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

https://github.com/ytgong/ENV322_group_project

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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 was to better understand the effects of storm events on rivers and streams in Florida. The following questions and hypotheses guided the study: Question 1: Is there a correlation between hydrologic and chemical flashiness in rivers and streams?

Hypothesis 1: There is a correlation between hydrologic and chemical flashiness. Sites with high hydrologic flashiness are more likely to be chemically flashy because of shared predictor variables.

Question 2: How do rural / urban features of a site impact its chemical flashiness?

Hypothesis 2: There is a correlation between the urbanness / ruralness of a site and its chemical flashiness. Sites with high urbanness are more likely to be chemically flashy because of impervious surfaces and non-point source discharge potential.

2 Dataset Information

Data for 21 water bodies (7 rivers, 7 springs, 3 creeks, and 4 canals) in Florida will be collected. They were chosen by searching all USGS Florida sites with high frequency nitrate and discharge data that had significant periods of overlap. Each site's data was shortened to focus on period of time with consistent data collecting.

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 and discharge data as a measure of chemical flashiness. The data will be combined into one dataframe, along with site information, for trend analysis.

For question / hypothesis 2 regarding the properties of each site that may affect chemical flashiness, data will be retrieved from United States Geological Survey (USGS). Specifically, county population values, irrigation water use levels, thermoelectric water use levels, and a chemostatic coefficient will be examined. Maps taken from ArcGIS 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	Abbr.
2326526	WACISSA RIVER NR WACISSA FLA	Jefferson	WAC
2319302	MADISON BLUE SPRING NR BLUE SPRINGS, FL	Madison	MAD
2319950	BLUE SPRINGS NEAR DELL,FL	Lafayette	BLUE
2323566	MANATEE SPRING NR CHIEFLAND FLA	Levy	MAN
2323502	FANNING SPRINGS NR WILCOX FLA	Levy	FAN
2322800	SANTA FE RIVER NR HILDRETH FLA	Gilchrist	SANTA
2322700	ICHETUCKNEE R @ HWY27 NR HILDRETH, FL	Columbia	ICHE
2322688	BLUE HOLE SPRING NR HILDRETH, FL	Columbia	HOL

Site No.	Station Name	County	Abbr.
2310743	HUNTER SPR RUN AT BEACH LANE AT CRYSTAL RIVER FL	Citrus	HUN
2310678	HOMOSASSA SPRINGS AT HOMOSASSA SPRINGS FL	Citrus	HOM
2310650	CHASSAHOWITZKA RIVER NEAR HOMOSASSA FL	Citrus	CHAS
2313100	RAINBOW RIVER AT DUNNELLON, FL	Marion	RAIN
2313098	RAINBOW RIVER NEAR DUNNELLON, FL	Marion	BOW
2292900	CALOOSAHATCHEE RIVER AT S-79, NR.OLGA, FLA	Lee	CAL
2289035	THREE MILE CANAL BELOW G409 NEAR CLEWISTON, FL	Hendry	THREE
2248350	TURNBULL CREEK NR OAK HILL, FL	Volusia	TURN
2248600	DRAINAGE CANAL AT PLAZA PKWY AT COCOA, FL	Brevard	DRAIN
2249500	CRANE CREEK AT MELBOURNE, FL	Brevard	CRANE
2250030	TURKEY CREEK AT PALM BAY, FL	Brevard	TURK
2251767	FELLSMERE CANAL NEAR MICCO, FL	Brevard	FELL
2253000	MAIN CANAL AT VERO BEACH, FL	Indian River	MAIN

3 Exploratory Analysis

Figure 1 is a map that shows the watershed and water feature information of Florida and location of the sites we chose to analyze. It can be seen that the sites chosen encompass a variety of water features, ranging from streams, banks, to canals. They are also located in different regions of Florida, and the hydrological heterogeneity among sites offers an opportunity to study the potentially different interactions between chemostaticity and hydrological flashiness.

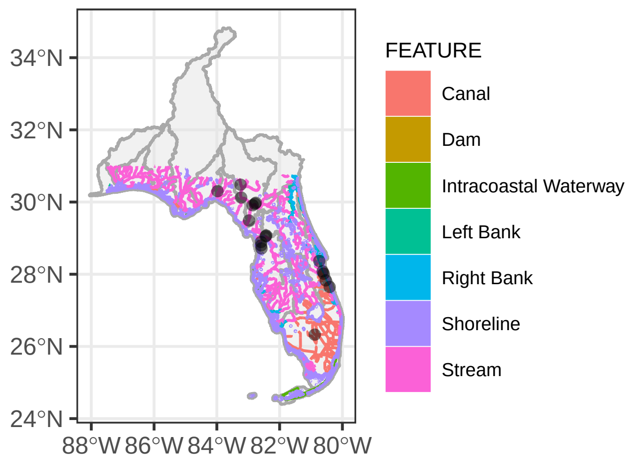

Figure 1: Location of sites analyzed on watersheds

We created 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 noticed the difference between the canal plots and the other waterway types (Figure 2). The canal plots have values much more concentrated in their lower ranges, and contain less variation overall. Visualizing the differences in canal variable distributions alerts us that they may influence our later data analysis.

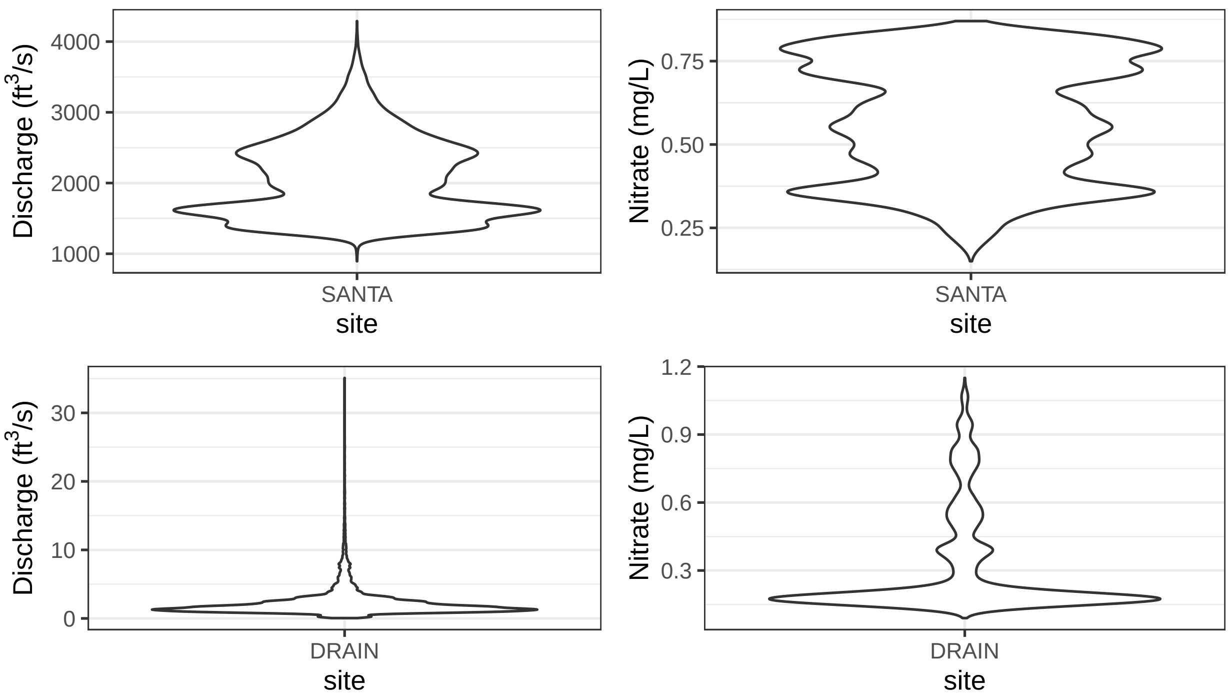

Figure 2: Distribution of discharge and nitrate values of a stream and a canal

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 so here we present the discharge plot without CAL and SANTA to better visualize the smaller discharges (Figure 3). A similar plot for nitrate was also made (Figure 4).

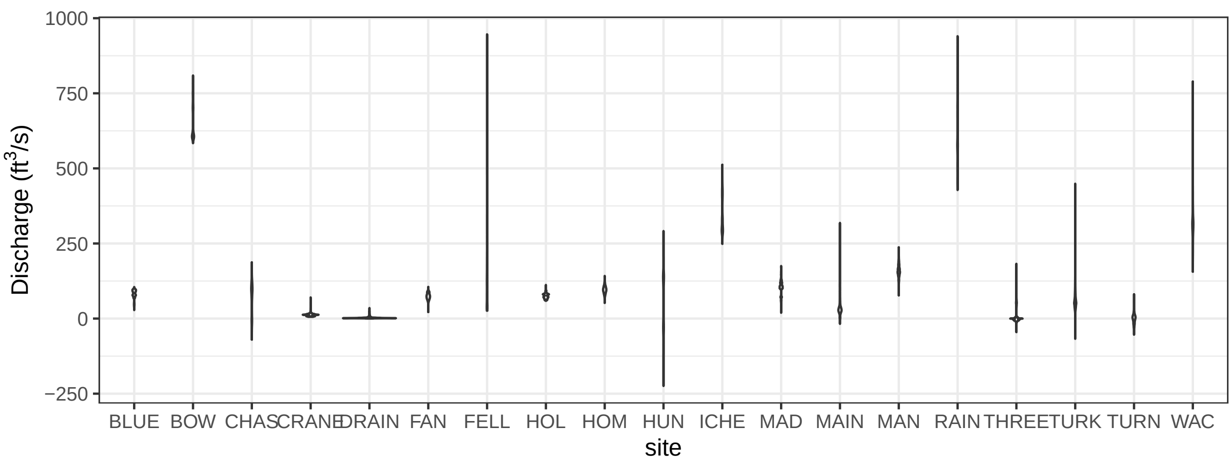

Figure 3: Distribution of discharge values of all sites (except CAL and SANTA)

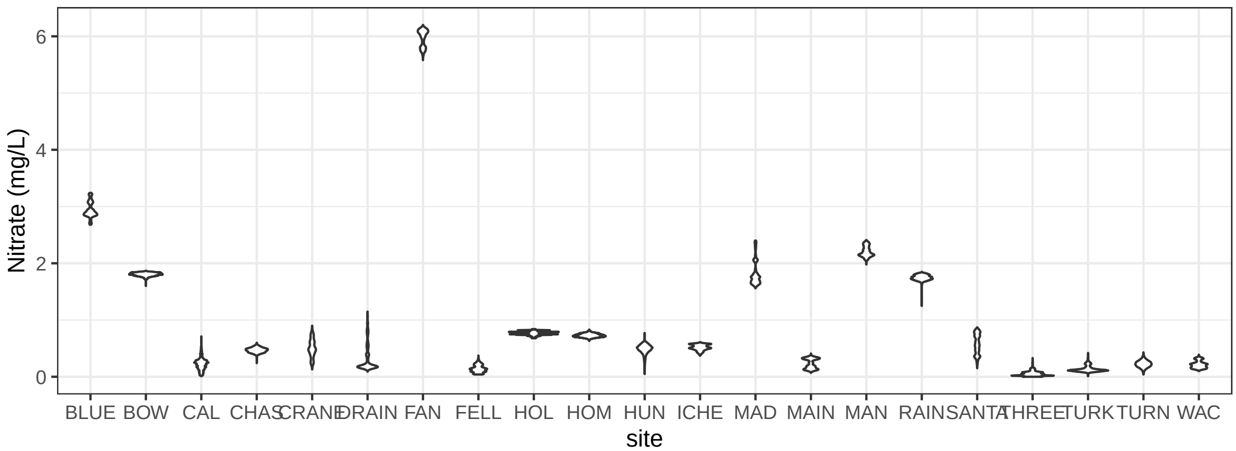

Figure 4: Distribution of nitrate concentration values of all sites

Our final exploratory analysis consisted of 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 canal, and one creek (Figure 5) - all to give a sense of the range of site types and the data trends at each.

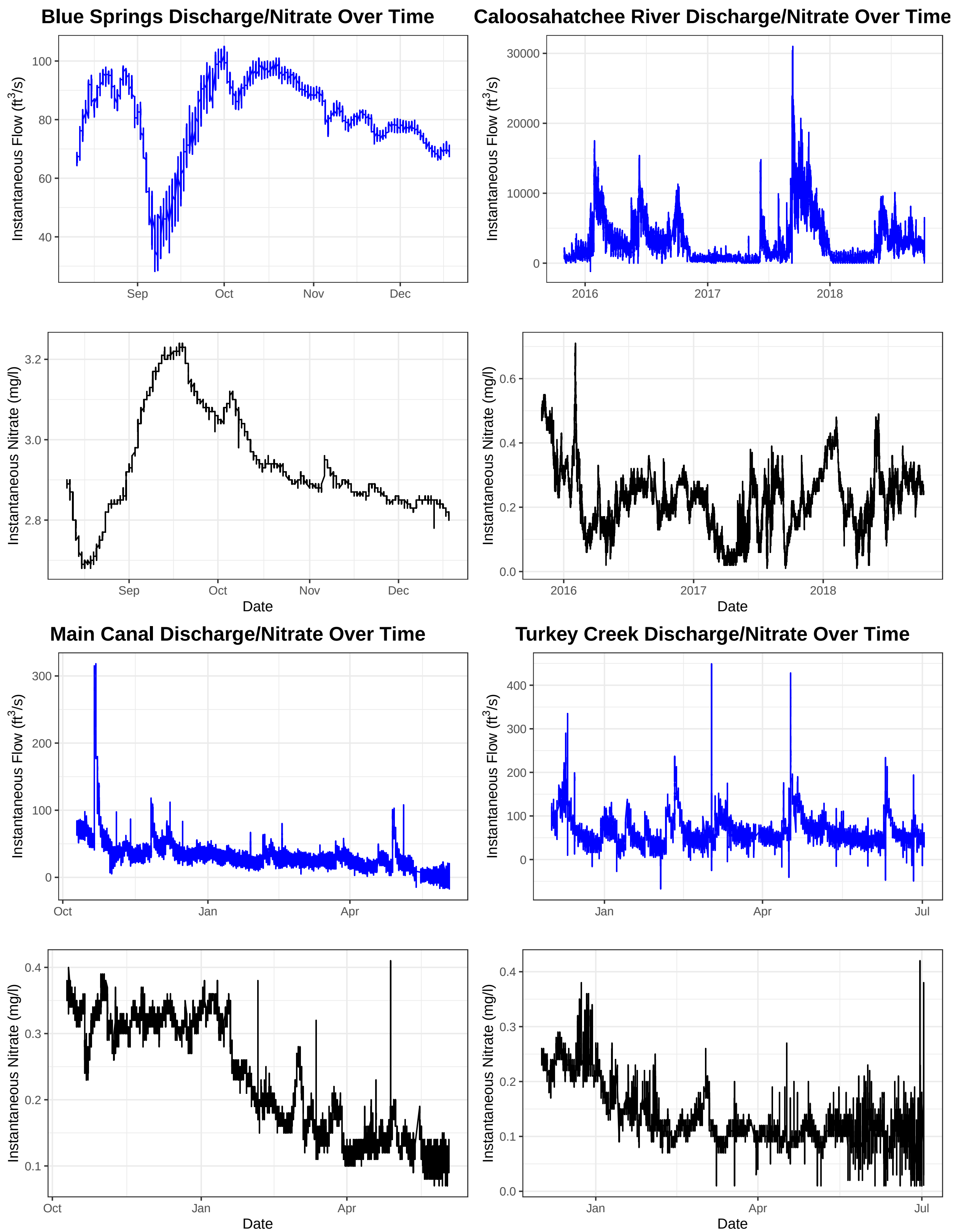

Figure 5: Discharge and nitrate value patterns of example sites

4 Analysis

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

To analyze our first question, on the relationship between hydrolic flashiness and chemical flashiness, we calculated the Richards-Baker Index of each site to quantify hydrologic flashiness. We had to exclude catchment size in the formula because 17 out of 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.

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 overall flashiness, as absolute value would account for large chemostaticity in either a flushing or diluting system.

We created ggplot visualizations of Chemostatic Coefficient vs. RBI (Figure 6) and Absolute Chemostatic Coefficient vs. RBI (Figure 7) 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 distributions were viewed between site type, except that the largest outlier for both Chemostatic Coefficient and RBI are canals.

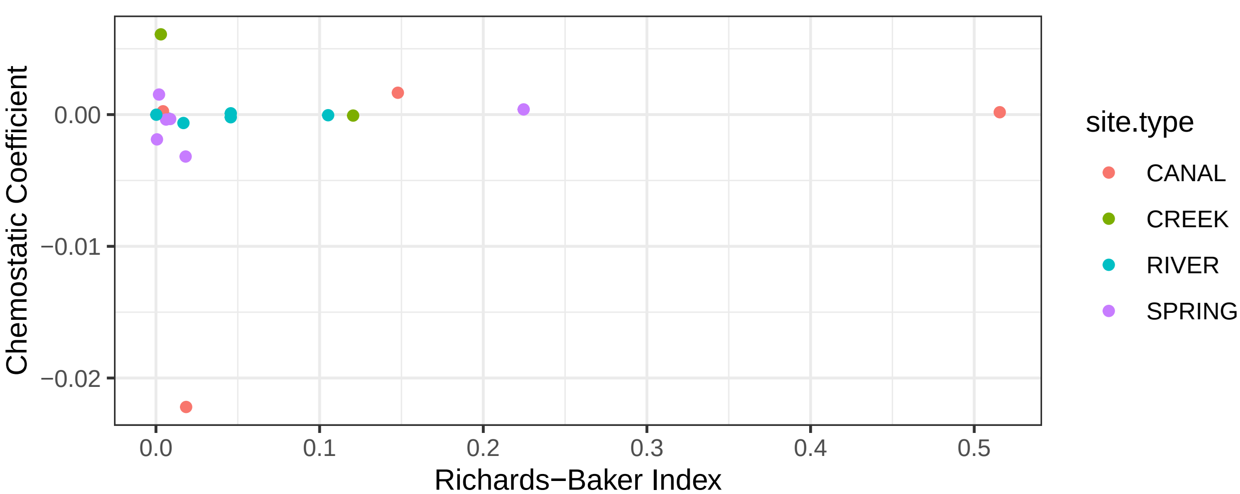

Figure 6: Chemostatic coefficient values and Richards-Baker Index of 18 sites

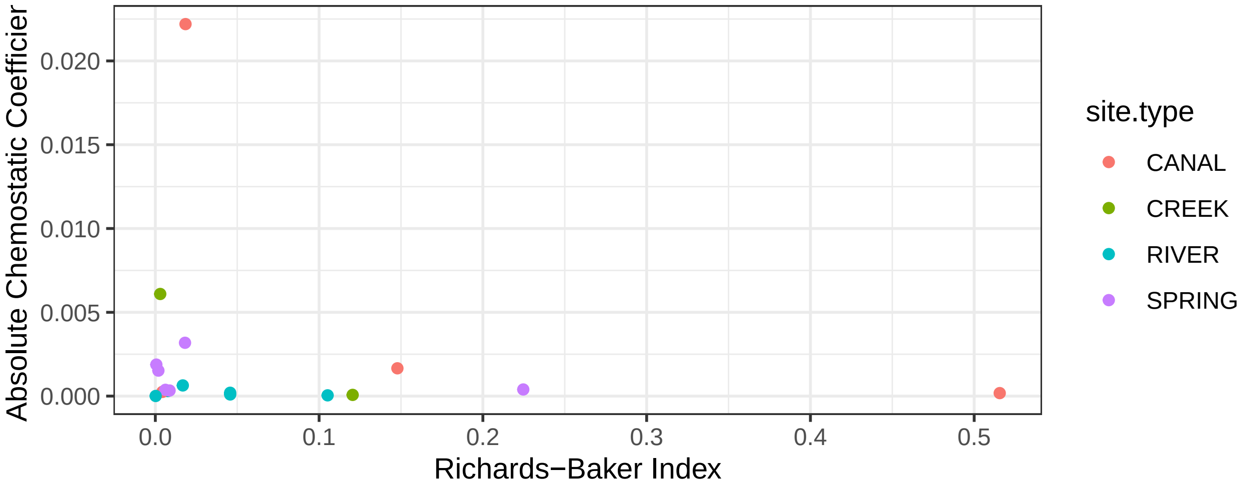

Figure 7: Absolute Chemostatic coefficient values and Richards-Baker Index of 18 sites

We ran a linear regression on log(Absolute Chemostatic Coefficient) vs. RBI, which was the closest fit that we could find. The regression produced a coefficient of -2.6847 (16 degrees of freedom, P-value of 0.473, multiple r-squared 0.03264). The model does not adequately predict the data.

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 (Figure 8). The visualizations show a more concise version of the trends in Figure 6 and Figure 7, where low RBI results in a high Absolute Chemostatic Coefficient. We ran the same linear regression on the data without canals.

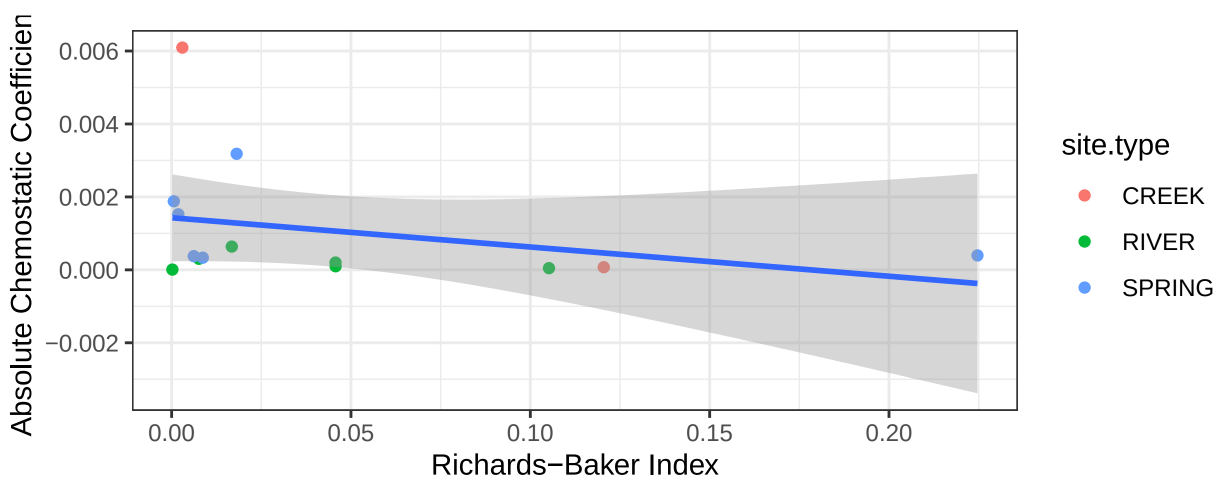

Figure 8: Absolute Chemostatic coefficient values and Richards-Baker Index of 14 non-canal sites

The linear regression for Absolute Chemostatic Coefficient vs. RBI provided a Coefficient of

-6.889 (12 degrees of freedom, P-value 0.39, and a multiple r-squared 0.06228). While the fit still isn't significant, it is better than the data with canals and suggests that there is a negative relationship between hydrologic flashiness and chemical flashiness.

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 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.

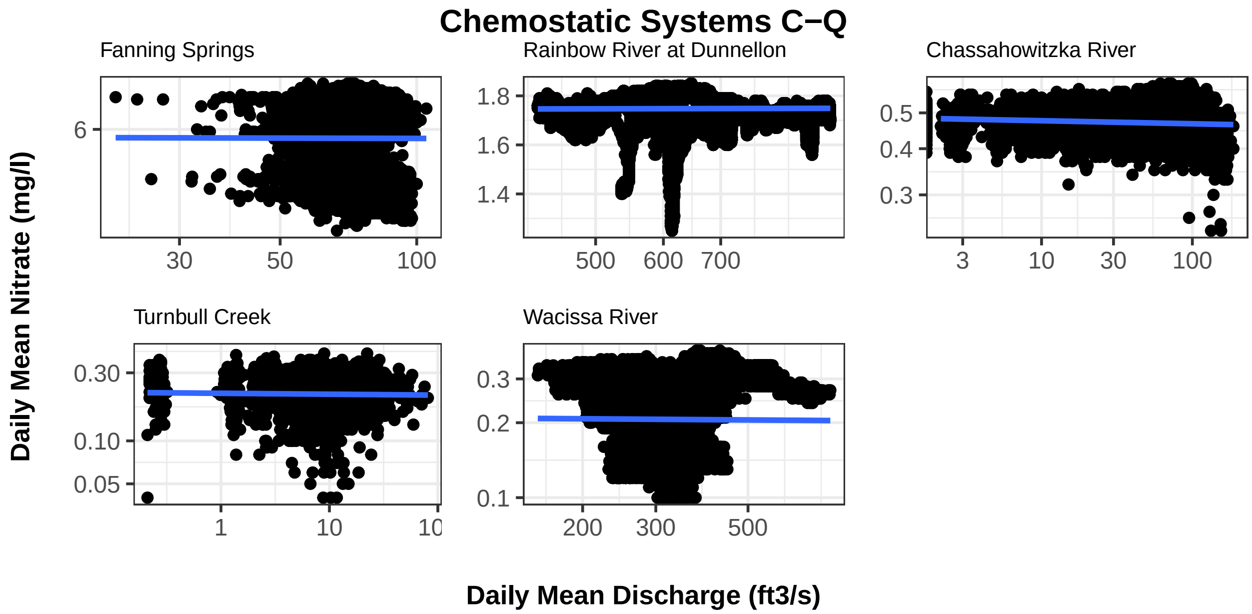

Figure 9: C-Q Plots of Chemostatic Sites

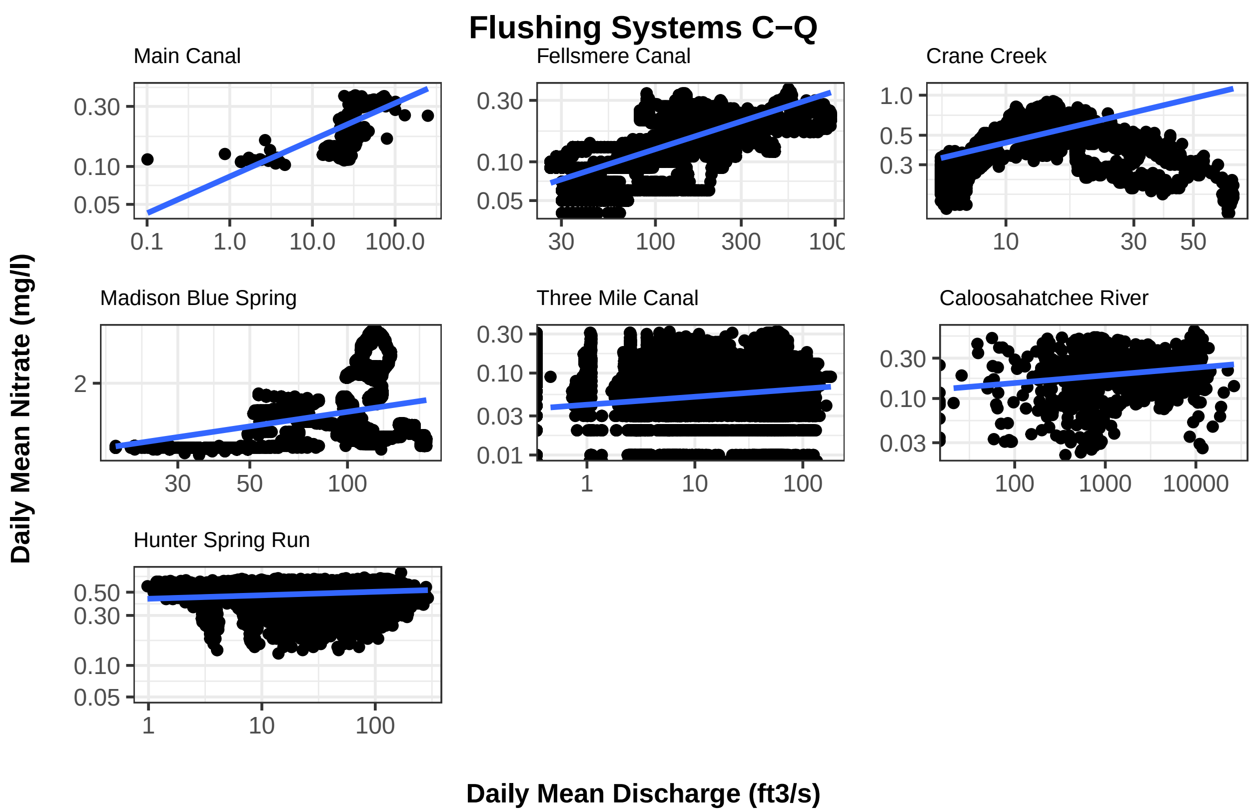

Figure 10: C-Q Plots of Flushing Sites

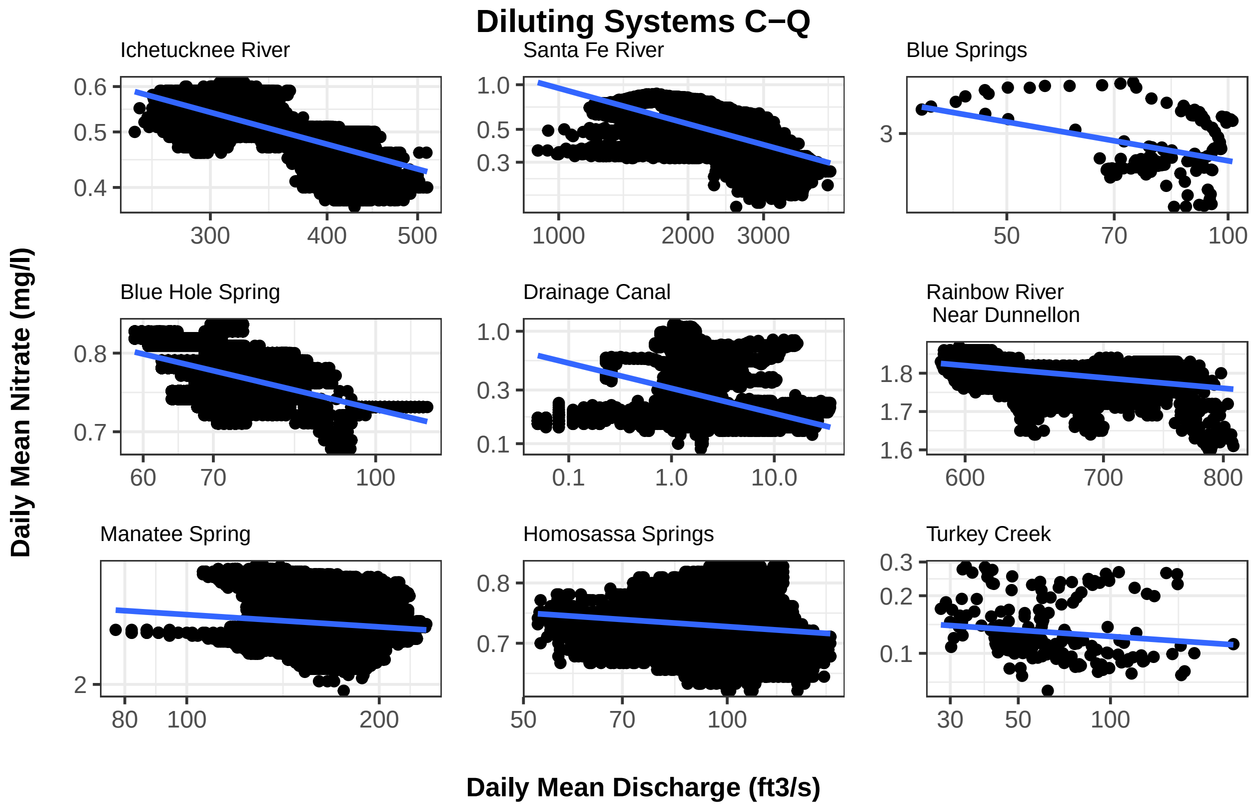

Figure 11: C-Q Plots of Diluting Sites

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

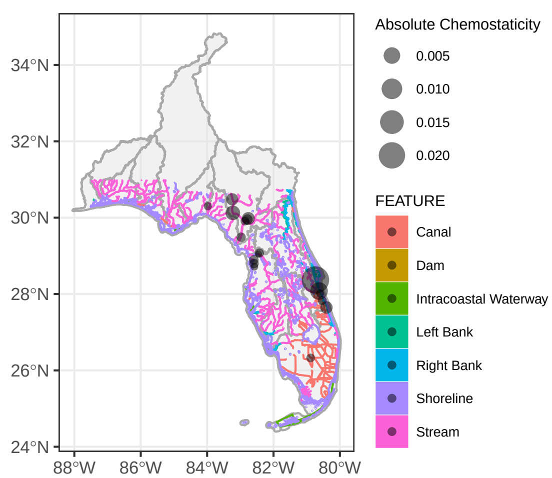

Figure 12: Location of sites and respective absolute chemostatic coefficient

Figure 12 shows each site's chemostaticity (absolute chemostatic coefficient) on the water feature map. Based on the map, it appears that sites on the right bank are less chemostatic, compared to sites in central-northern part of Florida. However, since many factors are confounding and sample size is not big enough, no definite conclusion can be drawn.

We then used county population and water use data from USGS to conduct a quantitative analysis on how sites in different locations have different levels of chemical flashiness. Specifically, for water use, we looked at billion gallons of water used per day for irrigation and thermo electricity generation in each county. We believe that the more water used for irrigation in a county, the higher probability the sites in that county have of being influenced by nutrient run-off from farms within the county. A large amount of water used for thermo electricity generation may either imply that the water is well-managed and therefore more chemically stable, or imply that pollution may come from the generation process and make the water chemically flashy.

Figure 13 shows that sites in counties with higher population seem to have a higher probability of having higher absolute chemostatic coefficient, which means that they are less chemically stable. However, relationship between water use and chemical flashiness is not convincing enough.

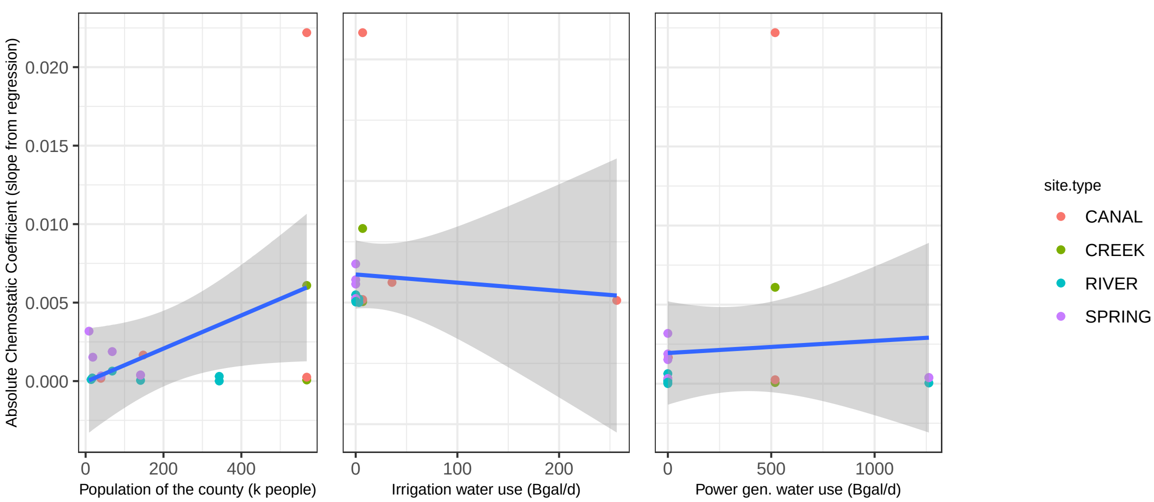

Figure 13: Relationship between a site's chemical flashiness and population and water use of the county the site is in

We ran a linear regression to quantify the relationship between population, water use and chemical flashiness. The regression result shows that the impact of water use (both irrigation and thermoelectric) on chemical flashiness is not significant. But for population, we got a coefficient of 1.057e-05 (16 degrees of freedom, a P-value of 0.06, multiple r-squared of 0.1972). That is, we are 94% confident that on average, adding one thousand people to a county, the absolute value of chemostatic coefficient will increase by 1.

5 Summary and Conclusions

This examination of hydrologic and chemical flashiness on 21 water bodies in Florida yielded a few notable results. Correspondingly, there are a few recommendations that managers of rivers, springs, creeks, canals, etc. in Florida might want to consider.

First, there is no clear or statistically significant correlation between hydrologic and chemical flashiness. Our research suggests that there could be a negative correlation between hydrologic flashiness and chemical flashiness, but further research is needed to develop a clear relationship. As a result, in order to maintain the health of their rivers and streams, it is recommended that river and stream managers start tracking or continue to track proxies for both hydrologic and chemical flashiness and not simply just for one or the other. For hydrologic flashiness, river and stream managers should track high frequency discharge levels during storms. For chemical flashiness, river and stream managers should track high frequency nitrate and conductance levels during storms. If further research confirmed a negative relationship between hydrologic flashiness and chemical flashiness, managers could better predict problems for certain streams and respond accordingly.

A second conclusion of this examination is that there exists a relationship between the location of a water body and its chemical flashiness behavior. More specifically, the water bodies that were located closest to airports tended to exhibit flushing behavior, while the water bodies located in or near state parks tended to exhibit diluting behavior. Also water bodies located in counties that have higher population tended to exhibit more chemical flashiness. However, due to the limited scope both in site number and variable number of this study, these trends may be misleading or misrepresentative of other processes at work. For Florida water managers, it is recommended to at least pay closer attention to the possible interactions between airports or similar, large human operations and watersheds - the diluting nature of systems in state parks may be important as well, but they are likely already closely monitored.

6 References

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