Nutrient Concentrations in Big Creek Correlate to Regional Watershed Land Use (BCRET) – A Technical Response

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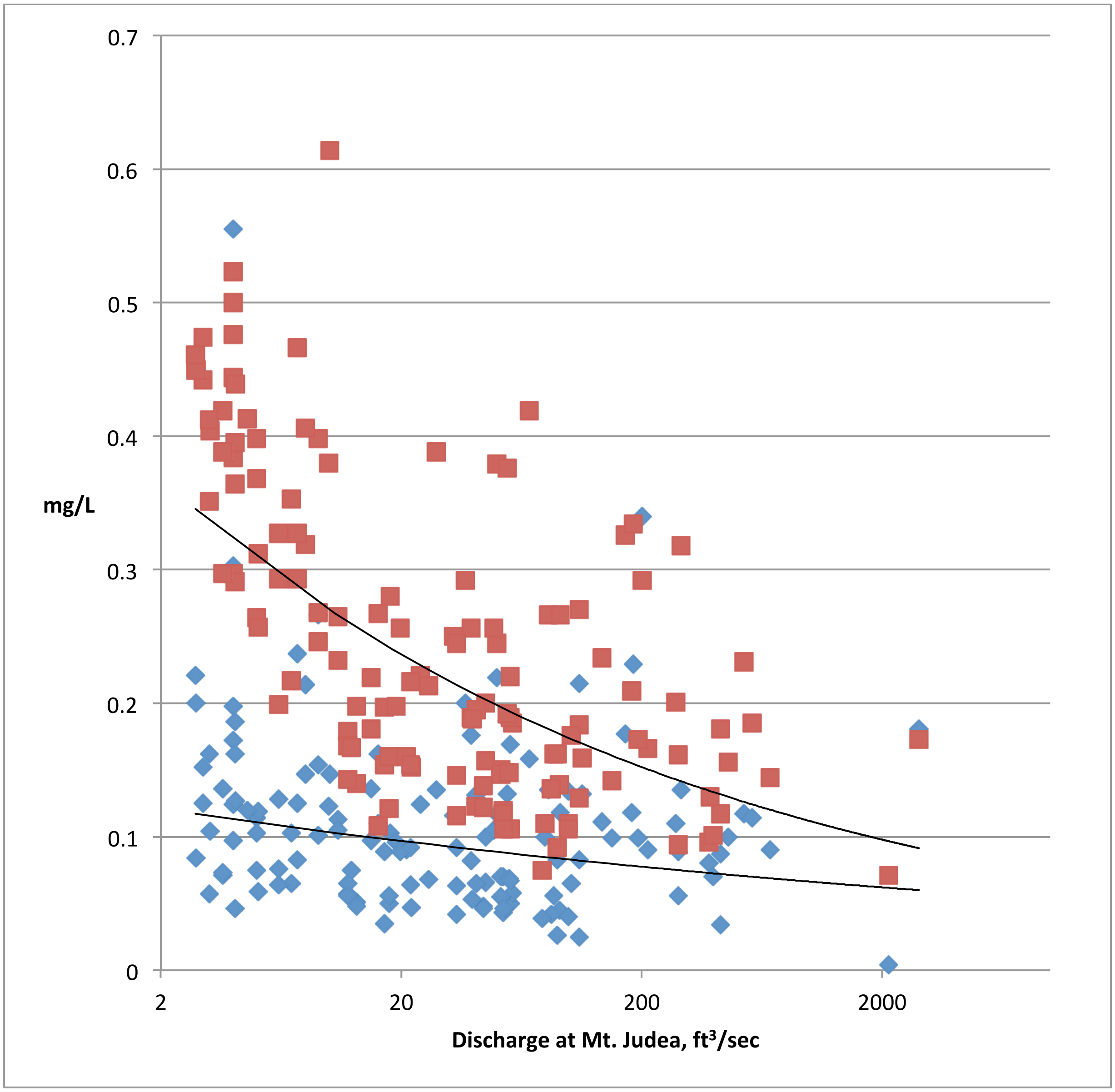

Nitrate Concentrations: Above C&H - BLUE, below C&H - RED SQ

The BCRET paper attempts to compare nutrient pollution at the location of C&H hog farm on Big Creek to that of other Buffalo River tributaries. Several members of the BCRET team, particularly Brian Haggard, have a long history of technic{al writing and research on these topics. The methods and analysis are standard, although digging through reference papers is required for deciphering jargon and understanding methods.

Three conclusions need rebuttal or at least a critical review.

i) “flow adjusted NO_3-N concentrations decreased over time (R^2 =0.05, P = 0.01) by 7% yr^{-1}”

[Note: Flow adjusted concentrations produce a polygonal regression line, R^2 measures the % of variation accounted for by the regression curve, p < .01 is a measure of statistical significance, and a 7% slope/year in long term data would be unlikely, surprising even.]

ii) “Concentrations in Big Creek were similar to other watersheds in the eco region with similar land use, suggesting limited impact of the CAFO on Big Creek at the present time.”

iii) “At this point in time… it is evident that nutrient concentrations in Big Creek have not increased at the monitored site.”

Item iii) when taken out of context could be construed to mean that there have been no nutrient increases at Big Creek due to the farm. As is shown below, there are increases of up to 137% between upstream to downstream. The statement should have read, increased in time, rather than just “increased.”

Full BCRET paper, https://dl.sciencesocieties.org/publications/ael/pdfs/2/1170027

Rebuttal to i)

i) is a weakly supported observation but it is potential fodder for two misinterpretations:

a) That CAFO’s, being so meticulously managed by agencies like ADEQ, can actually be beneficial to streams.
b) If a pollution problem is not getting worse, then it really isn’t a problem.

Basic assumptions: Nitrogen is a pass through nutrient since there is little capacity for year-to-year net storage in soils or field residue. Some of the nitrogen in liquid waste leaves the farm in cow carcasses, in evaporation from volatile ammonia, nitrification and denitrification processes, and so forth but the rest, being soluble, runs off or reaches ground water on its way to streams. A significant change in nitrate implies a major shift in watershed land use or, perhaps climate variability.

Flow adjusted concentration models are impenetrable, but the graph below (Fig. 1), using actual data rather than flow adjusted data, illustrates the basis for the claim. Indeed the regression line has a negative slope, -.0002, which estimates a 10 % decrease over 3 1/3 years. But if we were to look at recent data, say the last 101 data points then the story changes (Fig. 2).

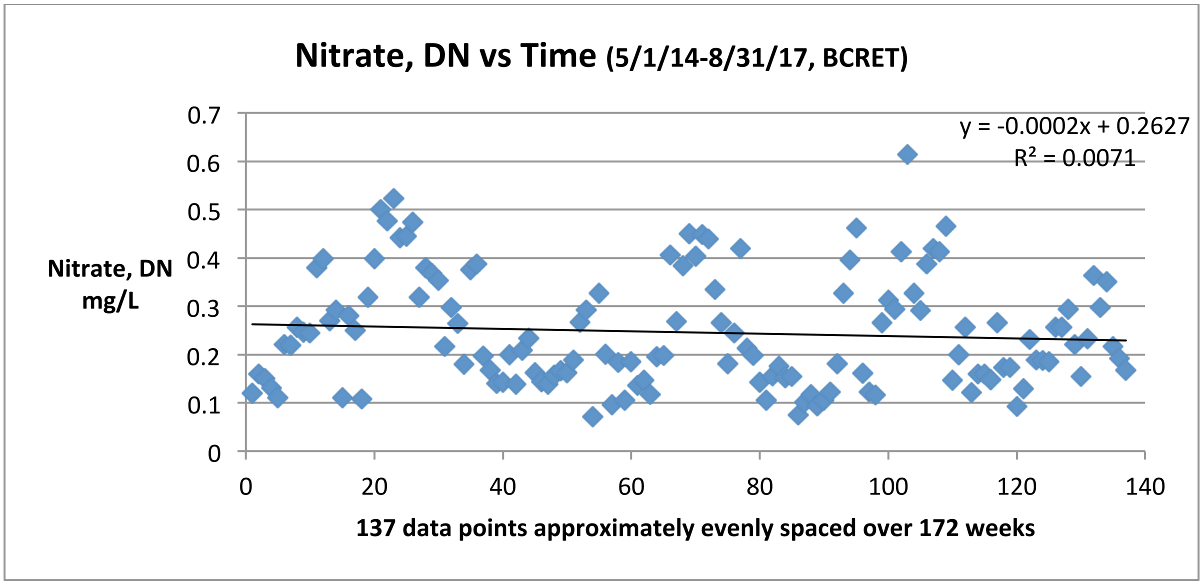

Figure 1

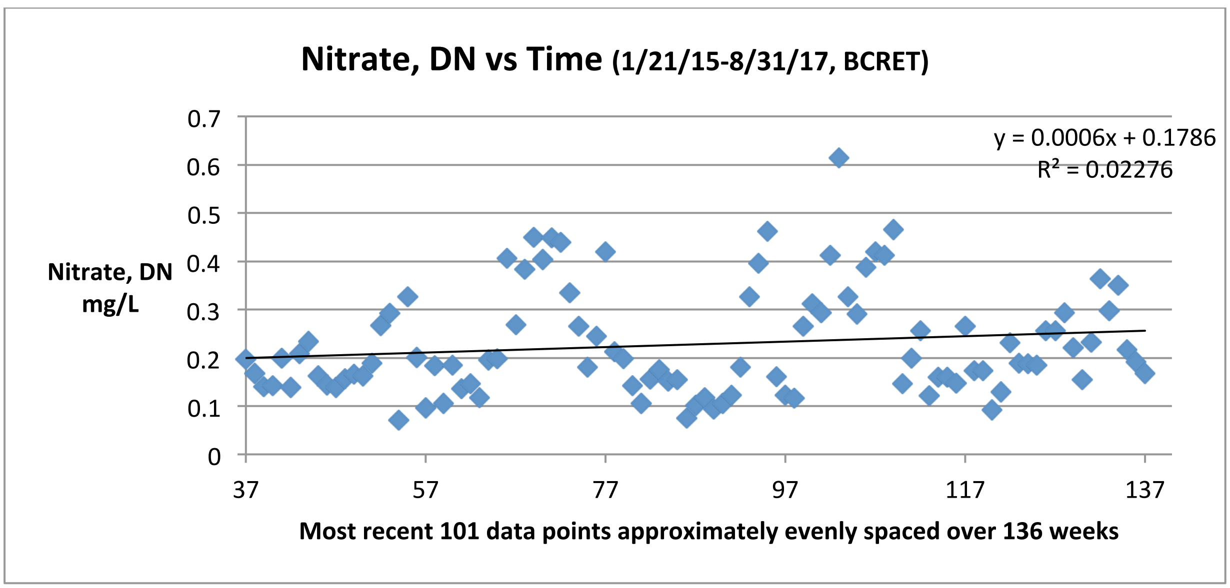

Figure 2

The slope is positive and 3 times larger than before, giving an estimated 34% **increase** over 2 ¾ years. Of course this is cherry picking the data (both times), but it also confirms that more time is needed for reliable decisions. There are lots of data points, n = 137, but only n = 3 years of weather cycles.

But this is not **the major complaint**. To the extent that there is really a significant decline in the downstream nitrate data, it is because there was a much larger decline in upstream nitrate.

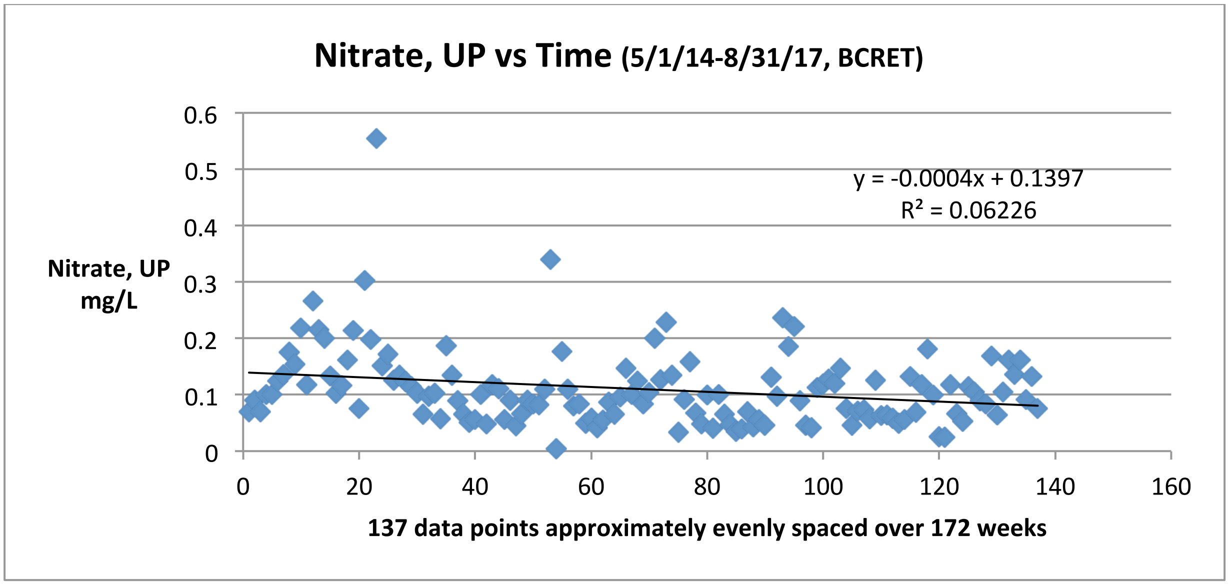

Figure 3

The decrease in nitrate upstream, slope = -0.0004, is twice as large as downstream. And, on average, downstream levels are 124% higher than upstream. This is only possible if the in-flow nitrate levels in the middle (farm) stretch are significantly higher than either upstream or downstream, and furthermore increasing in time (though insignificantly in this case).[1]

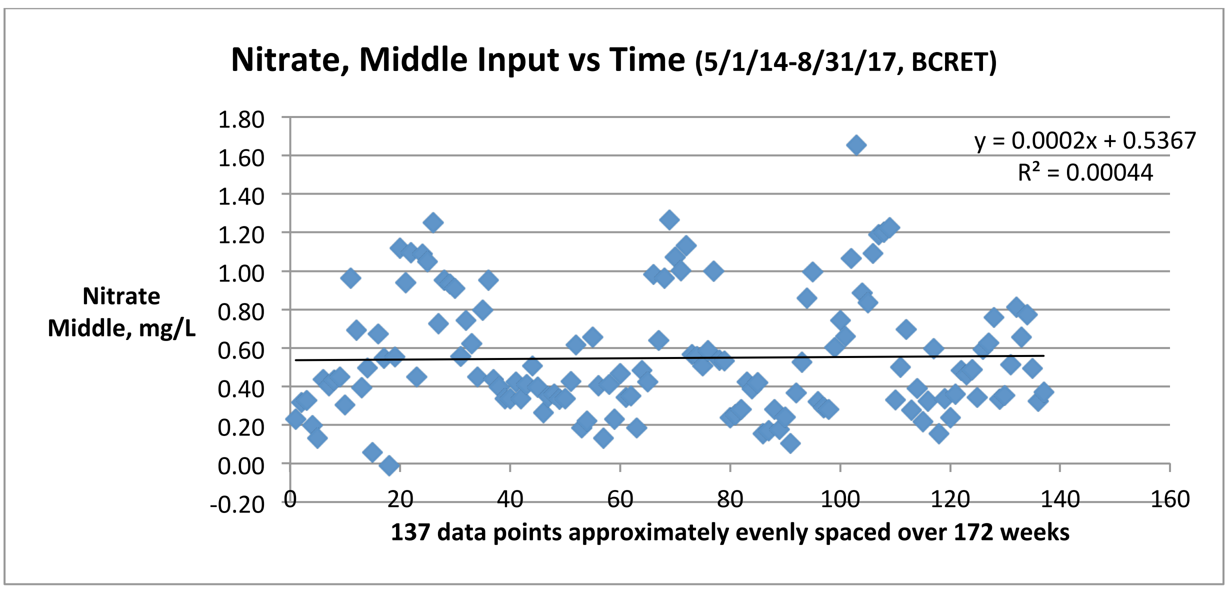

Figure 4

The "sine" like waves that occur in figures 1 and 4, but to a lesser extent in figure 3, have peaks that coincide with low flow. This implies that ground water nitrate levels in the middle section are much higher than upstream levels. These conclusions are supported by figure 5 which shows that the high nitrate source(s) that dominate(s) in low flows, only become diluted enough to be unimportant at flows above 20 ft^3/sec. The slope of the nitrate regression line at Carver matches the upstream slope, -.0004, making the middle stretch the uniquely increasing stretch. Of course this could all be a momentary coincidence, but surely we couldn't conclude a significant decrease.

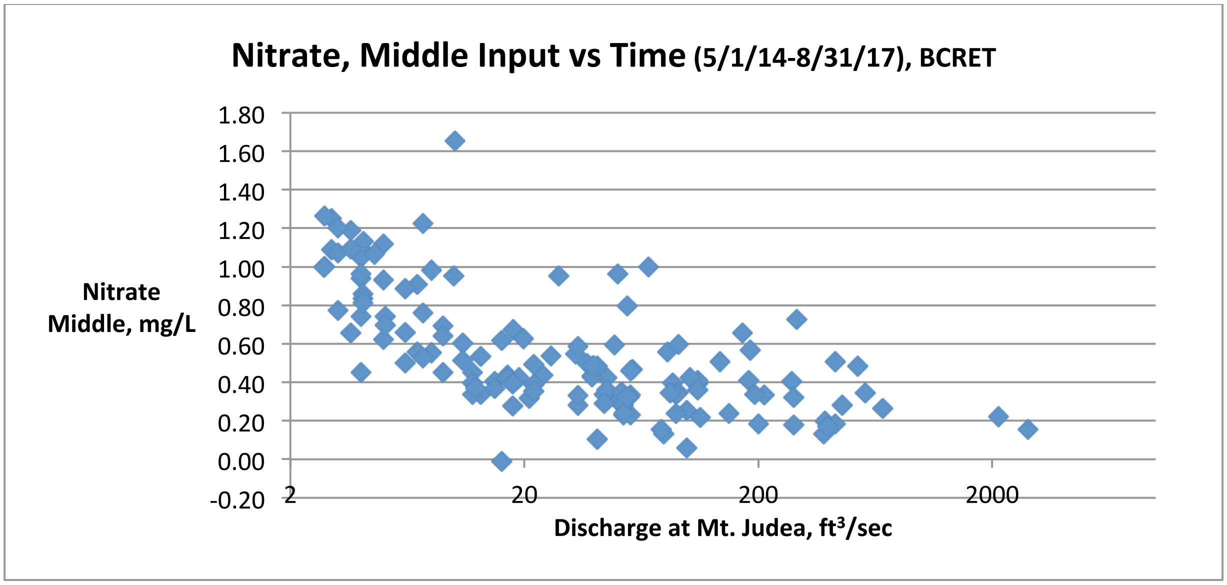

Figure 5

Critical Review of ii)

An upstream vs downstream data comparison makes it impossible to maintain that there is no significant increase in nutrients as Big Creek passes the farm. The gist of the BCRET paper is to blame someone other than C&H, or actually, to make the case that C&H is no worse than anyone else. This blaming argument is more sophisticated than finger pointing at feral hogs, school boys peeing in the creek, rogue honey wagons, and devious environmentalists. They argue that the stream biota is not threatened, and even with the increases, nutrients are not unusually high for comparable streams.

- **The Data**

The mean, geomean, and median are most commonly used to predict eutrophic stream conditions and the general health of stream biota. Flow weighted means (mfw) predict the mass transport of nutrients from the watershed, e.g. total load = mfw x total discharge.[2] Nearly all measures increase significantly.

	mean	**geomean**	**median**	**mfw (flow weighted mean)**
dP, UP	0.0099 mg/L	0.0083	0.0090	0.0111
dP, DN	0.014	0.011	0.011	0.025
% increase	41%	33	22	125
TP, UP	0.0346	0.0284	0.0260	0.0653
TP, DN	0.050	0.032	0.026	0.147
% increase	45	13	0	125

Table 1. Geomeans are always less than means for mathematical reasons not connected to stream conditions. Often, geomean ~ median, which would be the case if the data were lognormal.[3] The

median and geomean are insensitive to high TP levels that occur during storm events . In terms of watershed export (load) of TP, the mfw data is the most important. Means are less than mfw because both dP and TP are positively correlated to discharge. This data is not restricted to base flow, n(base flow) = 109, n(storm flow) = 28.[3] (5/1/14-8/31/17, BCRET)

	mean	**geomean**	**median**	**mfw (flow weighted mean)**
Nitrate, UP	0.110 mg/L	0.093	0.099	0.103
Nitrate, DN	0.246	0.220	0.216	0.166
% increase	124%	137	118	61
Nitrate,	0.134 (2016)			
Carver (USGS)	0.152 (2017)			
BCRET dates	0.142	0.112	0.099	0.146*
Middle[1]	0.548	undef	0.452	0.306

***** USGS data is available for only some of the BCRET dates, n=50 vs n=137.

Table 2. Flow weighted means for nitrate are less than means because nitrate levels are negatively correlated to discharge. The nitrate increase is largest because the nitrate/TN ratio increases with increasing farming intensity.

	mean	**geomean**	**median**	**mfw (flow weighted mean)***
TN, UP	0.210 mg/L	0.181	0.175	0.329 (0.241)
TN, DN	0.377	0.328	0.320	0.666 (0.359)
% increase	80%	81	83	102 (49)

Table 3. These are uniformly large increases by any of the 4 measures, but somewhat less than for nitrate. The figures in parentheses exclude the two very high flow events. These deletions don't affect mean, geomean, and median, but the mean, geomean and median also don't catch some enormous nutrient loads in storm flow as in this case.

* Normally, if nutrients are negatively correlated to discharge, then mean > mfw, but there were two outliers with very high flows (>2000 cfs) with high TN levels downstream but lower upstream levels {0.24, 0.74 mg/L UP; 1.12, 1.49 mg/L DN). Thus these were major nutrient events occurring in the middle section. Interestingly, during these two exceptional storm flows there was no corresponding high level of nitrate, which is usually correlated with TN.

Evidence for unusually high nitrate levels in the middle section comes from comparing the steep response at low flows in the middle section (Fig. 5), to the upstream graph (Fig. 6) which shows no such trend. Data from Carver also shows no such trend either, suggesting that the middle section has uniquely high levels of ground water nitrate.

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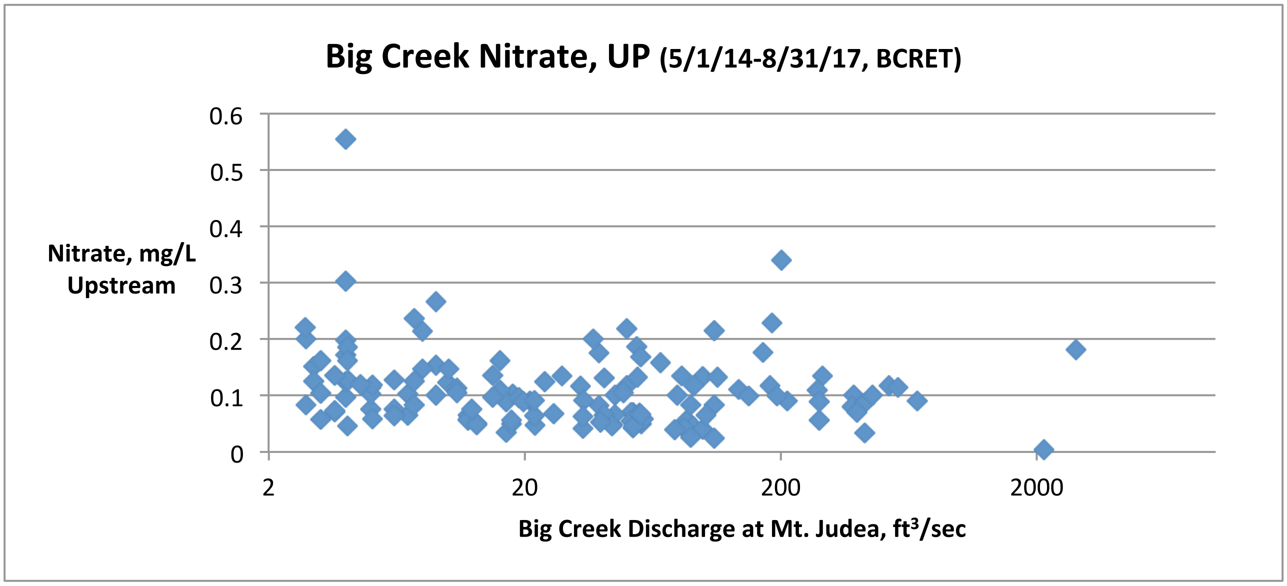

Figure 6. The upstream nitrate levels are much smaller than downstream, and negatively correlated but not nearly as much as downstream. In contrast to downstream, there is little evidence of a high level ground water nitrate source at low flows. We conclude that the middle section is a nitrate polluter of Big Creek.

Conclusion: The data shows very large increases in all nutrients as Big Creek passes C&H. There are high nitrate levels in the middle section at low flows, indicating ground water sources. This doesn't occur upstream from C&H or at Carver.

- **The Model**

For many years farm hydrologists have produced graphs that show a correlation between increasing stream nutrient levels and the intensity of watershed land use and development – in this case percent pasture/urban serves as a rough measure of intensity.

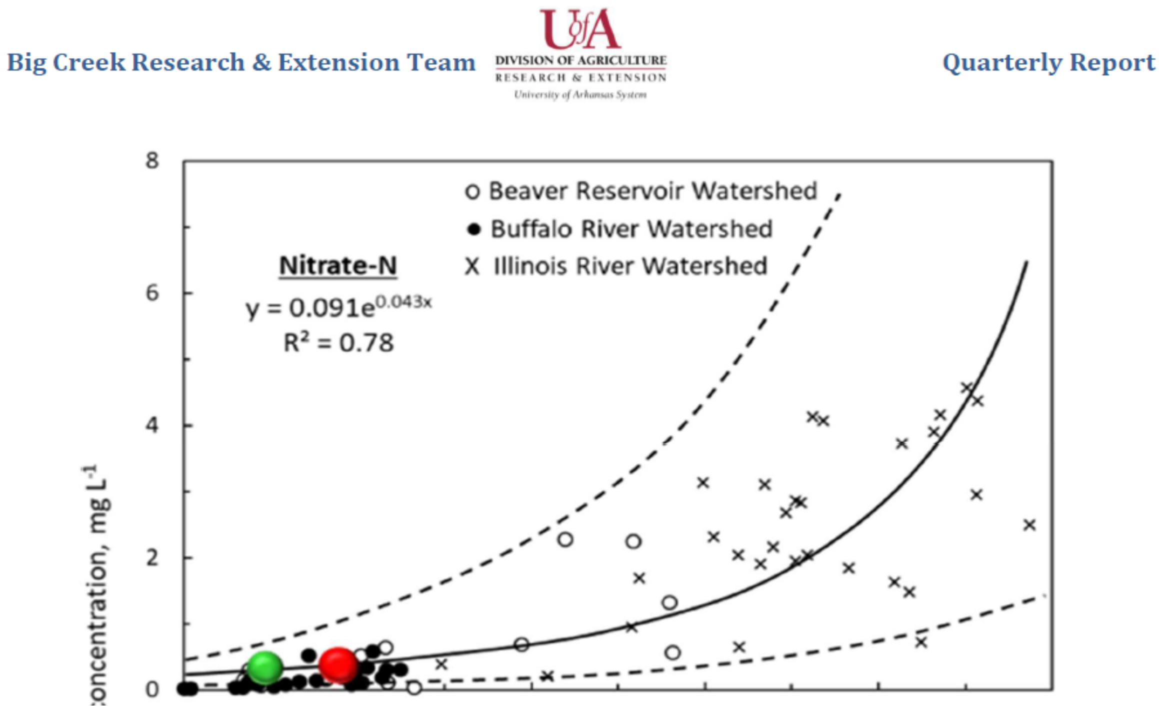

Figure 7. This graph attempts to show: that nitrate levels on Buffalo River tributaries (black dots) are much lower than on the heavily contaminated Illinois River watershed (x's), that there is a general exponential increase in geomean nitrate levels with % pasture/urban land use, and that the nitrate levels from above the farm on Big Creek (green dot) and at the downstream sampling site (red dot) fit right on the regression curve, and so the farm has little impact. The x-axis is percent pasture/urban land use. BCRET estimates that 10.6% of the watershed above the C&H sample site is pasture/urban, whereas 20.5% of the watershed above the downstream sampling site is pasture/urban – this accounts for the location of the red and green dots. The other three nutrients have similar models. (BCRET Quarterly Report, April-June 2017)

The green and red dots are big, but the model is a clear miss at the upstream site: model = 0.143 mg/L, actual = 0.093. The model predicts a 53% increase as pasture/urban goes from 10.6 to 20.5 percent, but the actual increase is 137%.

For TN the model predicts a 39% increase, but the actual increase is 81%

For TP, the model predicts 0.016 mg/L at the upstream site vs the actual 0.0284. The predicted increase is 22% but the actual increase is 12%. For dP the predicted increase is 24% but the actual increase is 33%.

The ratio of dP to TP at Mt Judea is 0.29 (UP) and 0.34 (DN). The model predicts, dP/TP = 0.615exp(0.002x), greater than 0.615 for all x – and therefore not remotely close at Mt. Judea and implausible for the other tributaries, e.g. 0.40, 0.065, 0.31 for Mill Creek, Tomahawk Creek, and Leatherwoods Creek.

How about the predicted ratio of nitrate to TN, nitrate/TN = 0.42exp(.01x), which is greater than 1 for x > 85%, whereas by definition, nitrate < TN!

The 95% confidence intervals are predictibly large given the incompatibility of the three watersheds, and the variable intensity of land use within watersheds. For instance, Big Creek and Mill Creek have essentially the same percent pasture/urban (13.2 vs 14.4 %), yet the given nitrate level at Big Creek is 0.13 mg/L and at Mill Creek it is 0.53. It is true that the nutrient levels at Big Creek fit within 95% confidence intervals, but that doesn't say much. With this much variability in the data there is little confidence in making fine distinctions.

Conclusions: The model does not do a very good job of predicting the actual increases, which was the original intent. Put another way, the predicted rate of change as derived from other watersheds aren't reliable indicators on Big Creek. It may be that part of the problem is unreliable data.

- Dodgy Data

A check of data from ADEQ (1992-2017) for 4 tributaries does not confirm the data reported in the April-June 2017 BCRET Quarterly Report. Note: it is not totally clear if the data sited in BCRET (BNR & ADEQ shared data) came from tributary values found on the ADEQ website, but that is the assumption below.

	dP		TP		Nitrate		TN	
mg/L	BCRET	Actual ADEQ	BCRET	Actual ADEQ	BCRET	Actual ADEQ	BCRET	Actual ADEQ
Big Creek	0.019	0.019	0.021	0.045	0.13	0.13	0.34	0.21
Mill Creek, Pruitt	0.015	0.15	0.025	0.39	0.53	0.58	0.75	0.93
Tomahawk Creek	0.013	0.013	0.016	0.028	0.31	0.39	0.37	.50
Leatherwoods Creek	0.011	0.012	0.031	.037	0.03	0.038	0.14	0.015

Table 4. Only nitrate was consistently sampled by ADEQ, all dP data was before 2014 and almost all TKN after 2014. By definition, TN = nitrate + TKN, but it is not true that geomean(nitrate +TKN) = geomean(nitrate) + geomean(TKN).[5] Therefore unpaired data can't be used for estimating TN. As a partial result, sample sizes were very small. For leatherwoods Creek, n = 5 for TN and 6 for TP. For Big Creek, n= 9 for both TN and TP. For Mill Creek, n = 12 for TP, 11 for TN.

The data includes mismatched sampling times. For instance, at Mill Creek (Pruitt), the nitrate level is given as 0.53 mg/L (ADEQ, 1991-2017), whereas for contemporary data comparisons from 2014-2017, geomean = 0.71 mg/L.

The ADEQ samples for Big Creek are from Carver, not Mt Judea, and Carver data is influenced by the Buffalo River.

The BCRET data, which forms the basis for the "no impact" conclusion, has a storm flow bias. BCRET data was sampled with corresponding mean discharge of 112 ft^3/sec , while the USGS discharge for this period was 84.1, 78.5, and 91.7 ft^3/sec, 2015-2017. This could make a difference. For instance, the base flow geomean for TP at Mt. Judea **understates** the geomean by 19%, and the base flow geomean for nitrate **overstates** the geomean by 7%.

Conclusions: The Illinois watershed is comparable to the Buffalo River watershed only in physical proximity. In particular, there is currently one permitted and one unpermitted swine CAFO and 4 or 5 chicken CAFO's operating in the Buffalo River watershed vs thousands of chicken houses and major urban sources in the Illinois River watershed. It is a stretch to think that the chronic nutrient problems found on the Illinois River should have predictive validity on nutrient responses on Big Creek due to C&H. In addition, the models presented in BCRET publications do not correctly predict changes that occurred at Mt. Judea (nor other tributaries) nor does it even come close. Part of the reason may be dodgy data – incorrect entries, or incompatible time periods. In addition there is an intrinsic problem in the model assumptions and construction, see below.

However, The Illinois River data does serve as a reminder to make the current moratorium on swine CAFOs permanent.

- **Model Assumptions**

- Intensity

The model assumes that each square mile of additional pasture/urban conversion from forest causes the same increase in stream concentration. The effluent from 1,000,000 lbs of hogs at C&H is sprayed on some 600+ acres, about one square mile. 5,000 humans have approximately 1,000,000 pounds of biomass with resulting effluent. Are there 5,000 people any square mile in the Mt. Judea metropolitan area, which is in White Township, population 830 spread over 36 sq. mi., density 23 people/sq. mi.? 1,000 cow units (1,000 lbs of cow by USDA definition) have about the same biomass as the C&H hogs. Cow/calf density in Newton County is 23/sq. mi. (<< 1,000 units/ sq mi).

According to BCRET estimates, 5.45 square miles of the middle watershed is pasture/urban. Are there 5,000± cow units in the middle watershed. Are more than ¼ of the cows in Newton County raised in the 1.5% of the land contained in the middle stretch around Mt. Judea?

Conclusion: Okay, around Mt. Judea, biomass density in "pasture/urban land" doesn't even come close to matching that of the C&H hog farm. The "finger pointing" to other such sources is disingenuous.

Statistical techniques

For all nutrients, BECRET uses exponential models,

$$c(x) = a \exp(bx), \quad (1)$$

where x = % pasture/urban, and a and b are data determined constants, a= c(0) and b is the slope of the best fit line to ln(c(x)).[5] Or looked at another way, these are two parameter families entirely determined by the endpoints, a = c(0), and b= ln(c(1)/c(0)). That is, given the resulting concentration for all pasture and for no pasture, all other in between combinations are determined. An odd thing. One can imagine lots of different nutrient distributions with the same endpoints, or imagine different data sets for which ln(X) has the same regression line.

From equation 1, it follows that the marginal rate of change is proportional to the current concentration,

$$\text{marginal rate of change} = c'(x) = b[a \exp(bx)] = b \cdot c(x).$$

These things are somewhat counterintuitive and are entirely data driven, i.e. there is no underlying theory using physical properties of hydrology. In equation 1, the term, b*x, is where the assumption that all pasture has equal intensity enters. It seems reasonable to replace b*x with an intensity term, $I(x) = c_1 r(x) + c_2 (x - r(x))$, where r(x) is the percent CAFO/urban, with $c_1 >> c_2$.

There are models that arise from conservation of mass principles that don't give exponential solutions. For water discharge resulting from two types of land use, forest and pasture, assume concentration and discharge rates of c_f, c_p, d_f, and d_p, the units of d are $(ft^3/sec)/mi^2$. If x is the proportion of pasture, then the resulting concentration of the mixture is,

$$c(x) = [x(c_p d_p - c_f d_f) + c_f d_f]/[x(d_p - d_f) + d_f)].$$

This is a standard "bilinear form" that has the virtue of allowing for different discharge rates depending on land use. The curves can be used to fit the data. Note that $c(0) = c_f$, and $c(1) = c_p$ as should be the case.

Conclusion: The exponential model does not give useful estimates of change due to a CAFO. Some of this may be due to dodgy data, or perhaps it just an impossible task given the variability of local stream conditions, deeply influenced by sporadic human interventions (Mill Creek is a prime example). But maybe the model can be improved.

Geomeans

The geomean is the n^{th} root of the product of data points. Geomeans are used throughout the paper even though they are not easy to manipulate and don't have some of the useful algebraic properties of means or flow weighted means. The main problem is non-linearity. For two random variables X and Y, mean(X+Y) = mean(X) + mean (Y), but geomean(X+Y) $\neq$ geomean(X) + geomean(Y), and so geomean(nitrate +TKN) $\neq$ geomean(nitrate) + geomean(TKN).

The geomean is unrelated to the other measures of central tendency except geomean $\leq$ mean. For instance, if the random variable X has mean = 1, then the geomean can take on any value between 0 and 1.[6]

By design, the geonorm is insensitive to "outliers", perhaps useful in the same way quartiles are, but not useful in estimating stream loads. For any fixed non zero discharge, the geomean can be 1 while the load ranges to infinity.[7] Therefore, geomeans are not a good indicator for phosphorus load which is heavily influences by outliers.

Geomeans do not preserve relationships. For instance, if geomean(X) < geomean(Y), there is no possible conclusion about the relationship between mean(X) and mean(Y), likewise medians, or flow weighted means.

- Dilution is a Pollution Solution

The pasture/urban land use estimates by BCRET are: 10.5% above Mt. Judea, 20.5% above the downstream sampling site, and 13.2% at Carver. This implies that the middle watershed around Mt.

Judea is 43% pasture/urban (about 5.4 square miles) and the lower stretch, including the Left Fork, is 6% pasture/urban - somewhat surprising since the Left Fork is not exactly pristine and there are lots of small farms. For the disjoint individual stretches going downstream the percent pature/urban are: 10.5, 43, and 6%. The discharge at Carver is 132 percent more than at Mt. Judea.

This suggests that the dose of nutrient pollution in the middle section has a chance to be diluted by the time the water reaches Carver. The **most reliable** data at Carver is for nitrate (there are small sample sizes and possibly other problems for ADEQ data for dP, TP, and TN).

	dP	TP	Nitrate	TN
Upstream	0.0083 mg/L	0.0284	0.093	0.241
Downstream	0.011	0.032	0.220	0.359
Carver	undef	0.045	0.142	0.210

Table 4. Nitrate is diluted by 35% the time the stream reaches Carver.

Aside from a catastrophic spill from the lagoons at C&H there is no prospect that the large increases in nutrients at Mt. Judea have a “significant” impact on mainstream Buffalo River levels. The average annual discharge at Harriet is 1,060 ft^3/sec, compared to 80 ft^3/sec at Mt. Judea, 2015-17. The 0.136 mg/L increase in mean nitrate at Mt. Judea could, at most, lead to an increase 0.011 mg/L at Harriet, a 124% increase becomes a 10% increase. Of course this doesn’t account for the complexity of the nitrogen cycle.

1. The formula connecting the three concentrations is, c(mid) = (c(DN)-.69c(UP))/.31. It assumes that discharge is proportional to watershed size, a conclusion which is supported by gage data from Carver and Mt. Judea. The Big Creek watershed above Carver is 89.9 mi^2, above the Mt. Judea gage is 40.8 mi^2, and then about 12.6 in the middle stretch.

2. For a discussion of the nutrients see [page 1-2, PET]

3. The definition of storm flow varies. The criteria I used was, flow greater than three medians. There are more technical definitions. That geomean $\leq$ mean is a consequence of Young’s inequality, E(ln(x)) $\leq$ ln(E(X). A random variable X is log normal if ln(X) has a normal distribution.

4. This is easy to see. In computing geomean(nitrate) and geomean(TKN) the order of the data is irrelevant. But in computing geomean(nitrate + TKN), order of the variables is important. Try nitrate ={1,4}, TKN = {9,1}.

5. If c(x) = a exp(b x), then c’(x) = b [a exp(b x)] = b c(x). And so d(ln(c(x)0/dx = c’(x)/c(x) = b. Thus the slope of the best fit line to ln(c(x)) is b. The exponential model is fore-ordained by the BCRET team when using linear regression fits of ln(c(x)).

6. This is mathematical overkill. For the two point data sets, {1-x,1+x} , 0 $\leq$ x$\leq$ 1, the mean = 1 for all x, but geomean = $\sqrt{1-x^2}$ varies between 0 and 1.

7. For discharge {d_1,d_2}, and c = {x,1/x}, then geomean(c) = 1, but mfw = d_1x +d_2/x which goes to infinity as x goes to 0.