Update to the 2019 Nutrient Loads and Yields in Kentucky Study

Study period extended: 2005 – 2019

Includes five additional ORSANCO stations measuring contributions from major Ohio River tributaries

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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 the Commonwealth's total nutrient contribution to the Gulf of Mexico, and plays a key role in the Commonwealth's Nutrient Reduction Strategy. Analyzing loads and yields at these and other monitoring stations informs progress towards meeting goals and warns of areas that may need more attention.

This update to *Nutrient Loads and Yields in Kentucky: 2005-2017* (Chan, 2019), or "the 2019 Study" (original located here), examines the same 57 monitoring stations, with two additional years of data (2018 and 2019). The Ohio River Sanitation Commission (ORSANCO) has long-term monitoring stations at several major Ohio River tributaries. This update includes five monitoring sites representing contributions of these major river catchments: the Big Sandy, Cumberland, Green, Licking, and Tennessee Rivers. The addition of these stations moves us closer to understanding the total contribution of nutrients to the Gulf that originate in or flow through Kentucky.

Data Collection and Analysis

This update employed the same methods outlined in the 2019 Study for data screening, total nitrogen calculation, discharge estimation, and load and yield estimation. Please refer to the 2019 Study for these methods. ORSANCO supplied the data for the five additional monitoring stations (Ohio River Valley Water Sanitiation Commission, 2020).

A few changes are noted. Two monitoring stations, PRI069 and PRI107, were moved slightly for safety reasons during the 2019 Study. These stations are identified as PRI069-1 and PRI107-1 to reflect updated station identifications and locations.

The contributing catchments of the additional ORSANCO monitoring stations were delineated by StreamStats (USGS, 2017), where possible. The StreamStats tool has a national interface, but functions as a state-by-state composite of delineation and estimation equations. Where StreamStats did not delineate a contributing catchment due to multistate coverage, DOW evaluated catchment drainage by combining contributing hydrologic units and editing in GIS to reflect catchment topology.

For station and discharge details on the ORSANCO stations, see **Table 1**. For all other stations, please refer to Tables 1 and 4 of the 2019 Study. Dam discharge data were obtained from the Tennessee Valley Authority or the U.S. Army Corps of Engineers, depending on dam management responsibility.

Table 1. ORSANCO monitoring station identification and discharge source data.

ORSANCO Station	ORSANCO Station Name	USGS stream-gaging stations used for discharge	Drainage Area (mi^2)	Latitude	Longitude
Major Tributaries to the Ohio					
OSR20.3M	Big Sandy R at Louisa	03212500 03214500	3894	38.17111	-82.63472
OLR-4.5M	Licking R at Covington	03254520 03253500	3702	39.05139	-84.49500
OGR41.3M	Green R at Sebree	03320000 03316500	8638	37.64415	-87.49797
OCR16.0M	Cumberland R at Pinkneyville	Barkley Dam discharge	17,833	37.18556	-88.23944
OTR-5.0M	Tennessee R at Paducah	Kentucky Dam discharge	40,388	37.04028	-88.53389

In this update, DOW initially looked at the relationship between precipitation and loading. Annual precipitation totals were obtained from nine NOAA meteorological stations (NOAA: National Centers for Environmental Information, n.d.) representing the drainage area in the study. See Appendix 2: Precipitation Data for details.

Results and Discussion

Update to the 2019 Study

Tabular results of loads and yields can be found in Appendix 1, while **Figure 1** visualizes these results. The addition of two years of data reinforced the general trends found in the 2019 Study: that nutrient yields were greater in those parts of Kentucky with higher percentages of agriculture land uses (see **Figure 2** and **Figure 3**). The eastern part of the state, with relatively little agriculture had the lowest nutrient loads, while the Bluegrass region (north central Kentucky) has a higher portion of animal agriculture and higher levels of naturally-occurring phosphorus with moderately high nutrient levels. The Jackson Purchase region, to the west, has the highest proportion of row cropland cover, which is reflected in the yields.

Figure 1. Updated loads and yields.

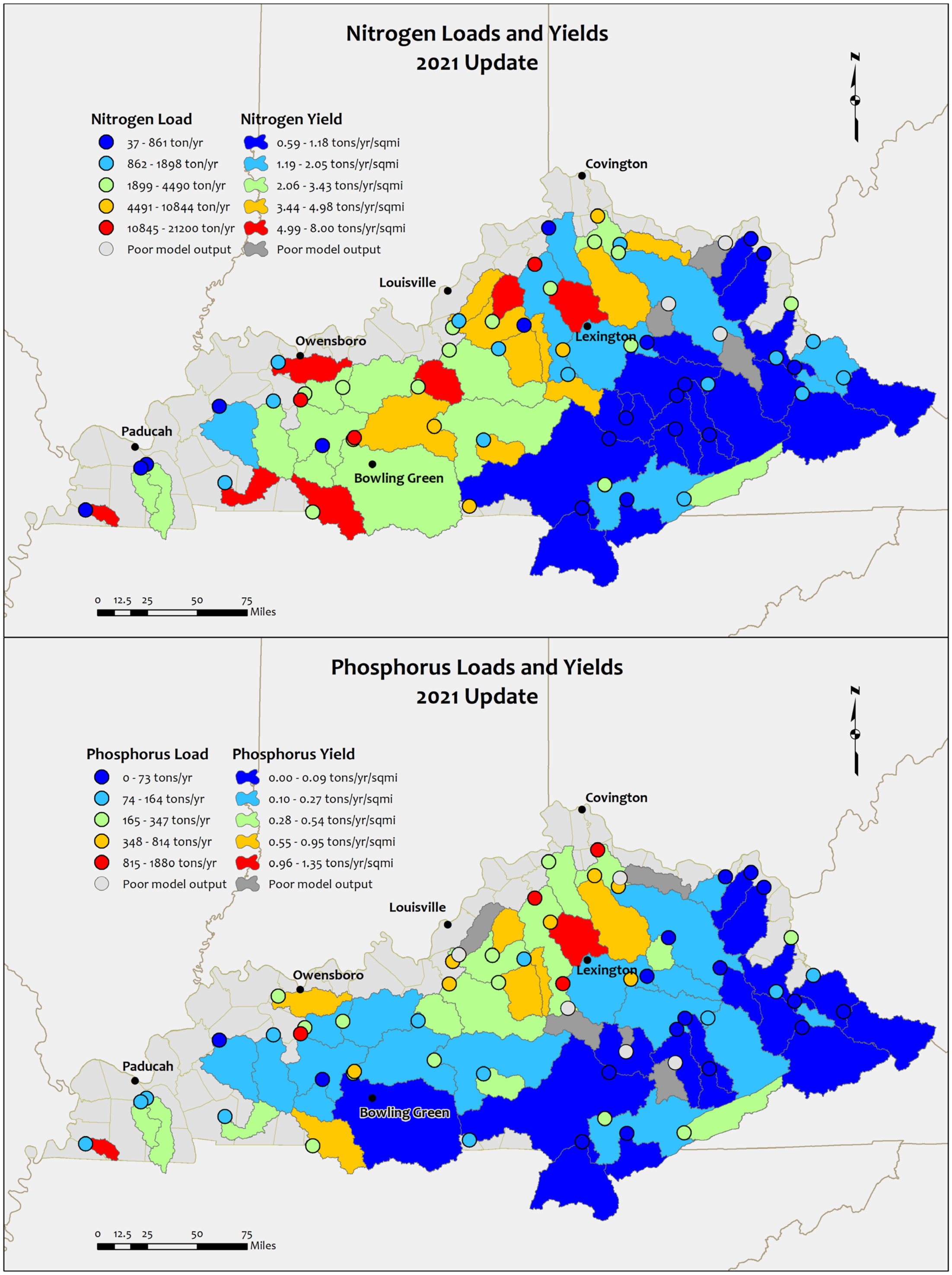


Figure 2. Nitrogen yield as a percentage of land cover class.

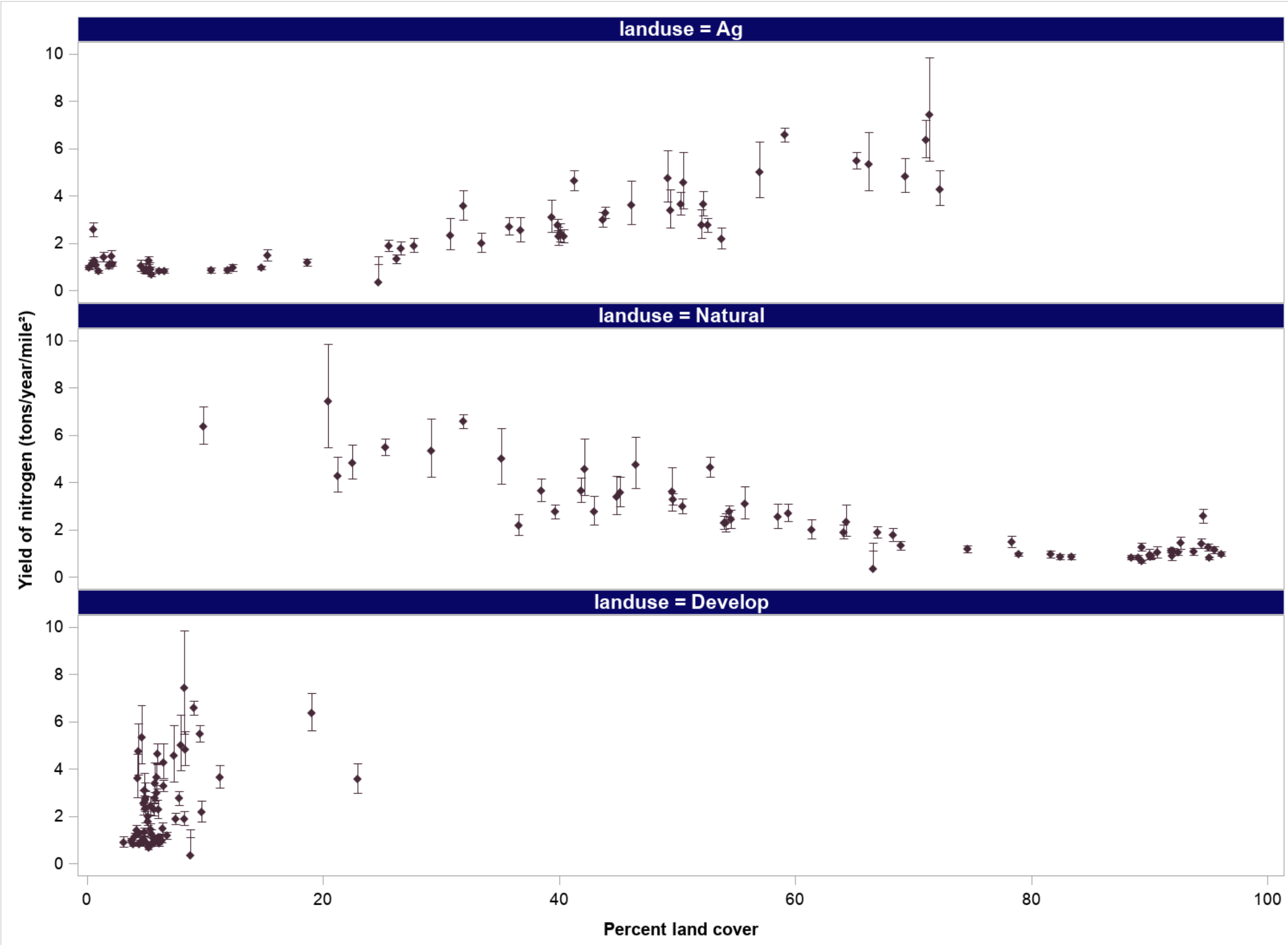
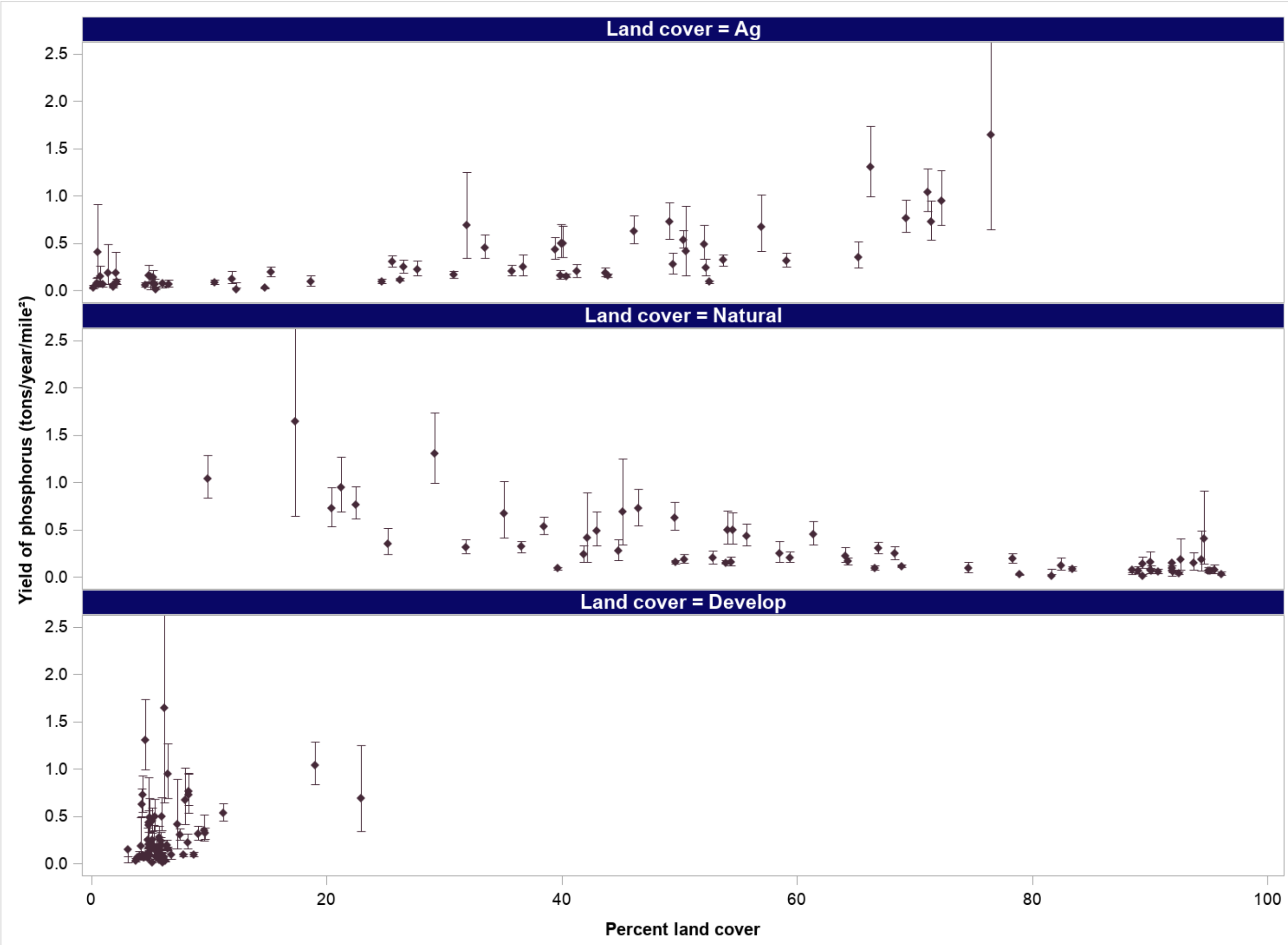


Figure 3. Phosphorus yield as a percentage of land cover class.



Statistically, more data helps reduce variability and tighten confidence intervals. This update found an increase in the number of nutrient load estimates with a poor model fit (**Table 2**), a decrease in the association between land use and nitrogen yields with widening of the confidence interval (**Table 3** and **Figure 4**), and stronger trends when looking at 5-year rolling averages (**Table 4**). While the association between agricultural land use and nutrient loads is still evident, more frequent, intense precipitation events also appear to affect loads. Interestingly, the association between land use and phosphorus yields increased (**Table 3** and **Figure 5**) while the confidence intervals remained unaffected.

Table 2. Comparison of the number of stations and analytes with poor model fit.

Analyte	2019 Study	Update
Nitrogen	0 Stations	3 Stations
Phosphorus	2 Stations	5 Stations

Table 3.The variability explained by land use (R^2 value) has decreased for total nitrogen.

	2019 Study				Update without ORSANCO stations				Update with ORSANCO stations			
Land Use	Total nitrogen		Total phosphorus		Total nitrogen		Total phosphorus		Total nitrogen		Total phosphorus	
	R^2	p-value	R^2	p-value	R^2	p-value	R^2	p-value	R^2	p-value	R^2	p-value
Agriculture	0.75	<0.0001	0.42	<0.0001	0.46	<0.0001	0.56	<0.0001	0.45	<0.0001	0.55	<0.0001
Natural	0.74	<0.0001	0.44	<0.0001	0.45	<0.0001	0.57	<0.0001	0.44	<0.0001	0.55	<0.0001
Developed	0.14	<0.0057	0.14	<0.0046	0.06	<0.0726	0.13	<0.0057	0.05	<0.0775	0.12	<0.0058

The LOADEST program flags load estimates that are less accurate than taking the mean of the data (i.e., poor model fit) (Runkel, 2004). The increased number of stations with poor model fit indicates that some station measurements deviated in 2018 and 2019 from prior years (see **Figure 4**, **Figure 5**). One possible source of variation is a change in precipitation patterns. **Figure 6** compares the top three years of loading at each monitoring station (for nitrogen (a) and phosphorus (b)), and the top three annual precipitation totals for nine representative weather stations. The figure indicates that more monitoring stations had their top three highest annual loads in 2011, 2018 and 2019 than in any of the other years. Therefore, adding two of the highest loading years (2018 and 2019) to the 2019 Study increased study variability.

The National Oceanic and Atmospheric Administration (NOAA) projects that the “number and intensity of heavy precipitation events” during winter and spring in Kentucky will increase over the next few decades (Runkle, Kunkel, Champion, Frankson, & Stewart, 2017). Continued monitoring and analysis over time will clarify whether the increased loading, and its relationship to precipitation, are outliers or a new pattern.

Figure 4. The regressions for land use and yield for nitrogen, comparing the update with the 2019 Study. Note the widening of the confidence interval in the update regressions.

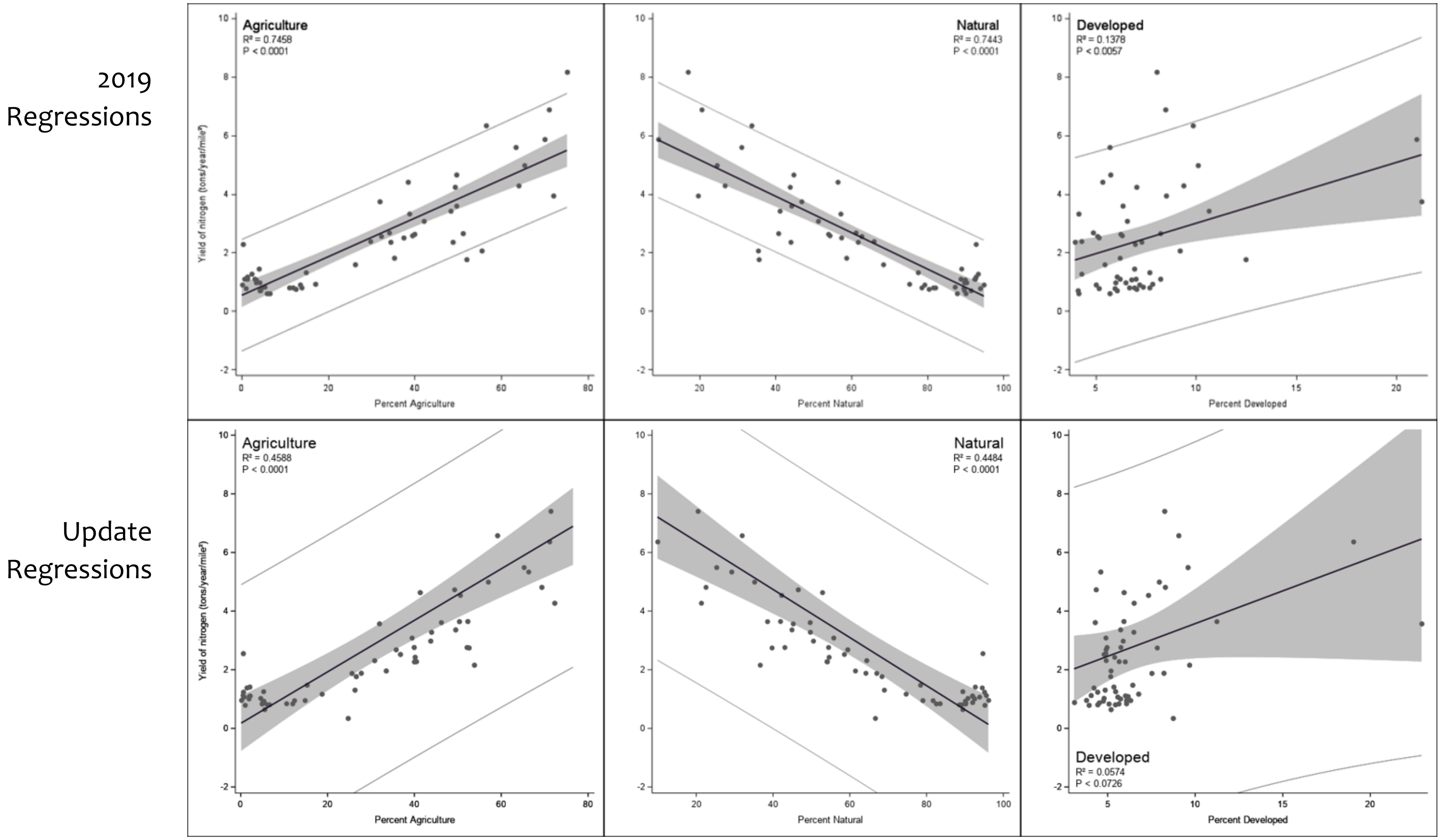


Figure 5. The regressions for land use and yield for phosphorus; the update compared to the 2019 Study.

2019 Regressions

Update Regressions

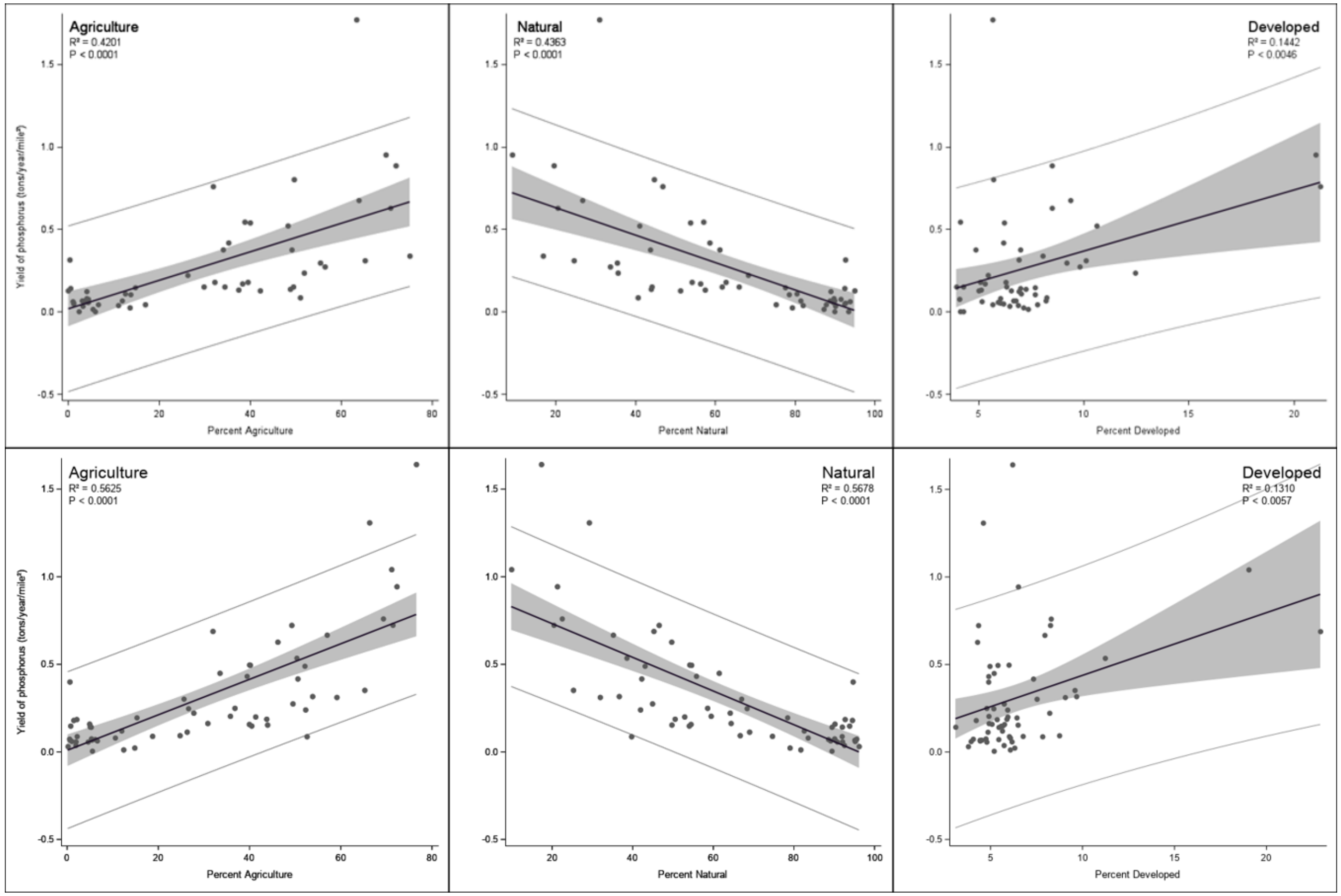
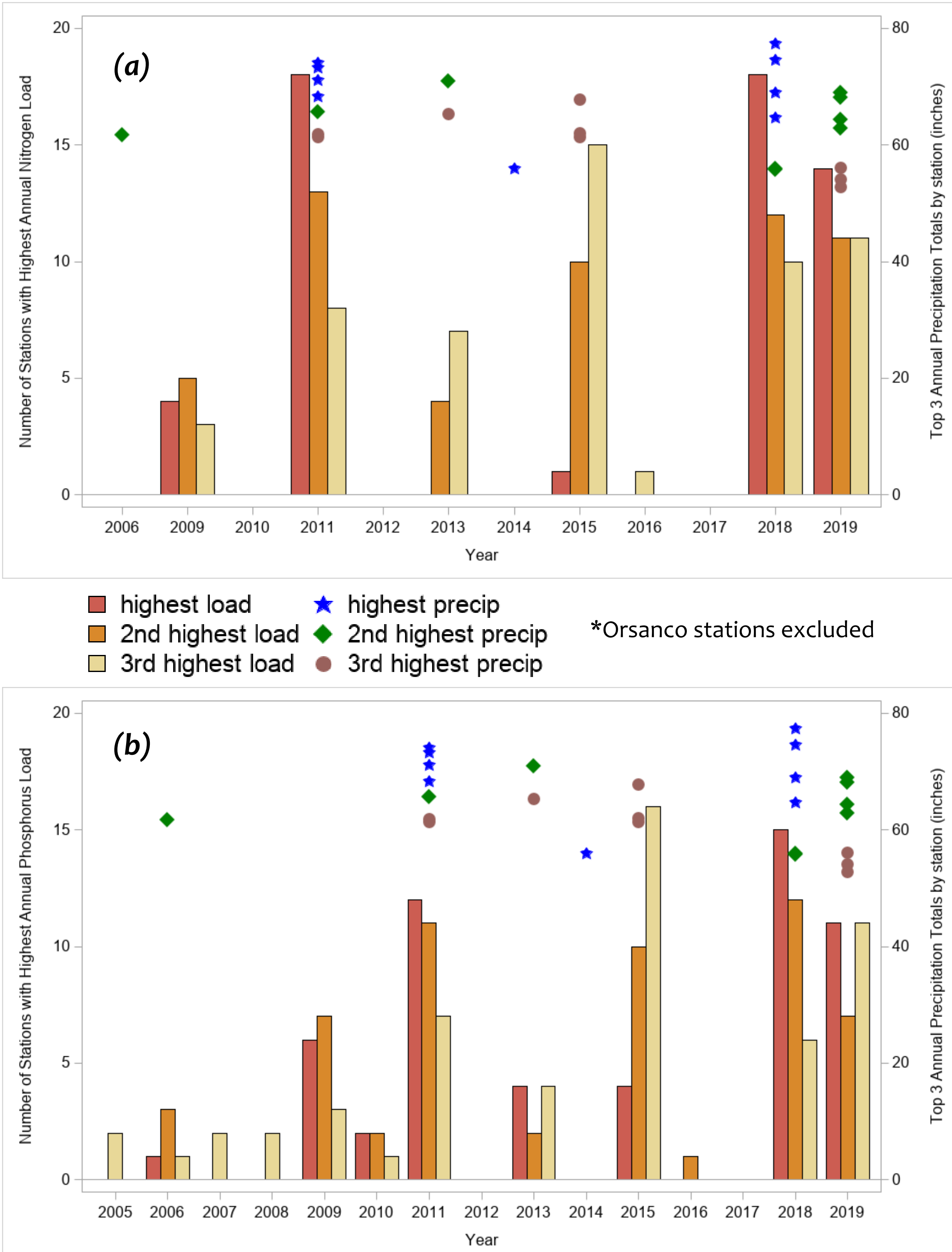


*Figure 6. The three highest years for (**a**) nitrogen and (**b**) phosphorus loads for each monitoring station, and highest three annual precipitation totals for each of the nine weather stations across the 15-year study period.*



Rolling 5-year averages

Weather cycles create variability in nutrient loading from year to year. A consistent record over time allows generation of 5-year rolling average loads and yields to mitigate annual variability. This update calculated eleven, 5-year mean loads for stations with a complete record (**Appendix 3: Rolling 5-Year Average Loads**).

The 2019 Study showed a significant increasing trend for nitrogen, but no trend for phosphorus. This update shows significant increases in both nitrogen and phosphorus yields at stations across the state (**Table 4**). The increase in slope for nitrogen indicates a stronger increase in yield over time. For phosphorus, the increase in slope and widening of the confidence interval, while moving to trend significance, indicates that higher yields in 2018 and 2019 varied enough from previous years to affect trends for the entire study.

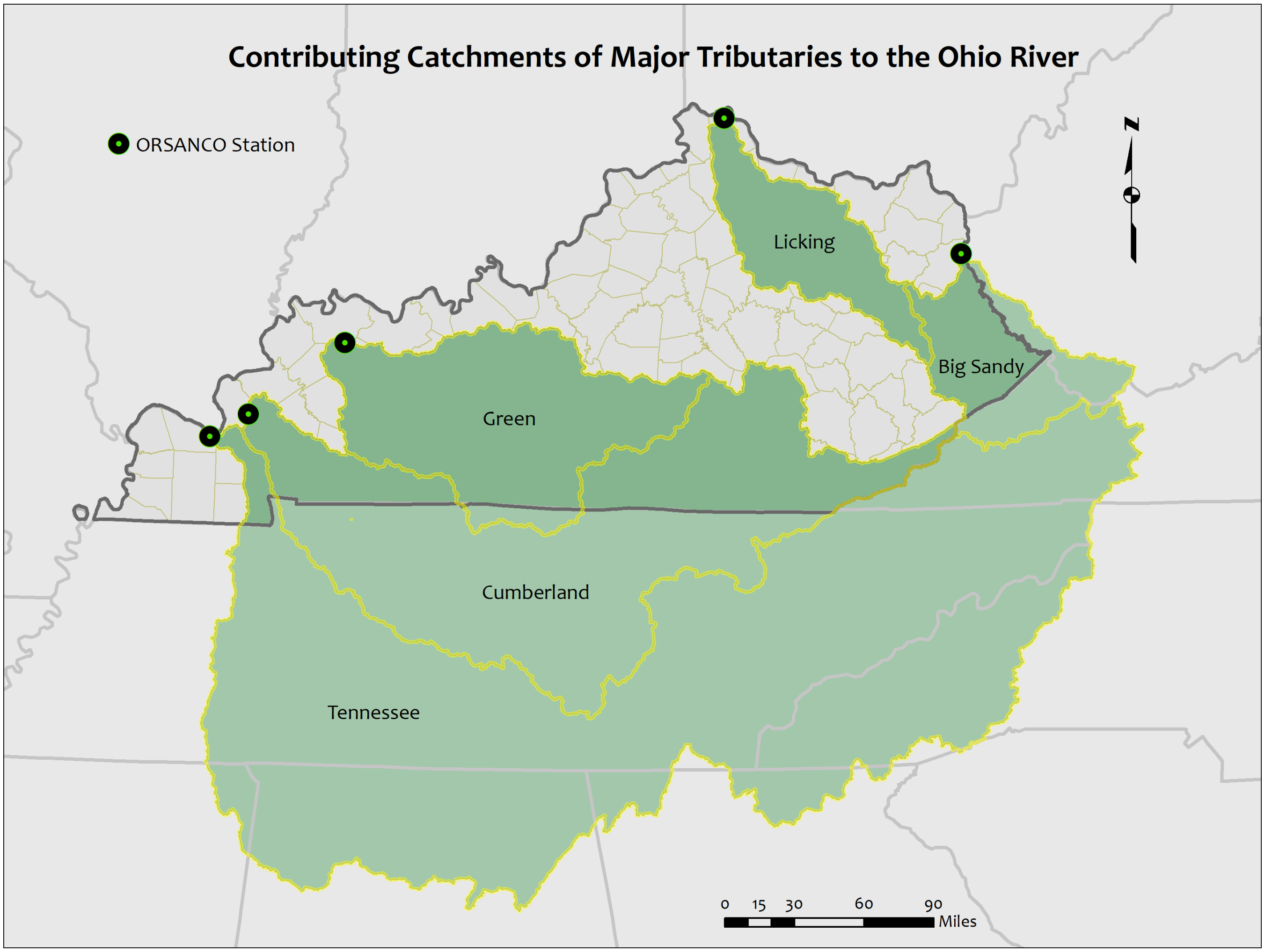
Table 4. Mean and confidence interval of regression parameters for 5-year rolling yields at all ambient monitoring stations, statewide. If the confidence interval of the slope does not cross zero, the trend is significant.

	DOW Stations 2005 - 2017			DOW Stations 2005 - 2019			DOW & ORSANCO Stations 2005-2019 / 2010-2019		
Regression parameter	lower 95% CI	mean	upper 95% CI	lower 95% CI	mean	upper 95% CI	lower 95% CI	mean	upper 95% CI
	Total Nitrogen			Total Nitrogen			Total Nitrogen		
slope	0.043	0.064	0.085	0.053	0.083	0.112	0.046	0.076	0.105
intercept	-168.4	-125.8	-83.2	-222.1	-163.5	-104.9	-208.7	-149.4	-90.1
R^2	0.37	0.44	0.52	0.41	0.49	0.57	0.41	0.49	0.56
	Total Phosphorus			Total Phosphorus			Total Phosphorus		
slope	-0.001	0.003	0.006	0.002	0.009	0.017	0.002	0.009	0.017
intercept	-11.6	-5.1	1.4	-34.2	-18.5	-2.8	-33.2	-18.7	-4.2
R^2	0.21	0.28	0.35	0.30	0.38	0.47	0.32	0.40	0.48

Major Tributaries to the Ohio

In addition to analyzing DOW station data, this update evaluates data from ORSANCO's bimonthly monitoring program near the mouths of major Ohio River tributaries (**Figure 7**). ORSANCO stations differ from DOW stations primarily in the size of their contributing catchments. The DOW stations range from 62 to 6423 square miles, with a median catchment area of 536 square miles. The ORSANCO stations range from 3702 to 40,388 square miles, with a median of 8638 square miles. The larger ORSANCO catchments may encompass several different physiographic regions, reflecting more varied land use within a larger area (**Figure 7**). As such, these stations are less helpful in determining priority areas for targeted mitigation measures, but more helpful in characterizing larger-scale nutrient loading trends.

Figure 7. ORSANCO monitoring stations with contributing catchments.



Nutrient Sources

The association between station nutrient loads, yields, and land use observed in the 2019 Study, was also observed at some ORSANCO stations in this update (see **Table 5**, **Figure 7**). Green River yields reflect the agricultural nature of the contributing watershed, with the highest agricultural land use (43%) among ORSANCO monitored catchments (**Table 6**). Higher yields in the Licking River watershed reflect the sizeable pastureland, and phosphorus-rich geology found in the Bluegrass physiographic region. Conversely, the Big Sandy watershed is primarily forested (87%), with negligible agriculture and lower nutrient loads and yields.

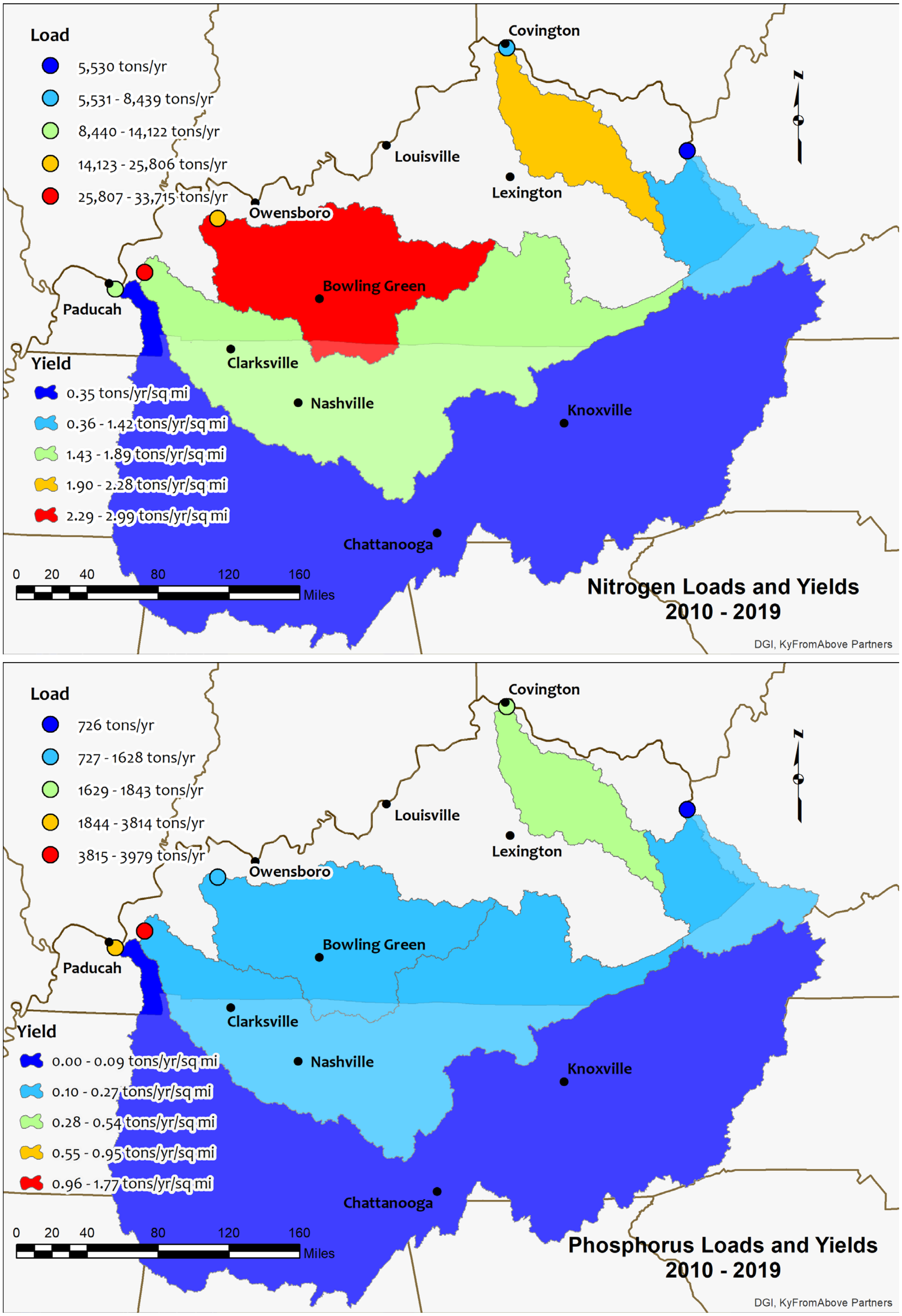
Table 5. Loads and yields for ORSANCO stations.

Station ID	River	Period of record	Drainage Area (mi²)	Estimated mean annual load		Estimated mean annual yield		Prediction error	
				total nitrogen	phosphorus	total nitrogen	phosphorus	total nitrogen	phosphorus
				(ton/yr)(+/-SEP)		(ton/yr)/mi²		(percent)	
Major Tributaries to the Ohio River									
OCR16.0M	Cumberland	2010-2019	17,833	33715(3E3)	3979(701)	1.89	0.22	8	18
OGR41.3M	Green	2010-2019	8638	25806(1E3)	1628(197)	2.99	0.19	5	12
OLR-4.5M	Licking	2010-2019	3702	8439(708)	1843(332)	2.28	0.5	8	18
OSR20.3M	Big Sandy	2010-2019	3894	5530(482)	726(336)	1.42	0.19	9	46
OTR-5.0M	Tennessee	2010-2019	40,388	14122(3E3)	3814(471)	0.35	0.09	24	12

Table 6. Land cover and use for ORSANCO stations.

Station ID	River	Drainage Area (mi²)	Percent land cover in 2016						
			Pasture/Hay	Row Crop	Total Agriculture	Forested	Wetlands	Natural	Developed
Major Tributaries to the Ohio River									
OCR16.0M	Cumberland	17,833	21.1	6.6	27.7	60	0.45	64	8.2
OGR41.3M	Green	8638	30.7	13	43.7	47	1.27	50	5.9
OLR-4.5M	Licking	3702	38.6	1.4	39.9	53	0.06	54	6
OSR20.3M	Big Sandy	3894	2	0	2	87	0.01	93	5.3
OTR-5.0M	Tennessee	40,388	21.2	3.4	24.7	59	1.68	67	8.7

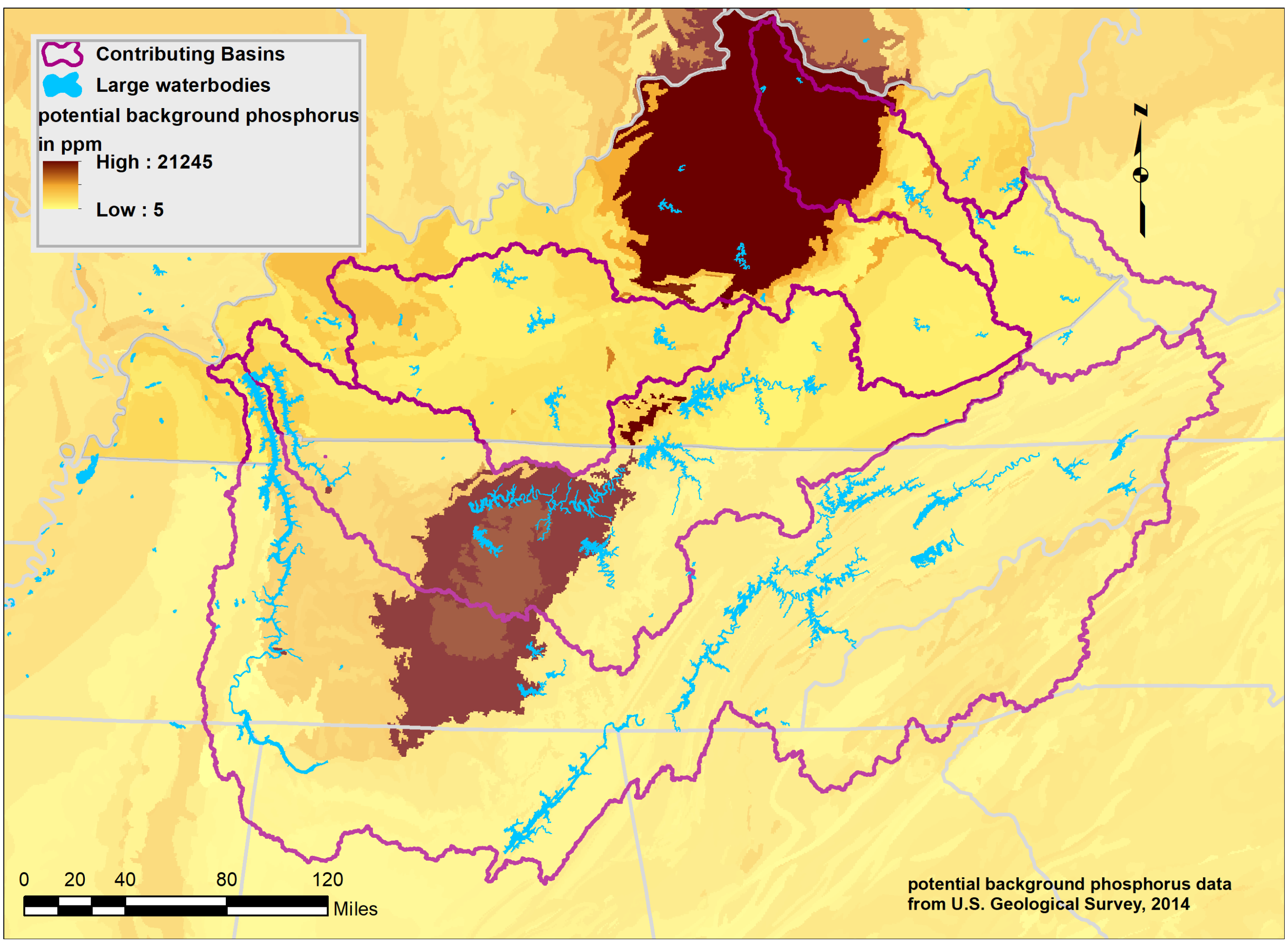
Figure 8. Nitrogen and phosphorus loads and yields for ORSANCO stations and contributing catchments.



The ORSANCO monitored drainage catchments for the Tennessee and Cumberland Rivers are largely outside Kentucky, but flow to dams in Kentucky just before meeting the Ohio River. Compared with other ORSANCO stations, the size and contributing land use in the Tennessee and Cumberland River catchments suggests that substantial nutrient removal occurs at Kentucky dams (**Table 5** and **Table 6**).

While both catchments fall within three percentage points of each other for agricultural land use, the nitrogen load estimates for the Tennessee River are less than half that of the Cumberland River, despite having a much larger drainage area. However, both phosphorus load estimates for the rivers are roughly the same. One possible explanation is that monitoring samples are taken below the dams, and pool size influences nutrient loads. The Kentucky dam on the Tennessee River creates a substantially larger pool, covering 160,000+ acres (Tennessee Valley Authority, n.d.). In contrast, Lake Barkley dam on the Cumberland River covers 57,900 acres at summer pool (US Army Corps of Engineers, n.d.). Phosphorus is removed more efficiently than nitrogen in dammed waters (Maavara, et al., 2020). Both of these monitoring locations have contributing catchments that include an area of potentially high natural phosphorus levels from geochemical weathering (U.S. Geological Survey, 2014) as shown in **Figure 9**. Additional data are needed on nutrient contributions from the Tennessee portions of these catchments before the impacts of reservoir nutrient removal can be ascertained.

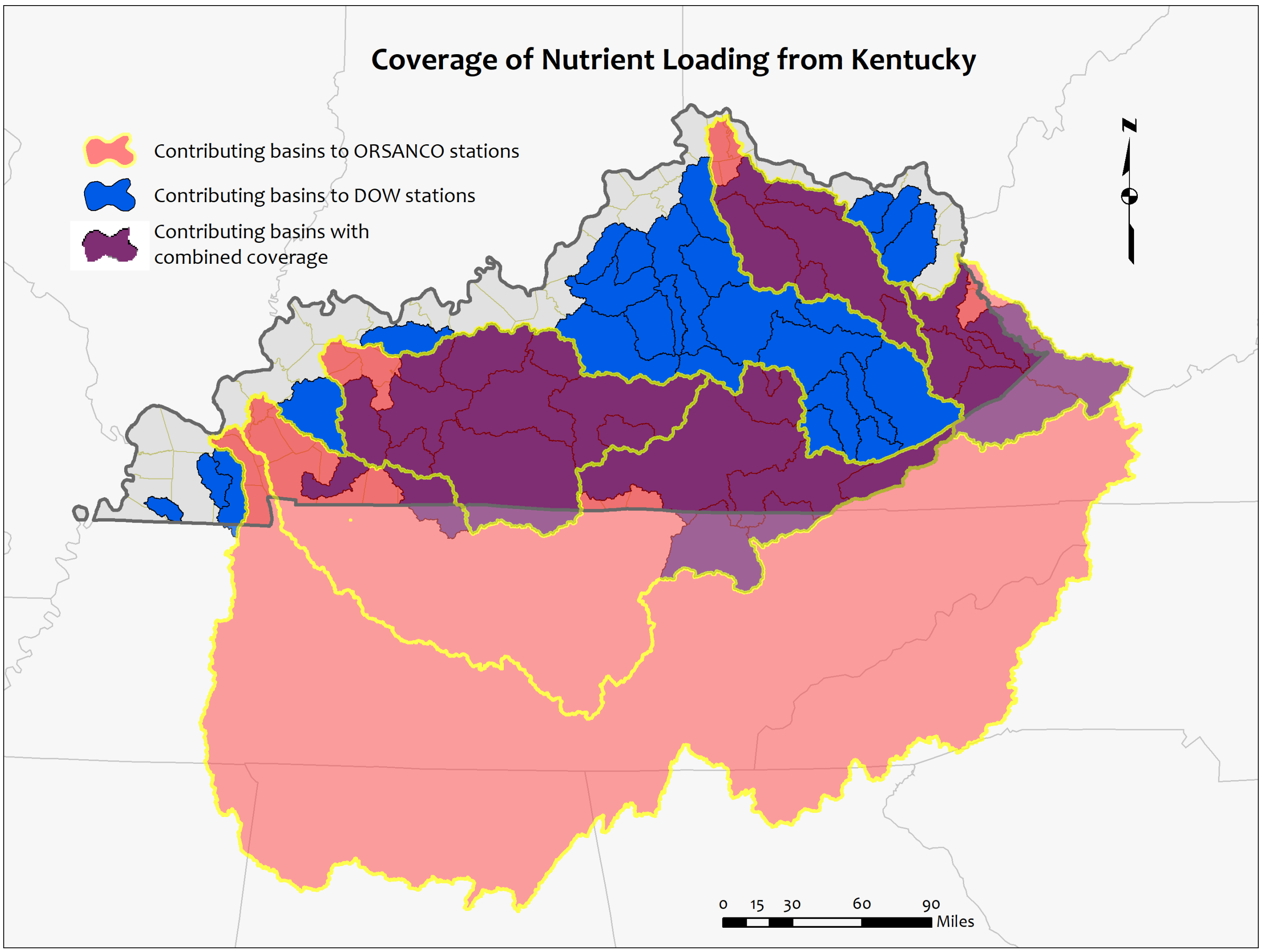
Figure 9. Potential background phosphorus due to underlying geochemistry in the major river catchments flowing through Kentucky.



Total Contribution of Nutrients

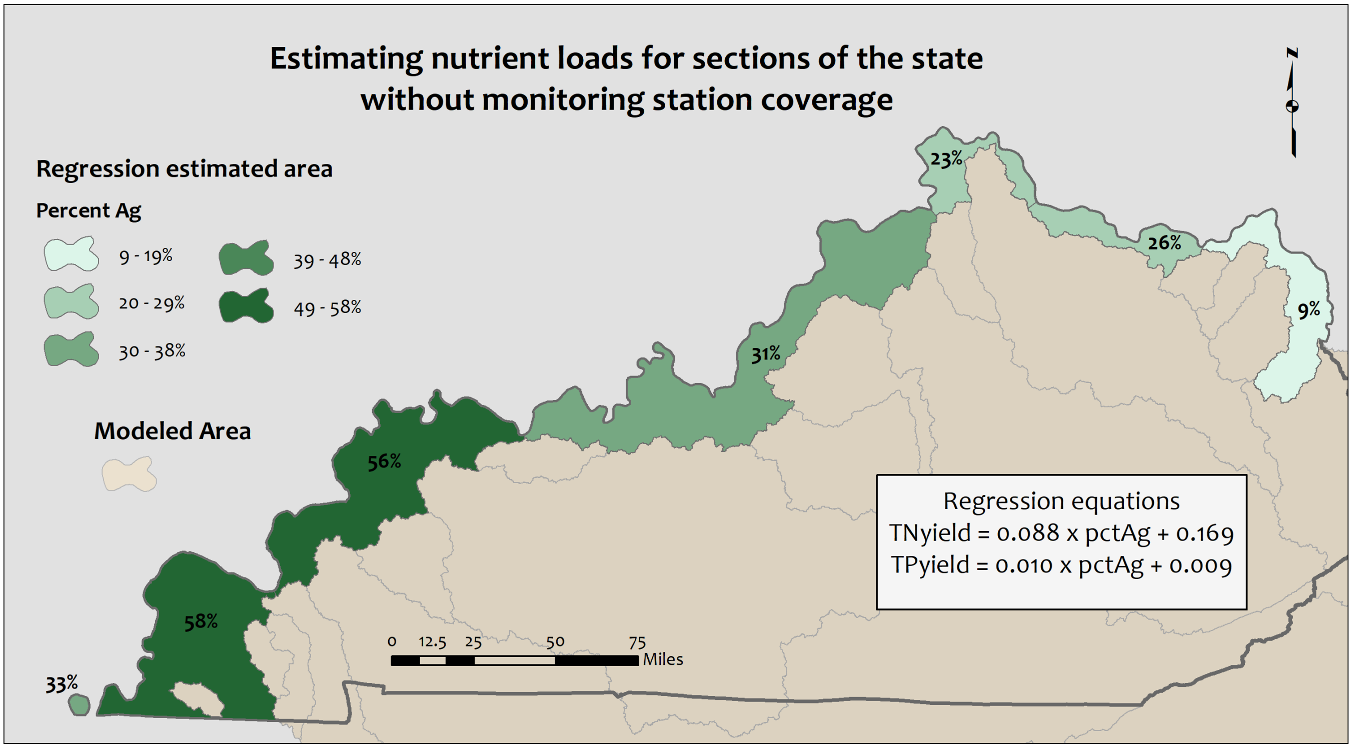
The inclusion of the ORSANCO monitoring stations seeks to determine the total load of nutrients that leave Kentucky and eventually enter the Gulf of Mexico. The state falls completely within the Mississippi River Basin. Ongoing long-term nutrient monitoring at all major tributaries into the Ohio and Mississippi Rivers provides the most cost-effective and sustainable framework to make that determination. This update seeks to improve that estimation by merging the larger ORSANCO catchments with DOW's smaller catchments. The combination of the two networks accounts for 82% of Kentucky's drainage area, while including loads from other states flowing through Kentucky (**Figure 10**). Remaining spatial gaps include areas in far western Kentucky that drain directly into the Mississippi River, and catchments lining the Ohio River, which tend to be smaller.

Figure 10. Combining ORSANCO and DOW station contributing catchments covers 82% of the state's area.



Land use regression demonstrates that agriculture has the strongest relationship to nutrient loads (see **Figure 4**, **Figure 5**). Therefore, loads and yields in areas of the state without coverage were estimated by the regression equation between percent agriculture and total nitrogen and total phosphorus yields from DOW monitoring stations (see **Figure 11**). These estimates should be interpreted with caution. This area contains some of the most developed areas in the state, but the land use regressions in the 2019 Study and this update did not include areas with a high percentage of developed land. Assuming the relationship with agricultural land use drives loading without clear evidence of the relationship with developed land use is a weak association, so all conclusions should be drawn with caution.

Figure 11. Areas of the state without model coverage display percent agriculture.



The contribution of total nitrogen load leaving Kentucky was estimated by adding DOW loads, determined by the LOADEST model from non-overlapping contributing catchments, and adding the estimated ORSANCO loads to fill in spatial gaps (**Table 7**). This method does not take into account that some larger catchments, particularly the Cumberland and Tennessee Rivers that flow through the state, have large parts of their contributing catchments outside of state boundaries.

The Tennessee River catchment falls almost completely outside of Kentucky's borders, while roughly half the Cumberland River catchment is inside Kentucky. To estimate the contribution of nutrient loads originating from Kentucky, the loads from the Tennessee and Cumberland catchments were subtracted from the total, but the contributions from PRI043, PRI069-1, and PRI007 were added back in to represent Kentucky's portion of the Cumberland as shown in Figure 12. This process estimates a total annual nitrogen load of 104,830 tons/year from within Kentucky's borders, with an additional ~46,000 tons flowing through Kentucky. Phosphorus loads from within the state are almost 12,000 tons/year, with an additional ~7000 tons flowing into the state.

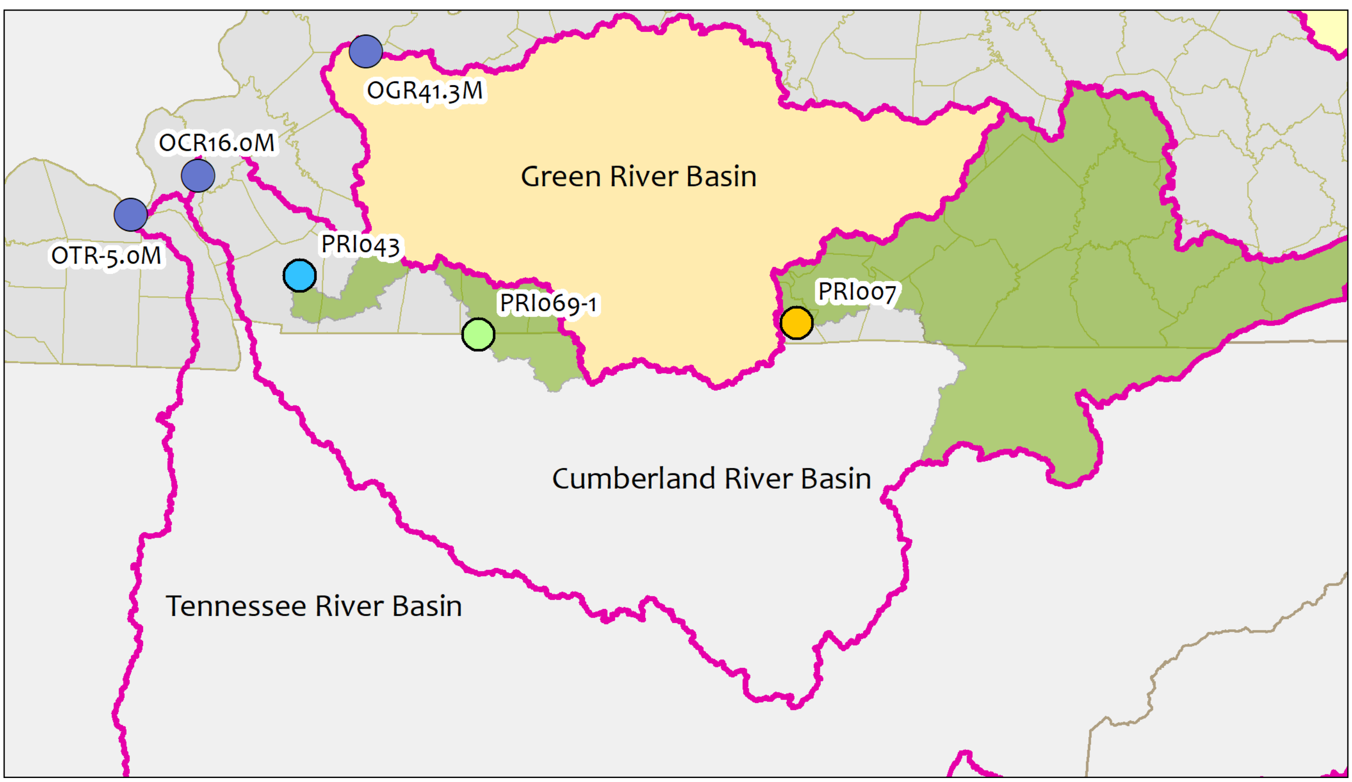
Table 7. Calculated loads from Kentucky.

	Total Nitrogen tons/yr	Total Phosphorus tons/yr
Modeled Load	114,061	16,019
Estimated Load	15,942	1,739
Total Load	130,003	17,758
Deduct Out-of-State Contributions		
Tennessee R	14,122	3,814
Cumberland R	21673	3438
Total Kentucky Load	**94,208**	**10,506**

	TN	TP
Total Cumberland	33715	3979
Cumberland in KY	12042	541
Out-of-State Cumberland	21673	3438

Note: "Total Load" indicates loads entering the Ohio and Mississippi Rivers from Kentucky, including nutrients flowing into the state. "Total Kentucky Load" is an estimate of load contributions from within Kentucky's borders.

Figure 12. Portions of the Cumberland catchment, in green, were added back into the Kentucky loading calculations.



Conclusions

This update to the 2019 Study provides insights and additional information into nutrient trends in Kentucky. The addition of two years of data shows an increase in variability, indicating a departure from the previous loading pattern. The rolling 5-year averages with the additional data show increased loading rates for both nitrogen and phosphorus. This increase corresponds to years with high precipitation. Future updates will determine whether this increased loading reflects a new trend or natural variation. Understanding the loads and yields of the 57 DOW monitoring stations improves resource prioritization to reduce nutrient loads, while continuing long-term monitoring to identify changing trends.

The additional five ORSANCO monitoring stations at the mouths of major Ohio River tributaries will help determine the total contribution of nutrients that flow from Kentucky into the Gulf of Mexico. Decision-makers seek to understand where the greatest loads originate in order to prioritize funding to the states, tribes, and territories for implementation of nutrient reduction strategies. The addition of these five monitoring stations moves us closer to answering that question.

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Appendix 1: Updated Mean Annual Loads and Yields

Station	Period of record	Drainage Area (mi^2)	Estimated mean annual load		Estimated mean annual yield		Prediction error	
			total nitrogen	phosphorus	total nitrogen	phosphorus	total nitrogen	phosphorus
			(ton/yr)(+/-SEP)		(ton/yr)/mi^2		(percent)	
Big and Little Sandy, Tygarts								
PRI002	2005-2019	1278	1591(95)	88(15)	1.25	0.07	6	17
PRI003	2005-2019	781	883(51)	58(18)	1.13	0.07	6	31
PRI006	2005-2019	1230	1248(55)	47(11)	1.01	0.04	4	23
PRI048	2005-2019	275	263(18)	4(4)	0.96	0.01	7	**
PRI049	2005-2019	539	460(33)	44(7)	0.85	0.08	7	17
PRI064	2005-2019	2323	2599(124)	208(33)	1.12	0.09	5	16
PRI094	2005-2019	1723	1887(110)	102(15)	1.10	0.06	6	14
PRI096	2005-2019	121	168(11)	22(15)	1.39	0.18	7	67
Four Rivers, Upper & Lower Cumberland								
PRI007	2005-2019	6245	5990(193)	150(11)	0.96	0.02	3	7
PRI008	2005-2019	964	785(47)	62(18)	0.81	0.06	6	29
PRI009	2005-2019	1976	2497(161)	281(62)	1.26	0.14	6	22
PRI010	2005-2019	604	712(44)	55(18)	1.18	0.09	6	33
PRI043	2005-2019	268	1767(40)	84(11)	6.58	0.31	2	13
PRI051	2005-2019	62	40(4)	0(0)*	0.65	0.01*	9	53
PRI069-1	2005-2019	550	4285(113)	307(135)	7.79	0.56	3	44
PRI086	2005-2019	519	1329(80)	208(106)	2.56	0.40	6	51
PRI087	2005-2019	370	325(18)	26(7)	0.88	0.07	6	29
PRI106	2005-2019	310	672(69)	99(11)	2.17	0.32	10	11
PRI107-1	2005-2019	186	515(58)	91(15)	2.77	0.49	11	16
PRI109	2005-2019	103	551(66)	135(18)	5.34	1.31	12	14

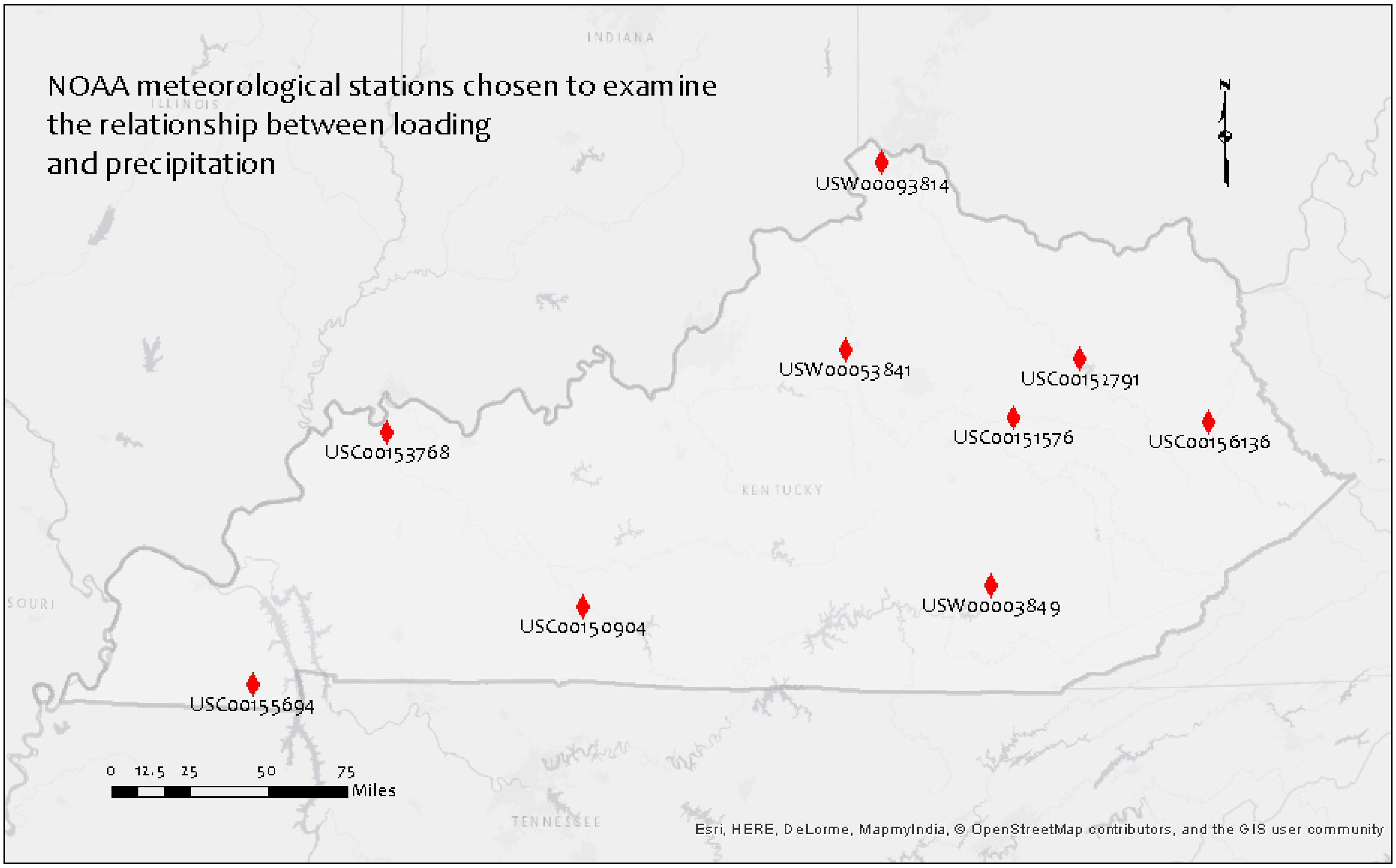
Station	Period of record	Drainage Area (mi²)	Estimated mean annual load		Estimated mean annual yield		Prediction error	
			total nitrogen	phosphorus	total nitrogen	phosphorus	total nitrogen	phosphorus
			(ton/yr)(+/-SEP)		(ton/yr)/mi²		(percent)	
Kentucky River								
PRI022	2005-2019	437	861(91)	197(29)	1.97	0.45	11	15
PRI031	2005-2019	1101	1186(84)	164(55)	1.08	0.15	7	33
PRI032	2005-2019	536	427(18)	33(3)	0.80	0.06	4	10
PRI033	2005-2019	692	715(84)	40(7)	1.03	0.06	12	18
PRI045	2005-2019	317	1161(84)	77(15)*	3.66	0.24*	7	19
PRI046	2006-2019	362	307(18)	44(11)	0.85	0.12	6	25
PRI058	2005-2019	3235	2723(153)	518(146)	0.84	0.16	6	28
PRI066	2005-2019	6178	11651(712)	1872(183)	1.89	0.30	6	10
PRI067	2005-2019	4588	6800(562)	902(117)	1.48	0.20	8	13
PRI092	2005-2019	251	204(11)	18(1)*	0.81	0.07*	5	7
PRI098	2005-2019	473	3011(193)	493(55)	6.37	1.04	6	11
PRI104	2005-2019	227	219(11)	7(2)	0.97	0.03	5	24
Salt, Licking								
PRI029	2005-2019	1197	4369(292)	642(55)	3.65	0.54	7	9
PRI041	2005-2019	436	1577(204)	274(33)	3.62	0.63	13	12
PRI052	2005-2019	173	832(62)	131(15)	4.82	0.76	7	11
PRI057	2005-2019	1374	4249(467)	595(84)	3.09	0.43	11	14
PRI059	2013-2019	838	3588(314)	792(124)	4.28	0.94	9	16
PRI060	2005-2019	287	1361(161)	208(29)*	4.74	0.72*	12	14
PRI061	2005-2019	1966	3493(266)	489(69)	1.78	0.25	8	14
PRI062	2005-2019	334	314(37)*	26(5)	0.94*	0.08	12	18
PRI063	2005-2019	229	204(26)*	33(4)	0.89*	0.14	13	11
PRI093	2005-2019	185	624(77)*	51(11)	3.37*	0.28	12	21
PRI100	2005-2019	259	927(84)	179(62)*	3.57	0.69*	9	35
PRI105	2005-2019	262	1942(296)	190(29)	7.41	0.72	15	15
PRI111	2005-2019	3375	8220(672)	1675(281)	2.44	0.50	8	17

Station	Period of record	Drainage Area (mi^2)	Estimated mean annual load		Estimated mean annual yield		Prediction error	
			total nitrogen	phosphorus	total nitrogen	phosphorus	total nitrogen	phosphorus
			(ton/yr)(+/-SEP)		(ton/yr)/mi²		(percent)	
Tradewater, Green								
PRI012	2005-2019	578	1343(193)	95(11)	2.32	0.16	14	12
PRI014	2014-2019	757	1916(204)	190(44)	2.53	0.25	11	23
PRI018	2005-2019	1680	4654(197)	266(40)	2.77	0.16	4	15
PRI021	2005-2019	351	1931(66)	124(26)	5.50	0.35	3	21
PRI054	2014-2019	1067	2873(201)	219(29)	2.69	0.21	7	13
PRI055	2005-2019	6423	21123(777)	996(69)	3.29	0.16	4	7
PRI056	2005-2019	268	613(40)	40(4)	2.29	0.15	7	9
PRI072	2005-2019	2264	6234(336)	201(15)	2.75	0.09	5	7
PRI077	2005-2019	262	1190(161)	110(51)	4.55	0.42	13	47
PRI103	2005-2019	3136	14556(657)	631(113)	4.64	0.20	5	18
PRI112	2005-2019	605	796(62)	69(4)	1.32	0.11	8	5
PRI113	2011-2019	372	1858(226)	248(58)	5	0.67	12	24
Major Tributaries to the Ohio River								
OCR16.0M	2010-2019	17833	33715(3E3)	3979(701)	1.89	0.22	8	18
OGR41.3M	2010-2019	8638	25806(1E3)	1628(197)	2.99	0.19	5	12
OLR-4.5M	2010-2019	3702	8439(708)	1843(332)	2.28	0.50	8	18
OSR20.3M	2010-2019	3894	5530(482)	726(336)	1.42	0.19	9	46
OTR-5.0M	2010-2019	40388	14122(3E3)	3814(471)	0.35	0.09	24	12

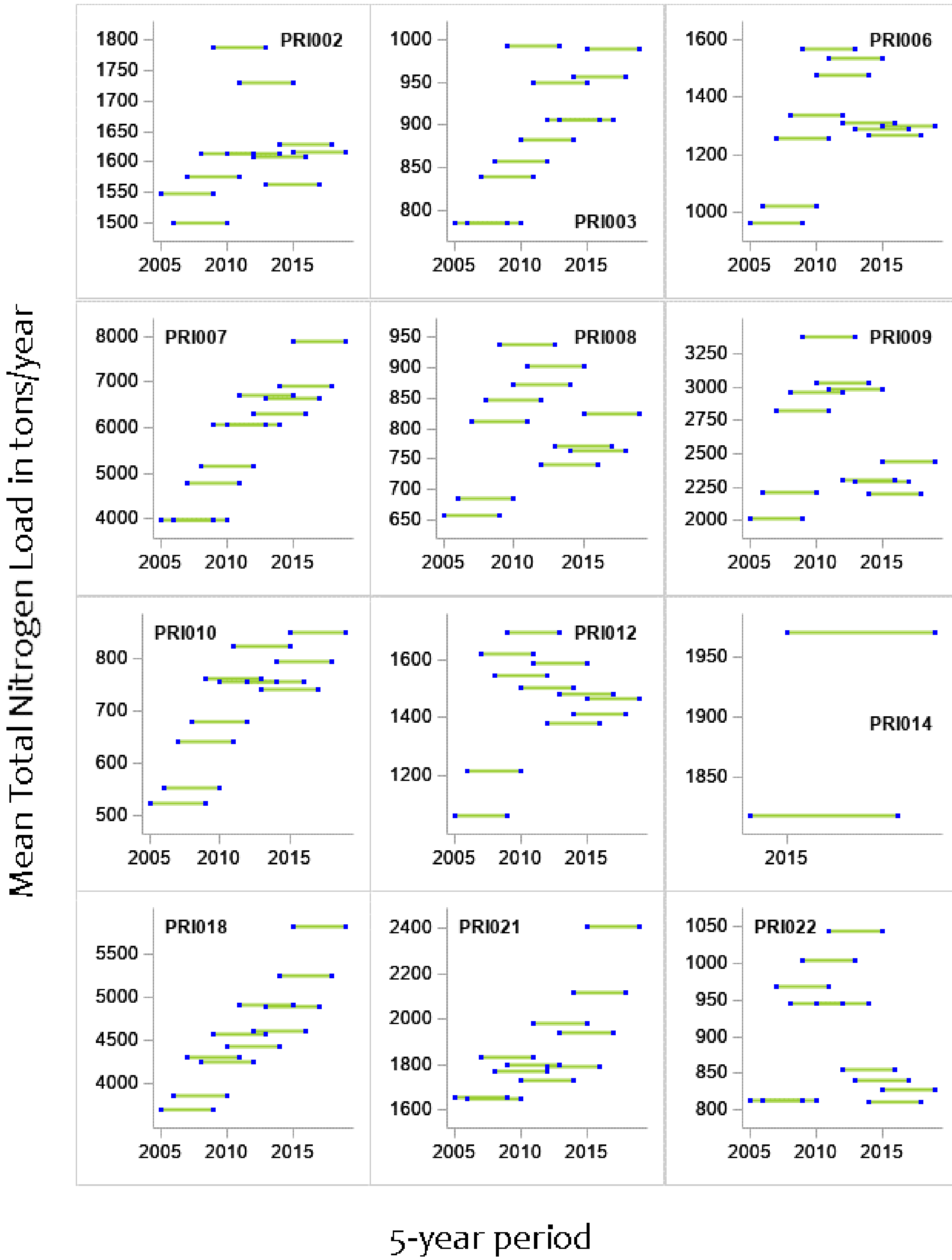
*Bp (load bias in percent) > ±25%, indicating load estimation is highly uncertain.

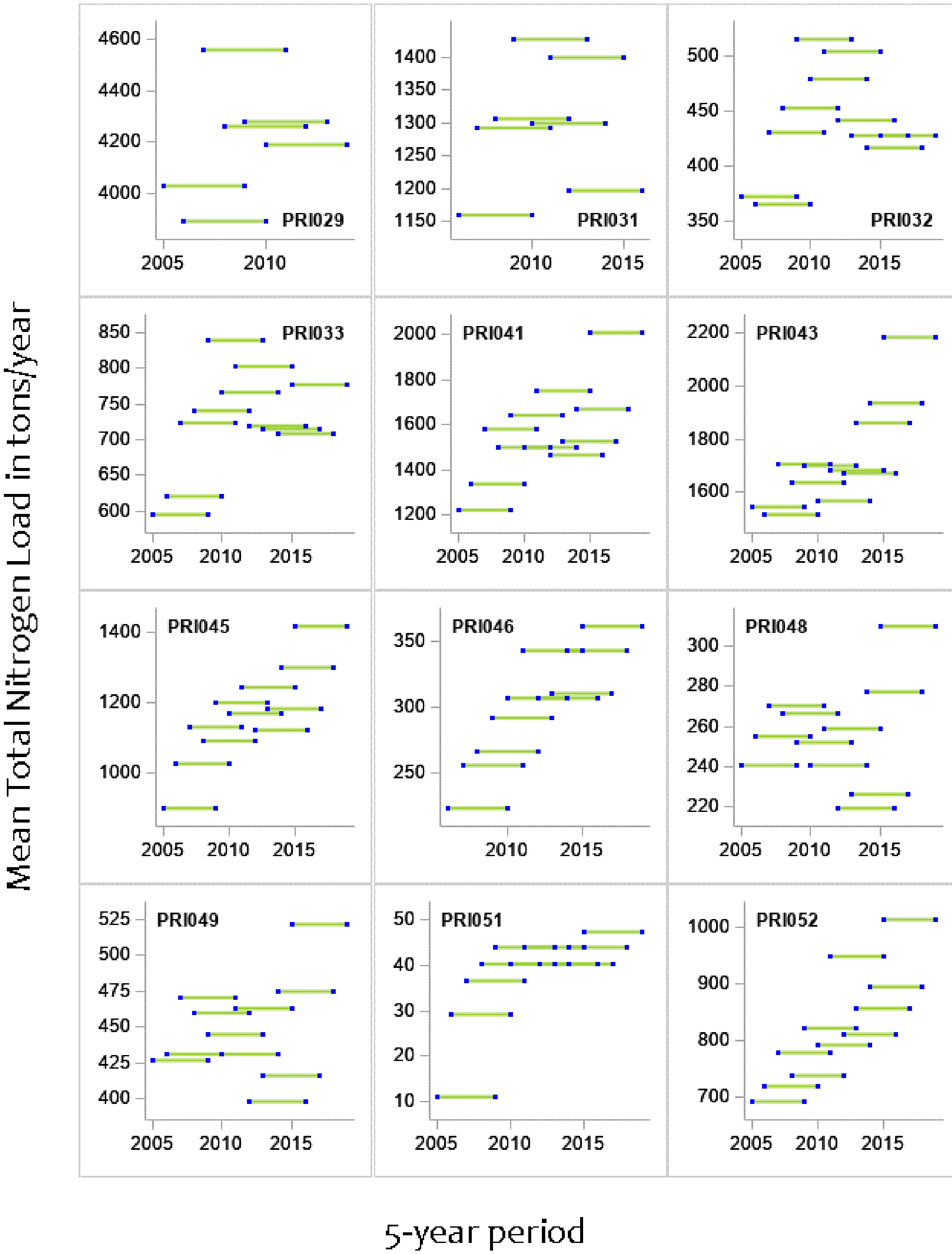
Appendix 2: Precipitation Data

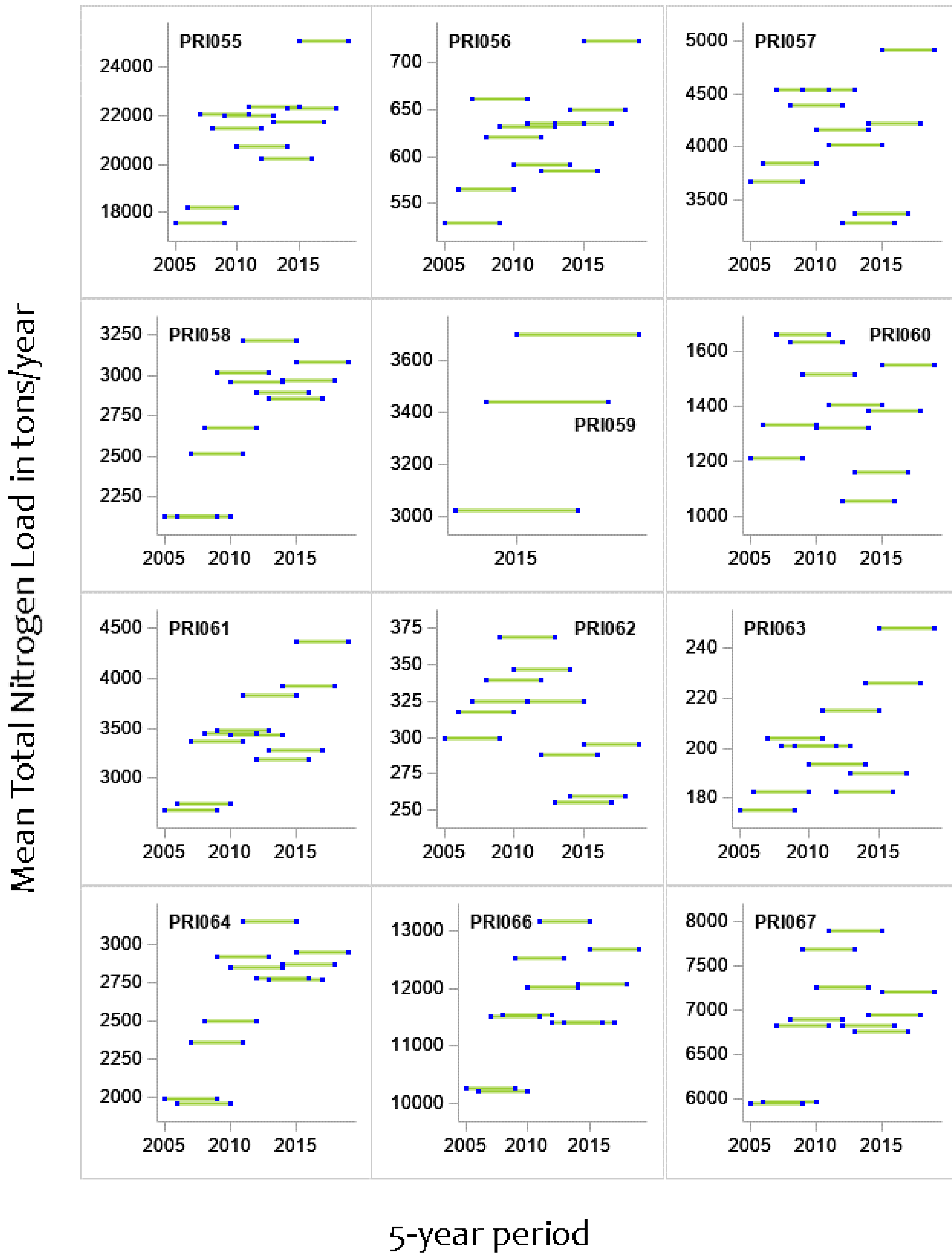
Precipitation data from nine meteorological stations were obtained from NOAA (NOAA: National Centers for Environmental Information, n.d.). The nine stations are shown below. For each station, the top three annual precipitation totals were used to compare to top loading years for monitoring stations (**Figure 6**).



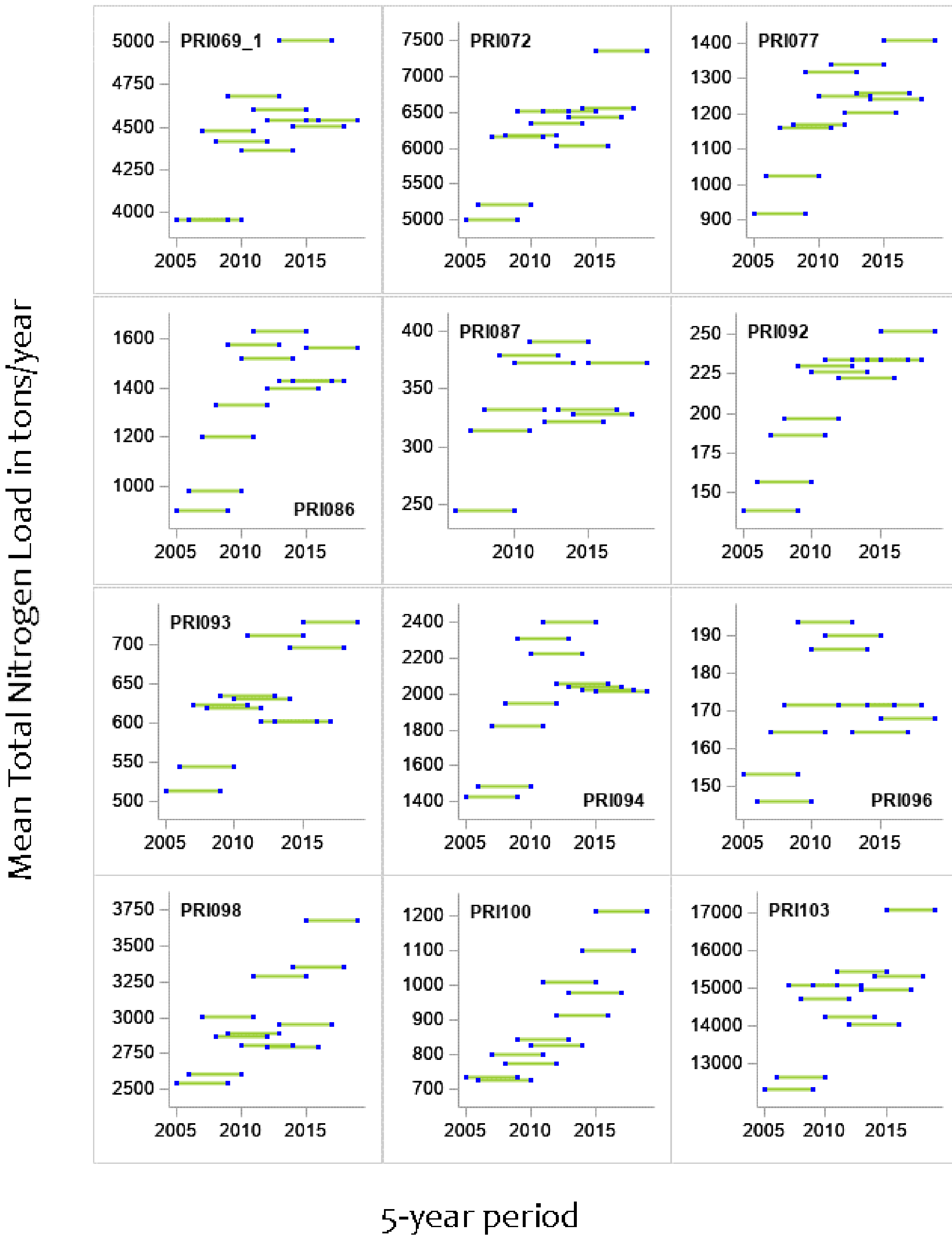
Appendix 3: Rolling 5-Year Average Loads

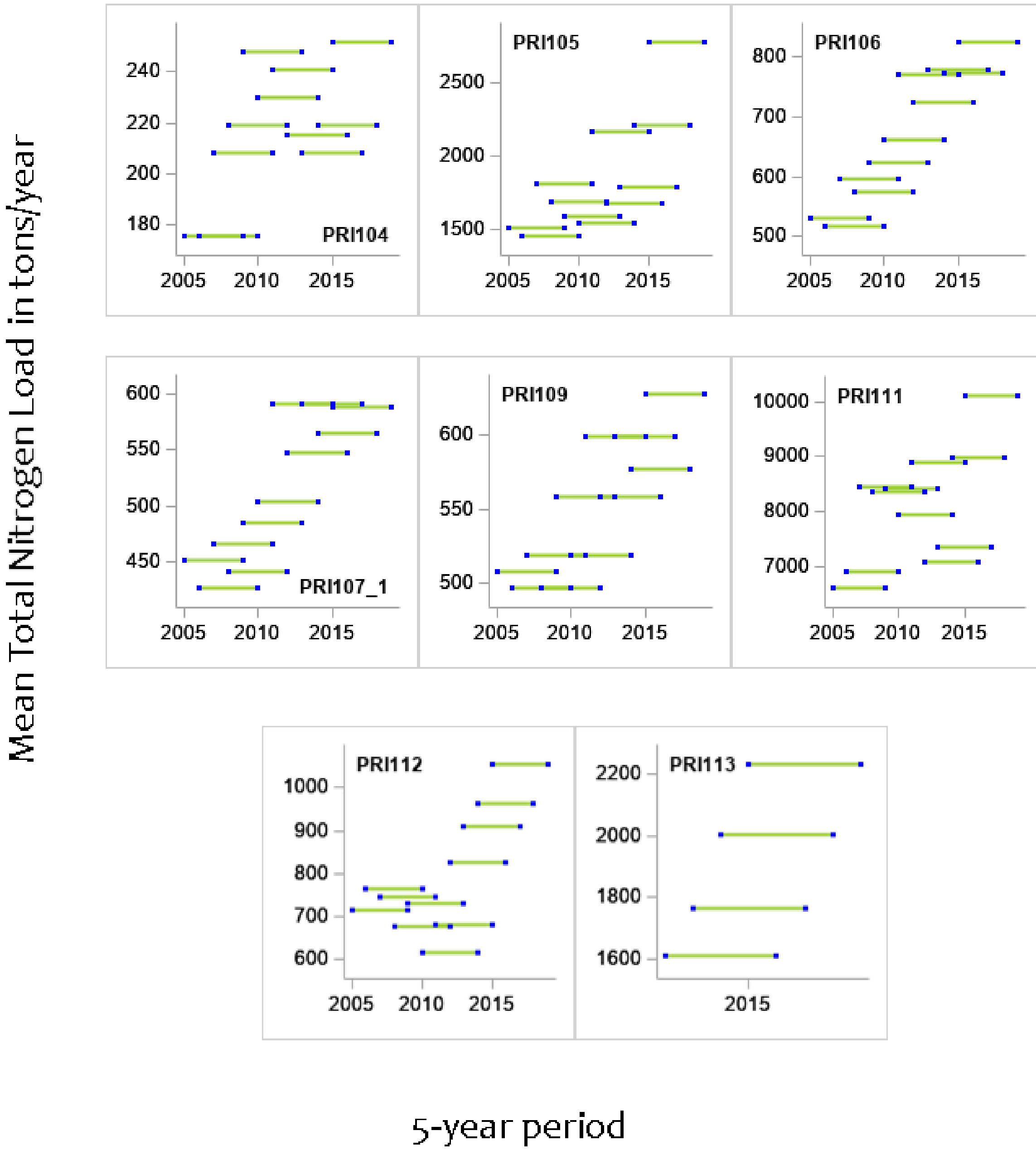


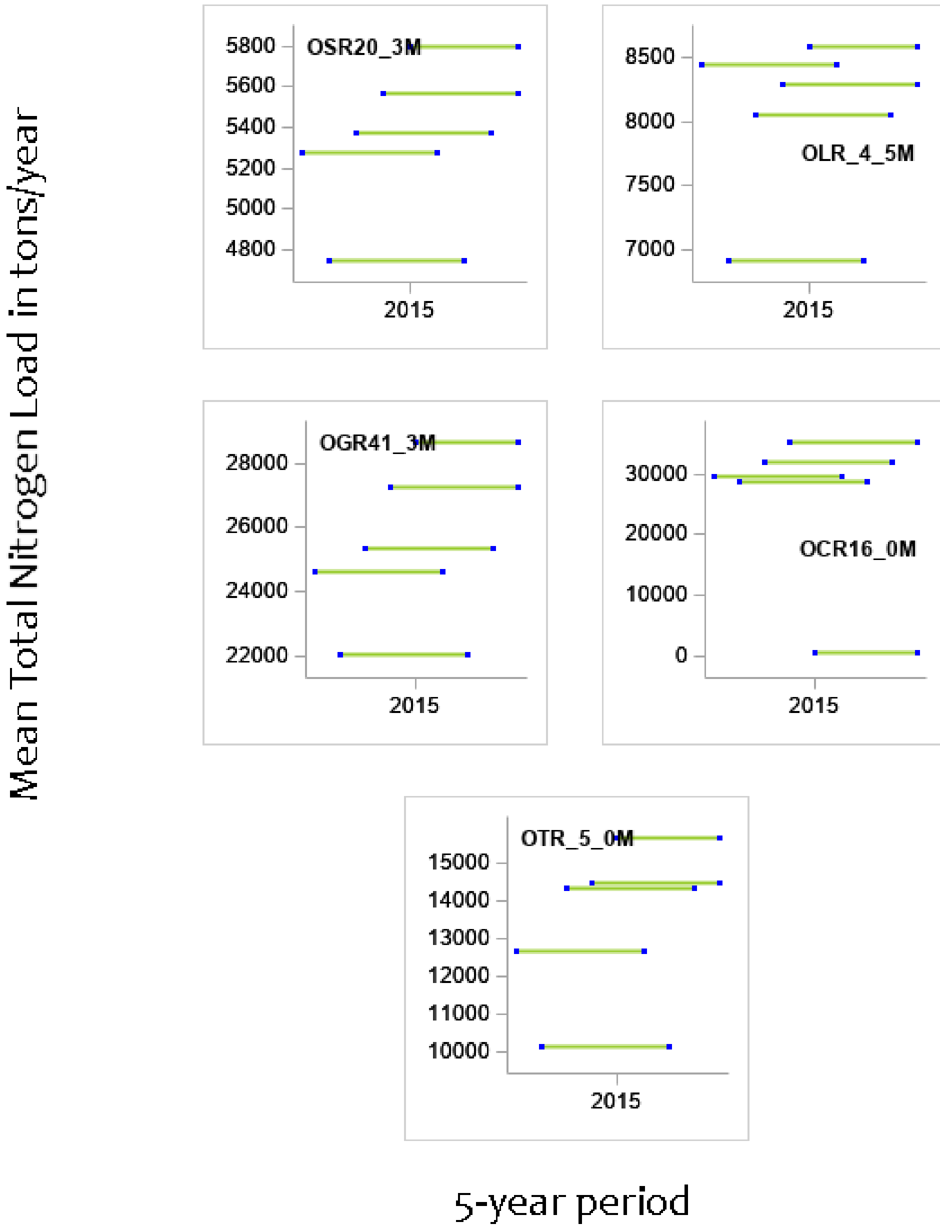

Mean Total Nitrogen Load in tons/year
PRI029
PRI031
PRI032
PRI033
PRI041
PRI043
PRI045
PRI046
PRI048
PRI049
PRI051
PRI052
5-year period

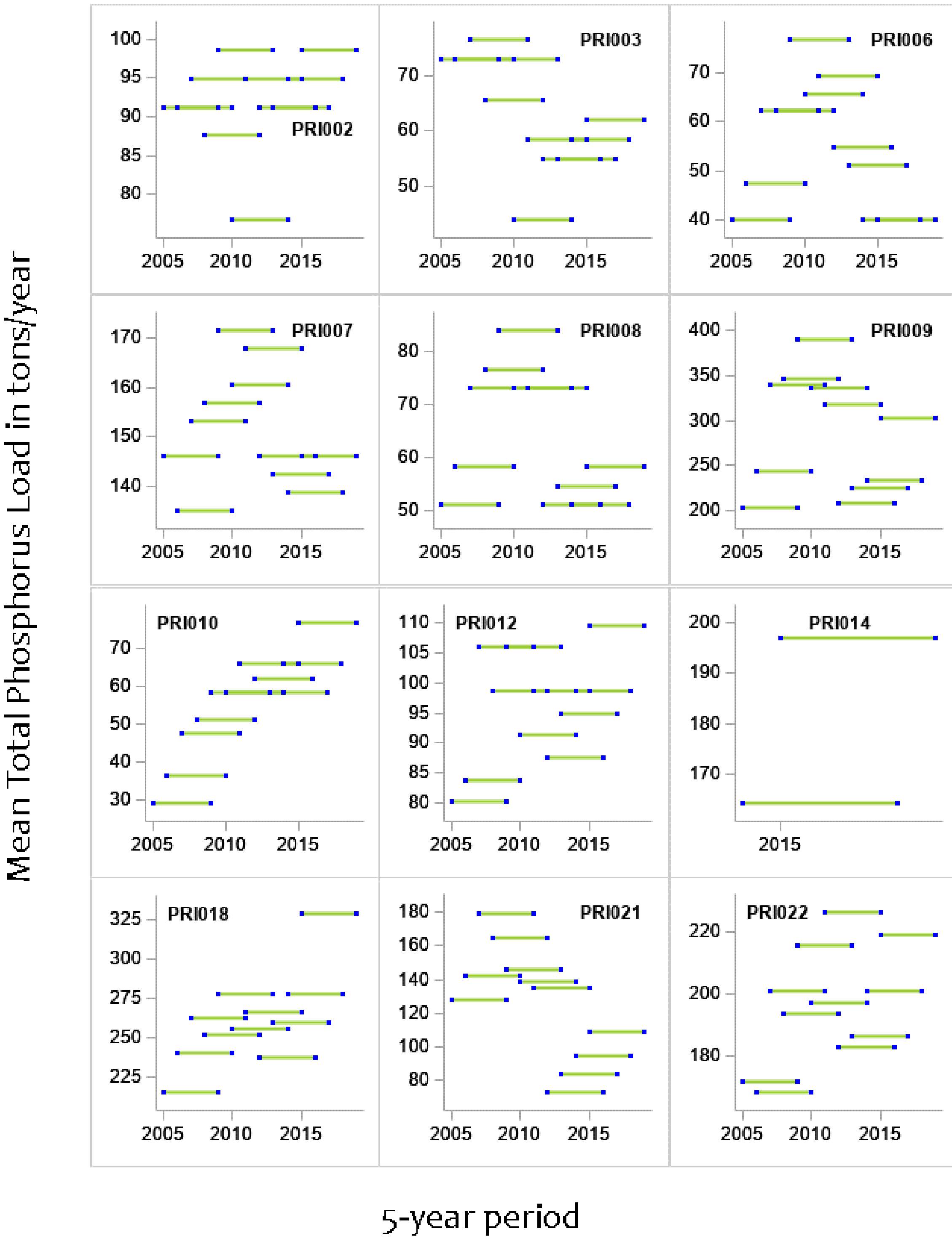


Mean Total Nitrogen Load in tons/year
PRI055
PRI056
PRI057
PRI058
PRI059
PRI060
PRI061
PRI062
PRI063
PRI064
PRI066
PRI067
5-year period

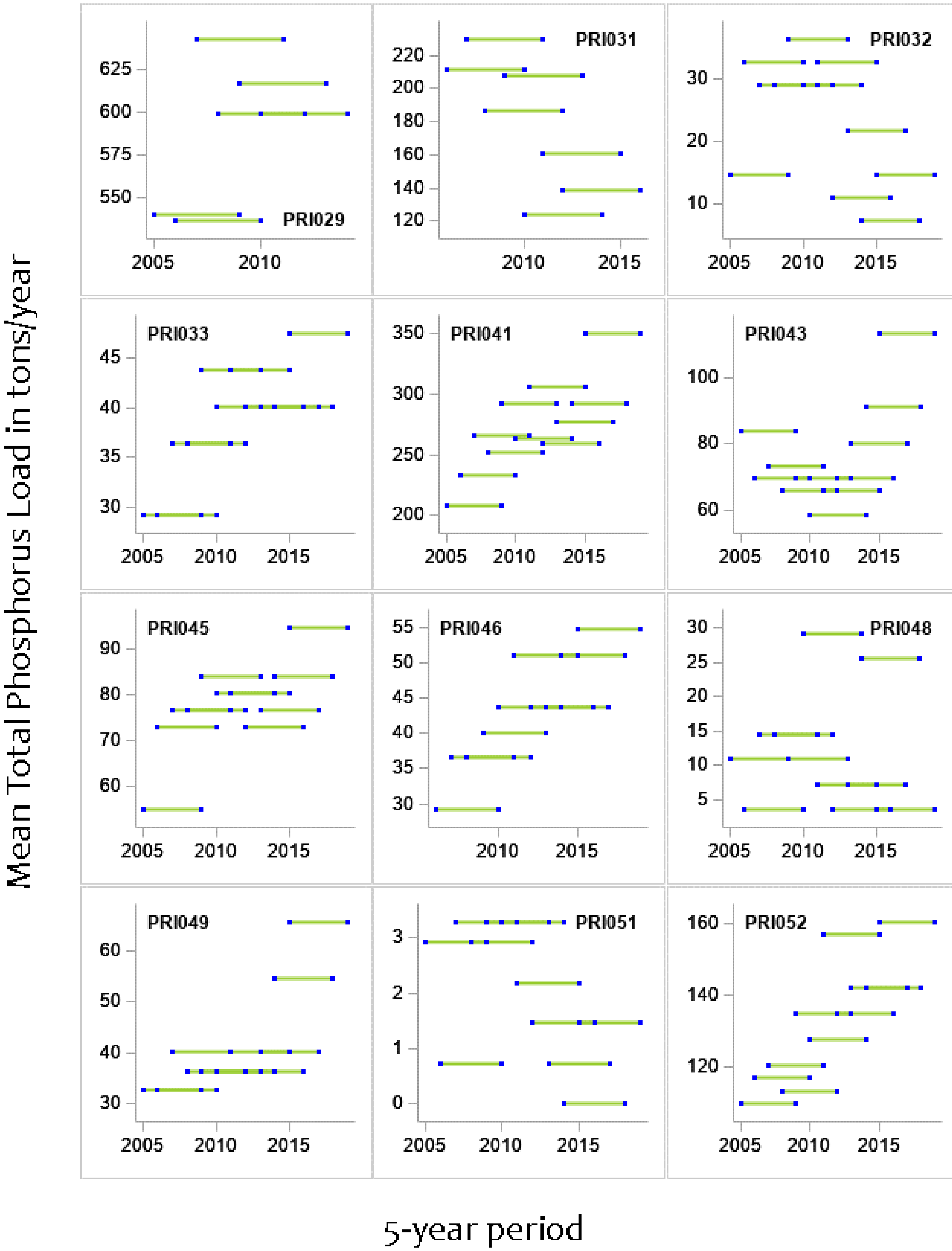

Mean Total Nitrogen Load in tons/year
PRI069_1
PRI072
PRI077
PRI086
PRI087
PRI092
PRI093
PRI094
PRI096
PRI098
PRI100
PRI103
5-year period

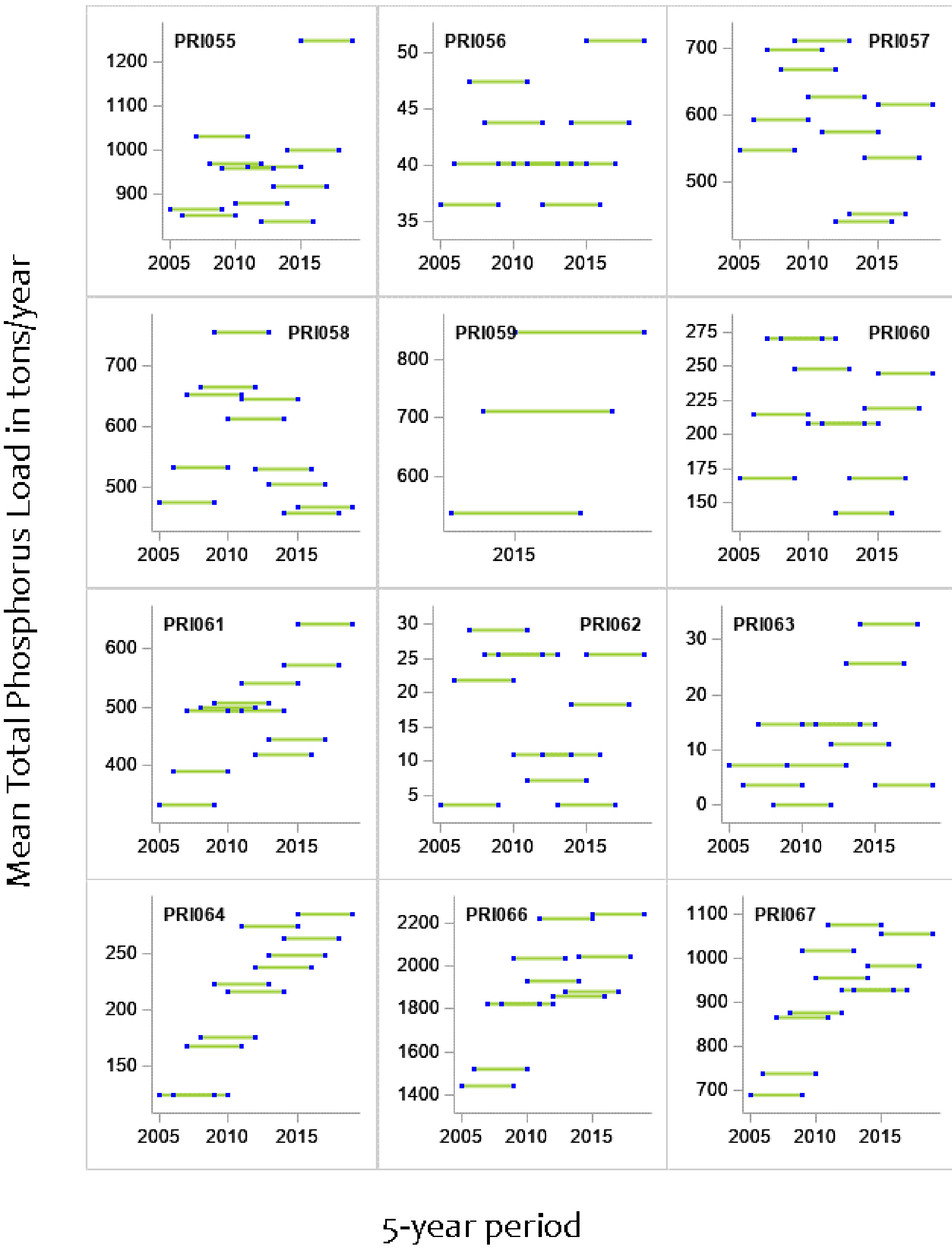

Mean Total Nitrogen Load in tons/year
PRI104
PRI105
PRI106
PRI107_1
PRI109
PRI111
PRI112
PRI113
5-year period

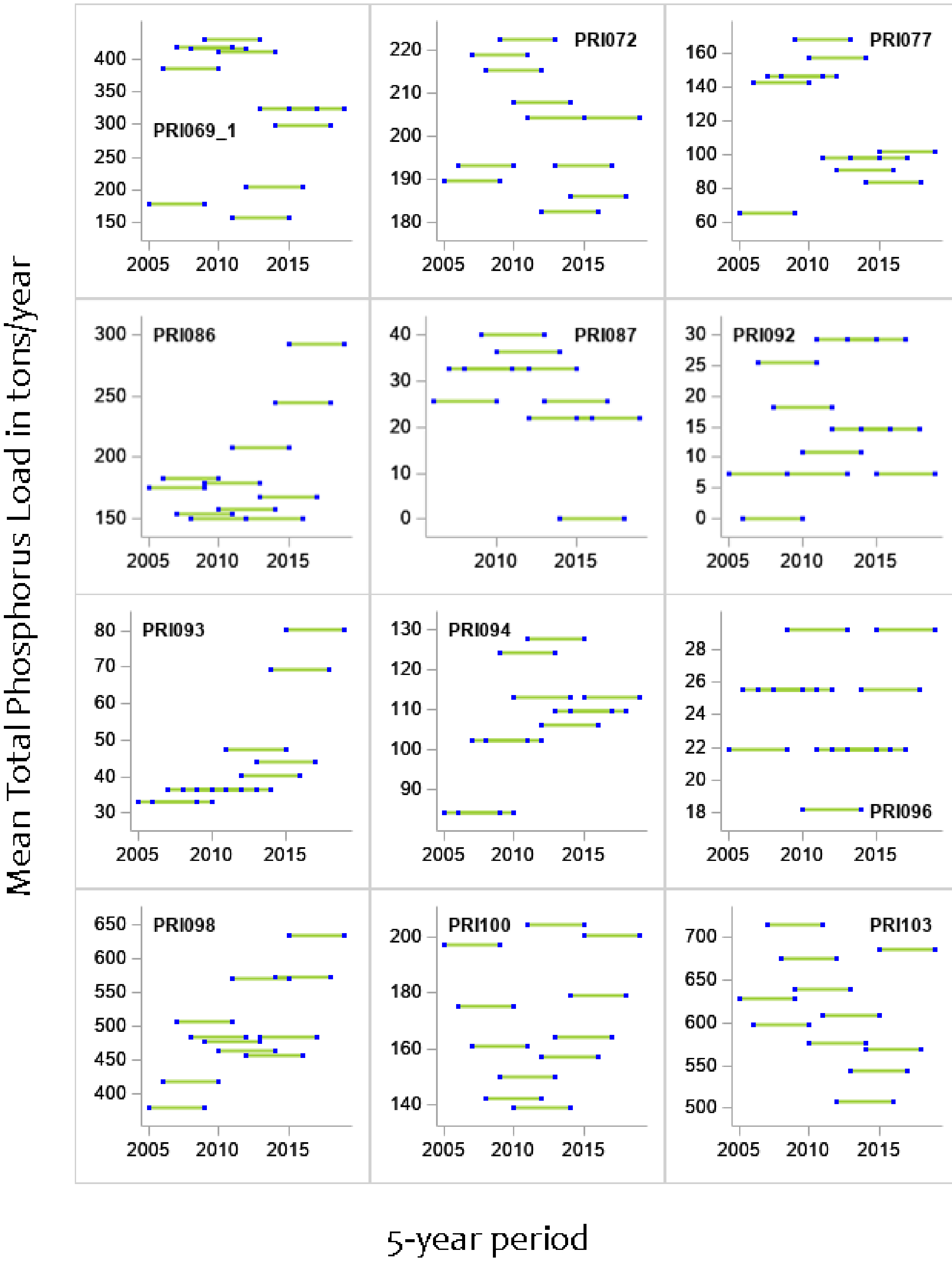

Mean Total Nitrogen Load in tons/year
OSR20_3M
5800
5600
5400
5200
5000
4800
2015
OLR_4_5M
8500
8000
7500
7000
2015
OGR41_3M
28000
26000
24000
22000
2015
OCR16_0M
30000
20000
10000
0
2015
OTR_5_0M
15000
14000
13000
12000
11000
10000
2015
5-year period

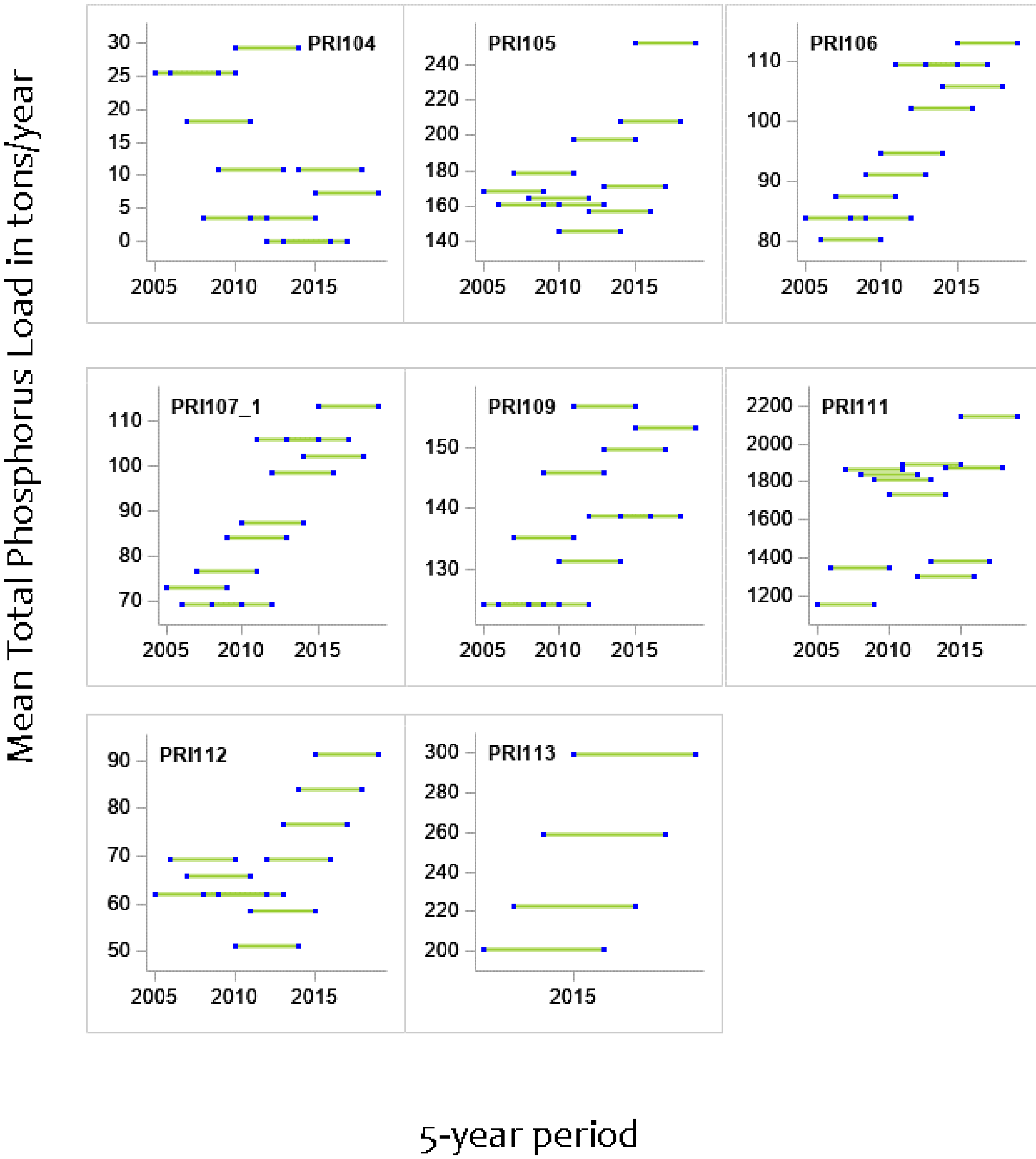


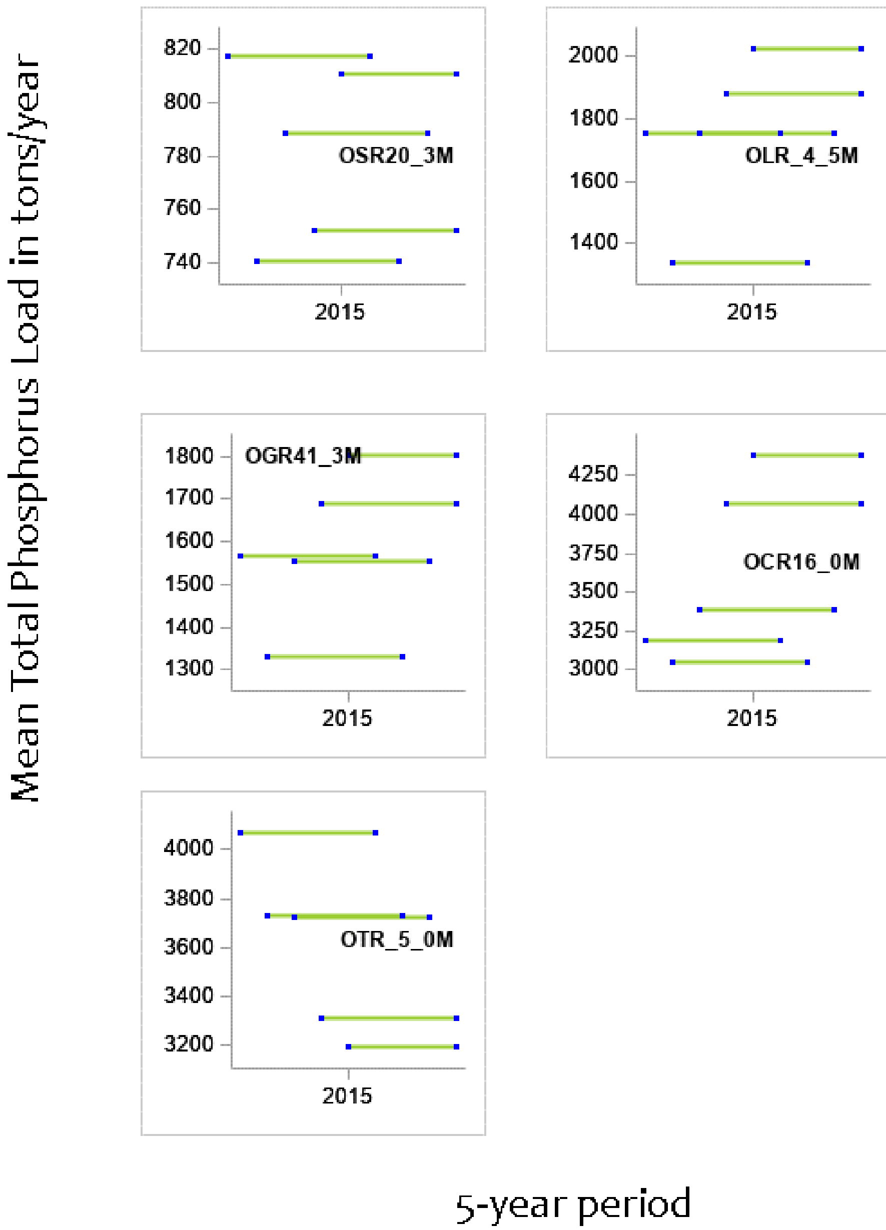
Mean Total Phosphorus Load in tons/year
PRI002
PRI003
PRI006
PRI007
PRI008
PRI009
PRI010
PRI012
PRI014
PRI018
PRI021
PRI022
2005
2010
2015
5-year period


Mean Total Phosphorus Load in tons/year
PRI029
PRI031
PRI032
PRI033
PRI041
PRI043
PRI045
PRI046
PRI048
PRI049
PRI051
PRI052
5-year period


PRI055
PRI056
PRI057
PRI058
PRI059
PRI060
PRI061
PRI062
PRI063
PRI064
PRI066
PRI067
Mean Total Phosphorus Load in tons/year
5-year period


Mean Total Phosphorus Load in tons/year
PRI069_1
PRI072
PRI077
PRI086
PRI087
PRI092
PRI093
PRI094
PRI096
PRI098
PRI100
PRI103
5-year period


Mean Total Phosphorus Load in tons/year
PRI104
PRI105
PRI106
PRI107_1
PRI109
PRI111
PRI112
PRI113
5-year period


Mean Total Phosphorus Load in tons/year
OSR20_3M
820
800
780
760
740
2015
OLR_4_5M
2000
1800
1600
1400
2015
OGR41_3M
1800
1700
1600
1500
1400
1300
2015
OCR16_0M
4250
4000
3750
3500
3250
3000
2015
OTR_5_0M
4000
3800
3600
3400
3200
2015
5-year period