NUTRIENT AND BACTERIA TRENDS IN BIG CREEK UP AND DOWN STREAM OF THE C&H FARM

Contents

Summary

1. Phosphorus and nitrogen (N) concentrations in Big Creek were greater downstream than upstream of the C&H Farm. For example, the 5-year mean nitrate-N concentration was 0.13 mg/L at the

upstream site (BC6) and 0.29 mg/L at the downstream site (BC7). This difference was greater at low base flow conditions in Big Creek.

2. This difference is due to a number of factors, such as a change in land use between upstream and downstream sites, which can influence both the amounts of nutrients available to be transported, as well as the propensity and speed by which nutrients move to a stream.
3. Using WRTDS to estimate flow-normalized concentrations of nutrients and E. coli over five water years (i.e., May 1, 2014 to April 30, 2019), we are able to remove the effect of inter- and intra-annual stream flow variability, for both up and down stream of the C&H Farm. Thus, providing a more reliable representation of the effects of changes in source inputs, land use, and watershed response to management, than simple concentrations or fluxes.
4. Based on WRTDS analysis, it is evident that flow-adjusted P concentrations decreased, while flow-adjusted N concentrations increased, both upstream and downstream of the C&H Farm during the monitoring period.
5. The was no consistent increase or decrease in P, N, E. coli analyte concentrations between September 1 and December 31, 2013 when no slurry had been land applied and in subsequent years following land application for the same four-month period.
6. Differences in nitrate-N concentrations between down and upstream sites were strongly influenced by stream flow, where the difference (i.e., downstream was greater than upstream) is very large at low flow and small at high flow. This suggests that at low flows, base flow nitrate-N emerges into Big Creek between upstream and downstream sites and that this base flow has a higher nitrate-N concentration than in base flow above the upstream site. However, at high flows it appears that water entering Big Creek from both the subwatershed above the upstream site and the intervening subwatershed between the downstream site is similar.
7. Despite higher nitrate-N concentrations at the down than upstream site on Big Creek, the relationship between upstream and downstream concentrations is unchanged over time, suggesting that over the 5 years of monitoring, the input of nitrate-N into Big Creek between up and downstream sites has not changed (i.e., no increase or decrease).

List of Tables

List of Figures

List of Supplementary Figures

Background

The Memorandum of Understanding with ADEQ states that BCRET will “Undertake and complete a study of the potential for water quality impacts within the Buffalo River Watershed from animal wastes produced by the permitted CAFO, C&H Farm, and its operation within the watershed.” Installation of the USGS-gaged site on Big Creek downstream of the watershed impacted by CAFO-generated slurry application to permitted fields (BC7) and the site upstream of permitted fields (BC6) provides locales to assess the impact of C&H operation on Big Creek.

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. Discharge measurements at BC7 started May 1, 2014. Thus, spatial and temporal trend analysis Big Creek water quality was conducted on a water year basis of May 1 to April 30 for 2015, 2016, 2017, 2018, and 2019.

Methods of Trend Analysis

Locally estimated scatterplot smoothing – LOESS Analysis

Simple trend analysis of in-stream nutrient concentrations was completed using three steps (see White et al., 2004). Briefly, the steps include:

i. Daily mean discharge and nutrient concentrations were log transformed to account for typical log-normal distribution of water quality data and to minimize the effects of outliers within the data (Hirsch et al., 1991; Lettenmaier et al., 1991);
ii. Log-transformed TP concentrations were adjusted against log-transformed daily mean discharge using the LOESS two-dimensional smoothing technique (Richards and Baker, 2002; Hirsch et al., 1991); and
iii. Flow-adjusted TP concentrations (derived from residuals of the LOESS regression of discharge versus concentration) were analyzed for temporal trends using regression tree analysis and LOESS.

The relationship between log-transformed stream discharge and log-transformed TP concentrations were quantified using LOESS two-dimensional smoothing, with a sampling proportion of 0.5 and a first order polynomial function (Systat Software, Inc., San Jose, CA). Bekele and McFarland (2004) observed that a sampling proportion of 0.5 was adequate to reduce variability in concentrations with stream discharge. The LOESS smoothing uses locally weighted regression algorithms and overcomes limitations often associated with parametric techniques that are more sensitive to outliers in the data (Lettenmaier et al., 1991). The residuals from this LOESS smoothing of log-transformed discharge and concentration represent the flow-adjusted concentrations.

Data from Big Creek were paired with discharge available from a gaging station just downstream from the swine CAFO, where the USGS developed the rating curve; discharge information was only available from May 2014 through June 2019. The data were then used in a simple three-step process (White et al., 2004) to look at monotonic changes in the nutrients at Big Creek:

i. Log-transform concentration (mg/L) and associated instantaneous discharge (ft^3/s);
ii. Use locally weighted regression (LOESS) to smooth the data with a sampling proportion (*n*) of 0.5; and
iii. Plot the residuals from LOESS (i.e., the flow-adjusted concentrations) over time and use linear regression to evaluate monotonic trends.

Weighted Regressions on Time, Discharge, and Season – WRTDS Analysis

Weighted Regressions on Time, Discharge, and Season (WRTDS), developed by USGS personnel, is a relatively new approach to the analysis of long-term (a minimum of a 5-year record of data) surface water-quality data (Hirsch et al., 2010). This statistical approach increases the amount of information that can be gleaned from water-quality monitoring data, such as that obtained by BCRET, eliminating the influence of year-to-year variations in streamflow to provide concentration and flux estimates. It has been shown to be a useful diagnostic tool to evaluate changes in watershed land use; in this case, the Big Creek watershed defined by our stream sampling sites (i.e., BC6 and BC7) related to surface- and ground-water flows and nutrient fluxes (Hirsch et al., 2010). Ideally, long-term, water-quality trend analysis by WRTDS should include more than 200 water samples collected over 20 years.

In general, WRTDS can produce two types of concentration and loading estimates, which are called "true-condition" and "flow-normalized" estimates, respectively. True-condition estimates are model-based approximations of the real history of riverine concentration or loading and are relevant to understanding actual downstream impacts (Moyer et al., 2012). By contrast, the flow-normalization method uses the full history of flows on the given calendar date to effectively remove the effects of inter-annual streamflow variability. It should therefore better reflect the effects of changes in source inputs and watershed system response (Chanat et al., 2016; Hirsch and De Cicco, 2015).

Nutrient Concentrations over Time

Nutrient concentrations for the monitoring period upstream and downstream of the C&H Farm are given in Supplemental Figures S1 to S6 for dissolved P, total P, nitrate-N, total N, E.coli, and chloride, respectively. A seasonal fluctuation in nitrate-N (Figure S3) and chloride (Figure S6) reflects a varying contribution of surface and subsurface flow to Big Creek. During the generally drier summer months, Big Creek base flow originates predominantly from the influx of ground water. During spring and fall rains, "flashy" storms are dominated by water originating from surface or near surface water flows in the Big Creek Watershed (Figure 1). As nitrate-N and chloride are soluble constituents, they can move preferentially with ground water, rather than in surface runoff, which a more important transporter of P from fields to streams.

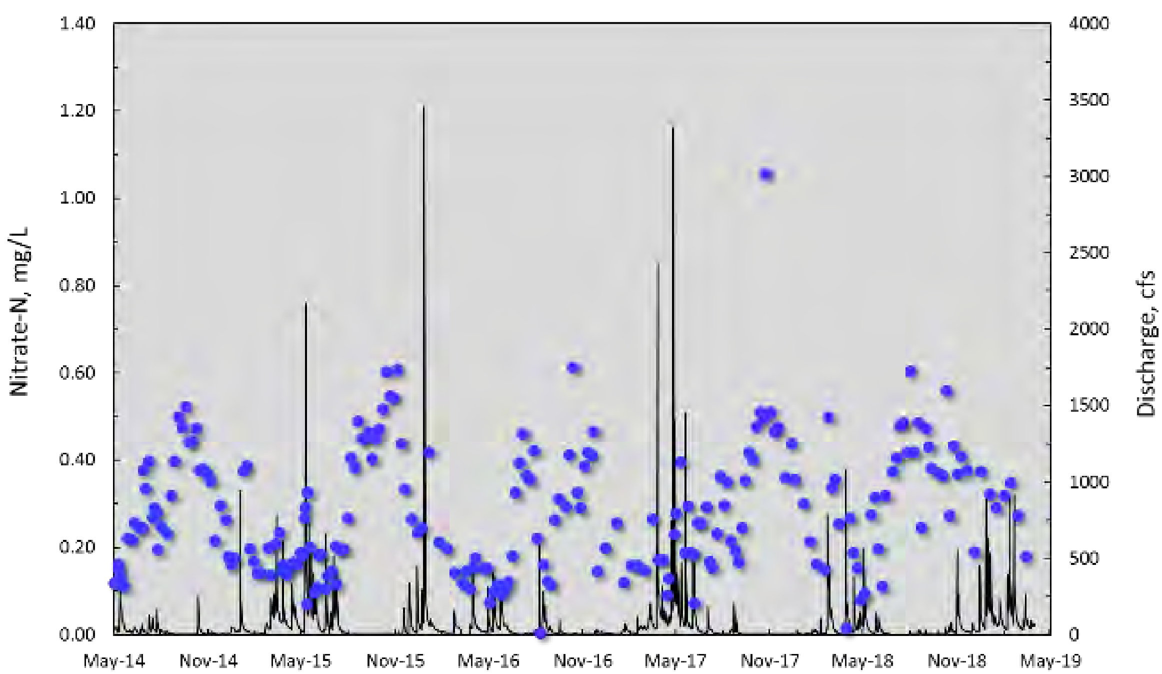

Figure 1. Nitrate-N concentration and discharge at the downstream site (BC7) over the sampling period.

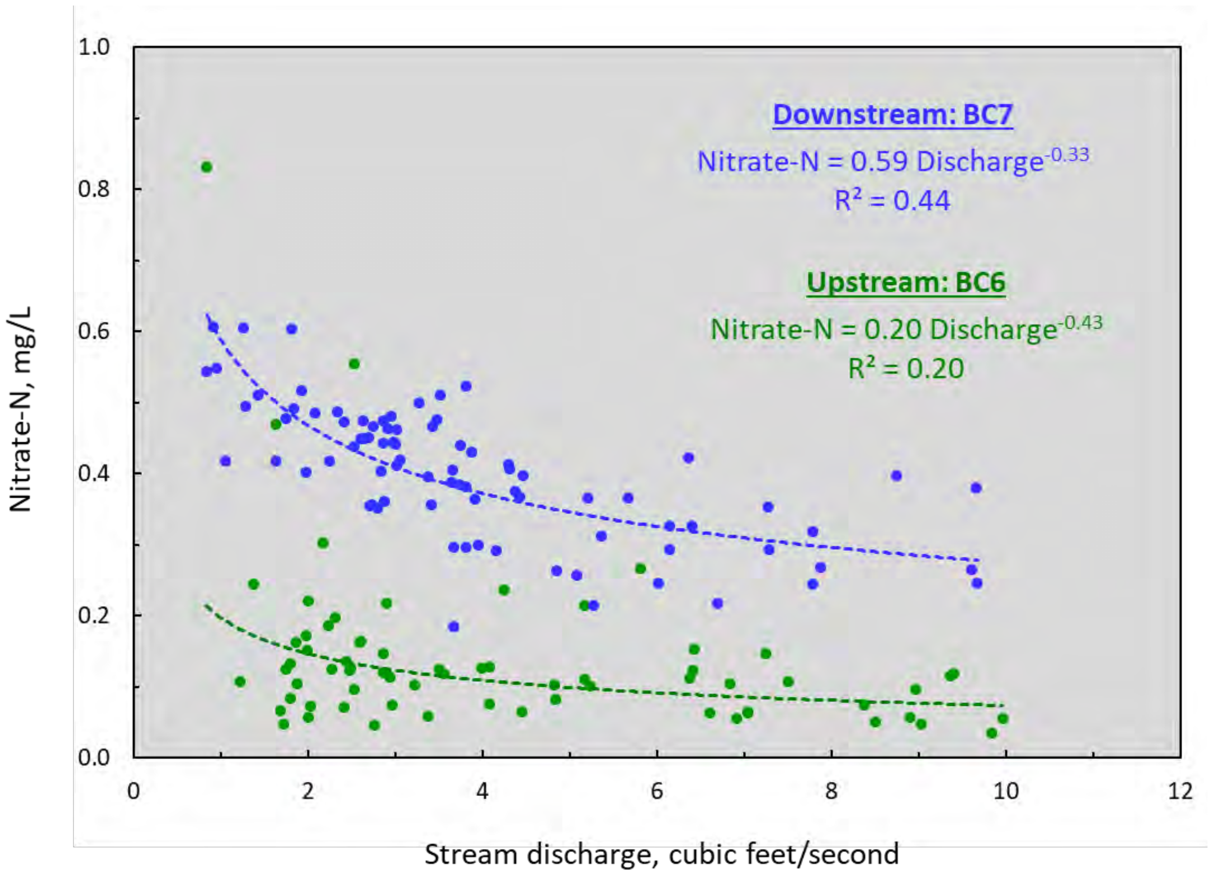

Figure 2. Nitrate-N concentration as a function of discharge for the upstream (BC6) and downstream sites (BC7) for stream discharge below 10 cubic feet/second, between May 1, 2014 and April 30, 2019.

Nitrate concentrations in Big Creek tend to be greater at the downstream site than at the upstream site. For example, mean nitrate-N concentration for the 5-year monitoring period was 0.133 mg/L at the upstream site (BC6) and 0.286 mg/L at the downstream site (BC7). This difference was greater at low base flow conditions in Big Creek, as shown in Figure 2. Other nutrients, dissolved P, total P, and total N were also greater at down than at the upstream sites. This difference is due to a number of factors, such as a change in land use between upstream and downstream sites, which can influence both the amounts of nutrients available to be transported, as well as the propensity and speed by which nutrients move to a stream. Also, ground water is the main contributor of flow and thereby nitrate-N, during base flow conditions in Big Creek. Thus, nitrate-N concentrations in Big Creek under low flow conditions tend to gravitate towards ground water nitrate-N, which we can best measure at the well adjacent to the animal barns (collects water from 265 to 285 feet deep). Over the well-sampling period (April 2014 to July 2019), nitrate-N had a mean of 0.62 mg/L, median of 0.59 mg/L, and geomean of 0.60 mg/L (see section titled "Nutrient and E. coli Trends: Trench, Well, Ephemeral Stream and Left Fork).

The effect of land use on nutrient flux in and from watersheds in the karst region of the Boston Mountains and Ozark Highlands has been demonstrated by McCarty and Haggard (2016), Giovannetti et al. (2013), and Sharpley et al. (2017). Big Creek monitoring did not provide sufficient information to distinguish the relative roles of changing land use along Big Creek and the operation of C&H as a source of nutrients to Big Creek.

Comparison of Time Period Trends With and Without Slurry Applications

Collection of water quality samples from Big Creek upstream and downstream of the C&H Farm was initiated in the beginning of September 2013. As no slurry generated on the Farm was applied to any of the permitted fields prior to December 31, 2013, we compared nutrient and E. coli concentrations measured between September 1 and December 31 each year of our monitoring. The comparison is depicted as box plots, in Figures 3 through 5. Median, first (25^{th}), and third (75^{th}) quantile values from this analysis are given in Table 1.

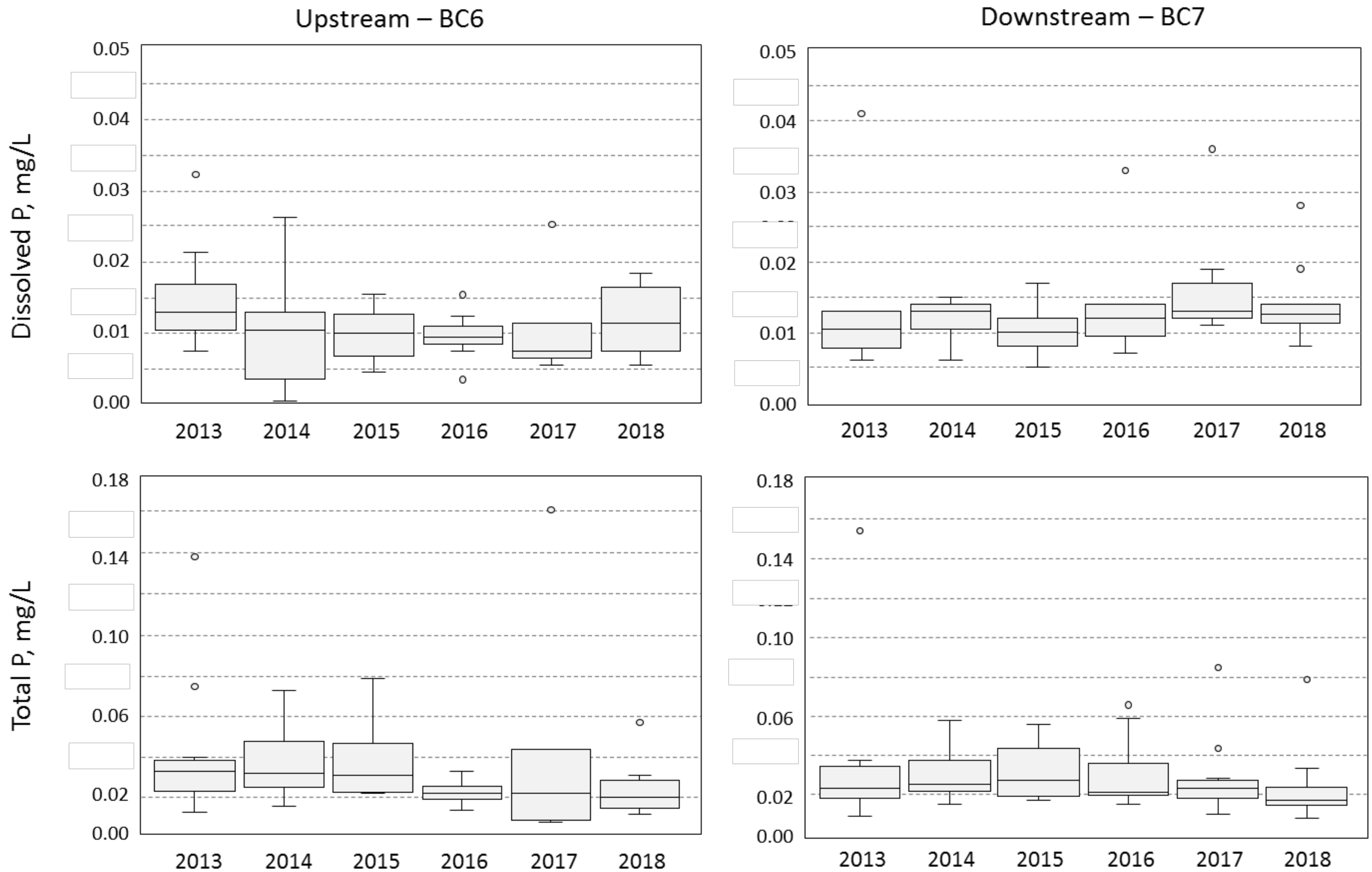

Figure 3. Comparison of dissolved and total P concentrations measured up and downstream of the C&H Farm between September 1 and December 31 for 2013 to 2018.

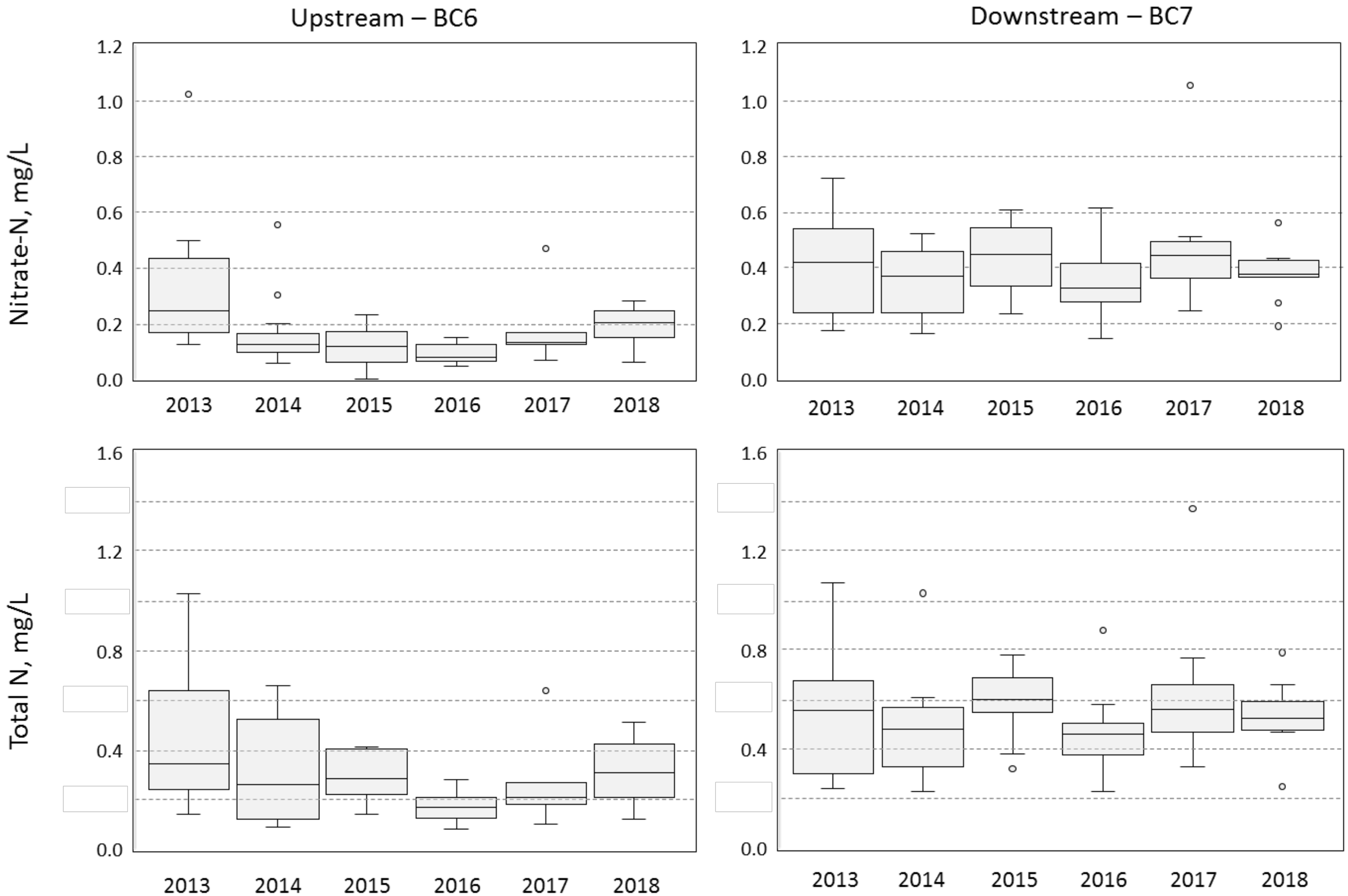

Figure 4. Comparison of nitrate-N and total N concentrations measured up and downstream of the C&H Farm between September 1 and December 31 for 2013 to 2018.

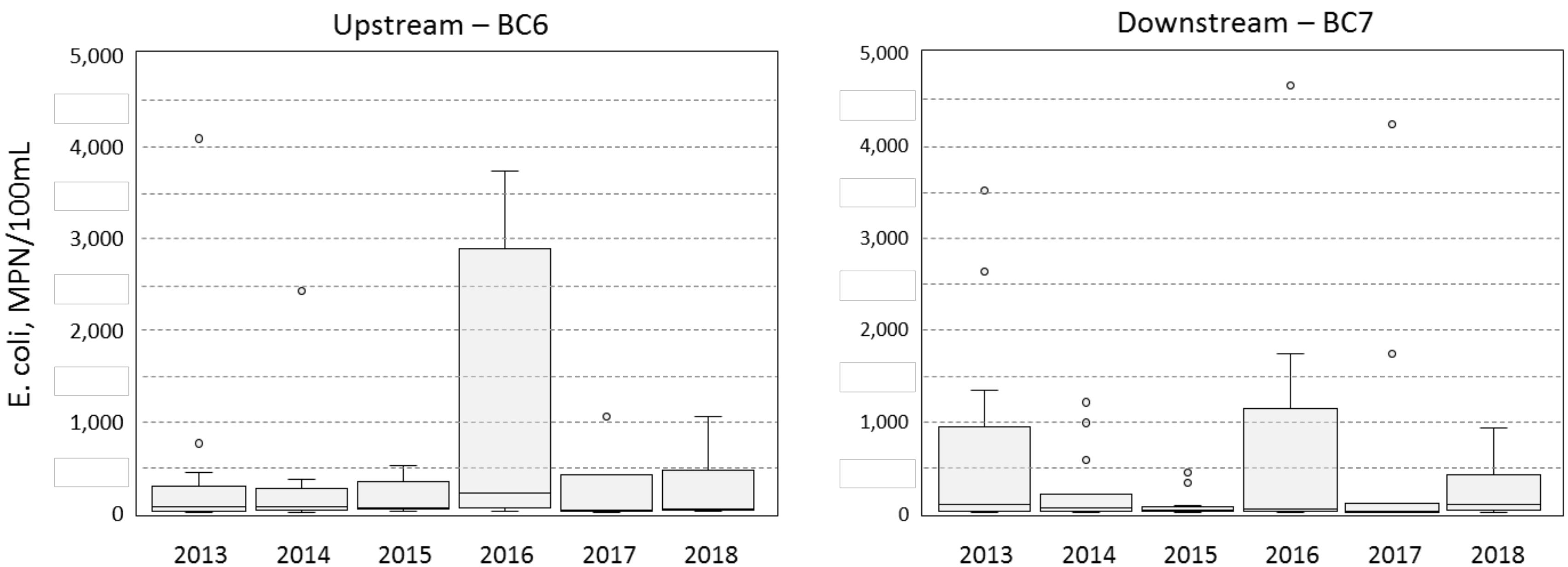

Figure 5. Comparison of E. coli concentrations measured up and downstream of the C&H Farm between September 1 and December 31 for 2013 to 2018.

Median nitrate-N and total N concentrations, and 25th and 27th quantiles for Big Creek were greater downstream than upstream of the C&H Farm, as noted previously. However, the analysis showed there was no consistent increase or decrease in these values between 2013 when no slurry had been land applied and in subsequent years following land application, for this specific four-month period.

Table 1. Median, 25th quantile, and 75th quantile concentrations for P, N, and E.coli upstream (BC6) and downstream (BC7) of the C&H Farm for the period September 1 and December 31 for 2013 through 2018.

	2013	2014	2015	2016	2017	2018
Median concentration, mg/L						
Upstream, BC6						
Dissolved P	0.013	0.010	0.010	0.009	0.010	0.011
Total P	0.031	0.029	0.029	0.020	0.032	0.018
Nitrate-N	0.25	0.12	0.12	0.08	0.13	0.20
Total N	0.34	0.22	0.29	0.71	0.20	0.31
E. coli †	71	68	53	216	238	42
Downstream, BC7						
Dissolved P	0.011	0.013	0.010	0.010	0.012	0.013
Total P	0.024	0.026	0.028	0.022	0.023	0.018
Nitrate-N	0.42	0.37	0.45	0.33	0.45	0.38
Total N	0.56	0.48	0.60	0.46	0.54	0.53
E. coli †	87	56	32	216	19	86
25th quantile concentration, mg/L						
Upstream, BC6						
Dissolved P	0.010	0.004	0.006	0.008	0.007	0.007
Total P	0.020	0.023	0.021	0.017	0.020	0.012
Nitrate-N	0.17	0.10	0.06	0.06	0.08	0.15
Total N	0.24	0.12	0.22	0.13	0.12	0.21
E. coli †	23	32	47	60	25	34
Downstream, BC7						
Dissolved P	0.008	0.010	0.008	0.010	0.012	0.011
Total P	0.019	0.022	0.020	0.021	0.019	0.015
Nitrate-N	0.24	0.23	0.33	0.28	0.36	0.37

	2013	2014	2015	2016	2017	2018
Total N	0.30	0.33	0.55	0.38	0.47	0.48
E. coli †	20	20	20	24	7	36
75th quantile concentration, mg/L						
Upstream, BC6						
Dissolved P	0.017	0.013	0.012	0.011	0.022	0.016
Total P	0.037	0.039	0.045	0.024	0.013	0.027
Nitrate-N	0.44	0.17	0.07	0.02	0.38	0.25
Total N	0.64	0.53	0.41	0.21	0.53	0.43
E. coli †	295	270	337	2885	887	461
Downstream, BC7						
Dissolved P	0.010	0.014	0.012	0.014	0016	0.014
Total P	0.034	0.031	0.044	0.037	0.027	0.025
Nitrate-N	0.54	0.47	0.54	0.42	0.50	0.43
Total N	0.68	0.56	0.69	0.51	0.65	0.59
E. coli †	941	200	66	1436	79	411

† E. coli concentration is MPN/100mL.

Trends Determined by WRTDS

Flow-Adjusted Concentrations

Using WRTDS to estimate flow-normalized concentrations of nutrients and E. coli over five water years (i.e., May 1, 2014 to April 30, 2019), we are able to remove the effect of inter- and intra-annual stream flow variability for both up and down stream of the C&H Farm (i.e., BC6 and BC7). These flow-adjusted or normalized concentrations provide a more reliable representation of the effects of changes in source inputs, land use, and watershed response to management, than simple concentrations or fluxes.

Flow-adjusted concentrations for up and downstream sites for dissolved P, total P, nitrate-N, total N, and E. coli are presented in Figures 6 to 10. It is evident from these relationships that dissolved and total P decreased during the monitoring period (Figures 6 and 7) and based on the slope of that relationship the decrease was slightly greater for total P at the upstream than downstream site (Figure 7). In contrast to P, nitrate-N and total N increased over the five-year monitoring (Figures 8 and 9, respectively), although this relationship showed similar increases up and downstream, based on slope values.

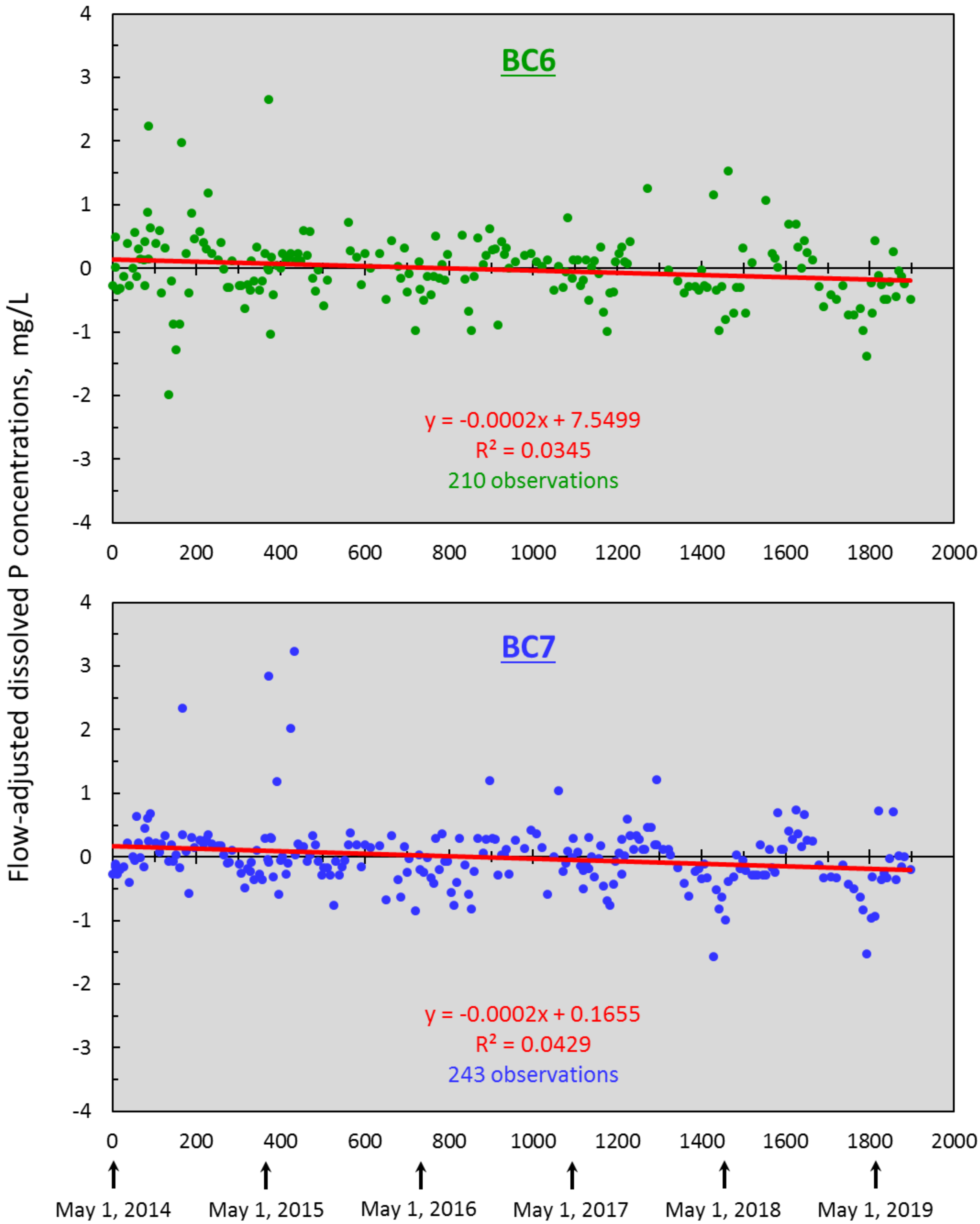

Figure 6. Flow-adjusted dissolved P concentrations upstream (BC6) and downstream sites (BC7) of the C&H Farm over time since May 1, 2014, when discharge measurements started.

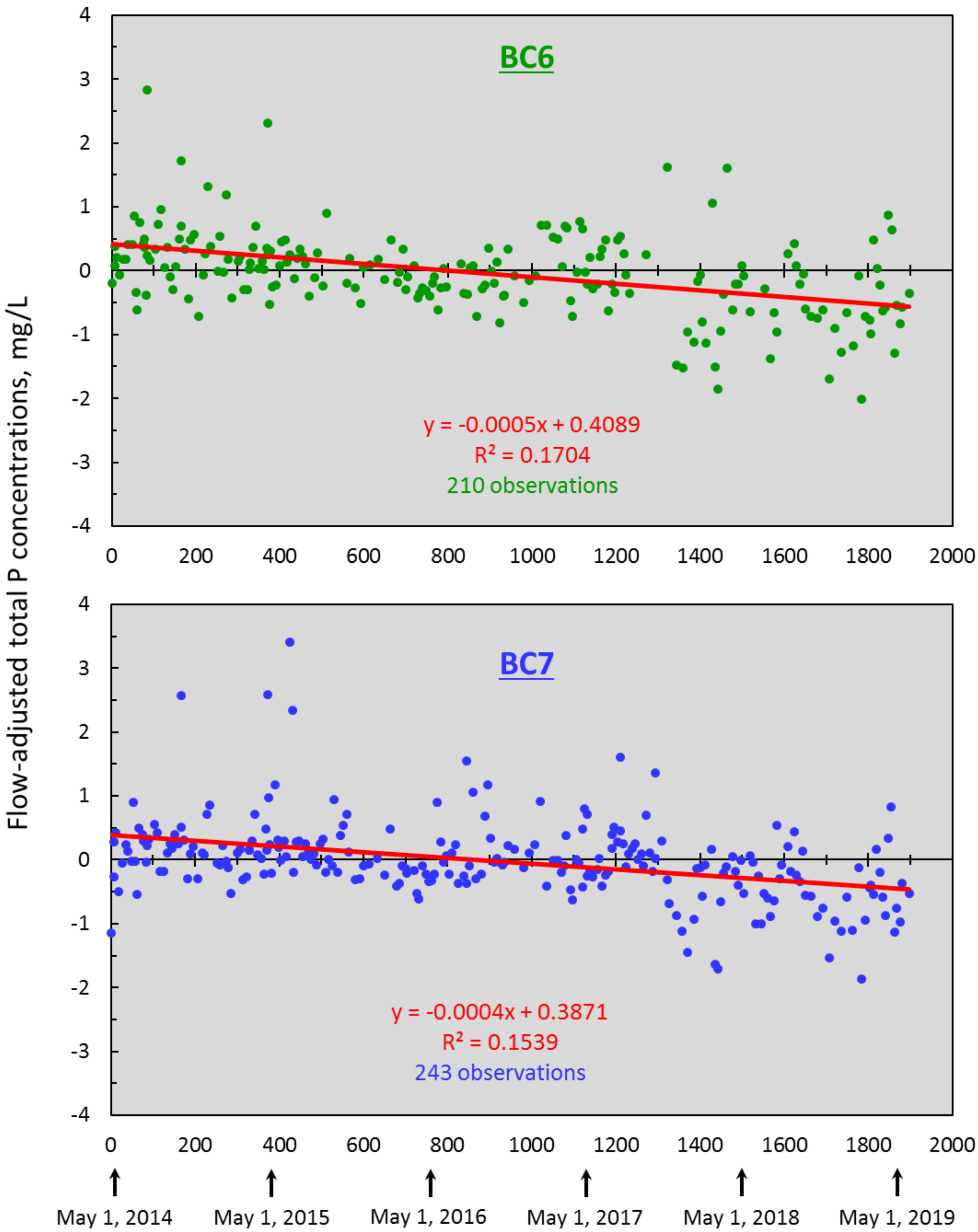

Figure 7. Flow-adjusted total P concentrations upstream (BC6) and downstream sites (BC7) of the C&H Farm over time since May 1, 2014, when discharge measurements started.

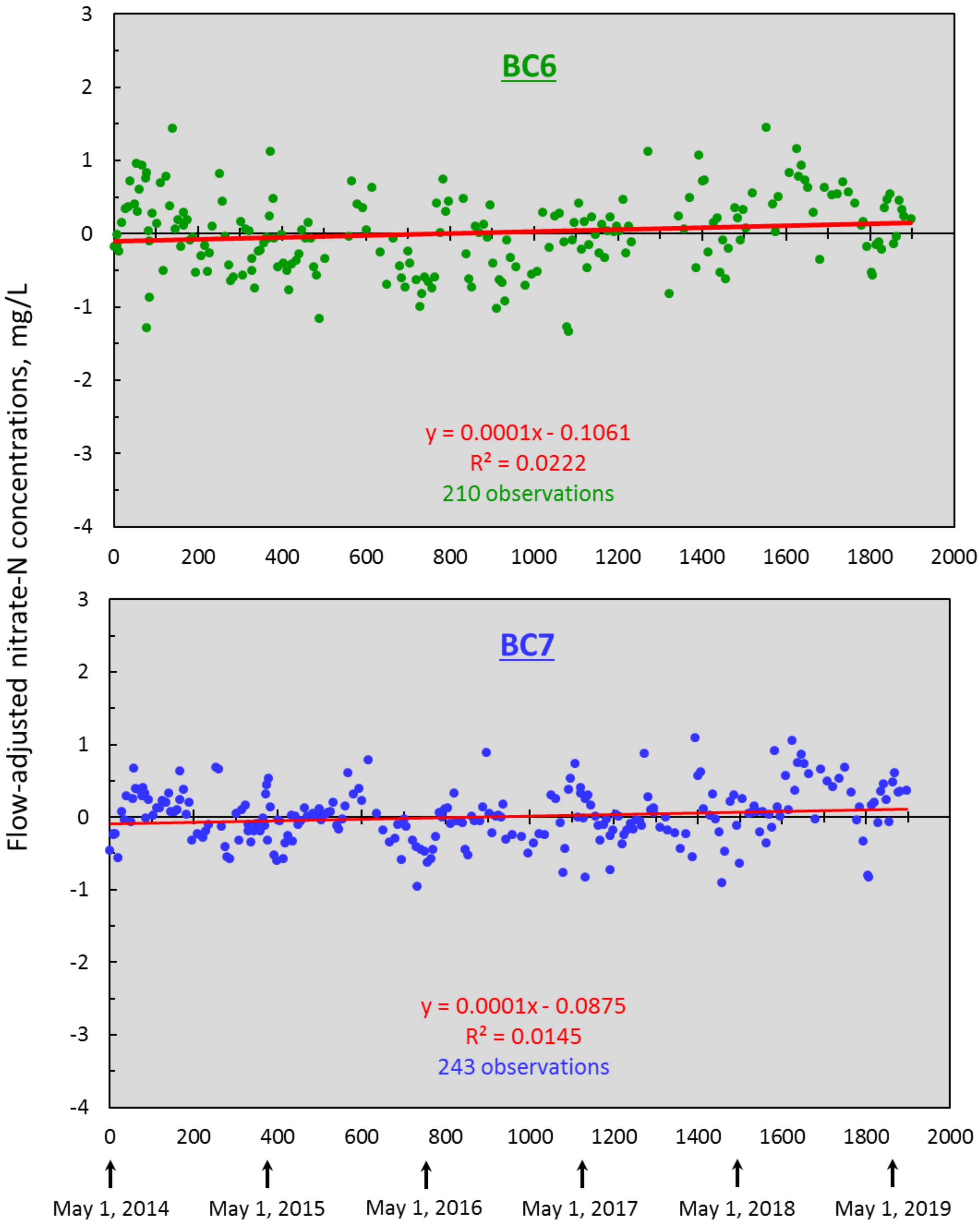

Figure 8. Flow-adjusted nitrate-N concentrations upstream (BC6) and downstream sites (BC7) of the C&H Farm over time since May 1, 2014, when discharge measurements started.

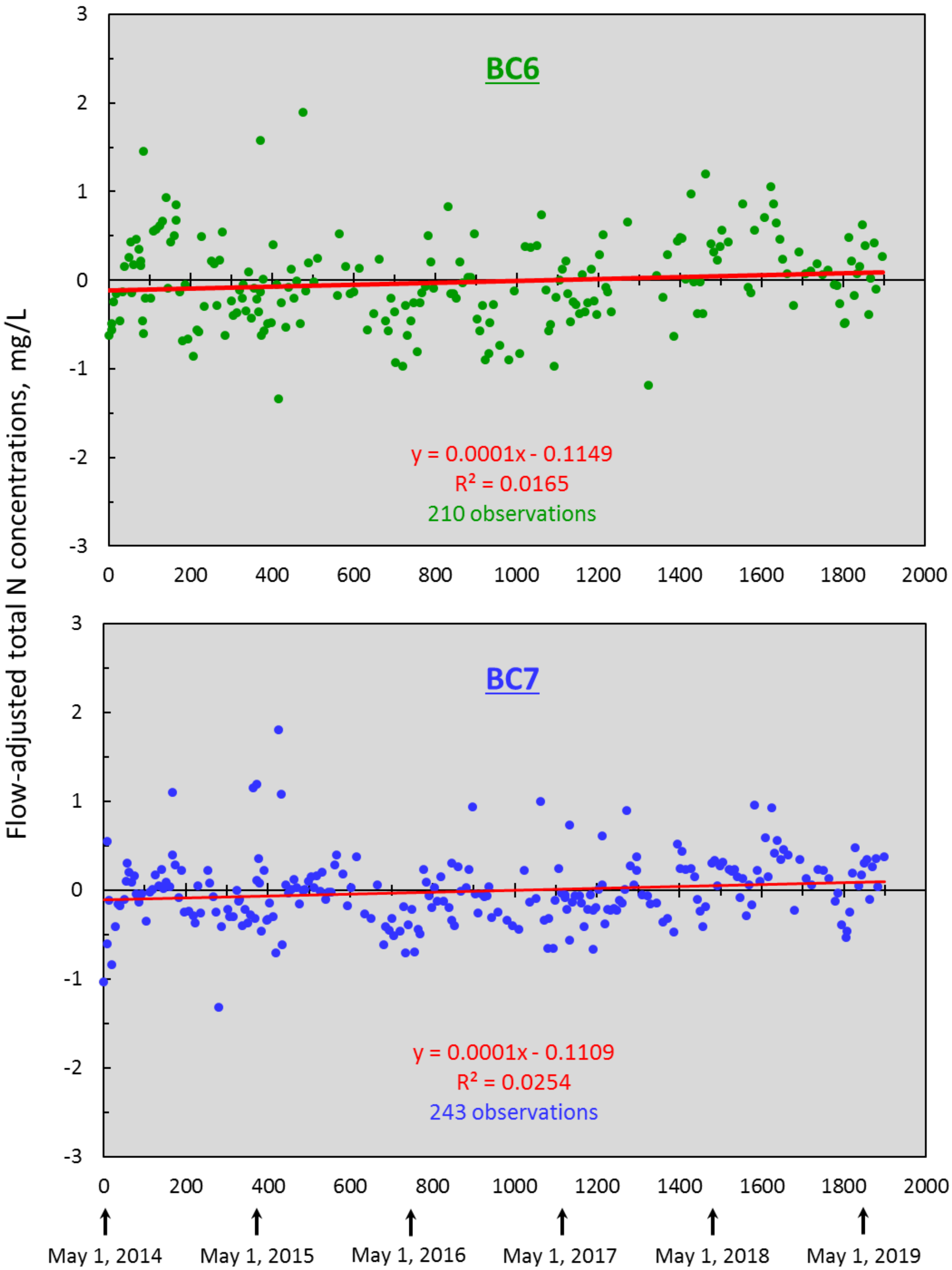

Figure 9. Flow-adjusted total N concentrations upstream (BC6) and downstream sites (BC7) of the C&H Farm over time since May 1, 2014, when discharge measurements started.

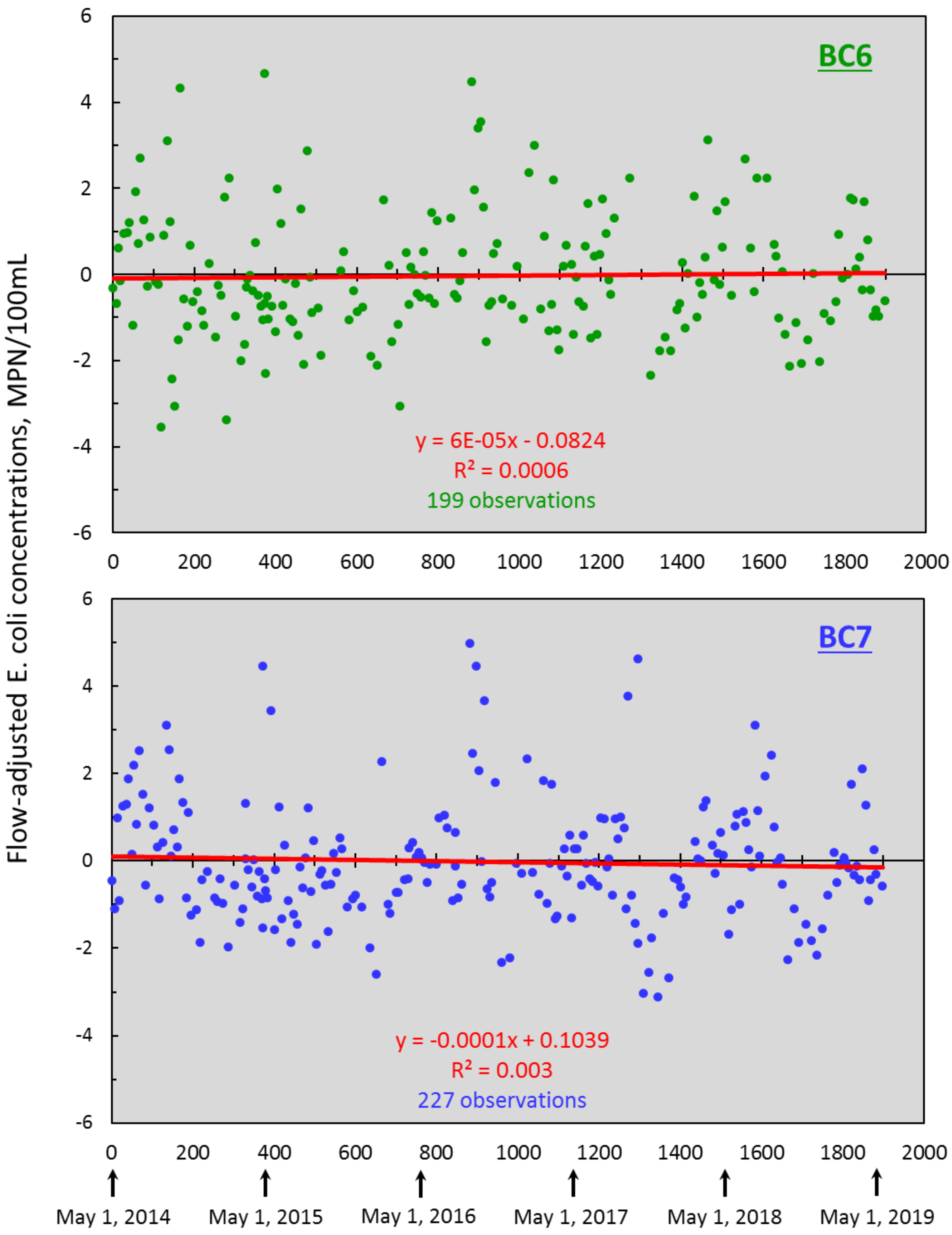

Figure 10. Flow-adjusted E. coli concentrations upstream (BC6) and downstream sites (BC7) of the C&H Farm over time since May 1, 2014, when discharge measurements started.

Trends as a function of Flow Regime

Big Creek flows were classified as base, intermediate or storm flows using hydrographs provided by the United States Geological Survey (USGS – see https://nwis.waterdata.usgs.gov/ar/nwis/uv?cb_00060=on&format=gif_default&site_no=07055790&period=&begin_date=2014-04-16&end_date=2017-04-10). Base flows were assessed by lower, level plateaus of the hydrograph curve, while storm flows were determined by sharp, elevated peaks within the hydrograph. Intermediate flows were determined as being between base and storm and located mid-slope as storm flows descended to base flows on the curve. If the hydrograph for a certain sampling event had pronounced peaks, but did not vary significantly in discharge, the resulting flow was characterized as base flow.

The mean concentrations of analytes measured under each flow condition between April 2014 and June 2019 are presented for Big Creek sites upstream and downstream of the C&H Farm operation in Table 2, along with differences determined by paired "t". In addition, trends over time were assessed by the Seasonal Kendall's Tau Test, where negative tau (τ) values represent a decreasing concentration trend over time and a positive τ, an increasing trend at a given probability (Table 2). These relationships provide insight into the dominant flow pathways for P, N, sediment, and bacteria transport in this watershed.

Table 2. Mean concentration and differences as determined by paired "t" test of analytes in Big Creek at upstream (BC6) and downstream (BC7) sites, and multivariate correlations for Seasonal Kendall's Test, as a function of flow regime.

Flow regime	Upstream - BC6			Downstream - BC7		
	Mean †	Kendall τ	Probability ‡	Mean †	Kendall τ	Probability ‡
Dissolved P, mg/L						
Base #	0.009 b	-0.0789	0.2022	0.011 b	0.0141	0.8033
Intermediate ¶	0.008 b	-0.2280	0.0301*	0.009 b	-0.3309	0.0009*
Storm ††	0.018 a	-0.0048	0.9653	0.026 a	-0.0308	0.7681
Total P, mg/L						
Base	0.034 b	-0.2558	<.0001*	0.027 b	-0.2207	<.0001*
Intermediate	0.019 b	-0.3720	0.0003*	0.021 b	-0.4148	<.0001*
Storm	0.145 a	0.0106	0.9222	0.108 a	0.0233	0.8301
Nitrate-N, mg/L						

Flow regime	Upstream - BC6				Downstream - BC7		
	Mean †	Kendall τ	Probability ‡		Mean †	Kendall τ	Probability ‡
Base	0.119 a	0.0067	0.9108		0.308 a	0.1584	0.0043*
Intermediate	0.119 a	0.1374	0.1746		0.260 b	0.0126	0.8966
Storm	0.126 a	0.1794	0.095		0.212 b	0.0135	0.8945
Total N, mg/L							
Base	0.217 b	0.0705	0.2443		0.420 b	0.2084	0.0001*
Intermediate	0.198 b	0.1296	0.2076		0.359 b	0.1075	0.2719
Storm	0.400 a	0.2312	0.0318*		0.536 a	0.1595	0.1202
E. coli, MPN/100 mL							
Base	633 b	0.0395	0.5102		271 b	-0.0815	0.1405
Intermediate	182 b	-0.0730	0.4852		145 b	-0.0704	0.4858
Storm	2577 a	0.1128	0.3413		2297 a	0.0947	0.4099
Chloride, mg/L							
Base	1.748 a	0.0000	1.0000		2.481 a	0.1743	0.0034*
Intermediate	1.482 b	-0.1416	0.1708		1.863 b	-0.0742	0.4832
Storm	1.340 b	-0.2857	0.0296*		1.538 c	-0.0648	0.5614
Electrical conductivity, µS/cm							
Base	150 a	0.2388	0.0004*		227 a	0.2230	0.0002*
Intermediate	117 b	-0.1835	0.0765		170 b	-0.0067	0.9499
Storm	96 b	-0.2469	0.0606		144 b	-0.1580	0.1696

† Mean concentrations within columns (i.e., flow regime, upstream, and downstream) with different letters are significantly different as determined by paired "t" test at a 5% level of significance.

‡ Probability values with * designate a significant trend with time.

Upstream (BC6) had 129 and downstream (BC7) 155 observations for base flow.

¶ Upstream (BC6) had 47 and downstream (BC7) 51 observations for intermediate flow.

†† Upstream (BC6) had 42 and downstream (BC7) 46 observations for storm flow.

Conclusions where trends are significant:

1. Dissolved and total P concentrations in storm flow were greater than in base and intermediate flows at sites up (BC6) and downstream (BC7) of the Big Creek farm.
2. Nitrate-N concentrations were greater for base flow than the other flow types at the downstream site only (BC7). The greater concentration of total N in storm than base and intermediate flows, likely reflects an increased transport of particulate N during higher energy, storm flow events.
3. E. coli concentrations were appreciably greater in storm than base and intermediate flows.
4. There was a greater decrease in dissolved and total P concentrations at the downstream site (BC7) during the monitoring period (2013 to 2019) compared to the upstream site (BC6), as represented by Kendall's Tau.
5. There was a greater increase in nitrate-N and total N concentrations at the downstream site (BC7) than at the upstream site (BC6) with time during base flow conditions, as represented by Kendall's Tau. Chloride concentrations and electrical conductivity showed the same trend.
6. A better understanding these flow – concentration relationships in Big Creek, will help identify and target effective conservation measures aimed at minimizing P, N, sediment, and bacterial transport and input to Big Creek.

Table 3. Statistically different mean concentrations in Big Creek upstream (BC6) and downstream (BC7) of C&H determined by paired "t" test of analytes for paired samplings as a function of flow regime; with and without two outlier samples.

Flow regime	All data			Two outliers excluded		
	# Obs.	Upstream	Downstream	# Obs.	Upstream	Downstream
Dissolved P, mg/L						
Base	123	0.009 b†	0.011 a	123	0.009 b†	0.011 a
Intermediate	50	0.008 b	0.009 a	50	0.008 b	0.009 a
Storm	38	0.015 a	0.020 a	38	0.015 a	0.020 a
Total P, mg/L						
Base	123	0.034 a	0.027 a	122‡	0.027 a	0.027 a
Intermediate	50	0.020 a	0.020 a	50	0.020 a	0.020 a
Storm	38	0.014 a	0.010 a	37#	0.063 a	0.098 a
Nitrate-N, mg/L						

Flow regime	All data				Two outliers excluded		
	# Obs.	Upstream	Downstream		# Obs.	Upstream	Downstream
Base	123	0.119 b	0.276 a		123	0.119 b	0.276 a
Intermediate	50	0.116 b	0.253 a		50	0.116 b	0.253 a
Storm	38	0.134 b	0.226 a		38	0.134 b	0.226 a
Total N, mg/L							
Base	123	0.215 b	0.383 a		123	0.215 b	0.383 a
Intermediate	50	0.196 b	0.352 a		50	0.196 b	0.352 a
Storm	38	0.390 a	0.526 a		37 ¶	0.329 b	0.525 a
E. coli, MPN/100 mL							
Base	120	657 a	289 a		119 ††	404 a	282 b
Intermediate	46	173 a	121 a		46	173 a	121 a
Storm	34	1962 a	2469 a		34	1962 a	2469 a
Chloride, mg/L							
Base	97	1.780 b	2.307 a		97	1.780 b	2.307 a
Intermediate	44	1.475 b	1.852 a		44	1.475 b	1.852 a
Storm	30	1.317 b	1.605 a		30	1.317 b	1.605 a
Electrical conductivity, µS/cm							
Base	95	153 b	208 a		95	153 b	208 a
Intermediate	44	114 b	170 a		44	114 b	170 a
Storm	30	101 b	144 a		30	101 b	144 a

† Mean concentrations within rows (i.e., flow regime, upstream, and downstream) with different letters are significantly different as determined by paired "t" test at a 5% level of significance.

‡ Outlier for total P of 0.888 mg/L during base flow at BC6 on April 22, 2014 excluded due to sampling of stagnant water at BC6.

Outlier for total P of 2.956 mg/L during storm flow at BC6 on August 20, 2015 excluded due to sampling of stagnant water at BC6.

¶ Outlier for total N of 2.640 mg/L during storm flow at BC6 on August 20, 2015 excluded due to sampling of stagnant water at BC6.

†† Outlier for E. coli of 30,760 MPN/100ml during base flow on August 8, 2019 excluded due to sampling of stagnant water at BC6.

Conclusions where trends are significant:

1. When samples were collected at both up (BC6) and downstream sites (BC7) on the same day, dissolved P, total P, nitrate-N, total N, chloride, and electrical conductivity were greater downstream of the C&H Farm (0.05 % level of significance) for all three flow regimes (i.e., base, intermediate, and storm flows).
2. Excluding total P, total N, and E. coli outliers, all measured upstream of the C&H Farm, resulted in one change; E. coli was lower at the down than upstream site (0.05 % level of significance).

Trends as a function of Season

Table 4. Mean concentration and differences as determined by paired "t" test of analytes in Big Creek at upstream (BC6) and downstream (BC7) sites, and multivariate correlations for Seasonal Kendall's Test, as a function of season March to June, July to October, and November to February.

Season †	Upstream - BC6			Downstream - BC7		
	Mean ‡	Kendall τ	Probability #	Mean ‡	Kendall τ	Probability #
Dissolved P, mg/L						
March - June [¶]	0.011 a	-0.1362	0.0606	0.012 a	-0.1063	0.1314
July - October [††]	0.011 a	0.0112	0.8930	0.015 a	-0.0714	0.3215
November – February [‡‡]	0.009 a	-0.4416	<.0001*	0.012 a	-0.2108	0.0284*
Total P, mg/L						
March - June	0.047 a	-0.1772	0.0114*	0.045 a	-0.1222	0.0732
July - October	0.077 a	-0.3122	0.0002*	0.043 a	-0.3027	<.0.0001*
November - February	0.026 a	-0.3459	0.0005*	0.026 a	-0.2606	0.0053*
Nitrate-N, mg/L						
March - June	0.102 b	0.1421	0.0408*	0.196 c	0.1288	0.0568
July - October	0.148 a	0.0404	0.6196	0.358 a	0.048	0.4914
November - February	0.117 b	0.1980	0.0455*	0.299 b	0.1131	0.2187
Total N, mg/L						
March - June	0.221 b	0.2499	0.0004*	0.363 b	0.2409	0.0004*
July - October	0.325 a	0.0332	0.6871	0.512 a	0.148	0.0351*

Season †	Upstream - BC6			Downstream - BC7		
	Mean ‡	Kendall τ	Probability #	Mean ‡	Kendall τ	Probability #
November - February	0.191 b	0.1604	0.1099	0.403 b	0.1542	0.0964
E. coli, MPN/100mL						
March - June	858 a	0.0953	0.1812	976 a	0.0618	0.3809
July - October	1372 a	0.0564	0.5077	333 a	-0.0079	0.9139
November - February	200 a	-0.1242	0.2133	250 a	-0.0379	0.6870
Chloride, mg/L						
March - June	1.393 b	-0.2054	0.0068*	1.716 b	-0.0620	0.3930
July – October	1.744 a	-0.0604	0.5405	2.521 a	-0.0422	0.5947
November - February	1.878 a	-0.1344	0.1932	2.486 a	-0.1659	0.0928
Electrical conductivity, µS/cm						
March - June	107 b	-0.1351	0.0753	155 c	-0.0137	0.8517
July - October	186 a	-0.1443	0.1450	258 a	-0.0855	0.2892
November - February	121 b	-0.0999	0.3461	192 b	-0.1161	0.2558

† Three seasons of equal length (i.e., 4 months) are designated according to runoff potential based on historical rainfall and stream flow data for the area. The potential for runoff increases in the periods July to October, to March to June, to November to February (see Sharpley et al., 2010). The Arkansas P Index assigns loss rating factors of 0.1, 0.25, and 0.60 for these periods, respectively.

‡ Mean concentrations within columns (i.e., season, upstream, and downstream) with different as determined by paired "t" test at a 5% level of significance.

Probability values with * designate a significant trend with time.

¶ Upstream (BC6) had 98 and downstream (BC7) 99 observations for base flow.

†† Upstream (BC6) had 71 and downstream (BC7) 95 observations for intermediate flow.

‡‡ Upstream (BC6) had 49 and downstream (BC7) 56 observations for storm flow.

Conclusions where trends are significant:

1. Nitrate-N and total N concentrations were greatest during the summer (July to October period), while there was no seasonal difference in dissolved or total P concentration.

2. There was no seasonal difference in E. coli concentrations at the up (BC6) and downstream sites (BC7).

Table 5. Statistically different mean concentrations in Big Creek upstream (BC6) and downstream (BC7) of C&H determined by paired "t" test of analytes for paired samplings as a function of flow regime; with and without two outlier samples.

Season †	# Obs.	Upstream ‡	Downstream ‡
Dissolved P, mg/L			
March - June	97	0.011 a	0.013 a
July - October	65	0.009 b	0.012 a
November - February	49	0.009 b	0.011 a
Total P, mg/L			
March - June	97	0.047 a	0.052 a
July – October #	64	0.026 a	0.027 a
November - February	49	0.026 a	0.025 a
Nitrate-N, mg/L			
March - June	97	0.101 b	0.197 a
July – October	65	0.154 b	0.348 a
November - February	49	0.117 b	0.276 a
Total N, mg/L			
March - June	97	0.221 b	0.377 a
July - October	65	0.312 b	0.460 a
November - February	49	0.191 b	0.371 a
E. coli, MPN/100 mL			
March - June	91	833 a	984 a
July – October ¶	61	613 a	399 b
November - February	47	204 a	196 a
Chloride, mg/L			
March - June	82	1.395 b	1.739 a
July - October	47	1.767 b	2.384 a
November - February	42	1.896 b	2.350 a
Electrical conductivity, µS/cm			
March - June	82	107 b	155 a
July - October	47	189 b	246 a
November - February	40	123 b	183 a

† Three seasons of equal length (i.e., 4 months) are designated according to runoff potential based on historical rainfall and stream flow data for the area. The potential for runoff increases in the periods July to October, to March to June, to November to February (see Sharpley et al., 2010). The Arkansas P Index assigns loss rating factors of 0.1, 0.25, and 0.60 for these periods, respectively.

‡ Mean concentrations within columns (i.e., season, upstream, and downstream) with different as determined by paired “t” test at a 5% level of significance.

Outlier for total P of 0.888 mg/L at BC6 on August 20, 2015 excluded due to sampling of stagnant water at BC6.

¶ Outlier for E. coli of 30,760 MPN/100mL BC6 on August 8, 2019 excluded due to sampling of stagnant water at BC6.

Conclusions where trends are significant:

1. Removal of outliers basically eliminated any season differences in N, P, E. coli, chloride or conductivity differences.

Comparison of Upstream and Downstream Trends as a Function of Time and Discharge

Monthly mean nitrate-N and dissolved P concentration values for all 61 months of record (May 2014 through May 2019 inclusive) for up (BC6) and downstream Sites (BC7) were estimated using an autoregressive model in WRTDS, which enables interpolation between the measured days (i.e., when water quality sample was taken).

What this means is that for any given day when no sample was collected, three pieces of information are used: (a) the WRTDS estimate for that day – based on the discharge, time of year, and year; (b) the amount of error the WRTDS model had on the most recent sampled day; and (c) the amount of error the WRTDS model had on the next sampled day.

When the day being estimated is close to one of the sampled days, that sampled day value gets a large weighting. When there is a long time (e.g., two weeks) from the day being estimated to the nearest sampled day, the WRTDS model dominates the estimate. On sampled days, the sampled value for that day is used. From the time series of monthly mean concentrations at both sites, the difference between the concentration at the downstream site (BC7) and upstream site (BC6; always a positive number) is computed.

The difference in monthly mean nitrate-N and dissolved P concentrations over the 5-year monitoring period are presented in Figure 11. More emphasis will be given the discussion of nitrate-N due to downstream increases noted earlier in this section (see Figure 1). There is no apparent strong trend in this record, but there is a period of relatively high nitrate-N concentrations in 2015. These high values lie in the months of August, September, and October of 2015, which were months of very low flow but they lie between the two very high flow period in May and December of 2015. This suggests this time series of nitrate-N differences might be very strongly influenced by streamflow.

The difference in down and upstream nitrate-N concentrations is larger at low flows than at high flows. What that means is that at low flows, there is a source of higher nitrate-N concentration base flow that emerges into the stream between up and downstream sites than in baseflow above the upstream site.

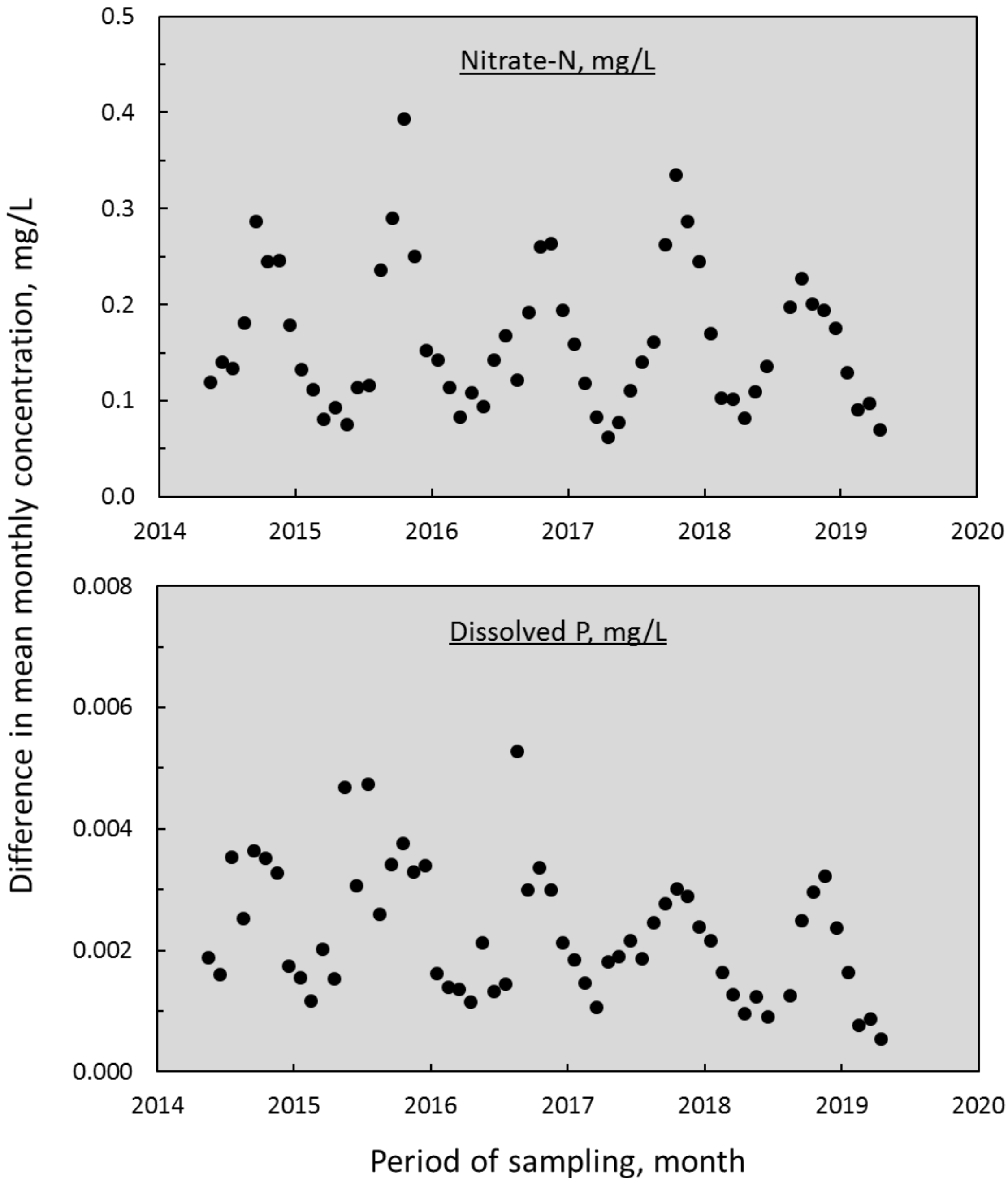

Figure 11. Difference in monthly mean nitrate-N and dissolved P concentrations between sites down (BC7) and upstream (BC6) of the C&H Farm as a function of time (May 1, 2014 to May 31, 2019).

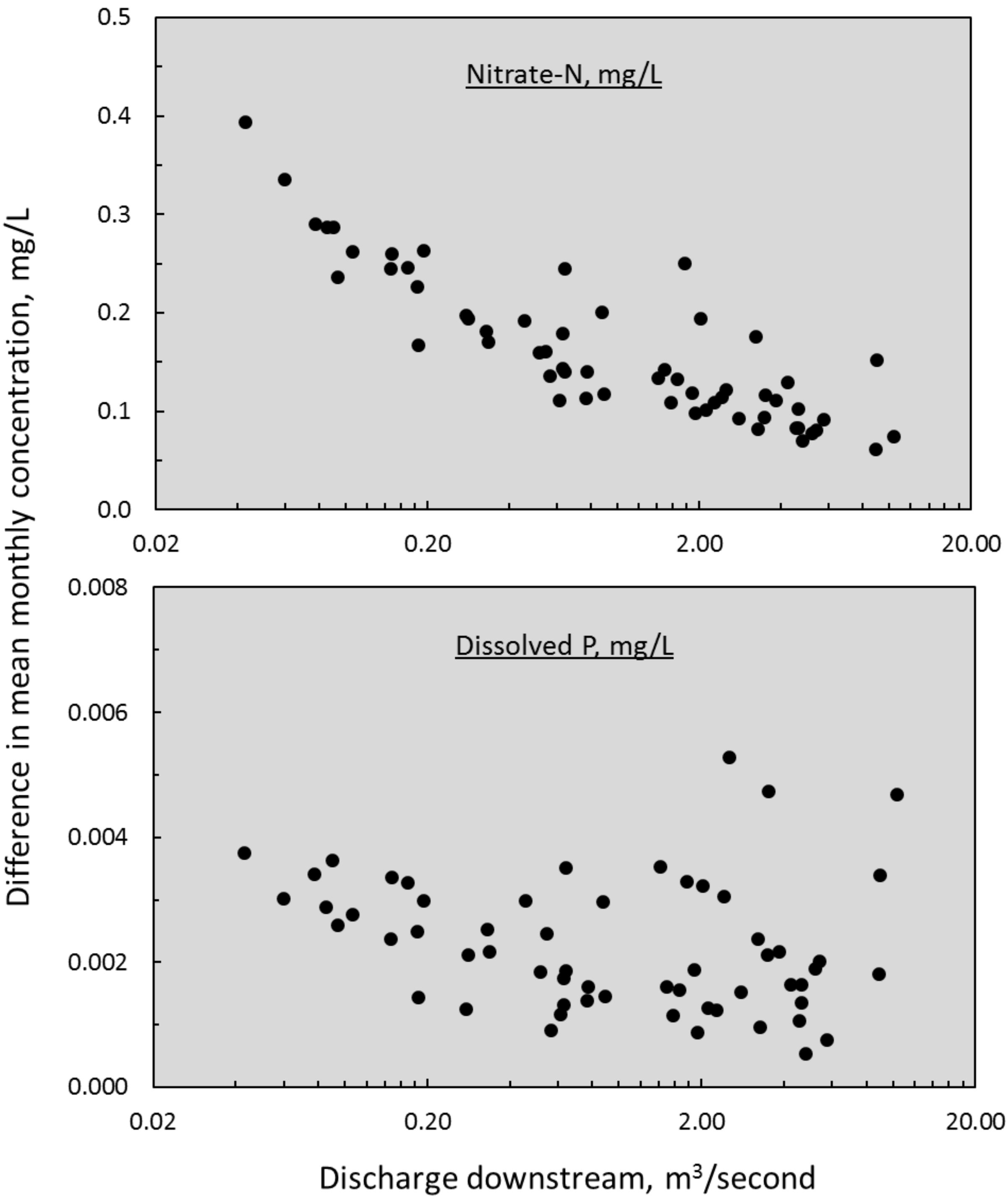

Figure 12. Difference in monthly mean nitrate-N and dissolved P concentrations between sites down (BC7) and upstream (BC6) of the C&H Farm as a function of downstream discharge (May 1, 2014 to May 31, 2019).

At high flows, it appears that the water coming from both the subwatershed above the upper site and the intervening subwatershed is closer, with nitrate-N concentrations slightly higher at BC7 than BC6.

As there is an influence of discharge on the difference in monthly nitrate-N concentrations between down and upstream sites, the following multiple regression was applied to nitrate-N concentration differences;

$D = b_0 + b_1 * \log(Q) + b_2 * (\log(Q))^2 + DecYear$ Regression Model [1]

Where Q is monthly mean discharge in m^3/sec and DecYear is decimal year. Output from this model is given in Table 6.

Table 6. Output of regression Model 1 for nitrate-N.

	Estimate	Standard error	t value	Probability (>t)
Intercept, b_0	1.43656	9.28658	0.155	0.878
DecYear	-0.00065	0.00460	-0.141	0.888
Log Q	-0.03032	0.00505	-6.005	1.41e-07 ***
Log Q2	0.01174	0.00330	3.561	0.00075 ***
Multiple R^2	0.5931			
Adjusted R^2	0.5717			

The multiple regression shows that the two flow terms are highly significant but the time trend term (DecYear) is not close to being significant (*p*-value is 0.88). This non-significant slope is negative, meaning slightly lower BC7 to BC6 differences in nitrate-N concentrations from one year to the next. However, decrease it is very small (i.e., -0.00065 mg/L/year). A plot of residuals and estimated concentration differences exhibits homoscedasticity, where model variable can be assumed to have the same finite variance, simplifying further statistical analysis (Figure 13).

Removing the two flow terms from the regression Model [1], the following Model focusing on time is applied to the nitrate-N concentration differences.

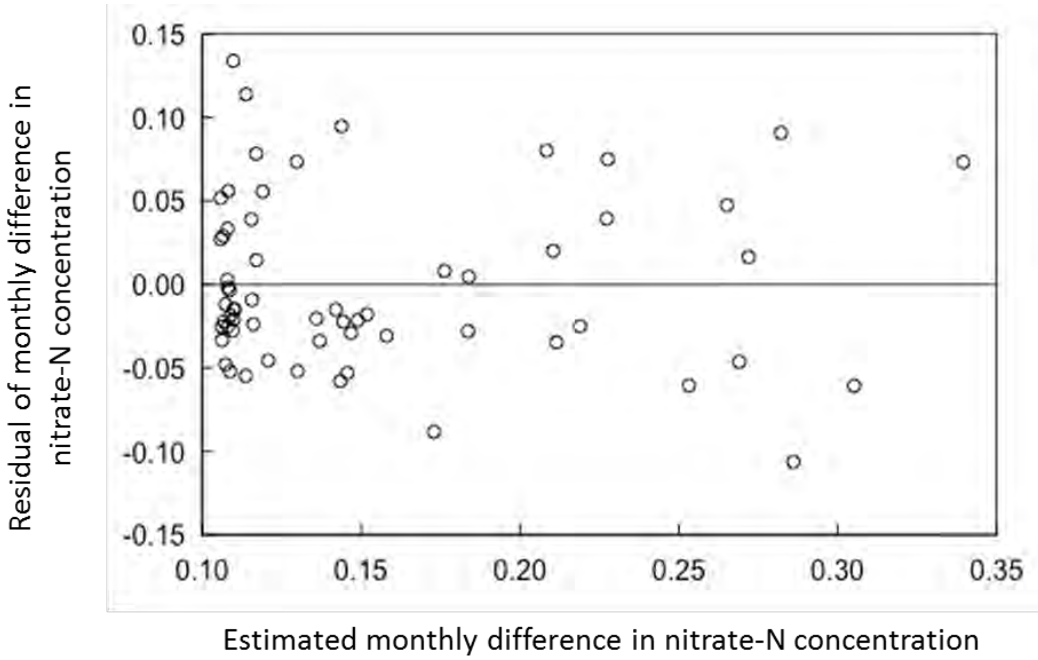

Figure 13. Relationship between the residuals and estimated mean monthly nitrate-N concentrations difference between BC7 and BC6 from regression Model [1].

1 month = Concentration~ Log Q + Log Q2 Regression Model [2]

Output from this model is given in Table 7. Note that the R^2 value from regression Model [1] of 0.5929 is very similar to that for Model [2] 0.5931; due to the fact that the DecYear time variable explained little of the variance. Plotting the residuals with time over the monitoring period shows little influence of time (Figure 14).

Applying the Kendall's Seasonal test to the residuals of regression Model [2] provided a slope of 0.0011 mg/L/year and probability values for this trend of 0.41, which is not significant.

Table 7. Output of regression Model 2 for nitrate-N.

	Estimate	Standard error	t value	Probability (>t)
Intercept, b_0	0.1266	0.0096	13.183	< 2e-16***
Log Q	-0.0304	0.0050	-6.127	8.42e-08 ***
Log Q2	0.0117	0.0033	3.594	0.00067
Multiple R^2	0.5929			
Adjusted R^2	0.5789			

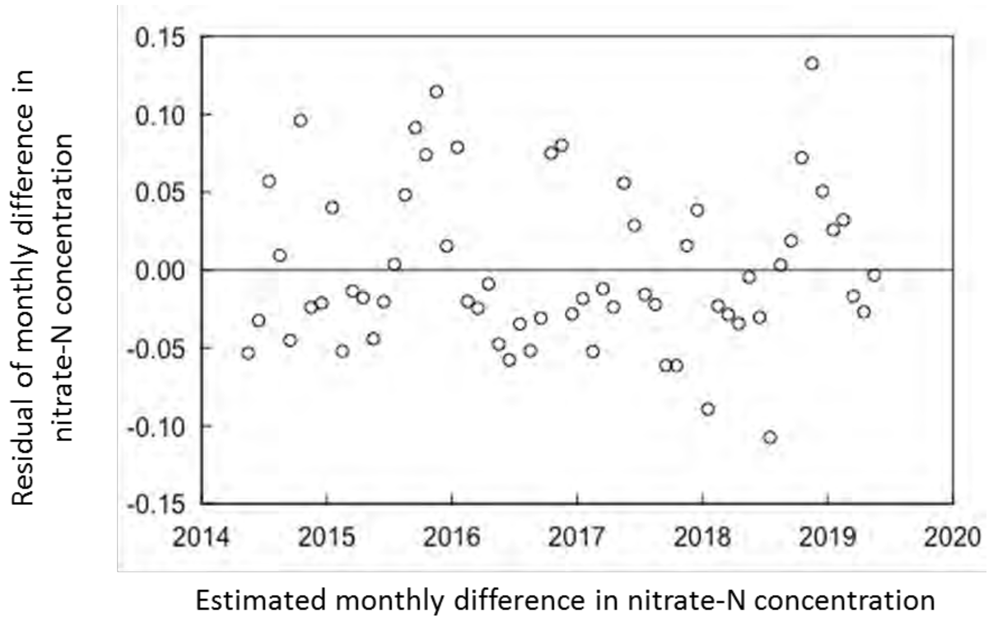

Figure 14. Relationship between the residuals and estimated mean monthly nitrate-N concentrations difference between BC7 and BC6 from regression Model [1].

Conclusion

The main conclusion from the above trend analysis of the difference between down (BC7) and upstream (BC6) nitrate-N concentrations, is the relationship between up and downstream concentrations is virtually unchanged over time. The two different trend analysis approaches give different signs to the relationship slope; but in either case, they are nowhere near being significantly different from zero and have very small magnitudes (i.e., -0.0006 mg/L/yr and 0.0011 mg/L/yr for regression Models [1] and [2] respectively). Thus, up to this point in time, the relationship between nitrate-N concentrations upstream and downstream of the farm are unchanged over the 5 years of data collection.

Acknowledgement

The Big Creek Research and Extension Team acknowledge and are extremely grateful to Dr. Robert Hirsch (retired U.S. Geological Survey) for advice and help in conducting, analyzing, and interpreting Weighted Regressions on Time, Discharge, and Season (WRTDS) analysis of discharge and nutrient data collected from Big Creek up and downstream of the C&H Farm. His vast experience informed and provided state of the science analysis of in-stream trends,

References

Bekele, A., and A. McFarland. 2004. Regression-based flow adjustment procedures for trend analysis of water quality data. Trans. ASAE 47:1093–1104.

Chanat, J.G., D.L. Moyer, J.D. Blomquist, K.E. Hyer, and M.J. Langland. 2016. Application of a weighted regression model for reporting nutrient and sediment concentrations, fluxes, and trends in concentration and flux for the Chesapeake Bay Nontidal Water-Quality Monitoring Network, results through water year 2012. U.S. Geological Survey, Reston, VA. 76 pages. Available at http://dx.doi.org/10.3133/sir20155133

Giovannetti, J., L.B. Massey, B.E. Haggard, and R.A. Morgan. 2013. Land use effects on stream nutrients at Beaver Lake watershed. J. Am. Water Works Assoc. 105:E1–E10.

Helsel, D.R., and R.M. Hirsch. 2002. Statistical methods in water resources. Chapter A3. *In* Techniques of Water-Resources Investigations of the United States Geological Survey. Book 4, Hydrologic Analysis and Interpretation. U.S. Geological Survey. Available at https://pubs.usgs.gov/twri/twri4a3/pdf/twri4a3-new.pdf. 524 pages.

Hirsch, R.M. 2012. Flux of nitrogen, phosphorus, and suspended sediment from the Susquehanna River basin to the Chesapeake Bay during tropical storm Lee, September2011, as an indicator of the effects of reservoir sedimentation on water quality. U.S. Geological Survey, Reston, VA. 17 pages. Available at http://pubs.usgs.gov/sir/2012/5185/

Hirsch, R.M., and L. De Cicco. 2015. User guide to exploration and graphics for RivEr Trends (EGRET) and Data Retrieval: R Packages for Hydrologic Data (Version 2.0, February2015). U.S. Geological Survey, Reston, VA. 93 pages. Available at http://dx.doi.org/10.3133/tm4A10.

Hirsch, R.M., R.B. Alexander, and R.A. Smith. 1991. Selection of methods for the detection and estimation of trends in water quality. Water Resour. Res. 27:803–813.doi:10.1029/91WR00259

Hirsch, R.M., D.L. Moyer, and A.S. Archfield. 2010. Weighted regressions on time, discharge, and season (WRTDS, with an application to Chesapeake Bay River inputs. J. Am. Water Resour. Assoc. 46(5):857-880. DOI: 10.1111⁄j.1752-1688.2010.00482.x

Lettenmaier, D.P., E.R. Hooper, C. Wagner, and K.B. Faris. 1991. Trends in stream quality in the continental United States, 1978–1987. Water Resour. Res. 27:327–339.doi:10.1029/90WR02140

McCarty, J.A., and B.E. Haggard. 2016. Can we manage nonpoint-source pollution using nutrient concentrations during seasonal baseflow? Agric. Environ. Lett. 1:160015

Moyer, D.L., R.M. Hirsch, and K.E. Hyer. 2012. Comparison of two regression-based approaches for determining nutrient and sediment fluxes and trends in the Chesapeake Bay Watershed. U.S. Geological Survey, Reston, VA. 118 pages. Available at http://pubs.usgs.gov/sir/2012/5244/

Sharpley, A.N., B.E. Haggard, L. Berry, K. Brye, J. Burke, M.B. Daniels, E. Gbur, T. Glover, P. Hays, T. Kresse, and K.W. VanDevender. 2017. Nutrient concentrations in Big Creek correlate to regional watershed land use. Agric. Environ. Lett. 2017 2:170027.

Sharpley, A.N., P. Moore, K. VanDevender, M. Daniels, W. Delp, B. Haggard, T. Daniel, and A. Baber. 2010. Arkansas Phosphorus Index. Cooperative Extension Service, Division of Agriculture, University of Arkansas. Fact Sheet FSA 9531. 8 pages. Available at http://www.uaex.edu/Other_Areas/publications/PDF/FSA-9531.pdf.

White, K.L., B.E. Haggard, and I. Chaubey. 2004. Water quality at the Buffalo National River, Arkansas, 1991–2001. Trans. ASAE 47(2):407–417. doi:10.13031/2013.16042

Zhang, Q., D.C. Brady, and W.P. Ball. 2016. Decadal-scale export of nitrogen, phosphorus, and sediment from the Susquehanna River basin, USA: Analysis and synthesis of temporal and spatial patterns. Sci. Total Environ. 563-564:1016-1029.

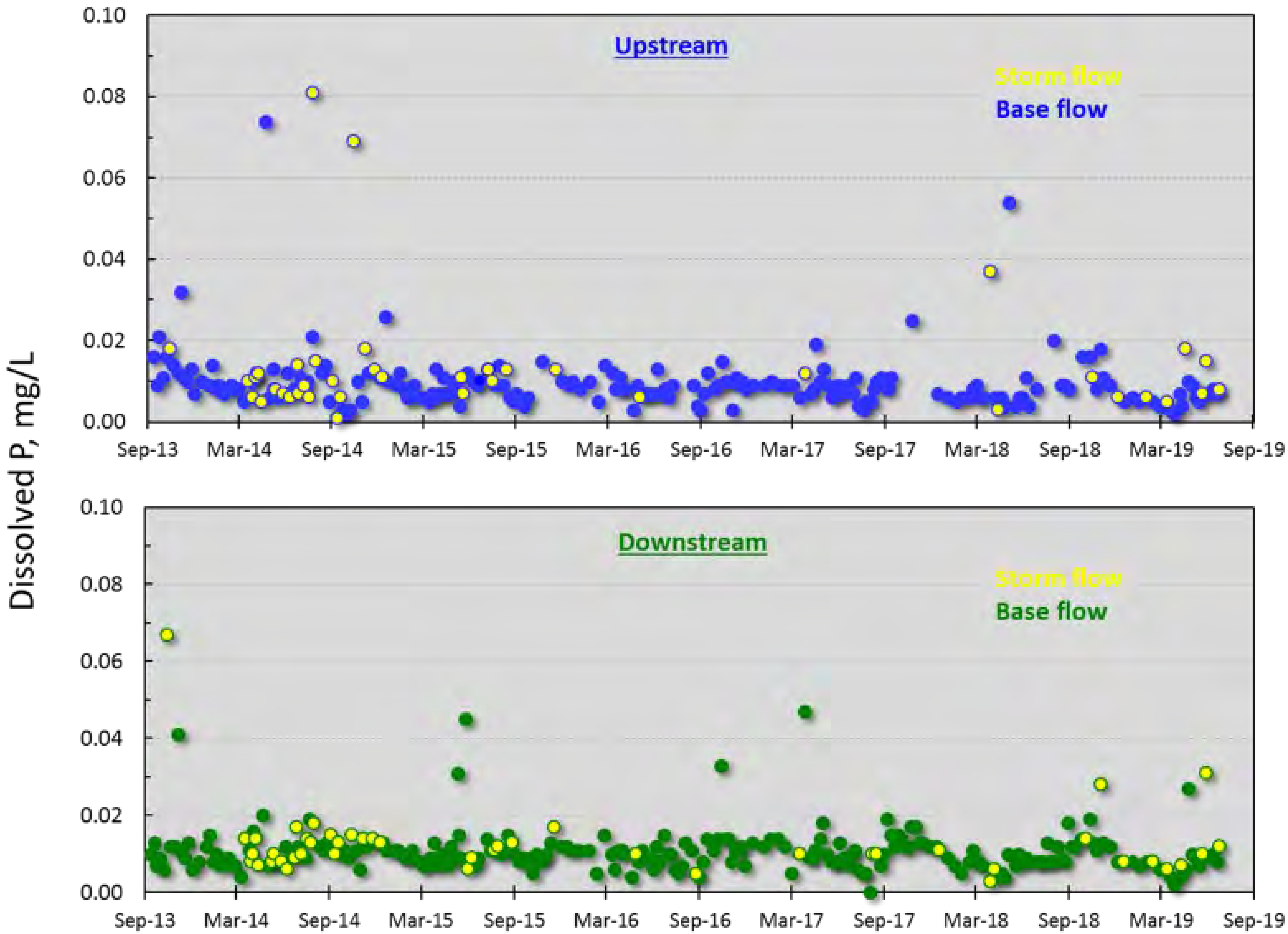

Figure S 1. Dissolved P concentration at the Big Creek monitoring site up- and downstream of the C&H Farm.

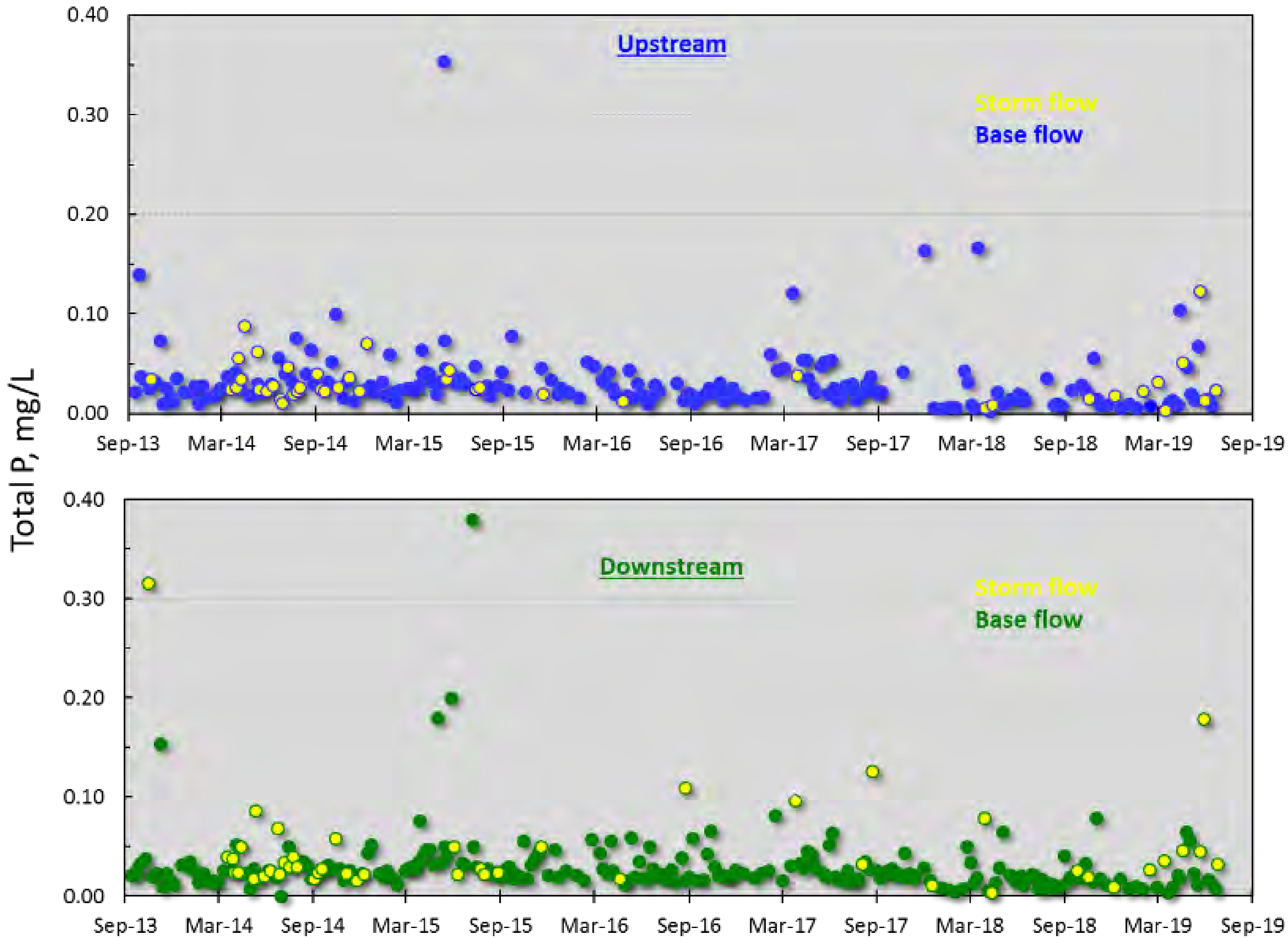

Figure S 2. Total P concentration at the Big Creek monitoring site up- and downstream of the C&H Farm.

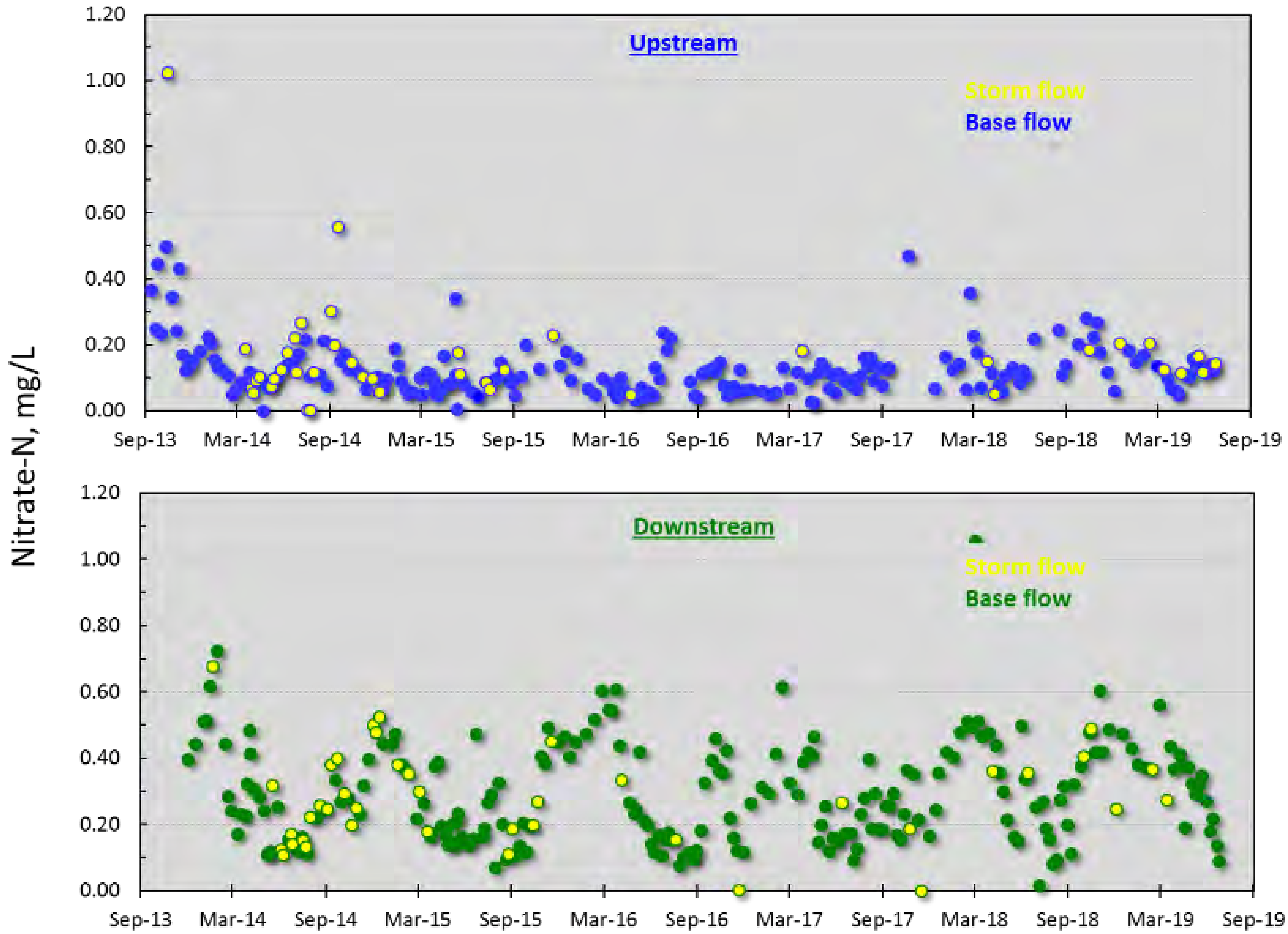

Figure S 3. Nitrate-N concentration at the Big Creek monitoring site up- and downstream of the C&H Farm.

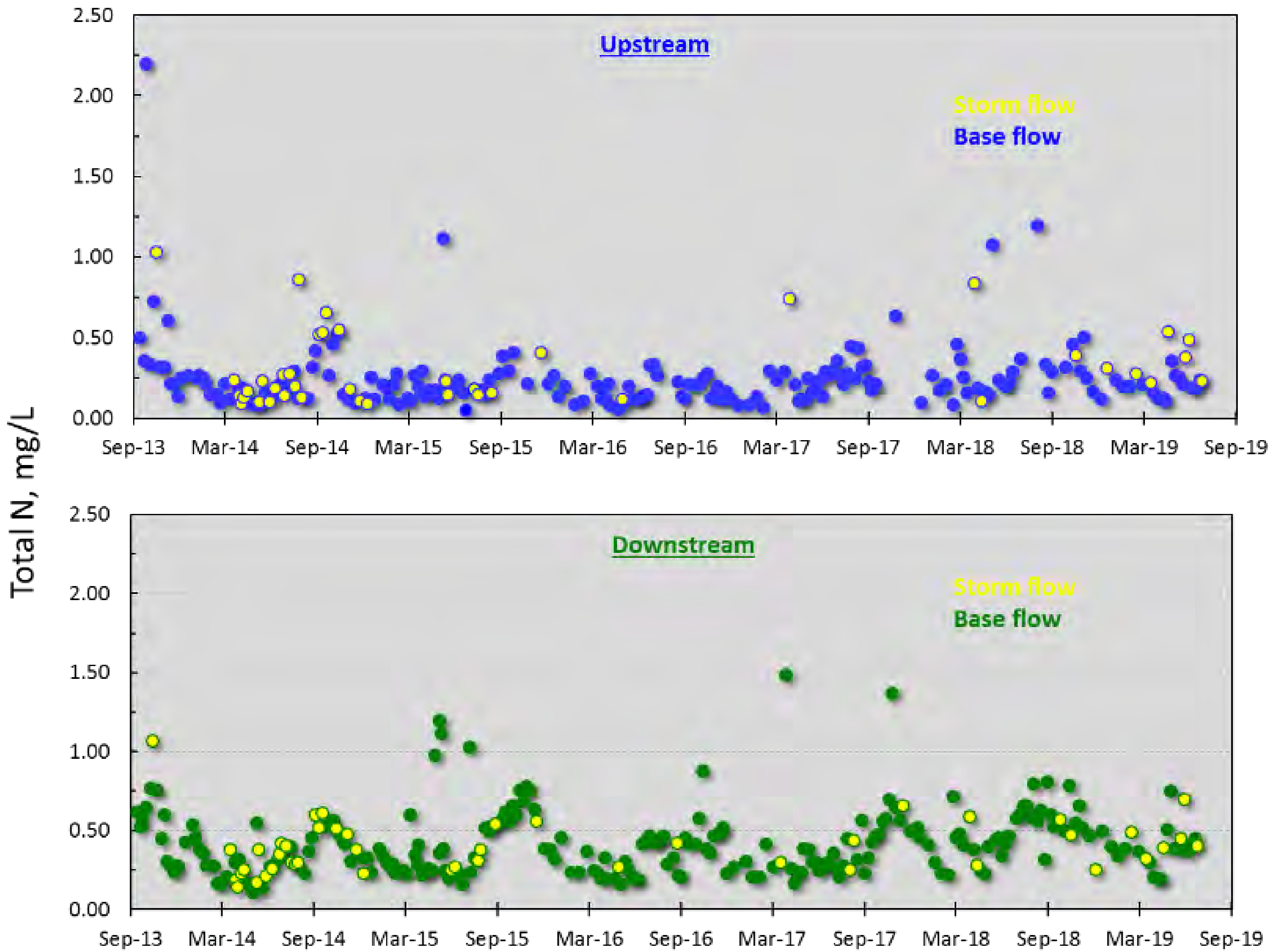

Figure S 4. Total N concentration at the Big Creek monitoring site up- and downstream of the C&H Farm.

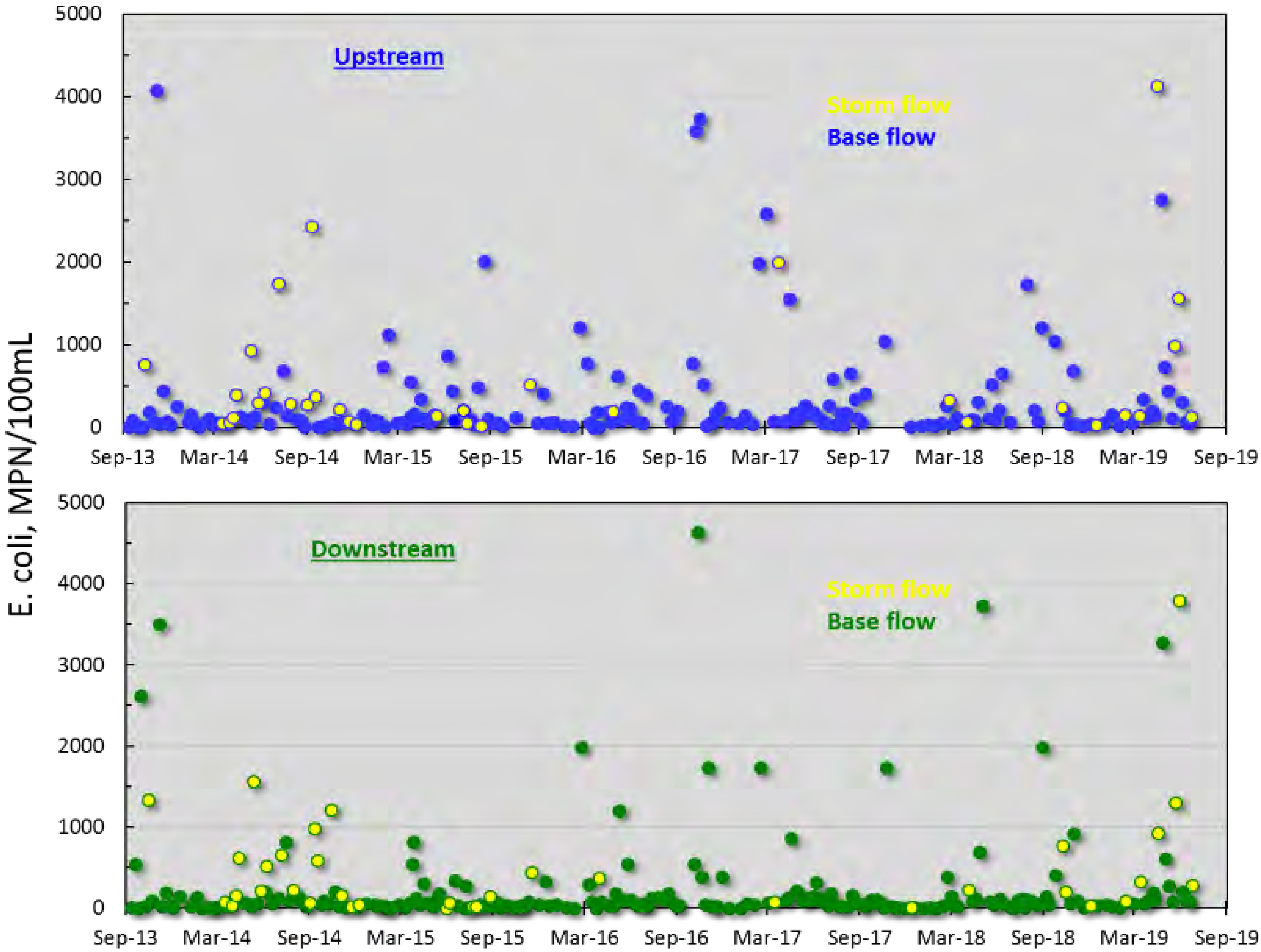

Figure S 5. E. coli numbers at the Big Creek monitoring site up- and downstream of the C&H Farm.

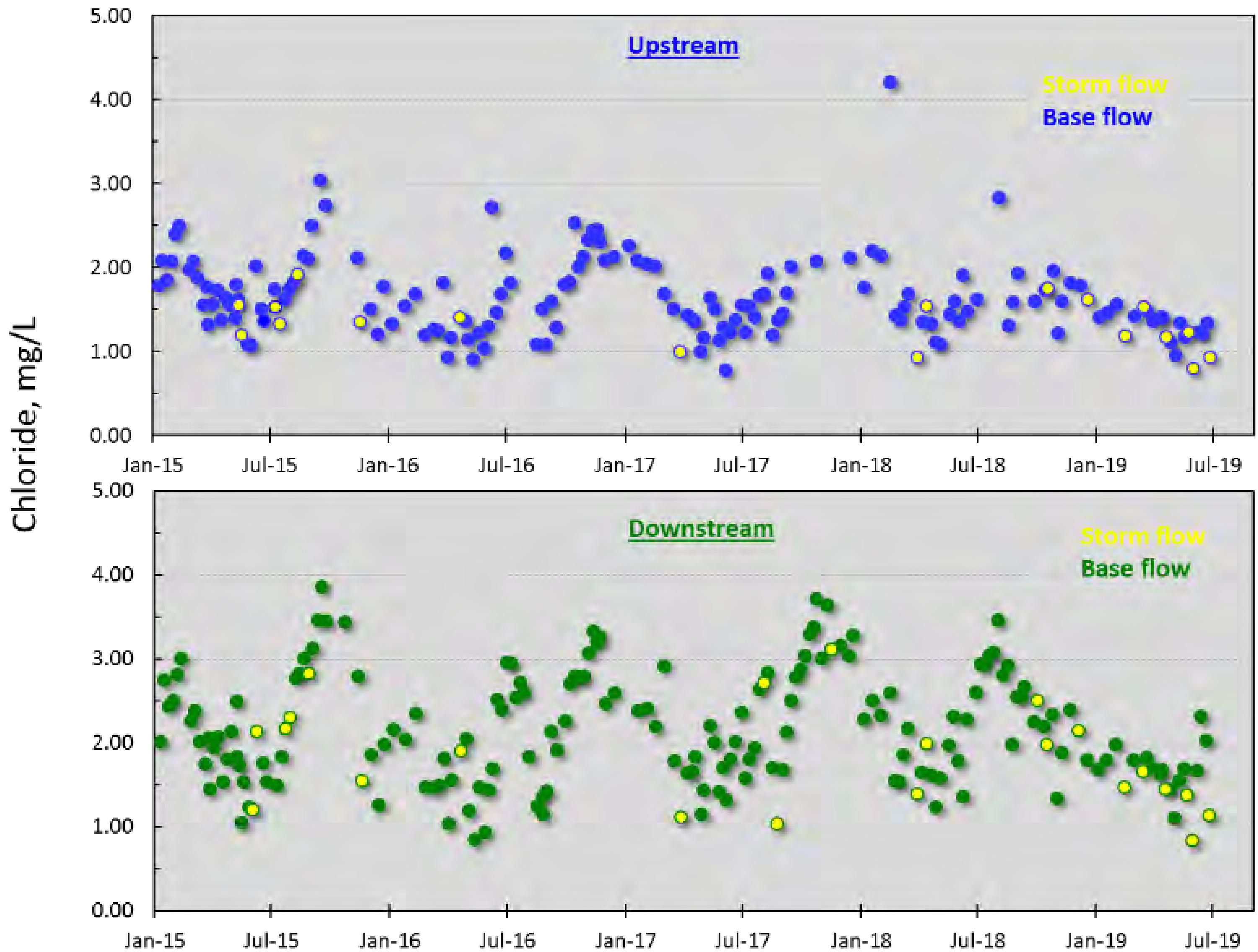

Figure S 6. Chloride concentration at the Big Creek monitoring site up- and downstream of the C&H Farm.