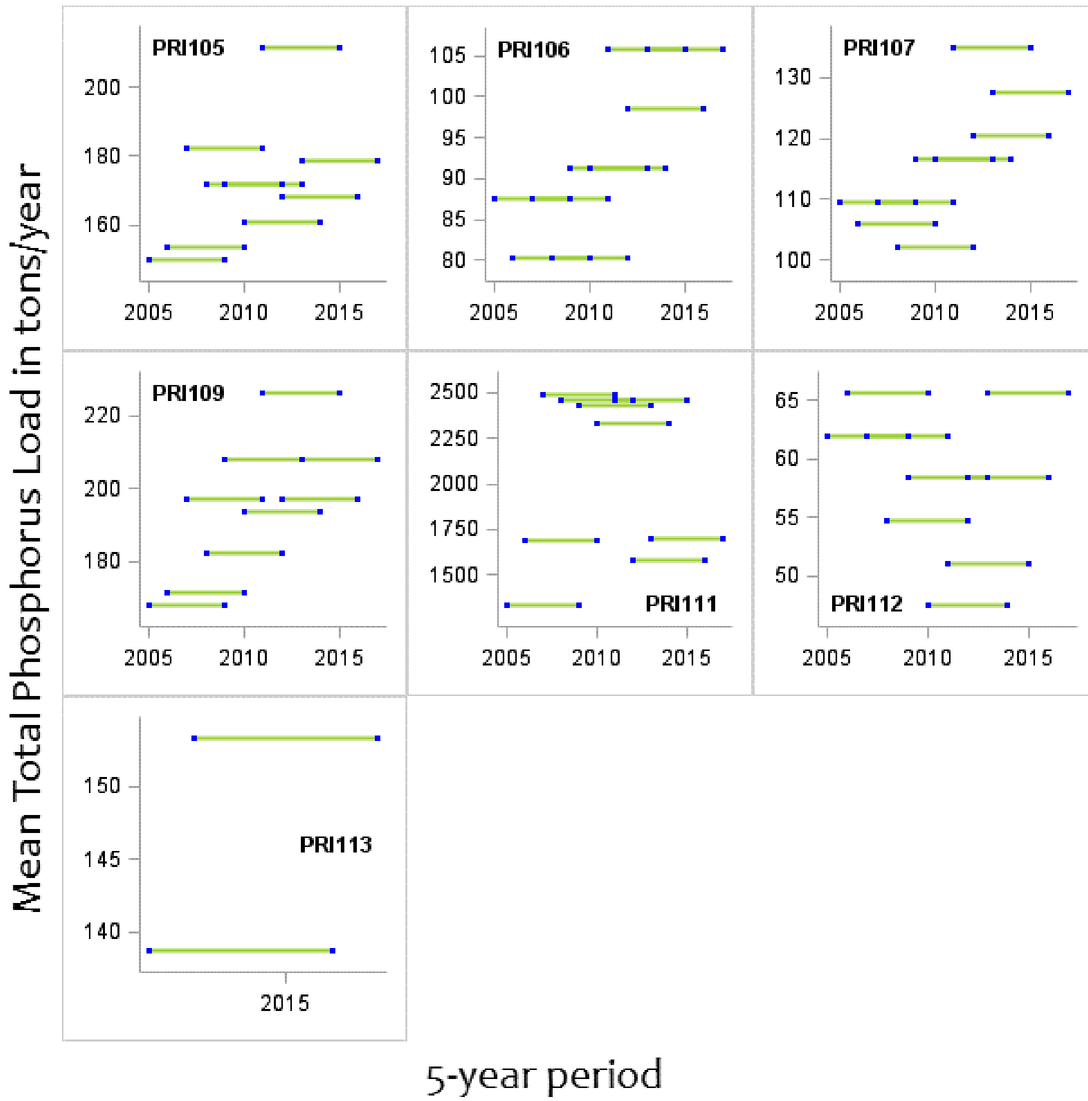




Mean Total Phosphorus Load in tons/year
PRI031
PRI032
PRI033
PRI041
PRI043
PRI045
PRI046
PRI048
PRI049
PRI051
PRI052
PRI055
5-year period


Mean Total Phosphorus Load in tons/year
PRI056
PRI057
PRI058
PRI059
PRI060
PRI061
PRI062
PRI063
PRI064
PRI066
PRI067
PRI069
740.95
5-year period


Mean Total Phosphorus Load in tons/year
PRI072
PRI077
PRI086
PRI087
PRI092
PRI093
PRI094
PRI096
PRI098
PRI100
PRI103
PRI104
5-year period



Mean Total Phosphorus Load in tons/year
PRI105
200
180
160
2005
2010
2015
PRI106
105
100
95
90
85
80
2005
2010
2015
PRI107
130
120
110
100
2005
2010
2015
PRI109
220
200
180
2005
2010
2015
2500
2250
2000
1750
1500
PRI111
2005
2010
2015
65
60
55
50
PRI112
2005
2010
2015
150
PRI113
145
140
2015
5-year period