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Nutrient contamination from non-point sources: Dissolved phosphate in surface and subsurface waters at EKU Meadowbrook Farm, Madison County, Kentucky

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Dissolved Phosphate Concentration in Surface and Groundwater of EKU Meadowbrook Farm

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Submitted to Walter S. Borowski

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ABSTRACT

Farms are non-point sources for nutrient contaminants that drain into waterways and contribute to eutrophication and other environmental problems. EKU's Meadowbrook Farm raises both crops and livestock, contributing dissolved phosphorus in the form of orthophosphate (PO_4^{3-}) to surface and subsurface waters, eventually flowing into Muddy Creek, a tributary of the Kentucky River. We sampled springs, surface water from the farm, tile drains, and Muddy Creek waters from May through August 2016. One to two days after sampling, we measured orthophosphate concentration using the established colorimetric, ascorbic acid method and a UV-VIS spectrophotometer with general accuracy and precision of ~0.1 mg/L (ppm).

Phosphate concentrations are generally low when compared to nitrate ranging from 0 to 0.1 mg/L P-PO_4 with higher concentrations of 0.5 to 2.7 mg/L P-PO_4 occurring sporadically. With some exceptions, we saw little difference in phosphate concentration between different sample sources whether spring water, water from subsurface drains, surface waters flowing over the Farm, or Muddy Creek waters. Overall patterns of phosphate concentration were similar whether sampling during periods with little or no rainfall, or periods following rain events. However, one sub-watershed draining the Farm had increased levels of phosphate on 24 May (up to 2.7 mg/L P-PO_4), and on 24 June (0.5 mg/L P-PO_4), immediately following a significant rain event.

Overall, Farm and Muddy Creek waters had lower median dissolved orthophosphate (0.02 mg/L P-PO_4) than runoff from agricultural areas nationally (0.15 mg/L P-PO_4). Subsurface water from springs had a median level of phosphate (0.04 mg/L P-PO_4) higher as compared to springs nationally (<0.01 mg/L P-PO_4).

INTRODUCTION

Pollution sources are classified as either being point source or non-point source (EPA, 2002). Point source pollutants are generally associated with industrial operations where contaminant sources can be directly identified. Non-point-source contamination comes from many, dispersed sources that cause significant contamination in the aggregate. In rural areas, farms are a major non-point source for contaminants in the United States (Dubrovsky et al., 2010). Farming activities mobilize nutrients (phosphate, PO_4^{3-}; nitrate, NO_3^-, and ammonium, NH_4^+) that eventually enter watersheds.

Excess nutrients in natural waters cause a variety of problems (Nixon, 1995). The overabundance of nutrients results in algal blooms (Smith, 2003). Decomposition of dead algae depletes water of its oxygen, resulting in dysoxic to anoxic water eventually leading to the deaths of many plants and aquatic species (WRI). Ultimately, excess nutrients travel downstream and are then released into the oceans, causing additional environmental problems (NOAA, 2008).

Meadowbrook Farm

Meadowbrook Farm in Madison County, Kentucky (Fig. 1) is an operational farm used as a teaching facility by the Department of Agriculture at Eastern Kentucky University. The Farm grows crops including corn and soy beans as feed for livestock. Livestock on the farm are dominantly beef and dairy cattle with swine and sheep. Manure from livestock is utilized for fertilizer and commercial fertilizer is also applied. Fertilizer and animal waste are sources of nutrient contamination, making Meadowbrook Farm a non-point-source of nutrient contamination.

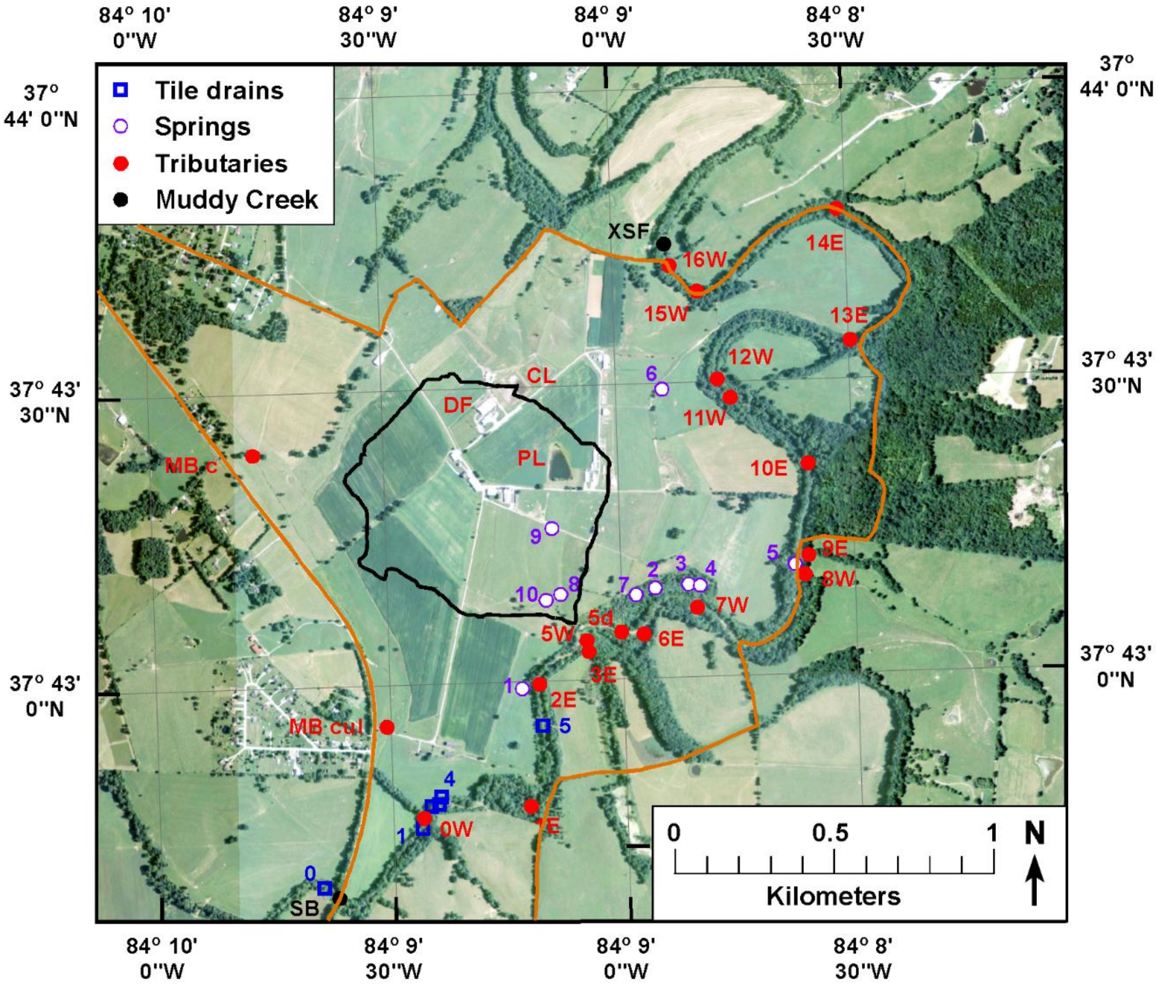

Figure 1. Aerial photo of EKU's Meadowbrook Farm showing farm property (gold outline) and the location of sample sites identified by water source. The Farm's dairy complex (DF) is located next to the cow lagoon (CL). Note also the pig lagoon (PL) and cropland versus pasture. Muddy Creek flows from south to north and can be traced by its tree line. The creek enters Farm property at station SB and leaves at station XSF. Note the samples sites for tile drains and tributaries along Muddy Creek. A prominent subwatershed, the Big Runoff Channel (BRC) is shown by the black outline.

Land on the Farm is used mainly for crops, and beef and dairy cattle pasture. Cropland and pasture are interchanged periodically. Dairy cattle require milking twice daily, thus their activities are confined proximal to the milking facilities (DF, Fig. 1). Dairy cattle feed in adjacent pasture or within an open-air barn. Cattle manure deposited in the barn is flushed into a trench where solid manure is separated from liquid waste. Solid waste is dried and applied as fertilizer to cropland and pasture. Liquid waste is stored in a lined pond, the cow lagoon (CL, Fig.1), and is also applied as fertilizer.

Water Sources

Nutrients from fertilizer and animal manure are the dominant contaminants and are eventually transported into the adjacent Muddy Creek (Fig. 1). Nutrient contaminants occur within several different water sources emanating from the Farm.

Natural springs are found at several sites on Farm property (Fig. 1), seeping from outcrops of the Boyle Dolomite (Green, 1968). These springs drain into the watershed through small, overland streams that form tributaries entering Muddy Creek. Spring water within the streams may travel overland for 10’s of meters to 100’s of meters. Most tributaries entering Muddy Creek from the west from the Farm property are spring fed.

Runoff from rainfall drains into Muddy Creek through conventional tributaries that enter Muddy Creek from both the Farm (west) and non-Farm (east) areas. Conventional tributaries are those that are not obviously associated with springs or are dominated by runoff from rainfall. Only two tributaries enter Muddy Creek from the west: a stream that parallels Meadowbrook Road on the western boundary of the Farm (Station 0W; Fig. 1), and the Big Runoff Channel (BRC, Station 5W) that drains the area shown in Fig. 1. Tributaries entering Muddy Creek from the east are apparently not associated with springs.

Much of the field areas on the Farm are underlain by French drains, or tile drains, that drain excess water from fields. The tile drains are constructed from perforated PVC pipe that act as gutters to drain soil more effectively and prevent the occurrence of standing water. The tile drains either empty into overland rills or are funneled into the Meadowbrook Road or BRC drainages. Five tile drains empty directly into Muddy Creek (Fig. 1).

Rainfall

Rainfall is a critical part of understanding the water budget and nutrient transport in any watershed. The Farm is equipped with a Kentucky Mesonet Station, ELST, located in the western portion of the BRC subwatershed providing accurate rainfall records (Fig. 2; www.kymesonet.org). We sampled during both dry and wet periods occurring in the summer field season, and specifically sampled to test the effects of rainfall on nutrient concentration.

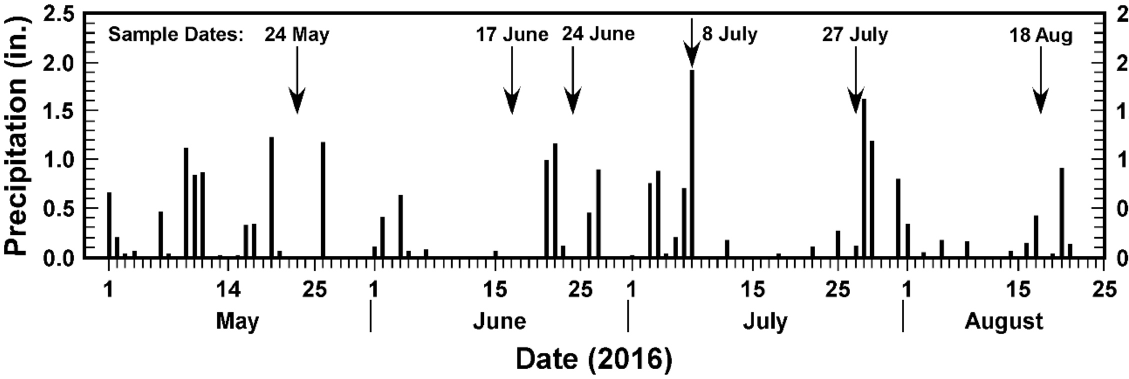

Figure 2. Rainfall amounts and sampling dates during the 2016 field season at Meadowbrook Farm. Rainfall data is from a weather station (ELST) located directly on the Farm operated by the Kentucky Mesonet (www.kymesonet.org).

Study Objectives

This study's objectives are to:

1. determine patterns of phosphate contamination in various sample types;
2. identify consistent sources of phosphate; and
3. test for links between rainfall events and phosphate concentration in samples.

METHODS

We sampled Meadowbrook Farm waters in the summer months, May through August of 2016, totaling eight days in the field (Fig. 2). We established 40 sites on the Farm and within Muddy Creek (Table A1, A2; Fig.1). Muddy Creek samples began at the upstream site of steel bridge (SB), occurred at many tributary entry points along the stream course, and ended at the downstream site, XSF, when Muddy Creek exits farm property (Fig 1). Each tributary that enters Muddy Creek was sampled. We also sampled the stream paralleling Meadowbrook Road at a confluence of several rills, and at culvert on the northwest side of the farm, which drains cow pasture and cropland. The Big Runoff Channel and its tributaries were sampled. Springs were sampled where they bubbled to the surface. Lastly, we sampled the cow and pig lagoons.

All samples were collected using a 60-mL syringe fitted with a 0.45 micron filter. After filtering, samples were placed into vials and acidified with sulfuric acid to a pH of 2 (Clesceri et al., 1998). Samples were put on ice in the field and then refrigerated, and generally were measured one to two days after collection.

Dissolved phosphate, as orthophosphate (PO_4^{3-}), was measured using the colorimetric, ascorbic acid method (Strickland and Parsons, 1968). We specifically used the protocol developed by Gieskes et al. (1991). The procedure involves pipetting 1 mL of sample, 1 mL of nanopure water (18 MΩ), and 2 mL of mixed reagent. The mixed reagent consists of ammonium molybdate, sulfuric acid, ascorbic acid, and potassium antimonyl-tartrate. Phosphate concentration is proportional to the intensity of blue that is developed by the reaction, and measured using a UV-VIS spectrophotometer.

Phosphate standard concentrations ranged from 0 mg/L to ~2 mg/L P-PO_4. Correlation coefficients (r^2 values) for linear standard curves were generally above 0.95 (Fig. 3). Measurement accuracy and precision is around 0.1 mg/L.

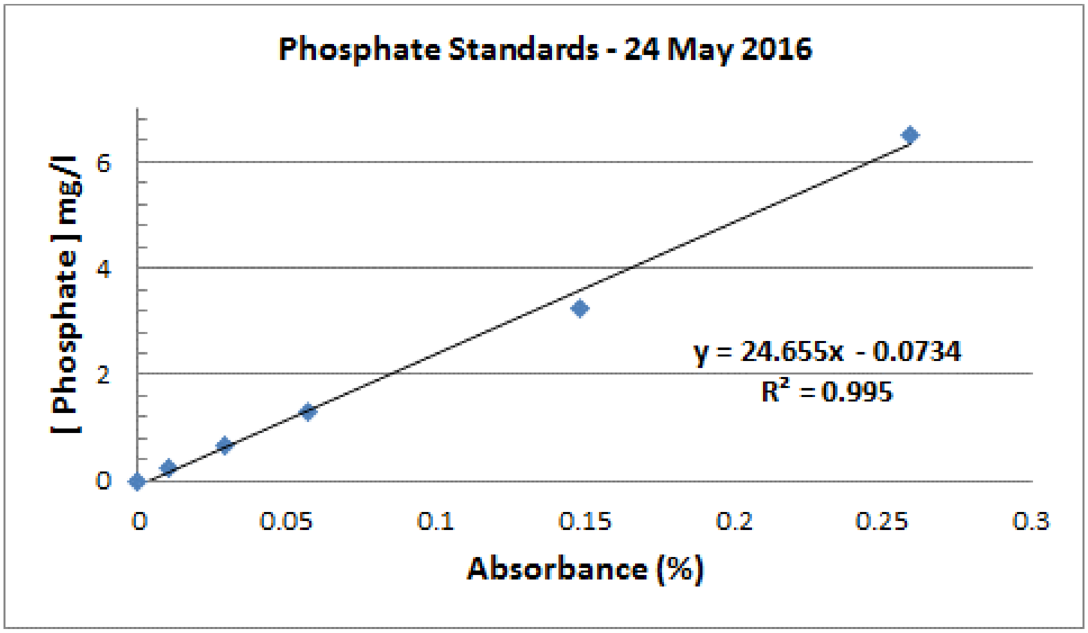

Fig. 3. Typical phosphate standard curve. Note the high correlation coefficient (r^2).

RESULTS

Phosphate values typically range from 0 to 0.1 mg/L P-PO_4, sporadically show higher concentrations of 0.5 to 2.7 mg/L P-PO_4, and vary markedly on successive sampling days during the field season (Fig. 4, Fig. A1, Table A3). Phosphate contamination is apparently much lower than that of nitrate, which posted typical values of 0 to 0.2 mg/L N-NO_3 with higher values ranging from 7.0 to 14.3 mg/L (Buskirk et al., 2017). Many to most sites registered no dissolved phosphate, especially during the months of July and August, although sporadic occurrence of high phosphate values did occur at some sites (Fig 5).

Samples from the sub-watershed of the Big Runoff Channel (BRC) and springs consistently show higher PO_4 values (Fig. 5). BRC samples often showed phosphate concentrations 2 to 3 times that of background concentration (0 to 0.1 mg/L P-PO_4), and showed the highest concentration values of 2.7, 0.4, and 0.6 mg/L P-PO_4 on 24 May, 24 June, and 27 July, respectively. Phosphate values from spring samples were slightly higher than background values, but were consistently so with Spring 1 flowing most commonly (Fig. 1, 4, and 5). Perhaps because the tributaries entering Muddy Creek are associated with springs, phosphate values are persistently higher in western versus eastern tributaries (Fig. 4, 5, and A1).

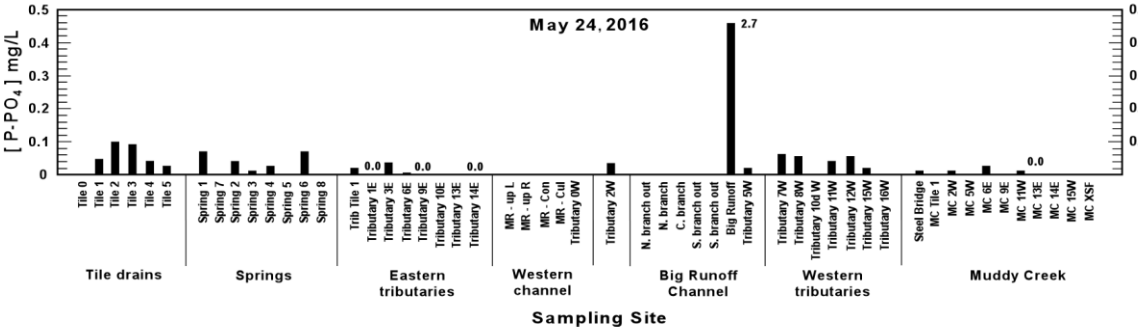

Fig. 4. Graph showing phosphate concentration in water samples from the Farm from a typical sampling day (24 May 2016). Note that samples are categorized by sample type (tile drains, springs, eastern tributaries, the western drainage along Meadowbrook Road, the Big Runoff Channel, western tributaries, and Muddy Creek) and are organized from upstream to downstream, left to right. Sample stations without data because of no available water are distinguished from stations with zero orthophosphate by showing zero concentration values (0.0 above the station position.).

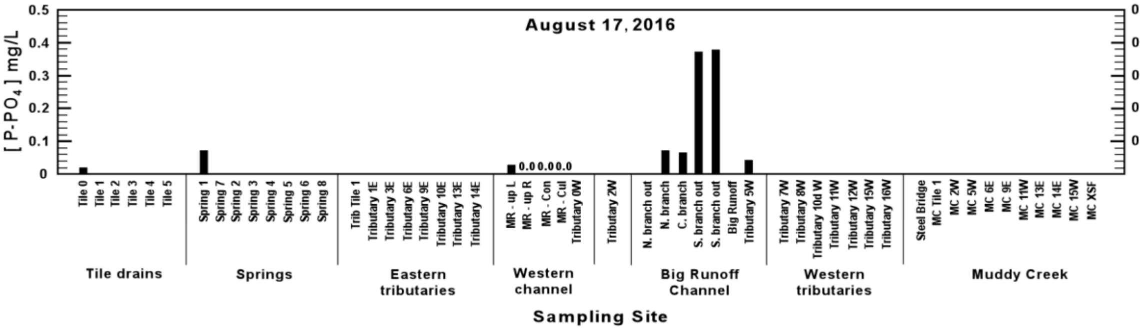

Fig. 5. Graph showing phosphate concentration in water samples from the Farm on sampling day (17 August 2016). Sample stations without data because of no available water are distinguished from stations with zero orthophosphate by showing zero concentration values (0.0 above the station position).

DISCUSSION

Phosphate values from our sampling stations were generally low, but higher values do occur at specific sites. The Big Runoff Channel had the highest consistent and sporadic values of dissolved orthophosphate. The BRC is the largest drainage on the Farm and drains both cropland and pasture; and the dairy complex (DF), cow lagoon (CL) and pig lagoon (PL) are also within its drainage basin (Fig.1). We suspect that most phosphate contributions come from runoff from planted areas of the farm with smaller contributions from pasture. Other tributaries draining dominantly pasture (e.g., 6E and 9E) consistently show low values of dissolved phosphate. Both the cow and pig lagoons are lined at their bottoms, so should not leak phosphate into groundwater; moreover, we have no evidence at present that suggest any leakage.

Springs on the Farm have the next highest concentrations of dissolved phosphate, showing that groundwater is receiving phosphate from upgradient sources. These potential sources could be located on the Farm, from an adjacent area to the north underlying a housing development served by septic systems, or from highlands generally to the west of Meadowbrook Road. We have no idea of the subsurface plumbing of the region and therefore cannot determine the sources of elevated groundwater phosphate.

Rainfall Effects

To test the effect of rainfall on dissolved phosphate concentration, we sampled Farm stations on a day with little prior rainfall (17 June) and then on a day following a significant rainfall event (24 June) (Fig. 2). Phosphate values were about the same at most of stations, but there was a significant spike in phosphate values in the Big Runoff

Channel (Fig 6). In the BRC, all sample locations were flowing and showed phosphate values 2 to 5 times higher than background values. Phosphate concentration also increased slightly in Muddy Creek with some stations showing increases from zero values to background values, indicating addition of dissolved phosphate from tributaries.

Interestingly, phosphate concentration values after a significant rainfall on 27 July (Fig. A1) were only high in BRC, but not at other stations. There was a significant dry period before this sampling day (Fig. 2), and we infer that rapid infiltration of rain prevented runoff at most localities with the BRC being an exception.

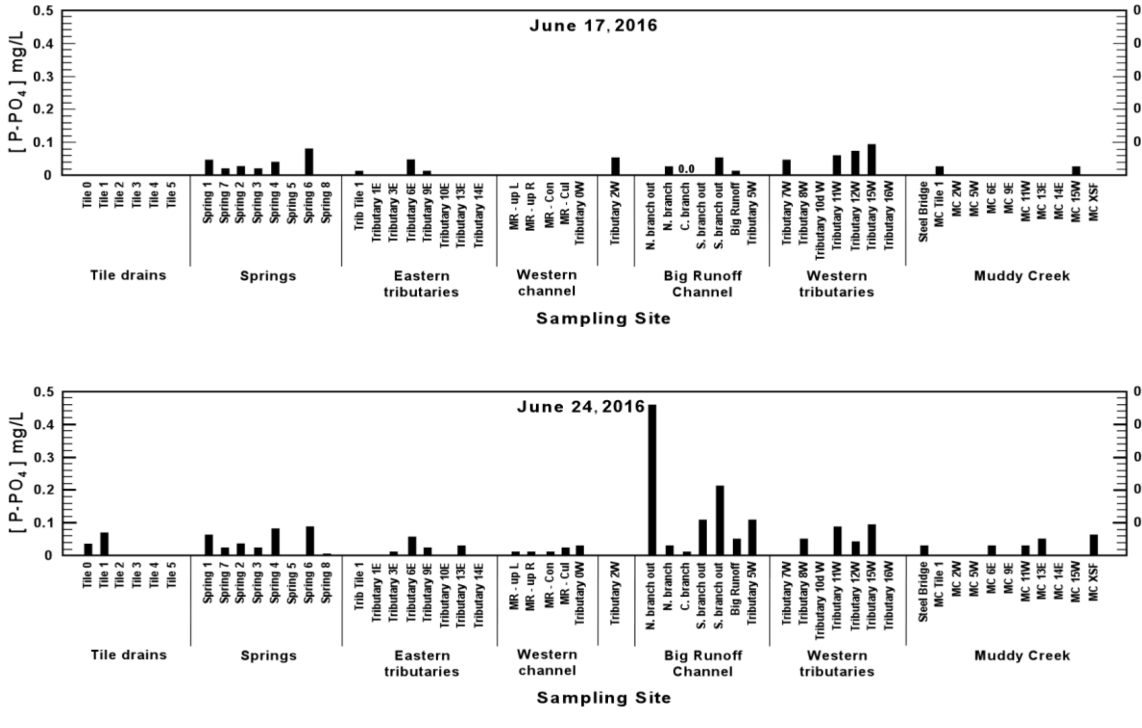

Figure 6. Graphs showing comparison of phosphate concentrations before (17 June) and after (24 June) rainfall event. See Fig. 2 for rainfall amounts. Sample stations without data because of no available water are distinguished from stations with zero orthophosphate by showing zero concentration values (0.0 above the station position).

Comparison to National Values

We compare Farm phosphate values in surface and subsurface water to a national data set that establishes orthophosphate concentrations in pristine and agriculturally impacted areas (Dubrovsky et al., 2010) (Fig. **7**). Values from pristine sampling localities show a concentration of 0.01 mg/L $P\text{-}PO_4$. Farm surface waters show values higher than that of pristine streams, but are lower than national values affected by agricultural runoff with median values of 0.02 mg/L and 0.1 mg/L-$P\text{-}PO_4$, respectively.

Subsurface waters from the Farm showed much greater dissolved orthophosphate as compared to national data. The national value for pristine groundwater is 0.01 mg/L $P\text{-}PO_4$. The median value of spring water at the Farm is 0.03 mg/L $P\text{-}PO_4$ as compared to the national median value of <0.01 mg/L $P\text{-}PO_4$. Thus, Farm spring water contains about 3 times more phosphate than pristine groundwater and agriculturally-impacted groundwater nationally.

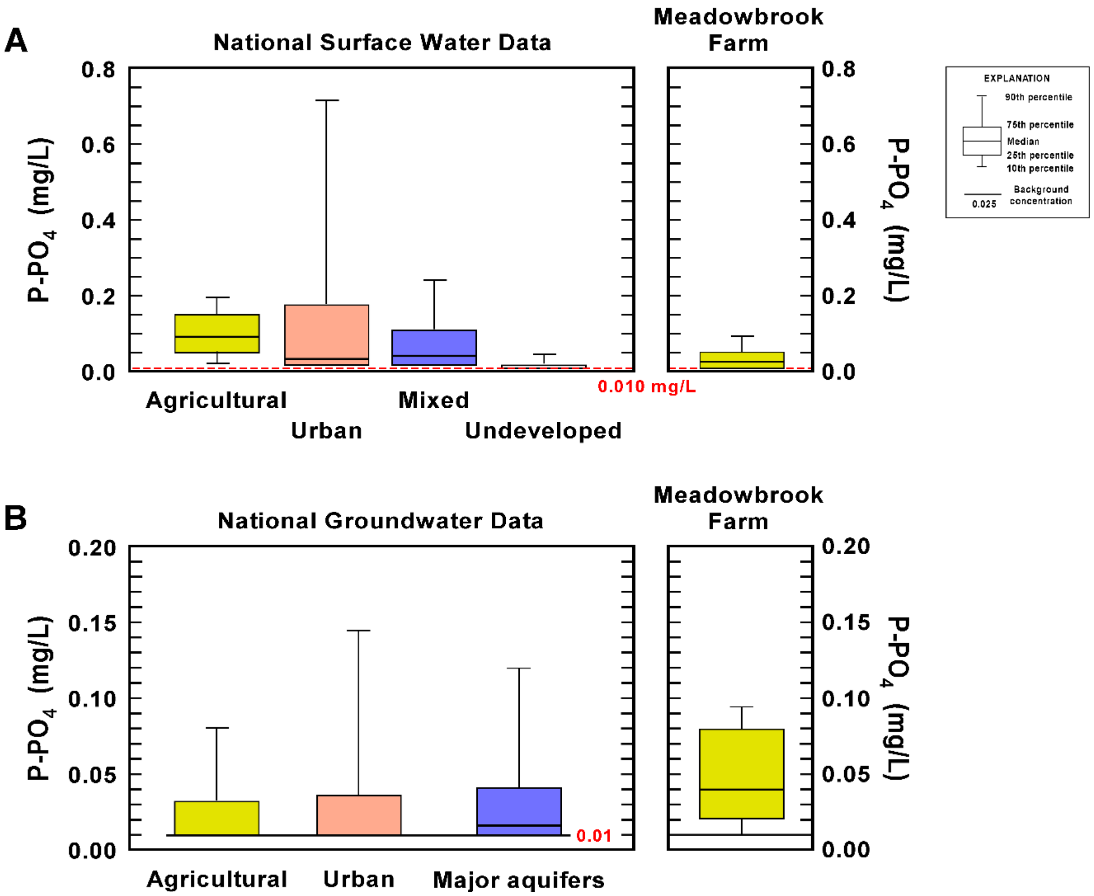

Figure 7. Box-and-whisker plots comparing orthophosphate contamination in Farm surface (A) and subsurface (B) waters to phosphate contamination nationally (data from Dubrovsky et al., 2000). The key at the upper right shows the positions of the 10th, 25th, 50th (median), 75th, and 90th percentiles.

SUMMARY

Overall, our findings reveal that:

1. Phosphate values from sampling stations were generally low and ranged from 0 to 0.1 mg/L P-PO_4 with sporadic spikes of 0.6 to 2.7 mg/L P-PO_4 occurring at other sites.
2. The Big Runoff Channel and springs displayed the highest dissolved orthophosphate values, almost 2 to 3 times greater than most other sampling sites.
3. The Big Runoff Channel had the highest, most consistent, and highest sporadic values of phosphate in surface runoff.
4. Springs were second highest in phosphate concentration values likely due to up-gradient sources.
5. During periods of rainfall, phosphate levels tend to decrease.
6. Compared to national data, Farm surface water contains significantly less phosphate (~0.02 mg/L P-PO_4) than surface agricultural runoff nationally (~0.1 mg/L P-PO_4).
7. Compared to national data, Farm dissolved orthophosphate in subsurface water emanating from springs was three times higher than national values from agricultural areas with respective orthophosphate concentrations of 0.03 and <0.01 mg/L P-PO_4, respectively.
8. Cropland is likely to be the main source for dissolved orthophosphate contamination due to fertilizer and animal manure applications.

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APPENDIX

Table A1. Sampling stations established at Meadowbrook Farm and Muddy Creek.

Sample Code	Sampling Site	Description	Runoff Type
t0	Tile drainage 0	Off-farm	Cropland
MC SB	Steel bridge; upstream farm boundary	Muddy Creek sample	Cropland, pasture
t1*	Tile drainage 1		Cropland
MR-L	Meadowbrook Rd-upstream, left fork	westerly farm drainage	Cropland, pasture
MR-R	Meadowbrook Rd-upstream, right fork	westerly farm drainage	Cropland, pasture
MR-Con	Meadowbrook Rd-upstream, confluence	westerly farm drainage	Cropland, pasture
MR-Cul	MR culvert	westerly farm drainage	Cropland, pasture
trib 0W*	Tributary 0W	westerly farm drainage	Cropland, pasture
t2	Tile drainage 2		Cropland
t3	Tile drainage 3		Cropland
t4	Tile drainage 4		Cropland
trib 1E*	Tributary 1E	Surface farm/off-farm drainage	Pasture
t5	Tile drainage 5		Cropland
spr 1	Spring 1		Cattle pasture
tib 2E*	Tributary 2E		Cattle pasture
tirb 3E*	Tributary 3E		Cattle pasture
	North branch	Surface farm drainage	Cornfied
	North branch outlet	Surface farm drainage	Cattle pasture
	Central branch	Surface farm drainage	Cattle pasture
	South branch outlet	Surface farm drainage	Cattle pasture
	South branch corn	Surface farm drainage	Cornfied
	Big Runoff	Confluence of surface drainage	Cattle pasture
trib 5W	Tributary 5W	Big Runoff entry MC	Cattle pasture
trib 6E*		Surface farm/off-farm drainage	Cattle pasture
spr 2	Spring 2	No clear entry into MC	Cattle pasture
spr 3	Spring 3	Spring flows overland 10's m	Cattle pasture
spr 4	Spring 4	Spring flows overland 10's m	Cattle pasture
trib 7W*	Tributary 7W*	Spring fed (sp 3,4)	Cattle pasture
spr 7	Spring 7	Surface off-farm drainage	Cattle pasture
trib 8W*	Tributary 8W*	Spring fed (sp 7)	Cattle pasture
trib 9E*	Tributary 9W*	Surface off-farm drainage	Cattle pasture
trib 10E*	Tributary 10E*	Surface off-farm drainage	Forest
spr 6	Spring 6	Spring flows overland 100+ m	Cattle pasture
trib 11W*	Tributary 11W*	Surface farm drainage (spr 6)	Cattle pasture
trib 12W	Tributary 12W	Surface farm drainage (spr 6?)	Cattle pasture
trib 13W*	Tributary 13W*	Surface off-farm drainage	Forest
trib 14E	Tributary 14E	Surface off-farm drainage	Cattle pasture
trib 15W*	Tributary 15W*	Surface farm drainage	Cattle pasture
trib 16W	Tributary 16W	Surface farm drainage	Cattle pasture
MC XSF	Downstream MC farm boundary	Muddy Creek sample	
PL	Pig lagoon	Surface pond	Pig effluent
CL	Cow lagoon	Surface pond	Cow effluent
	*Samples of Muddy Creek also taken		

Table A2. GPS coordinates for the sampling sites.

			NORTH LATITUDE				WEST LONGITUDE		
Source	**Site**		**Degrees**	**Minutes**	**Seconds**		**Degrees**	**Minutes**	**Seconds**
Springs	Spring 1		37	42	59.736		-84	9	13.164
	Spring 2		37	43	9.126		-84	8	56.429
	Spring 2B		37	43	7.864		-84	8	55.211
	Spring 3		37	43	9.349		-84	8	52.255
	Spring 4		37	43	9.284		-84	8	50.910
	Spring 5		37	43	10.995		-84	8	38.553
	Spring 6		37	43	28.487		-84	8	54.910
	Spring 7		37	43	8.505		-84	8	58.903
	Spring 8		37	43	9.040		-84	9	7.555
	Spring 9		37	43	14.747		-84	9	9.281
	Spring 10		37	43	7.903		-84	9	10.192
Surface	Steel bridge		37	42	38.355		-84	9	37.900
	MR C		37	43	23.718		-84	9	46.797
	MR culvert		37	42	55.457		-84	9	30.885
	trib 0 W		37	42	46.349		-84	9	26.313
	trib 1 E		37	42	47.129		-84	9	13.138
	trib 2 W		37	42	59.890		-84	9	11.650
	trib 3 E		37	43	3.554		-84	9	5.603
	North Branch		37	43	7.888		-84	9	7.999
	North Branch Outlet		37	43	14.286		-84	9	7.409
	Central Branch		37	43	11.197		-84	9	9.021
	South Branch Outlet		37	43	9.517		-84	9	18.608
	South Branch corn		37	43	9.319		-84	9	19.256
	Big runoff channel		37	43	6.068		-84	9	7.343
	trib 5 W		37	43	4.948		-84	9	6.236
	trib 5W-d		37	43	5.499		-84	9	2.517
	trib 6 E		37	43	3.994		-84	8	57.405
	trib 7 W		37	43	7.755		-84	8	52.581
	trib 8 W		37	43	10.735		-84	8	38.019
	trib 9E		37	43	12.049		-84	8	36.165
	trib 10 E		37	43	22.453		-84	8	35.866
	trib 10d W		37	43	27.181		-84	8	43.314
	trib 11 W		37	43	27.594		-84	8	45.532
	trib 12 W		37	43	29.485		-84	8	47.649
	trib 13 E		37	43	32.537		-84	9	28.761
	trib 14 E		37	43	46.541		-84	9	30.957
	trib 15 W		37	43	39.309		-84	8	49.294
	trib 16 W		37	43	42.711		-84	8	53.661
	XSF		37	43	43.587		-84	8	54.01
Tile drains	Tile 0		37	42	39.618		-84	9	38.661
	Tile 1		37	42	45.661		-84	9	26.486
	Tile 2		37	42	47.848		-84	9	25.242
	Tile 3		37	42	48.187		-84	9	24.375
	Tile 4		37	42	48.724		-84	9	23.937
	Tile 5		37	42	55.383		-84	9	11.301

Table A3. Phosphate concentration data for samples taken at and around Eastern Kentucky University's Meadowbrook Farm in in 2016.

Date	Sample	P - PO$_4$ (mg/L)	PO$_4$ (mg/L)		Date	Sample	P - PO$_4$ (mg/L)	PO$_4$ (mg/L)
24 May 2016	Tile 0	-	-		17 June 2016	Tile 0	-	-
	Tile 1	0.1	0.2			Tile 1	-	-
	Tile 2	0.1	0.3			Tile 2	-	-
	Tile 3	0.1	0.3			Tile 3	-	-
	Tile 4	0.0	0.1			Tile 4	-	-
	Tile 5	0.0	0.1			Tile 5	-	-
	Spring 1	0.1	0.2			Spring 1	0.0	0.1
	Spring 7	-	-			Spring 7	0.0	0.1
	Spring 2	0.0	0.1			Spring 2	0.0	0.1
	Spring 3	0.0	0.0			Spring 3	0.0	0.1
	Spring 4	0.0	0.1			Spring 4	0.0	0.1
	Spring 5	-	-			Spring 5	-	-
	Spring 6 (C)	0.1	0.2			Spring 6 (C)	0.1	0.3
	Spring 8	-	-			Spring 8	-	-
	Trib Tile 1	0.0	0.1			trib at tile 1	0.0	0.0
	Trib 1E	0.0	0.0			Trib 1E	-	-
	Trib 3E	0.0	0.0			Trib 3E	-	-
	Trib 6E	0.0	0.0			Trib 6E	0.0	0.1
	Trib 9E	0.0	0.0			Trib 9E	0.0	0.0
	Trib 10E	-	-			Trib 10E	-	-
	Trib 13E	-	-			Trib 13E	-	-
	Trib 14E	0.0	0.0			Trib 14E	-	-
	MR-L	-	-			MR-L	-	-
	MR-R	-	-			MR-R	-	-
	MR-Con	-	-			MR-Con	-	-
	MR-Cul	-	-			MR-Cul	-	-
	Trib 0W	-	-			Trib 0W	-	-
	Trib 2W	0.0	0.1			Trib 2W	0.1	0.2
	N. Branch Outlet	-	-			N. Branch Outlet	-	-
	N. Branch	-	-			N. branch	0.0	0.1
	C. Branch	-	-			C. branch	0.0	0.0
	S. Branch Corn	-	-			S. Branch Corn	-	-
	S. Branch Outlet	-	-			S. Branch Outlet	0.1	0.2
	Big Runoff	2.7	8.3			Big Runoff	0.0	0.0
	Trib 5W	0.0	0.1			Trib 5W	-	-
	Trib 7W	0.1	0.2			Trib 7W	0.0	0.1
	Trib 8W	0.1	0.2			Trib 8W	-	-
	Trib 10d	-	-			Trib 10d	-	-
	Trib 11W	0.0	0.1			Trib 11W	-	-
	Trib12W	0.1	0.2			Trib 12W	0.1	0.2
	Trib 15W	0.0	0.1			Trib 15W	0.1	0.3
	Trib 16W	-	-			Trib 16W	-	-
	Steel Bridge	0.0	0.0			Steel bridge	-	-
	MC Tile 1	-	0.0			MC tile 1	0.0	0.1
	MC 2W	0.0	0.0			MC 2W	-	-
	MC 3E	-	-			MC 3E	-	-
	MC 5W	-	-			MC 5W	-	-
	MC 6E	0.0	0.1			MC 6E	-	-
	MC 9E	-	-			MC 9E	-	-
	MC 11W	0.0	0.0			Trib 11W	0.1	0.2
	MC 13E	0.0	0.0			Trib 13E	-	-
	MC 14E	-	-			Trib 14E	-	-
	MC 15W	-	-			MC 15W	0.0	0.1
	MC XSF	-	0.0			MC XSF	-	-
	Pig Lagoon	-	-			Pig Lagoon	-	-
	Cow Lagoon	-	-			Cow Lagoon	-	-
	LYS 1	-	-			LYS 1	-	-
	Runoff 1A	0.2	-			Runoff 1A	-	-

Table A3, Continued.

Date	Sample	P - PO$_4$ (mg/L)	PO$_4$ (mg/L)		Date	Sample	P - PO$_4$ (mg/L)	PO$_4$ (mg/L)
24 June 2016	Tile 0	0.0	0.1		8 July 2016	Tile 0	-	-
	Tile 1	0.1	0.2			Tile 1	-	-
	Tile 2	-	-			Tile 2	-	-
	Tile 3	-	-			Tile 3	-	-
	Tile 4	-	-			Tile 4	-	-
	Tile 5	-	-			Tile 5	-	-
	Spring 1	0.1	0.2			Spring 1	-	-
	Spring 7	0.0	0.1			Spring 7	-	-
	Spring 2	0.0	0.1			Spring 2	0.0	0.0
	Spring 3	0.0	0.1			Spring 3	0.0	0.0
	Spring 4	0.1	0.3			Spring 4	0.0	0.0
	Spring 5	-	-			Spring 5	-	-
	Spring 6 (C)	0.1	0.3			Spring 6 (C)	-	-
	Spring 8	0.0	0.0			Spring 8	-	-
	Trib Tile 1	-	-			Trib Tile 1	-	-
	Trib 1E	-	-			Trib 1E	-	-
	Trib 3E	0.0	0.0			Trib 3E	-	-
	Trib 6E	0.1	0.2			Trib 6E	0.0	0.0
	Trib 9E	0.0	0.1			Trib 9E	0.0	0.0
	Trib 10E	-	-			Trib 10E	-	-
	Trib 13E	0.0	0.1			Trib 13E	0.0	0.0
	Trib 14E	-	-			Trib 14E	-	-
	MR-L	0.0	0.0			MR-up L	-	-
	MR-R	0.0	0.0			MR-up R	-	-
	MR-Con	0.0	0.0			MR-Con	-	-
	MR-Cul	0.0	0.1			MR Cul	-	-
	0W	0.0	0.1			Trib 0W	-	-
	Trib 2W	-	-			Trib 2W	-	-
	N. Branch Outlet	0.5	1.4			N. Branch Outlet	0.0	0.0
	N. Branch	0.0	0.1			N. Branch	-	-
	C. Branch	0.0	0.0			C. Branch	0.0	0.0
	S. Branch Corn	0.1	0.3			S. Branch Corn	0.0	0.0
	S. Branch Outlet	0.2	0.7			S. Branch Outlet	0.0	0.0
	Big Runoff	0.1	0.2			Big Runoff	0.0	0.0
	Trib 5W	0.1	0.3			Trib 5W	0.0	0.0
	Trib 7W	-	-			Trib 7W	0.0	0.0
	Trib 8W	0.1	0.2			Trib 8W	0.0	0.0
	Trib 10d	-	-			Trib 10d	0.2	0.6
	Trib 11W	0.1	0.3			Trib 11W	0.0	0.0
	Trib12W	0.0	0.1			Trib 12W	0.0	0.0
	Trib 15W	0.1	0.3			Trib 15W	0.0	0.0
	Trib 16W	-	-			Trib 16W	-	-
	Steel Bridge	0.0	0.1			Steel Bridge	-	-
	MC Tile 1	-	-			MC Tile 1	-	-
	MC 2W	-	-			MC 2W	0.0	0.0
	MC 3E	-	-			MC 3E	-	-
	MC 5W	-	-			MC 5W	0.0	0.0
	MC 6E	0.0	0.1			MC 6E	0.0	0.0
	MC 9E	-	0.1			MC 9E	0.0	0.0
	MC 11W	0.0	0.1			MC 11W	0.0	0.0
	MC 13E	0.1	0.2			MC 13E	0.0	0.0
	MC 14E	-	-			MC 14E	-	-
	MC 15W	-	-			MC 15W	-	-
	MC XSF	0.1	0.2			MC XSF	0.0	0.0
	Pig Lagoon	0.0	0.0			Pig Lagoon	-	-
	Cow Lagoon	-	-			Cow Lagoon	-	-
	LYS 1	0.2	0.7			LYS 1	0.05423	0.16625
	Runoff 1A	-	-			Runoff 1A	-	-

Table A3, Continued.

Date	Sample	P - PO_4 (mg/L)	PO_4 (mg/L)		Date	Sample	P - PO_4 (mg/L)	PO_4 (mg/L)
27 July 2016	Tile 0	-	-		17 Aug 2016	Tile 0	0.0	0.1
	Tile 1	-	-			Tile 1	-	-
	Tile 2	-	-			Tile 2	-	-
	Tile 3	-	-			Tile 3	-	-
	Tile 4	-	-			Tile 4	-	-
	Tile 5	-	-			Tile 5	-	-
	Spring 1	0.1	0.2			Spring 1	0.1	0.3
	Spring 7	-	-			Spring 7	-	-
	Spring 2	-	-			Spring 2	-	-
	Spring 3	-	-			Spring 3	-	-
	Spring 4	-	-			Spring 4	-	-
	Spring 5	-				Spring 5	0.2	0.7
	Spring 6 (C)	-	0.2			Spring 6 (C)	0.1	0.3
	Spring 8	-	-			Spring 8	-	-
	Trib Tile 1	-	-			trib at tile 1	0.0	0.0
	1E	-	-			Trib 1E	-	-
	3E	-	-			Trib 3E	0.0	0.0
	6E	-	-			Trib 6E	0.0	0.1
	9E	-	-			Trib 9E	0.0	0.1
	Trib 10E	-	-			Trib 10E	-	-
	Trib 13E	-	-			Trib 13E	0.0	0.0
	Trib 14E	-	-			Trib 14E	-	-
	MR-L	-	-			MR-L	0.0	0.1
	MR-R	-	-			MR-R	0.0	0.0
	MR-Con	-	-			MR-Con	0.0	0.0
	MR-Cul	-	-			MR-Cul	0.0	0.0
	Trib 0W	-	-			Trib 0W	0.0	0.0
	Trib 2W	-	-			Trib 2W	-	-
	N. Branch Outlet	0.1	0.4			N. Branch Outlet	0.1	0.4
	N. Branch	-	-			N. Branch	0.1	0.2
	C. Branch	-	-			C. Branch	0.1	0.2
	S. Branch Corn	-	-			S. Branch Corn	0.4	1.1
	S. Branch Outlet	0.6	1.9			S. Branch Outlet	0.4	1.2
	Big Runoff	0.1	0.4			Big Runoff	-	-
	Trib 5W	-	-			Trib 5W	0.0	0.1
	Trib 7W	-	-			Trib 7W	0.0	0.1
	Trib 8W	-	-			Trib 8W	0.1	0.2
	Trib 10d	-	-			Trib 10d	-	-
	Trib 11W	-	-			Trib 11W	0.1	0.2
	Trib 12W	-	-			Trib 12W	0.0	0.1
	Trib 15W	-	-			Trib 15W	-	-
	Trib 16W	-	-			Trib 16W	-	-
	Steel Bridge	-	-			Steel bridge	0.0	0.1
	MC Tile 1	-	-			MC tile 1	-	-
	MC 2W	-	-			MC 2W	0.0	0.1
	MC 3E	-	-			MC 3E	-	-
	MC 5W	-	-			MC 5W	0.0	0.1
	MC 6E	-	-			MC 6E	0.1	0.2
	MC 9E	-	-			MC 9E	0.0	0.0
	MC 11W	-	-			MC 11W	0.0	0.0
	MC 13E	-	-			MC 13E	0.0	0.1
	MC 14E	-	-			MC 14E	0.0	0.0
	MC 15W	-	-			MC 15W	-	-
	MC XSF	-	-			MC XSF	0.1	0.3
	Pig Lagoon	-	-			Pig Lagoon	0.0	0.0
	Cow Lagoon	-	-			Cow Lagoon	15.0	46
	LYS 1	-	-			LYS 1	-	-
	Runoff 1A	-	-			Runoff 1A	-	-

Figure A1. Phosphate concentration graphs for samples taken at and around Eastern Kentucky University's Meadowbrook Farm in in 2016.

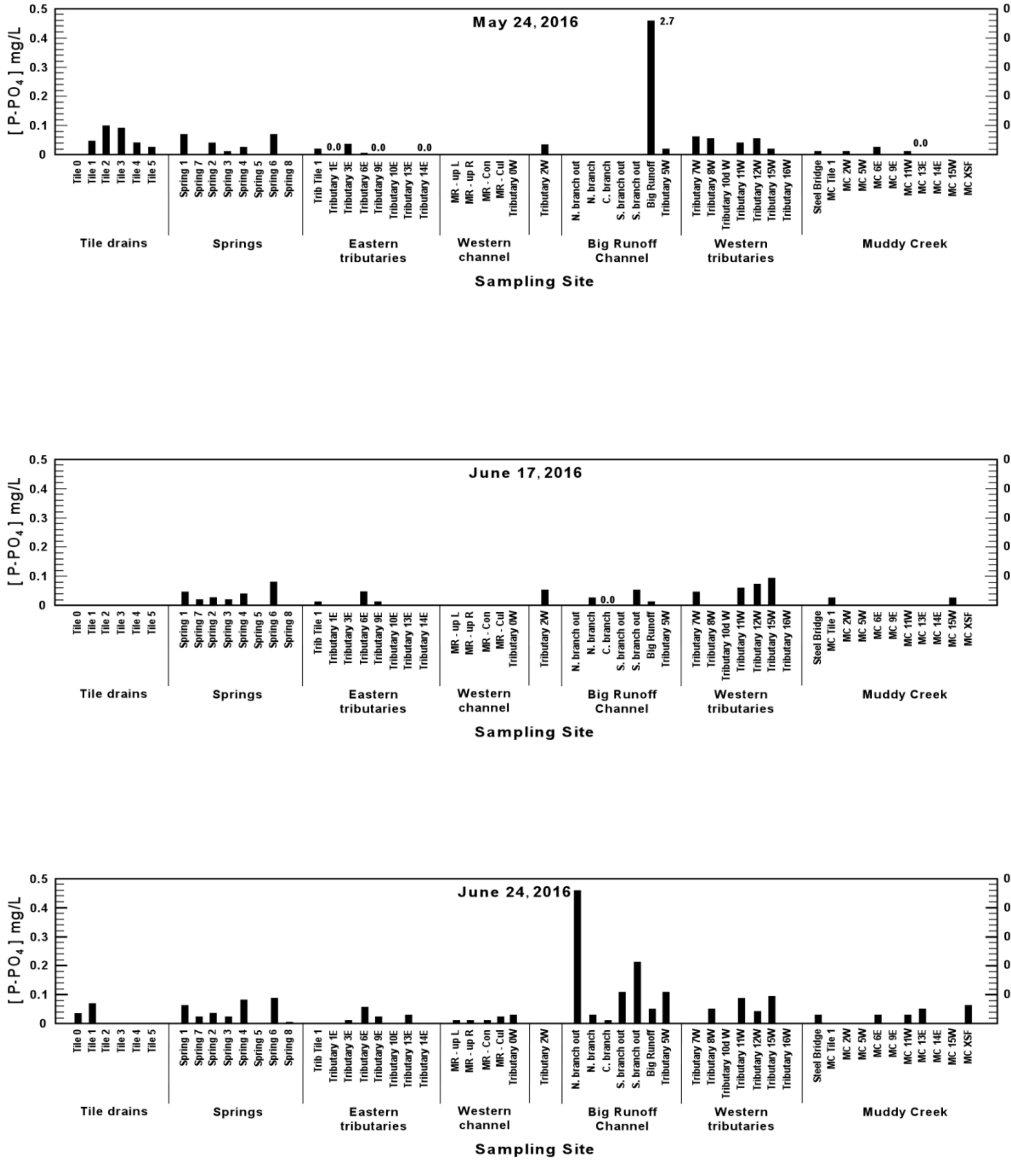

Figure A1, Continued.