A Case Study on Chemical Flashiness of Streams and Canals in Florida

https://github.com/ytgong/ENV322_group_project

Ethan Ready, Gabi Richichi, Theo Cai, Yutao Gong

1 Rationale and Research Questions

1.1 Rationale

Storm events have the potential to influence rivers and streams by temporarily altering their discharge levels and chemical composition. Rapid changes in stream discharge is known as hydrologic flashiness (1). A stream that "experiences a rapid increase in flow shortly after onset of a precipitation event, and an equally rapid return to base conditions shortly after the end of the precipitation event" is considered to be hydrologically "flashy" (1). Rapid changes in chemical composition, such as nutrient concentrations or conductance levels, is known as chemical flashiness or a departure from chemostasis. "Chemostasis occurs when DOM [dissolved organic matter] remains unchanged despite changes in discharge" (2).

Both hydrologic and chemical flashiness can alter the natural processes of rivers and streams, particularly if these rivers and streams are experiencing an increase in flashiness over time. These alterations can disrupt human activity such as hunting, fishing, recreation, and the utilization of water for drinking, and, as a result, people incur costs. One consequence of hydrologic flashiness is flooding of nearby lands. Flooding events in the U.S. cost an average of 4.4 billion USD per event in damages (5). One alteration caused by storm-induced flashiness is eutrophication. Eutrophication "is characterized by excessive plant and algal growth due to the increased availability of one or more limiting growth factors needed for photosynthesis, such as sunlight, carbon dioxide, and nutrient fertilizers" (6). In this case, the limiting growth factor that chemical flashiness can increase is nutrient levels. As nutrient levels increase, this can cause "blooms of blue-green algae(i.e., cyanobacteria), tainted drinking water supplies, degradation of recreational opportunities, and hypoxia. The estimated cost of damage mediated by eutrophication in the U.S. alone is approximately $2.2 billion annually" (7).

The effects of storm events on bodies of water are compounded by human activity. The use of pesticides and fertilizers on agricultural land, as well as the way in which sewage is managed, can make nutrients such as nitrogen and phosphorus accessible for storm transport in the first place (8). Furthermore, anthropogenically-induced climate change is intensifying natural precipitation events by making them wetter, longer, and more intense (9). As storms worsen, so do their effects.

This applies to the region of this study in particular. Florida is a state that has a history of extreme weather events such as hurricanes and tropical storms, as well as a history, particularly recently, of eutrophication events. High levels of nutrient loading, in combination with high temperatures that are typical of Florida's climate, create an environment conducive to eutrophication (5). The Florida Department of Environmental Protection lists more than 1,400 water bodies as "impaired by pollutants" (5). In this study, 21 water bodies including rivers, creeks, springs, and canals in Florida are examined for their hydrologic and chemical flashiness, the urbanness or ruralness of their surrounding lands, as well as the water use levels of the surrounding communities.

These sites are of great importance to people. For example, Chassahowitzka River is a spring-fed river in a national wildlife refuge, on which people engage in sportfishing, crabbing, camping, and hiking activities (6). The Main Relief Canal in Vero Beach, managed by the Indian River Farms Water Control District, drains much of Indian River County and the City of Vero Beach to prevent flooding on residential and commercial land (10). Turnbull Creek is a "critical waypoint for waters flowing north into Turnbull Bay, Spruce Creek, the Indian River, and Atlantic Ocean" (11) and a habitat for numerous species (12). A majority of the people of New Smyrna Beach (75% of constituents) just voted in favor of a referendum to pay $8.94 million to protect the land along Turnbull Creek from development (13). Many of the sites of this study are well-managed, located in state or national parks, and all of the canals are artificially created. There are already management-schemes and policies in place to protect these water bodies. For example, to reduce nutrient total maximum daily loads, there exists action plans (14) and the Springs Protection Act (15). It is useful, then, to better understand the effects of flashiness on these water bodies in order to inform managers to implement more efficient and cost-effective management practices.

1.2 Research Questions

The goal of this study is to better understand the effects of storm events on rivers and streams in Florida.

1. Are sites with high hydrologic flashiness more or less likely to have high chemical flashiness?

a) Hypothesis: sites with high hydrologic flashiness are more likely to be chemically flashy because of shared predictor variables.

b) This question will be answered using USGS NWIS high frequency discharge and nitrate data on water bodies within the state of Florida.

2. The second question to answer is: how do features of a site impact its chemical flashiness?

a) This question will be approached qualitatively by ascertaining the presence or absence of urban and/or rural features, such as airports, commercial development, or farmland, and their proximity to each site. GIS maps will be analyzed for this part.

b) The hypotheses related to the qualitative approach are: (1) that urbanness / ruralness will be correlated with the stream exhibiting flushing, diluting, or chemostatic behavior, or (2) that the urbanness / ruralness will not be correlated with any particular behavior of the stream, whether flushing, diluting, or chemostatic in nature.

c) This question will also be approached quantitatively or statistically by ascertaining the level of human activity surrounding each site. Human activity will be measured using population totals and water use levels for the counties surrounding each water body.

d) The corresponding hypotheses are that: (1) population and water use will be correlated with chemical flashiness, and (2) population and water use will not be correlated with chemical flashiness.

2 Dataset Information

Data for 21 water bodies (7 rivers, 7 springs, 3 creeks, and 4 canals) in Florida will be collected.

For question / hypothesis 1 regarding hydrologic and chemical flashiness, high frequency discharge and nitrate data will be extracted from the USGS NWIS DataRetrieval package. A Richards-Baker Index will be calculated using the discharge data as a measure of hydrologic flashiness. C-Q plots will be generated using the nitrate data as a measure of chemical flashiness.

For question / hypothesis 2 regarding the properties of each site that may affect chemical flashiness, data will be retrieved from ______ . Specifically, county population values, irrigation water use levels, thermoelectric water use levels, and a chemostatic coefficient will be examined. Maps taken from _____ will be examined to ascertain the presence or absence of features indicative of urbanness or ruralness surrounding each site, such as airports, commercial center, or farms, as well as the proximity of these features to each water body.

Table 1: Variables used for analysis

Variable	Units	Type
Nitrate concentrations – high frequency	ng/L	Independent
Discharge – high frequency	m^3/s	Independent
Richards-Baker Index value		Independent
County population	k people	Independent
Irrigation water use	Bgal/day	Independent
Thermoelectric water use	Bgal/day	Independent
Chemostatic coefficient		Dependent

Table 2: USGS sites selected for analysis

Site No.	Station Name	County
2326526	WACISSA RIVER NR WACISSA FLA	Jefferson
2319302	MADISON BLUE SPRING NR BLUE SPRINGS, FL	Madison
2319950	BLUE SPRINGS NEAR DELL,FL	Lafayette
2323566	MANATEE SPRING NR CHIEFLAND FLA	Levy
2323502	FANNING SPRINGS NR WILCOX FLA	Levy
2322800	SANTA FE RIVER NR HILDRETH FLA	Gilchrist
2322700	ICHETUCKNEE R @ HWY27 NR HILDRETH, FL	Columbia
2322688	BLUE HOLE SPRING NR HILDRETH, FL	Columbia
2310743	HUNTER SPR RUN AT BEACH LANE AT CRYSTAL RIVER FL	Citrus
2310678	HOMOSASSA SPRINGS AT HOMOSASSA SPRINGS FL	Citrus
2310650	CHASSAHOWITZKA RIVER NEAR HOMOSASSA FL	Citrus
2313100	RAINBOW RIVER AT DUNNELLON, FL	Marion

Site No.	Station Name	County
2313098	RAINBOW RIVER NEAR DUNNELLON, FL	Marion
2292900	CALOOSAHATCHEE RIVER AT S-79, NR.OLGA, FLA	Lee
2289035	THREE MILE CANAL BELOW G409 NEAR CLEWISTON, FL	Hendry
2248350	TURNBULL CREEK NR OAK HILL, FL	Volusia
2248600	DRAINAGE CANAL AT PLAZA PKWY AT COCOA, FL	Brevard
2249500	CRANE CREEK AT MELBOURNE, FL	Brevard
2250030	TURKEY CREEK AT PALM BAY, FL	Brevard
2251767	FELLSMERE CANAL NEAR MICCO, FL	Brevard
2253000	MAIN CANAL AT VERO BEACH, FL	Indian River

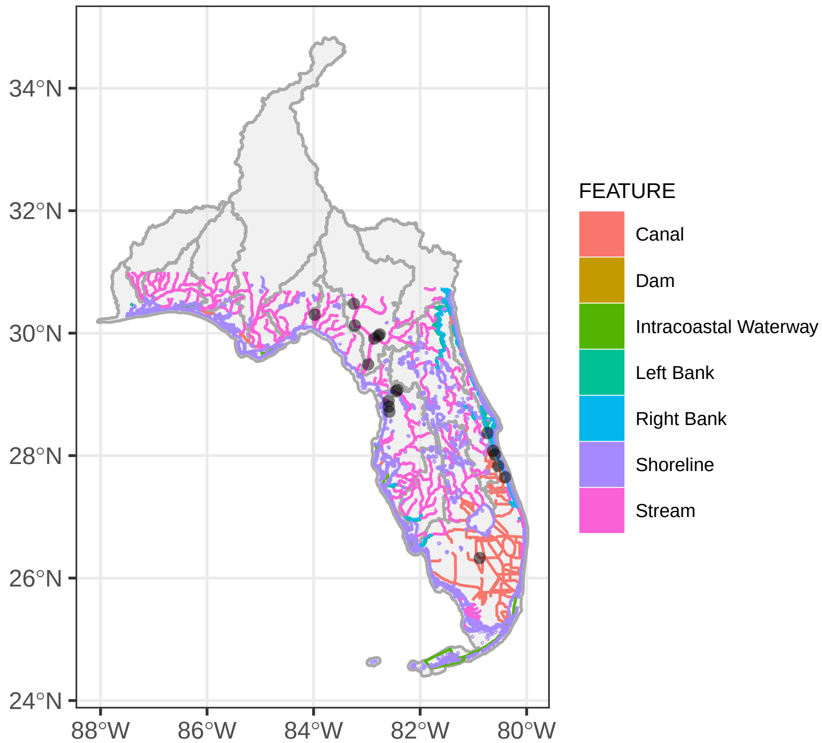


Figure 1: Location of sites analyzed on watersheds

3 Exploratory Analysis

Figure 1 is a map that shows the location of the sites we chose to analyze.

We decided to use violin plots to visualize the ranges of discharge and nitrate in the different sites. We made individual violin plots for discharge and nitrate for each site, and used cowplot to combine the discharge and nitrate for each site. The first thing we noticed was the difference between the canal plots and the other waterway types. The canal plots have values much more concentrated in their lower ranges, and much less variation overall. Visualizing the differences in canal variable distributions alerts us that they may influence our data analysis.

We then created combined violin plots of discharge and nitrate for all the sites. The CAL and SANTA sites had much more discharge than any other site. We made another discharge plot without CAL and SANTA to better visualize the smaller discharges. We then made a similar plot for nitrate.

Part of our data exploration process included plotting discharge and nitrate over time at all 21 of our sites. This served two purposes: one, it helped us get a preliminary sense of the diversity in distributions and behaviors at all of the sites, and two, it highlighted any possible gaps in the data that we would need to wrangle out. In general, we did not notice any trends between sites, indicating a deeper analysis was needed.

This report includes four examples of the graphs we generated: one spring, one river, one

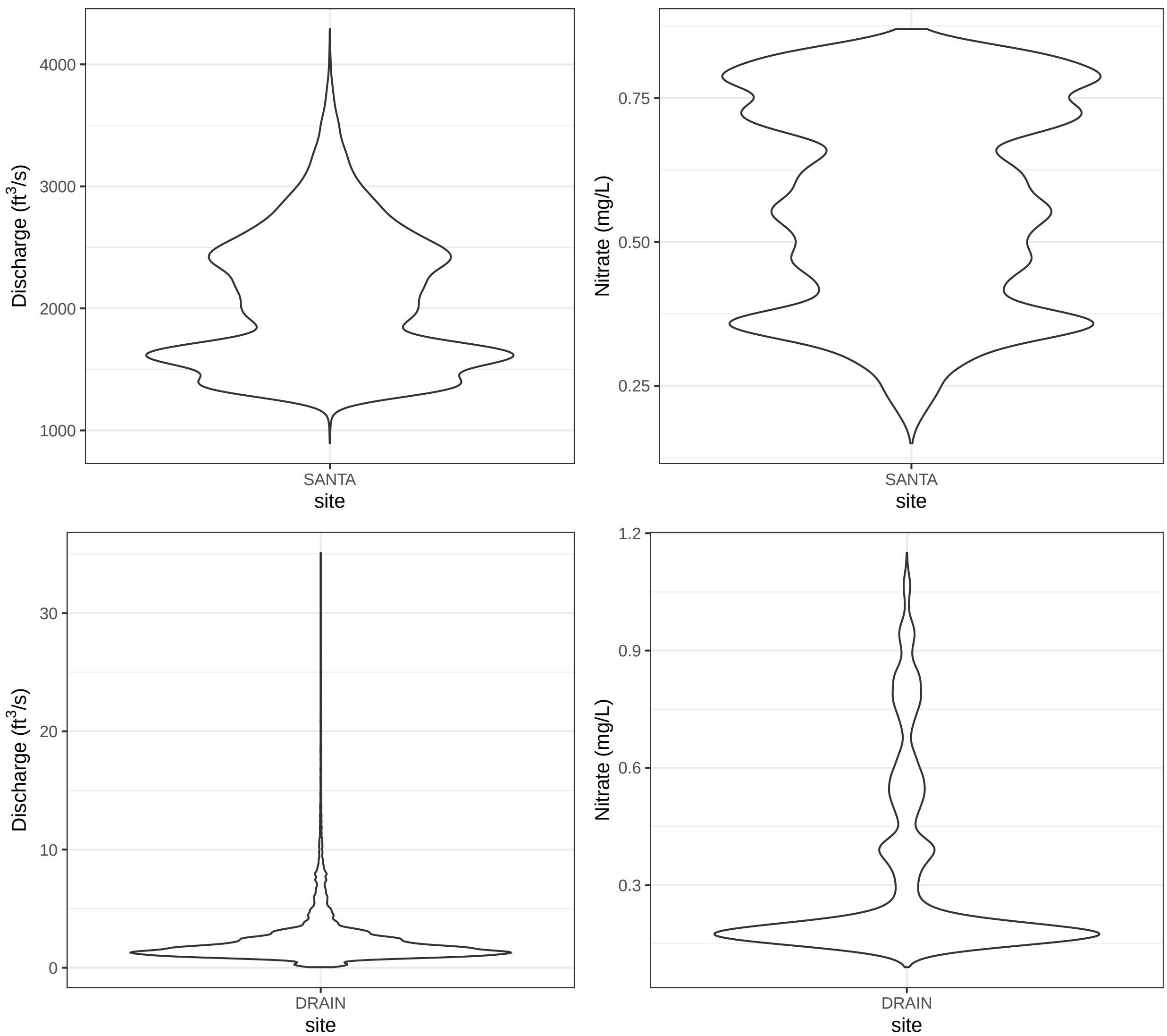


Figure 2: Distribution of discharge and nitrate values of a stream and a canal

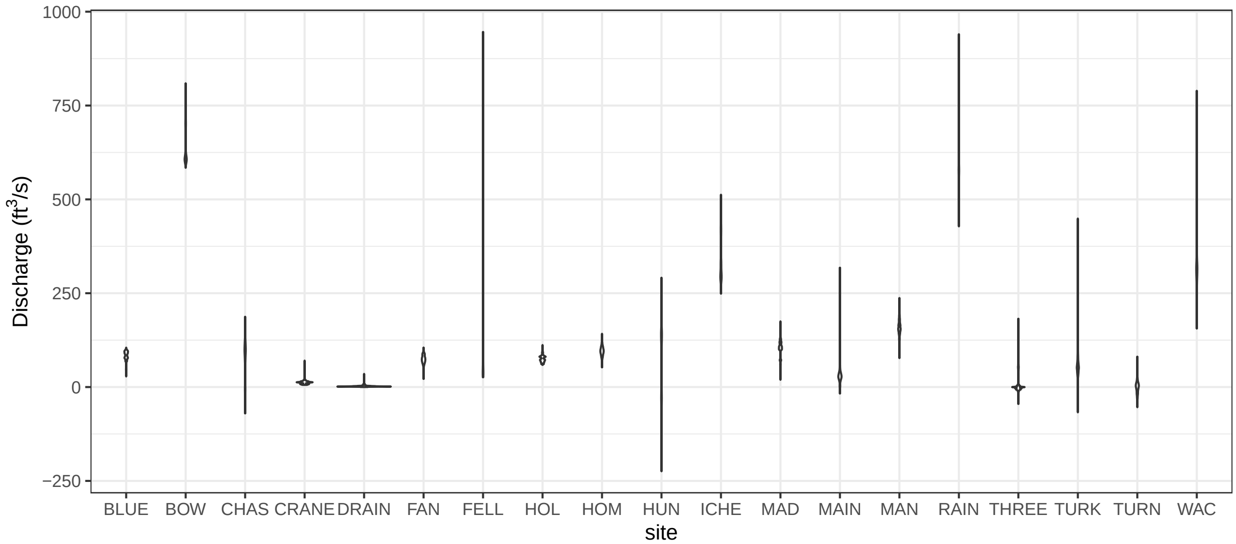


Figure 3: Distribution of discharge values of all sites (except CAL and SANTA

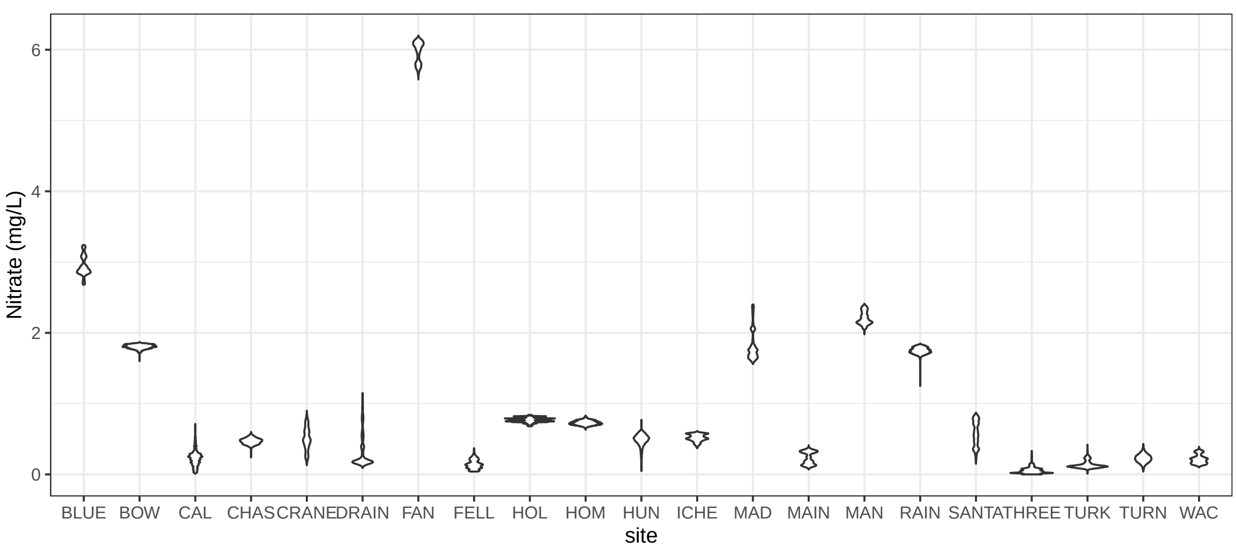


Figure 4: Distribution of nitrate concentration values of all sites

canal, and one creek - all to give a sense of the range of site types and the data trends at each.

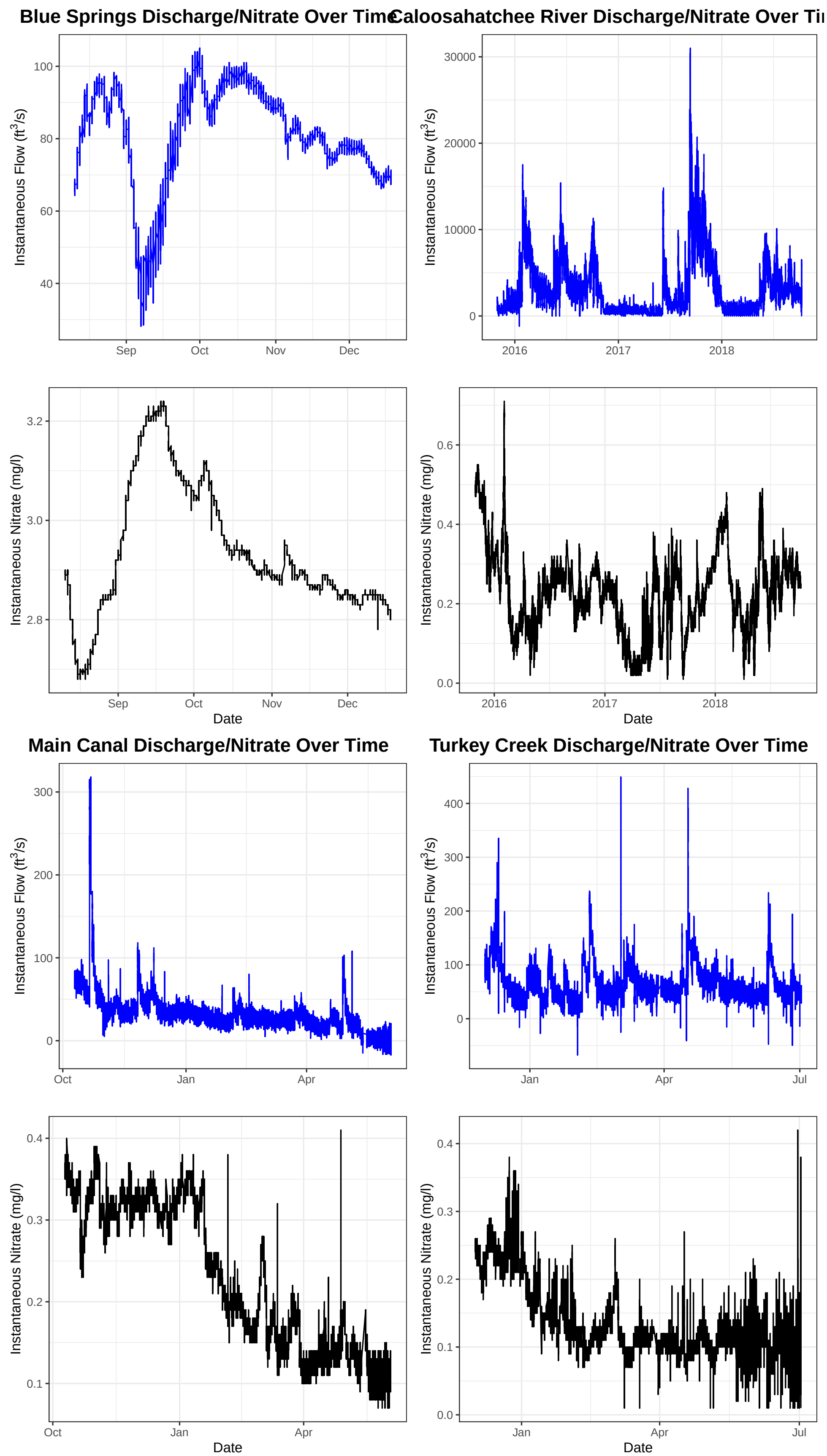


Figure 5: Discharge and nitrate value patterns of example sites

4 Analysis

4.1 Question 1: Are sites with high hydrologic flashiness more or less likely to have high chemical flashiness?

We chose to analyze our first question, on the relationship between hydrologic flashiness and chemical flashiness, using sites with high frequency nitrate and discharge measurements. At each site, we calculated the Richards-Baker Index to quantify the hydrologic flashiness.

We had to exclude catchment size in the formula because 17/21 sites did not have a recorded catchment size.

To quantify chemical flashiness, we ran a linear regression between mean daily nitrate and mean daily discharge values and took the coefficient as our chemostaticity value. We excluded 3 sites with poor linear regression fits, 1 of which had a large outlier for chemostaticity coefficient.

We wrangled the RBI values and Chemostaticity Coefficients to create a dataframe with columns site, site type(canal, river, etc.), chemostaticity coefficient, chemostaticity coefficient absolute value, and RBI value. We included the absolute value of the Chemostaticity Coefficient to investigate the flashiness, as absolute value would account for large chemostaticity in either a flushing or diluting system.

We created ggplot visualizations of Chemostaticity Coefficient vs. RBI and |Chemostaticity Coefficient vs. RBI| separating site type by color. The visualization without absolute value shows a distribution that follows the x and y axis. Sites with large RBI values have low Chemostatic Coefficients, and sites with low RBI values have Chemostatic Coefficients that are far above 0 or far below 0. The absolute value visualization reinforces this finding, as large absolute Chemostatic Coefficients correspond with small RBI values. Similar trends were viewed between site type, except that the largest outlier for both Chemostatic Coefficient and RBI are both canals.

We ran a linear regression on log(Absolute Chemostaticity Coefficient) vs. RBI, which was the closest fit that we could find. The regression produced a coefficient of -2.6847 , a P-value of 0.473, and a multiple r-squared of 0.03264. The model does not adequately predict the data.

```
##
## Call:
## lm(formula = log(chemo.coef.abs) ~ RBI_value_ind_noncatch, data = RBI_CHEMO_data)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -4.2881 -0.8347 -0.0628  1.2037  3.7717
##
## Coefficients:
##                        Estimate Std. Error t value Pr(>|t|)
```

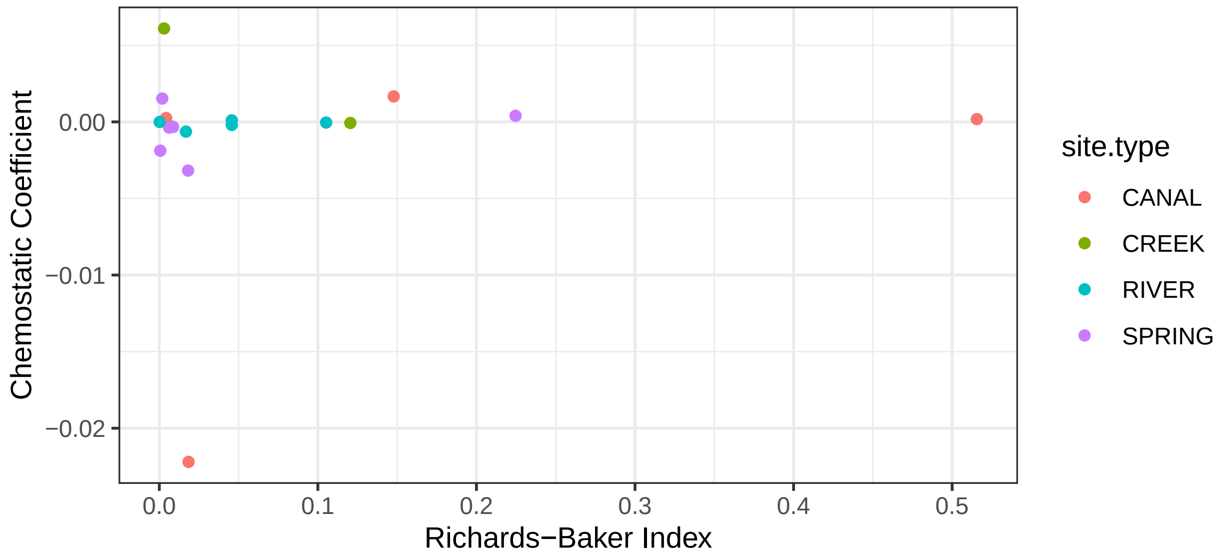


Figure 6: Chemostatic coefficient values and Richards-Baker Index of 18 sites

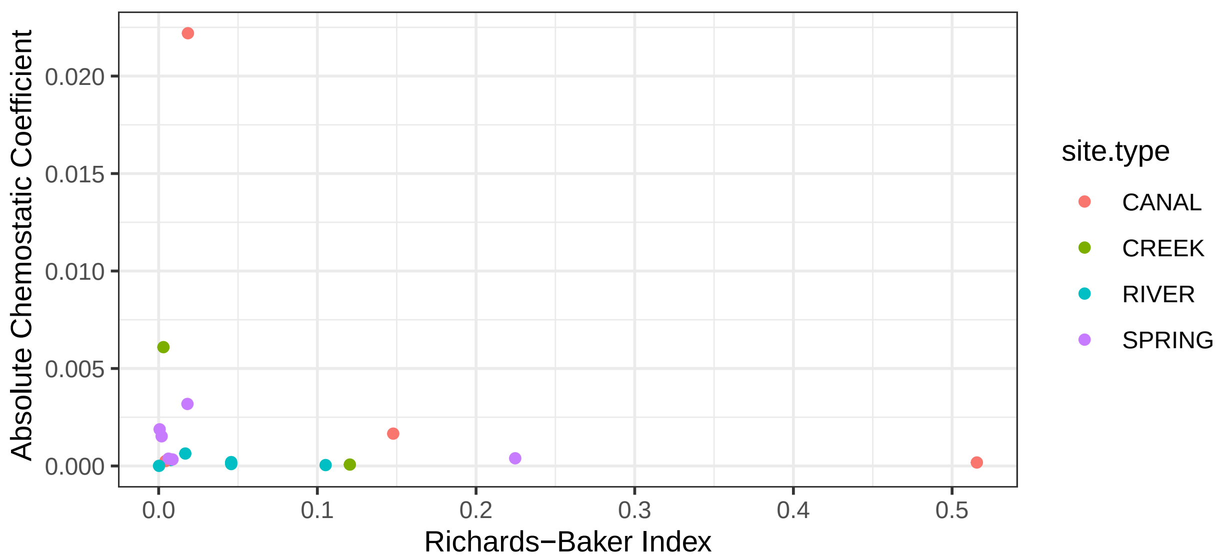


Figure 7: Absolute Chemostatic coefficient values and Richards-Baker Index of 18 sites

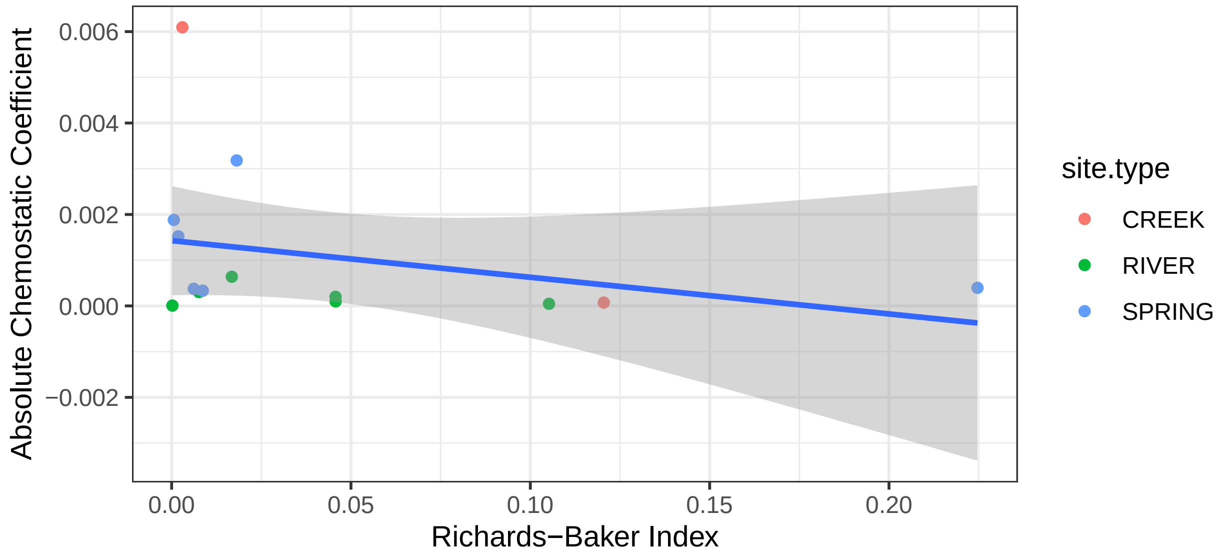


Figure 8: Absolute Chemostatic coefficient values and Richards-Baker Index of 14 non-canal sites

```
## (Intercept)             -7.5299     0.5232 -14.392 1.42e-10 ***
## RBI_value_ind_noncatch  -2.6847     3.6538  -0.735    0.473
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.921 on 16 degrees of freedom
## Multiple R-squared:  0.03264,    Adjusted R-squared:  -0.02782
## F-statistic: 0.5399 on 1 and 16 DF,  p-value: 0.4731
```

Since canals often act differently than natural waterways, and the largest outlier for both RBI and Chemostaticity Coefficient are canals, we also visualized the data without canals. The visualizations are more clear due to smaller axis ranges, and show similar results to the first visualizations. We ran the same linear regression on the Absolute Chemostatic Coefficient without canals.

```
##
## Call:
## lm(formula = log(chemo.coef.abs) ~ RBI_value_ind_noncatch, data = RBI_nocanals)
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -4.1233 -0.8833 -0.2023  1.3591  2.6141
##
## Coefficients:
##                         Estimate Std. Error t value Pr(>|t|)
```

```
## (Intercept)               -7.694      0.587 -13.106  1.8e-08 ***
## RBI_value_ind_noncatch   -6.889      7.716  -0.893     0.39
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.808 on 12 degrees of freedom
## Multiple R-squared:  0.06228,    Adjusted R-squared:  -0.01586
## F-statistic: 0.797 on 1 and 12 DF,  p-value: 0.3895
```

The linear regression for Absolute Chemostatic Coefficient vs. RBI provided a Coefficient of -6.889, a P-value of 0.39, and a multiple r-squared of 0.06228. While the fit doesn't sufficiently match the data, it is better than the data with canals and does provide some idea of the relationship between the variables.

4.2 Question 2: How do features of a site impact its chemical flashiness?

4.2.1 Qualitative Approach: How do geographical features impact the site's chemical flashiness?

We made observations by first sorting sites into three categories - Chemostatic, Flushing, and Diluting - based on the slopes of the regression lines of their C-Q plots - values near 0, positive values, and negative values, respectively. Then, we went site by site and searched their coordinates into Google Maps and ArcGIS, and noted the general surrounding geography - is it mostly urban or rural? Is it in a state park, adjacent to it, or nowhere near? Where, generally, in Florida is this site located? We also paid special attention to the site type - river, spring, or canal - as each most likely have differing management strategies and hydrologies.

When we were done listing the qualitative traits of all the sites in each hydrologic behavioral categorical, we noticed some trends had emerged. For the most flushing sites, or, the ones with the steepest regression line slopes, we noticed that all are located near airports. (Main Canal, Fellsmere Canal, Crane Creek, and Madison Blue Spring) There does not seem to be a correlation with the urbanity of the location, however, as two out of four of these sites are mostly rural and two are mostly urban - Fellsmere, Madison Blue Spring and Main Canal, Crane Creek, respectively. We hesitate to draw any concrete conclusions about possible relationships between flushing systems and proximity to airports, as there may be many other factors involved that are not within the scope of this project. One important factor could be the management style of the site; three out of four of the canals analyzed in this project tend towards flushing. This, too, could be a coincidence, and we would need to do a deeper analysis with more sites to draw conclusions.

Our list of diluting sites show more convincing trends - seven out of nine of the sites are located in very rural locations, most in or on the edge of a Florida state park. (Ichetucknee, Santa Fe, Blue Spring, Blue Hole Spring, Manatee Spring, Homosassa Spring, Turkey Creek) However, this number may be slightly inflated because three of the four most diluting

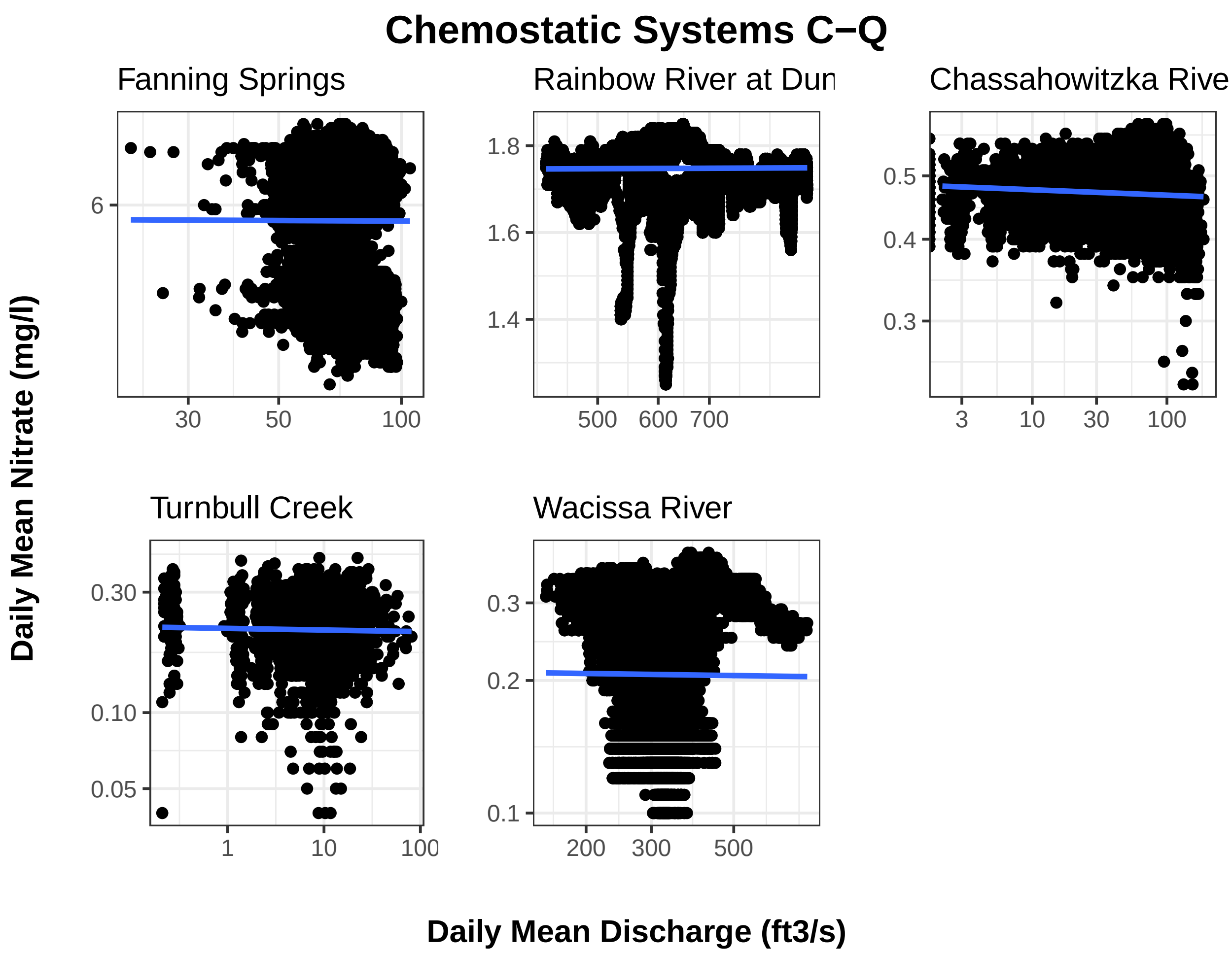


Figure 9: C-Q Plots of Chemostatic Sites

sites are directly interconnected, increasing the likelihood of similar hydrologic tendencies between them. (Ichetucknee, Santa Fe, Blue Hole Spring) There seem to be no other notable qualitative trends for diluting sites.

Chemostatic or mostly chemostatic systems do not seem to display any particular kind of trend. They are located in all kinds of environments - from hyper-urban to deep in state parks.

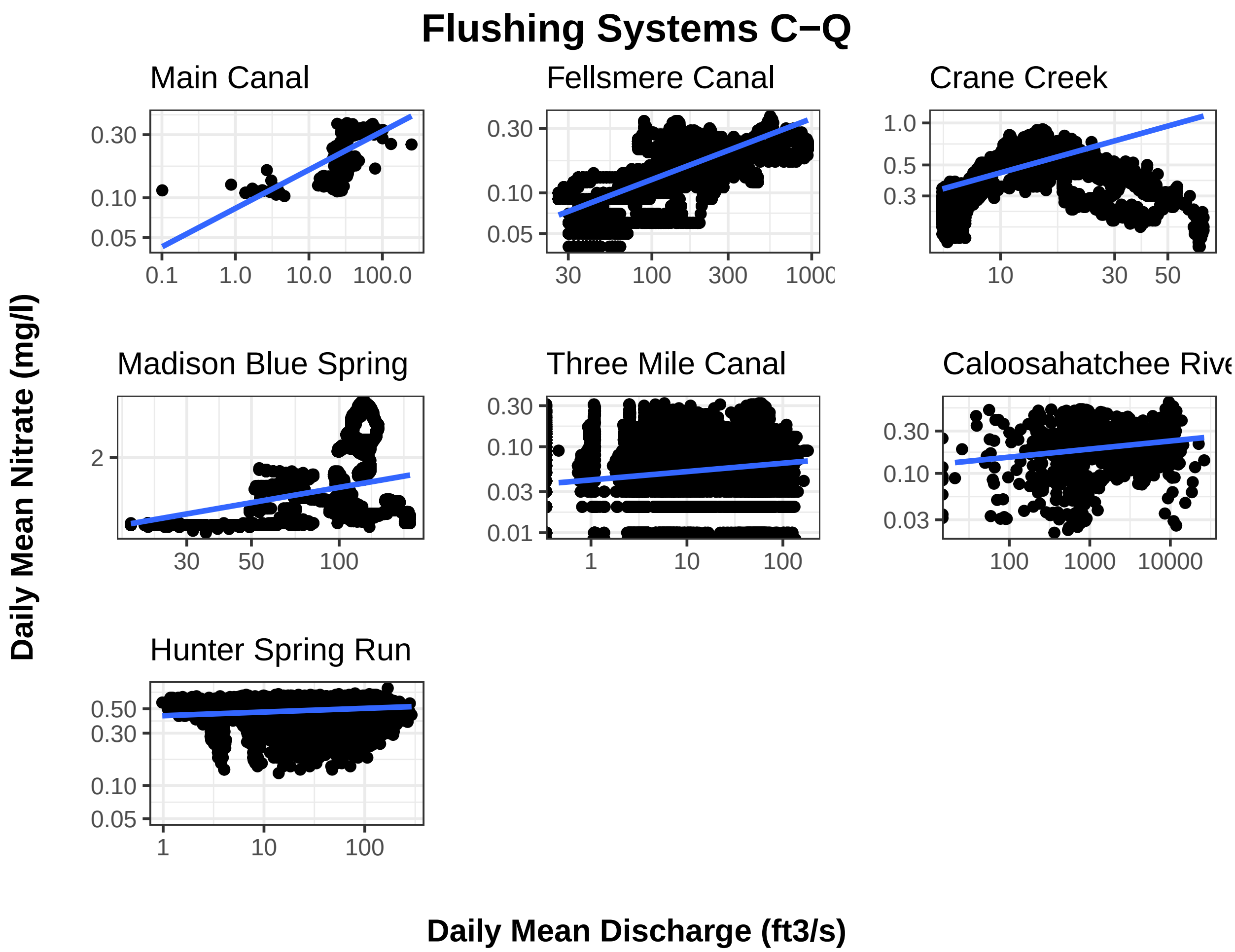


Figure 10: C-Q Plots of Flushing Sites

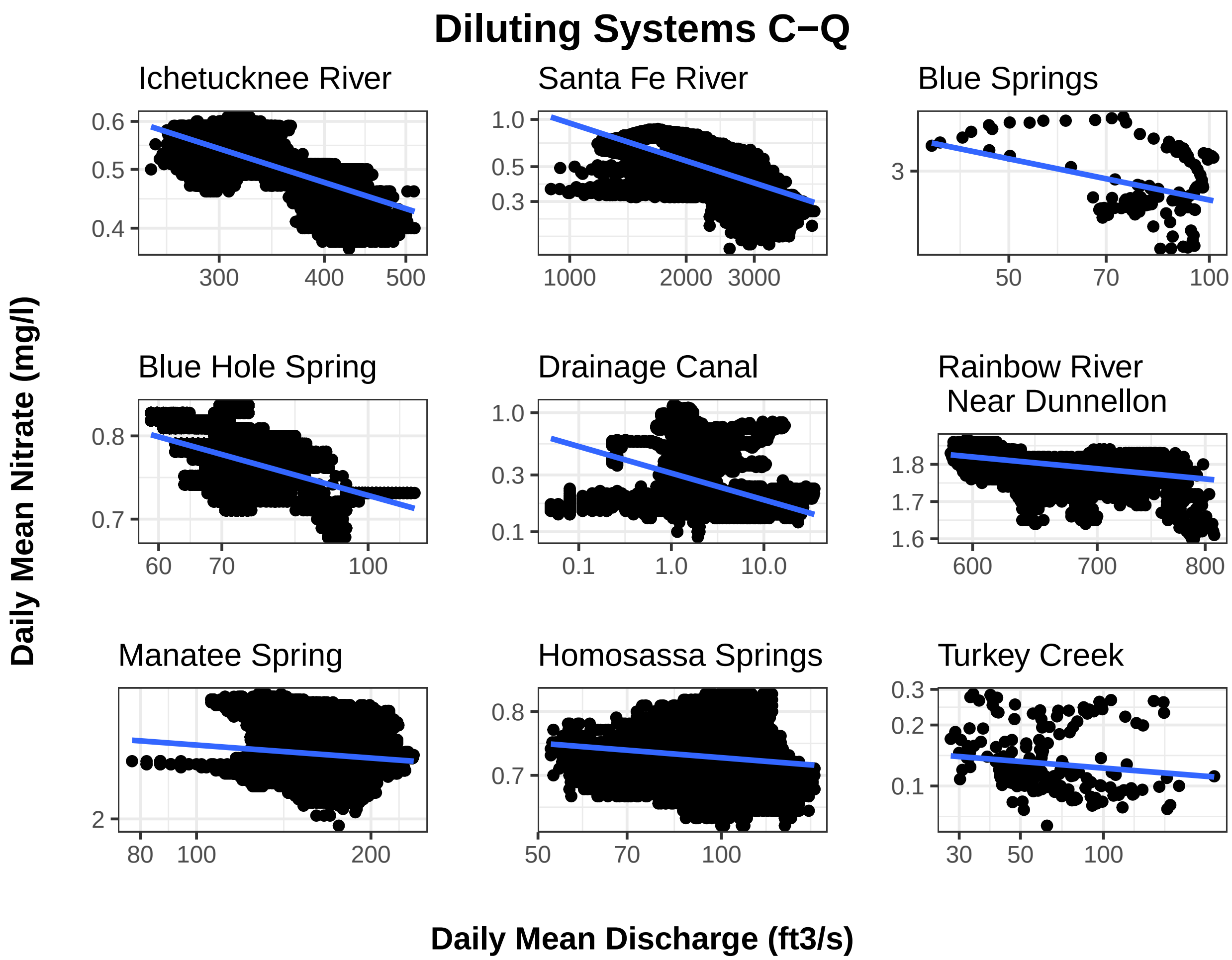
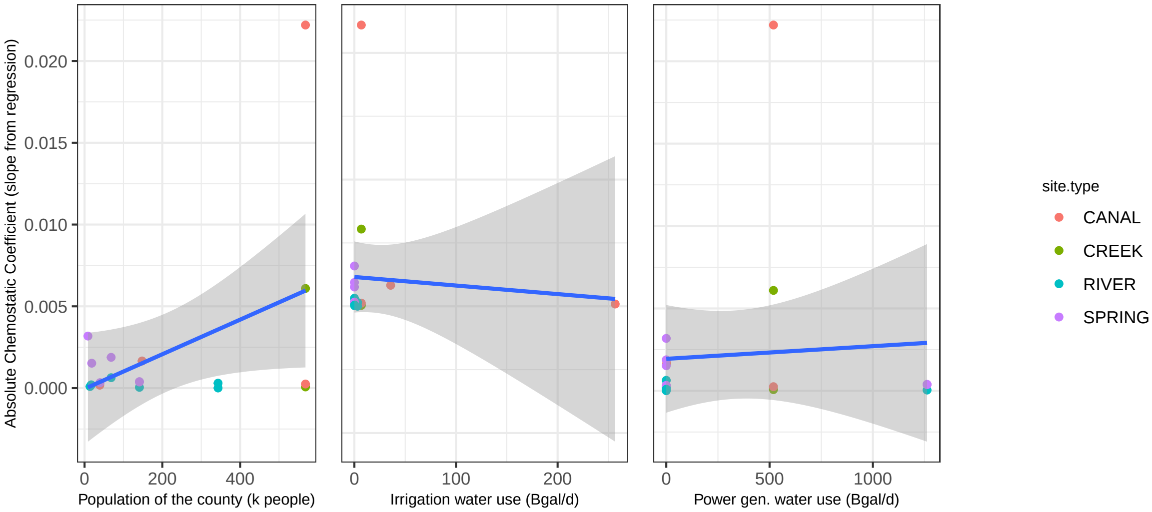
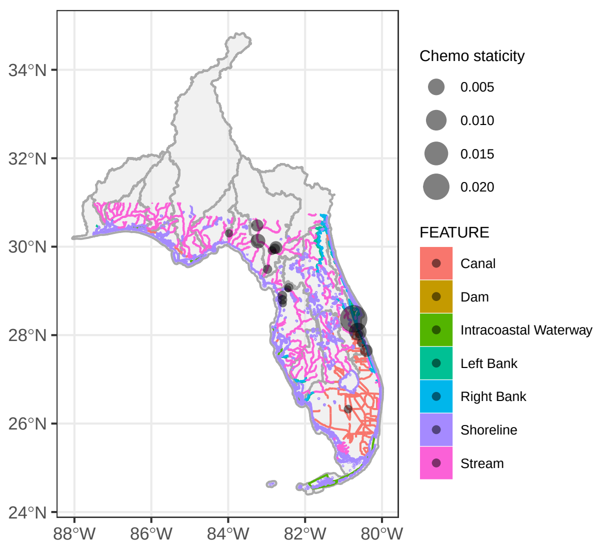


Figure 11: C-Q Plots of Diluting Sites

4.2.2 Quantitative/Statistical Approach: How do counties' population and water usage impact the chemical flashiness of sites within the county?





5 Summary and Conclusions

<Summarize your major findings from your analyses in a few paragraphs. What conclusions do you draw from your findings? Relate your findings back to the original research questions and rationale.>

6 References

(1) "Hydrologic Flashiness." Kansas River Inventory. Accessed November 21, 2019. Web: http://www.kansasriverinventory.org/home/hydrologic-flashiness

(2) Creed, I.F., et al. (2015). "The river as a chemostat: fresh perspectives on dissolved organic matter flowing down the river continuum." Can. J. Fish. Aquat. Sci. 72: 1272-1285.

(3) "Calculating the Cost of Weather and Climate Disasters." NOAA: National Centers for Environmental Information. Accessed November 21, 2019. Web: https://www.ncei.noaa.gov/news/calculating-cost-weather-and-climate-disasters

(4) Smith, V. H. and Schindler, D. W. (2009). "Eutrophication science: where do we go from here?" Trends in Ecology and Evolution. 24, 201-207.

(5) Stephenson, C. "Addressing Eutrophication in Florida, one watershed at a time." University of Florida: IFAS Extension. July 23, 2018. Accessed November 21, 2019. Web: https://nwdistrict.ifas.ufl.edu/nat/2018/07/23/addressing-eutrophication-in-florida-one-watershed-at-a-time/.

(6) "Chassahowitzka River and Coastal Swamps." Southwest Florida Management District. Accessed November 21, 2019. Web: https://www.swfwmd.state.fl.us/recreation/chassahowitzka-river-and-coastal-swamps

(7) Chislock, M. F., Doster, E., Zitomer, R. A. & Wilson, A. E. (2013). "Eutrophication: Causes, Consequences, and Controls in Aquatic Ecosystems." Nature Education Knowledge 4(4):10.

(8) Walker, S. "In World That Says It's Cutting Nutrient Pollution, Progress is Lacking." World Resources Institute. March 4, 2019. Accessed November 21, 2019. Web: https://www.wri.org/blog/2019/03/world-says-its-cutting-nutrient-pollution-progress-lacking

(9) "Extreme weather gets a boost from climate change." Environmental Defense Fund. Accessed November 21, 2019. Web: https://www.edf.org/climate/climate-change-and-extreme-weather

(10) Begley, J. "Pioneers had foresight to drain area for development; set up canal system in use today." TC Palm News. November 7, 2018. Accessed November 21, 2019. Web: https://www.tcpalm.com/story/news/local/verobeachcentennial/2018/11/07/without-canals-dug-vero-beach-area-1900-s-wed-under-water/1821047002/

(11) "City of NSB Voter Information: Turnbull Creek." Marine Discovery Center. October 10, 2018. Accessed November 21, 2019. Web: https://www.marinediscoverycenter.org/city-of-nsb-voter-information-turnbull-creek/

(12) Harrison, C. "NSB responds to growth with effort to preserve Turnbull Creek." June 14, 2018. Accessed November 21, 2019. The Daytona Beach News Journal. Web: https://www.news-journalonline.com/news/20180613/nsb-responds-to-growth-with-effort-to-preserve-turnb

(13) Coston, D. "NSB To Purchase More Property Along Turnbull Creek." WNDB: News Daytona Beach. June 27, 2019. Accessed November 21, 2019. Web: https://www.newsdaytonabeach.com/wndb-news/nsb-to-purchase-more-property-along-turnbull-creek/

(14) Division of Environmental Assessment and Restoration, Water Quality Restoration Program, Department of Florida. "Basin Management Action Plan for the Implementation of the Nutrient Total Maximum Daily Load by the Florida Department of Environmental Protection in the Jackson Blue Spring and Merritts Mill Pond Basin." May 2016. Accessed November 21, 2019. Web. https://floridadep.gov/sites/default/files/JacksonBlueBMAP.pdf

(15) Florida Department of Environmental Protection. "Protecting Florida's Springs." Accessed November 21, 2019. Web. https://floridadep.gov/springs/protect-restore/content/protecting-floridas-springs