# Extension of an LA-QUAL (version 8.0) model for the proposed HCWID#1 wastewater discharge to realistic Bear Creek temperature and flow conditions

Chris Herrington
Watershed Protection & Development Review Department
City of Austin

SR-08-04. March 2008

*Multiple steady-state LA-QUAL(version 8.0) models for varying temperature and flow conditions were evaluated and used to generate a time-series prediction of water quality impacts from the proposed HCWID#1 discharge to Bear Creek at the upper boundary of the Barton Springs portion of the Edwards Aquifer Recharge Zone. LA-QUAL predicted output is sensitive to dilution (amount of natural creek flow present) and temperature (removal rates are temperature-dependent), and the use of multiple models is a more accurate representation of the temporal variability in flow and temperature. Using this approach, the proposed HCWID#1 discharge is predicted to degrade the water quality of Bear Creek and the Edwards Aquifer. However, this analysis is still only a conservative approximation of the actual degradation expected and does not simulate more dynamic ecological responses such as nutrient spiraling or storm event driven sediment re-suspension.*

## Introduction

Hays County Water Control and Improvement District #1 (HCWID1) serving the Belterra Subdivision has applied to the Texas Commission on Environmental Quality (TCEQ) for a permit (Table 1) to discharge up to 500,000 gal/day (0.774 $ft^3/s$) of treated wastewater directly to the headwaters of Bear Creek, Hays County, Texas. The water quality of Bear Creek with the proposed discharge was previously predicted at the upstream recharge zone boundary of the Barton Springs segment of the Edwards Aquifer using the steady-state one-dimensional LA-QUAL (version 8.0) model (Miertschin and Obenour 2006, COA 2006, Herrington 2008) for several varying temperature and flow scenarios. However, the temporal distribution of the varying temperature and flow scenarios has not been previously assessed against measured discharge and ambient temperature. Thus, the increase in long-term average concentrations and mass loading from the proposed discharge to the Edwards Aquifer has not been accurately represented. By developing LA-QUAL models for multiple sets of temperature and flow conditions and then applying model output to measured daily time-series discharge and temperature measurements, a more realistic assessment of the long-term impacts of the proposed discharge may be conducted. Utilizing these distributions of results allows toxicologists, aquatic scientists, and risk assessors a more familiar probability basis to make evaluate impacts to aquatic ecology in the discharge route, Edwards aquifer, and at Barton Springs Pool.

Table 1. Final phase draft permit limitations for proposed HCWID1 discharge (WQ0014293-001).

| Effluent Characteristic | Daily Average | 7-day Average | Daily Maximum | Single Grab Maximum |
|---|---|---|---|---|
| Flow, MGD | 500,000 | n/a | n/a | n/a |
| Carbonaceous BOD (5-day), mg/L | 5 | 10 | 20 | 30 |
| Ammonia Nitrogen, mg/L | 2 | 5 | 10 | 15 |
| Total Phosphorus, mg/L | 0.15* | 0.3 | 0.6 | 0.9 |

*expressed as a daily median

Previous LA-QUAL model results of the impacts of proposed discharge (Miertschin and Obenour 2006, COA 2006, Herrington 2008) have demonstrated that model predictions are highly sensitive to selected ambient temperatures and Bear Creek flow rates. TCEQ assessed the potential impacts of the discharge using the steady-state QUAL-TX model (version 3.5, updated November 1999) in a single condition with warm water temperature (29.7 ºC) and no ambient Bear Creek headwater or tributary flow additions. The low flow, hot temperature condition represents a system with maximum hydraulic residence time and maximum nutrient removal in the QUAL-TX or LA-QUAL models. Although this may be appropriate for assessing critical dissolved oxygen (DO) conditions, it may not represent time periods when biochemical oxygen demand (BOD) or nutrient loadings to the aquifer are higher. Therefore, it is only a local extreme of critical conditions whereas the low temperature and low dilution rates may yield a worse condition for aquifer and Barton Springs water quality. From the time series of flow at the Bear Creek USGS gage, it is evident that this low flow winter condition has occurred in the past and is a reasonable scenario for TCEQ to assess for evaluating permit limits and special conditions in the permit.

## Methods

Bear Creek daily average discharge and average Austin air temperature are variable across the year (Figure 1). Bear Creek daily average discharge may be represented by the United States Geological Survey (USGS) gage 08158810 upstream of the upper recharge zone boundary from 1978 to present. Long-term records of daily Bear Creek water temperature are not available. Air temperature data at the Austin Mueller municipal airport station were obtained from the National Climatic Data Center of the National Weather Service from 1930 to 2007. Daily maximum and minimum air temperature values were averaged to yield daily average temperature. Daily average air temperature data were converted to daily average water temperatures by linear regression ($T_{water} = 0.8139*T_{air} + 3.3732$) of 99 ambient instantaneous water temperature readings recorded by the USGS and COA at the Bear Creek gage 08158810 site and concurrent average Austin air temperature (Figure 2).

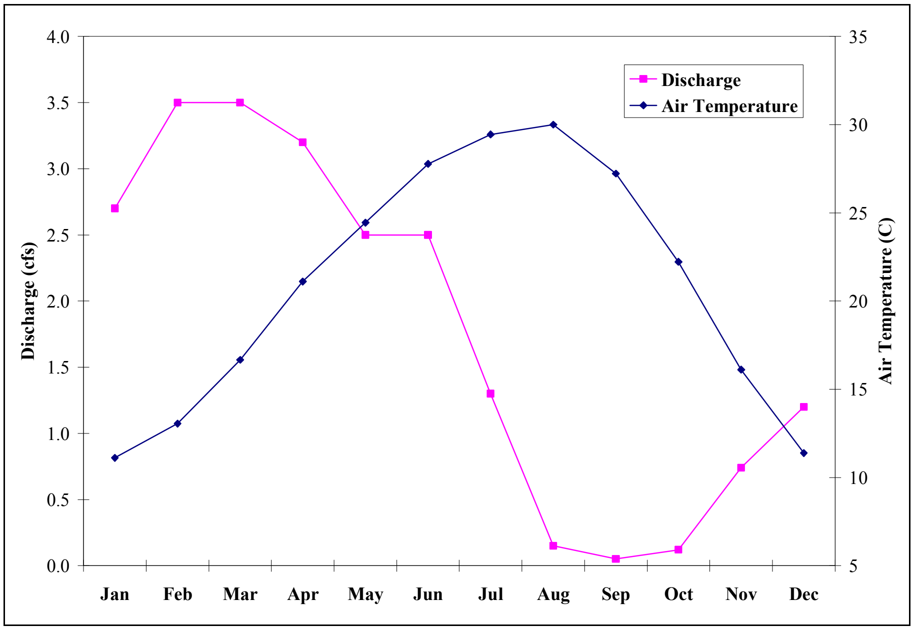


Figure 1. Monthly average Bear Creek discharge at 08158810, calculated from daily average USGS discharge measurements 1978-2007 with monthly average Austin air temperature, calculated from daily average NCDC temperature 1930-2007.

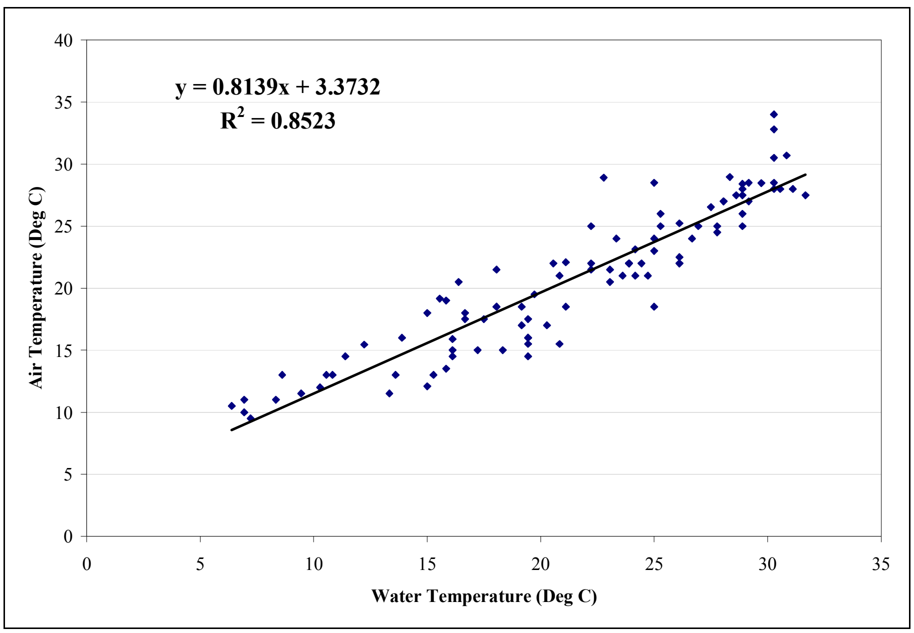


Figure 2. Scatter plot of daily average air temperature from NCDC Austin Mueller gage and instantaneous water temperature at Bear Creek USGS gage 08158810 with linear regression. Regression equation used to predict daily average water temperature from daily average air temperature in model.

LA-QUAL reach identifications, program constants, temperature correction constants, reaeration coefficients and advective hydraulic characteristics were identical to the original TCEQ model and previous COA model (Herrington 2008). Nutrient removal rates were also identical to the TCEQ and previous COA model (Herrington 2008) (Table 2). HCWID#1 effluent discharge concentrations were set to daily average permit limits (Table 1) except for total phosphorus, which was modeled at a concentration of 0.3 mg/L. Because the 0.15 mg/L daily limit for total phosphorus is calculated as a daily median, it is possible in any given month to meet the 7-day average, daily maximum and daily median permit requirements but maintain a daily average 0.3 mg/L total phosphorus concentration. The draft permit indicates that the 0.15 mg/L total phosphorus daily median limit is based on a long-term average of 0.10 mg/L but there is no description of how the long-term average should be calculated or any compliance restriction to insure that the 0.10 mg/L long-term average is achieved. From the TCEQ implementation manual for permitting, it is evident that this median permit limit is unique and does not follow the assumed distributions for effluent quality determined from statewide variability in discharge and stream water quality modeling. Additionally, a conservative material was modeled in LA-QUAL with a discharge concentration of 1.0, so that predicted output concentrations reflect the fraction of any conservative material remaining after dilution. Note that if dilution reduces the percentage of the conservative material to less than 1%, LA-QUAL output reports the percent remaining as 0.00.

Table 2. Nutrient removal rates.

| **Parameter** | **Removal Rate (day$^{-1}$)** |
|---|---|
| Organic Nitrogen | 0.03 |
| Ammonia ($NH_3$) | 0.30 |
| Nitrate ($NO_3$) | 0.14 |
| Total Phosphorus | 0.08 |

Bear Creek ambient (background) concentrations were calculated using all available USGS and COA data at the USGS gage 08158810 (1978-2006), with mean values for parameters with censored observations (i.e, values less than detection limits) estimated by non-parametric Kaplan-Meier methods (Kaplan and Meier 1958, Allison 1995, Helsel 2005) (Table 3). Average ambient concentrations were estimated separately for storm and non-storm flow conditions. Current day mean daily discharge was compared to previous day mean daily discharge to determine if storm or base flow ambient concentrations should be used, following the procedures of Barrett and Charbeneau (1996). If the ratio of current day to previous day mean daily discharge was greater than 1.5, the current day was considered a storm influenced sampling event.

Table 3. Bear Creek ambient concentrations calculated from USGS and COA data, used for all natural incremental inflows in the model.

| **Parameter (mg/L)** | **Base Flow** | **Storm Flow** |
|---|---|---|
| BOD | 0.529 | 1.577 |
| Org-N | 0.307 | 0.594 |
| $NH_3$ | 0.034 | 0.038 |
| $NO_3$+$NO_2$ | 0.117 | 0.233 |
| TP | 0.015 | 0.041 |
| TN | 0.458 | 0.865 |

Three water temperature ranges were evaluated (Table 4) using predicted water temperatures from NCDC average daily air temperatures. Five Bear Creek flow scenarios (not including HCWID#1 discharge) were evaluated based on target flow as measured at the USGS gage 08158810 (Table 5). Flow ranges were selected based on desired ratios of wastewater effluent to ambient (natural) Bear Creek discharge at gage 08158810. Concurrent daily average Bear Creek flow and predicted water temperature (assuming water was present) were determined for the matched period of record (P-O-R) of the USGS gage and NCDC climate data (07/07/1979 – 07/31/2007).

Table 4. Bear Creek ambient water temperature ranges (P-O-R = 1979-2007) as represented in model scenarios.

| Scenario Name | Range of Water Temp (ºC ) | Water Temp Used in Model (º C) | % of Time from P-O-R |
|---|---|---|---|
| Cold | <15 | 10 | 23.6 |
| Moderate | 15-25 | 20 | 45.6 |
| Hot | >25 | 30 | 30.8 |

Table 5. Bear Creek mean daily discharge ranges at 08158810 as represented in model scenarios (P-O-R= 1979-2007). Percentile of all mean daily discharge measurements shown for target discharge value.

| Scenario Name | Range of Daily Average Discharge ($ft^3/s$) | Target Discharge at 08158810 used in Model ($ft^3/s$) | Target Discharge as Percentile | Ratio of wastewater to natural flow (Qww/Qnat) | % of Time from P-O-R |
|---|---|---|---|---|---|
| No | 0 | 0 | 16th | ∞ | 16.1 |
| Low | 0.01 – 0.5 | 0.10 | 28th | ∞ – 1.5 | 22.4 |
| Median | 0.5 – 1.5 | 1.1 | 50th | 1.5 – 0.5 | 16.9 |
| High | 1.5 – 15 | 10 | 85th | 0.5 – 0.05 | 35.4 |
| Flood | >15 | 22 | 95th | <0.05 | 9.0 |

Incremental ambient inflows were added at tributaries junctions to achieve the target discharge at the 08158810 gage. Bear Creek flow was apportioned based on fraction of drainage area relative to drainage area of gage 08158810 (Table 6).

Table 6. Incremental inflows in model for varying flow scenarios. Area fraction represents fraction of drainage area for reach relative to USGS gage 08158810 drainage area. Area fractions were multiplied by target flow at USGS gage to determine total flow in each reach. Incremental inflows were then determined by subtraction.

| Reach ID | Name | Drainage Area (acres) | Area Fraction | Incremental Inflow in Model (m3/s) | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | No | Low | Median | High | Flood |
| 1 | headwaters | 0 | 0.000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 9 | unknown trib | 1021.3 | 0.130 | 0.00000 | 0.00037 | 0.00405 | 0.03678 | 0.08091 |
| 24 | spring creek | 6479.1 | 0.824 | 0.00000 | 0.00197 | 0.02162 | 0.19654 | 0.43240 |
| 30 | friday mtn | 6981.8 | 0.888 | 0.00000 | 0.00018 | 0.00199 | 0.01810 | 0.03983 |
| 36 | north fork | 11483.2 | 1.460 | 0.00000 | 0.00162 | 0.01783 | 0.16210 | 0.35663 |

Previous models have used ambient DO concentrations of 6.0 mg/L. In this evaluation, ambient DO was allowed to vary with temperature scenario (Table 7). Average DO concentrations were estimated from all available ambient instantaneous USGS and COA field measurements for the 3 temperature ranges (Table 4).

Table 7. Bear Creek ambient DO concentration (mg/L) by temperature scenario.

| Temperature Scenario | Background DO (mg/L) |
|---|---|
| Cold | 10.012 |
| Moderate | 8.157 |
| Hot | 7.091 |

Combining the flow, temperature and base/storm conditions yields 30 model scenarios (Table 8). LA-QUAL was used to determine predicted concentrations at the upper recharge zone boundary for each scenario. Predicted output were then applied to reported daily average discharge (without HCWID#1), water temperature and flow condition (storm/base) for the discharge data period of record to provide a daily estimate of Bear Creek concentrations at the recharge zone boundary. Essentially, the steady-state concentrations output from multiple LA-QUAL models were combined to generate a time-series record of predicted concentrations.

Table 8. LA-QUAL model scenarios evaluated, and fraction of time each scenario occurred from 1979-2007.

| Scenario Name | Bear Creek Flow | Water Temperature | Storm Condition | Fraction of Time |
|---|---|---|---|---|
| Flood - Cold - Base | Flood | Cold | Base | 0.0271 |
| Flood - Cold - Storm | Flood | Cold | Storm | 0.0034 |
| Flood - Hot - Base | Flood | Hot | Base | 0.0116 |
| Flood - Hot - Storm | Flood | Hot | Storm | 0.0010 |
| Flood - Moderate - Base | Flood | Moderate | Base | 0.0367 |
| Flood - Moderate - Storm | Flood | Moderate | Storm | 0.0102 |
| High Flow - Cold - Base | High Flow | Cold | Base | 0.0946 |
| High Flow - Cold - Storm | High Flow | Cold | Storm | 0.0029 |
| High Flow - Hot - Base | High Flow | Hot | Base | 0.0801 |
| High Flow - Hot - Storm | High Flow | Hot | Storm | 0.0020 |
| High Flow - Moderate - Base | High Flow | Moderate | Base | 0.1649 |
| High Flow - Moderate - Storm | High Flow | Moderate | Storm | 0.0097 |
| Low Flow - Cold - Base | Low Flow | Cold | Base | 0.0386 |
| Low Flow - Cold - Storm | Low Flow | Cold | Storm | 0.0021 |
| Low Flow - Hot - Base | Low Flow | Hot | Base | 0.0838 |
| Low Flow - Hot - Storm | Low Flow | Hot | Storm | 0.0041 |
| Low Flow - Moderate - Base | Low Flow | Moderate | Base | 0.0876 |
| Low Flow - Moderate - Storm | Low Flow | Moderate | Storm | 0.0073 |
| Median Flow - Cold - Base | Median Flow | Cold | Base | 0.0375 |
| Median Flow - Cold - Storm | Median Flow | Cold | Storm | 0.0014 |
| Median Flow - Hot - Base | Median Flow | Hot | Base | 0.0548 |
| Median Flow - Hot - Storm | Median Flow | Hot | Storm | 0.0013 |
| Median Flow - Moderate - Base | Median Flow | Moderate | Base | 0.0732 |
| Median Flow - Moderate - Storm | Median Flow | Moderate | Storm | 0.0030 |
| No Flow - Cold - Base | No Flow | Cold | Base | 0.0285 |
| No Flow - Cold - Storm | No Flow | Cold | Storm | 0.0000 |
| No Flow - Hot - Base | No Flow | Hot | Base | 0.0690 |
| No Flow - Hot - Storm | No Flow | Hot | Storm | 0.0000 |
| No Flow - Moderate - Base | No Flow | Moderate | Base | 0.0636 |
| No Flow - Moderate - Storm | No Flow | Moderate | Storm | 0.0000 |

Models were evaluated with and without HCWID#1 discharge. Model output without HCWID#1 was used to represent adjusted background concentrations to determine the magnitude of the water quality impact of the proposed discharge. Using LA-QUAL to adjust background concentrations is a more equivalent comparison than simply comparing predicted output to measured concentrations since some nutrient removal beyond what is observed is predicted to occur in Bear Creek in LA-QUAL even without the proposed discharge.

## Results

Predicted concentrations at the recharge zone boundary with and without HCWID#1 by model scenario are presented in Appendix A and B, respectively. Long-term averages were calculated for the period of record (1979-2007), and indicate that HCWID#1 discharge will degrade Bear Creek concentrations of DO, BOD, nitrogen and phosphorus at the upper recharge zone boundary (Table 9). Phosphorus concentrations are predicted to increase 300% based on change in long-term average at the upper recharge zone boundary. Total nitrogen concentrations are predicted to increase 270% based on the change in long-term average concentrations at the upper recharge zone boundary. Additionally, on average 39.1% of any conservative materials in the HCWID#1 discharge such as chloride or any personal care and pharmaceutical products will be recharged to the aquifer.

Table 9. Long-term average (1979-2007) predicted concentrations at the upper recharge zone boundary from LA-QUAL output with and without HCWID#1 proposed discharge. CM = conservative material fraction remaining.

| Parameter | Unit | With HCWID#1 | Without HCWID#1 |
|---|---|---|---|
| CM | * | 0.391 | 0.000 |
| DO | mg/L | 8.316 | 8.409 |
| BOD | mg/L | 0.515 | 0.384 |
| ORG-N | mg/L | 0.370 | 0.252 |
| NH3-N | mg/L | 0.052 | 0.028 |
| NO3-N | mg/L | 0.583 | 0.091 |
| TOTN | mg/L | 1.007 | 0.372 |
| TOTP | mg/L | 0.028 | 0.009 |

Bear Creek concentrations at the upper recharge zone boundary with the proposed HCWID#1 discharge are predicted to be degraded relative to predicted background concentrations for all modeled constituents for the majority of the time (Table 10). Relative to actual estimated long-term average concentrations input to the models, the proposed HCWID#1 discharge is predicted to degrade the water quality of Bear Creek at the upper recharge zone boundary at least 30% of the time for all constituents and as much as 99% of the time for nitrate-nitrogen.

Table 10. Percent of period of record (1979-2007) HCWID#1 is predicted to degrade Bear Creek water quality at the upper recharge zone boundary versus predicted and measured ambient (background) concentrations.

| Parameter | % of Time HCWID#1 Degrades Bear Creek Recharge | |
|---|---|---|
| | vs. predicted | vs. measured |
| CM-I | 55.57 | 55.57 |
| DO | 78.29 | 30.76 |
| BOD1 | 99.87 | 42.79 |
| ORG-N | 99.90 | 79.60 |
| NH3-N | 84.92 | 69.24 |
| NO3-N | 100.00 | 99.59 |
| TOTN | 100.00 | 99.46 |
| TOTP | 97.37 | 33.53 |

Daily loadings at the upper recharge zone boundary for each constituent were calculated using Bear Creek mean daily discharge and predicted concentrations with and without the proposed HCWID #1 discharge. The proposed HCWID#1 is predicted to increase loads to the recharge zone from Bear Creek for all constituents based on averages over the period of record (1979-2007) (Table 11). Expression of the average increase in daily loads with HCWID#1 as a percentage of the daily load discharged from HCWID#1 based on permit limits is a representation of the average fraction of material in HCWID#1 effluent that will recharge the aquifer.

Table 11. HCWID#1 daily load from permit limits at point of discharge, average increase in daily load with HCWID#1 over the period of record at upper recharge zone boundary (1979-2007), and expression of the average increase in daily load as a percentage of daily load discharged by HCWID#1.

| Parameter | Daily Load from HCWID#1 at permit limits at point of discharge (kg/d) | Avg. Increase in Daily Load with HCWID#1 at recharge zone boundary (kg/d) | Avg. Increase at recharge zone boundary as % of HCWID#1 Discharge (%) |
|---|---|---|---|
| CM | 1.893 | 0.931 | 49.2 |
| BOD1 | 9.464 | 1.853 | 19.6 |
| ORG-N | 1.893 | 0.998 | 52.7 |
| NH3-N | 3.785 | 0.286 | 7.6 |
| NO3-N | 32.176 | 4.509 | 14.0 |
| TOTN | 37.854 | 5.720 | 15.1 |
| TOTP | 0.567 | 0.178 | 31.4 |

## Conclusions

The combination of multiple steady-state LA-QUAL models varying water temperature and creek flow with daily records of actual temperature and creek flow provide a unique opportunity to use LA-QUAL output to generate a time-series dataset. This method provides a more complete representation of the potential impacts of a proposed wastewater discharge using the LA-QUAL model as it more accurately represents the temporal scale of effluent dilution in ambient flow and sensitivity of removal rates to temperature. While this approximation is useful, a model capable of simulating processes occurring in the discharge route would necessarily be dynamic in construction.

Based on model output, the proposed HCWID#1 will increase loads for all constituents from Bear Creek to the Barton Springs portion of the Edwards Aquifer, and will increase or degrade long-term average concentrations of all constituents in Bear Creek.

## References


Allison, P.D. 1995. Survival Analysis Using the SAS System: A Practical Guide. SAS Institute, North Carolina.

Barrett, M., and R. Charbeneau. 1996. A parsimonious model for simulation of flow and transport in a karst aquifer. The University of Texas at Austin Center for Research in Water Resources. Technical Report 269.

City of Austin (COA). 2006. Predicted impacts from the proposed Hays County Water Control and Improvement District #1 Discharge in Bear Creek and Barton Springs. City of Austin Environmental Resource Management Division, Watershed Protection and Development Review Department. SR-06-07.

Helsel, D.R. 2005. Nondetects and Data Analysis: Statistics for Censored Environmental Data. John Wiley & Sons, New Jersey.

Herrington, C. 2008. LA-QUAL (version 8.0) modeling of potential water quality impacts to Bear Creek from proposed HCWID#1 wastewater discharge. City of Austin Environmental Resource Management Division, Watershed Protection and Development Review Department. SR-08-03.

Herrington, C., and M. Scoggins. 2006. Potential impacts of Hays County WCID No. 1 proposed wastewater discharge on the algae communities of Bear Creek and Barton Springs. City of Austin Environmental Resource Management Division, Watershed Protection and Development Review Department. SR-06-08.

Kaplan, E.L. and P. Meier. 1958. Nonparametric Estimation from Incomplete Observations. Journal of the American Statistical Association 53: 457-481.

Mierstschin, J., and D. Obenour. 2006. Technical Memorandum-Proposed Contributing Zone Wastewater Discharge Evaluation, Austin, Texas. James Miertschin and Associates, Inc., prepared for the Barton Springs/Edwards Aquifer Conservation District. March 4, 2006.

Turner, M. 2006. Predicting phosphorus with the parsimonious model. City of Austin Environmental Resource Management Division, Watershed Protection and Development Review Department. SR-06-08 (Draft).

**Appendix A. Predicted Bear concentrations at upper recharge zone boundary with HCWID#1.**

| | Temp | CM | DO | BOD | Org-N | NH3-N | NO3-N | TOTN | TOTP |
|---|---|---|---|---|---|---|---|---|---|
| Code | deg C | * | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L | mg/L |
| Flood - Cold - Base | 10 | <0.01 | 10.3 | 0.57 | 0.31 | 0.05 | 0.33 | 0.69 | 0.02 |
| Flood - Cold - Storm | 10 | <0.01 | 10.26 | 1.55 | 0.59 | 0.06 | 0.43 | 1.08 | 0.04 |
| Flood - Hot - Base | 30 | <0.01 | 6.87 | 0.51 | 0.31 | 0.03 | 0.21 | 0.55 | 0.02 |
| Flood - Hot - Storm | 30 | <0.01 | 6.79 | 1.45 | 0.58 | 0.04 | 0.31 | 0.93 | 0.04 |
| Flood - Moderate - Base | 20 | <0.01 | 8.27 | 0.54 | 0.31 | 0.04 | 0.27 | 0.62 | 0.02 |
| Flood - Moderate - Storm | 20 | <0.01 | 8.21 | 1.5 | 0.59 | 0.05 | 0.38 | 1.01 | 0.04 |
| High Flow - Cold - Base | 10 | <0.01 | 10.42 | 0.6 | 0.32 | 0.07 | 0.48 | 0.87 | 0.02 |
| High Flow - Cold - Storm | 10 | <0.01 | 10.37 | 1.53 | 0.59 | 0.07 | 0.59 | 1.25 | 0.05 |
| High Flow - Hot - Base | 30 | <0.01 | 6.78 | 0.49 | 0.31 | 0.03 | 0.23 | 0.57 | 0.02 |
| High Flow - Hot - Storm | 30 | <0.01 | 6.68 | 1.36 | 0.57 | 0.04 | 0.33 | 0.94 | 0.04 |
| High Flow - Moderate - Base | 20 | <0.01 | 8.31 | 0.54 | 0.32 | 0.04 | 0.35 | 0.71 | 0.02 |
| High Flow - Moderate - Storm | 20 | <0.01 | 8.24 | 1.45 | 0.58 | 0.05 | 0.45 | 1.08 | 0.04 |
| Low Flow - Cold - Base | 10 | 0.8 | 10.69 | 0.93 | 0.48 | 0.17 | 2.16 | 2.81 | 0.07 |
| Low Flow - Cold - Storm | 10 | 0.8 | 10.68 | 1.05 | 0.52 | 0.17 | 2.17 | 2.87 | 0.07 |
| Low Flow - Hot - Base | 30 | 0.8 | 6.51 | 0.16 | 0.36 | 0.02 | 0.22 | 0.6 | 0.01 |
| Low Flow - Hot - Storm | 30 | 0.8 | 6.5 | 0.24 | 0.4 | 0.02 | 0.23 | 0.65 | 0.02 |
| Low Flow - Moderate - Base | 20 | 0.8 | 8.36 | 0.43 | 0.42 | 0.05 | 0.79 | 1.27 | 0.04 |
| Low Flow - Moderate - Storm | 20 | 0.8 | 8.34 | 0.53 | 0.46 | 0.05 | 0.81 | 1.32 | 0.04 |
| Median Flow - Cold - Base | 10 | 0.3 | 10.66 | 0.76 | 0.38 | 0.12 | 1.3 | 1.8 | 0.04 |
| Median Flow - Cold - Storm | 10 | 0.3 | 10.61 | 1.34 | 0.56 | 0.13 | 1.37 | 2.06 | 0.06 |
| Median Flow - Hot - Base | 30 | 0.3 | 6.57 | 0.33 | 0.34 | 0.02 | 0.24 | 0.6 | 0.02 |
| Median Flow - Hot - Storm | 30 | 0.3 | 6.48 | 0.8 | 0.51 | 0.03 | 0.29 | 0.83 | 0.03 |
| Median Flow - Moderate - Base | 20 | 0.3 | 8.36 | 0.51 | 0.36 | 0.04 | 0.62 | 1.02 | 0.03 |
| Median Flow - Moderate - Storm | 20 | 0.3 | 8.29 | 1.04 | 0.54 | 0.05 | 0.68 | 1.27 | 0.04 |
| No Flow - Cold - Base | 10 | 1 | 10.69 | 0.96 | 0.51 | 0.18 | 2.35 | 3.04 | 0.08 |
| No Flow - Cold - Storm | 10 | 1 | 10.69 | 0.97 | 0.51 | 0.18 | 2.36 | 3.04 | 0.08 |
| No Flow - Hot - Base | 30 | 1 | 6.51 | 0.12 | 0.37 | 0.02 | 0.21 | 0.6 | 0.01 |
| No Flow - Hot - Storm | 30 | 1 | 6.51 | 0.12 | 0.37 | 0.02 | 0.21 | 0.61 | 0.01 |
| No Flow - Moderate - Base | 20 | 1 | 8.36 | 0.41 | 0.44 | 0.05 | 0.82 | 1.32 | 0.04 |
| No Flow - Moderate - Storm | 20 | 1 | 8.36 | 0.41 | 0.44 | 0.05 | 0.83 | 1.32 | 0.04 |

**CM = fraction of conservative material remaining**

**Appendix B. Predicted Bear concentrations at upper recharge zone boundary without HCWID#1.**

| Code | Temp degC | CM * | DO mg/L | BOD mg/L | ORG-N mg/L | NH3-N mg/L | NO3-N mg/L | TOTN mg/L | TOTP mg/L |
|---|---|---|---|---|---|---|---|---|---|
| Flood - Cold - Base | 10 | 0 | 10.31 | 0.51 | 0.3 | 0.04 | 0.11 | 0.45 | 0.01 |
| Flood - Cold - Storm | 10 | 0 | 10.27 | 1.51 | 0.58 | 0.04 | 0.22 | 0.85 | 0.04 |
| Flood - Hot - Base | 30 | 0 | 6.89 | 0.48 | 0.3 | 0.03 | 0.11 | 0.44 | 0.01 |
| Flood - Hot - Storm | 30 | 0 | 6.8 | 1.43 | 0.58 | 0.04 | 0.22 | 0.83 | 0.04 |
| Flood - Moderate - Base | 20 | 0 | 8.28 | 0.5 | 0.3 | 0.03 | 0.11 | 0.45 | 0.01 |
| Flood - Moderate - Storm | 20 | 0 | 8.22 | 1.48 | 0.58 | 0.04 | 0.22 | 0.84 | 0.04 |
| High Flow - Cold - Base | 10 | 0 | 10.44 | 0.49 | 0.3 | 0.04 | 0.11 | 0.44 | 0.01 |
| High Flow - Cold - Storm | 10 | 0 | 10.39 | 1.46 | 0.57 | 0.05 | 0.22 | 0.84 | 0.04 |
| High Flow - Hot - Base | 30 | 0 | 6.79 | 0.45 | 0.29 | 0.03 | 0.11 | 0.43 | 0.01 |
| High Flow - Hot - Storm | 30 | 0 | 6.69 | 1.35 | 0.56 | 0.04 | 0.21 | 0.81 | 0.04 |
| High Flow - Moderate - Base | 20 | 0 | 8.33 | 0.47 | 0.29 | 0.03 | 0.11 | 0.44 | 0.01 |
| High Flow - Moderate - Storm | 20 | 0 | 8.25 | 1.41 | 0.57 | 0.04 | 0.21 | 0.83 | 0.04 |
| Low Flow - Cold - Base | 10 | 0 | 10.83 | 0.13 | 0.14 | 0.03 | 0.05 | 0.22 | 0 |
| Low Flow - Cold - Storm | 10 | 0 | 10.8 | 0.38 | 0.27 | 0.05 | 0.1 | 0.41 | 0.01 |
| Low Flow - Hot - Base | 30 | 0 | 6.53 | 0.06 | 0.11 | 0.01 | 0.03 | 0.14 | 0 |
| Low Flow - Hot - Storm | 30 | 0 | 6.5 | 0.17 | 0.21 | 0.01 | 0.05 | 0.28 | 0.01 |
| Low Flow - Moderate - Base | 20 | 0 | 8.42 | 0.09 | 0.12 | 0.01 | 0.04 | 0.18 | 0 |
| Low Flow - Moderate - Storm | 20 | 0 | 8.39 | 0.27 | 0.24 | 0.03 | 0.08 | 0.34 | 0.01 |
| Median Flow - Cold - Base | 10 | 0 | 10.72 | 0.39 | 0.26 | 0.04 | 0.1 | 0.39 | 0.01 |
| Median Flow - Cold - Storm | 10 | 0 | 10.64 | 1.15 | 0.5 | 0.06 | 0.18 | 0.74 | 0.03 |
| Median Flow - Hot - Base | 30 | 0 | 6.56 | 0.29 | 0.25 | 0.02 | 0.08 | 0.35 | 0.01 |
| Median Flow - Hot - Storm | 30 | 0 | 6.45 | 0.86 | 0.48 | 0.03 | 0.15 | 0.66 | 0.02 |
| Median Flow - Moderate - Base | 20 | 0 | 8.38 | 0.34 | 0.25 | 0.03 | 0.09 | 0.37 | 0.01 |
| Median Flow - Moderate - Storm | 20 | 0 | 8.29 | 1.02 | 0.49 | 0.04 | 0.17 | 0.7 | 0.03 |
| No Flow - Cold - Base | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No Flow - Cold - Storm | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No Flow - Hot - Base | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No Flow - Hot - Storm | 30 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No Flow - Moderate - Base | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| No Flow - Moderate - Storm | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**CM = fraction of conservative material remaining**

**Note:** Concentrations of 0.00 mg/L for no-flow scenario represent time periods when creek is dry/not flowing.