Parsimonious Analysis of a Proposed Wastewater Treatment Plant Discharge to the Long Branch Tributary and Barton Creek

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ABSTRACT

The Sawyer-Cleveland Partnership is proposing to discharge treated wastewater effluent in Long Branch, a tributary of Barton Creek. In general, discharging treated wastewater in riverine systems provides an energy source for the growth of periphyton, which has the potential to change the aesthetics of the receiving stream and adversely impact aquatic species by consuming dissolved oxygen. For the special case of discharging treated wastewater in Barton Creek, the effluent has an additional harmful influence on the water quality of the underlying Edwards Aquifer. A water quality model predicting the impact of this discharge on the receiving water bodies was developed using a simplified approach. The parsimony of the model allows for quick assessment of the impact and incorporates the variability and uncertainty of the environment through different scenarios. Inputs into the model consisted of site-specific parameters, such as flow and solar radiation, as well as more general, default values, such as periphyton growth rates and periphyton death rates. These parameter values were input into the parsimonious model, including any variability and uncertainty. The result was that mesotrophic status of Barton Creek was predicted to be between 1.2 and 27.8 miles under high and low flow conditions, respectively.

INTRODUCTION

Barton Creek is a significant waterway in Austin, which contributes flow to Barton Springs Pool, a popular destination spot approaching almost 1,000,000 visits a year, as well as home to two species of endangered salamanders, the Barton Springs Salamander (*Eurycea sosorum)* and the Austin Blind Salamander (*Eurycea waterlooensis)*. Furthermore, Barton Creek is located in the Barton Springs contributing and recharge zone that feeds the underlying Edwards Aquifer, a sole-source aquifer to 60,000 people. The importance of Barton Creek and other streams in the Barton Springs Zone has resulted in acquisition of open space by the City resulting in over 28,000 acres of Water Quality Protection Lands and in the promulgation of specific water quality ordinances for this area. To protect these assets, the City also actively monitors the Barton Creek watershed for potential water quality impacts to Barton Creek.

In 2018, the Sawyer-Cleveland Partnership applied to the Texas Commission on Environmental Quality (TCEQ) for a new Texas Pollutant Discharge Elimination System (TPDES) permit to discharge treated wastewater effluent into the Barton Creek Watershed in the Contributing Zone of the Barton Springs Segment of the Edwards Aquifer (Proposed Permit No. WQ0015594001, EPA I.D. No. TX0137863). The proposed permit would authorize a discharge of treated wastewater not to exceed a daily average flow of 0.092 MGD (92,000 gallons per day). The location of the proposed wastewater treatment plant is approximately 220 m (720 ft) southwest of the intersection of US Highway 290 and Sawyer Ranch Rd. (Figure 1). The proposed discharge would travel through a series of in-line detention ponds, approximately 9770 m (6.1 miles) through the Long Branch Tributary to Barton Creek, and approximately 37,945 m (23.6 miles) through Barton Creek to the boundary of the Recharge Zone. The permit application requested treatment standards of 10 mg/L 5-day Biochemical Oxygen Demand (BOD5), 15 mg/L total suspended solids (TSS), 2 mg/L ammonia nitrogen (NH_3), and 6 mg/L dissolved oxygen (DO). Richter (2018) analyzed the impact of the proposed effluent to just downstream of the series of ponds. The result from his model was effluent concentrations in Long Branch of 31.5 mg/L of Nitrogen, 6.0 mg/L of Phosphorus, and 3.5 mg/m^2 of chlorophyll-a.

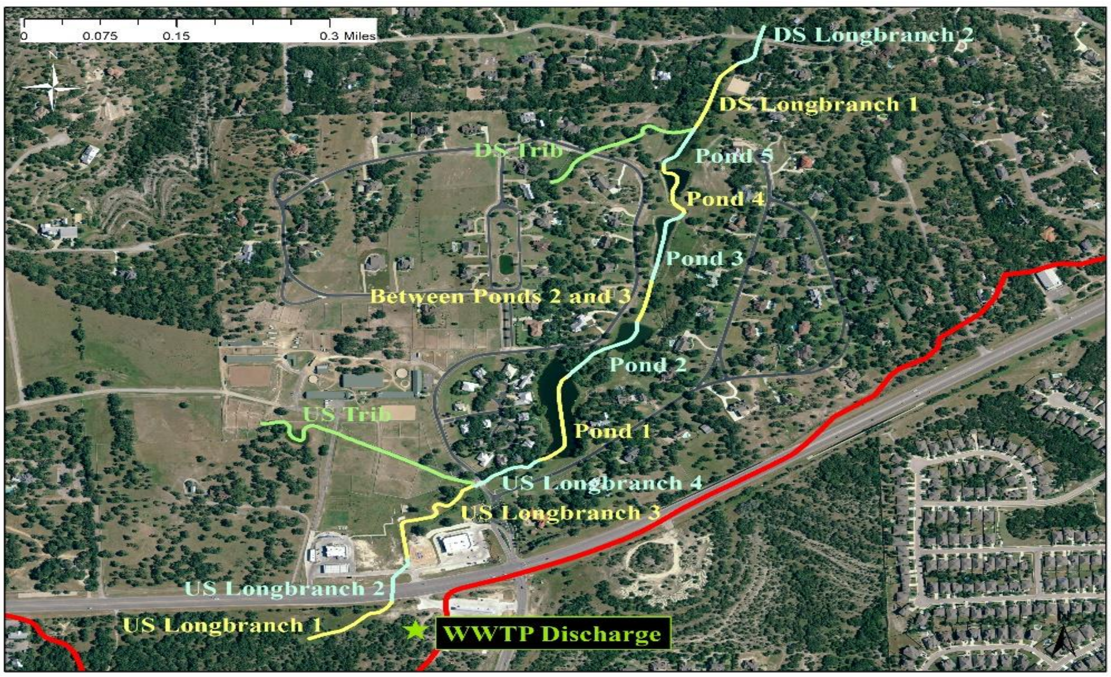

Figure 1: Location of the proposed WWTP and WASP segmentation for the water quality model. The location of the WWTP is southwest of the intersection of US Highway 290 and Sawyer Ranch Rd. on the southern border of the Barton Creek watershed (red line). Figure obtained from Richter (2018).

This report extends Richter's analysis to Barton Creek using Chapra's (2014) parsimonious model, which simplifies in-stream nutrient dynamics to a set of analytic equations without engendering the additional workload required by more complicated in-stream analyses. The trade-off is that some complexity in nutrient chemistry and stream heterogeneity is lost. Porras (2016) described and applied Chapra's model to simulate the impacts of effluent on Onion Creek from the Dripping Springs Wastewater Treatment plant. The analysis in this report takes the outputs from Richter's WASP model as inputs to Chapra's parsimonious model. Given these inputs and preliminary watershed characteristics, Chapra's parsimonious model estimates the impact of the proposed Sawyer effluent for the remainder of Long Branch and into Barton Creek. This report documents those results. A brief primer on the theory behind the parsimonious model will be described followed by the inputs to the model and then results.

THEORY

The underlying theory behind the analysis in this report is that cycling of nutrients in a riverine system can be explained through four mass balances. Nitrogen and phosphorus provide a supply of food for the growth of periphyton. The periphyton then respires or excretes back the nitrogen and phosphorus to create a nutrient cycle. Additionally, the death of periphyton produces organic matter in the form of organic carbon, nitrogen, and phosphorus which is not readily available for periphyton uptake. Through hydrolysis and decomposition, the organic matter is converted back to available forms of nitrogen and phosphorus. Figure 2 below illustrates this through a schematic of the nutrient cycling.

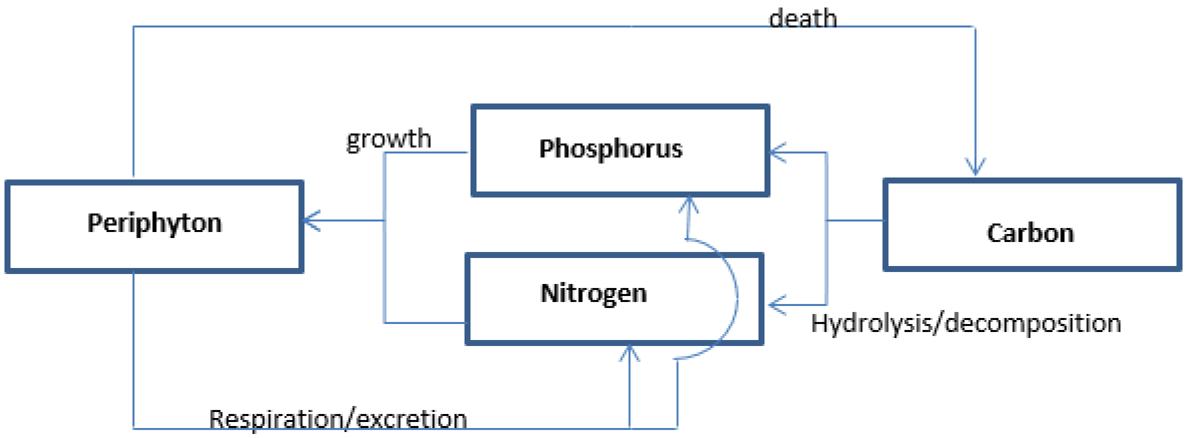

Figure 2: A schematic of the nutrient cycle in a riverine system.

The mass balances derived from the schematic can be expressed as differential equations (see Porras, 2016). The differential equations can then be solved to predict the concentrations of nitrogen, phosphorus, and periphyton (represented by chlorophyll *a*) along the length of the creek. The initial concentration of periphyton will consume the nitrogen and phosphorus, reducing the supply of food for downstream periphyton, which in turn limits further growth of the periphyton. After some length of creek, the supply of nutrients is exhausted constraining any more growth in periphyton. Denote this length the *critical* distance. The constrained concentration of periphyton is then transported downstream for as long as the wastewater effluent is being discharged. An average value of 36 mg/m^2 of periphyton is suggested as the threshold by which the riverine system goes from an oligotrophic to mesotrophic state (Dodds, 2006). Applying this simple model can be used to predict the trophic status of Barton Creek.

MODEL INPUTS

<u>Physical Geography</u>

Figure 3 below shows the extent of the watershed contributing to the model inputs. The end of the WASP model (and start of this model) is shown as a purple dot in the figure along with the model domain as a thick polyline. The light blue polyline represents Long Branch and the darker blue line signifies Barton Creek. Differentiating between Long Branch and Barton Creek is useful because the two water bodies operate under different hydrologic regimes. Long Branch is an intermittent stream with a 6.9 mi^2 (17.87 km^2) drainage area, whereas Barton Creek continuously has flow and a 51 mi^2 (132 mi^2) drainage at the confluence with Long Branch. Thus, the model was partitioned to take into account the low flow nature of Long Branch. Outputs from Long Branch then became input for Barton Creek using flow upstream of the confluence of Long Branch with Barton Creek.

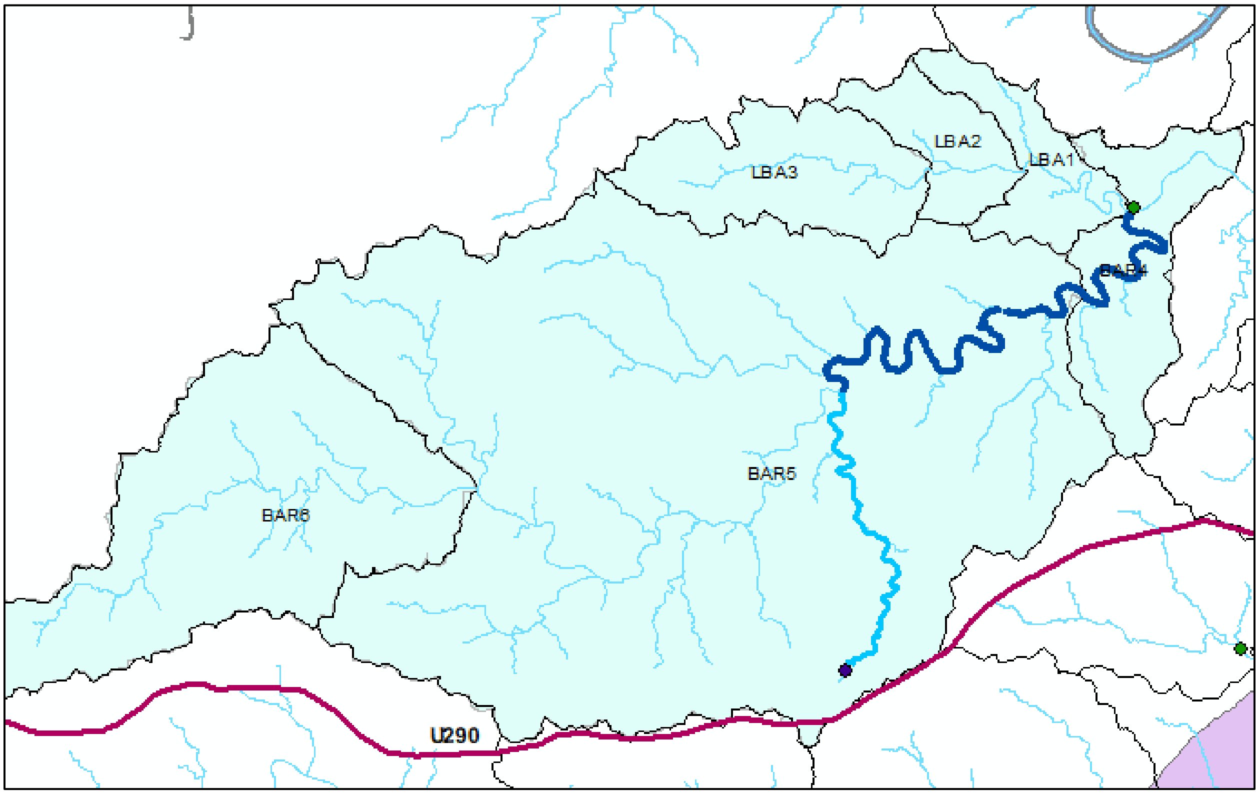

Figure 3: Areal view of the Barton Creek watershed showing the extents of the model domain as a thick polyline. The light blue polyline represents Long Branch and the darker blue line signifies Barton Creek. Dark green dot at the downstream point of Barton Creek represents USGS gage 08155200.

The dark green dot at the downstream point of Barton Creek shows the location of USGS gage 08155200, which was used to ground truth flows. The drainage areas and the corresponding flows under different conditions can be seen on Figure 4 and 5, respectively below.

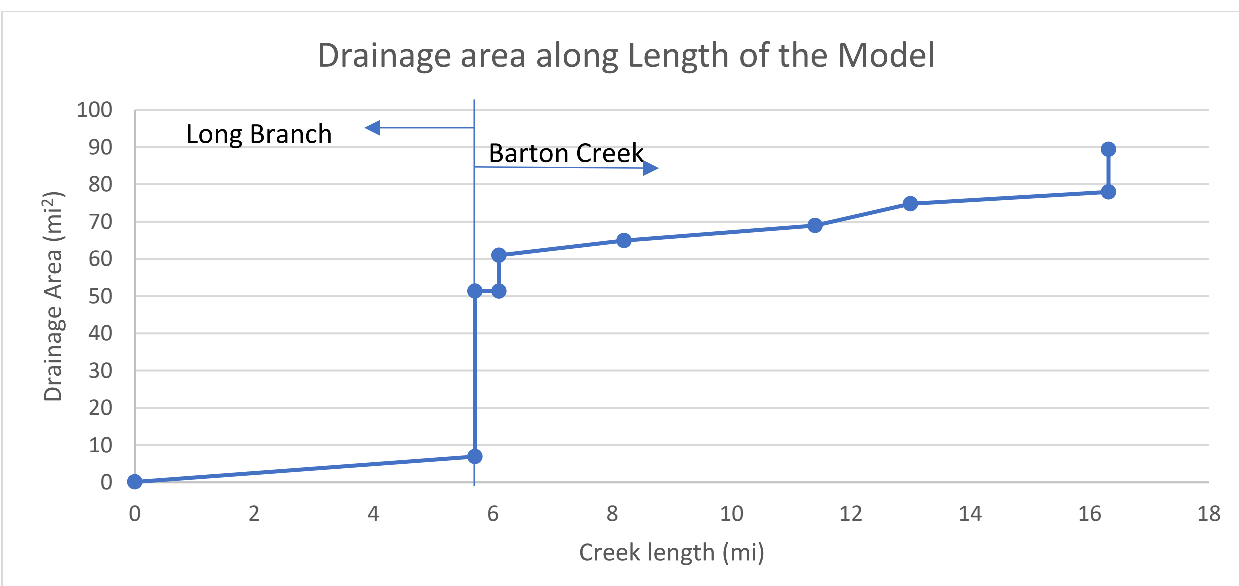

Figure 4: Drainage area of the model domain as a function of creek length

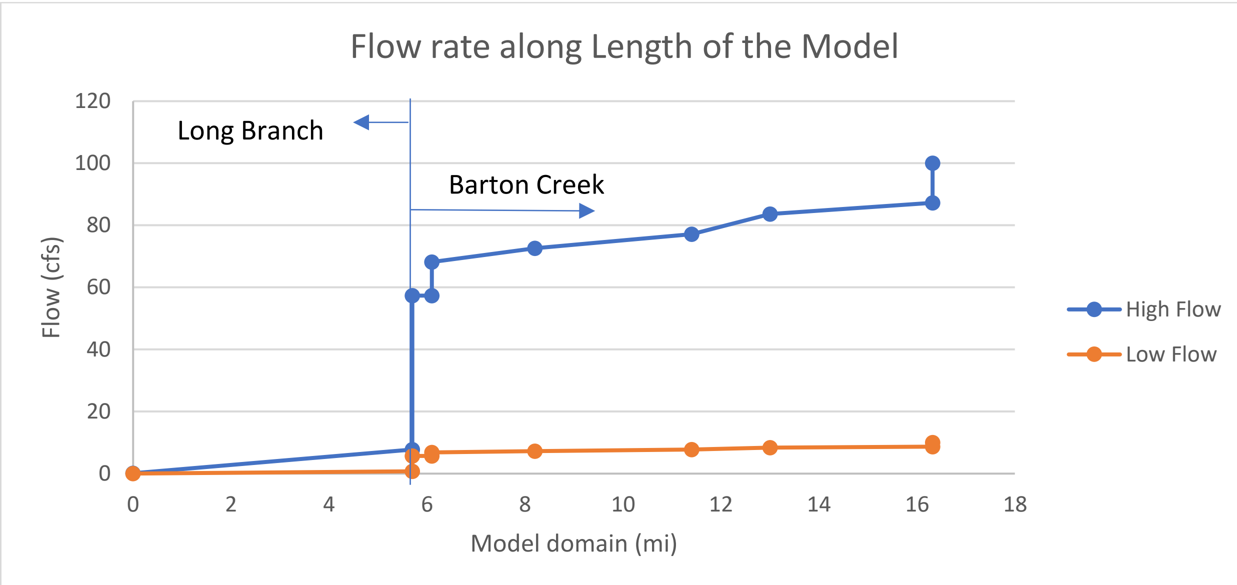

Figure 5: Stream flow inputs for the model as a function of creek length

The observations of stream flow at USGS gage station 8155200 show that flow will be at or less than 10 cfs roughly 40% of the time[1]. Denote this "low flow". Similarly, flow at the gage station greater than 100 cfs occurs about 10% of the time. This is designated as high flow. Values of flow upstream of the gage station (Figure 5) were assumed to be proportional to drainage area.

Parameter Input Values

The main inputs driving the model are the influent concentrations of nitrogen and phosphorus for a given rate. These values (taken from Richter, 2018) are approximately 31.5 mg/L and 6.0 mg/L, respectively, at a discharge rate of 92,000 gallons per day (0.14 cfs). The other parameter values are default values from Chapra (2012) and are displayed in the table below.

Table 1: Values for Parameter in Initial Periphyton Biomass

Parameter	Parameter Name	Value	Units
$C_{g,T}$	Growth rate of periphyton	200	mg/(m^2-day)
k_r	Respiration and excretion rate of periphyton	0.2	1/day
k_d	Death rate of periphyton	0.3	1/day

Inputting the growth rate of periphyton, $C_{g,T}$, into Chapra's model for Austin, Texas (see Porras, 2016) results in initial values of 207 mg/m^2 of periphyton biomass in the summer, when periphyton is expected to be more abundant. From this, the model inputs given in Table 2 can be used to determine estimates of downstream phosphorus and nitrogen concentrations, as well as length of mesotrophication from chlorophyll-*a* concentrations.

[1] Over a 5-year time period beginning in Dec 2013.

Table 2: Values for Parameter in Nutrient Concentrations

Parameter	Parameter Name	Value	Units
k_{sp}	Half saturation constant for available phosphorus	5	µg/L
k_{sn}	Half saturation constant for available nitrogen	20	µg/L
k_h	hydrolysis rate of periphyton	0.05	1/day
k_d	death rate of periphyton	0.3	1/day
r_{pa}	Stoichiometric coefficients for phosphorus to periphyton	1.2 – 1.7	mgP/mgA
r_{na}	Stoichiometric coefficients for nitrogen to periphyton	7.2	mgN/mgA
r_{ca}	Stoichiometric coefficients for carbon to periphyton	0.04	gC/mgA
r_{pc}	Stoichiometric coefficients for phosphorus to carbon	2.0 – 13.3	mgP/gC
r_{nc}	Stoichiometric coefficients for nitrogen to carbon	50 – 100	mgN/gC

RESULTS

Predictions from the parsimonious model are depicted in Figures 6 to 9 below. Figure 6 shows that under low flow conditions, nitrogen becomes the limiting nutrient. That is, the nitrogen concentration approaches its half saturation constant of 20 µg/L before the phosphorus concentration reaches its half saturation constant of 5 µg/L. The distance that the nitrogen concentration approaches its half saturation constant is denoted as the *critical distance*. Under low flow conditions, the critical distance is 21.26 miles (34.2 km) from the model origin or roughly 15.6 miles (25.1 km) downstream of the confluence of Barton Creek with Long Branch.

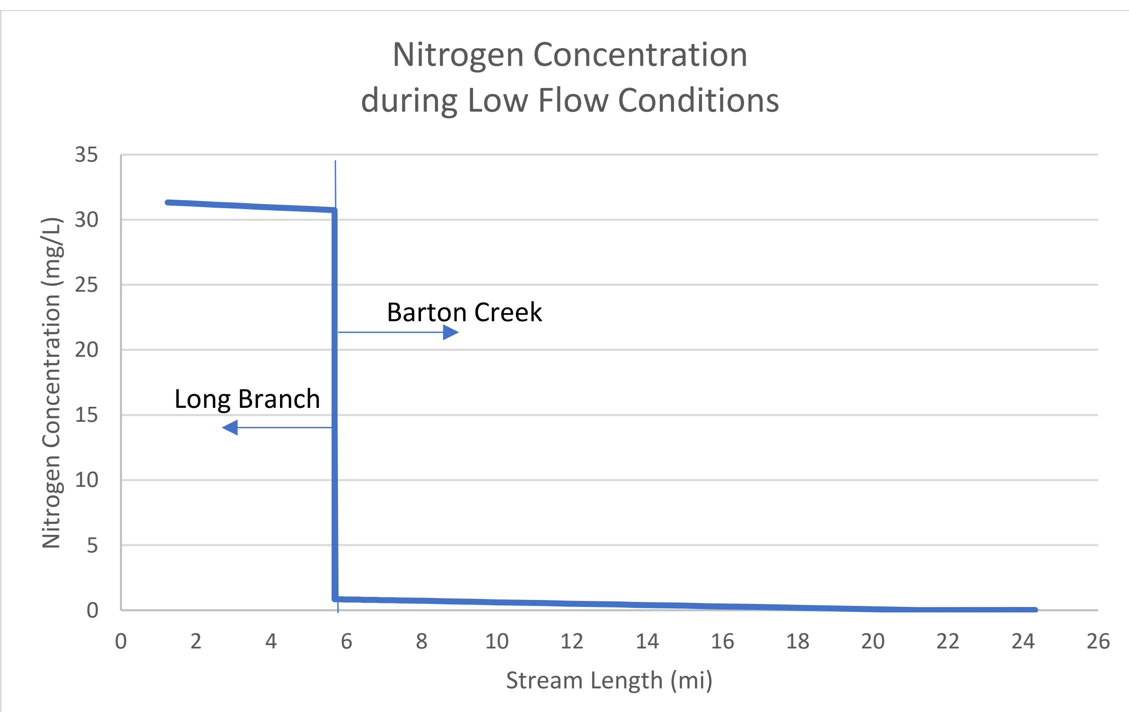

Figure 6: Nitrogen Concentrations along the length of the stream under Low Flow Conditions

This implies that the wastewater discharge provides available nutrients throughout the length of the critical distance. The impact on the stream can be more clearly seen in Figure 7, which shows the concentration of chlorophyll-*a* as a function of distance. This figure illustrates that the chlorophyll-*a* concentrations are estimated to be around 200 mg/m^2 at the wastewater discharge point and then, as nitrogen becomes less available along the length of the stream, its concentration is reduced to about 100 mg/m^2. Throughout the critical distance and even further, the creek can be classified as eutrophic (Dodds, 2006).

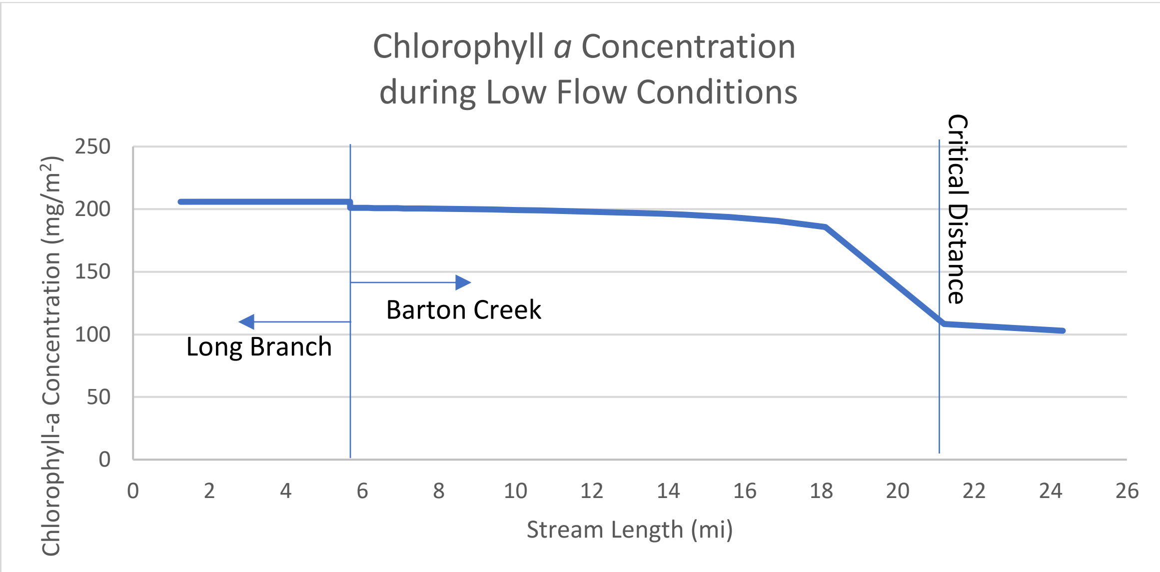

Figure 7: Chlorophyll-*a* Concentrations along the length of the stream under Low Flow Conditions

Under high flow conditions, phosphorus is the limiting nutrient, as it reaches it half saturation constant of 5 µg/L faster than nitrogen reaches its half saturation constant of 20 µg/L. The critical distance under high flow conditions is 8.57 mi (13.8 km) downstream from the model origin or about 2.9 miles (4.7 km) of Barton Creek will have these elevated concentrations of phosphorus.

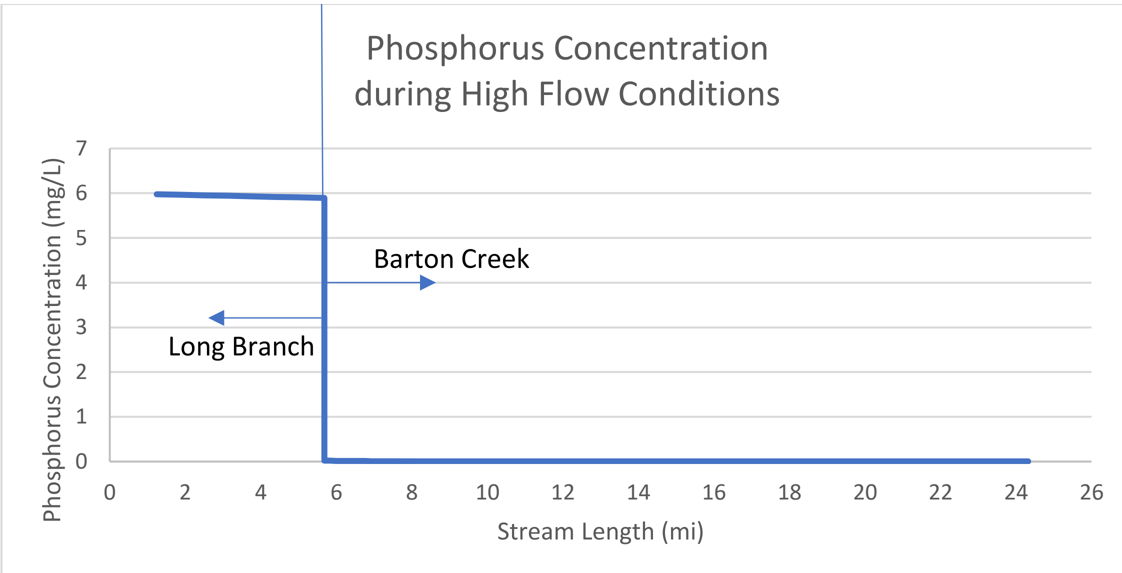

Figure 8: Phosphorus Concentrations along the length of the stream under High Flow Conditions

The result of elevated phosphorus during high conditions is chlorophyll-*a* concentrations starting at 200 mg/m^2 going down to about 100 mg/m^2 at the critical distance. Figure 9 shows the concentration of chlorophyll-*a* with respect to distance.

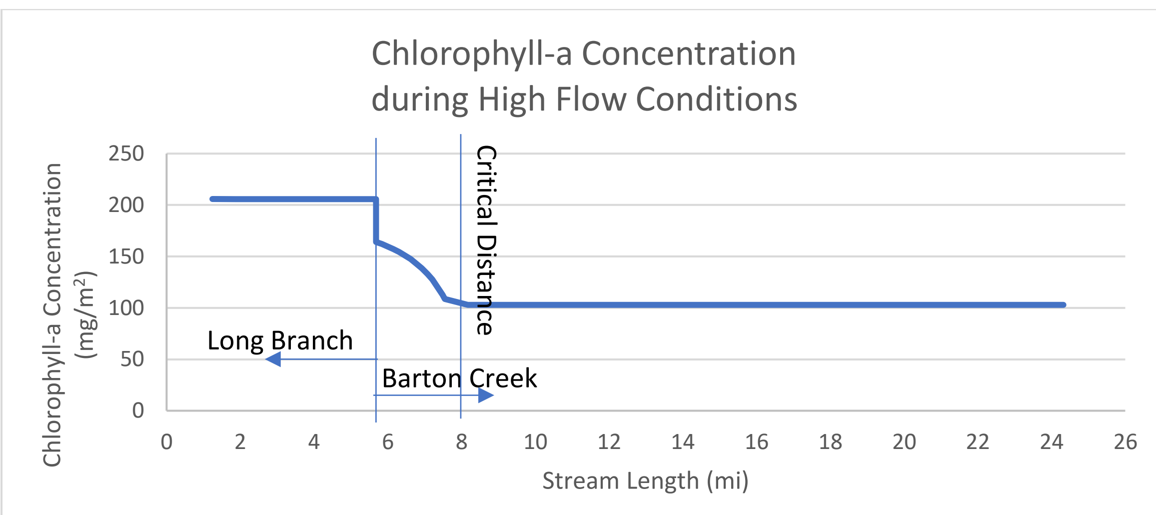

Figure 9: Chlorophyll-*a* Concentrations along the length of the stream under High Flow Conditions

During high flow conditions, the effluent concentrations from Long Branch are diluted by Barton Creek upstream of the confluence. This serves to reduce the length of the critical distance in Barton Creek to about 2 miles (3.2 km) of eutrophic conditions or about 7.5 miles (12.1 km) downstream of the model origin.

SENSITIVITY and UNCERTAINTY

In addition to looking at different flow events, a sensitivity and uncertainty analysis was performed on the model. For the sensitivity analysis, the periphyton growth rate, $C_{g,T}$, was reduced by 50% from 200 mg/(m^2-day) to 100 mg/(m^2-day). The resulting chlorophyll *a* concentration under this reduction ranged from a high of 80 mg/m^2 at the origin of the model down to about 50 mg/m^2 at the critical distance. These lower chlorophyll *a* values are closer to modeled values in Richter (2018). However, under the low flow scenario, the model predicts that this reduction in periphyton growth rate increases the critical distance to over 40 miles (64 km). Under high flow scenario, the reduction in periphyton growth rate increases to 9.62 miles (15.5 km). Reducing the periphyton growth rate moderates the consumption rate of nutrients as well as their concentration, thus, keeping the nutrients in the water column longer and allowing for algae growth further downstream.

An uncertainty analysis was also performed where values of the different parameters in the model were selected at random from a normal probability distribution. Table 3 below depicts which parameters were changed and from what normal distribution the values were selected. The model was then run 500 times with each run using different randomly generated parameters sets.

Table 3: Values for Parameter in Uncertainty Analysis

Parameter	Mean	Standard Dev	Units
r_{pa}	1.0	0.1	ugP/ugA
k_r	0.2	0.02	1/day
k_h	0.05	0.01	1/day
k_d	0.3	0.06	1/day
a_0	208	17	mg/m^2

The results from the uncertainty analysis are shown in Figures 10 and 11. Figure 10 shows the range of critical distances under low flow conditions. The figure indicates that about 98% of the model runs resulted in a critical distance between 17 miles (27 km) and 33.4 miles (53 km). This is equivalent to between 11.4 and 27.8 miles (18.3 and 44.7 km) of mesotrophic status in Barton Creek downstream of Long Branch.

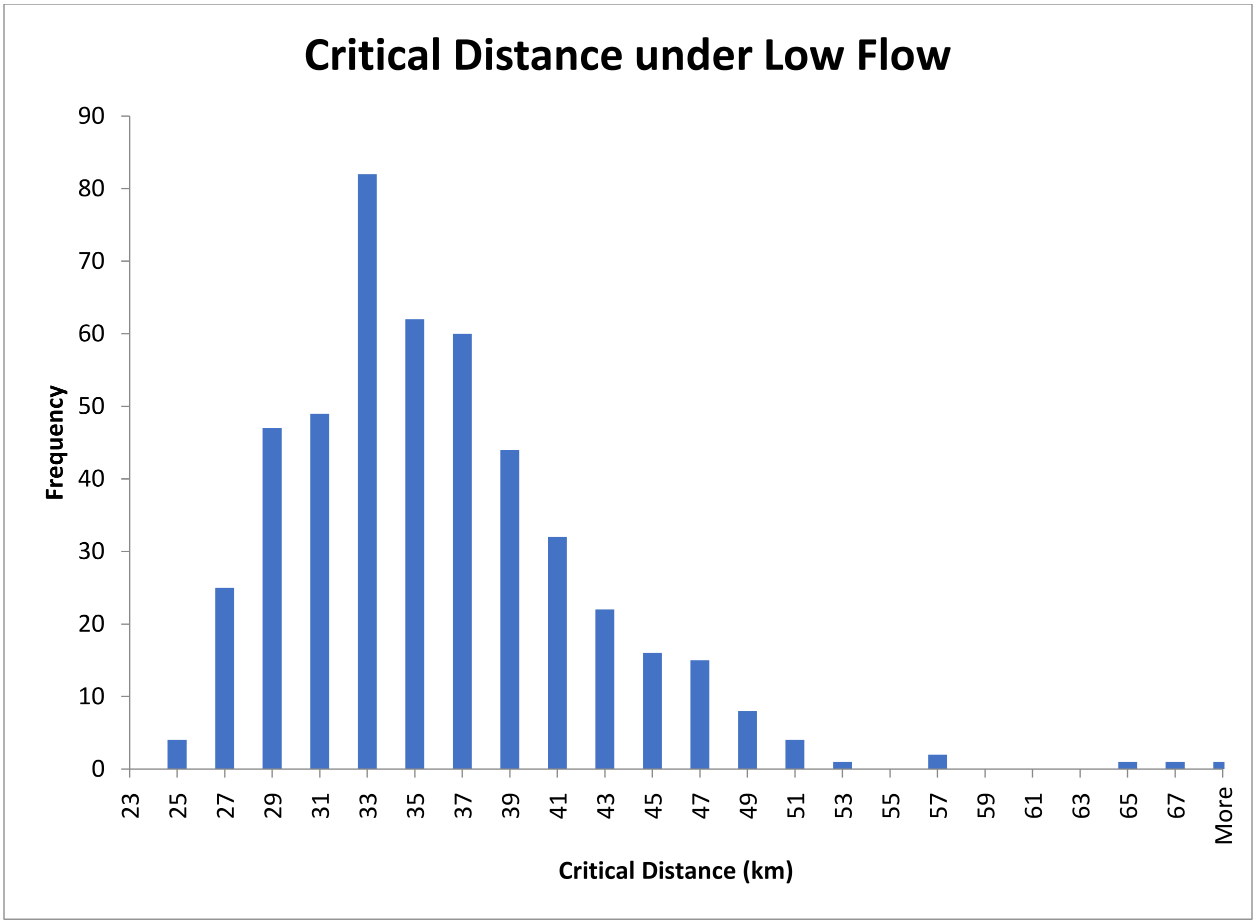

Figure 10: Histogram of critical distance for 500 model runs under low flow conditions

Figure 11 shows the range of critical distances under high flow conditions. Under this scenario, 98% of the model runs produced a critical distance of between 6.84 miles (11 km) and 9.32 miles (15 km) from the model origin. This translates to between 1.2 and 3.7 miles (1.9 and 6 km) of mesotrophic status in Barton Creek downstream of Long Branch

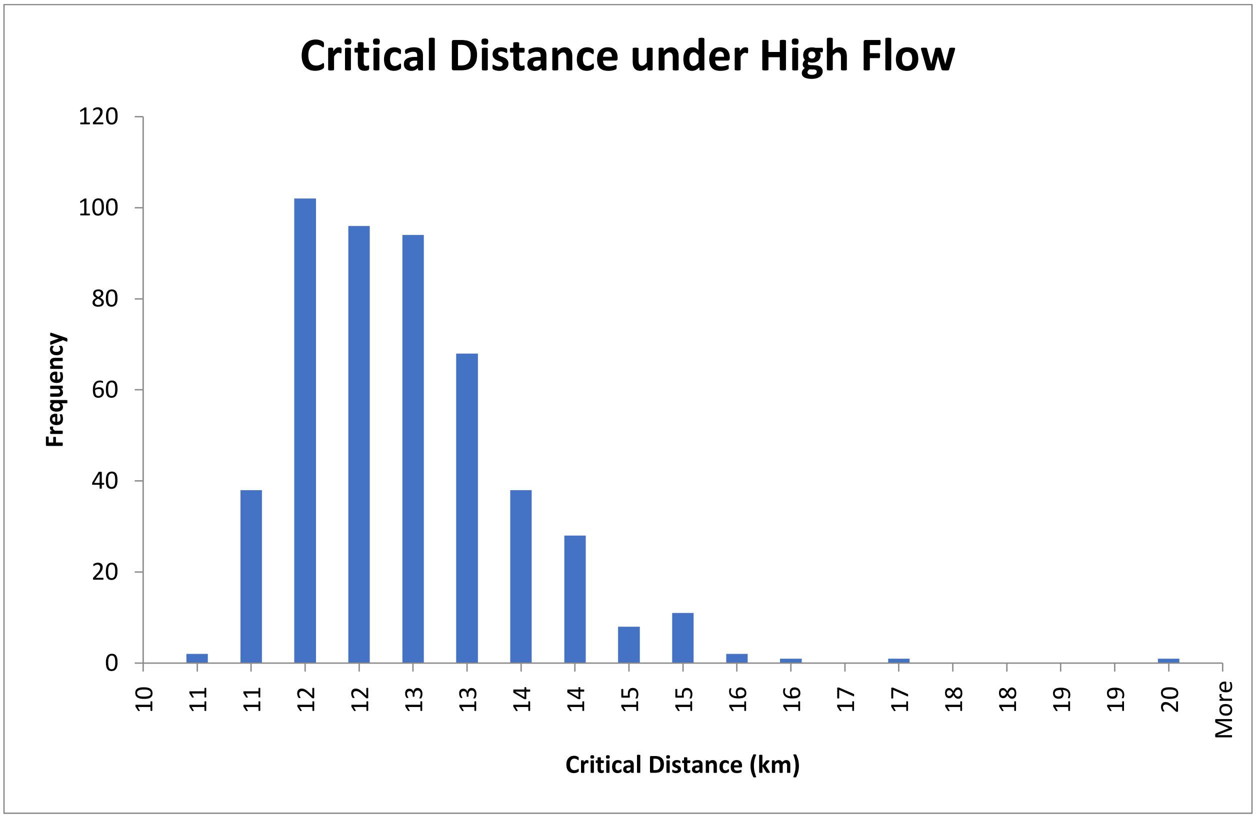

Figure 11: Histogram of critical distance for 500 model runs under high flow conditions

CONCLUSION

A water quality model simulating in-stream nutrient dynamics was run for a proposed wastewater discharge in Long Branch, a tributary to Barton Creek. The parsimonious nature of the model allows for the variability of the environment to be assimilated through different scenarios. The main factor influencing the impact on the stream is stream flow. Flow in Barton Creek at a downstream USGS gage was found to vary between 10 cfs and 100 cfs. Both conditions were input into the model along with uncertainty in other parameter values. The result was that mesotrophic status of Barton Creek was predicted to be between 1.2 and 27.8 miles (1.9 and 44.7 km) under high and low flow conditions, respectively. Any flow between these two conditions can be expected to yield a deleterious change in trophic status along lengths between these two values. This change in trophic status adversely impacts the recreational and aesthetic value of Barton Creek, the habitat of the residing aquatic species, and the water quality of the underlying Edwards Aquifer.

REFERENCES

Chapra, Steven C., Kyle F. Flynn, and J. Christopher Rutherford. 2014. "Parsimonious model for assessing nutrient impacts on periphyton-dominated streams." Journal of Environmental Engineering 140.6 (2014): 04014014.

Dodds, WK. 2006. Eutrophication and trophic state in rivers and streams. Limnology & Oceanography, 51: pp 671-680.

Porras, A. 2016. An Analytic Water Quality Model of Onion Creek examining Impacts from a Proposed Waterwater Point Source Discharge. City of Austin Watershed Protection Department. SR-17-01.

Richter, A. 2018. Analysis of a Proposed Wastewater Treatment Discharge to the Long Branch Tributary of Barton Creek. City of Austin Watershed Protection Department. DR-18-08.