



Trends in Water Quality in Youngs Branch, Manassas National Battlefield Park

Natural Resource Report NPS/NCRN/NRR—2021/2307



ON THE COVER

Youngs Branch in Manassas National Battlefield Park

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Trends in Water Quality in Youngs Branch, Manassas National Battlefield Park

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Executive Summary

The National Capital Region Inventory and Monitoring Network has monitored water quality in Youngs Branch in Manassas National Battlefield Park since 2005. Measurements taken at the stream include acid neutralizing capacity, discharge, dissolved oxygen concentration, pH, salinity, specific conductance, total nitrogen concentration, total phosphorus concentration and water temperature. This report assesses water quality in the stream in terms of trends over time, seasonal changes and relationships with discharge. Additionally, we find that several water quality characteristics frequently fall in ranges that can negatively affect aquatic life. These include high specific conductance, low values of dissolved oxygen, and seasonal drying of the stream. Other characteristics rarely (salinity, total nitrogen, total phosphorus) or never (acid neutralizing capacity, pH, temperature) fall outside of an acceptable range.

Several water quality characteristics follow a seasonal pattern with low water temperatures, high dissolved oxygen concentrations and high discharge in the winter months followed by high temperatures, low dissolved oxygen and low discharge in the summer. High discharge is also associated with low pH and acid neutralizing capacity, perhaps due to differences in chemistry between rainwater and ground water. The only long-term trends detected were small increases in dissolved oxygen and decreases in pH.

Seasonal drying of the stream and lack of dissolved oxygen are likely related to overheating of the stream during the winter months. Youngs Branch flows through several small ponds and these should be investigated to determine if they are impeding water flow or are locations of depleted dissolved oxygen. Chronic high specific conductance is likely due to sediment and pollutants in the stream. The small tributaries entering the park should be checked to determine if any of them have particularly elevated specific conductance.

Acknowledgments

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Introduction

Water quality monitoring at Youngs Branch in Manassas National Battlefield Park is part of a larger stream monitoring program carried out by the NPS National Capital Region Inventory & Monitoring Network (NCRN). Since 2005, the NCRN has carried out water monitoring in 10 National Park units in and around Washington DC, including Manassas. The goal of this program is to provide park managers with the status and trends of key water quality characteristics to aid in assessing the condition of streams in their parks.

This report is the first assessment of trends in water quality for Youngs Branch. For each water quality characteristic, we compare data from Youngs Branch to relevant threshold values to identify water quality concerns. In this report, we analyze three different types of water quality trends: 1) long-term changes over time, 2) cyclical seasonal patterns, and 3) relationships between water quality and discharge. These trends were chosen as they are potentially relevant to almost any water quality characteristic and provide a solid foundation for understanding stream condition. Furthermore, as demonstrated in this report, these analyses can provide insight into ongoing water quality problems and suggest potential management actions.

Analysis involving additional explanatory covariates is outside the scope of the current report. A wide variety of additional factors could potentially influence water quality in Youngs Branch. These include weather, land use, canopy cover and urbanization. It is anticipated that future analyses will focus on the influence of factors such as these on water quality.

Study Area

Youngs Branch is a third order stream in Manassas National Battlefield Park. The stream originates as several small tributaries to the west and south of the park, and empties into Bull Run on the park's eastern border. Bull Run is part of the Chesapeake watershed, emptying into the Occoquan River, which is itself a tributary of the Potomac.

After entering the park, the most prominent western tributary flows into and out of several small artificial ponds. Two of these ponds, located at Stuart's Hill, are shallow and have restricted outflows. The areas upstream and including these ponds is in an electric right-of-way and has no canopy cover. One southwestern tributary enters the park and immediately flows into a retaining pond just north of I-66, and then north to Youngs Branch. As the stream flows east, several small tributaries, including Dogans Branch and Chinn Branch flow into it.

The Youngs Branch watershed drains ~70% of the area of Manassas, with the major exceptions being the eastern and northern edges of the park that drain directly into Bull Run (Figure 1). The park includes almost 70% of the watershed; the remainder extends to the southwest of the park and into developed areas south of I-66.

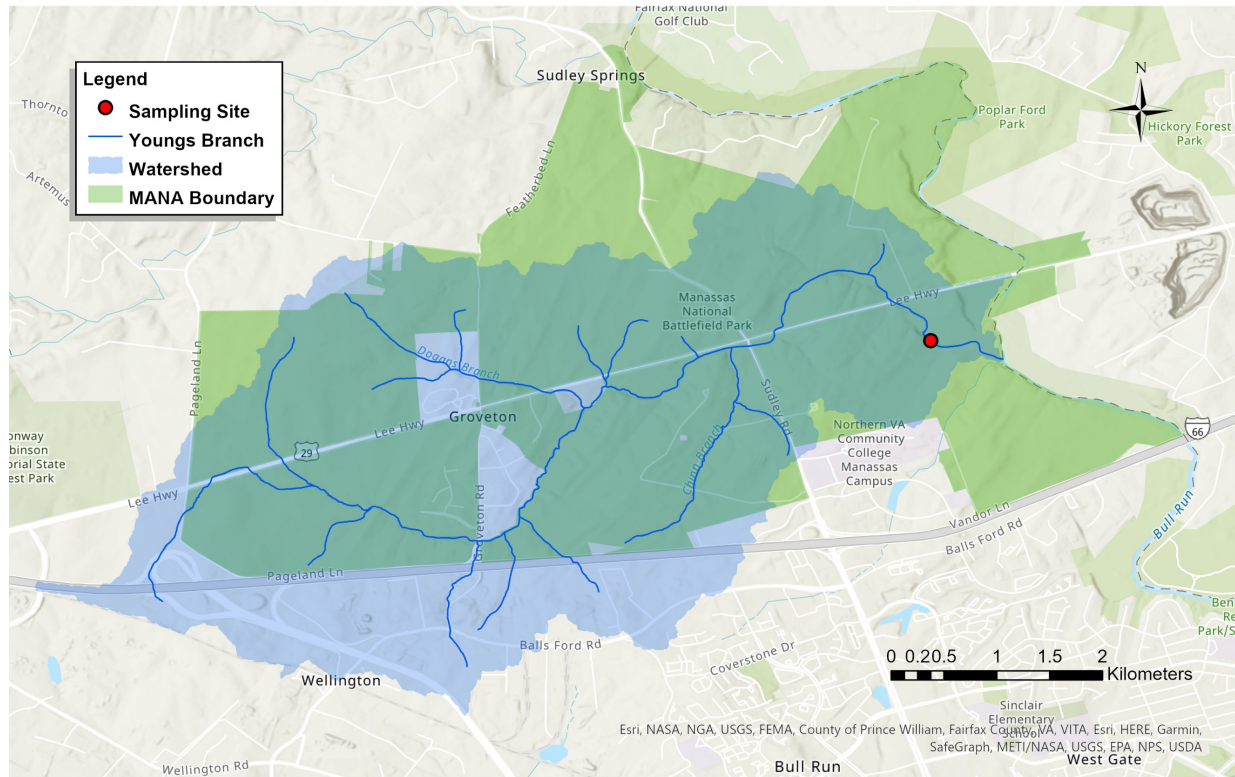


Figure 1. Youngs Branch Watershed in Manassas National Battlefield Park.

Within the park, land-use in the Youngs Branch watershed is largely a mix of forests and open areas, with relatively little developed area (Figure 2, Table 1). Open areas largely consist of fields, many of which are used for hay production. Only a small percentage of the watershed inside the park is developed, although this number does not include the area of the roads that bisect the park, as they are not park property.

In contrast, land use in the watershed outside of the park, particularly to the south, is more heavily developed. Developed areas are the largest land use outside of the park, whereas open areas are much less common. Forested land is also common, but less than inside the park.

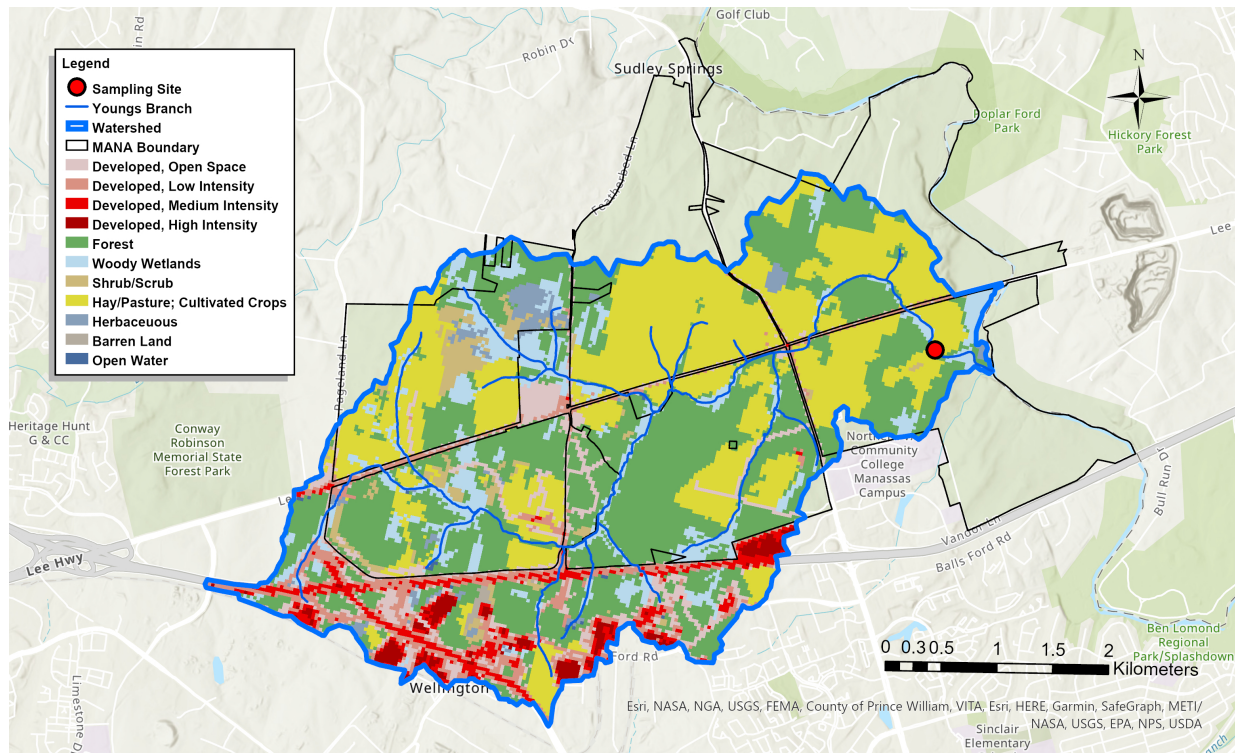


Figure 2. Land use in Youngs Branch Watershed.

Table 1. Land-use of Youngs Branch watershed inside and outside of Manassas National Battlefield Park.

Land Use	Area inside park (ha)	Area inside park (%)	Area outside park (ha)	Area outside park (%)	Total Area (ha)	Total Area (%)
Forested	484.6	39%	168.2	31%	632.8	35%
Wooded Wetland	128.0	10%	46.1	8%	174.1	10%
Developed	49.4	4%	282.9	52%	332.3	19%
Open	581.7	47%	52.2	10%	633.9	35%
Total	1243.7	70%	543.2	30%	1786.9	—

Approximately 19% of the Youngs Branch watershed is developed to some extent. Numerous studies have demonstrated that development in a watershed can have negative consequences on aquatic life. The effects of land use on aquatic macroinvertebrates (Utz et al., 2009) and fish (Morgan and Cushman, 2005; Utz et al., 2010) were studied using data collected by the Maryland Biological Stream Survey (MBSS). These studies showed that both fish and macroinvertebrate communities in Maryland's Piedmont streams, which are similar to Youngs Branch, are more sensitive to urbanization than stream communities in the Coastal Plain or Western Highlands of Maryland. In the Piedmont, urbanization-sensitive macroinvertebrate species were eliminated from streams with between 10 and 45% development and between 2.5% and 15% impervious surface. Piedmont streams lost the most sensitive fish species when urbanization was over 6% or impervious surface was over

1.8%. Taxa which were found in both the Piedmont and the Coastal Plain are more sensitive to urbanization in Piedmont streams. Agricultural activity, on the other hand, had mixed effects with some species benefiting from agriculture and others being harmed. They speculate that species which are sensitive to agriculture may have been entirely eliminated decades ago when agriculture was more widespread. Further studies of MBSS data (Baker and King 2010, King and Baker 2010) have shown that some aquatic macroinvertebrates are even more sensitive to urbanization, showing population declines in watersheds with as little as 2.5% developed area. These authors caution that the Benthic Index of Biological Integrity can be insensitive to the population declines seen in areas with this level of urbanization.

Morgan et al. (2007) linked several water quality characteristics, including specific conductance and nutrient concentrations to the declines in aquatic life seen in the MBSS data (see Water Quality Assessments below). Given the percentage of developed land in the Youngs Branch, poor water quality due to urbanization is a concern.

Designated Uses

Under the Clean Water Act, all states are required to designate how each waterway is used, and then ensure that those uses are not impaired by human activity (Virginia DEQ et al., 2019). In Virginia, all natural waters, including Youngs Branch, have designated uses of recreation, wildlife habitat, production of edible resources (such as fish) and for “the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them” (Virginia Administrative Code 9VA25-260-10, 2020). These designations guide water quality criteria for streams, including criteria for discharge, dissolved oxygen, pH and water temperature (see Water Quality Assessments below). Youngs Branch is categorized as an impaired stream due to high concentrations of *E. coli* bacteria which impact recreational uses (Virginia DEQ et al., 2019). It is designated as a “4a” stream which indicates it is impaired but that there is already an accepted Total Maximum Daily Load (TMDL) plan in place, and it is being implemented.

Water Quality Monitoring at Youngs Branch

Within each park, monitoring locations are chosen within each park based on several criteria. Water monitoring occurs in 1st through 4th order, non-tidal, wadable streams. Ephemeral and intermittent streams are excluded due to the difficulty of determining when data collection can take place. Each stream is sampled either at its confluence with a higher order stream or where the stream exits NPS property. In Manassas, Youngs Branch is currently the only stream being monitored. NCRN originally monitored Chinn Branch, Dogans Branch, and Holkums Branch, but this was discontinued because of the drying in those streams.

Stream monitoring in the NCRN has four major components:

Water quantity is monitored by taking measurement of stream discharge – the amount of water passing through the stream. The most obvious reason for monitoring discharge is that aquatic life requires water. Discharge varies both seasonally and across years, and trends of decreasing discharge can be a warning sign of problems within the watershed. While precipitation is the most direct driver of stream discharge, changes in land use, particularly

increases in impervious surfaces, are also important. High levels of impervious surface can lead to “flashy” streams which have high discharge immediately after precipitation events but are prone to low discharge and drying between storms. Water quantity can also be important in that many other aspects of stream quality are affected by discharge, as rainwater and runoff can have substantially different water chemistry than that of the groundwater that dominates stream baseflows.

Water chemistry is monitored by measuring dissolved oxygen, pH, acid neutralizing capacity, salinity, specific conductance and water temperature of the stream. These characteristics determine the suitability of the stream for aquatic life (e.g. see Southerland et al. 2007). Dissolved oxygen is required by aquatic animals, but can be depleted by high stream temperatures, particularly during low flows. pH, a measure of acidity/alkalinity of a stream can influence a wide variety of chemical reactions. Extreme values of pH are harmful to aquatic life. Acid neutralizing capacity is related to pH in that it is a measure of the ability of stream to buffer strongly acidic waters and maintain an acceptable pH. Salinity and specific conductance are two closely related measures of the concentration of solutes present in streams. High values of either indicate harmful amounts of dissolved solutes or suspended sediments in a stream. Water temperature varies with the season and can influence other characteristics, particularly dissolved oxygen. High water temperatures are known to be stressful to aquatic life, particularly to some species of fish.

Nutrients, specifically N as total nitrogen and P as total phosphorus are measured in water samples taken from the stream. While N and P are required for life, they are often overabundant in freshwater streams and lead to eutrophication. There are wide variety of sources of nutrient pollution, including yard and agricultural chemicals, leaking sewage and septic systems, animal waste and car exhaust (Manuel, 2014).

Aquatic Organisms, specifically fish and macroinvertebrates, are monitored in streams on an occasional basis using the methods of the Maryland Biological Stream Survey (MBSS – Klauda et al. 1998, Southerland et al 2007). The Fish Index of Biological Integrity was calculated for Youngs Branch using fish community data collected in 2004 and 2010. In both years fish communities were given a rating of Poor (2.67 on a scale of 1 to 5) indicating that these communities have been impacted by anthropogenic stressors. The Benthic Index of Biological Integrity assesses communities of macroinvertebrates. Youngs Branch was rated as Very Poor (1.25 on a scale of 1 to 5) in 2004 and Fair (3.0) in 2010, again indicating anthropogenic impacts.

Water Quality Assessments

On its own, water quality data can be difficult to interpret. A common way of putting the data in context is to compare measurements with threshold values that indicate a desirable range for various characteristics. These threshold values can be developed to meet a variety of needs, such as ensuring safe drinking water, or providing acceptable conditions for aquatic life.

Unfortunately, there is no single set of water quality assessments that covers all of the water quality characteristics monitored by the NCRN. In order to assess all monitored characteristics, the NCRN uses a variety of water threshold values from state and federal agencies as well as from scientific literature. While all of the threshold values are meant to assess the ecological health of the streams, values from the State of Virginia are the water quality criteria established by law for non-tidal waters. Table 2 lists the threshold values for Youngs Branch. In some cases, there is more than one assessment value for a single water quality characteristic. This reflects that fact that aquatic species may differ in their tolerance for poor water quality.

Table 2. Water quality threshold values used in this report.

Characteristic	Threshold Value	Source	State Criteria	Purpose
ANC	>200 µeq/l	Kaufmann et al. 1988	No	Susceptibility of freshwater bodies to acidification.
Discharge	>0 cfs	Virginia Administrative Code. 2020a. 9VAC25-260-40.	Yes	Human alterations to streamflow should not negatively impact the protection and propagation of aquatic life.
Dissolved Oxygen concentration (DO)	>5.0 mg/l daily average	Virginia Administrative Code. 2020b. 9VAC25-260-50.	Yes	Assessment of nontidal coastal and piedmont natural waters for impairment by humans.
Total Nitrogen	< 1.3 mg/L	Morgan et al. 2007.	No	Impact of water quality on aquatic macroinvertebrates.
Total Nitrogen	< 0.69 mg/L	EPA 2000.	No	Assessment of anthropogenic eutrophication for nutrient ecoregion IX.
pH	Between 6.0 and 9.0	Virginia Administrative Code. 2020b. 9VAC25-260-50.	Yes	Indication of impairment by humans for nontidal coastal and piedmont natural waters.
Total Phosphorus	< 0.043 mg/L	Morgan et al. 2007.	No	Impact of water quality on aquatic macroinvertebrates.
Total Phosphorus	< 0.037 mg/L	EPA 2000.	No	Assessment of anthropogenic eutrophication for nutrient ecoregion IX.
Salinity	< 0.5 ppt	Odum, 1988.	No	Definition of threshold between fresh and brackish water.
Specific Conductance	< 247 µS/cm	Morgan et al. 2007.	No	Impact of water quality on aquatic macroinvertebrates.
Specific Conductance	< 171 µS/cm	Morgan et al. 2007.	No	Impact of water quality on fish.
Water Temperature	< 32° C	Virginia Administrative Code. 2020b. 9VAC25-260-50.	Yes	Indication of impairment by humans for nontidal coastal and piedmont natural waters.

Methods

Field Sampling

Sampling Effort

Sampling takes place at Youngs Branch near its confluence with Bull Run. Starting in June 2005, sampling took place at the small foot bridge where the First Manassas Trail crosses the stream. This sampling site was chosen to be close to the confluence with Bull Run because that location will show the net impacts of upstream stressors and it coincides with the location of fish and macroinvertebrate sampling. In January 2007, the sampling site was moved approximately 30 meters downstream, below the ford where the dirt access road crosses the river. This was done as the streambed is artificially raised at the ford and was causing pooling upstream at the footbridge. By moving the site below the ford, the pooling was avoided. Unfortunately, the stream widens below the ford, and this frequently led to water levels too low to measure for discharge. Therefore, in October 2012, the site was moved to its current location approximately 100 meters upstream from the foot bridge. This site is narrow enough to allow for consistent discharge readings and far enough upstream from the ford to avoid pooling. Given the short distance between sites, the absence of tributaries entering Youngs Branch in this area and the similarity in surrounding vegetation, we believe that parameters other than discharge will be unaffected by differences in the exact site sampled. Data that was taken during pooling events was not used in analysis as many water quality characteristics showed anomalous values. Graphical exploratory analysis did not reveal any other changes concurrent with changes in sampling location.

Starting in October 2005, sampling took place monthly. In 2014 sampling was pared back to 8 months/year (sampling in Jan, March, April, July, Aug, Oct, and Dec) and in 2018 was further reduced to 6 months/year (sampling in Feb, April, June, Aug, Oct, Dec). However, there is some variation in these schedules based on factors such as equipment failures, extreme weather, and crew availability.

Sampling Techniques

Sampling follows the procedures described in the NCRN Water Monitoring Protocol (see Norris et al., 2011 for full details). In general, all measurements and samples are taken during each field visit. Discharge, along with stream width, depth and flow were measured using a SonTek FlowTracker. The number of water chemistry measurements (excluding ANC) taken during a single visit varies with stream width. One set of measurements is taken for every 10ft (or fraction thereof) of stream width – spaced out across the stream.

Water temperature, dissolved oxygen, pH, salinity, and specific conductance were measured using handheld sondes. Originally measurements were taken with a YSI 100 (pH, water temperature) and a YSI 85 (DO, SC, salinity). In 2007 the YSI 100 was replaced with a YSI 63. Starting in April of 2009, all measurements were taken using a YSI ProPlus, which in turn was replaced with a YSI ProDSS in January 2018. Other than the YSI ProPlus, the instruments were each in use for a short period of time. Given the high degree of variability in the data, including variation driven by seasonality and discharge levels, we cannot do a reliable statistical analysis to determine any effect of

shifting instruments on the data. Graphs of the data do not reveal any large shifts in values corresponding to changes in instrumentation. For the purposes of this report these instruments are considered to be interchangeable, and no attempt is made to statistically distinguish them.

Water grab samples for ANC, Total N, and Total P were collected on site. Each of these characteristics is measured from a single sample regardless of stream width. Starting in 2005, ANC was determined in an NPS laboratory using phenolphthalein and sulfuric acid titration (Hach, 2018). Since October 2018, ANC was measured using the USGS alkalinity and acid neutralizing capacity procedures, inflection point method (Rounds, 2012). The inflection point method was chosen as it was less subjective and more precise than the titration method. Data from both methods are considered to be interchangeable in these analyses. Samples for nutrient analysis were sent to the University of Maryland Chesapeake Biological Laboratory, beginning in October 2016. Total N was determined using method EPA 353.2 (EPA, 1993a). Total P was determined using method EPA 365.1 (EPA, 1993b). In addition to regular samples, duplicate quality control samples are collected during each sampling month from four of the streams monitored by the NCRN. No quality control problems were uncovered, and QC samples are not included in the data analyzed for this report.

Statistical Analysis

Regression analysis were used to characterize seasonality and long-term trends in water quality. We originally anticipated using generalized linear models to model linear relationships in the data. However, after some initial modeling, it soon became evident that there were several drawbacks to this approach. Several relationships in the data, particularly the relationship between discharge and season, were clearly non-linear and resulted in poor model fits.

We decided that a better modeling approach was to use Generalized Additive Modeling (GAM, Wood, 2017), following methods discussed in the NCRN statistical analysis SOP for water quality. Unlike more traditional regression techniques, GAMs can fit highly non-linear models. The tradeoff is that GAMs have a much more limited ability to predict values outside the scope of the data, such values in future years or when discharge is above previously observed values. Initial explorations of the data showed that conditions of some water quality characteristics (e.g. DO, discharge) were of management concern, whereas the few long-term trends were not concerning. Therefore, we felt that GAM's more accurate modeling of past data made it the better analysis framework. Statistical analyses were carried out using R 3.6.2 (R Core Team 2019) and the mgcv package, version 1.8-31(Wood, 2011).

The analyses considered up to four possible influences on water quality. For all characteristics (ANC, Discharge, DO, pH, SC, salinity, Total N, Total P, and water temperature), modeling investigated relationships between water quality, seasonality, and long-term trends over the entire data set. For characteristics other than discharge and water temperature, modeling also examined relationships between water quality, water temperature and discharge. The following models were fit using GAMs:

- 1) $\text{Measurement} \sim 1$
- 2) $\text{Measurement} \sim 1 + s(\text{Seasonality})$

- 3) $\text{Measurement} \sim 1 + s(\text{Water Temperature})$
- 4) $\text{Measurement} \sim 1 + s(\text{Discharge})$
- 5) $\text{Measurement} \sim 1 + s(\text{Trend})$
- 6) $\text{Measurement} \sim 1 + s(\text{Trend}) + s(\text{Seasonality})$
- 7) $\text{Measurement} \sim 1 + s(\text{Trend}) + s(\text{Water Temperature})$
- 8) $\text{Measurement} \sim 1 + s(\text{Trend}) + s(\text{Discharge})$

Model 1 serves as a null model. Models 2 through 4 fit a model with no long-term trends. The use of “s()” in the formulas indicates that models fit a thin spline smoothing function rather than a strictly linear function. Models 5 through 8 add a smoothed long-term trend to the first four models. None of the models include both water temperature and discharge or either of these combined with seasonality. Water temperature and discharge both show strong seasonal patterns (see Results below). Initial modeling revealed that using both of these as predictors or combining either with a separate seasonal effect in a single model lead to overfitted models with little practical improvement over the 8 models listed above.

Seasonality was modeled by first using trigonometric basis functions to convert day of year (e.g. Jan 1st = 1, Feb 1st = 29) to sine and cosine components (Cohn et al 1992, Meals et al. 2011). These were then fit together using a single thin plate smoothing function in the GAM model. The trend term was modeled by adding the fractional day of year to the year a measurement was taken (e.g. April 18, 2006 = 2006.296) and then centering.

Models were fit with a gamma error function and a log link, as the water quality data is continuous and non-negative. Initially we intended to use generalized cross validation to determine the number of knots used in smoothing. However, initial models often appeared to be overfit with small deviations that may have been the result of unusual values and/or the irregular sampling schedule. In order to prevent overfitting, smooth terms for trend, discharge and water temperature were limited to at most 5 knots, and smooths for seasonality were limited to at most 4 knots. Visual inspections showed that limiting the number of knots did not change the overall patterns in the model fits but did eliminate potential artifacts. Once the final model was selected (see below) residuals were visually assessed to ensure that there was no evidence of patterns or systematic error in the model.

Models were then compared using the corrected Akaike’s information criterion (AICc, Akaike 1974, Burnham and Anderson 2004). Model selection then followed the suggestions of Arnold (2010). The model with the lowest AICc score was considered the preferred model, so long as it was at least 2 AICc units lower than any other model. In instances where two or more models were within 2 units of the lowest AICc, then the most parsimonious of those models was preferred, as adding a single non-informative parameter to a model will result in a gain of <2 in AICc values. In a few cases, estimated degrees of freedom of the predictors were ≈ 1 (or ≈ 2 for the seasonality term), indicating the most parsimonious model was essentially linear. When this occurred, the final model was refit using a generalized linear model using the base R glm function with the same predictors and error function. In some cases, the final model has a percent deviance explained 40%, and plotting indicates

that those models did not illustrate any pattern in the underlying data. In these instances, no model is presented. AICc tables and final models are found in Appendix I.

Due to inconsistencies in measuring discharge in the first two locations, models were initially fit using only data from the sampling site upstream from the bridge. In cases where the preferred model did not include discharge, the models without discharge were excluded and the remaining models were refit on the entire data set, prior to final model selection.

Initial modelling examined if it was useful to retain all the measurements and use sample data as a random effect for characteristics with multiple measurements per visit. In most cases, the measurements taken on a single day were identical or nearly so, and variation within a day was always much less than variation between days. Adding random effects did not change results of the modeling so it was omitted in the final models. In cases where there were multiple measurements in a single day, the average measurement was used in modeling. Similarly, the use of an autocorrelation term in the models were ruled out. Due to changes in sampling schedules, drying and freezing of the streams, equipment issues, and other factors, the samples were taken at an irregular schedule. An autocorrelation term in the form of a continuous AR1 correlation structure based on date was added to initial models but provided no improvements. Residuals were also checked to ensure there was no autocorrelation, however, given the irregular sampling schedule this would be difficult to detect from residuals alone.

Water Temperature

Water temperature was modeled in a similar fashion, but only models 1,2,5 and 6 were used. Unlike the other water quality characteristics, water temperature can be slightly below zero, when solutes in the water prevent freezing. This makes a gamma error structure unsuitable for this data, so a gaussian error function was used instead.

Discharge

Analysis of discharge was complicated by the fact that Youngs Branch went dry several times since monitoring began. To account for this, two types of analysis were performed. The first focused on determining trends and seasonality in stream drying. This analysis used data from all sample locations on the assumption that they are close enough together that if the stream is dry at one location, it will be dry at all others as well. Models 1, 2, 5 and 6 were run with stream condition (0 = dry and 1= flowing) as the response variable. A binomial error structure with a logit link was used in the GAM.

The second analysis focused on discharge when the stream was flowing. Due to difficulties measuring the discharge at the foot bridge and ford locations, only the data upstream from the foot bridge was used. On three occasions (Sept-2014, Oct-2016 and Oct-2017) the stream had discharge, but water levels were too low to take a reading. Discharge as low as 0.2 cfs has been successfully measured, and the FlowTracker measures discharge to the nearest 0.1cfs, therefore the discharge on these days were estimated to be 0.1cfs. Models 1, 2, 5, and 6 were fit, using a gamma error structure and a log link.

Results

Discharge

Discharge in Youngs Branch varied from 0 to 23.3 cubic feet per second (cfs – Figure 3) with a median of 2.2 cfs. The stream was dry approximately 5% of the time. While there are no quantitative state water quality criteria for discharge, this stream is generally considered to be perennial; a lack of discharge is a concern.

Given the proximity of the three sites, it is unlikely that discharge is changing between them. The sites do have different stream widths, which can affect our discharge measurements as wider portions of the stream are shallower, and we cannot measure discharge in streams less than ~0.2 feet deep. The site upstream from the foot bridge, which has been monitored since October 2012 is the narrowest site and consequently has the most consistent discharge data.

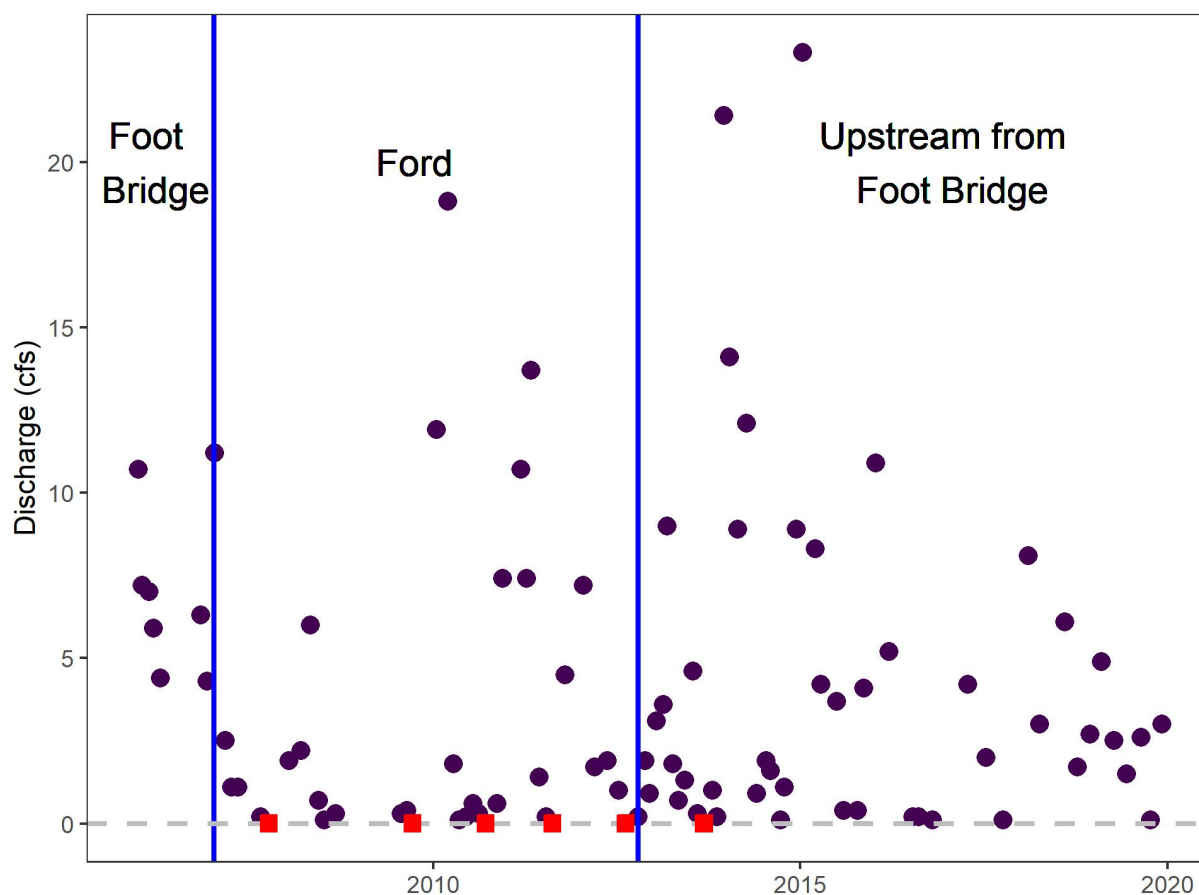


Figure 3. Discharge (cfs) in Youngs Branch. “Foot Bridge”, “Ford” and “Upstream from Foot Bridge” are the three sampling locations used during monitoring. Light grey horizontal line and red squares indicate when the stream is dry (0 cfs).

Seasonal Drying

Drying in Youngs Branch is a seasonal phenomenon. The stream had been dry during visits that occurred between August and October (Figure 4). Statistical modeling indicates that the probability of the stream being dry peaks at ~50% in September (Appendix I). However, there is considerable uncertainty in the probability of drying during the fall. There was no evidence that drying has become more or less likely over the years we have been monitoring. Although the stream is not flowing during drying events, there may be persistent pools of water that act as refuges for aquatic life.

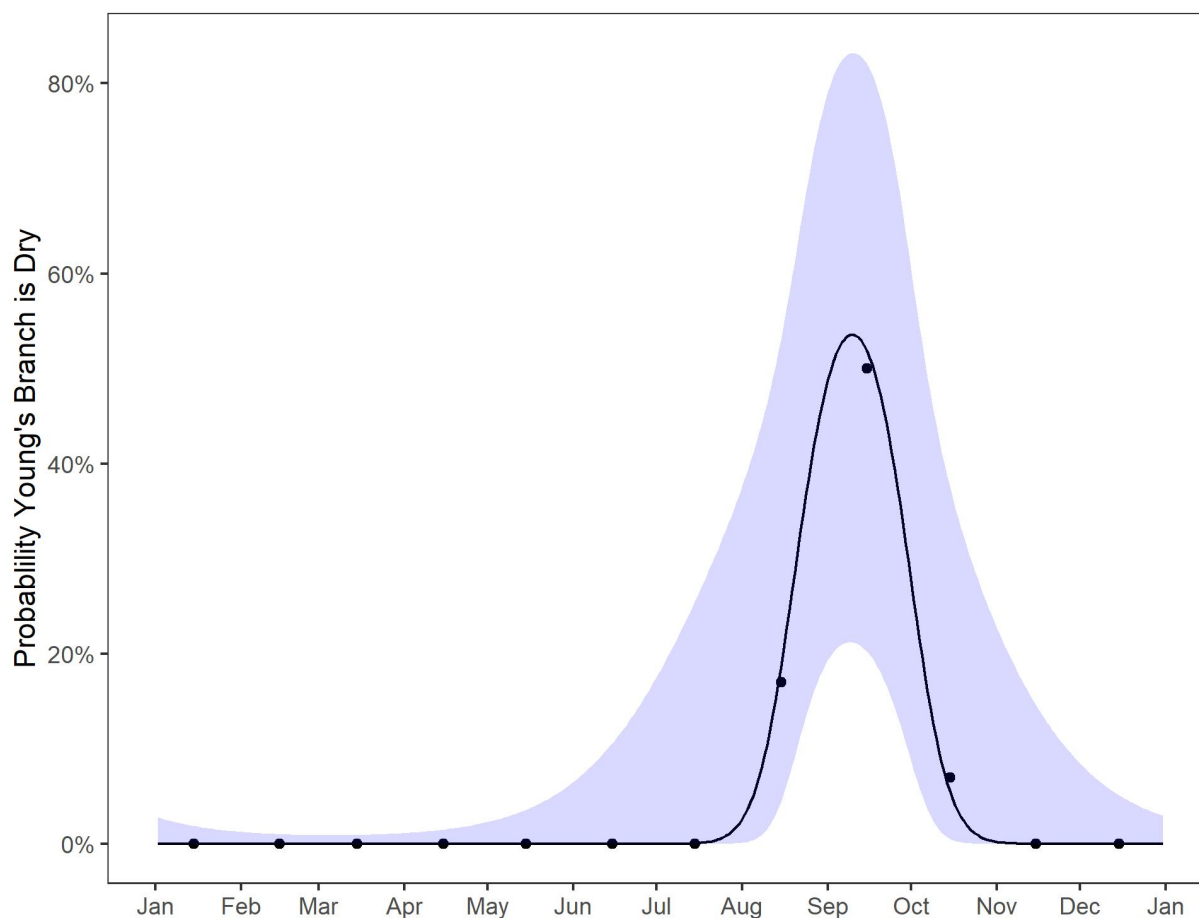


Figure 4. Probability that Youngs Branch is dry, modeled on data from all three sites. Solid line = estimated probability, black circles = observed % drying during each month, shaded area = 95% confidence interval (CI). Drying occurs between August and October, and peaks at ~ 50% probability in September.

Volume of Discharge

Based on the data collected upstream from the footbridge, the preferred model shows a significant seasonal cycle in discharge, but no long-term trend. (Appendix I). The seasonal cycle starts with relatively high levels of discharge in January that slowly decline until reaching a low in August –

October, consistent with the seasonal drying of the stream (Figure 5). Discharge then rapidly climbs during the late fall, until once again reaching highs in January.

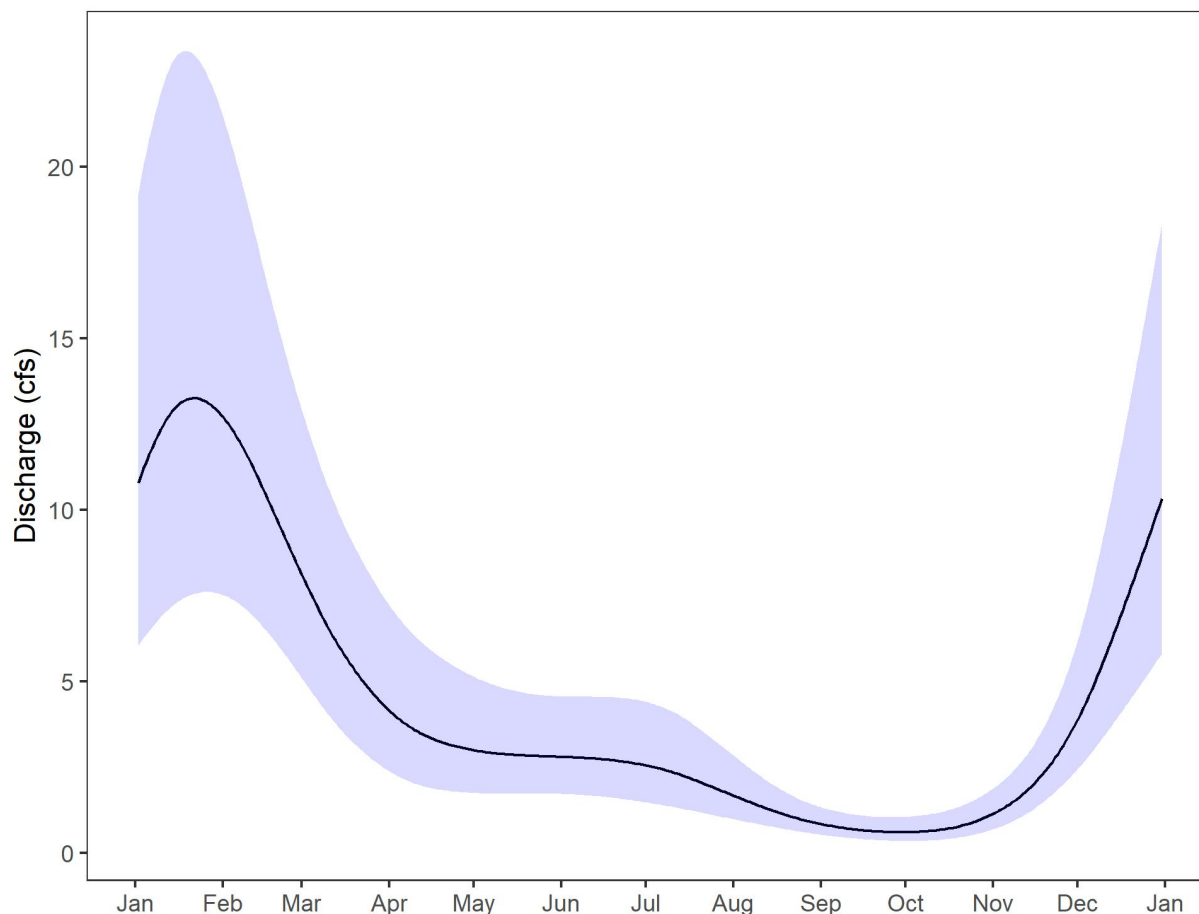


Figure 5. Seasonal cycle of discharge. Solid line = estimated discharge, shaded area = 95% CI.

Discharge can be estimated for the entire data series using the seasonal model (Figure 6). While the estimates match the general pattern of discharge, there are many outliers not accounted for by the model (model deviance explained = 47%). An obvious explanation for these outliers is that the model does not include any direct measure of precipitation, but instead uses the date as a proxy for precipitation and evapotranspiration patterns. Measurements taken immediately after a significant amount of precipitation will temporarily have a much higher discharge than the model predicts as runoff from the rainwater flows through the stream. Similarly, measurements taken during unusually long dry periods will have lower discharge than predicted. Despite this, the data does generally display the seasonal pattern predicted by the model. The model also correctly indicates that the discharge is more variable during the first half of the year, when discharge is high.

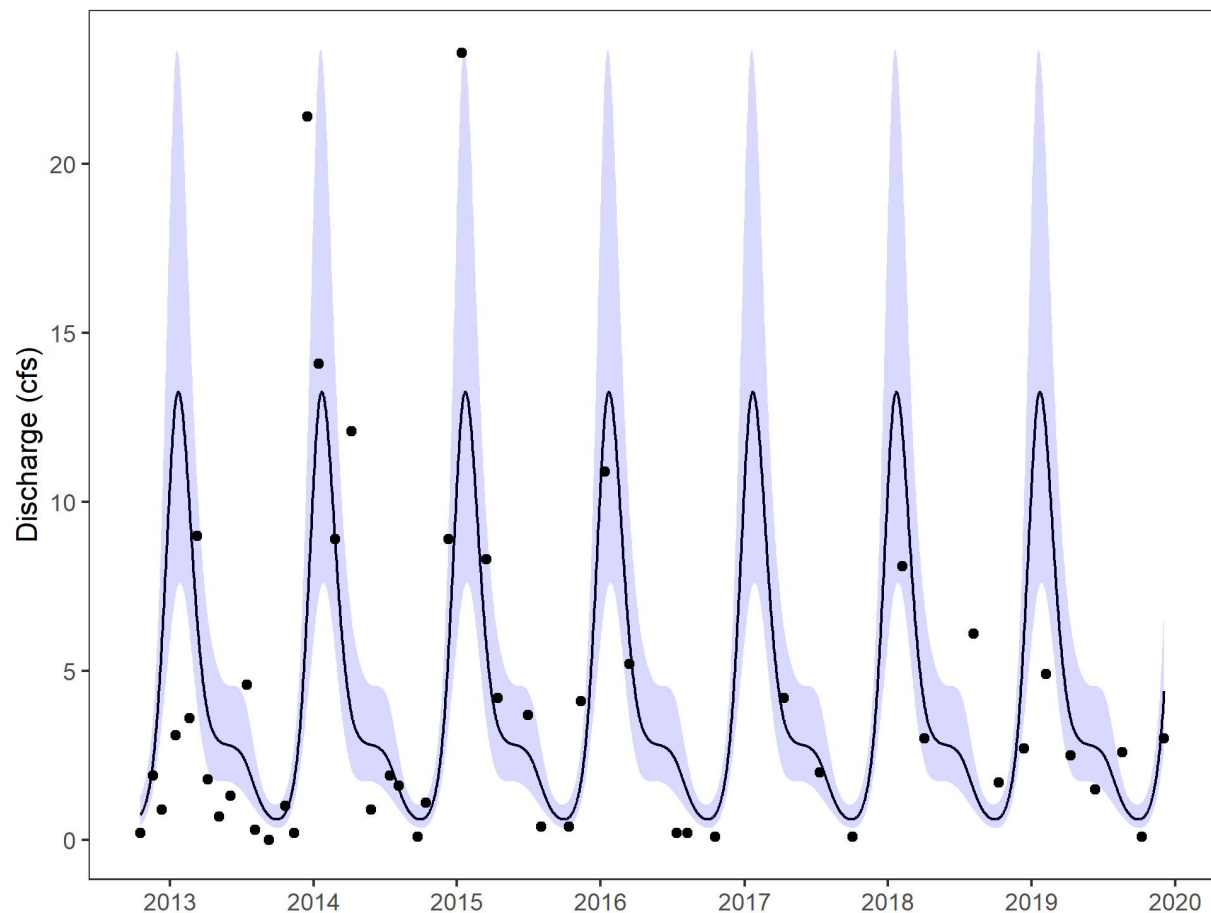


Figure 6. Discharge (cfs), 2013–2019. Points = measured discharge, black line = model predictions based on seasonal model, shaded area = 95% CI.

Water Temperature

Water temperature in Youngs Branch varied from 0.1 to 24.5 °C on a seasonal basis (Figure 7). Data could not be taken on two occasions due to freezing of the stream. As this represents less than 2% of the data, it was excluded from further analysis.

Modeling indicated that unlike discharge, the seasonal variation in stream temperature is symmetrical. Water temperature peaks around mid-July and hits a low point in mid-January. Temperatures typically range from a high of 23 °C to a low of 3 °C, but during extreme weather temperature can fall outside that range. There was no evidence for a trend in water temperature.

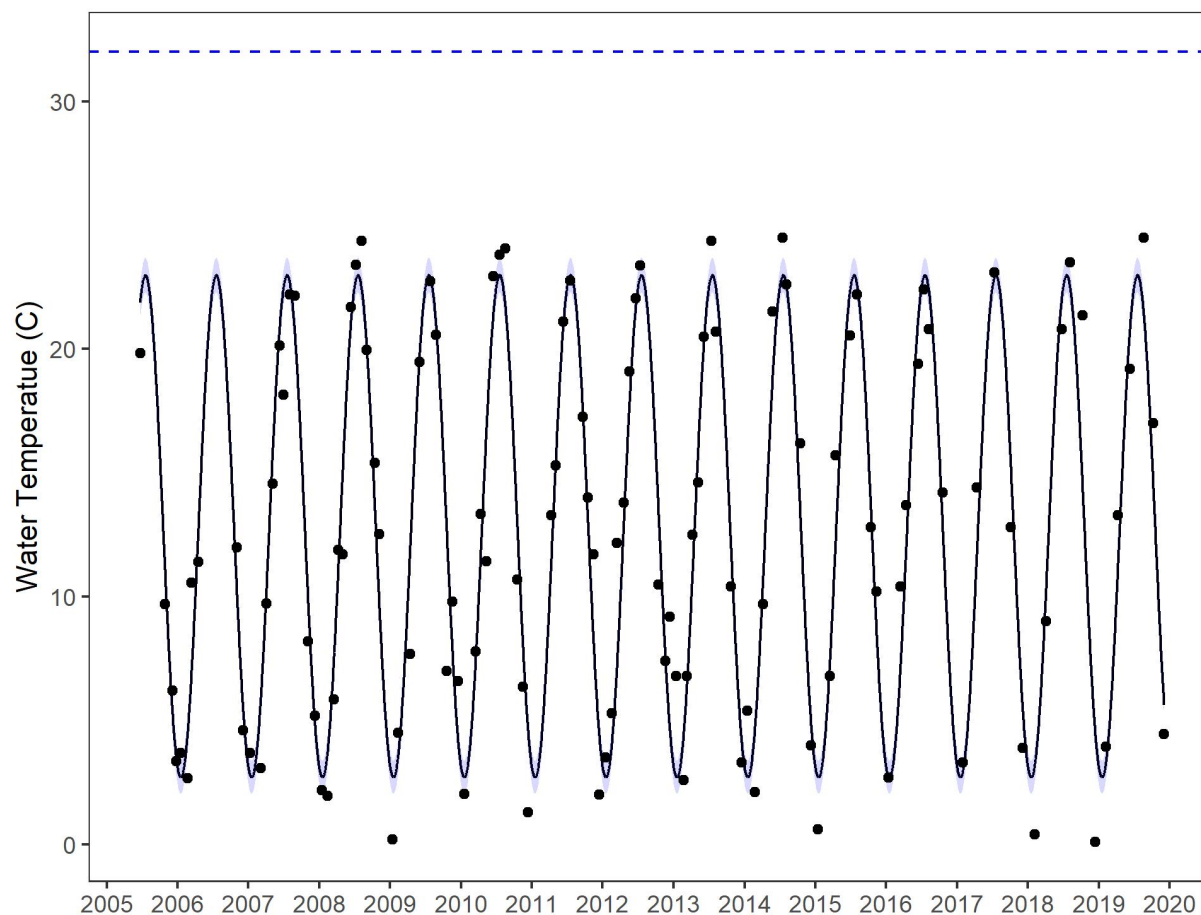


Figure 7. Water temperature (°C) 2005–2019. Points = measured temperature in °C, horizontal blue dashed line indicates the 32°C threshold value, black line = predictions from model, shaded area = 95% CI.

Given the length of time between samples, it is inevitable that on some days water temperatures exceed those measured here. Furthermore, the monitoring locations have been in areas with some canopy cover, and more exposed locations would have higher temperatures. That said, the measured temperatures are well below the 32° threshold value, it is unlikely that there are widespread issues with excessive water temperature.

Dissolved Oxygen

Dissolved oxygen (DO) concentration varied between 3.1 and 15 mg/l, with a mean of 8.9 mg/l. DO concentration is negatively correlated with water temperature (Figure 8). On nine occasions (8.6% of all measurements) DO fell below the 5.0 mg threshold value. When water temperature exceeds 17°C, DO concentrations can fall below the 5.0 mg/l acceptable threshold, but they do not always do so.

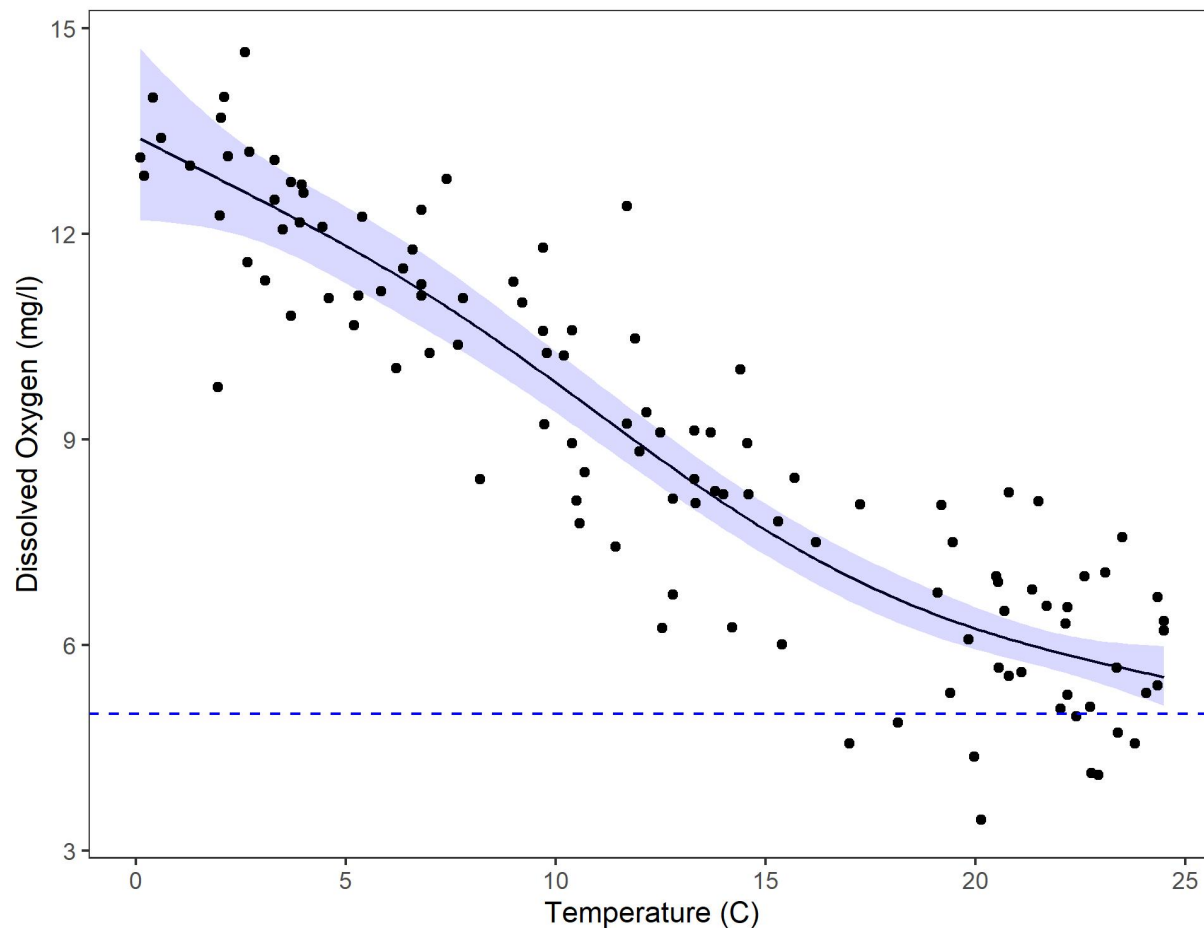


Figure 8. Dissolved oxygen (mg/l) vs water temperature (°C). Points = measured data, blue dashed line = 5.0 mg/l threshold value, black line = modeled relationship between DO and water temperature, shaded area = 95% CI. Note: this figure does not take into account the long-term trend in DO concentrations.

Modeling indicates that DO concentrations showed a significant relationship with water temperature and a long-term trend (Appendix I). Water temperature has a nearly linear relationship with DO, with slight leveling off at the hottest and coldest temperatures (Figure 8.). DO is only estimated to approach the 5.0 mg/l water quality threshold at the highest water temperatures.

The model detected a small non-linear trend in DO over time (Figure 9.). From 2005 until approximately 2019, there was an increase of about 0.5 mg/l in DO concentration. After 2015, DO concentrations increased, but slightly less rapidly. It is surprising that DO concentration increased without a corresponding change in water temperatures. It is unclear what caused that increase.

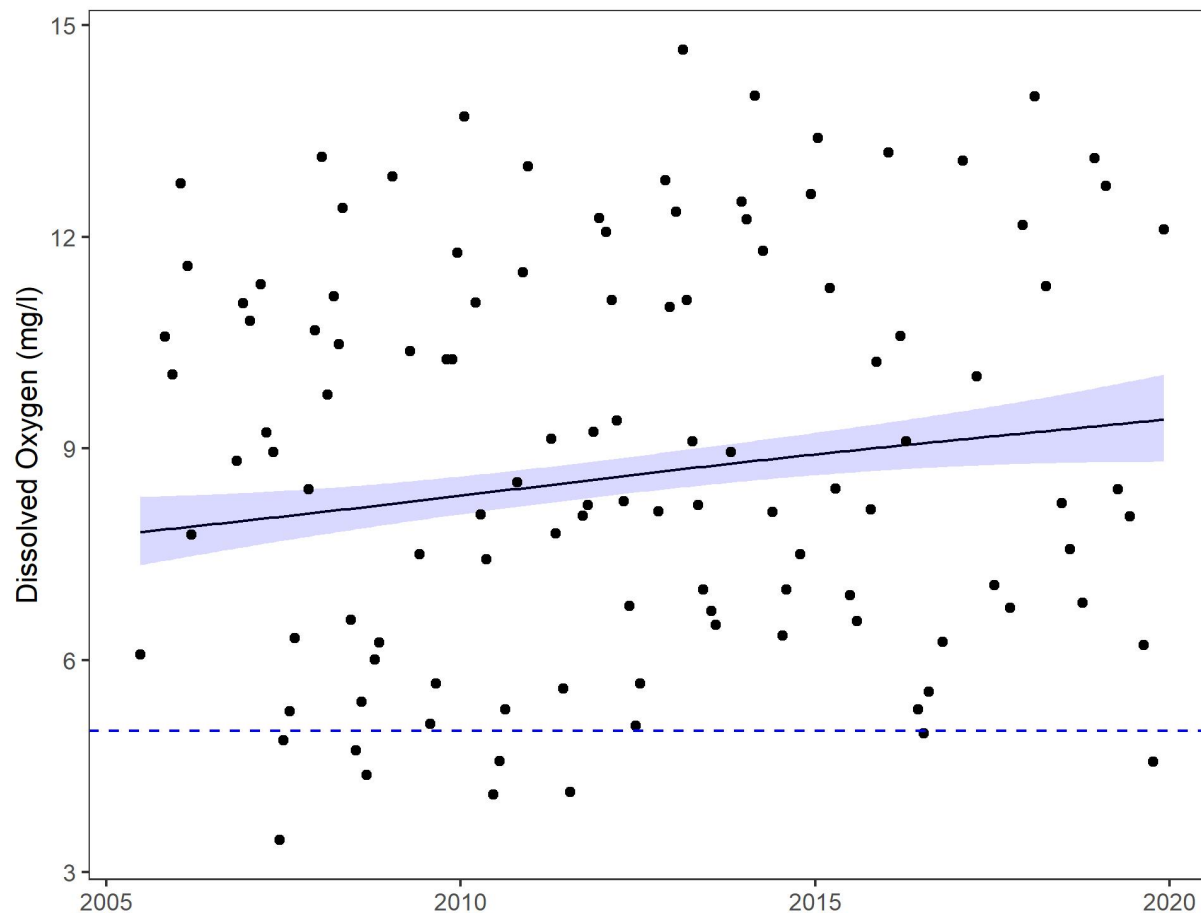


Figure 9. Dissolved oxygen (mg/l) vs date. Points = measured data, blue dashed line = 5mg/l threshold value, black line = modeled relationship between DO and Date, shaded area = 95% CI. Note: this figure does not take into account the relationship between temperature and DO concentrations.

Figure 10 compares the model estimates to the data. As expected, there is a strong seasonal pattern in DO, with maximum concentrations occurring in February and minimums in July. Early in the monitoring period, DO concentrations routinely fell below the 5.0 mg/l threshold value in the summer months. As DO concentrations increased, concentrations below 5.0 mg/l became less common.

Despite the increasing trend, low DO is likely a persistent problem in this stream. Water temperatures in excess of 17°C are quite common (Figure 7). In any given year we are unlikely to have monitored on the hottest day, so we are also unlikely to have measured the lowest DO concentrations.

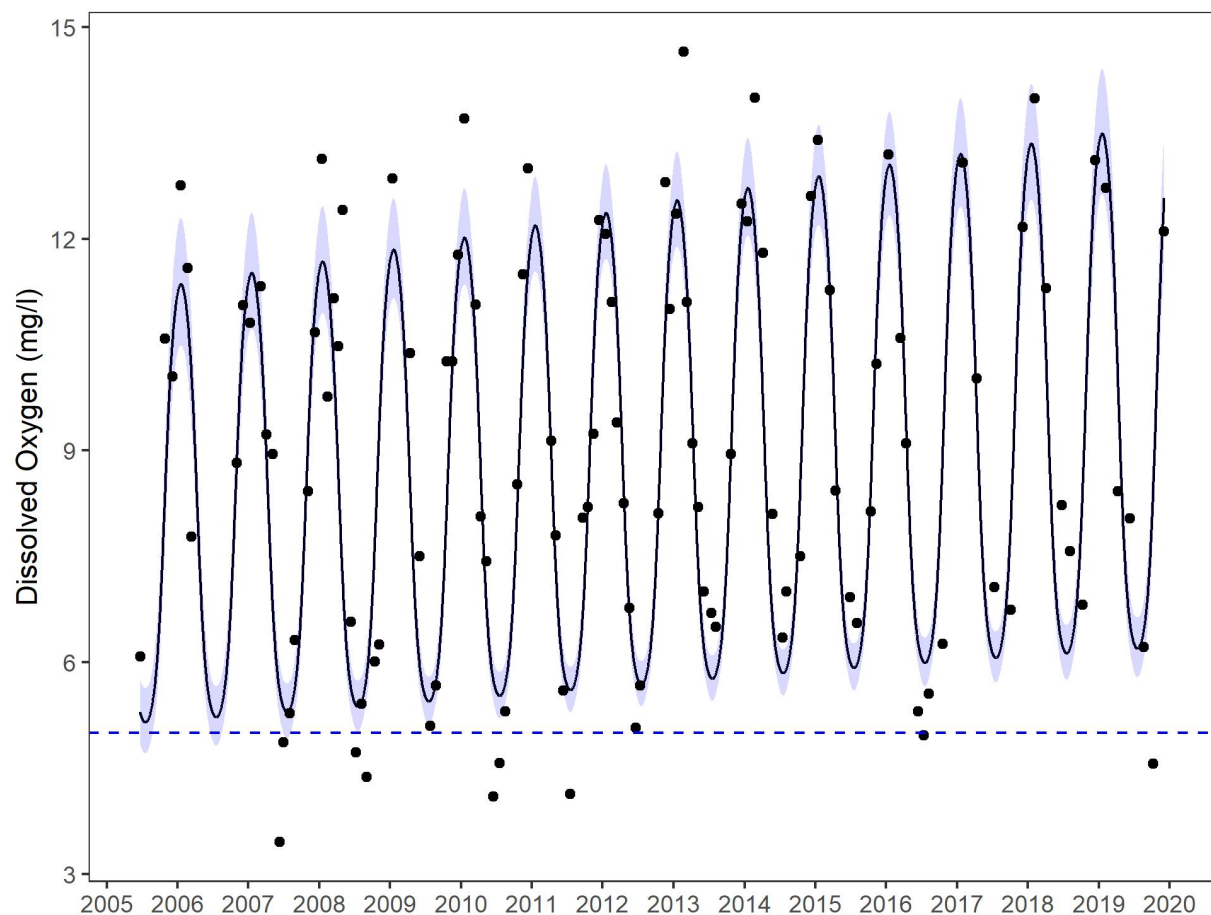


Figure 10. Dissolved oxygen (mg/l) 2005–2019. Points = measured dissolved oxygen concentration in mg/l, horizontal blue dashed line = 5.0 mg/l threshold value, black line = predictions from model, shaded area = 95% CI.

pH

pH varied between 7.01 and 8.13 with a mean of 7.61 (Figure 11). None of the measurements were outside of the acceptable range between 6.0 and 9.0.

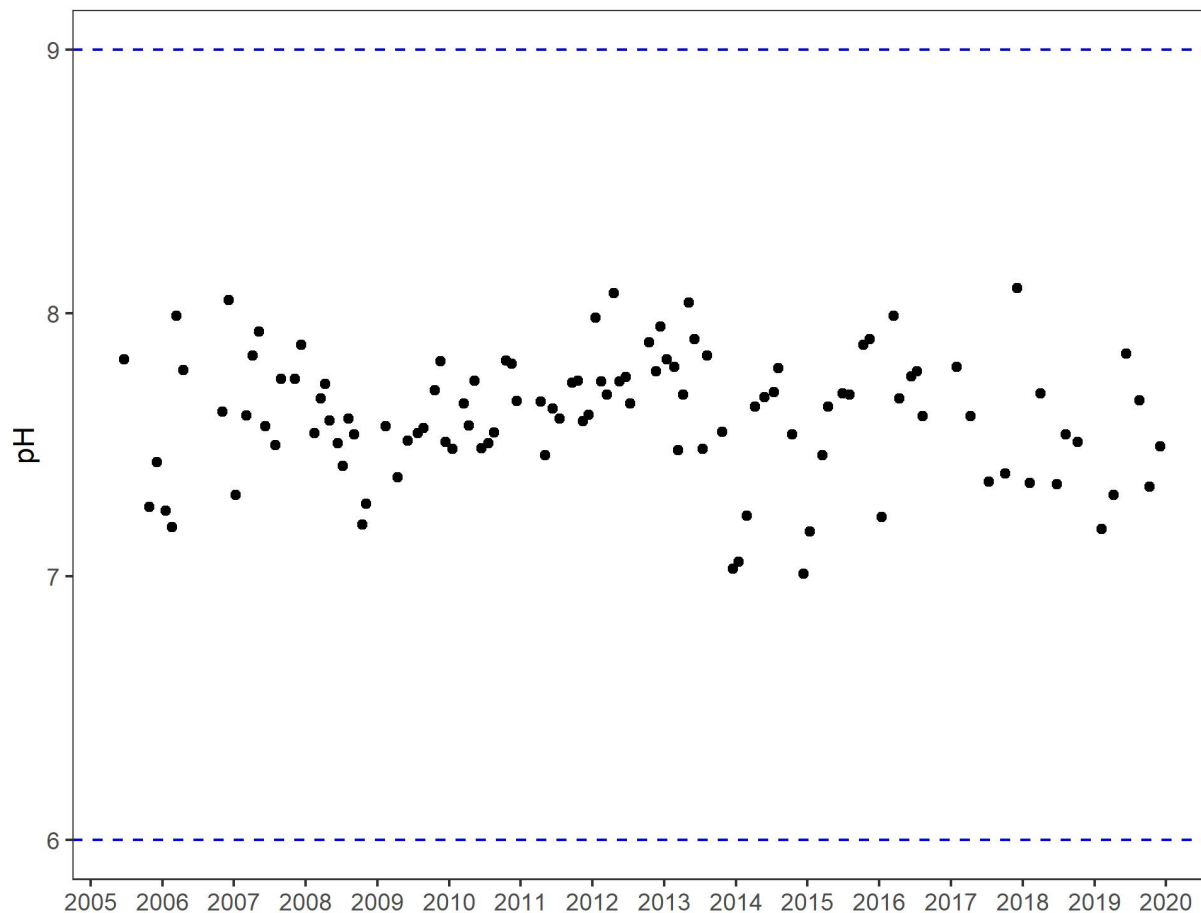


Figure 11. pH 2005–2019. Black points = measured pH, horizontal blue dashed line = 6.0 and 9.0 threshold values.

Modeling found no evidence of a seasonal cycle but did find evidence that pH is affected by the amount of discharge in the stream and shows a slight decreasing trend over time (Appendix I). Focusing solely on the relationship of discharge to pH (Figure 12), higher discharge leads to a lower pH. This relationship is most evident when discharge > 5cfs. When discharge < 5cfs, pH can vary considerably, but does not drop below 7.3. During high discharge events, pH can drop to nearly 7.0. According to maps available from the National Atmospheric Deposition Program (NADP) the pH of rainwater near Manassas has gradually increased from about 4.7 to about 5.3 (<http://nadp.slh.wisc.edu/ntn/annualmapsByYear.aspx>) over the course of the monitoring. It is likely that heavy precipitation events are both driving up discharge and driving down pH.

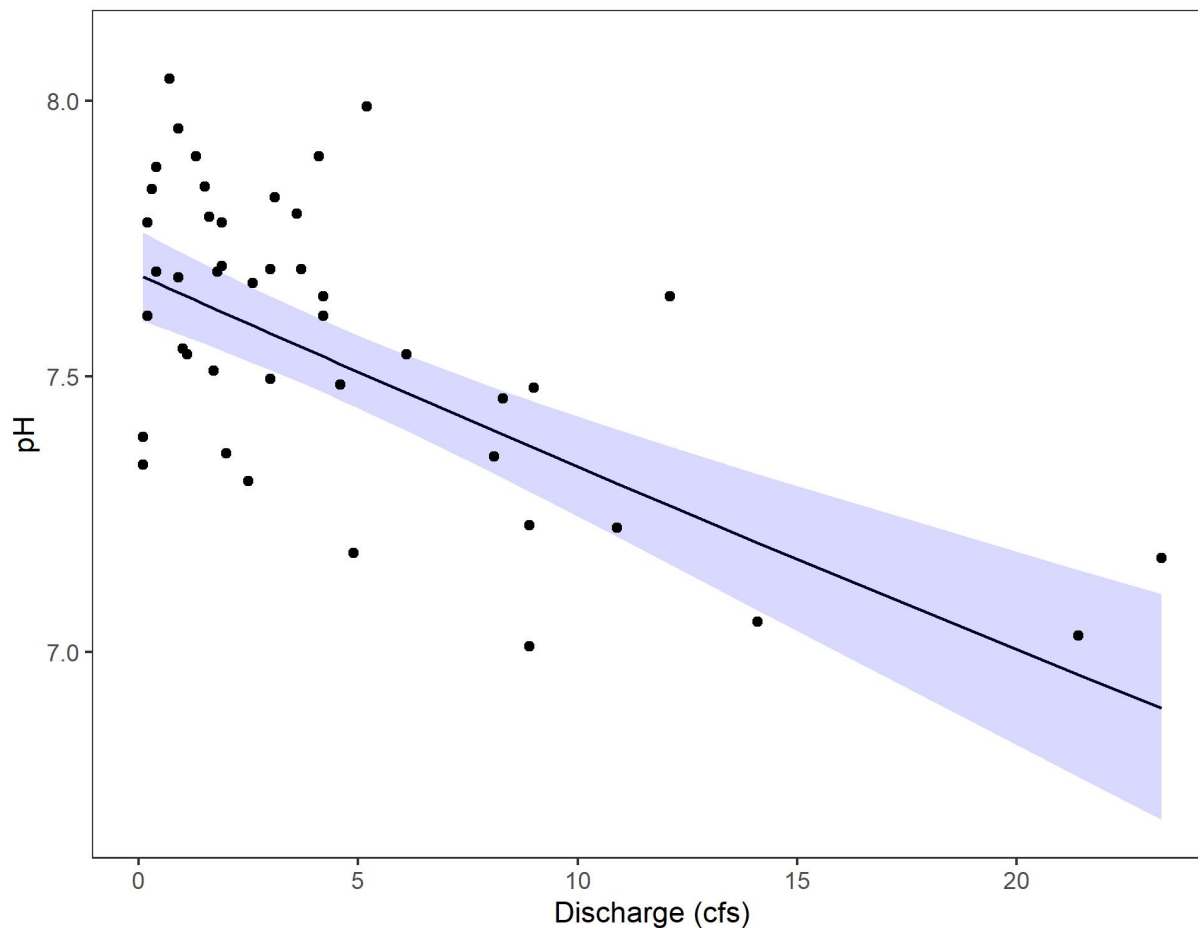


Figure 12. pH vs Discharge. Black circles = observed data, black line = estimate relationship between pH and discharge, shaded area = 95% CI. Note: this figure does not take into account the long-term trend in pH.

The model was used to estimate pH from 2013 onward (Figure 13). To do this, the pH model required a daily estimate of discharge, which was obtained from the model of discharge discussed above. The 95% CI displayed in Figure 13 accounts for uncertainty in the pH model but does not take into account underlying uncertainty in discharge estimates.

The model correctly illustrates that dips in pH occur at the beginning of the calendar year when discharge is greatest. The model is much less capable of predicting pH during the warmer months when discharge is lower.

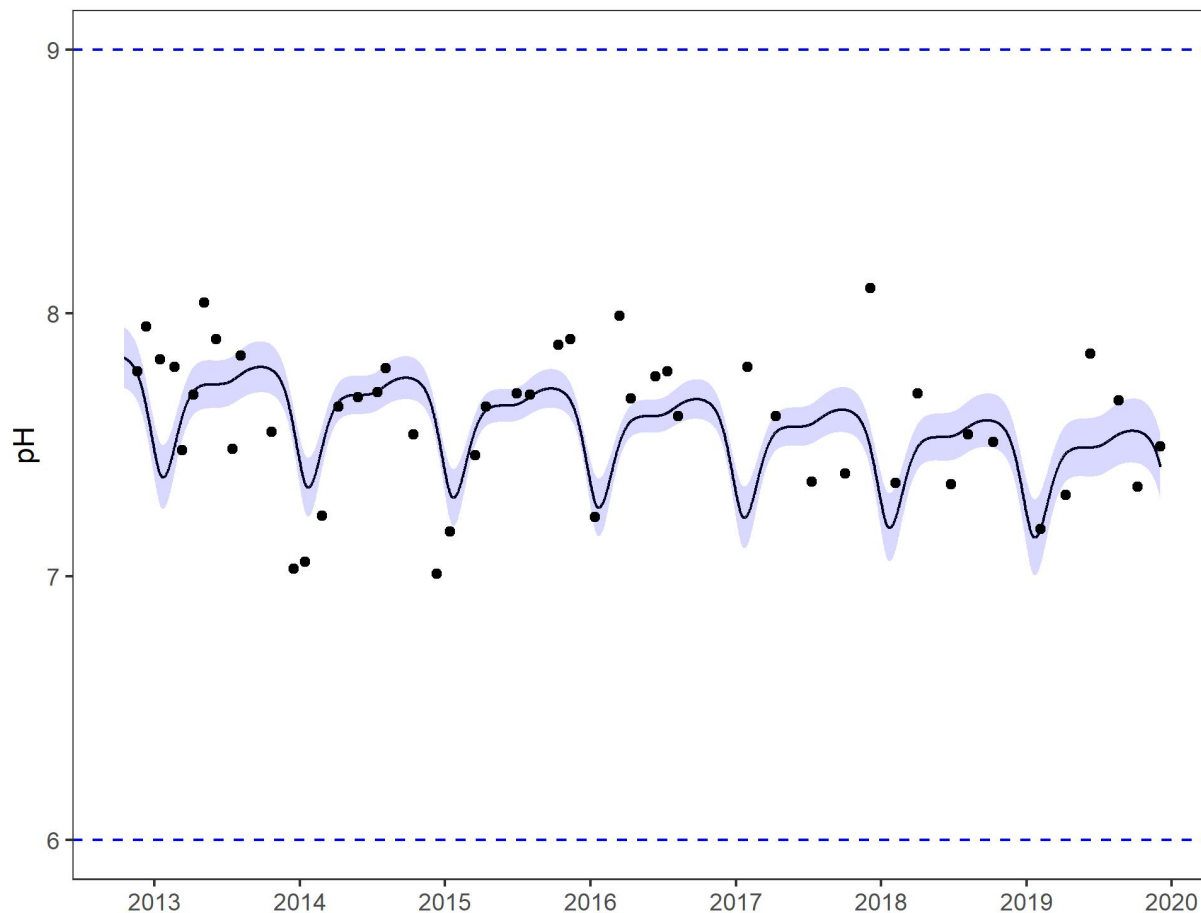


Figure 13. pH 2013–2019. Points = measured pH, horizontal blue dashed lines = 6.0 and 9.0 water threshold values, black line = predictions from model, shaded area = 95% CI.

Given that rainwater has a lower pH than Youngs Branch, it is likely that some of the unexplained variation in pH relates to the amount of time that has passed since the last rainstorm. Since 2013, the model estimates that pH had dropped ~0.3 units, even though rainwater has become slightly less acidic over time.

Specific Conductance and Salinity

Specific conductance (SC) and salinity are two closely related measurements of the concentration and type of solutes in stream water. In principle these are distinct measurements, SC being a measure of electrical conductivity under standard conditions and salinity a measure of salt concentrations. In practice, however, these values are calculated by the YSI instruments based on the temperature and conductivity of the stream. As a result, any trend or pattern in one of these characteristics will be mirrored by an identical trend or pattern in the other.

Specific conductance

Specific conductance varied between 232.6 and 1348.5 $\mu\text{S}/\text{cm}$ with a mean of 480.1 $\mu\text{S}/\text{cm}$ (Figure 14). All the measurements were too high to be acceptable for fish communities (171 $\mu\text{S}/\text{cm}$)

and almost all were too high to be acceptable macroinvertebrate communities ($247 \mu\text{S}/\text{cm}$). There was a notable spike in SC during the winter of 2007–2008, which is likely due to road salt washing into the stream at the time of monitoring.

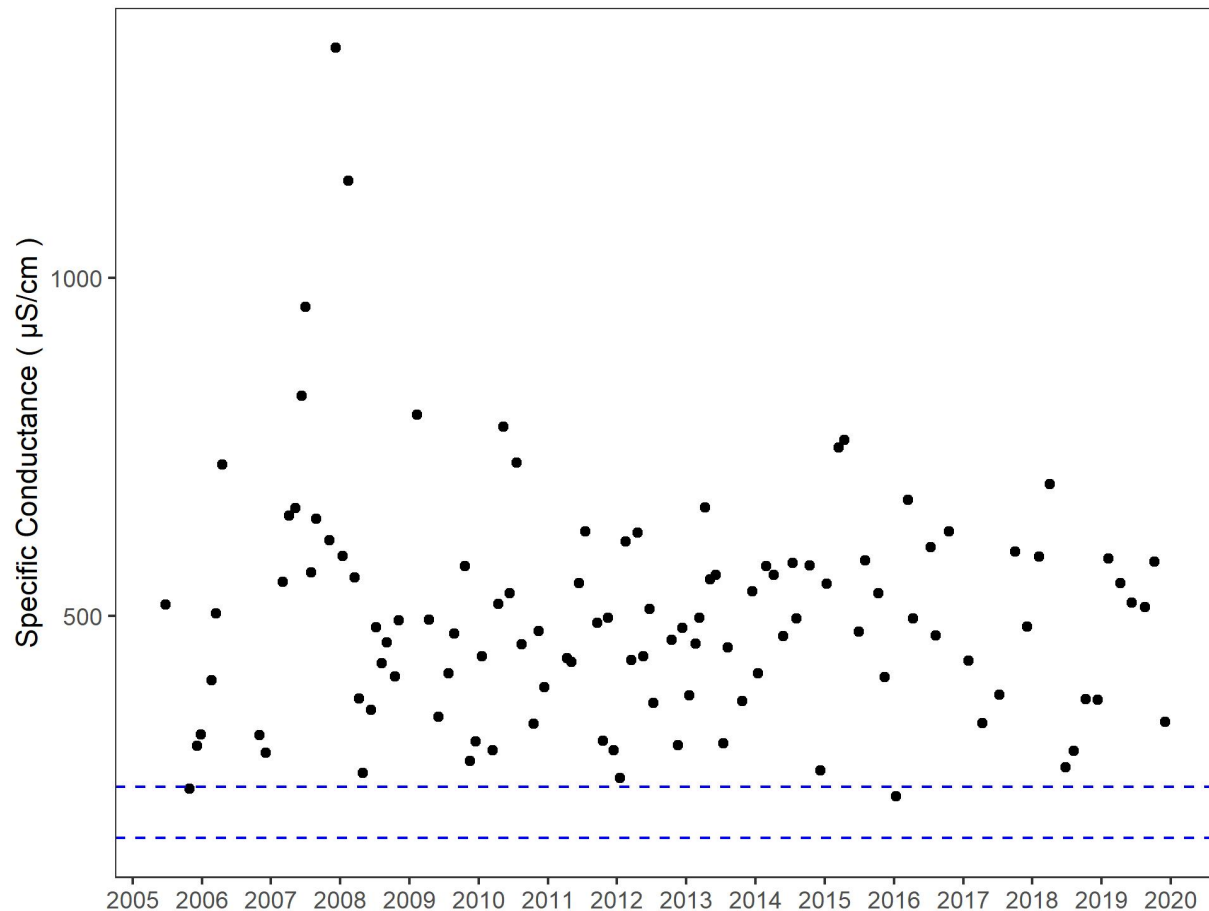


Figure 14. Specific conductance. Black circles = measured values, blue dashed line = threshold values for fish ($171 \mu\text{S}/\text{cm}$) and macroinvertebrates ($247 \mu\text{S}/\text{cm}$).

Trend analysis did not show a consistent trend over time, or a relationship between SC and water temperature or discharge. There is, however, a high degree of variability in SC readings but the drivers for this variation are unknown.

Salinity

Salinity varied between 0.09 and 1.03 ppt with a mean of 0.25 ppt (Figure 15). Almost all the measurements were below 0.5 ppt. There was a notable spike in salinity during the winter of 2007–2008, which is likely due to road salt washing into the stream at the time of monitoring.

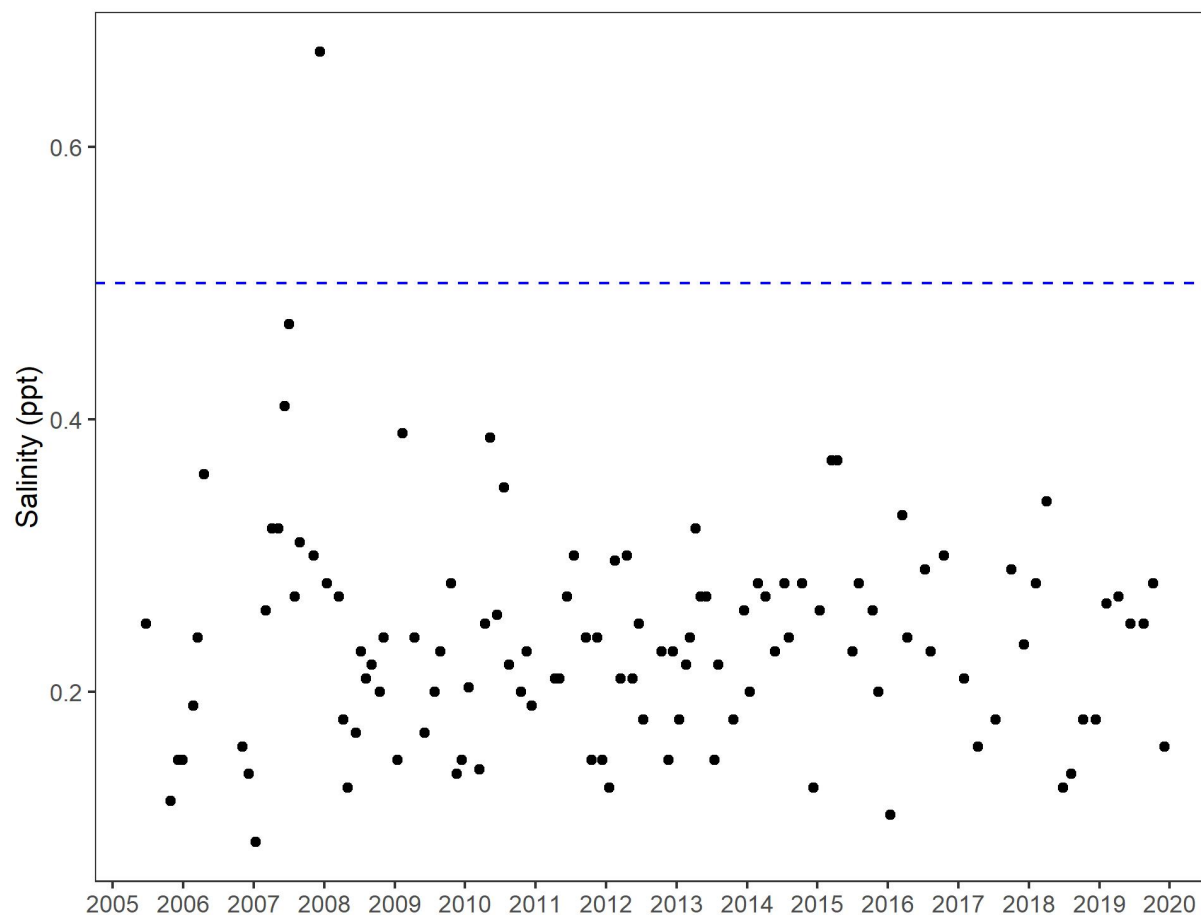


Figure 15. Salinity. Black circles = measured values, blue dashed line = threshold value.

As with SC, analysis did not reveal any seasonal pattern, long-term trend or relationship with discharge or water temperature.

ANC

Acid neutralizing capacity (ANC) varied between 776 and 3130 $\mu\text{eq/l}$ with a mean of 1728 $\mu\text{eq/l}$ (Figure 16). All the measurements were within the acceptable range above the 200 $\mu\text{eq/l}$ threshold value.

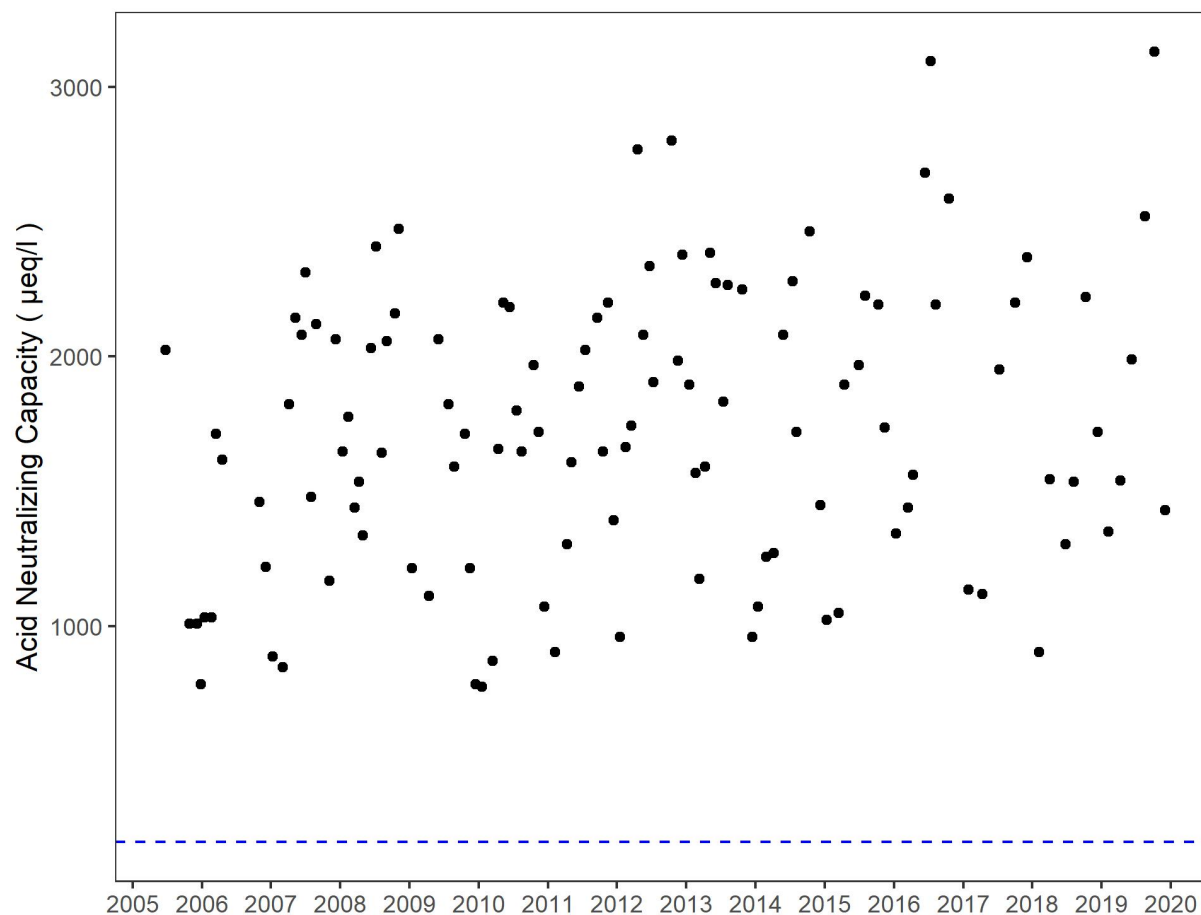


Figure 16. Acid Neutralizing Capacity. Black circles = measured values, blue dashed line = threshold value.

ANC was highest when discharge was low and decreased with increasing discharge (Figure 17). The decrease in ANC was steepest for discharge $< \sim 10$ cfs and leveled off at higher discharge. The effect is likely due to increasing contribution of rainwater and surface runoff to the stream at high discharge. Baseflow ANC is determined by local geology but will decline when discharge increases due to precipitation events (Rice, et al. 2004). Given the low pH in rainwater, it is not surprising that ANC in Youngs Branch is sensitive to discharge.

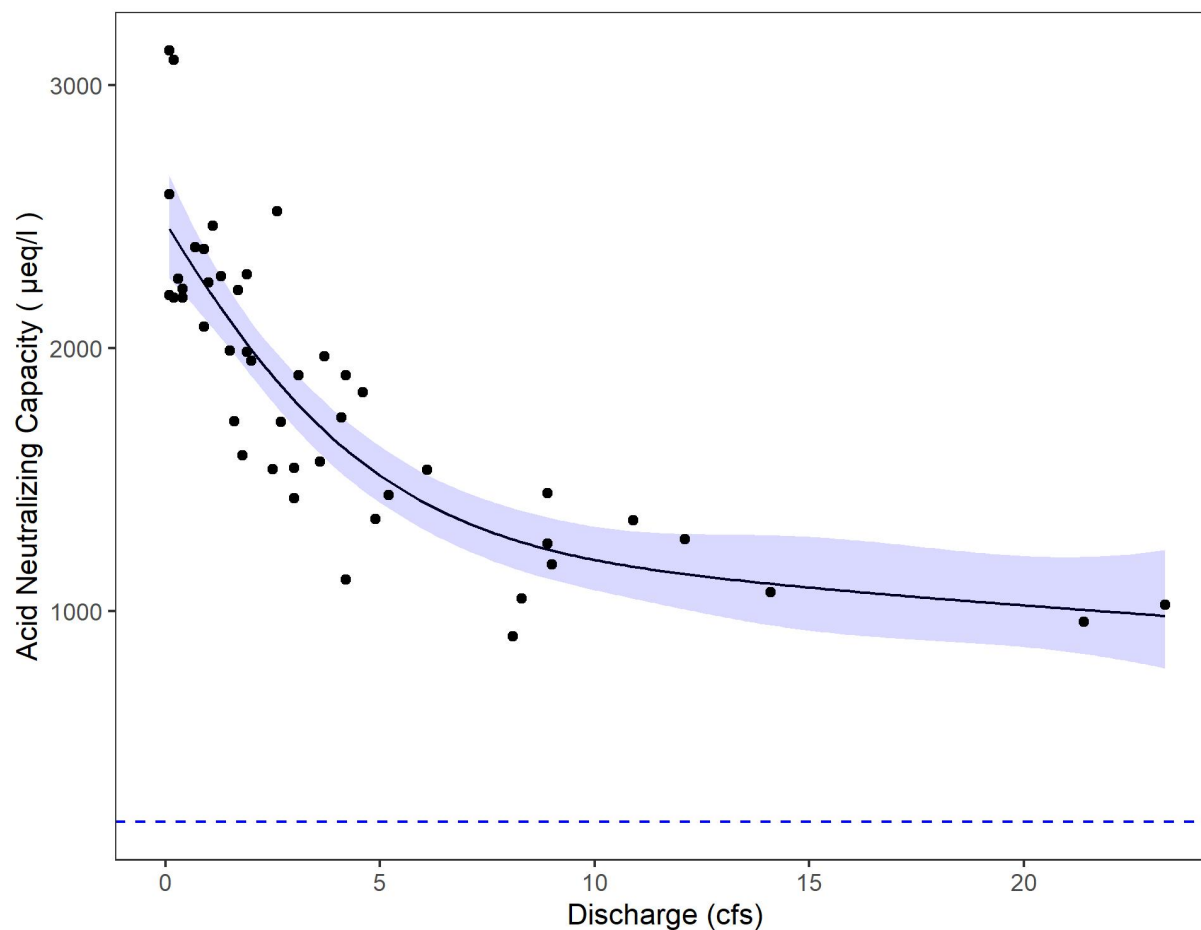


Figure 17. Changes in acid neutralizing capacity with discharge. Black circles = observed data, black line = estimate relationship between pH and discharge, shaded area = 95% CI, blue dashed line = threshold value.

The relationship between ANC and the predicted daily discharge (Figure 6) can be combined to make a daily ANC estimation (Figure 18). The confidence intervals on this estimation take into account the uncertainty in the ANC model, but not uncertainty in the discharge prediction. The estimates show an irregular seasonal pattern consistent with the seasonal discharge pattern. Peaks in ANC coincide with low discharge in the fall, followed by an immediate drop in ANC in winter months when discharge peaks. Similar to the discharge model, the ANC model generally captures the patterns in ANC values. However, there are several large outliers that possibly correspond to high discharge values immediately after precipitation or very low discharge during drought.

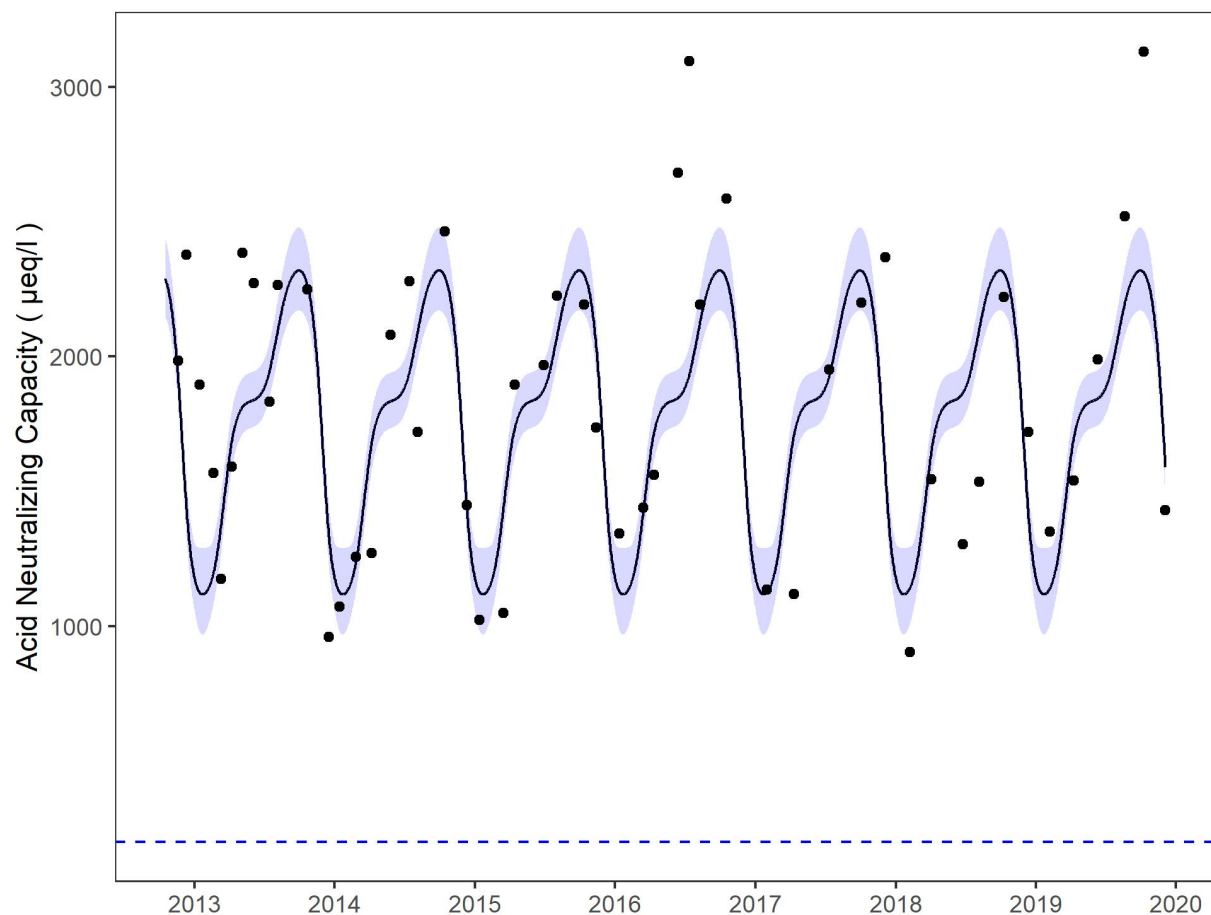


Figure 18. ANC 2013–2019. Points = measured ANC, horizontal blue dashed lines = threshold value, black line = predictions from model, shaded area = 95% CI.

Total Nitrogen

Total nitrogen varied between 0.10 and 2.50 mg/l with a mean of 0.53 mg/l (Figure 19). Most of the values were acceptable but four exceeded the eutrophication threshold value and one exceeded the macroinvertebrate threshold value.

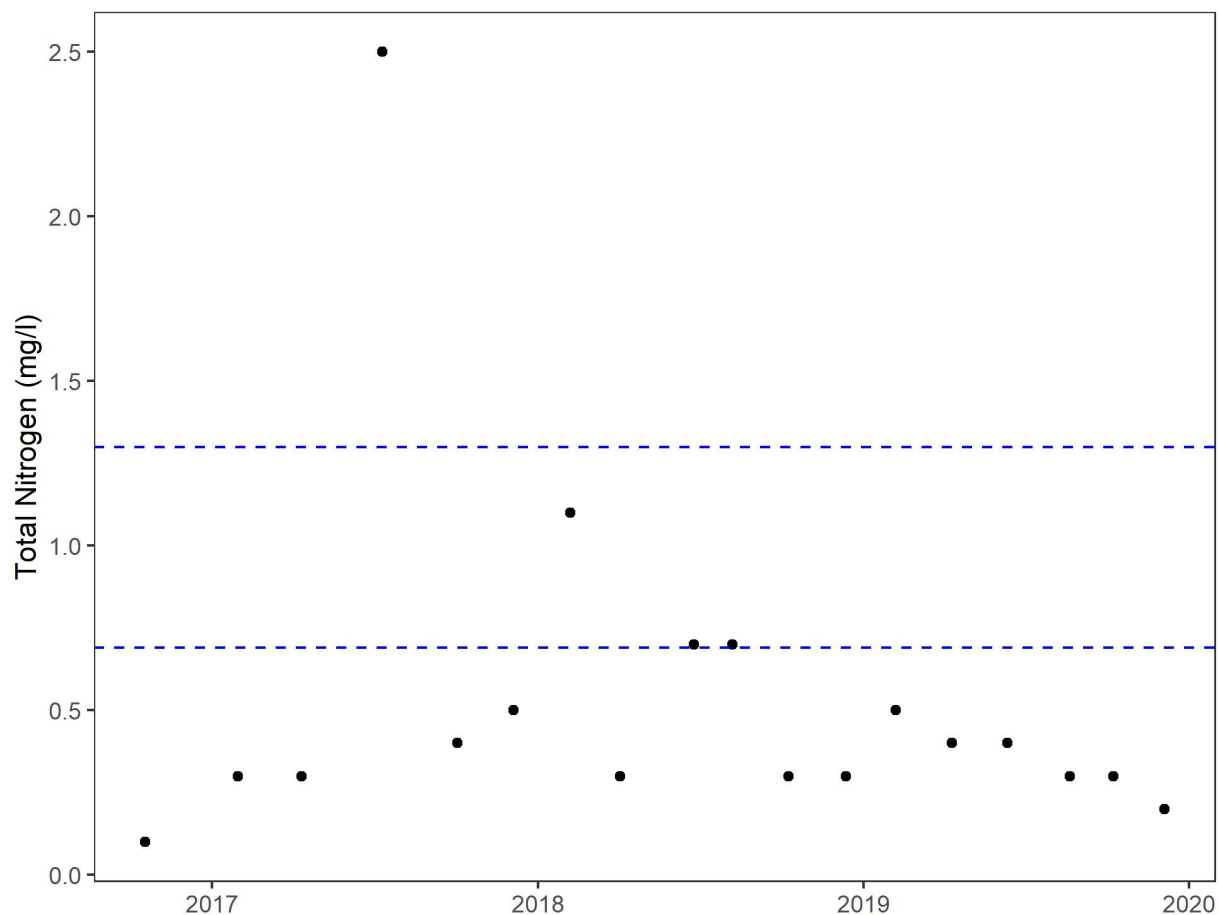


Figure 19. Total Nitrogen. Black circles = measured values, blue dashed lines = threshold values of 0.69 mg/l (eutrophication) and 1.3 mg/l (macroinvertebrates).

Due to the relatively small amount of data, only 18 measurements, trend analysis was not carried out.

Total Phosphorus

Total phosphorus varied between 0.0072 and 0.045 mg/l with a mean of 0.018 mg/l (Figure 20). Only one value exceeded the eutrophication (0.037 mg/l) and macroinvertebrate (0.043 mg/l) thresholds.

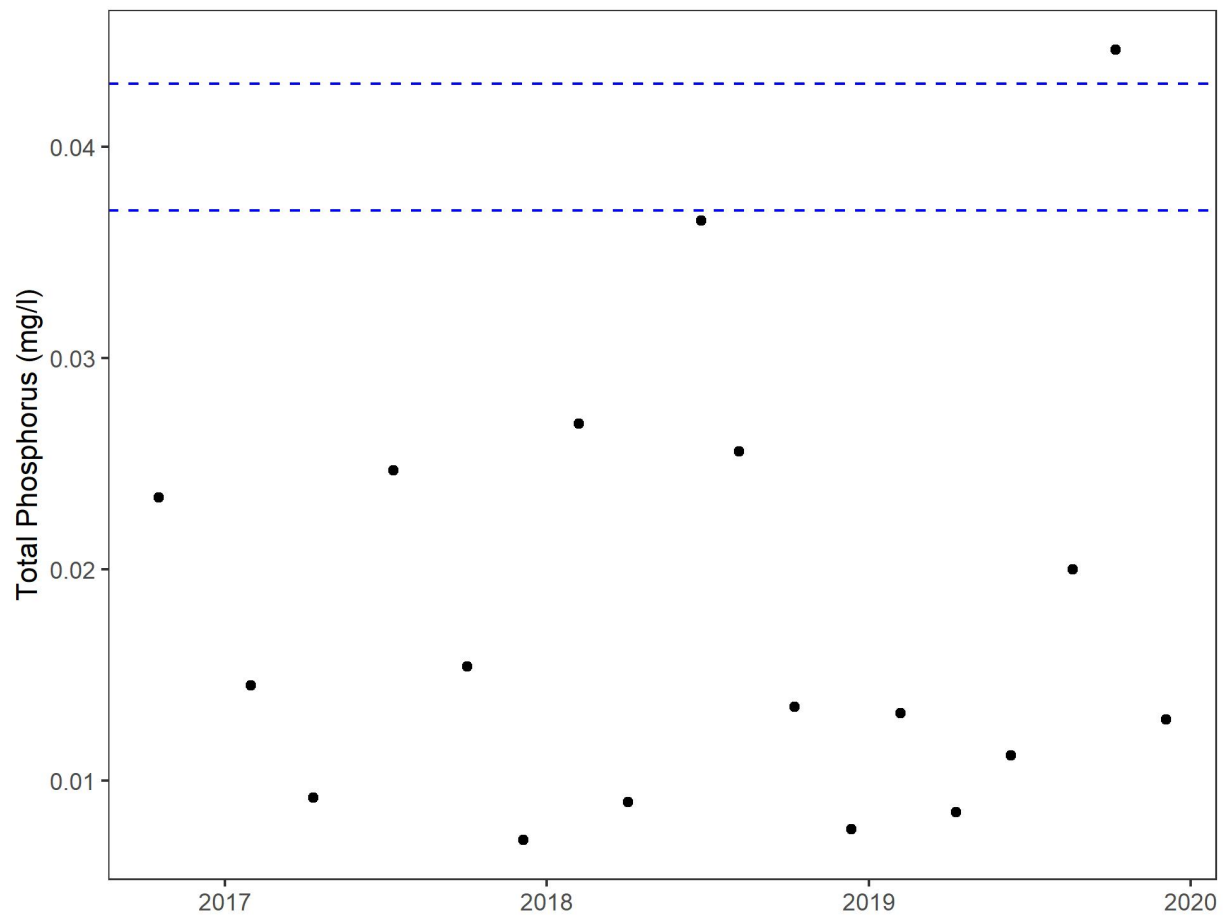


Figure 20. Total Phosphorus. Black circles = measured values, blue dashed lines = threshold values of 0.037 mg/l (eutrophication) and 0.043 (macroinvertebrates).

Due to the relatively small amount of data, only 18 measurements, trend analysis was not carried out.

Discussion

Water quality in Youngs Branch varies throughout the year. While some water quality characteristics, such as pH or ANC are consistently within an acceptable range, other characteristics are more problematic.

Although the measured water temperatures never exceeded the 32°C threshold value, high water temperatures can lead to low dissolved oxygen, which is a concern. Dissolved oxygen reaches a minimum in July and the measurements were often low enough to be detrimental to aquatic life. As we do not sample on most days of the year, it is unlikely that we measured the lowest DO levels in any year. Even in years where all DO measurements were above the threshold, there may have been days where DO fell below 5.0 mg/l. While there has been a slight increasing trend in DO over time, unacceptable DO values were still recorded as recently as 2019.

Discharge also shows a seasonal pattern. The highest discharge occurs in the beginning of the year, and levels slowly decline until the fall, after which they quickly rise again. In some years, the fall discharge is so low as to result in complete drying of the stream. Any aquatic life that cannot withstand drying or cannot quickly repopulate the stream once flow is restored, will be severely impacted.

Discharge also influences other characteristics. pH is always within an acceptable range, but it drops to its lowest values during times of high discharge. Similarly, ANC is consistently high, but is highest when discharge is low.

Specific conductance and salinity were quite variable over the course of monitoring, but there was no evidence of a relationship with season, water temperature or discharge. Specific conductance is consistently too high for fish species and usually too high for macroinvertebrates, indicating excess sediment or pollutants in the water. In one instance, salinity was high enough for Youngs branch to be classified as brackish rather than fresh water.

Nutrient levels were generally acceptable in Youngs Branch. Only one Total P measurement and four Total N measurements exceed threshold values. Of the four Total N exceedances only one exceeded the threshold values for macroinvertebrate community health.

Land Use, Aquatic Life and Water Quality

As summarized in the introduction, the Youngs Branch watershed is urbanized to an extent that may have negative effects on aquatic species. The mechanism by which urbanization harms aquatic life likely varies from species to species. Conversion of forest to developed or agricultural land is known to alter water quality in ways that can harm aquatic life and are similar to the water quality changes seen in Youngs Branch. For example, changes in land use can lead to changes in stream hydrology. Urbanization increases impervious surfaces, which can prevent precipitation from being absorbed by the soil and entering the groundwater. Impervious surfaces instead divert precipitation directly into streams as runoff (Konrad et al. 2005). This leads to short periods of high discharge immediately after precipitation events but can also lead to more days of below average discharge due to a lack of

groundwater. Stream temperatures are also known to be elevated and dissolved oxygen levels depressed in watersheds with even modest amounts of development (Price and Leigh 2006). Wherly et al. (2006) found that temperatures increased in watersheds with less forested and more agricultural land use. They also note that diversion of water away from the groundwater and into runoff increases water temperature as surface water is hotter than groundwater. Surface runoff can also carry elevated levels of dissolved solids and other pollutants which leads to high specific conductance as well as elevated nutrient concentrations (Jones et al 2001). Even watersheds with very low levels of conversion away from forest can show significant increases in SC (Price and Leigh 2006).

Implications for Management

Measures of fish and macroinvertebrate biological integrity in Youngs Branch have varied between very poor and fair. Given the issues with little or no discharge, low DO, and high SC, this is not a surprising result. Unfortunately, while measurements at a single location can highlight problems, they provide limited guidance for management actions to improve water quality throughout the watershed.

One major unanswered question is to what extent water quality issues are a result of conditions within the boundary of the park as opposed to conditions outside the park. Outside of the park, the watershed includes significant developed areas to the south, which are drained by several small tributaries entering the park from the west and southwest – not all of which are mapped. Changes in land would be expected to alter water quality in these streams and area downstream of the conjunctions with Youngs Branch.

Low discharge could be the result of changes in the watershed related to construction outside of the park, along and south of I-66. The highway has altered local hydrology by forming a barrier, and possibly redirecting water away from tributaries which join Youngs Branch. This may reduce stream discharge throughout the year. Within the park, open areas, particularly ponds, and the tributaries in the electric power right-of-way may have high evaporation rates. Evaporation will generally be highest on hot windy, sunny days particularly when humidity is low. High evaporation would primarily impact discharge in the summer and early fall, and would be most noticeable in the upper, more exposed portions of the stream.

Low dissolved oxygen is clearly related to stream temperatures. High stream temperatures will occur in areas exposed to direct sunlight, particularly shallow areas. While Youngs Branch is not a deep stream, Youngs Branch and its tributaries are shaded throughout most of the park. Outside of the park, the stream channel is largely exposed to sunlight and susceptible to warming. Within the park, the ponds and upper portions of the stream are not shaded, and in the summer could be subjected to high water temperatures and low DO concentrations. Water bodies, such as wetlands and ponds, have been shown to significantly contribute to high stream temperatures (Wherly et al 2006). Waterbodies can act as a heat reservoir and small streams that exit them can be significantly hotter than the streams that enter. The shallow depths and restricted flows of the Stuart's Hill ponds may be particularly susceptible to heating and subsequent loss of DO.

The high specific conductance has several potential causes. SC can spike in the winter when road salt washes into streams. Road salt from I-66, US-29 and other roads could explain the highest values of SC ($>1000 \mu\text{S}/\text{cm}$) which occurred during the winter of 2007–2008. However, even in the summer months, SC is too high, so road salt alone cannot be the only issue. Pageland Lane, on the southwestern boundary of the park is a gravel road where it passes over Youngs Branch. Gravel from the road has migrated into the stream channel and can be found in the park downstream from the road crossing. This gravel is one potential source of high SC. Another possibility is that SC is elevated by sediments entering the watershed from construction to the south of the park. The tributaries that drain these highly disturbed areas and could increase SC in the watershed. A final possibility is that enough road salt has been used in the area that the ground water itself now has increased salinity (and SC) year-round. This has been shown to occur in areas with high impervious surface (Kaushal et al. 2005).

Comparisons of Youngs Branch water quantity and quality of the many tributaries that enter the park, before and after the ponds, and for the main stem and the tributaries at each confluence would illuminate if water quality issues arise outside the park, in particular sections of the stream within the park or across the entire watershed. An initial study could be done over the course of a few months, particularly the summer and early fall as discharge and DO are lowest then, and SC is problematic year-round. This study could include a careful survey of the watershed to map all the tributaries to the stream. If problems originate outside of the park, then water quality should be poorest where streams enter the park and stay steady or improve throughout the park. The small, less developed tributaries contained within the park would be expected to have a better water quality than tributaries originating outside the park.

If the ponds are problematic, then the stream entering a pond should have higher discharge, lower temperatures and higher DO concentrations compared to the stream exiting the pond. SC, however, may be improved by the ponds, as ponds are generally still and may offer an opportunity for suspended materials to settle to the bottom. If temperature increases in those portions of the stream that are not shaded, planting buffer trees may help to alleviate the problem.

With better information about the causes of the water quality issues, managers can assess potential means of improving water quality. However, any solutions will have to take into account the need to preserve the historic landscape and features of the park and will also be limited by the fact that parts of the watershed are beyond managers' control. Regardless of the opportunities for improvement, managers can try to minimize further disturbances to the stream. By preserving the undeveloped nature of the park and seeking to mitigate any impacts from existing impervious surfaces, managers can prevent further impacts to the stream.

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Appendix I: Modeling Results

This appendix presents the modeling results for each characteristic measured for water quality monitoring at Youngs Branch in Manassas National Battlefield Park. For each characteristic considered below, there are two data tables and selected model information. The first table for the identified characteristic displays the degrees of freedom (df), the Akaike's information criterion (AICc) scores, and the % of deviance explained by the model, with the selected model in bold. The second table provides statistical details for the selected model, including parameter estimates, standard errors (SE) and estimated degrees of freedom (edf) and p-values for the GAM smooths.

Discharge

Dry vs Not Dry

Table 3. Model selection table for Dry vs. Not Dry.

Predictors	df	AICc	Δ AICc	% Deviance Explained
Seasonality + s(Trend)	5.48	30.59	0.00	59.1%
s(Seasonality) + s(Trend)	4.94	30.59	0.00	59.1%
Seasonality	3.00	30.81	0.22	48.3%
s(Seasonality)	3.07	44.07	13.48	20.9%
Intercept only	1.00	49.94	19.35	0.0%
s(Trend)	2.87	49.98	19.39	8.0%

Seasonality was the model selected for Dry vs. Not Dry. For these models the edfs of the seasonality term indicated it was linear, therefore the smoothing term was unnecessary. Models with linear fits on seasonality, with or without a smoothed Trend term were added to the models considered. The top three models were all within 2 AICc units of one another, and among these the model with a linear fit of seasonality it the simplest and is preferred.

Model details

Model Type: GLM using binomial distribution with logit link

Model Formula: Flowing (1) vs. Dry (0) ~ Seasonality

Table 4. Model coefficients table for Dry vs. Not Dry.

Predictor	Estimate	SE
Intercept	16.58	7.04
sine	15.62	7.13
cosine	5.92	2.88

Discharge (cfs)

Table 5. Model selection table for Discharge.

Predictors	df	AICc	Δ AICc	% Deviance Explained
s(Seasonality)	4.93	207.56	0.00	47.2%
s(Seasonality)+s(Trend)	9.00	209.10	1.54	47.7%
Intercept only	2.00	238.74	31.18	0.0%
s(Trend)	3.00	239.59	32.03	1.9%%

The s(Seasonality) model was selected for Discharge. The model is smooth for both Seasonality, has the lowest AICc, and is simpler than the model that includes smoothers for both Seasonality and Trend.

Model details

Model Type: GAM using gamma distribution with log link

Model Formula: Discharge (cfs)~ s(Seasonality)

Table 6. Model coefficients table for Discharge – Parametric Fit.

Predictor	Estimate	SE
Intercept	1.03	0.14

Table 7. Model coefficients table for Discharge – GAM Smooths.

Predictor	edf	p
Seasonality	2.93	1.38e-07

Water Temperature (°C)

Table 8. Model selection table for Water Temperature.

Predictors	df	AICc	Δ AICc	% Deviance Explained
Seasonality	4.00	517.57	0	91.9%
s(Seasonality)	4.00	517.57	0	91.9%
Seasonality + Trend	5.00	517.77	0.20	92.0%
Seasonality + s(Trend)	5.00	517.77	0.20	92.0%
s(Seasonality)+s(Trend)	5.00	517.77	0.20	92.0%
Intercept only	2.00	807.04	289.47	0.0%
s(Trend)	3.00	807.66	290.09	1.16%

Seasonality was the model selected for Water Temperature. The models with a Seasonality term had drastically better fits than those without seasonality. Comparisons of models with and without a Trend term indicates there is no evidence for a trend. Among the models with the lowest AICc, the model with a linear fit of seasonality is the simplest and is preferred.

Model details

Model Type: GLM using normal distribution with identity link

Model Formula: Water Temperature ~ Seasonality

Table 9. Model coefficients table for Water Temperature.

Predictor	Estimate	SE
Intercept	12.85	0.20
sine	-3.11	0.29
cosine	-9.64	0.28

Dissolved Oxygen (mg/l)

Table 10. Model selection table for Dissolved Oxygen Concentration.

Predictors	df	AICc	Δ AICc	% Deviance Explained
s(Trend) + s(Temperature)	6.26	383.82	0	80.7%
s(Temperature)	4.49	394.80	10.98	77.5%
s(Seasonality) + s(Trend)	5.00	398.10	14.28	77.6%
s(Seasonality)	4.00	402.61	18.79	76.3%
Intercept only	2.00	564.42	180.60	0.0%
s(Trend)	3.00	566.02	182.20	0.3%

The s(Trend) + s(Temperature) was the model selected for Dissolved Oxygen. Initial modeling (not shown) fit only on data collected at site upstream from the footbridge, indicated that a smooth term on discharge did not improve the fit of candidate models. Models were refit without a discharge term using data from all sampling locations. A GAM model with smoothers for Trend and Temperature is the preferred model.

Model details

Model Type: GAM using gamma distribution with log link

Model Formula: Dissolved Oxygen ~ s(Trend) + s(Temperature)

Table 11. Model coefficients table for Dissolved Oxygen Concentration – Parametric Fit.

Predictor	Estimate	SE
Intercept	2.15	0.01

Table 12. Model coefficients table for Dissolved Oxygen Concentration – GAM Smooths.

Predictor	edf	p
Trend	1.26	0.001
Water Temperature	2.95	< 2e-16

pH

Table 13. Model selection table for pH.

Predictors	df	AICc	Δ AICc	% Deviance Explained
Trend + Discharge	4.00	-14.73	0	50.4%
s(Trend) + s(Discharge)	4.00	-14.73	0	50.4%
s(Seasonality) + s(Trend)	8.76	-13.38	1.35	58.8%
s(Trend) + s(Temperature)	7.72	-11.89	2.84	55.3%
s(Discharge)	3.00	-8.25	6.48	39.9%
s(Temperature)	4.14	-1.16	13.57	32.9%
s(Seasonality)	4.62	6.31	21.04	22.2%
s(Trend)	3.00	11.94	26.67	4.8%
Intercept only	2.00	12.13	26.86	0.0%

The model with the lowest AICc has smooth terms for both Trend and Discharge. The only other model within 2 AICc units has smooth terms for trend and seasonality and is not the simpler model. The edfs of the Trend and Discharge model indicate linear fits for both predictors, therefore the model was refit as a GLM.

Model details

Model Type: GLM using normal distribution with identity link.

Model Formula: pH ~ Trend + Discharge

Table 14. Model coefficients table for pH.

Predictor	Estimate	SE
Intercept	12.65	3.59
Trend	-0.0053	0.0018
Discharge	-0.0046	0.0008

Specific Conductance

Table 15. Model selection table for Specific Conductance.

Predictors	df	AICc	Δ AICc	% Deviance Explained
Seasonality	4.00	1459.03	0.00	6.7%
s(Seasonality)	4.00	1459.03	0.00	6.7%
s(Seasonality) + s(Trend)	5.00	1460.16	1.13	1.0%
Intercept Only	2.00	1463.03	4.00	0.0%
s(Trend)	3.00	1463.85	4.82	1.0%
s(Temperature)	3.00	1465.02	5.99	0.0%
s(Trend) + s(Temperature)	4.00	1465.82	6.79	1.0%

An initial set of models fit the data from the site upstream from the footbridge indicated that discharge was not a useful predictor, instead the models without discharge were refit on the entire dataset. However, the GAM model with a Seasonality smooth only explained 6.72% of the deviance indicating a poor fit, therefore no model was selected for specific conductance.

Salinity

Table 16. Model selection table for Salinity.

Predictors	df	AICc	Δ AICc	% Deviance Explained
s(Seasonality)	4.30	-271.43	0.00	7.7%
s(Seasonality) + s(Trend)	5.31	-269.57	1.86	7.8%
Intercept Only	2.00	-266.77	4.66	0.0%
s(Temperature)	3.57	-266.64	4.79	2.6%
s(Trend)	3.00	-264.98	6.45	0.2%
s(Trend) + s(Temperature)	4.55	-264.84	6.59	2.7%

An initial set of models fit the data from the site upstream from the footbridge indicated that discharge was not a useful predictor, instead the models without discharge were refit on the entire dataset. However, the GAM model with a Seasonality smooth only explained 7.69% of the deviance indicating a poor fit, therefore no model was selected for salinity.

ANC

Table 17. Model selection table for Acid Neutralizing Capacity.

Predictors	df	AICc	Δ AICc	% Deviance Explained
s(Discharge)	4.77	649.19	0	77.1%
s(Trend) + s(Discharge)	5.72	650.99	1.80	77.1%
s(Seasonality) + s(Trend)	8.68	668.97	19.78	70.3%
s(Seasonality)	4.74	678.84	29.65	56.4%
s(Trend) + s(Temperature)	8.47	682.99	33.80	59.4%
s(Temperature)	4.03	686.34	37.15	47.2%
Intercept only	2.00	711.96	62.77	0.0%
s(Trend)	3.00	713.73	64.54	0.5%

The s(Discharge) model was selected for ANC. The model with the lowest AICc has a smooth term for Discharge. The only other model within 2 AICc units is more complicated because it has smooth terms for both Trend and Discharge but does not explain more of the deviance. The lowest AICc model is preferred.

Model details

Model Type: GAM using gamma distribution with log link

Model Formula: ANC ~ s(Discharge)

Deviance explained: 77.1%

Table 18. Model coefficients table for Acid Neutralizing Capacity – Parametric Fit.

Predictor	Estimate	SE
Intercept	7.48	0.02

Table 19. Model coefficients table for Acid Neutralizing Capacity – GAM Smooths.

Predictor	edf	p-value
Discharge	2.77	<2e-16

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