NUTRIENT LOADS IN BIG CREEK UP AND DOWNSTREAM OF C&H FARM

Contents

Summary

1. Water discharge and nutrient load in Big Creek was monitored starting in May 2014, when USGS installed a gaging station at BC7 (USGS 07055790 Big Creek near Mt. Judea, AR). Discharge and loads are determined on a climate year basis of May 1 to April 30.

2. The two largest storms occurring during each of the 5-year monitoring accounted for 44, 49, 37, and 42% of the total 5-year load of dissolved P, total P, nitrate-N, and total N, respectively, and 43% of discharge measured at BC7. At the upstream site (BC6), these same storms comprised 45, 47, 42, and 44% of dissolved P, total P, nitrate-N, and total N load, respectively, and 43% of total discharge.

3. During these large storm events, the monitored application fields BC5a and BC12 were mostly flooded as Big Creek breached its banks. Thus, the effectiveness of conservation practices, such as buffer strips or no-application zones for slurry would have little impact on the conservation of nutrients or limiting their movement to Big Creek, under such extreme flow events.

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Discharge Determination

Water discharge was measured at 15 minute intervals at the downstream site (BC7) on Big Creek, starting in May, 2014, when USGS installed a gaging station at BC7; USGS 07055790 Big Creek near Mt. Judea, AR (see https://nwis.waterdata.usgs.gov/ar/nwis/uv/?cb_00065=on&cb_00045=on&cb_00010=on&format=gif_default&period=&begin_date=2014-04-16&end_date=2014-04-23&site_no=07055790). As detailed earlier in this Final Report, gaging of the upstream site was not possible and USGS used a watershed area ratio for BC6 to BC7 of 0.66 to estimate upstream discharge (i.e., the upstream drainage area of 27.1 sq. mi divided by the downstream drainage area of 40.8 sq. mi). While not ideal, it proved to be the sole option available.

Storm flow samples were collected by ISCO autosamplers and base flow samples collected manually at weekly to biweekly intervals at up and downstream sites (BC6 and BC7). More information on sample collection and analysis is available in the first section (see "Method of Water Flow Measurement, Sample Collection, and Constituent Analysis") of this final report. Discharge and loads are determined on a climate year basis of May 1 to April 30.

Nutrient Load Estimation Using LOADEST

Nutrient loads in Big Creek were determined by the USGS tool LOAD ESTimator (LOADEST), which uses RStudio to estimate constituent loads in streams and rivers (https://water.usgs.gov/software/loadest/; Runkel, 2013; Runkel et al., 2004). LOADEST is based on two previously undocumented software programs known unofficially as LOADEST2 and ESTIMATOR [see Crawford (1996) and Cohn (1988) for relevant details]. Given a time series of streamflow, additional data variables, and constituent concentration, LOADEST assists the user in developing a regression model for the estimation of constituent load (calibration).

The calibration and estimation procedures within LOADEST are based on three statistical estimation methods. The first two methods, Adjusted Maximum Likelihood Estimation (AMLE) and Maximum Likelihood Estimation (MLE), are appropriate when the calibration model errors (residuals) are normally distributed (Runkel et al., 2004). Of the two, AMLE is the method of choice when the calibration data set (time series of streamflow, additional data variables, and concentration) contains censored data. The third method, Least Absolute Deviation (LAD), is an alternative to maximum likelihood estimation when the residuals are not normally distributed. LOADEST output includes diagnostic tests and warnings to assist the user in determining the appropriate estimation method and in interpreting the estimated loads. The LOADEST package tests many different regression models with different combinations of explanatory variables and selects the best model by minimization of the Akaike Information Criterion (AIC) (Runkel et al., 2004).

We selected Model 3 based on the lowest AIC value for Total P and N estimates for climate year 2015 (Table 1). We eliminated Models 2 and 9 from consideration as they had abnormally high load estimates due to the quadratic equation applied to flow used in these two models (see annual load estimates for each model in Table 1). Model 3 was selected over Model 4, which had similar AIC and

AMLE metric values (Table 1), as Model 3 was simpler than Model 4 and it includes a seasonality / time variable, which was highly significant (p-value for the time coefficient was 0.0001).

Explanatory variables within the regression model include various functions of streamflow, decimal time, and additional user-specified data variables. The formulated regression model is then used to estimate loads over a user-specified time interval (estimation) (Runkel et al., 2004). Mean load estimates, standard errors, and 95 percent confidence intervals are developed on a monthly and (or) seasonal basis.

We worked with USGS personnel in Little Rock, AR to develop and implement the R script used at the Carver site (USGS site 07055814 Big Creek at Carver, AR: https://waterdata.usgs.gov/ar/nwis/uv?site_no=07055814) for the BCRET downstream (BC7) site (i.e., USGS site 07055790 Big Creek near Mt. Judea, AR: https://waterdata.usgs.gov/ar/nwis/uv?site_no=07055790).

Nutrient Loading of Big Creek

Monthly discharge and nutrient flux varied dramatically over the 5-year monitoring period but the dominance of the large storm events on May 11 and December 26, 2005 is clear (Table 2). Discharge during these two large storms (Figure 1) contributed to in the two highest monthly discharge at the monitored sites on Big Creek (978 and 845 cubic feet/second for May and December 2015, respectively, at BC7). On a climate year basis (i.e., May 1 to April 30), the variance in rainfall and Big Creek flow led to a wide variation in annual dissolved P, total P, nitrate-N, and total N flux at both the up and downstream sites BC6 and BC7 (Figure 2).

The two largest storms occurring during each of the 5-year monitoring accounted for 44, 49, 37, and 42% of the total 5-year load of dissolved P, total P, nitrate-N, and total N, respectively, and 43% of discharge measured at BC7. At the upstream site (BC6), these same storms comprised 45, 47, 42, and 44% of dissolved P, total P, nitrate-N, and total N load, respectively, and 43% of total discharge.

The dominance of a few large rainfall and thus, flow events over extended periods of monitoring is found in many watersheds across the U.S. and overseas (Haygarth et al., 1998; Ockenden et al., 2017; Pionke et al., 1996) and is certainly not unique to the Big Creek or Buffalo River Watershed. During these large storm events, the monitored application fields BC5a and BC12 were mostly flooded as Big Creek breached its banks. Thus, the effectiveness of conservation practices such as buffer strips or no-application zones for slurry would have little impact on the conservation of nutrients or limiting their movement to Big Creek, under such extreme flow events.

Supplementary Table S1 gives monthly discharge and nutrient loads at the up- (BC6) and downstream (BC7) sites. Supplementary Tables S2 and S4 present annual nutrient loss (tons) and loads (lbs/ac), respectively, and in Tables S2 and S4 as Mg (i.e., 1,000 kg) and g/ha, respectively. The difference in nutrient load between up (BC6) and downstream sites (BC7) is depicted in Supplementary Figures S 1 and 2 for P and N forms, respectively. A slight decrease in particulate P was observed between up and downstream sites (i.e., BC6 and BC7) in 2015, a year which had the lowest annual flow (1,528 cubic feet*10^6) compared with the other monitored years (1,908 to 3,344 cubic feet*10^6; Table 3).

The decrease particulate P is likely due to a greater in-channel deposition of sediment in 2015, which would probably be resuspended during subsequent high flow storm events. A similar decrease in particulate N was not observed, due to a greater proportion of organic N rather than sediment bound forms (as in the case of P). These lighter, less dense organic particles and colloids are less likely to be deposited in the stream channel, even under low flow conditions.

Stream discharge and percent water-year loss of P and N on a monthly basis are depicted in Supplementary Figures S3 and S4, respectively. Cumulative flows and P and N loads at the up and downstream sites are presented in Supplementary Figures S5, S6, and S7, respectively.

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Acknowledgement

The Big Creek Research and Extension Team acknowledge and are extremely grateful to Brian Breaker (formerly U.S. Geological Survey) for advice and help in conducting, analyzing, and interpreting nutrient load estimations for Big Creek using LOADEST. His vast experience informed and provided state of the science estimation of constituent loads.

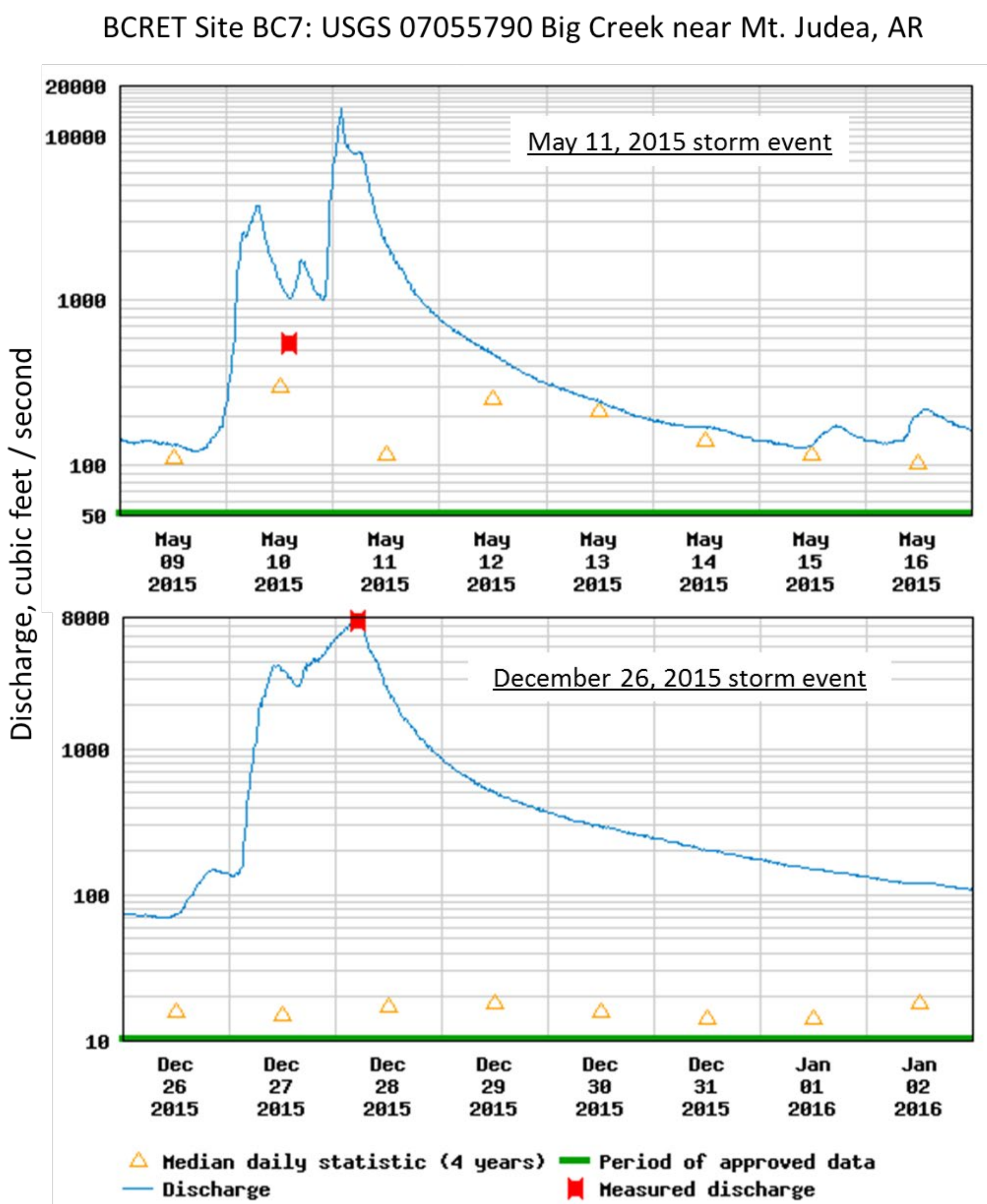

Figure 1. Discharge at BC7 (USGS 07055790 Big Creek near Mt. Judea, AR) downstream of the C&H Farm for the May 11 and December 26, 2015 storm events.

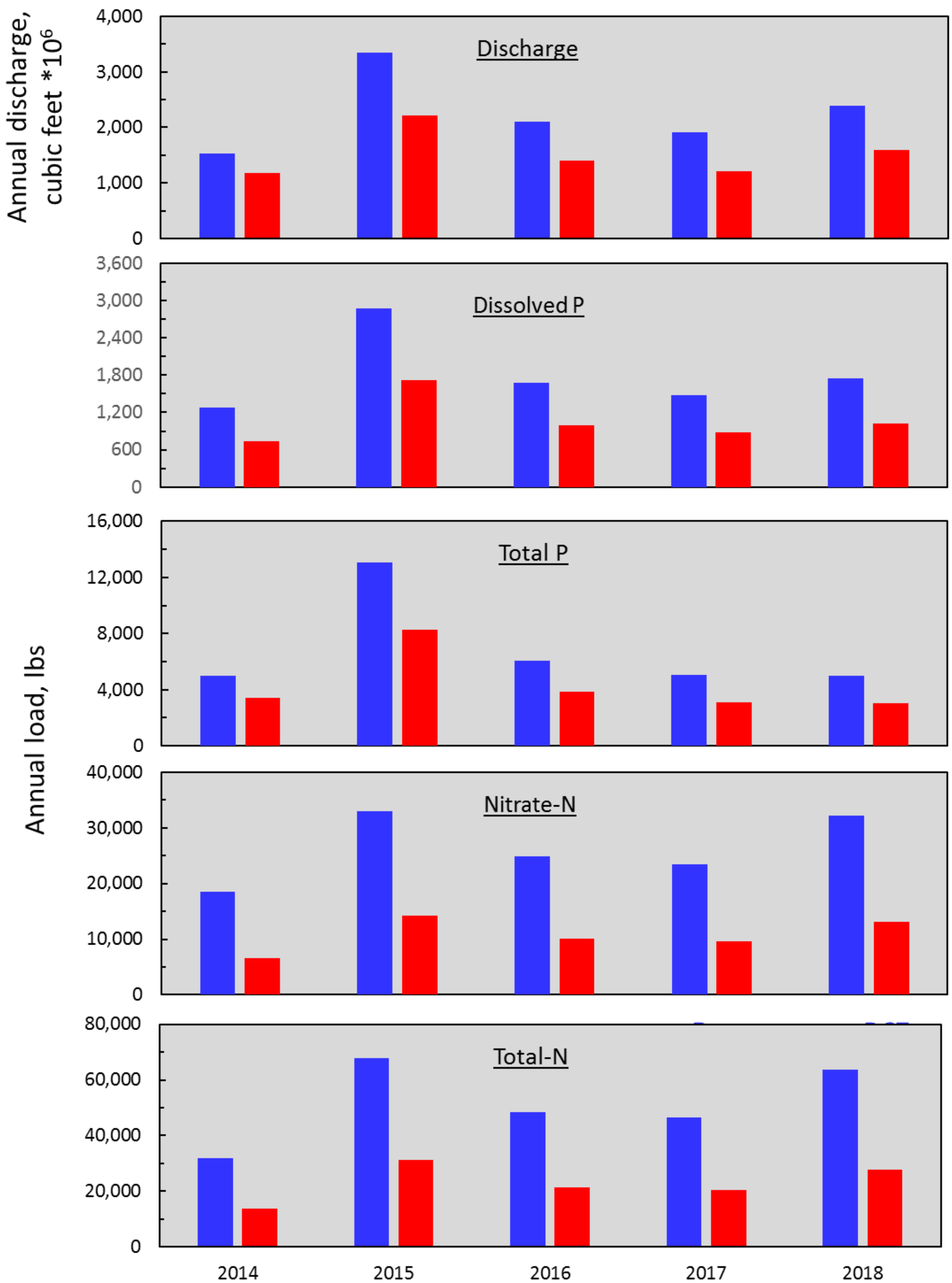

Figure 2. Annual discharge and load of phosphorus and nitrogen up- (BC6) and downstream (BC7) of the C&H Farm (water-year basis; May 1 to April 30).

Table 1. Akaike Information Criteria (AIC) and Adjusted Maximum Likelihood Estimation (AMLE) was used to select the most appropriate model to estimate chemical constituent loads at the site downstream of the C&H Farm (BC7) for climate year 2015 (i.e., May 1. 2015 to April 30, 2016).

Model	Total P and N load for climate year 2015	AIC	AMLE regression statistics	
			Residual variance	R^2
Regression model †				
1	$a_0 + a_1 lnQ$			
2	$a_0 + a_1 lnQ + a_2 lnQ^2$			
3	$a_0 + a_1 lnQ + a_2 dtime$			
4	$a_0 + a_1 lnQ + a_2 sin(2\pi dtime) + a_3 cos(2\pi dtime)$			
9	$a_0 + a_1 lnQ + a_2 lnQ^2 + a_3 sin(2\pi dtime) + a_4 cos(2\pi dtime) + a_5 dtime + a_6 dtime^2$			
Total P, lbs				
1	18,124,156	445.7	0.3475	91.79
2	68,639,195	391.4	0.2714	93.50
3	21,025,214	415.0	0.3053	92.83
4	23,311,620	422.3	0.3140	92.67
9	85,907,930	325.7	0.2044	95.20
Total N, lbs				
1	78,754,748	283.4	0.1858	93.76
2	235,549,647	204.3	0.1334	95.53
3	71,847,289	269.3	0.1745	94.16
4	101,492,646	249.1	0.1599	94.67
9	231,481,266	155.5	0.1073	96.47

† Equation parameters are; I, Integer; lnQ = ln(streamflow) - center of ln(streamflow); dtime = decimal time - center of decimal time; per = period, 1 or 0 depending on defined period. From Runkel et al. (2004).

Table 2. Monthly flow and nutrient loss for the downstream (BC7) sampling site and percent of annual value, based on a climate year (i.e., May 1 to April 30).

Month and year	Flow		Dissolved P		Total P		Nitrate-N		Total N	
	Volume	Percent of annual	Loss	Percent of annual	Loss	Percent of annual	Loss	Percent of annual	Loss	Percent of annual
	$ft^3 *10^6$	%	lbs	%	lbs	%	lbs	%	lbs	%
Climate year 2014										
May, 2014	178	11.6	151	11.8	612	12.3	2,090	11.3	3,583	11.2
June, 2014	70	4.6	57	4.5	189	3.8	1,029	5.6	1,539	4.8
July, 2014	133	8.7	111	8.7	414	8.3	1,700	9.2	2,797	8.7
August, 2014	31	2.0	24	1.9	70	1.4	536	2.9	726	2.3
September, 2014	8	0.5	6	0.5	14	0.3	189	1.0	213	0.7
October, 2014	60	4.0	49	3.8	177	3.6	827	4.5	1,308	4.1
November, 2014	15	1.0	12	0.9	29	0.6	313	1.7	387	1.2
December, 2014	60	3.9	47	3.7	146	2.9	919	5.0	1,363	4.3
January, 2015	156	10.2	132	10.4	540	10.9	1,811	9.8	3,229	10.1
February, 2015	52	3.4	41	3.2	128	2.6	798	4.3	1,196	3.7
March, 2015	510	33.3	435	34.1	1,855	37.3	5,233	28.4	10,256	32.1
April, 2015	254	16.6	210	16.5	798	16.0	3,001	16.3	5,394	16.9
Sum	**1,528**		**1,275**		**4,972**		**18,446**		**31,991**	

Month and year	Flow		Dissolved P		Total P		Nitrate-N		Total N	
	Volume	Percent of annual	Loss	Percent of annual	Loss	Percent of annual	Loss	Percent of annual	Loss	Percent of annual
	$ft^3 *10^6$	%	lbs	%	lbs	%	lbs	%	lbs	%
Climate year 2015										
May, 2015	978	29.2	874	30.5	4,551	34.8	8,102	24.6	18,321	27.1
June, 2015	220	6.6	181	6.3	685	5.2	2,625	8.0	4,723	7.0
July, 2015	330	9.9	280	9.8	1,190	9.1	3,416	10.4	6,747	10.0
August, 2015	9	0.0	6	0.2	13	0.1	208	0.6	242	0.4
September, 2015	7	0.0	5	0.2	10	0.1	175	0.5	198	0.3
October, 2015	4	0.0	3	0.1	5	0.0	111	0.3	118	0.2
November, 2015	161	4.8	134	4.7	527	4.0	1,793	5.4	3,444	5.1
December, 2015	845	25.3	746	26.0	3,809	29.1	6,922	21.0	16,238	24.0
January, 2016	140	4.2	110	3.8	350	2.7	1,955	5.9	3,275	4.8
February, 2016	68	2.0	52	1.8	155	1.2	1,041	3.2	1,641	2.4
March, 2016	438	13.1	361	12.6	1,418	10.8	4,702	14.3	9,401	13.9
April, 2016	143	4.3	113	3.9	372	2.8	1,923	5.8	3,339	4.9
Sum	**3,344**		**2,865**		**13,085**		**32,973**		**67,687**	
Climate year 2016										
May, 2016	328	15.6	265	15.8	964	16.0	3,828	15.4	7,323	15.1

Month and year	Flow		Dissolved P		Total P		Nitrate-N		Total N	
	Volume	Percent of annual	Loss	Percent of annual	Loss	Percent of annual	Loss	Percent of annual	Loss	Percent of annual
	$ft^3 * 10^6$	%	lbs	%	lbs	%	lbs	%	lbs	%
June, 2016	57	2.7	43	2.6	122	2.0	923	3.7	1,436	3.0
July, 2016	17	0.8	12	0.7	28	0.5	369	1.5	482	1.0
August, 2016	238	11.3	188	11.2	641	10.6	2,955	11.9	5,486	11.3
September, 2016	41	2.0	30	1.8	81	1.3	720	2.9	1,077	2.2
October, 2016	14	0.7	10	0.6	20	0.3	319	1.3	401	0.8
November, 2016	18	0.8	12	0.7	28	0.5	368	1.5	493	1.0
December, 2016	27	1.3	19	1.1	42	0.7	542	2.2	743	1.5
January, 2017	49	2.3	35	2.1	91	1.5	843	3.4	1,287	2.7
February, 2017	76	3.6	56	3.3	152	2.5	1,217	4.9	1,969	4.1
March, 2017	428	20.3	340	20.3	1,232	20.4	4,809	19.3	9,816	20.3
April, 2017	813	38.6	662	39.6	2,639	43.7	8,022	32.2	17,097	37.0
Sum	**2,106**		**1,672**		**6,040**		**24,915**		**48,420**	
Climate year 2017										
May, 2017	491	25.7	390	26.3	1,412	28.0	5,474	23.4	11,325	24.4
June, 2017	350	18.4	283	19.1	1,103	21.9	3,647	15.6	7,879	17.0
July, 2017	60	3.2	44	3.0	111	2.2	1,027	4.4	1,627	3.5

Month and year	Flow		Dissolved P		Total P		Nitrate-N		Total N	
	Volume	Percent of annual	Loss	Percent of annual	Loss	Percent of annual	Loss	Percent of annual	Loss	Percent of annual
	$ft^3 *10^6$	%	lbs	%	lbs	%	lbs	%	lbs	%
August, 2017	51	2.7	37	2.5	92	1.8	894	3.8	1,401	3.0
September, 2017	10	0.5	6	0.4	12	0.2	243	1.0	301	0.6
October, 2017	6	0.3	4	0.3	6	0.1	160	0.7	183	0.4
November, 2017	8	0.4	5	0.3	9	0.2	210	0.9	251	0.5
December, 2017	6	0.3	9	0.6	18	0.4	323	1.4	425	0.9
January, 2018	32	1.7	22	1.5	47	0.9	633	2.7	927	2.0
February, 2018	395	20.7	310	20.9	1,120	22.2	4,193	17.9	9,305	20.1
March, 2018	200	10.5	149	10.1	455	9.0	2,635	11.3	5,088	11.0
April, 2018	300	15.7	223	15.0	661	13.1	3,957	16.9	7,688	16.6
Sum	**1,908**		**1,482**		**5,046**		**23,396**		**46,400**	
Climate year 2018										
May, 2018	215	9.0	161	9.2	492	9.8	2,813	8.8	5,496	8.6
June, 2018	51	2.2	36	2.1	89	1.8	893	2.8	1,456	2.3
July, 2018	7	0.3	4	0.2	7	0.1	195	0.6	232	0.4
August, 2018	26	1.1	18	1.0	39	0.8	510	1.6	779	1.2
September, 2018	17	0.7	11	0.6	20	0.4	392	1.2	536	0.8

Month and year	Flow		Dissolved P		Total P		Nitrate-N		Total N	
	Volume	Percent of annual	Loss	Percent of annual	Loss	Percent of annual	Loss	Percent of annual	Loss	Percent of annual
	$ft^3 * 10^6$	%	lbs	%	lbs	%	lbs	%	lbs	%
October, 2018	82	3.4	58	3.3	143	2.9	1,363	4.2	2,338	3.7
November, 2018	184	7.7	134	7.7	379	7.6	2,564	8.0	4,932	7.7
December, 2018	304	12.7	223	12.8	643	12.9	4,013	12.5	8,071	12.7
January, 2019	399	16.7	293	16.8	859	17.2	5,133	16.0	10,528	16.5
February, 2019	490	20.5	364	20.9	1,113	22.3	5,911	18.4	12,707	19.9
March, 2019	183	7.7	128	7.3	312	6.2	2,859	8.9	5,215	8.2
April, 2019	429	18.0	313	18.0	902	18.0	5,492	17.1	11,457	18.0
Sum	**2,388**		**1,743**		**4,998**		**32,138**		**63,747**	

Table 3. Annual flow (million cubic feet) and nutrient loss (lbs) for the upstream (BC6) and downstream (BC7) sampling sites and difference between these two sites, based on a climate year (i.e., May 1 to April 30).

Parameter	2014	2015	2016	2017	2018
Flow, cubic feet * 10^6					
Upstream	1,185	2,221	1,399	1,207	1,586
Downstream	1,528	3,344	2,106	1,908	2,388
Difference	344	1,123	707	702	802
Dissolved P, lbs					
Upstream	738	1,714	988	878	1,024
Downstream	1,275	2,865	1,672	1,482	1,743
Difference	537	1,151	684	604	719
Particulate P, lbs [1]					
Upstream	2,709	6,567	2,847	2,247	2,025
Downstream	3,697	10,220	4,368	3,564	3,255
Difference	988	3,653	1,521	1,317	1,230
Total P, lbs					
Upstream	3,447	8,281	3,835	3,125	3,049
Downstream	4,972	13,085	6,040	5,046	4,998
Difference	1,525	4,084	2,205	1,921	1,949
Nitrate-N, lbs					
Upstream	6,552	14,218	10,041	9,627	13,152
Downstream	18,446	32,973	24,915	23,396	32,138
Difference	11,894	18,755	14,874	13,769	18,986
Particulate N, lbs [2]					
Upstream	7,035	17,059	11,340	10,875	14,452
Downstream	13,545	34,714	23,505	23,004	31,609
Difference	6,510	17,655	12,165	12,129	17,157

Parameter	2014	2015	2016	2017	2018
Total N, lbs					
Upstream	13,587	31,277	21,381	20,502	27,604
Downstream	31,991	67,687	48,420	46,400	63,747
Difference	18,404	36,410	27,039	25,898	36,143

[1] Particulate P is estimated as the difference between dissolved P and total P.

[2] Particulate N is estimated as the difference between nitrate-N and total N. Monitoring shows ammonium-N to be negligible in Big Creek.

Supplementary Tables and Figures

Table S 1. Monthly and annual flow (million cubic feet) and nutrient loss (lbs) for the upstream (BC6) and downstream (BC7) sampling sites, based on a climate year (i.e., May 1 to April 30).

Month and year	Flow		Dissolved P		Total P		Nitrate-N		Total N	
	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
	$ft^3 *10^6$		- lbs -							
Climate year 2014										
May, 2014	118	178	87	151	434	612	733	2,090	1,517	3,583
June, 2014	47	70	32	57	141	189	308	1,029	604	1,539
July, 2014	89	133	64	111	298	414	568	1,700	1,154	2,797
August, 2014	21	31	13	24	54	70	143	536	270	726
September, 2014	5	8	3	6	11	14	41	189	72	213
October, 2014	40	60	28	49	127	177	264	827	531	1,308
November, 2014	10	15	6	12	23	29	75	313	137	387
December, 2014	40	60	26	47	108	146	272	919	530	1,363
January, 2015	104	156	77	132	367	540	664	1,811	1,394	3,229
February, 2015	35	52	23	41	94	128	239	798	468	1,196
March, 2015	338	510	257	435	1,240	1,855	2,137	5,233	4,600	10,256
April, 2015	169	254	122	210	550	798	1,108	3,001	2,310	5,394
Sum	**1,185**	**1,528**	**738**	**1,275**	**3,447**	**4,972**	**6,552**	**18,446**	**13,587**	**31,991**

Month and year	Flow		Dissolved P		Total P		Nitrate-N		Total N	
	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
	$ft^3 * 10^6$		----------------------------------- lbs -----------------------------------							
Climate year 2015										
May, 2015	650	978	530	874	2,831	4,551	3,907	8,102	8,899	18,321
June, 2015	146	220	106	181	468	685	970	2,625	2,024	4,723
July, 2015	219	330	166	280	782	1,190	1,408	3,416	3,041	6,747
August, 2015	6	9	3	6	11	13	46	208	82	242
September, 2015	5	7	3	5	8	10	38	175	66	198
October, 2015	3	4	1	3	4	5	22	111	38	118
November, 2015	107	161	79	134	347	527	715	1,793	1,525	3,444
December, 2015	561	845	455	746	2,305	3,809	3,478	6,922	8,002	16,238
January, 2016	93	140	63	110	244	350	664	1,955	1,339	3,275
February, 2016	45	68	30	52	109	155	329	1,041	651	1,641
March, 2016	291	438	213	361	919	1,418	1,960	4,702	4,219	9,401
April, 2016	95	143	65	113	253	372	681	1,923	1,391	3,339
Sum	**2,221**	**3,344**	**1,714**	**2,865**	**8,281**	**13,085**	**14,218**	**32,973**	**31,277**	**67,687**
Climate year 2016										
May, 2016	218	328	155	265	634	964	1,515	3,828	3,202	7,323
June, 2016	38	57	25	43	86	122	287	923	563	1,436

Month and year	Flow		Dissolved P		Total P		Nitrate-N		Total N	
	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
	$ft^3 * 10^6$		----------------------------------- lbs -----------------------------------							
July, 2016	12	17	7	12	21	28	94	369	172	482
August, 2016	158	238	110	188	424	641	1,129	2,955	2,355	5,486
September, 2016	28	41	17	30	57	81	214	720	414	1,077
October, 2016	9	14	5	10	15	20	77	319	140	401
November, 2016	12	18	7	12	20	28	96	368	178	493
December, 2016	18	27	10	19	31	42	145	542	270	743
January, 2017	32	49	20	35	64	91	256	843	496	1,287
February, 2017	51	76	32	56	105	152	395	1,217	780	1,969
March, 2017	284	428	202	340	774	1,232	2,047	4,809	4,405	9.816
April, 2017	540	813	398	662	1,604	2,639	3,786	8,022	8,406	17,907
Sum	**1,399**	**2,106**	**988**	**1,672**	**3,835**	**6,040**	**10,041**	**24,915**	**21,381**	**48,420**
Climate year 2017										
May, 2017	326	491	232	390	880	1,412	2,365	5,474	5,107	11,325
June, 2017	233	350	170	283	669	1,103	1,659	3,647	3,654	7,879
July, 2017	40	60	25	44	76	111	325	1,027	636	1,627
August, 2017	34	51	21	37	63	92	280	894	544	1,401
September, 2017	6	10	3	6	9	12	58	243	103	301

Month and year	Flow		Dissolved P		Total P		Nitrate-N		Total N	
	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
	$ft^3 * 10^6$		------------------------------ lbs ------------------------------							
October, 2017	4	6	2	4	5	6	35	160	60	183
November, 2017	5	8	3	5	6	9	48	210	84	251
December, 2017	9	6	5	9	13	18	82	323	150	425
January, 2018	21	32	12	22	33	47	183	633	345	927
February, 2018	262	395	186	310	670	1,120	1,960	4,193	4,318	9,305
March, 2018	133	200	88	149	285	455	1,048	2,635	2,194	5,088
April, 2018	199	300	131	223	416	661	1,584	3,957	3,307	7,688
Sum	**1,207**	**1,908**	**878**	**1,482**	**3,125**	**5,046**	**9,627**	**23,396**	**20,502**	**46,400**
Climate year 2018										
May, 2018	143	215	95	161	305	492	1,134	2,813	2,383	5,496
June, 2018	34	51	21	36	58	89	292	893	574	1,456
July, 2018	5	7	2	4	5	7	44	195	77	232
August, 2018	17	26	10	18	26	39	154	510	295	779
September, 2018	11	17	6	11	14	20	104	392	191	536
October, 2018	55	82	33	58	92	143	472	1,363	941	2,338
November, 2018	122	184	78	134	234	379	1,013	2,564	2,107	4,932
December, 2018	202	304	131	223	393	643	1,668	4,013	3,512	8,071

Month and year	Flow		Dissolved P		Total P		Nitrate-N		Total N	
	Up	Down	Up	Down	Up	Down	Up	Down	Up	Down
	ft^3 *10^6		- lbs -							
January, 2019	265	399	173	293	520	859	2,182	5,133	4,622	10.528
February, 2019	326	490	216	364	663	1,113	2,652	5,911	5,708	12,707
March, 2019	121	183	74	128	198	312	1,059	2,859	2,141	5,215
April, 2019	285	429	185	313	541	902	2,378	5,492	5,053	11,457
Sum	**1,586**	**2,388**	**1,024**	**1,743**	**3,049**	**4,998**	**13,152**	**32,138**	**27,604**	**63,747**

Table S 2. Annual flow and nutrient loss (tons) for the upstream (BC6), downstream (BC7) sampling sites, and difference between these two sites, based on a climate year (i.e., May 1 to April 30).

Parameter	2014	2015	2016	2017	2018
Flow, cubic feet * 10^6					
Upstream	1,185	2,221	1,399	1,207	1,586
Downstream	1,528	3,344	2,106	1,908	2,388
Difference	344	1,123	707	702	802
Dissolved P, tons					
Upstream	0.37	0.86	0.49	0.44	0.51
Downstream	0.64	1.43	0.84	0.74	0.87
Difference	0.27	0.58	0.34	0.30	0.36
Particulate P, tons [1]					
Upstream	1.35	3.28	1.42	1.12	1.01
Downstream	1.85	5.11	2.18	1.78	1.63
Difference	0.49	1.83	0.76	0.66	0.62
Total P, tons					
Upstream	1.72	4.14	1.92	1.56	1.52
Downstream	2.49	6.54	3.02	2.52	2.50
Difference	0.76	2.04	1.10	0.96	0.97
Nitrate-N, tons					
Upstream	3.28	7.11	5.02	4.81	6.58
Downstream	9.22	16.49	12.46	11.70	16.07
Difference	5.95	9.38	7.44	6.88	9.49
Particulate N, tons [2]					
Upstream	3.52	8.53	5.67	5.44	7.23
Downstream	6.77	17.36	11.75	11.50	15.80
Difference	3.26	8.83	6.08	6.06	8.58
Total N, tons					
Upstream	6.79	15.64	10.69	10.25	13.80
Downstream	16.00	33.84	24.21	23.20	31.87
Difference	9.20	18.21	13.52	12.95	18.07

[1] Particulate P is estimated as the difference between dissolved P and total P.

[2] Particulate N is estimated as the difference between nitrate-N and total N. Monitoring shows ammonium-N to be negligible in Big Creek.

Table S 3. Annual nutrient load (lbs/acre/year) for the upstream (BC6), downstream (BC7) sampling sites, and difference between these two sites, based on a climate year (i.e., May 1 to April 30).

Parameter	2014	2015	2016	2017	2018
Dissolved P, lbs/acre/year					
Upstream	0.042	0.098	0.057	0.050	0.059
Downstream	0.049	0.109	0.064	0.057	0.066
Difference	0.006	0.011	0.007	0.006	0.008
Particulate P, lbs/acre/year [1]					
Upstream	0.155	0.376	0.163	0.129	0.116
Downstream	0.141	0.390	0.167	0.136	0.124
Difference	-0.014	0.014	0.004	0.007	0.008
Total P, lbs/acre/year					
Upstream	0.197	0.474	0.220	0.179	0.175
Downstream	0.190	0.499	0.230	0.192	0.191
Difference	-0.008	0.025	0.011	0.014	0.016
Nitrate-N, lbs/acre/year					
Upstream	0.375	0.814	0.575	0.551	0.753
Downstream	0.703	1.258	0.950	0.892	1.226
Difference	0.328	0.444	0.375	0.341	0.473
Particulate N, lbs/acre/year [2]					
Upstream	0.403	0.976	0.649	0.622	0.827
Downstream	0.517	1.324	0.896	0.877	1.205
Difference	0.114	0.347	0.247	0.255	0.378
Total N, lbs/acre/year					
Upstream	0.778	1.790	1.224	1.173	1.580
Downstream	1.220	2.581	1.847	1.770	2.431
Difference	0.442	0.791	0.623	0.596	0.851

[1] Particulate P is estimated as the difference between dissolved P and total P.

[2] Particulate N is estimated as the difference between nitrate-N and total N. Monitoring shows ammonium-N to be negligible in Big Creek.

Table S 4. Annual flow (million cubic feet) and nutrient loss (Mg) for the upstream (BC6), downstream (BC7) sampling sites, and difference between these two sites, based on a climate year of May 1 to April 31 (i.e., May 1 to April 30).

Parameter	2014	2015	2016	2017	2018
Flow, cubic meter * 10^6					
Upstream	33.6	62.9	39.6	34.2	44.9
Downstream	43.3	94.7	59.6	54.0	67.6
Difference	9.7	31.8	20.0	19.9	22.7
Dissolved P, Mg					
Upstream	0.3	0.8	0.4	0.4	0.5
Downstream	0.6	1.3	0.8	0.7	0.8
Difference	0.2	0.5	0.3	0.3	0.3
Particulate P, Mg [1]					
Upstream	1.2	3.0	1.3	1.0	0.9
Downstream	1.7	4.6	2.0	1.6	1.5
Difference	0.4	1.7	0.7	0.6	0.6
Total P, Mg					
Upstream	1.6	3.8	1.7	1.4	1.4
Downstream	2.3	5.9	2.7	2.3	2.3
Difference	0.7	2.2	1.0	0.9	0.9
Nitrate-N, Mg					
Upstream	3.0	6.4	4.6	4.4	6.0
Downstream	8.4	15.0	11.3	10.6	14.6
Difference	5.4	8.5	6.7	6.2	8.6
Particulate N, Mg [2]					
Upstream	3.2	7.7	5.1	4.9	6.6
Downstream	6.1	15.7	10.7	10.4	14.3
Difference	3.0	8.0	5.5	5.5	7.8
Total N, Mg					
Upstream	6.2	14.2	9.7	9.3	12.5
Downstream	14.5	30.7	22.0	21.0	28.9
Difference	8.3	16.5	12.3	11.7	16.4

[1] Particulate P is estimated as the difference between dissolved P and total P.

[2] Particulate N is estimated as the difference between nitrate-N and total N. Monitoring shows ammonium-N to be negligible in Big Creek.

Table S 5. Annual nutrient load (g/hectare/year) for the upstream (BC6), downstream (BC7) sampling sites and difference between these two sites, based on a climate year of May 1 to April 31 (i.e., May 1 to April 30).

Parameter	2014	2015	2016	2017	2018
Dissolved P, g/ha/yr					
Upstream	38	88	50	45	52
Downstream	43	98	57	50	59
Difference	6	10	6	6	7
Particulate P, g/ha/yr [1]					
Upstream	138	336	146	115	104
Downstream	126	348	149	121	111
Difference	-13	12	3	7	7
Total P, g/ha/yr					
Upstream	176	423	196	160	156
Downstream	169	446	206	172	170
Difference	-7	22	10	12	14
Nitrate-N, g/ha/yr					
Upstream	335	727	513	492	672
Downstream	628	1,123	849	797	1,095
Difference	293	396	335	305	422
Particulate N, g/ha/yr [2]					
Upstream	360	872	580	556	739
Downstream	461	1,182	801	783	1,076
Difference	102	310	221	228	338
Total N, g/ha/yr					
Upstream	694	1,599	1,093	1,048	1,411
Downstream	1,090	2,305	1,649	1,580	2,171
Difference	395	707	556	532	760

[1] Particulate P is estimated as the difference between dissolved P and total P.

[2] Particulate N is estimated as the difference between nitrate-N and total N. Monitoring shows ammonium-N to be negligible in Big Creek.

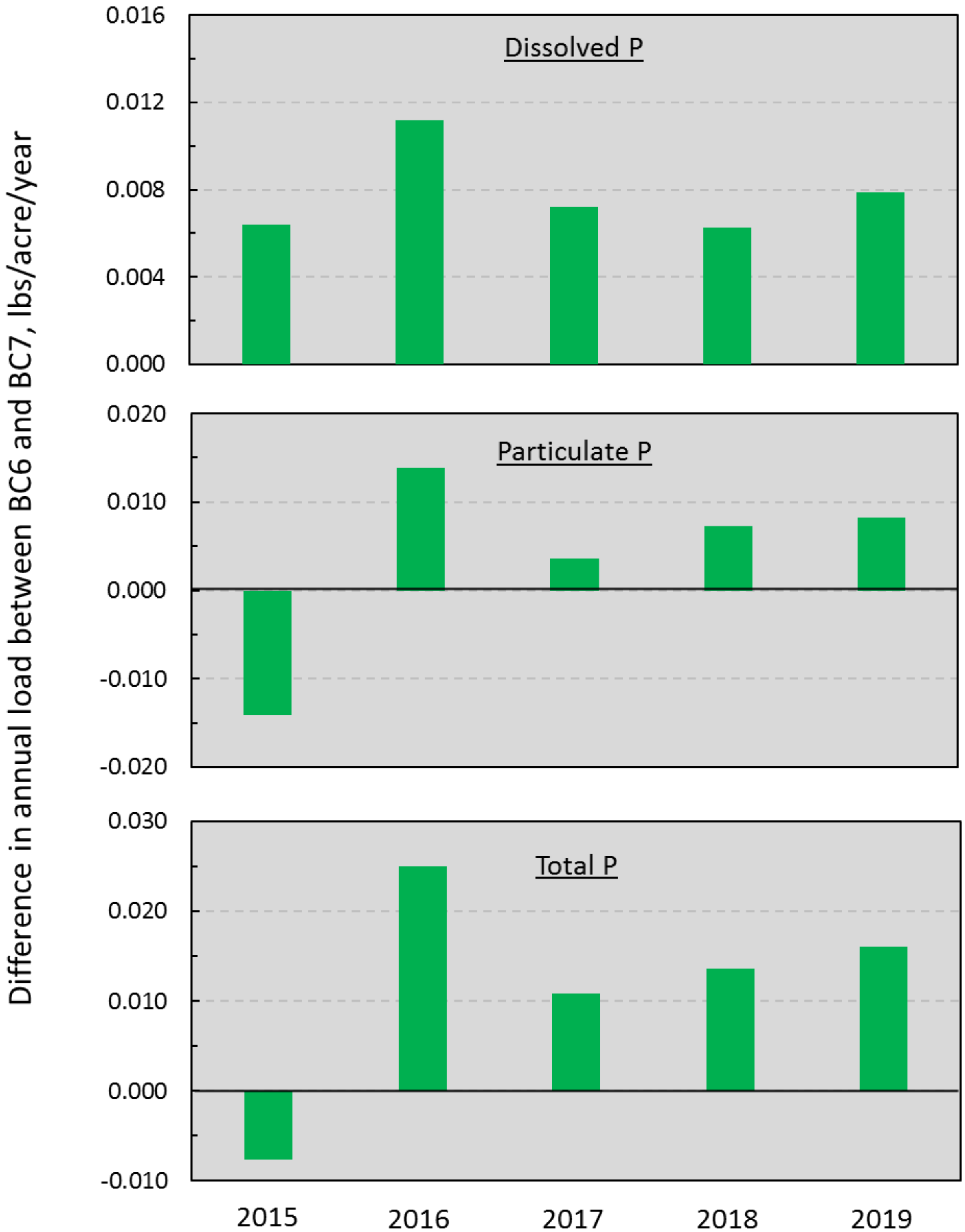

Figure S 1. Difference in P load between BC7 and BC6 for each monitored climate year (May 1, 2014 to April 30).

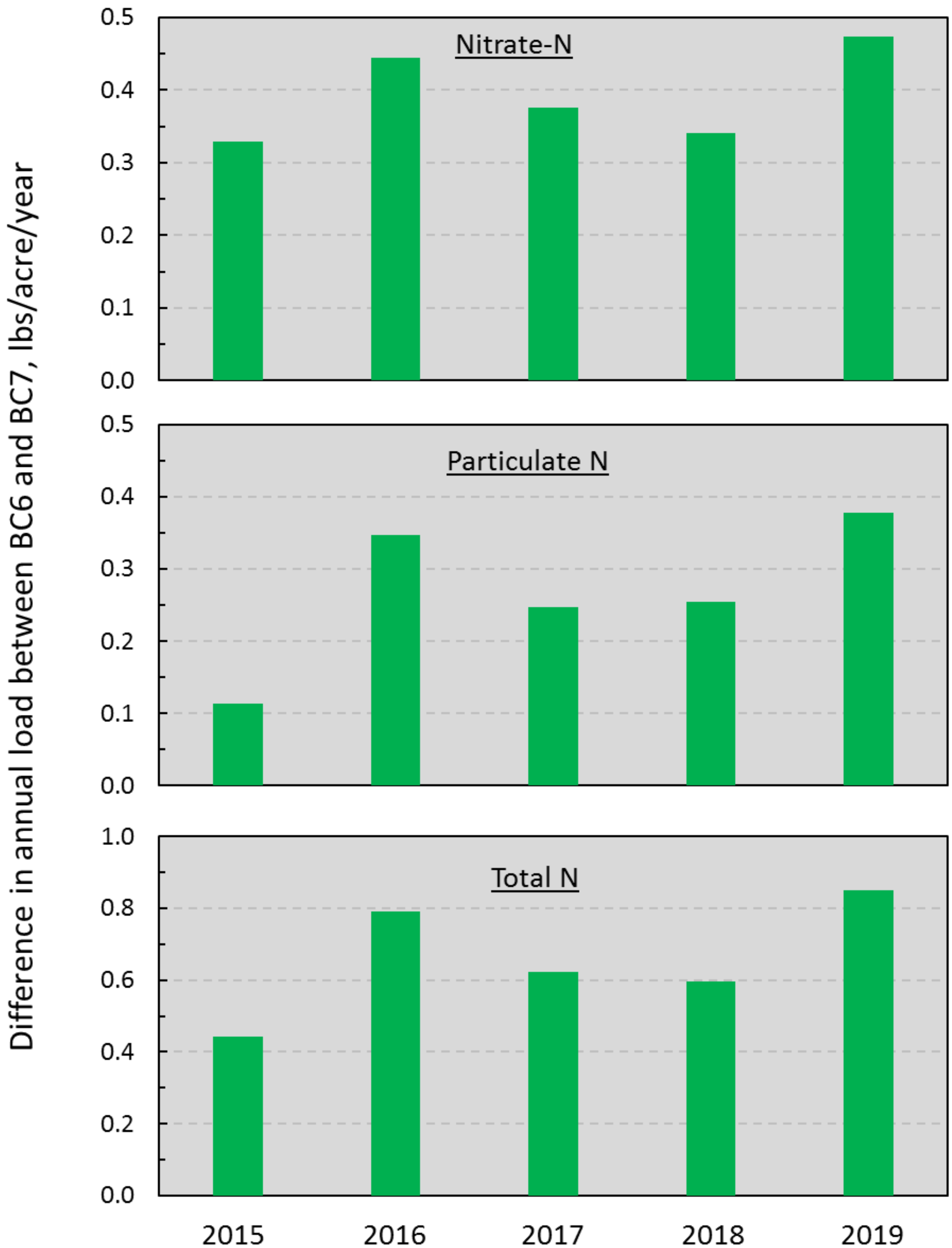

Figure S 2. Difference in N load between BC7 and BC6 for each monitored climate year (May 1, 2014 to April 30).

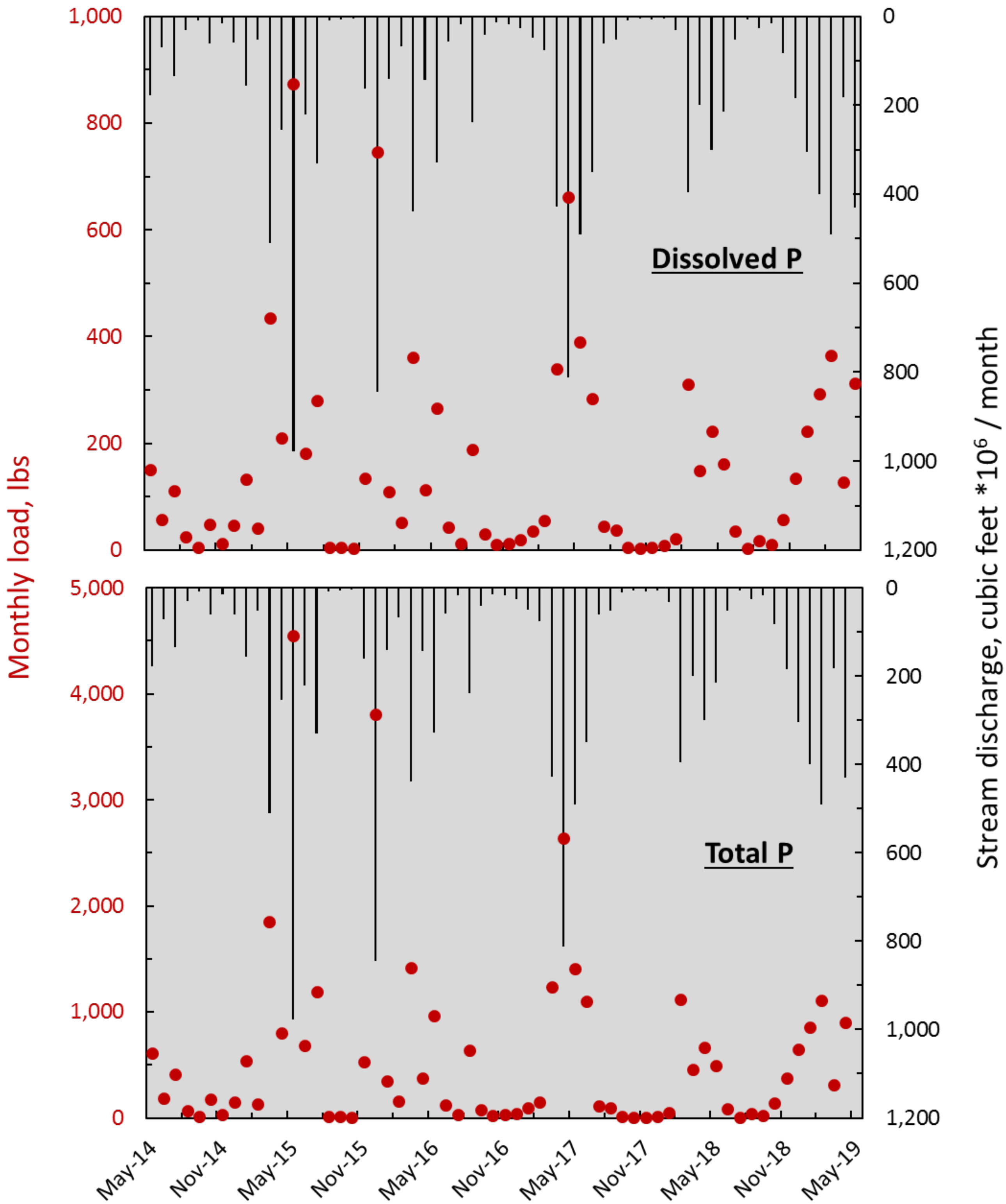

Figure S 3. Monthly dissolved and total P load for climate year (May 1, 2014 to April 30) and discharge at BC7 downstream of the C&H Farm.

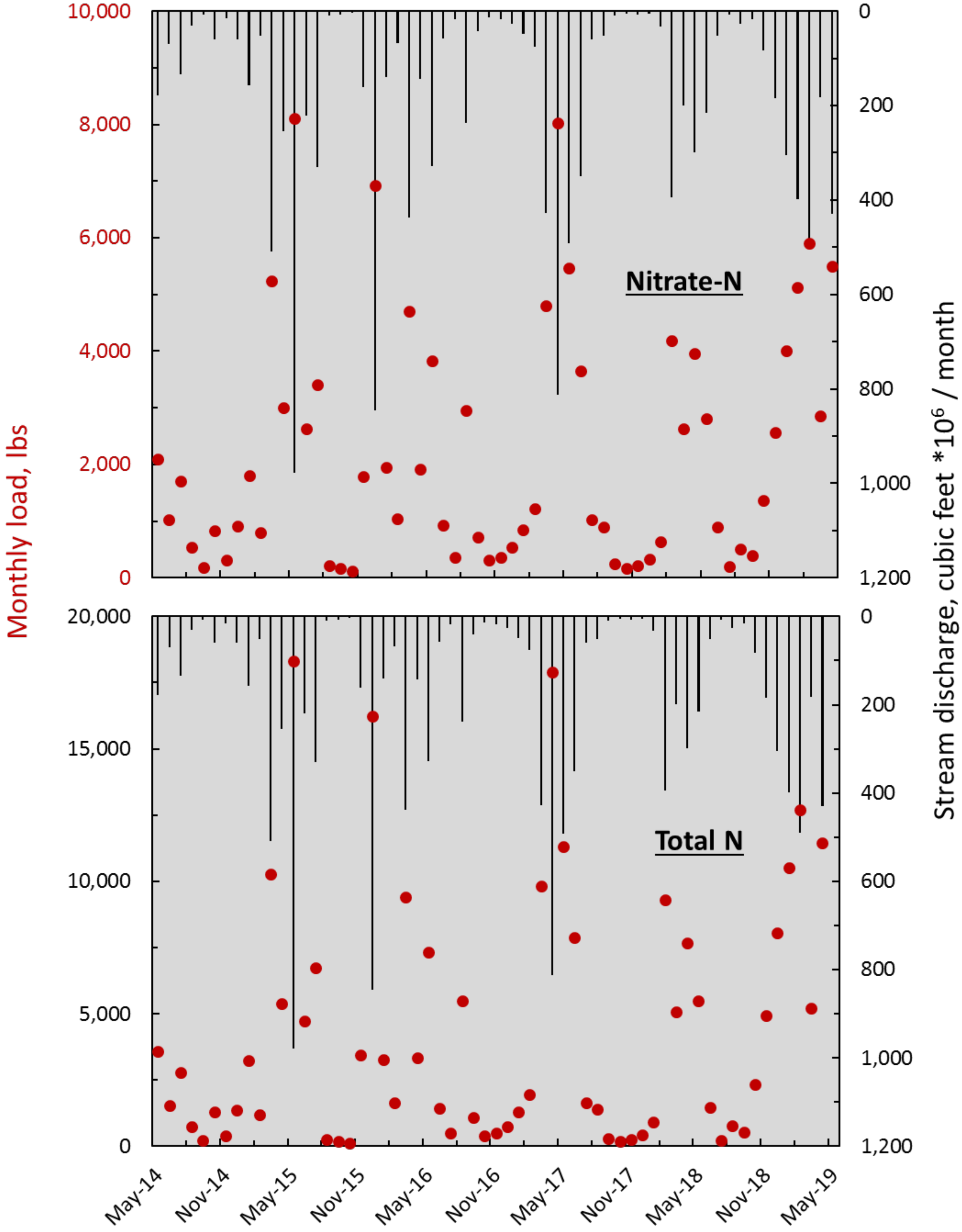

Figure S 4. Monthly nitrate-N and total N load a climate year (May 1, 2014 to April 30) and discharge at BC7 downstream of the C&H Farm.

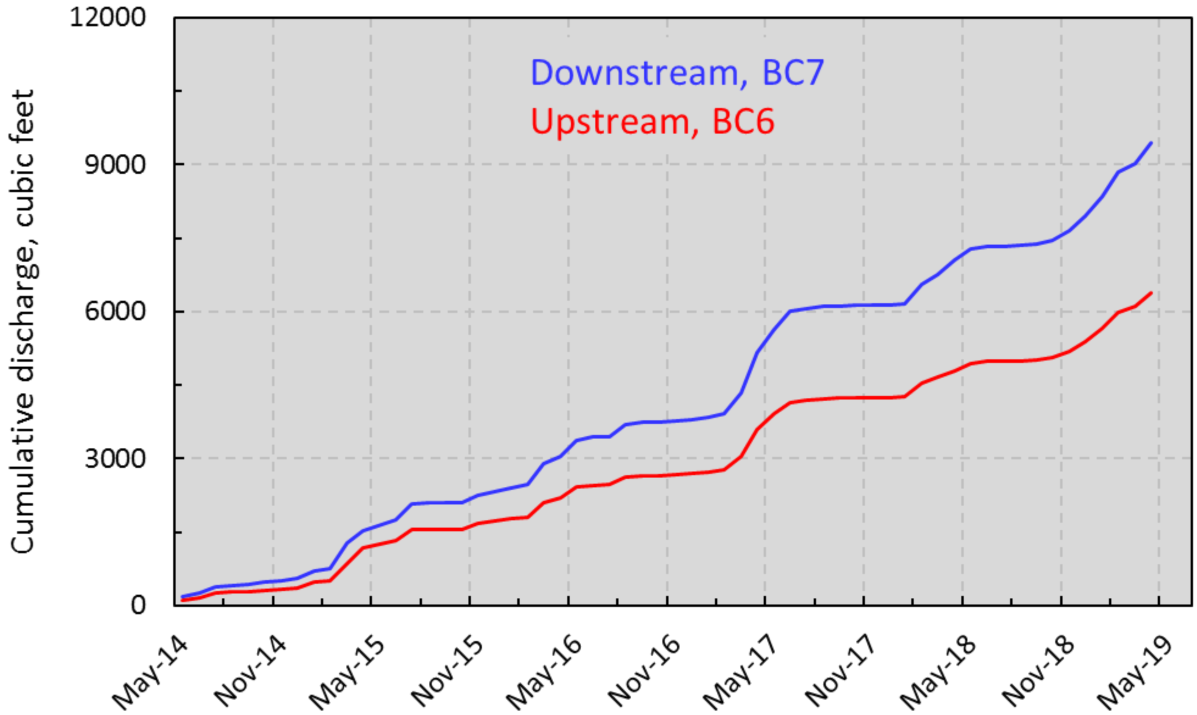

Figure S 5. Cumulative discharge up- (BC6) and down-stream (BC7) of the C&H Farm on Big Creek.

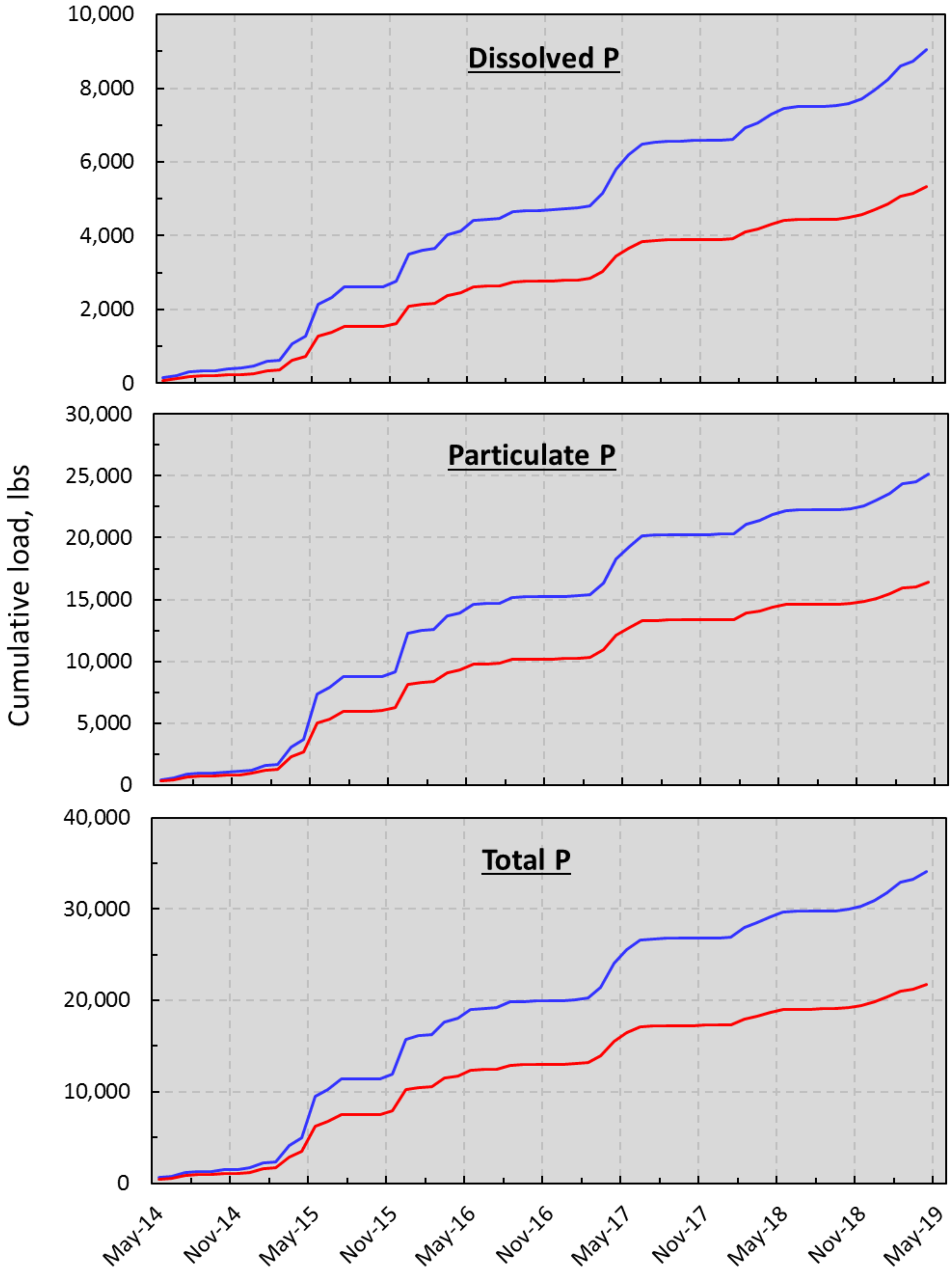

Figure S 6. Cumulative dissolved and total P load up- (BC6) and down-stream (BC7) of the C&H Farm on Big Creek.

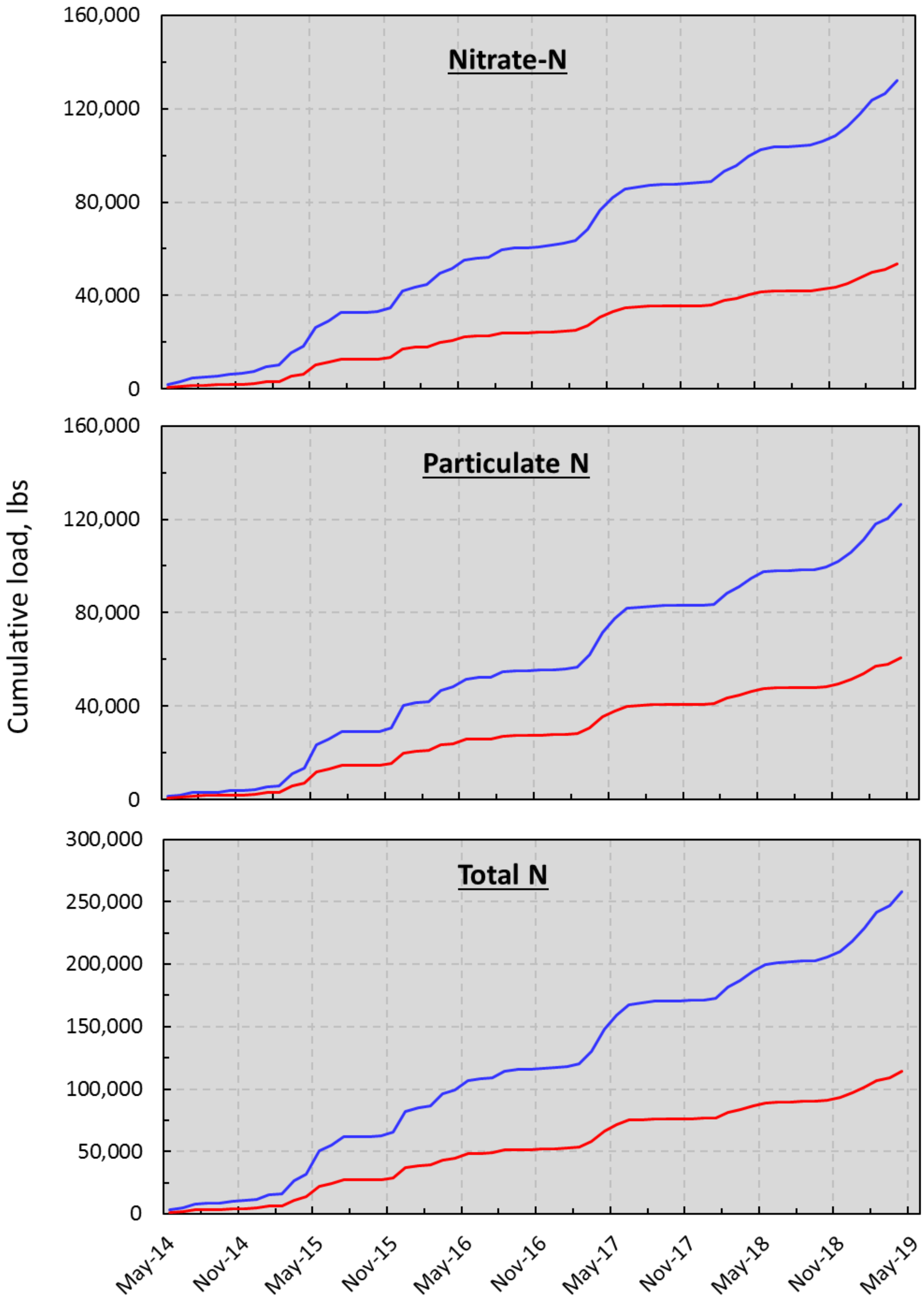

Figure S 7. Cumulative nitrate-N and total N load up- (BC6) and down-stream (BC7) of the C&H Farm on Big Creek.