BCRET Nutrient Data Analysis, 5/1/14 to 2/15/17

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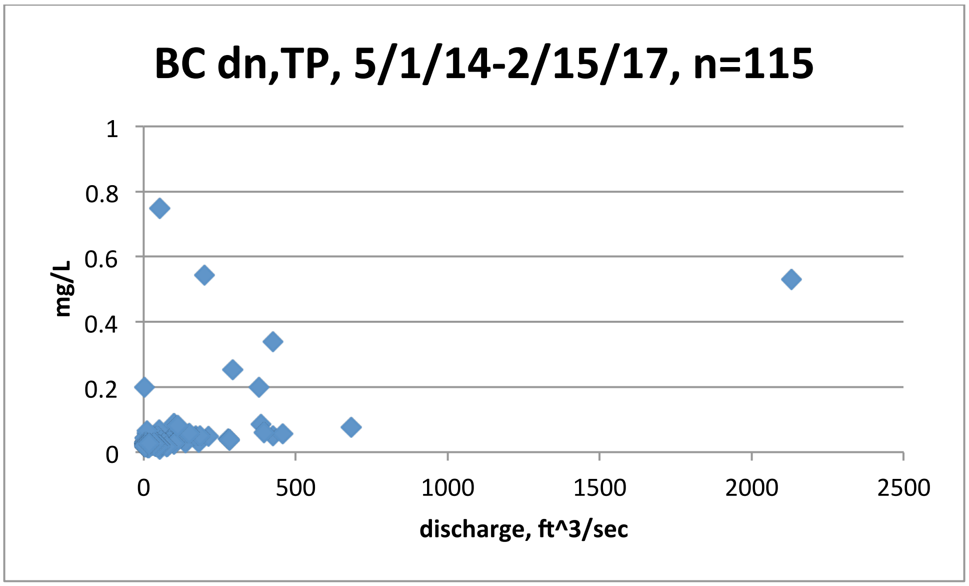
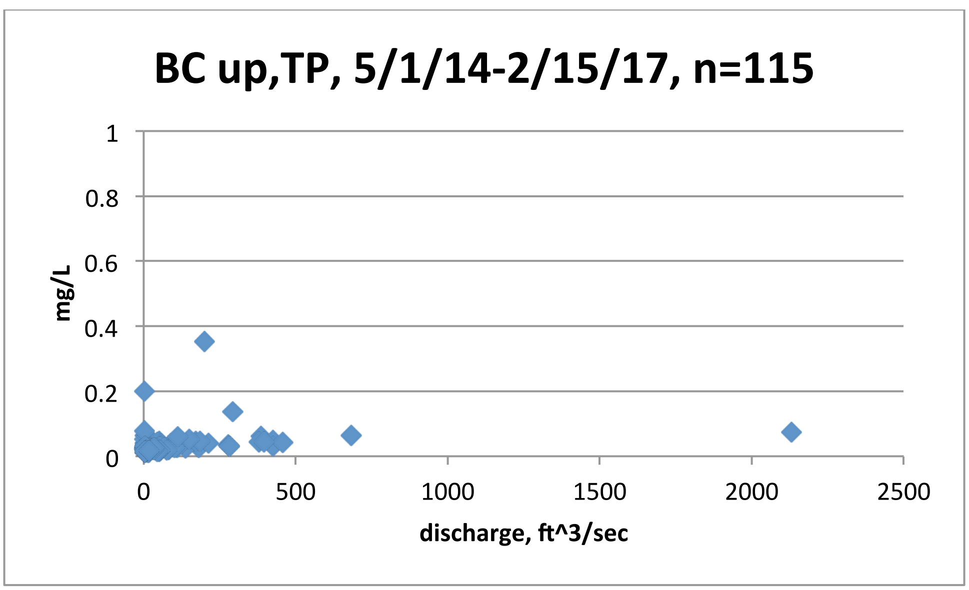
General Trends: The concentration (mg/L) of the nutrients phosphorus and nitrogen correlate to discharge (ft^3/sec), but in different ways. Phosphorus (TP) is positively correlated with discharge with more outliers downstream (7) than upstream (3), suggesting non ambient input from C&H, or some other source. Nitrogen (TN) is negatively correlated with discharge. The graphs for dissolved phosphorus (DP) and nitrates are similar.

7 clear outliers downstream from farm.

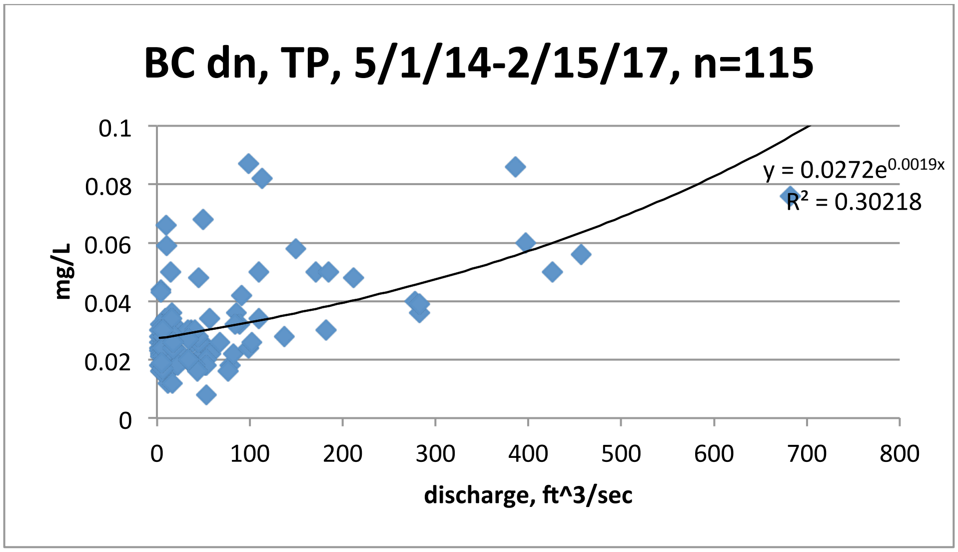


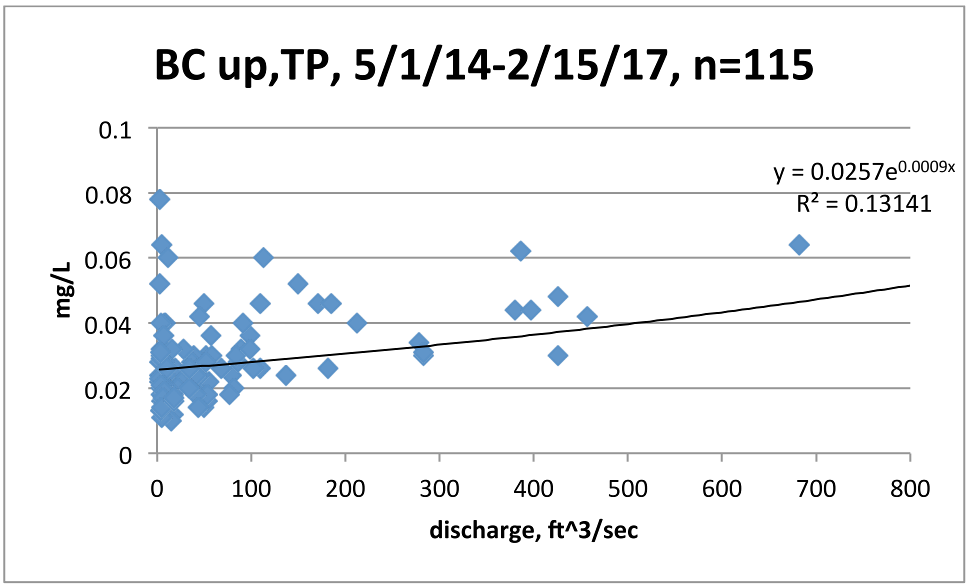
At most 3 outliers upstream from farm.



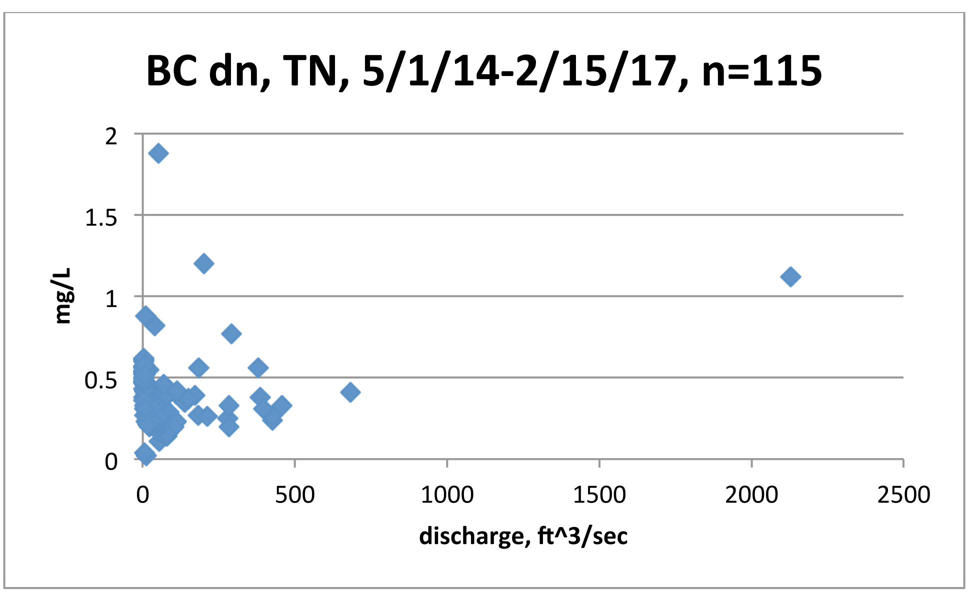
The next two truncated graphs show a clear positive correlation with discharge both upstream and downstream for non-outliers.

Somewhat stronger positive correlation for downstream than upstream for truncated data, R^2 is necessarily low.

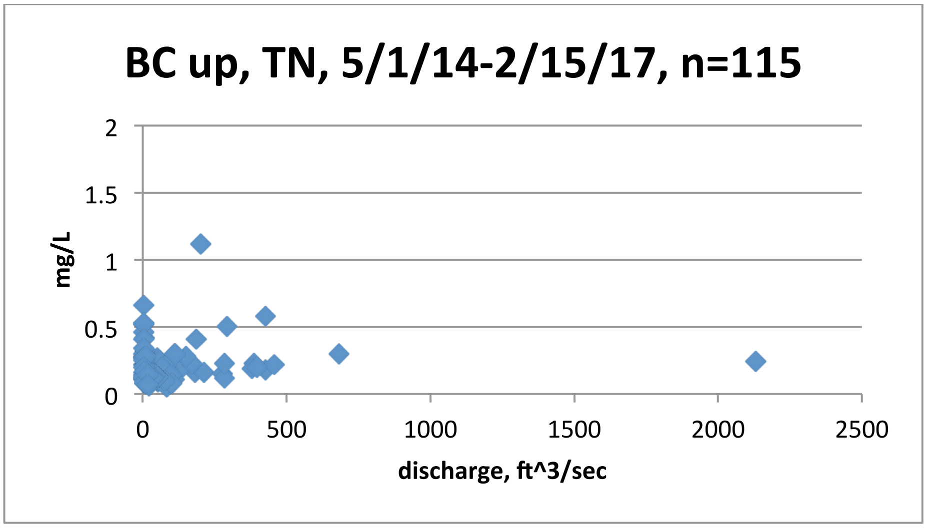




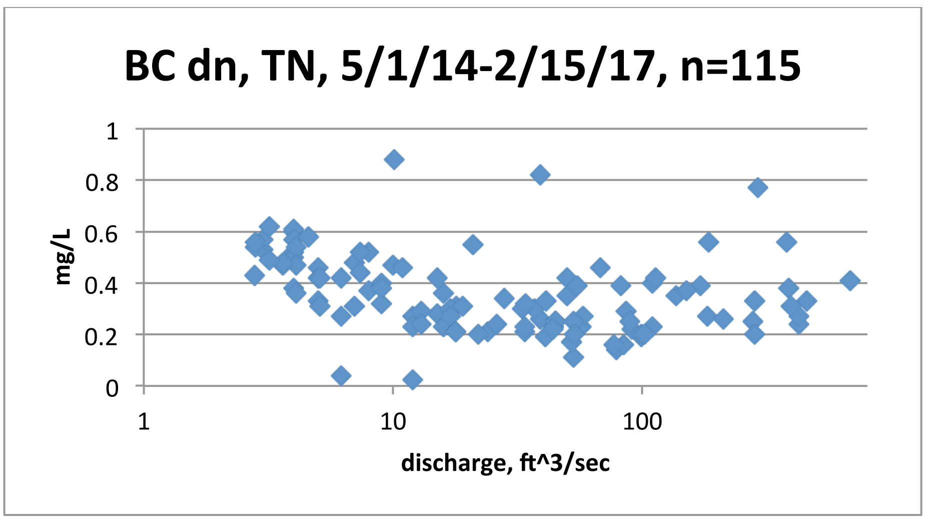
Downstream TN graph with several very high outliers for Ozark streams



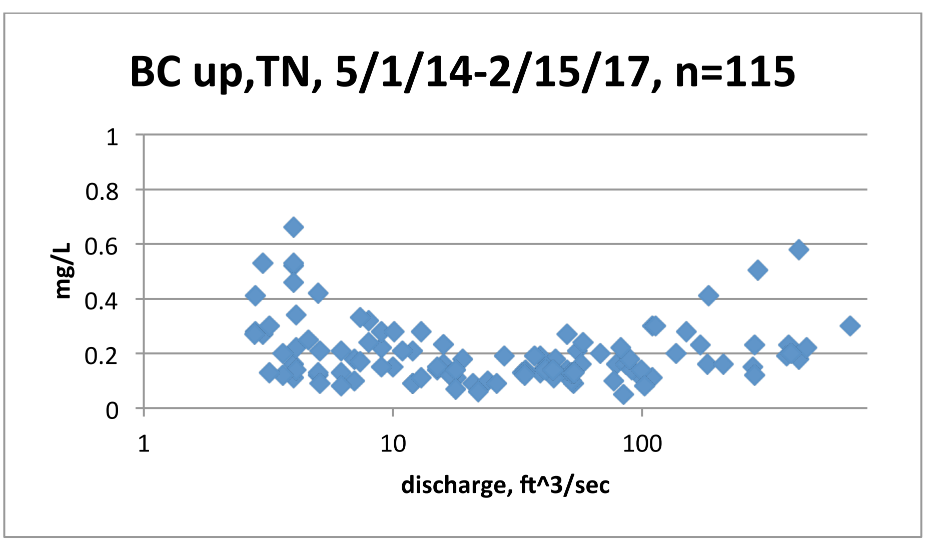
Upstream TN graph with one high outlier.



Downstream TN with weak negative correlation apparent for truncated data.



Upstream TN with much lower values, and weak negative correlation, for truncated data.



Basic Statistical Tools: Stream nutrient analysis uses 4 basic measurements of central tendencies. Assume that $\{c_j\}$ is the collection of measured concentrations (mg/L), d_j (ft^3/sec) is the discharge at the downstream gauge on Big Creek at the time of measurement c_j, and n =115 is the number of samples in this period.

- **Arithmetic mean:** The usual average. Mean = $\sum c_j/n$.
- **Median:** The middle value.
- **Discharge weighted mean:** Mean (flow weighted) = $\sum d_j c_j/D$, where D = $\sum d_j$ is the total discharge of the sample.
- **Geometric mean:** Geomean = the nth root of the product of all the data values.
- **T.test**: The t.test is used to compare data sets. The p-value is the likelihood that a difference in data values is just by chance. Generally $p < .05$ is considered to indicate a significant difference in the data sets. In the BCRET data comparing upstream and downstream values, the p values are extremely low. Which leads to the conclusion: Stream nutrient levels below the farm are undeniably higher than the ambient levels above the farm.

Relationships:

- The **arithmetic mean** is distorted by a few very large data points, but it is usefully related to yearly stream discharge. For a representative set of discharges, the yearly discharge can be estimated by: yearly discharge ≈ mean discharge · number of seconds in a year.
- The **geometric mean** reduces the effect of extreme outliers and is a useful tool for the analysis of e-coli outbursts, etc, but it is seldom used for comparing nutrient values since it reduces differences. It is always true (Young's Inequality) that the geometric mean is less than the arithmetic mean, and so the geometric mean always understates the nutrient levels in streams – an undesirable quality. Unlike the arithmetic mean the geometric mean is not directly useful for estimating physical parameters
- The **median** is insensitive to outliers and thus is relatively stable, which can be an advantage in year to year comparisons or a disadvantage when analyzing phosphorus which is positively correlated with flow – i.e. large discharge events should not be disregarded. Most nutrient data is skewed to the right, implying that the median will be less than the arithmetic mean in most cases. **Quartiles** are more useful for analysis than medians.
- The **flow weighted mean** is critical for estimating nutrient flow associated with stream flow. The discharge weighted mean times the yearly discharge gives an estimate of the total nutrient discharge in a year. This is critical in making a mass balance analysis of nutrients: that is, the nutrients spread on a field either leave the farm as an agricultural product, or are stored on the land (as TP is but nitrates are not), or leave via water paths. It is important to get an estimate of each. Stream discharge on Big Creek varies by a several orders of magnitude, and TP is positively correlated with discharge, for these reasons the arithmetic mean, median, and geometric mean are not good indicators of phosphorus load.

The Data: To get a notion of 4 different measurements of central tendencies, consider discharge (ft^3/sec) at the downstream gauge on Big Creek, n =115.

Arithmetic mean = 91.8 ft^3/sec

Median = 26

Geomean = 27.2

Mode = 4 (most frequent value)

Important Note 1: High discharge events essentially determine the nutrient flux, and therefore the total yearly nutrient load below the farm on Big Creek. The TP data corresponding to the lowest half of stream *discharge* (i.e. d_j

≤26) contributes about .7% of the TP mean flux (lbs/sec), and the discharges below the 3rd quartile (i.e. $d_j \leq 83$) contribute only 4.5%. For TN, which is negatively correlated with discharge, the corresponding numbers are 3.3% and 12% respectively. So low discharge days (at or below the median and/or geomean) are unimportant in terms of predicting nutrient load, though they might be relevant in terms of predicting stream habitat.

Important Note 2: To further emphasize the difference between TP and TN, only 1.7% of the mean flux (nutrient flow) of TP occurs at or below the median *concentration* of TP (i.e. $c_j \leq 0.26$ mg/L) whereas 22.7% of the total flux of TN occurs at or below the median concentration of TN (i. e. $c_j \leq 0.33$ mg/L). In other words, the median (or geomean) might be useful to indicate relative flux of TN but not for TP.

All useful BCRET/USGS data: 5/1/2014-2/5/2017 [incomplete data was deleted]

Phosphorus (mg/L)

	DP, up	DP, dn	% inc	TP, up	TP, dn	% inc
Mean	0.0101	0.0138	36%	0.0342	0.0533	81%
flow weighted mean	0.0113	0.0212	88%	0.0542	0.1797*	231%
Median	0.0090	0.0110	22%	0.0260	0.0260	0%
Geomean	0.0084	0.0111	32%	0.0278	0.0323	16%

t.tests			
Mean, dn > up	p-value	0.00002	0.0106

Nitrogen (mg/L)	nitrate, up	nitrate,dn	% inc	TN, up	TN, dn	% inc
Mean	0.111	0.251	127%	0.209	0.388	99%
Flow weighted mean	0.082	0.119	45	0.247	0.521*	121
Median	0.099	0.200	102	0.160	0.330	106
Geomean	0.094	0.210	123	0.179	0.332	85

t.tests, p-value		
Mean, dn > up	5.5E-29	3.14E-14
nitrate dn > 2·nitrate up**	0.008	
TN dn > 1.6·TN up		0.017

*The high downstream TP and TN numbers are partially attributable statistically to samples from May 8 & 11, 2015 which showed extremely high downstream TP levels of 0.544 and 0.53 (mg/L) and TN at 1.2 and 1.12 (mg/L). These are 3-15 times the ambient level above the farm. This occurred during a storm event with discharge amounting to about 20% of the entire discharge for the 115 samples. Deleting May 8 & 11 data changes the flow weighted means significantly, but not the mean, median, or geomean which are unaffected by discharge.

Flow weighted mean: May 8 & 11 data deleted: The numbers change significantly but the trend does not.

DP, up	DP, dn	inc	TP, up	TP, dn	inc	Nitr,up	Nitr, dn	inc	TN, up	TN, dn	inc
0.010	0.014	40%	0.042	0.080	90%	0.096	0.178	46%	0.228	0.349	53%

**In the case of nitrogen, the t.test shows that nitrate below the farm are more than twice as high as ambient levels above the farm and TN is 60% higher.

Yearly nutrient load: Yearly load (lbs/yr) ≈ flow weighted mean (lbs/ft^3)·mean discharge (ft^3/sec)·(3600·24·365 sec/year). A conservative approach is to estimate yearly loads with May 8 & 11 deleted. "Ambient load" is the load that would result from downstream discharge if nutrient levels were maintained at upstream levels. Loads can vary greatly from year to year depending on rainfall patterns and farming and other practices.

TP load	= 11,496 lbs
Ambient TP load	= 6,035
Difference	= 5,461

TN load	= 49,849
Ambient TN load	= 32,669
Difference	= 17,180

Nitrate load	= 25,432
Ambient nitrate load	= 13,784
Difference	= 11,648

DP load	= 2,077
Ambient DP load	= 1,459
Difference	= 618

The load differences can be used to estimate the added nutrient influence of the farm, or other entities, that drain into the farm section of Big Creek. For example, the farm section of Big Creek contributes an excess of 5,461 lbs TP above ambient levels by these estimates. But keep in mind that load estimates might be quite inaccurate given the variability due to storm events.

The yearly load of TP in the manure application from C&H is about 26,000 lbs., which eventually leaves as agricultural product or water pathways, or is retained in the soil. Some TP is removed by grazing (14-30%, but the efficiency of grazing is not reported in annual reports to ADEQ), and as we have seen, some TP leaves via Big Creek (20% if the above estimates are valid, say 5-30% depending on the year). So this data tends to support the contention that much of the excess TP produced by the farm remains to build up in the soil.

Much of yearly 60,000 lbs. of TN waste from C&H is volatile (ammonia) and evaporates from the barns and lagoons or during the spraying operation. The farm is "managed" for nitrogen utilization even though the nitrogen is not incorporated into the soil. There is some agricultural nitrogen export. But clearly there is a significant groundwater/surface water nitrogen source on the farm stretch of Big Creek (≈ 17,180 lbs.)

Putting nutrient levels into perspective

The Arkansas drinking water limit of nitrate is 10 mg/L. This limit could not be reached on Big Creek even if C&H applied all its manure directly into Big Creek. If thoroughly mixed and distributed evenly with flow, the mean concentration of nitrate would increase by about .5 mg/L. The stream would be a soupy algae mix but it would be drinkable from the nitrate point of view.

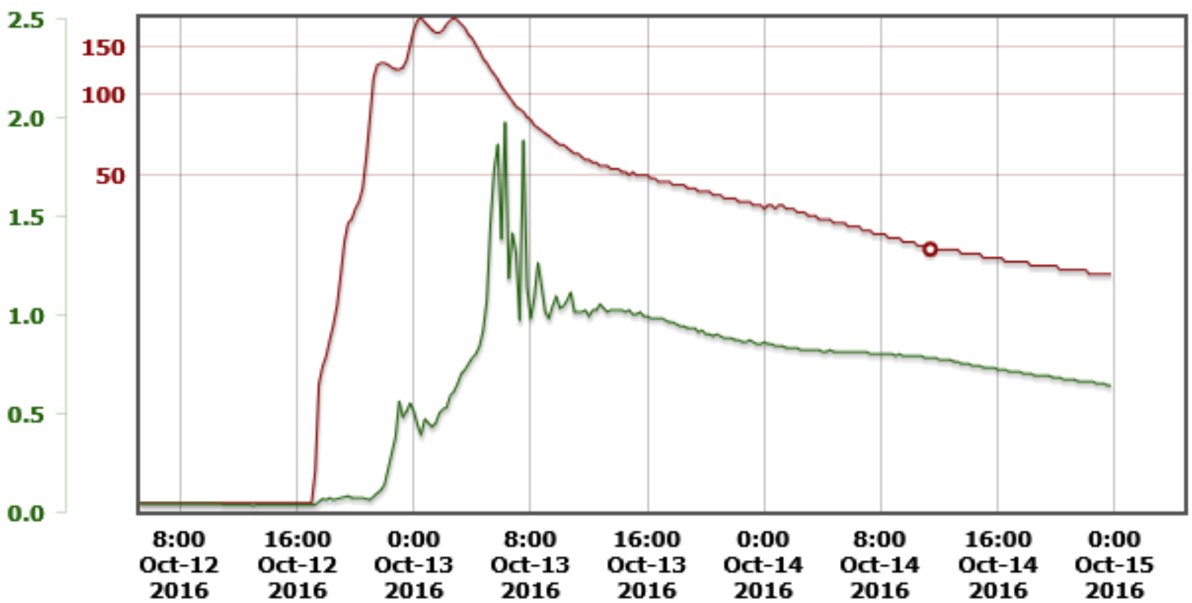
There are not numeric standards for TP levels in Arkansas streams but the EPA recommends 0.1 mg/L. Phosphorus is often the limiting nutrient in streams with eutrophic problems starting at 0.05 mg/L. Both mean and weighted mean levels of TP levels on Big Creek currently approach or exceed this level below the farm.

Change over time: The natural variation of weather patterns and the unnatural, time sporadic, intervention by humans makes changes over time difficult to discern without more years of data than are currently available, but I present half period comparisons anyway, 1st half (data points 1-59) and 2nd half (data points 60-115).

Mean	TP, up	TP, dn	inc	TN, up	TN,dn	inc
5/1/14-6/8/15	0.039	0.055	39%	0.229	0.379	66%
6/22/15-2/15/17	0.029	0.052	81	0.188	0.386	105

The mean discharge in the first half was 111 ft^3/sec, significantly more than 70 ft^3/sec in the second half so the data is probably not comparable (sampling conditions were different), and certainly not predictive. No increase in TP was observed although the percent increase, up vs dn, were higher in the second half for both nutrients. In the long run it is expected that TP will increase with increasing soil TP levels, and unless there are significant land use changes, TN levels should remain relatively constant since there is essentially no soil storage.

Storm sampling: The nitrate response (green, mg/L) to a small storm rise (red, discharge in ft^3/sec) on Big Creek (Carver Gauge) shows a delayed spike in nitrate concentrations followed by a slow decline to a new base level. TP response curves for the watershed are similar, but there is no real time sampling of TP on Big Creek. In contrast to base flow, a one-time "grab sample" during this storm event is unlikely to be representative of average event concentrations. So the effect of storm events on nutrients is difficult to ascertain with current sampling methods.



One proposed solution is to continuously monitor several storm events for TP and then create a mathematical model of TP response to storm events on Big Creek. The goal is to predict TP flux for the entire event by using just one or two data points. One difficulty of implementation (beyond cost) is that not all storm events have a nitrate/TP spike associated with them. Rainfall intensity/location/recent history and land use (e.g. recent manure application) are confounding variables.

Yearly trends in nitrate at Carver: Continuous monitoring of nitrate at Carver (near the junction with the Buffalo River) shows an increase over time and values that are considerably less than from the farm 5 miles upstream from Carver (mean nitrate below farm = 0.251 mg/L). This suggests that nitrate levels arising from the farm portion are uniquely high (estimates can be made). Confounding this conclusion:

- In high water conditions, the Carver gauge might be measuring concentrations from the Buffalo rather than Big Creek.
- The nitrate gauge at Carver frequently malfunctions, especially in high water conditions.
- The effect of ground water flow is uncertain.
- The BCRET data should be paired with the Carver data to take into account varying discharge levels.

USGS data from site 00631.

Water Year	00631, Nitrate plus nitrite, water, filtered, milligrams per liter as nitrogen
2014	0.100990909090909
2015	0.134028525641026
2016	0.179595679012346
** Incomplete data have been used for statistical calculation	

Karst and groundwater discharge: The karst features in the Big Creek valley provide a means for nutrients from C&H to get to the Buffalo River and Big Creek. It is certain that the wastewater ponds leak and nutrients leach into ground water from manure applications. But the significance of this is hard to establish without data such as BCRET has gathered on surface flow. In low flow regimes it is probable that ground water discharge is primary, but as has been demonstrated above, low discharge data contributes little to total nutrient flux. It would also be useful to have a concentration profile of groundwater nutrients. For instance, how are ground water nutrients levels correlated to discharge? The USGS (Tim Kresse) has studies of ground water nutrient flows and levels for some other Buffalo River tributaries that might be applicable.