

## **Modeling Benthic Algae Growth in Lake Creek, a High Nutrient Stream in Austin, TX**

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### **Abstract**

*The Water Quality Analysis Simulation Program (WASP) is a commonly used program to model water quality responses to nutrients in streams. Previous studies done by City of Austin engineers have used WASP to predict phytoplankton and benthic algal growth under low nutrient concentrations in local streams. Calibration of the WASP model to a creek with high concentrations of nutrients was performed for Lake Creek, located in north Austin, TX. This stream, was chosen because it has high concentrations of both nitrogen and phosphorus, flow above and below a Wastewater Treatment Plant (WWTP) discharge, and appropriate substrate. The maximum growth rate, maximum growth rate temperature coefficient, respiration rate, respiration rate temperature coefficient, nutrient excretion rate, nutrient excretion rate temperature coefficient, death rate, death rate temperature coefficient, half saturation uptake for extracellular nutrients, half saturation uptake for intracellular nutrients, minimum cell quotas for nutrients, maximum nutrient uptake rates, and light constants for algal growth were all used to calibrate the model for the high nutrient conditions. Benthic algae chlorophyll-a was over-predicted in the model because WASP does not separate benthic algae from macrophyte chlorophyll-a and only benthic algae chlorophyll-a was represented in the observed samples. All other variables were accurately predicted. One conclusion gleaned from this effort was that estimates of benthic algal growth in creeks with low nutrient concentrations may not be appropriate using the Lake Creek calibrated model as nutrient kinetics vary too much between these systems.*

### **Introduction**

After the Belterra (HCWCID1) wastewater treatment plant (WWTP) received a permit to discharge into the headwaters of Bear Creek, City of Austin engineers began to investigate how wastewater treatment plants affect other local creeks. The underlying goal was to calibrate several models to predict benthic algal growth under various levels of nutrient enrichment from different WWTP discharges. The Water Quality Analysis Simulation Program version 7.3 (WASP7.3) is an excellent program to “predict water quality responses to natural phenomena and man-made pollution for various pollution management

decisions” (USEPA 1988). This program has been used to model benthic algal growth under low nutrient conditions in previous projects (Richter 2010): therefore, we chose it to model benthic algal growth in streams under the different WWTP influenced nutrient conditions.

While it may be desirable to calibrate a single model and use it to predict benthic algal growth over all situations, it may be biologically invalid and lead to highly inaccurate predictions. It has been suggested that periphyton communities shift in species composition from a sensitive diatom community in low nutrient conditions to a filamentous and colonial algae community in high nutrient conditions (King et. al. 2009). The community nutrient kinetics such as nutrient uptake or half-saturation rates would then shift as the kinetics vary across different algal species (Borchardt et. al. 1994, Bothwell 1989, Rosemarin 1983, Wong and Clark 1976). Benthic algal nutrient kinetics are highly important when trying to calibrate a WASP model for benthic algal growth. Thus a WASP model calibrated using benthic algal nutrient kinetics under low nutrient conditions may not offer accurate predictions for algal growth under higher nutrient conditions.

City of Austin (COA) Watershed Protection Department (WPD) Environmental Resources Management division (ERM) Water Resource Evaluation section (WRE) staff set out to find a set of creeks that would span a wide range of nutrient conditions. Bear Creek was previously modeled using WASP and was considered as the low nutrient modeling location. Six other creeks were considered as potential locations for higher nutrient conditions while only two creeks were actually chosen for modeling. Each of the six creeks had a direct discharge from a wastewater treatment plant flowing into the main channel as the source for the higher nutrient conditions. In order to be selected for modeling, the sites were to have flow above and below the WWTP and measurable differences in nutrient concentrations between creeks. In order to keep the differences between the models to a minimum, we selected creeks with similar substrates. The South Fork San Gabriel near the Liberty Hill WWTP was chosen as a creek with moderate nutrient conditions while Lake Creek near the Anderson Mill MUD WWTP was chosen as a creek with high nutrient conditions. Results of the model for the South Fork San Gabriel are presented in a separate report (COA 2012). This report presents the results of the WASP model calibrated for high nutrient conditions on Lake Creek.

## Methods

Three sites on Lake Creek were chosen as monitoring locations where water chemistry and biological data would be collected (Table 1). Lake Creek @ Mellow Meadows was a shallow pool slightly upstream of the Anderson Mill MUD WWTP outfall. No backwater discharged from the plant into this section of the creek was observed; therefore, this site was gaged to be representative of upstream conditions.. Lake Creek @ Lake Creek Pkwy was the first monitoring location downstream of the outfall from the Anderson Mill MUD WWTP. This portion of the creek was a natural run/riffle where macrophytes were abundant in and surrounding the creek. Lake Creek @ Broadmeade Ave was the furthest downstream site which was somewhat channelized. In non-channelized portions of Lake Creek, macrophytes seemed to grow in great abundance in and around the creek edge. It is likely that this is due to the increased amount of nutrients that flow into this creek.

Table 1: Sites where observed data was collected and calibration was performed.

Site Name	Location
Lake Creek @ Mellow Meadows	Upstream of MUD outfall
Lake Creek @ Lake Creek Pkwy	~1150m downstream of outfall
Lake Creek @ Broadmeade Ave	~2090m downstream of outfall

WRE staff collected samples from the above sites every other month from April 2010 to February 2011. A full list of parameters collected at these sites can be seen in Table 2. Water quality samples were collected and preserved according to the WRE Standard Operating Procedures manual (WRE SOP 2010). Benthic algae rock scrapings followed Standard Operating Procedures as well, except a minimum of 9 rocks were scraped for analysis instead of 3 rocks. If more than 9 rocks were scraped then the number was recorded for reference. Samples were taken to Lower Colorado River Authority (LCRA) Environmental Lab Services for analysis. Phytoplankton and diatom identification was performed by Barbara Winsborough of Winsborough Consulting. Taxonomy, visual habitat assessment, and visual algae cover were not used in the WASP model; however, other parameters in Table 2 were useful. Water quality parameters and dissolved oxygen were used as ambient water column values to which the WASP model was calibrated. Benthic algae parameters were used to compute benthic algae nutrient ratios and to calibrate the cellular nutrients.

Table 2: Complete parameter list collected at site locations.

Description	Lab	Parameter
Water Quality	LCRA	Nitrate/Nitrite as N
		Ammonia as N
		Total Kjeldahl Nitrogen
		Orthophosphorus
		Total Phosphorus
		Phytoplankton Chlorophyll-a
		Total Suspended Solids
		Biochemical Oxygen Demand (BOD)
Algae Taxonomy	Winsborough Consulting	Soft bodied and diatom identification
Benthic Algae	LCRA	Nitrate/Nitrite as N
		Ammonia as N
		Total Kjeldahl Nitrogen
		Orthophosphorus
		Total Phosphorus
		Chlorophyll-a
		Total Suspended Solids
		Volatile Suspended Solids
		Total Organic Carbon
Field Parameters	Field	Dissolved Oxygen
		Conductivity
		pH
		Water Temperature
Visual Habitat	Field	EPA HQI
		Canopy Cover
Visual Algae Cover	Field	City of Austin Zig-Zag Method

Phytoplankton and benthic algae were modeled using WASP 7.3 in this calibration. Macrophytes were not incorporated into the modeling; however, WASP7.3 groups the chlorophyll-a of benthic algae and macrophytes into a single output.

The model was setup as an ‘Advanced Eutrophication’ model so that benthic algae could be simulated. The flow type was set to a 1-D Network Kinematic Wave (dynamic stream flow) and the solution technique was set to the iterative Euler technique, which is the traditional solution technique for hydrodynamic models (USEPA 2009). The maximum time step was set to 1 day, the minimum time step

to 0.0001 days, and the fraction of maximum time step to 90% (0.9) of the optimal time step. As the actual time step is calculated by the program and cannot be set in this version of WASP, the fraction of maximum time step specifies the fraction of the calculated time step to be used in the next time step which allows the modeler to keep the model stable (USEPA 2009). The start date of the WASP model was set to June 15, 2010, and was run to March 01, 2011. While there was data collected before this time period, flow data on Lake Creek was not available until the middle of June (Figure 1). At this time a USGS flow gage at Lake Creek Parkway (USGS 08105886) began collecting flow data that was used in this model. Flow inputs to the model were set at the Anderson Mill MUD WWTP outfall and the “dummy segment” prior to Mellow Meadows. Creek flow at the outfall input location was estimated as 69.63% of the flow at the USGS gage at Lake Creek Parkway based on drainage area. Upstream of the outfall was estimated as 5% of the flow at the outfall based on limited field data. Further inputs for the model included segmentation, initial conditions, loads, boundary conditions, kinetic parameters, temporal functions, and constants.

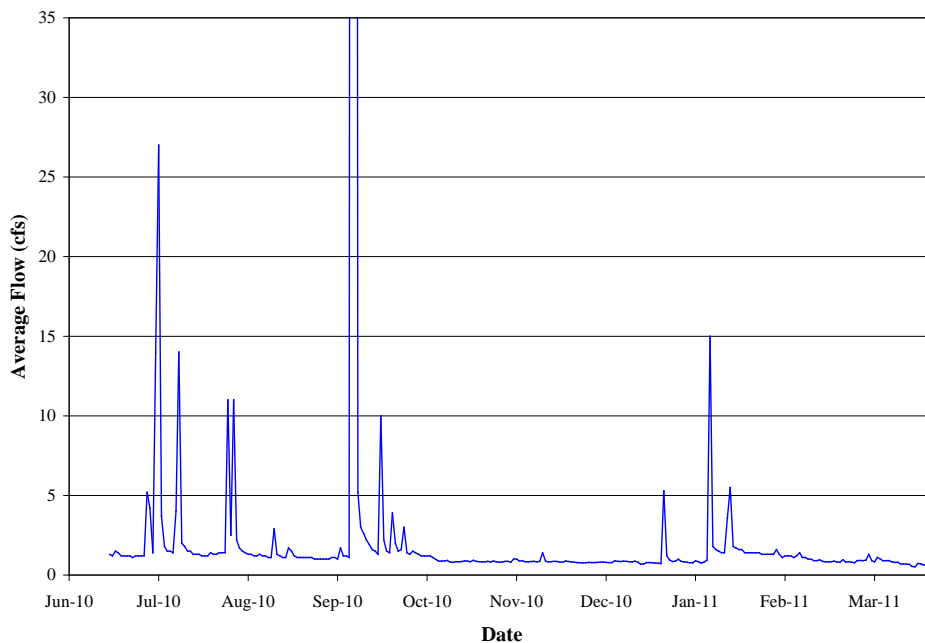


Figure 1: Average flow (cfs) at the Lake Creek Parkway gage (USGS 08105886) during the simulation time period. In September the flow exceeds the scale of the graph and was 230 cfs for two days.

Segmentation in the model was created based on WRE staff assessment of Lake Creek during a creek walk (Table 3). Contiguous areas of similar characteristics were placed into separate segments. The depth at the thalweg, length, and width were measured for each segment. The depth exponent was set according to the type of channel profile each segment presented and the depth multiplier was computed using the depth exponent and the measured depth (USEPA 2009). Minimum depth was set to the default of 0.001m for most of the segments. The segments identified as ‘Pool Downstream Bridge’, ‘Pool Upstream 183’, and ‘Downstream 183’ segments were large instream perennial pools on the creek. They were given a larger minimum depth as the creek is likely to stop flowing if the water level were low in these segments. The model would cease to run if these segments were given the default minimum depth. Slope was computed from an elevation layer in ArcMap. Roughness was set to 0.024 in most segments as this number was calibrated in another WASP model with a similar substrate (COA 2012). Adjustments to the roughness values and insertion of “dummy segments” were done to help with model stability.

Table 3: Model Segmentation.

Segment	Depth Mult	Depth Exponent	Length (m)	Width (m)	Min Depth	Slope	Roughness
Dummy Segment Start	0.5195	0.39	57.4	4.1159	0.001	0.003	0.024
Mellow Meadows	0.5195	0.39	57.4	4.115854	0.001	0.003036	0.024
Braid Upstream outfall	0.3155	0.3	17.2	1.509146	0.001	0.003036	0.024
Outfall	0.2969	0.39	22.6	2.743902	0.001	0.003036	0.024
Pool below outfall	0.6679	0.39	36.5	6.128049	0.001	0.003036	0.024
Upstream Bridge	0.7211	0.3	53.5	4.908537	0.001	0.003036	0.024
Bridge	0.5221	0.6	46.1	7.073171	0.001	0.009375	0.024
Pool Downstream Bridge	2.6675	0.5	32.3	5.487805	0.3	0.009375	0.05
Run to 183	0.5151	0.3	32.3	2.926829	0.001	0.009375	0.024
Pool Upstream 183	3.529	0.48	25.9	2.5	0.2	0.003	0.05
Under 183	0.6961	0.6	126.3	10.57927	0.001	0.002	0.01
Downstream 183	1.4971	0.48	152.2	12.0122	0.2	0.003509	0.024
Pecan Park channel	3.4807	0.6	160.7	1.676829	0.001	0.00582	0.024
Macrophyte channel	1.8554	0.39	210.3	4.115854	0.001	0.00378	0.024
Along Wal-Mart	2.9687	0.39	73	1.920732	0.001	0.010963	0.024
US Lake Creek Parkway	1.8554	0.39	181.7	7.347561	0.001	0.004661	0.024
Lake Creek Parkway	2.2265	0.39	273.2	3.841463	0.001	0.006283	0.024
Channel to Parliament	0.9648	0.39	155.9	1.158537	0.001	0.009453	0.024
Upstream Parliament	2.7804	0.48	169.2	7.439024	0.001	0.006454	0.024
Upstream Broadmeade	0.206	0.3	352.1	11.43293	0.001	0.004892	0.024
Dummy Segment	0.1545	0.3	109.8	3.658537	0.001	0.007346	0.024
Broadmeade	0.1545	0.3	109.8	3.6585	0.001	0.0073	0.024

Initial conditions were set to values from the June 16, 2010, samples collected at each monitoring location (Table 4). Data from Lake Creek @ Mellow Meadows was used for segments up to ‘US Lake Creek Parkway’, data from Lake Creek @ Lake Creek Parkway was used for additional segments up to ‘Upstream Broadmeade’, and data from Lake Creek @ Broadmeade was used for the ‘Broadmeade’ segment. Initial conditions for the second “dummy segment” were set to 0 otherwise the program would crash. No information was gathered for Silica data, so initial conditions were set to a high enough value for benthic algae to grow and were constant throughout the simulation. BOD was always less than the detection limit of 2 mg/L. Baseflow BOD levels of 0.5 mg/L were used for initial conditions in this simulation as well as in the Bear Creek and South Fork San Gabriel WASP models (COA 2010, COA 2012).

Table 4: Initial Conditions at each Lake Creek site.

Parameter	Lake Creek at Mellow Meadows	Lake Creek at Lake Creek Parkway	Lake Creek at Broadmeade
Ammonia (mg/L)	0.005	0.016	0.016
Nitrate (mg/L)	0.004	4.27	2.48
Dissolved Organic Nitrogen (mg/L)	0.234	0.368	1.42
Inorganic Phosphate (mg/L)	0.002	1.29	0.372
Dissolved Organic Phosphorus (mg/L)	0.004	0.09	0.133
Inorganic Silica (mg/L)	0.5	0.5	0.5
Dissolved Organic Silica (mg/L)	0.5	0.5	0.5
BOD (mg/L)	0.5	0.5	0.5
Dissolved Oxygen (mg/L)	3.3	11.4	15.51
Benthic Algae (gDW/m <sup>2</sup> )	19.89	11.46	4.71
Periphyton Cell Quota Nitrogen (mgN/gDW)	68.75	105.88	136.29
Periphyton Cell Quota Phosphorus (mgP/gDW)	6.05	18.29	39.3
Phytoplankton (ug/L)	1.7	1.8	4.2
pH (su)	7.55	7.91	9.39

Pollutant loads on Lake Creek come from the Anderson Mill MUD WWTP outfall and runoff from storm events. Data collected from the wastewater treatment outfall were input as loads into the WASP model. This data was sparse (only six data points over a year) so the data points were linearly interpolated within the model. Storm loads were handled using the boundary conditions. For each day of the simulation, the boundary inputs were set to either a baseflow concentration or a stormflow concentration based on flow conditions. A storm was considered to have occurred if the increase in flow from the previous day divided by the previous day flow was greater than or equal to one half. In other words, there was a 50% increase in flow from one day to the next. Baseflow concentrations used for the boundary conditions were parameter averages calculated from monitoring data collected. Stormflow concentrations were calculated as:

$$\text{Concentration} = (\text{previous day's flow} * \text{base flow concentration} + \text{change in flow} * \text{storm EMC}) / \text{flow}$$

There are no estimates of storm water event mean concentrations (EMC) in Lake Creek. However, storm EMCs have been developed for other areas based on drainage area and percent of impervious cover for the drainage area (Glick 2009). Base flow concentrations and storm EMCs used in the model are listed in Table 5.

Table 5: Baseflow and Event Mean Concentrations.

Parameter (mg/L)	Baseflow @ Front Segment	Baseflow @ End Segment	Storm EMC
Ammonia as N	0.012	0.035	0.095
Nitrate as N	0.035	5.810	0.662
Dissolved Organic Nitrogen	0.479	0.950	1.441
Inorganic Phosphate	0.004	1.101	0.104
Dissolved Organic Phosphorus	0.013	0.087	0.226

Constants were initially used from a previous model of Bear Creek (Table 6)(COA 2010), but several constants were changed in order to calibrate the model to a stream with high nutrients.

Table 6: Nutrient and Algal Constants.

<b>Inorganic Nutrient Kinetics</b>	
Nitrification rate at 20°C (1/day)	0.15
Nitrification Temperature Coefficient	1.08
Half Saturation Constant for Nitrification Oxygen Limit (mg/L)	2
Denitrification rate at 20°C (1/day)	0.1
Denitrification Temperature Coefficient	1.08
Half Saturation Constant for Denitrification Oxygen Limit (mg/L)	0.1
<b>Organic Nutrients</b>	
Detritus Dissolution Rate (1/day)	0.75
Dissolved Organic Nitrogen Mineralization Rate at 20°C (1/day)	0.09
Dissolved Organic Nitrogen Mineralization Temperature Coefficient	1.08
Dissolved Organic Phosphorus Mineralization Rate at 20°C (1/day)	0.15
Dissolved Organic Phosphorus Mineralization Temperature Coefficient	1.08
<b>CBOD</b>	
CBOD Decay Rate at 20°C (1/day)	0.4
CBOD Decay Rate Temperature Coefficient	1.05
CBOD Half Saturation Oxygen Limit (mg/L)	0.4
<b>Dissolved Oxygen</b>	
Oxygen to Carbon Ratio	2.67
Global Reaeration Rate at 20°C (1/day)	1

Table 6: Nutrient and Algal Constants.(continued)

<b>Benthic Algae</b>	
Benthic Algae D:C Ratio (mg D/mg C)	9.5
Benthic Algae N:C Ratio (mg N/mg C)	0.935
Benthic Algae P:C Ratio (mg P/mg C)	0.184
Benthic Algae Chl a:C Ratio (mg Chl/mg C)	0.056
Benthic Algae O <sub>2</sub> :C Production (mg O <sub>2</sub> /mg C)	2.69
Growth Model, 0 = Zero Order; 1 = First Order	0
Maximum Growth Rate (gD/m <sup>2</sup> -day, or 1/day)	20
Temperature Coefficient for Benthic Algal Growth	0.9
Respiration Rate (1/day)	0.2
Temperature Coefficient for Benthic Algal Respiration	0.9
Internal Nutrient Excretion Rate for Benthic Algae (1/day)	0.45
Temperature Coefficient for Benthic Algal Nutrient Excretion	0.9
Death Rate (1/day)	0.4
Temperature Coefficient for Benthic Algal Death	0.9
Half Saturation Uptake for Extracellular Nitrogen (mg N/L)	0.15
Half Saturation Uptake for Extracellular Phosphorus (mg P/L)	0.2
LIGHT OPTION, 1=Half saturation, 2=Smith, 3= Steele	2
Light Constant for growth (langleys/day)	350
Benthic Algae ammonia preference (mg N/L)	0.25
Minimum Cell Quota of Internal Nitrogen for Growth (mgN/gDW)	10
Minimum Cell Quota of Internal Phosphorus for Growth (mgP/gDW)	2
Maximum Nitrogen Uptake Rate for Benthic Algae (mgN/gDW-day)	200
Maximum Phosphorus Uptake Rate for Benthic Algae (mgP/gDW-day)	50
Half Saturation Uptake for Intracellular Nitrogen (mgN/gDW)	10
Half Saturation Uptake for Intracellular Phosphorus (mgP/gDW)	7
Fraction of Benthic Algae Recycled to Organic N	0
Fraction of Benthic Algae Recycled to Organic P	0
<b>Phytoplankton</b>	
Phytoplankton Nitrogen to Carbon Ratio (mg N/mg C)	0.25
Phytoplankton Phosphorus to Carbon Ratio (mg P/mg C)	0.025
Phytoplankton Carbon to Chlorophyll Ratio (mg C/mg Chl)	50
Phytoplankton Maximum Growth Rate at 20°C (1/day)	50
Phytoplankton Growth Temperature Coefficient	1.07
Optimal Temperature for Growth (°C)	25
Shape parameter for below optimal temperatures	0.05
Shape parameter for above optimal temperatures	0.05
Phytoplankton Respiration Rate at 20°C (1/day)	0.125
Phytoplankton Respiration Temperature Coefficient	1.045
Phytoplankton Death Rate Constant (Non-Zoo Predation) (1/day)	0.044
Phytoplankton death rate due to salinity toxicity (1/day)	0
Grazability (0 to 1)	0
Phytoplankton Half-Saturation for N Uptake (mg N/L)	0.025
Phytoplankton Half-Saturation for P Uptake (mg P/L)	0.004
Nitrogen fixation option (0 no, 1=yes)	0
Phytoplankton Optimal Light Saturation (Ly/day)	350
Fraction of Phytoplankton Death Recycled to Organic N	1
Fraction of Phytoplankton Death Recycled to Organic P	1

Time functions and parameters included in the model were water temperature, solar radiation, fraction of daily light, wind speed, air temperature, light extinction, ammonia benthic flux, phosphorus benthic flux, and sediment oxygen demand. Water temperature was measured by WRE staff every 2 months during the

simulation time period. Data points were linearly interpolated between sample times. Average monthly solar radiation, wind speed, and air temperature were calculated from daily values taken from station TX Austin 33 NW – Balcones National Wildlife Refuge (Flying “X” Ranch) in the National Climatic Data Center (NOAA Satellite and Information Service). Average monthly fraction of daily light was taken from previous WASP models and the assumption was made that the daily light fraction did not change from other years (Richter 2010). Ammonia benthic flux, phosphorus benthic flux, and sediment oxygen demand were also set to numbers used in previous WASP models and varied spatially (Table 7) (Richter 2010).

Table 7: Sediment Water Interaction Parameters

Parameter	Stream Segments	Ponds
Sediment oxygen demand (g/m <sup>2</sup> -day)	1.0	2.0
Ammonia flux (sediment to water) (mg/m <sup>2</sup> day)	0.015	0.015
Phosphate flux (sediment to water) (mg/m <sup>2</sup> -day)	0.015	0.015

Light extinction was calculated from data collected on March 21, 2011, at each of the three site locations. A quantum meter was used to collect the photosynthetic photon flux at the surface and every 0.0254 m down until the bottom of the creek was reached. The average difference in photon flux divided by the difference in depth was computed as the light extinction for each site (Table 8). In all cases the photosynthetic photon flux between the surface and the first 0.0254 m was not used in the light extinction calculation as measurements observed were judged to be highly skewed.

Table 8: Light extinction coefficients (per meter) and the model segments that each value was inserted into.

	Lake Creek @ Mellow Meadows	Lake Creek @ Lake Creek Pkwy	Lake Creek @ Broadmeade
Segments Used	1-11	12-18	19-22
Light Extinction	1.24	1.36	1.26

## Results

Benthic chlorophyll-a was predicted differently between sites upstream and downstream of the Anderson Mill WWTP outfall (Figure 2). Upstream of the outfall, the model predicted benthic chlorophyll-a well until October, when the predicted values dropped to almost 0 mg/m<sup>2</sup>. Downstream of the outfall, benthic chlorophyll-a was over-predicted for almost every sampling event. The over-prediction of benthic chlorophyll-a could be attributed to macrophyte growth, which is not compensated for in observed values. All sampled chlorophyll-a values consisted only of chlorophyll-a obtained from benthic algae, while WASP predictions included chlorophyll-a from macrophytes as well as benthic algae. Downstream of the WWTP outfall there was an abundance of macrophytes growing in and around the creek edge which could have contained a significant amount of chlorophyll-a. Since the observed values do not account for this extra amount of chlorophyll-a they are likely to be less than any predicted value of chlorophyll-a that WASP computes. It should become a priority to obtain chlorophyll-a content of macrophytes growing in streams as well as benthic algae chlorophyll-a content in order to calibrate WASP models more accurately, especially in areas where macrophytes are in great abundance.

Benthic constants that were changed in order to directly calibrate chlorophyll-a content included the maximum growth rate (with temperature coefficient), respiration rate (with temperature coefficient), death rate (with temperature coefficient), minimum cell quotas of internal nutrients for growth, and

maximum nutrient uptake rates. The maximum growth rate, respiration rate, and death rate were increased in order to allow for variation in chlorophyll-a values. The temperature coefficients were lowered so that predicted values would adhere to the overall trends supported by observed values. Maximum nutrient uptakes rates were decreased and minimum cell quotas of internal nutrients were increased in order to lower the predicted values of benthic chlorophyll-a.

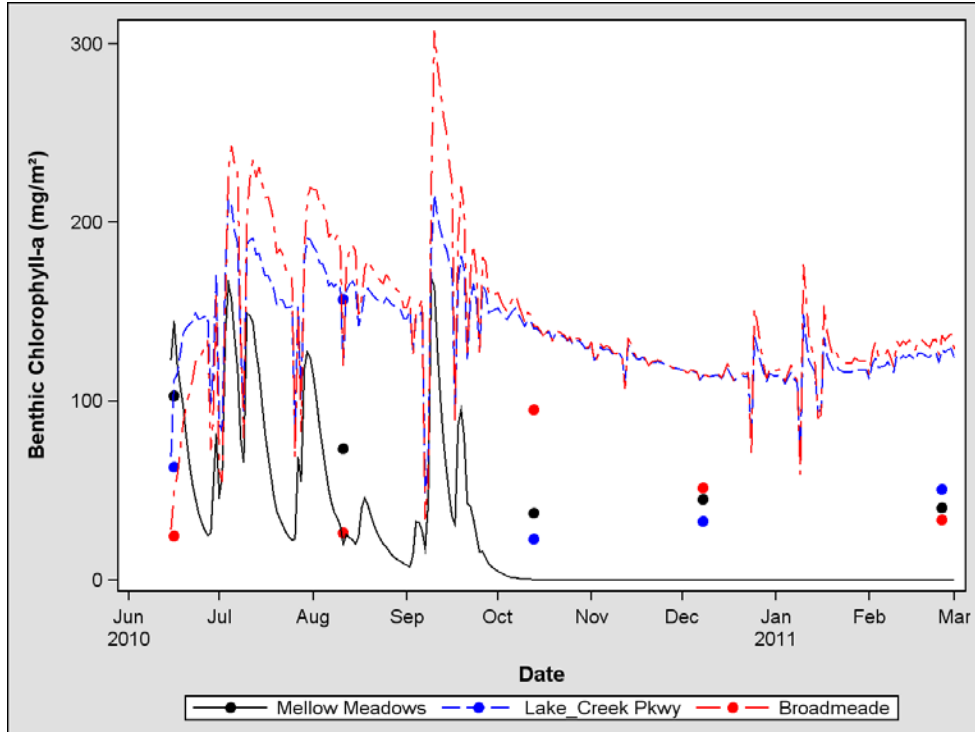


Figure 2: Predicted and observed values for benthic chlorophyll-a ( $\text{mg}/\text{m}^2$ ). WASP predictions are represented by lines while observed data are dots.

Phytoplankton chlorophyll-a was predicted well at Lake Creek @ Mellow Meadows and Lake Creek @ Lake Creek Pkwy, but the predictions at Lake Creek @ Broadmeade were consistently lower than the observed values (Figure 3). The phytoplankton chlorophyll-a values were under-predicted even though the phytoplankton maximum growth rate constant was set to 50/day. In previous WASP models this number was set to 2 or 3/day with accurate predictions. It is unclear why the maximum growth rate had to have been set this high in order to obtain phytoplankton chlorophyll-a values close to the observed values at Lake Creek @ Broadmeade. However, the overall trend in phytoplankton growth was predicted fairly well at all three sites. The optimal temperature for growth and the shape parameters for above/below optimal temperatures gave the predicted phytoplankton the shape for the overall trend.

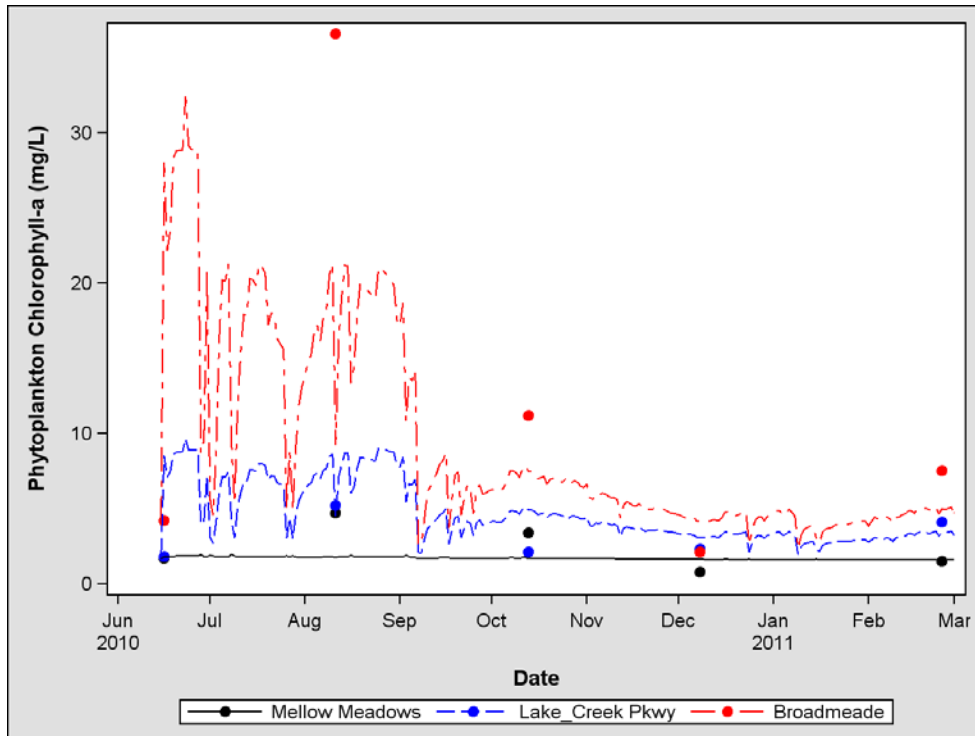


Figure 3: Predicted and observed values for phytoplankton chlorophyll-a (mg/L). WASP predictions are represented by lines while observed data are dots.

Predicted dissolved oxygen trends at Lake Creek Pkwy and Broadmeade matched observed dissolved oxygen fairly well (Figure 4). Predicted values at Broadmeade were 2-3 mg/L lower than observed values during the early portions of the simulation but were 4-5 mg/L higher than observed values during the later portions of the simulation. Lake Creek @ Lake Creek Pkwy predicted dissolved oxygen was also over-predicted by similar amounts in the later portion of the simulation. The Half Saturation Uptake of Extracellular Phosphorus was reduced to 0.2 from 0.3 mg/L and the Light constant for growth was increased from 135 to 350 langleys/day, in order to calibrate dissolved oxygen. In WASP models calibrated for streams with a lower concentration of phosphorus, benthic algal growth was highly sensitive to the Half Saturation Uptake of Extracellular Phosphorus. In the current calibration, no change in benthic algal biomass was detected upon changing the extracellular half saturation of phosphorus from 0.3 mg/L to a number as low as 0.04 mg/L. However, the dissolved oxygen was predicted to be triple the observed values when the extracellular half saturation of phosphorus was set to 0.3 mg/L. Because the variable was sensitive in other WASP models, we were reluctant to lower extracellular half saturation of phosphorus to a low value such as 0.04 mg/L. Instead the variable was lowered to 0.2 mg/L and the dissolved oxygen was further calibrated by raising the light constant for benthic algal growth.

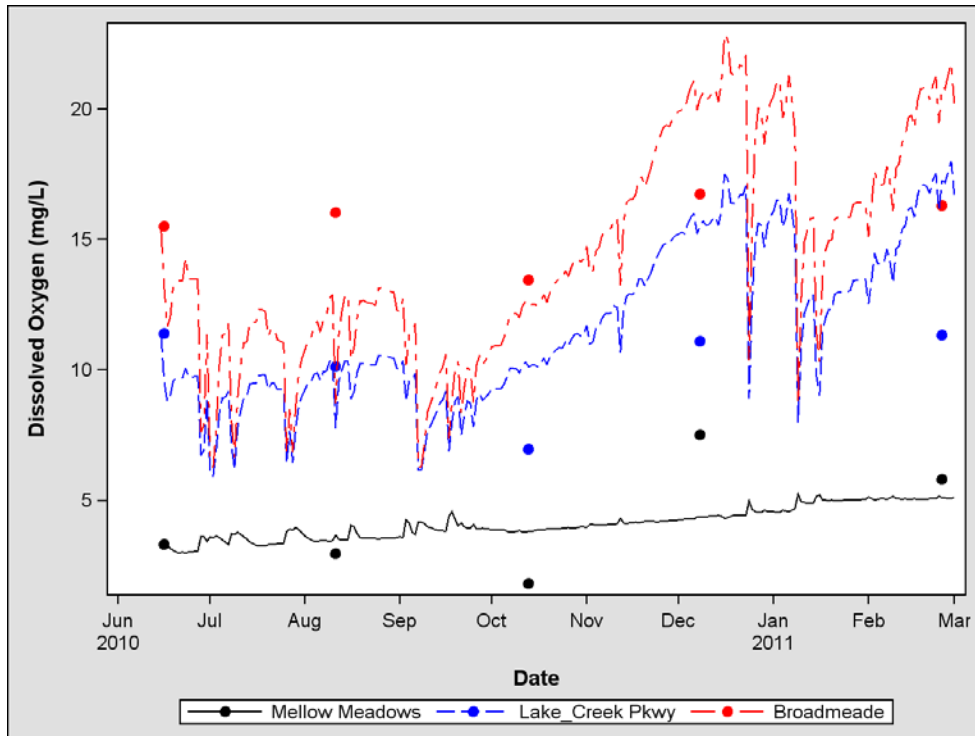


Figure 4: Predicted and observed values for dissolved oxygen (mg/L). WASP predictions are represented by lines while observed data are dots.

The predicted concentration of ammonia was quantitatively close to the observed ammonia concentrations, but the predicted ammonia concentration spiked two months prior to when the observed ammonia increased (Figure 5). No variable or temperature coefficient could be adjusted to make the predicted ammonia increase when the observed values were high. The Internal Nutrient Excretion Rate was increased and Maximum Nitrogen Uptake Rate was decreased in order to allow the increase in predicted ammonia concentrations. Otherwise the ammonia was predicted to never increase above 0.1 mg/L.

Predicted nitrate (Figure 6), orthophosphorus (Figure 7), and total phosphorus (Figure 8) were all close to observed values in both quantity and temporal trend. These output parameters were not sensitive to any of the model variables that were adjusted. There was no change in predicted nitrate, orthophosphorus, or total phosphorus between initial simulations and the calibrated simulations.

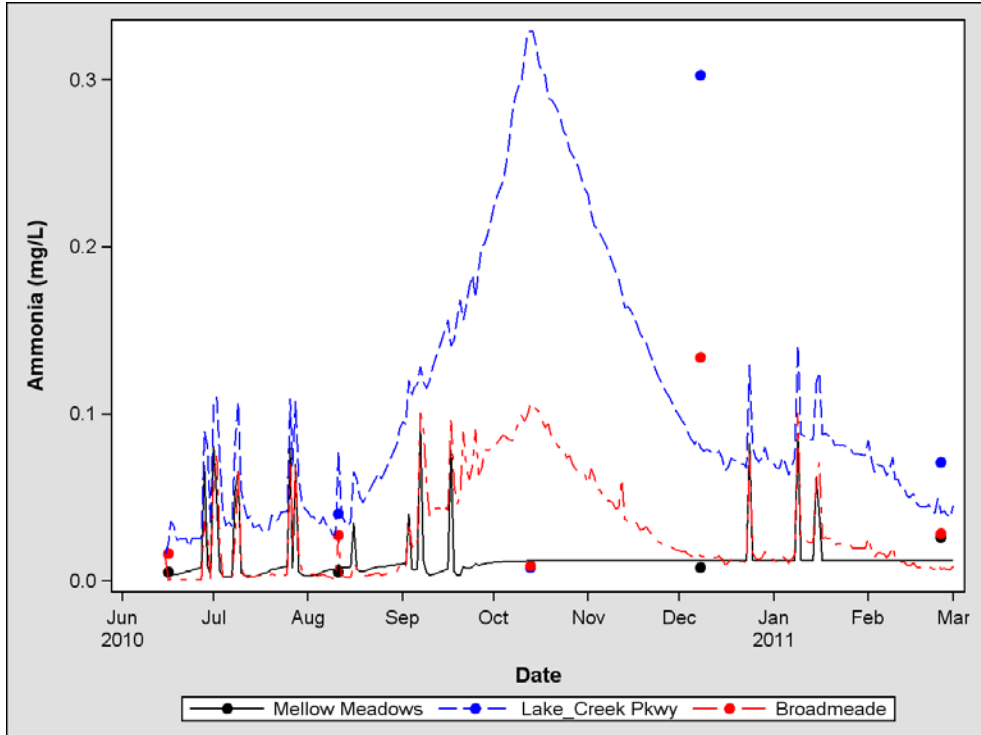


Figure 5: Predicted and observed values for free ammonia (mg/L). WASP predictions are represented by lines while observed data are dots.

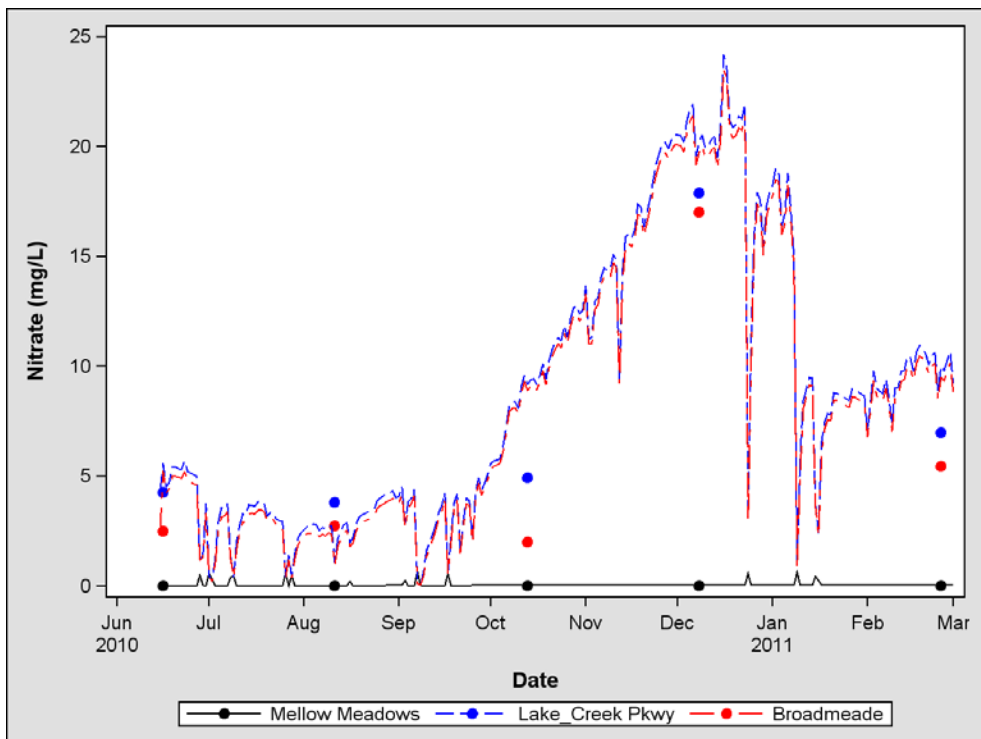


Figure 6: Predicted and observed values for free nitrate (mg/L). WASP predictions are represented by lines while observed data are dots.

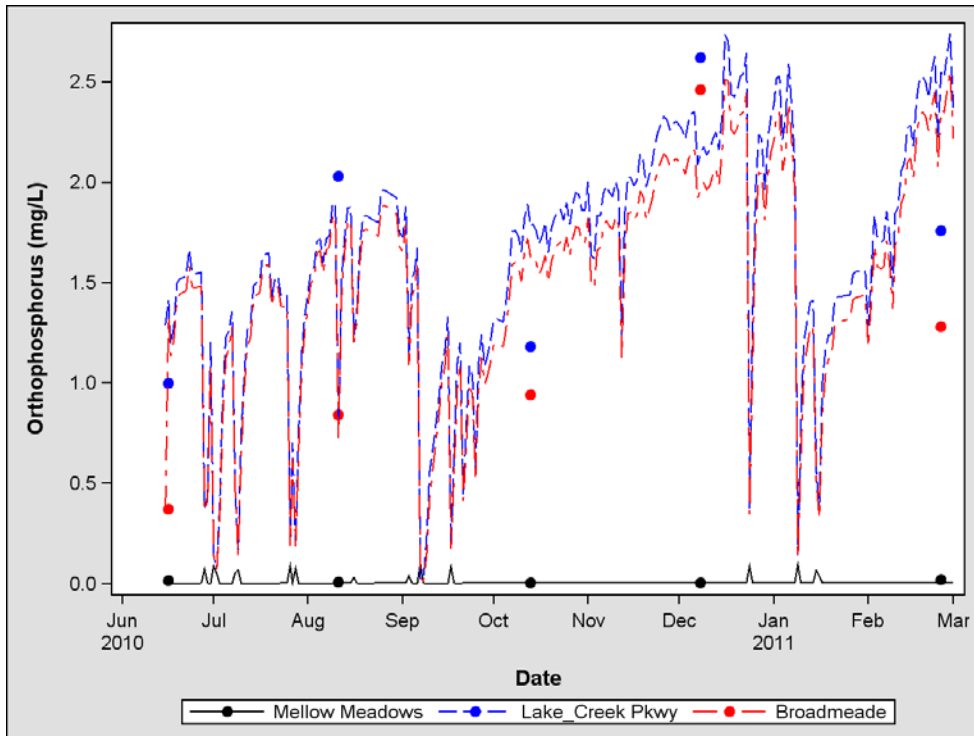


Figure 7: Predicted and observed values for free orthophosphorus (mg/L). WASP predictions are represented by lines while observed data are dots.

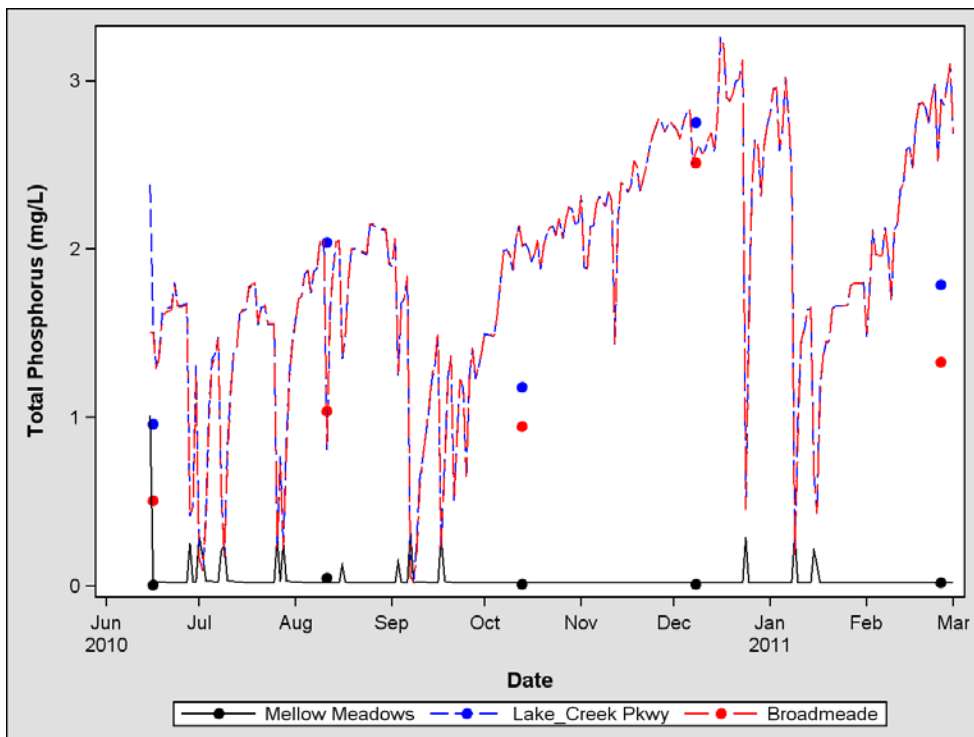


Figure 8: Predicted and observed values for total phosphorus (mg/L). WASP predictions are represented by lines while observed data are dots.

The benthic algal cellular nitrogen was under-predicted at each site (Figure 9). While under-predicted, the cellular nitrogen at Lake Creek @ Broadmeade and Lake Creek @ Mellow Meadows was relatively close to the observed concentrations and followed similar temporal trends. The cellular nitrogen predicted at Lake Creek @ Lake Creek Pkwy showed the largest difference from the observed values. Cellular nitrogen at the Broadmeade site was predicted to be higher than at the Lake Creek Pkwy site, while the observed values showed the opposite trend. This was the only output parameter where the predicted and observed showed this disagreement. It is unknown why this parameter was predicted to have a higher concentration at the Broadmeade site; however, no adjustment of model variables increased cellular nitrogen at the Lake Creek Pkwy site to values greater than that predicted at the Broadmeade site. Cellular nitrogen output was sensitive to the Internal Nutrient Excretion Rate, Minimum Cell Quota of Internal Nitrogen for Growth, and Maximum Nitrogen Uptake Rate. When the Maximum Nitrogen Uptake Rate was decreased and the Internal Nutrient Excretion Rate increased to calibrate other parameters the predicted concentration of cellular nitrogen decreased to very low levels. As the Minimum Cell Quota of Internal Nitrogen was increased the amount of predicted cellular nitrogen also increased. This parameter could not be increased greatly because benthic algae chlorophyll-a was sensitive to the minimum cell quota.

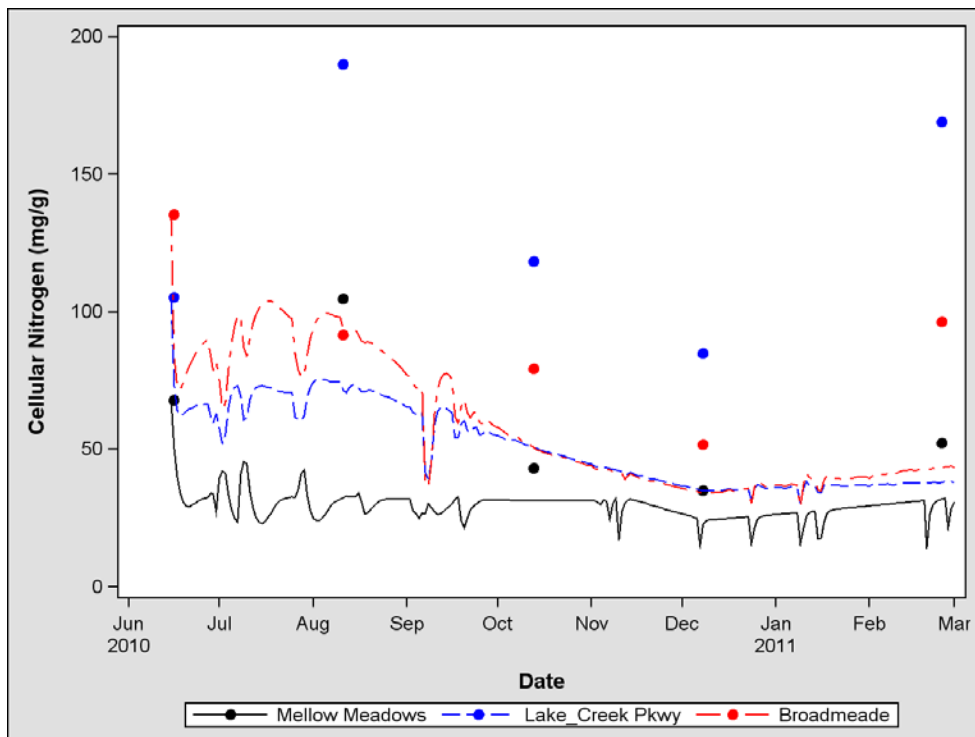


Figure 9: Predicted and observed values for benthic cellular nitrogen (mg/gDW). WASP predictions are represented by lines while observed data are dots.

Benthic algal cellular phosphorus was predicted well at the Lake Creek Pkwy site, but under-predicted at the other two sites (Figure 10). Early in the simulation cellular phosphorus at the Broadmeade site was predicted well, but during the later months of the simulation the predicted values were much lower than the observed values. The cellular phosphorus at the Mellow Meadows site seemed to always be under-predicted. Cellular phosphorus was sensitive to the Half Saturation Uptake for Intracellular Phosphorus, Maximum Phosphorus Uptake Rate, Minimum Cell Quota of Internal Phosphorus, and Internal Nutrient Excretion Rate. As the Maximum Phosphorus Uptake Rate was decreased and the Internal Nutrient Excretion Rate was increased to calibrate other output parameters, the cellular phosphorus decreased. When the Minimum Cell Quota of Internal Phosphorus was increased the amount of cellular phosphorus

increased slightly and the Half Saturation Uptake for Intracellular Phosphorus was increased to further increase the amount of cellular phosphorus.

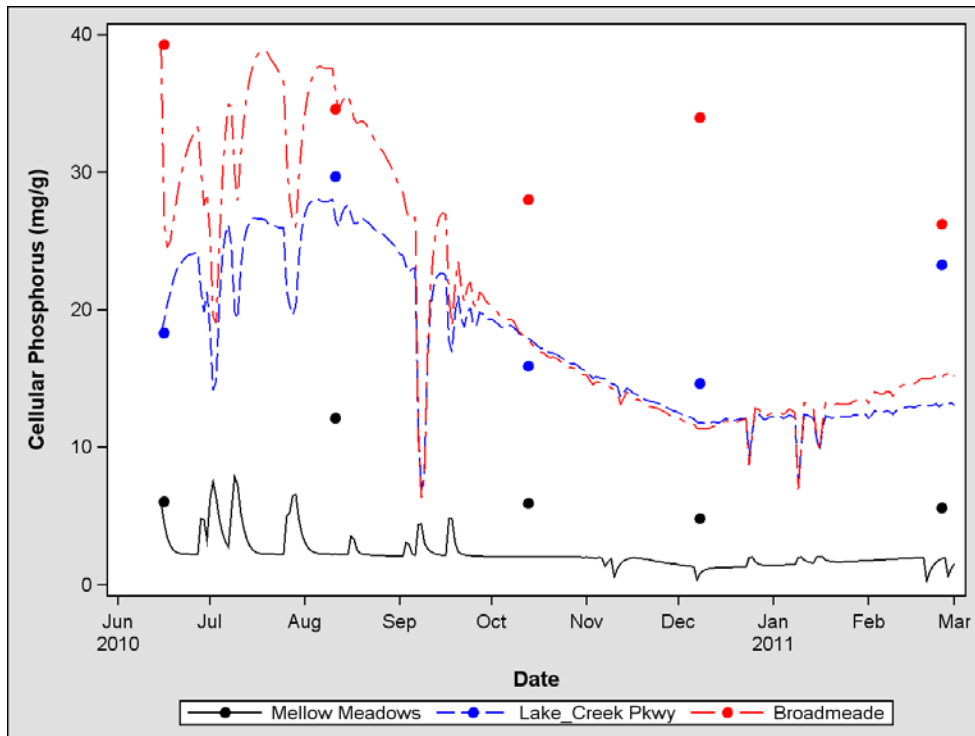


Figure 10: Predicted and observed values for benthic cellular phosphorus (mg/gDW). WASP predictions are represented by lines while observed data are dots.

## Conclusion

While the WASP model predicted water quality and algal data well enough to be used on high nutrient streams, some issues remain. A large number of constants pertaining to benthic algal growth were changed from previous WASP calibrations on nutrient poor streams. The maximum growth rate, maximum growth rate temperature coefficient, respiration rate, respiration rate temperature coefficient, nutrient excretion rate, nutrient excretion rate temperature coefficient, death rate, death rate temperature coefficient, half saturation uptake for extracellular nutrients, half saturation uptake for intracellular nutrients, minimum cell quotas for nutrients, maximum nutrient uptake rates, and light constants for algal growth were all altered from systems with lower nutrient concentrations. It is likely that the WASP model cannot accurately predict algal growth in streams of a different trophic status using the same benthic algal constants.

King and Winemiller (2009) showed that there is a shift in periphyton nutrient ratios and community structure as surface-water nutrients increase, especially phosphorus, in Texas. Periphyton C:P, N:P, and C:N have been shown to decline as surface-water total phosphorus increased. The periphyton chlorophyll-a:ash-free dry mass ratio has been shown to increase as total phosphorus increased in the surface water. Previous studies also suggest that periphyton communities shift from sensitive diatoms, calcareous cyanobacteria, and other non-chlorophyll bearing microbes to filamentous and colonial green algae under increasing nutrient conditions (King *et. al.* 2009). As community composition shifts and different species dominate the area, the maximum growth rate, half saturation uptake, maximum nutrient uptake rates, and minimum cell quotas of nutrients for growth can also shift as species have different

nutrient kinetics (Borchardt *et.al.* 1994, Bothwell 1989, Rosemarin 1983, Wong and Clark 1976). Because these variables change in the environment as nutrient enrichment occurs, it is not appropriate to calibrate the WASP model to a single set of constants and accurately predict algal growth.

As further evidence of this conclusion, the model did a good job of predicting benthic chlorophyll-a trends at the two downstream sites (high nutrients) but the chlorophyll-a predictions at the Mellow Meadows site were not accurate late in the simulation period. Algal growth was predicted relatively well at the Mellow Meadows site early in the simulation, but then chlorophyll-a concentration dropped to almost zero based on a nutrient limitation. The observed values of benthic chlorophyll-a showed that benthic algae should still be growing at this site. There were still nutrients available at the Mellow Meadows site, so under a different set of nutrient constants algal growth may have been predicted accurately at the upstream site. The current calibrated model should be used to predict algal growth on a previously modeled low nutrient system such as Bear Creek in order to determine how inaccurate predictions would be with all of the modifications. If the predictions are highly inaccurate it may be helpful to identify the periphytic community structure present within a creek and base benthic algal model constants on the dominance of either sensitive diatoms and non-chlorophyll bearing microbes or filamentous and colonial green algae. It is unknown if creeks with similar periphytic community structures could be calibrated similarly; however, the solution is biologically sound and may be a profitable further investigation as this might reduce calibration effort.

Another major note is the importance of macrophyte chlorophyll-a data. In some streams, macrophytes are not abundant and any chlorophyll-a data they contribute to the system might be negligible. Lake Creek was filled with macrophytes as well as benthic algae in the many of the visits to gather observed data. In this case the chlorophyll-a from macrophytes was likely to be significant and a more accurate chlorophyll-a prediction could have been modeled if the data was available. It is recommended that chlorophyll-a concentration of macrophytes somehow be quantified in the future so that more accurate predictions can be made using the WASP model.

Regardless of these two issues, this model is adequate for making gross estimates of algal growth in high nutrient streams. Most parameters were accurately predicted quantitatively and temporally in the downstream sites (high nutrients). It is doubtful that the model can currently be used for systems with low nutrients. Because of the many changes to the model constants it may be more appropriate to use this model for predicting algal growth downstream of proposed wastewater treatment plant discharges as opposed to a model calibrated to the ambient low levels of nutrients in the creek prior to the discharge.

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