Analysis of a Proposed Wastewater Treatment Plant Discharge to the Long Branch Tributary of Barton Creek
DR-18-08; November 2018

Aaron Richter

City of Austin
Watershed Protection Department
Environmental Resource Management Division

ABSTRACT
The Water Quality Analysis Simulation Program (WASP) is commonly used to model water quality responses to wasteloads. The City of Austin used the WASP model to create a continuous simulation of a proposed wastewater treatment plant (WWTP) discharge to the Long Branch Tributary of Barton Creek. The discharge would enter 5 detention ponds prior to entering the Long Branch Tributary. Results of the WASP model show that total nitrogen (TN) and total phosphorus (TP) concentrations downstream of the detention ponds will be similar to concentrations leaving the WWTP during the majority of the year and phytoplankton concentrations will be at hypereutrophic levels during blooms. Nutrients and chlorophyll *a* concentrations should be used as input into a parsimonious model to determine how far downstream the impacts will travel.

INTRODUCTION
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 (WWTP) 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 detention ponds, approximately 9.771 km (32,057 ft; 6.1 miles) through the Long Branch Tributary to Barton Creek, and approximately 37.945 km (124,589 ft; 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 (NH3), and 6 mg/L dissolved oxygen (DO).

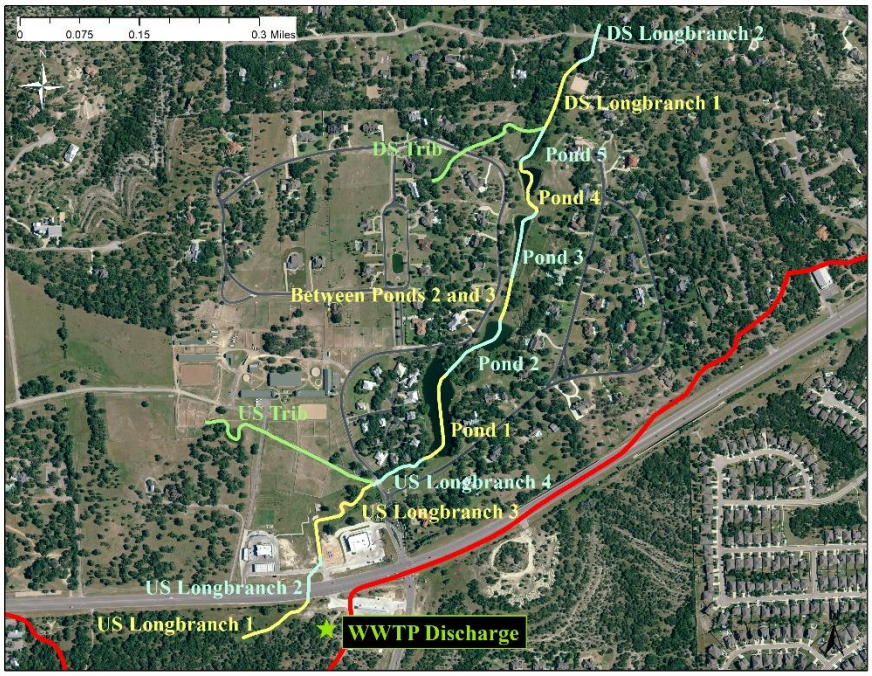

Figure 1: Location of the proposed WWTP and WASP segmentation for the water quality model. The location of the WWTP is southwest of the intersection of US Highway 290 and Sawyer Ranch Rd. on the southern border of the Barton Creek watershed (red line).

The City of Austin (COA) has an interest in maintaining the water quality of Barton Creek and the underlying Edwards Aquifer. Surface water in the contributing zone of the Edwards Aquifer, which includes Barton Creek, has previously been shown to be sensitive to nutrient enrichment (Herrington and Scoggins 2006; Mabe 2007; Herrington 2008a; Herrington 2008b; Richter 2010; Turner 2010). In aquatic systems, nutrients such as nitrogen and phosphorus support the growth of algae and aquatic plants. Nutrient enrichment can occur from the increase of either nitrogen or phosphorus to the aquatic system and can cause an increase in algal biomass to the extent that entire reaches of streams show aesthetic degradation (Wharfe et al. 1984; Biggs 1985; Biggs and Price 1987; Welch et al. 1988), loss of pollution-sensitive invertebrate taxa (Quinn and Hickey 1990), clogging of water intake structures (Biggs 1985), and degradation of dissolved oxygen and pH levels in the water column (Quinn and Gilliland 1989).

The COA Watershed Protection Department (WPD) constructed a Water Quality Analysis Simulation Program (WASP) model to examine impacts immediately downstream of the proposed WWTP effluent. Total nutrients and chlorophyll a predictions from this model can be used as input into a parsimonious model (Chapra et al. 2014) to determine how far downstream impacts might be seen.

METHODS

The Water Quality Analysis Simulation Program (WASP) is a program maintained by the US Environmental Protection Agency (US EPA) and "general dynamic mass balance framework for modeling contaminant fate and transport in surface waters" (Ambrose and Wool 2017). WPD used an 'Advanced Eutrophication' model type in WASPv8.2 to simulate phytoplankton and benthic algae biomass in the unnamed tributary, detention ponds, and initial stretch of Long Branch tributary immediately downstream of the treated effluent in the proposed discharge permit.

The WASP model simulated from 01 January 1999 through 31 December 2014 using a Euler solution technique, which is a typical solution technique for hydrodynamic models (Ambrose and Wool 2017). The maximum allowable timestep was set to 0.042 days (1 hour) so that predicted dissolved oxygen (DO)

could be examined at different times of the day rather than using a daily response value. In WASPv8.2, the user defines which state variables will be incorporated into a simulation. A list of the state variables simulated can be seen in Table 1.

Table 1: List of state variables used in the WASP model.

WASP System Type	Description
WTEMP	Water Temperature
DISOX	Dissolved Oxygen
NH-34	Ammonia
NO3O2	Nitrate-nitrite
ORG-N	Organic Nitrogen
D-DIP	Inorganic Phosphorus
ORG-P	Organic Phosphorus
CBODU	Background CBOD
CBODU	WWTP CBOD
DET-C	Detritus Carbon
DET-N	Detritus Nitrogen
DET-P	Detritus Phosphorus
PHYTO	Phytoplankton biomass
MALGA	MacroAlgae (Benthic) Biomass
MALGN	MacroAlgae (Benthic) Nitrogen
MALGP	MacroAlgae (Benthic) Phosphorus

Segmentation of the model was created with ArcGIS coupled with site visits to procure depths of ponded segments (Table 2). Slopes were calculated by taking the difference in elevation using 0.61 m (2 ft) contours at the beginning and end of the segment and dividing that value by the length of the segment. Roughness coefficients (manning's n) were estimated based on visual assessment of the channel (Chow 1959). The depth multiplier is the depth of the segment under average flow conditions and the depth exponent was taken from empirical hydraulic exponents that represent ephemeral streams in the semiarid US (Ambrose and Wool 2017).

Table 2: WASP segment names, transport mode for flow, and channel geometry for each segment.

Segment Name	Transport	Length	Width	Slope	Roughness	Depth Multiplier	Depth Exponent	Weir Height
DS Longbranch 2	Kinematic Wave	90.25	1.52	0.0068	0.05	0.6096	0.36	
DS Longbranch 1	Kinematic Wave	153.97	1.52	0.0238	0.05	0.6096	0.36	
pond5	Ponded Weir	71.54	11.7			0.3658	0.00	1.03
pond4	Ponded Weir	99.67	28.93			0.7620	0.00	2.13
pond3	Ponded Weir	130.45	20.38			1.3411	0.00	2.56
Between Ponds 2 and 3	Kinematic Wave	89.36	0.82	0.0478	0.025	0.1524	0.36	
pond2	Ponded Weir	125.84	42.37			1.6154	0.00	2.23
pond1	Ponded Weir	202.69	54.10			1.7374	0.00	2.35
US Longbranch 4	Kinematic Wave	115.13	0.82	0.0265	0.05	0.3048	0.36	
US Longbranch 3	Kinematic Wave	233.01	0.67	0.0209	0.04	0.3048	0.36	
US Longbranch 2	Kinematic Wave	90.84	0.61	0.0201	0.02	0.1524	0.36	
US Longbranch 1	Kinematic Wave	156.86	0.61	0.0039	0.02	0.0762	0.36	
DS Trib	Kinematic Wave	274.84	0.64	0.0270	0.03	0.0762	0.36	
US Trib	Kinematic Wave	410.03	0.49	0.0178	0.015	0.0762	0.36	
WWTP	Kinematic Wave	64.01	0.61	0.0476	0.02	0.0762	0.36	

Time functions and parameters included in the model were solar radiation, air temperature, wind speed, light extinction, ammonia benthic flux, phosphorus benthic flux, and sediment oxygen demand. Solar radiation, air temperature (minimum and maximum), and wind speed were obtained from the National Climatic Data Center (NOAA Satellite and Information Service). Ammonia benthic flux, phosphorus benthic flux, and sediment oxygen demand were set to 0.015 mg/m^2-day, 0.015 mg/m^2-day, and 1.0 g/m^2-day, respectively, for each WASP segment based on previous WPD WASP modeling efforts. Light extinction was set to 0.813/meter for each WASP segment based on photosynthetic photon flux data collected using a quantum meter in Onion Creek. A full list of the constants used in the model can be seen in Appendix A. Constants were taken from previous WPD WASP modeling efforts (Richter 2010; Richter 2016) with the exception of the maximum nitrogen and phosphorus uptake constants for macro algae and algal stoichiometry. These constants were set to the default values. The maximum nitrogen and phosphorus uptake constants were set to the default values because they were impairing phytoplankton growth within the system. Stoichiometry was set to default values because WPD has not obtained any biologic data from the ponds in the current model for calibration.

Daily flows were input into WASP segments US Longbranch 1, US Longbranch 3, US Longbranch 4, Pond 1, Pond 2, Between Ponds 2 and 3, Pond 3, Pond 4, DS Longbranch 1, US Trib, and DS Trib. (Figure 1). Flows into US Longbranch 1, US Trib, and DS Trib were assumed to be headwater flows while flows into other segments were considered to be overland flow into the segment. Flow time series were constructed using the United States Geological Survey (USGS) gage 08155200 based on drainage area at the input location relative to the drainage area at the gage (Table 3). As this section of creek network is typically dry, only storm flows were input into the WASP model. If the daily flow at the gage was 50% higher than the previous days flow then input flows for that day were considered storm flow and WASP segment flows were entered into the separate model time series, otherwise the input flows were set to zero. Additionally, a daily evapotranspiration (ET) time series was constructed using the Hargreaves method and local climatological data in the Soil & Water Assessment Tool (SWAT) (Peacock 2016) and input into the WASP model to represent evapotranspiration from ponded segments.

Table 3: Percent of drainage area at each flow input for the WASP model compared to the drainage area at USGS gage 08155200.

WASP Input	Drainage Area (km^2)	Percentage of gage
US Longbranch 1	0.156	0.067%
US Longbranch 3	0.232	0.100%
US Longbranch 4	0.075	0.032%
Pond 1	0.093	0.040%
Pond 2	0.098	0.042%
Between Ponds 2 and 3	0.059	0.025%
Pond 3	0.048	0.021%
Pond 4	0.039	0.017%
DS Longbranch 1	0.159	0.068%
US Trib	0.409	0.176%
DS Trib	0.233	0.100%
USGS gage 08155200	232.464	100%

Storm loads for water quality parameters were input into WASP as boundary time series. For days in the time series when flows into a WASP segment were non-zero values, storm concentrations were set to the storm event mean concentration (EMC) for each parameter in Table 4 for that WASP segment. Otherwise, the value was set to zero. Storm concentrations were taken from other COA work where stormwater EMCs were developed from similar areas (Glick et al. 2009).

Table 4: Pollutant concentrations used as boundary time series in the WASP model.

Parameter	Storm EMC (mg/L)
Background CBOD	1.577
Ammonia	0.038
Nitrate-nitrite	0.233
Organic Nitrogen	0.594
Inorganic Phosphorus	0.022
Organic Phosphorus	0.022

To model the Sawyer-Cleveland WWTP discharge, flow and loads were input into the WASP segment labeled as WWTP in Figure 1. The flow was set to a continuous 0.004 m^3/s (0.092 MGD) and loads were calculated by multiplying the WWTP pollutant concentrations by the discharge and converting the loads to kg/day. WWTP pollutant concentrations were taken as a combination of the requested permit concentrations in the application and adding nitrogen and phosphorus concentrations based on BioWin

process modeling (Table 5). Coefficients within the BioWin process model were initiated to values used in previous modeling of the City of Dripping Springs WWTP with no nitrogen limitation in the effluent (Carollo 2015) while basins within the BioWin model were determined from the Sawyer-Cleveland permit application. BioWin results did not include an effluent concentration for inorganic phosphorus so a value of 0.5 mg/L was chosen based on the initial modeling efforts regarding the City of Dripping Springs WWTP effluent (Richter 2016).

Table 5: Pollutant concentrations used in the WWTP discharge load calculations for the WASP model based on BioWin process modeling. The application contained no information regarding nitrogen or phosphorus limits.

Parameter	**Effluent Limits Proposed in Application (mg/L)**	**WWTP Effluent Concentrations predicted by BioWin (mg/L)**
WWTP CBOD	10	4.84
Ammonia	2	1.21
Nitrate-nitrite		17.31
Organic Nitrogen		2.98
Inorganic Phosphorus		0.5
Organic Phosphorus		3.83

RESULTS & DISCUSSION

To determine the potential impacts of the proposed Sawyer-Cleveland WWTP discharge to the Long Branch Tributary and the receiving Barton Creek, results of the model from the first segment downstream of the detention ponds (WASP segment DS Longbranch 1) will be used as input into a more parsimonious model[1]. When the WWTP effluent is added to the WASP model, flow from the effluent slowly fills the ponded segments and eventually enters the DS Longbranch 1 segment. After such time, this segment is constantly flowing. Total nitrogen (TN) and total phosphorus (TP) concentrations are shown to be higher than the TN and TP concentrations in the WWTP effluent (Figure 2). Biologic and chemical reactions occurring within the first detention pond convert the organic phosphorus into inorganic phosphorus, a form available to be used by vegetation, which allows for even more phytoplankton or benthic algae to grow in the downstream segments. The conversion of nutrients from excess phytoplankton growth contributes to the WWTP effluent concentrations and the combination increases the TN and TP concentrations to above the WWTP effluent concentrations in the WASP segment downstream of the ponds. Benthic algae concentrations were never above 10 mg/m^2 during the simulation; however, phytoplankton concentrations ranged from 120 to 140 µg/L during blooms in this segment (Figure 3). Dissolved oxygen dropped below 5 mg/L once during the simulation period but was above 6 mg/L during the majority of the simulation (Figure 4).

[1] As additional stream length gets modeled, the number of inputs increases, thereby greatly increasing the complexity of the model. A more parsimonious model can aid in estimating the impacts without engendering the additional workload.

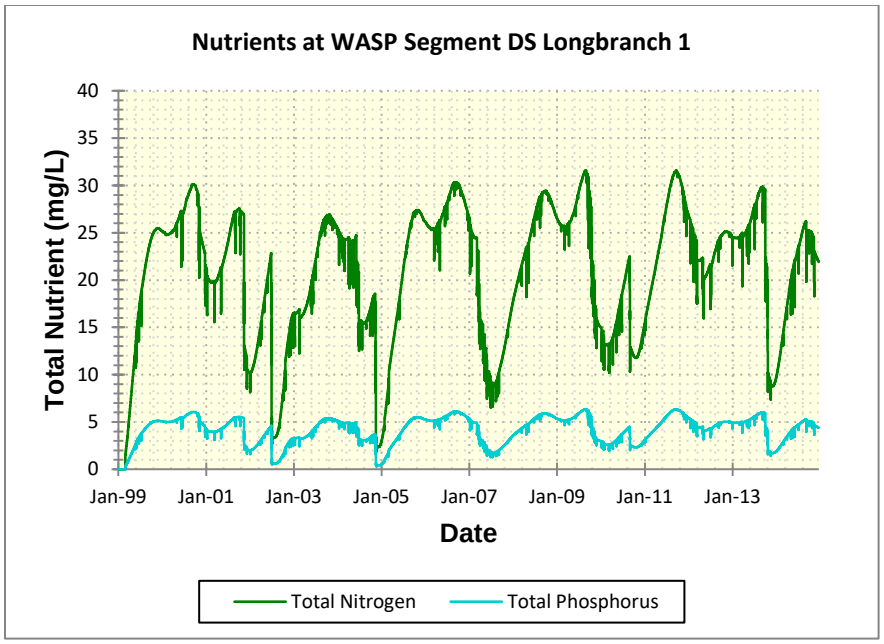

Figure 2: Total nitrogen (mg/L) and total phosphorus (mg/L) in WASP segment DS Longbranch 1, the first segment downstream of the 5 detention ponds immediately downstream of where the WWTP effluent enters Long Branch Tributary.

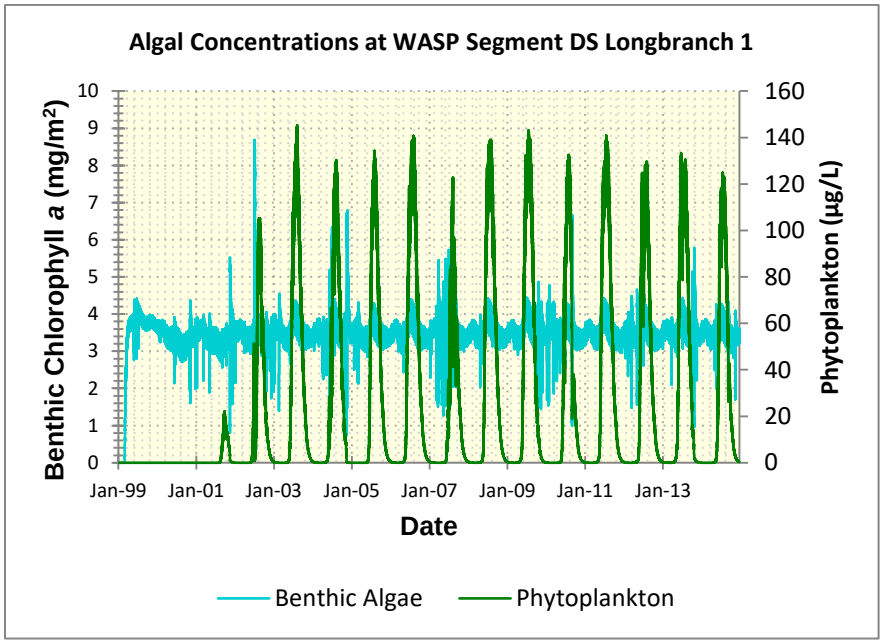

Figure 3: Benthic algae (mg/m^2) and phytoplankton (µg/L) concentrations in WASP segment DS Longbranch 1, the first segment downstream of the 5 detention ponds immediately downstream of where the WWTP effluent enters Long Branch Tributary.

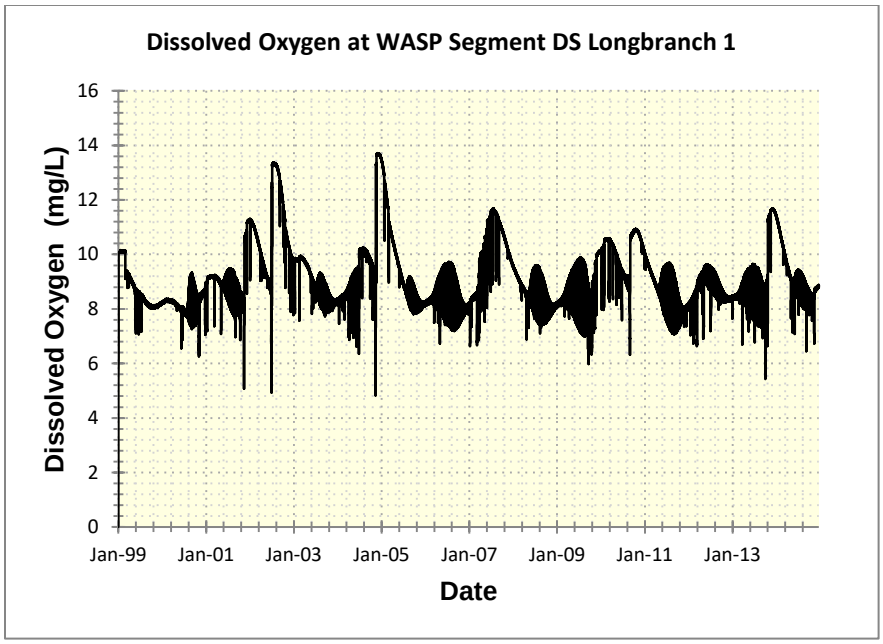

Figure 4: Dissolved Oxygen (mg/L) concentration in WASP segment DS Longbranch 1, the first segment downstream of the 5 detention ponds immediately downstream of where the WWTP effluent enters Long Branch Tributary.

CONCLUSIONS

Simulations indicate that the portion of the Long Branch Tributary downstream of the impacted detention ponds will be transformed from an ephemeral stream to a perennial stream with high concentrations of TN, TP, and phytoplankton. Modeled concentrations of phytoplankton vary by season with blooms occurring during the warmer months at concentrations around 120 to 140 µg/L which is well above the hypereutrophic threshold of 56 µg/L (Carlson and Simpson 1996). The TN and TP concentrations in this portion of the Long Branch Tributary are predicted to be similar to the WWTP effluent concentrations. Results from this model should be incorporated into a parsimonious model to determine how far downstream the nutrients and chlorophyll *a* concentrations remain elevated.

References

Ambrose RB, Wool TA. 2017. WASP8 Stream Transport - Model Theory and User's Guide.

Biggs BJF. 1985. Algae: a blooming nuisance in rivers. Soil Water. 21:27–31.

Biggs BJF, Price GM. 1987. A survey of filamentous algal proliferations in New Zealand rivers. New Zeal J Mar Freshw Res. 21(2):175–191. [accessed 2018 Feb 23]. http://www.tandfonline.com/doi/pdf/10.1080/00288330.1987.9516214.

Carlson RE, Simpson J. 1996. A Coordinator's Guide to Volunteer Lake Monitoring Methods. North Am Lake Manag Soc.:96 pp.

Carollo. 2015. Technical Memorandum No. 1 Conceptual Design Services City of Dripping Springs South Regional Wastewater Treatment Plant.

Chapra SC, Flynn KF, Rutherford JC. 2014. Parsimonious model for assessing nutrient impacts on periphyton dominated streams. J Environ Eng. 140(6).

Chow V Te. 1959. Open-Channel Hydraulics. Internatio. Davis HE, editor. New York, NY: McGraw-Hill Civil Engineering Series.

Glick R, Zhu T, Bai B, Hubka J, Robinson R, Mahmoud S, Manning S, Moezzi A, Selucky J. 2009. Stormwater Runoff Quality and Quantity from Small Watersheds in Austin , TX : Updated through 2008. Austin, Texas.

Herrington C. 2008a. Extension of an LA-QUAL (version 8 . 0) model for the proposed HCWID#1 wastewater discharge to realistic Bear Creek temperature and flow conditions.

Herrington C. 2008b. Impacts of the proposed HCWCID1 wastewater discharge to Bear Creek on nutrient and DO concentrations at Barton Springs.

Herrington C, Scoggins M. 2006. Potential Impacts of Hays County WCID No . 1 Proposed Wastewater Discharge on the Algae Communities of Bear Creek and Barton Springs.

Mabe JA. 2007. Nutrient and Biological Conditions of Selected Small Streams in the Edwards Plateau, Central Texas, 2005 – 06, and Implications for Development of Nutrient Criteria. Scientific. Reston, VA: U.S. Geological Survey.

Peacock ED. 2016. Summary of Water Balance and Discharge Evaluation for Dripping Springs TPDES Permit.

Quinn JM, Gilliland BW. 1989. The Manawatu River Cleanup - Has It Worked? Trans Inst Prof Eng New Zeal Civ Eng Sect. 16(1):22–26.

Quinn JM, Hickey CW. 1990. Magnitude of effects of substrate particle size, recent flooding, and catchment development on benthic invertebrates in 88 New Zealand rivers. New Zeal J Mar Freshw Res. 24(3):411–427. doi:10.1080/00288330.1990.9516433. [accessed 2018 Feb 23]. http://www.tandfonline.com/doi/abs/10.1080/00288330.1990.9516433.

Richter A. 2010. Comparison of Intermittent and Continuous Discharges on Bear Creek in WASP7.3 for Phytoplankton and Benthic Algae.

Richter A. 2016. WASP Model Analysis of a City of Dripping Springs Proposed Wastewater Treatment Plant Discharge to Onion Creek.

Turner M. 2010. Bear Creek Receiving Water Assessment – January 2009 – March 2010.

Welch EB, Jacoby JM, Horner RR, Seeley MR. 1988. Nuisance biomass levels of periphytic algae in streams. Hydrobiologia. doi:10.1007/BF00006968.

Wharfe JR, Taylor KS, Montgomery HAC. 1984. The growth of cladophora glomerata in a river receiving sewage effluent. Water Res. 18(8):971–979. doi:10.1016/0043-1354(84)90247-1. [accessed 2018 Feb 23]. https://www.sciencedirect.com/science/article/pii/0043135484902471.

APPENDIX A: List of constants used within the WASP model by constant group.

Constant Group	Value	Description
Global	0	Fresh water = 0- Marine Water = 1
	30.205	Latitude- degrees
	-97.995	Longitude- degrees
Inorganic Nutrient Kinetics	0.13	Nitrification Rate Constant @20 degree C (1/day)
	1.08	Nitrification Temperature Coefficient
	2	Half Saturation Constant for Nitrification Oxygen Limit (mg O2/L)
	0	Denitrification Rate Constant @20 degree C (1/day)
	1.04	Denitrification Temperature Coefficient
	0.1	Half Saturation Constant for Denitrification Oxygen Limit (mg O2/L)
Organic Nutrients	0.075	Dissolved Organic Nitrogen Mineralization Rate Constant @20 C (1/day)
	0.22	Dissolved Organic Phosphorus Mineralization Rate Constant @20 C (1/day)
	1.08	Dissolved Organic Nitrogen Mineralization Temperature Coefficient
	1.08	Dissolved Organic Phosphorus Mineralization Temperature Coefficient
CBOD	0.4	CBOD Decay Rate Constant @20 C (1/day)
	0.4	CBOD Decay Rate Constant @20 C (1/day)
	1.05	CBOD Decay Rate Temperature Correction Coefficient
	1.05	CBOD Decay Rate Temperature Correction Coefficient
	0.4	CBOD Half Saturation Oxygen Limit (mg O2/L)
	0.4	CBOD Half Saturation Oxygen Limit (mg O2/L)
Dissolved Oxygen	7	Global Reaeration Rate Constant @ 20 C (1/day)
	2.667	Oxygen to Carbon Stoichiometric Ratio
Phytoplankton	1	Phytoplankton Maximum Growth Rate Constant @20 C (1/day)
	1.08	Phytoplankton Growth Temperature Coefficient
	50	Phytoplankton Carbon to Chlorophyll Ratio (mg C/mg Chl)
	20	Optimal Temperature for Growth (C)
	0.05	Shape parameter for below optimal temperatures
	0.05	Shape parameter for above optimal temperatures
	0.125	Phytoplankton Respiration Rate Constant @20 C (1/day)
	1.045	Phytoplankton Respiration Temperature Coefficient
	0.044	Phytoplankton Death Rate Constant (Non-Zoo Predation) (1/day)
	0	Grazability (0 to 1)
	0	Nitrogen fixation option (0 no- 1=yes)
	350	Phytoplankton Optimal Light Saturation as PAR (watts/m2)
	0.025	Phytoplankton Half-Saturation Constant for N Uptake (mg N/L)
	0.004	Phytoplankton Half-Saturation Constant for P Uptake (mg P/L)
	0.5	Fraction of Phytoplankton Death Recycled to Detritus N
	0.5	Fraction of Phytoplankton Death Recycled to Detritus P
	0.25	Phytoplankton Nitrogen to Carbon Ratio (mg N/mg C)
	0.025	Phytoplankton Phosphorus to Carbon Ratio (mg P/mg C)

Constant Group	Value	Description
Light	0	Light Option (0 - light from lat-long; 1 - input diel light; 2 - input daily light-calculated diel light)
	0	Include Algal Self Shading Light Extinction in Steele (0=Yes- 1=No)
	0.813	Background Light Extinction Coefficient (1/m)
Macro Algae	4	Macro Algal Option: 1 = Floating forms (ave light) 2=Surface Algae (Top Light); 3 = submersed; 4 = benthic algae (not transported)
	0.025	MacroAlgae P:C Ratio (mg P/mg C)
	0.025	MacroAlgae Chl a:C Ratio (mg Chl/mg C)
	1	MacroAlgal Growth Model- 0 = Zero Order; 1 = First OrderMacroAlgal Growth Model-
	0.4	MacroAlgae Max Growth Rate (gD/m2-day- or 1/day)
	1.05	Temp Coefficient for Macro Algal Growth
	500	Macro Algal Carrying Capacity for First Order Model (g D/m2)
	0.2	Macro Algal Respiration Rate Constant (1/day)
	1.06	Temperature Coefficient for Macro Algal Respiration
	0.1	Internal Nutrient Excretion Rate Constant for Macro Algae (1/day)
	1.05	Temperature Coefficient for Macro Algal Nutrient Excretion
	0.15	Macro Algae Death Rate Constant (1/day)
	1.05	Temperature Coefficient for Macro Algal Death
	0.1	Macro Algal Half Saturation Uptake Constant for Extracellular Nitrogen (mg N/L)
	0.02	Macro Algal Half Saturation Uptake Constant for Extracellular Phosphorus (mg P/L)
	135	Macro Algal Light Constant for growth (langleys/day)
	10	Minimum Cell Quota of Internal Nitrogen for Macro Algal Growth (mgN/gDW)
	0.5	Minimum Cell Quota of Internal Phosphorus for Macro Algal Growth (mgP/gDW)
	720	Maximum Nitrogen Uptake Rate for Macro Algae (mgN/gDW-day)
	50	Maximum Phosphorus Uptake Rate for Macro Algae (mgP/gDW-day)
	10	Half Saturation Uptake Constant for Macro Algal Intracellular Nitrogen (mgN/gDW)
	2	Half Saturation Uptake Constant for Macro Algal Intracellular Phosphorus (mgP/gDW)
	2.5	MacroAlgae D:C Ratio (mg D/mg C)
	0.18	MacroAlgae N:C Ratio (mg N/mg C)
	2.69	MacroAlgae O2:C Production (mg O2/mg C)
	0.1	Fraction of Macro Algae Recycled to Organic N
	0.1	Fraction of Macro Algae Recycled to Organic P