LA-QUAL (version 8.0) modeling of potential water quality impacts to Bear Creek from proposed HCWID#1 wastewater discharge

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The Texas Commission on Environmental Quality (TCEQ) has issued a draft permit for Hays County Water Control and Improvement District #1 to discharge treated wastewater effluent directly to the headwaters of Bear Creek, Hays County, Texas. The steady-state LA-QUAL model was used to predict water quality of Bear Creek under varying conditions using reach definitions and advective hydraulic characteristics previously used by TCEQ in their Tier 2 non-degradation assessment of the permit. TCEQ concluded that degradation did not occur because effluent nutrients were assimilated in Bear Creek just above the Barton Springs Edwards Aquifer recharge zone. Further modeling determined that predicted concentrations are very sensitive to estimated decay rates and ambient water temperature input values. Predicted concentrations with the proposed discharge permit are above TCEQ screening levels as well as long-term ambient averages for multiple constituents at the upper recharge zone boundaries in some conditions.

Introduction

Hays County Water Control and Improvement District #1 (HCWID1) servicing the Belterra Subdivision has applied to the Texas Commission on Environmental Quality (TCEQ) for a permit 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 discharge is predicted to increase the growth of algae in the perennial pools of Bear Creek (Herrington and Scoggins 2006), and may have an impact on the water quality of the Edwards Aquifer (Slade 2006, COA 2006).

The water quality of Bear Creek with the proposed discharge was previously predicted at the recharge zone boundary of the Barton Springs segment of the Edwards Aquifer using the LA-QUAL (version 8.0) model (Miertschin and Obenour 2006) based on a wastewater discharge of 800,000 gal/day (1.2 ft^3/s) and a daily average total phosphorus limit of 1 mg/L. The draft permit issued by TCEQ contains a reduced discharge and a lower total phosphorus daily limit in the final phase (Table 1).

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

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 0.30 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.

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 temperature (29.7 ºC) with no Bear Creek headwater or tributary flow additions. Because of limitations on the number of computational elements, the TCEQ model split the reach of Bear Creek from the discharge point to the upper boundary of the recharge zone into two sequenced model units. Additionally, the TCEQ modeled total nitrogen as a separate non-conservative material in lieu of modeling ammonia, organic nitrogen and nitrate loss separately. Reach identifications and constituent loss rates differed between the Miertschin model (Miertschin and Obenour 2006) and the TCEQ version (Table 2).

Using the reach identifications of the TCEQ model, an LA-QUAL model version 8.0 was evaluated under two different natural flow conditions and using a range of ambient water temperatures to predict Bear Creek water quality at the upper boundary of the recharge zone with the proposed headwater discharge. Additionally, critical nutrient loss coefficients were determined to yield long-term average concentrations at the upper recharge zone boundary for qualitative comparison to rates determined by other site-specific studies. Calibration data sufficient to determine these rates in Bear Creek are not currently available, and would likely not be accurate once the stream becomes effluent dominated. The original TCEQ version was converted to LA-QUAL simply for ease of use because the original TCEQ version split the creek into two separate models due to a limitation on the number of computational elements in that version of QUAL-TX. Reach identifications, program constants, temperature correction constants, reaeration coefficients and advective hydraulic characteristics were identical to the TCEQ model. Ambient (background) concentrations were determined from long-term City of Austin (COA) and United States Geological Survey (USGS) monitoring data. Results were compared to TCEQ screening levels for nutrient parameters (TCEQ 2008) and to long-term ambient water quality concentrations from USGS and COA monitoring data at the USGS flow gage downstream of Bear Creek Pass (USGS 08158810).

This type of steady-state modeling will not accurately predict the full range of water quality impacts of the proposed discharge to Bear Creek as algal processes are not realistically represented. Thus, algal uptake of nutrients from the wastewater discharge is predicted to occur at a steady rate indefinitely without any additional oxygen demand due to increased algal respiration or release of nutrients back to the water column due to biomass decay.

Table 2. Summary of differences between LA-QUAL version 8.0 model used by Miertschin (2006) and QUAL-TX version 3.5 model used by TCEQ.

TCEQ	**Mierstchin 2006**
Different segmentation lengths and computational element lengths used by TCEQ and Mierstchin	
Modeled upper and lower reaches separately (presumably due to limitation on number of segments)	Modeled entire creek in single model
Modeled N and P separately; modeled total N as non-conservative material independently of other nitrogen constituents in N model	Modeled N and P together; modeled total P as a separate non-conservative material
Different advective hydraulic coefficients (depth constant F>0 in ponds)	Depth constant F=0 for all segments
Single scenario (summer low flow)	Multiple scenarios varying flow and temperature
Initial summer temp = 29.7	Initial summer temp = 30.7
Reaeration option in ponds = 1 (specified constant reaeration rate); k2 varies between 0.538 and 2.0 Creek segments use Texas Equation	Reaeration options in ponds = 20 (rates dependent on depth and oxygen transfer coefficient); a=1.0 Creeks segments use Texas Equation
Background sediment oxygen demand variable between ponds and creeks; creeks = 0.35 g/m^2/day ponds vary between 0.6→0.7 g/m^2/day	Background sediment oxygen demand constant (0.35 g/m^2/day)
No incremental inflows	Incremental inflows for 2 reaches, but minimal rates (0.16 ft^3/s total)
Headwater flow at Aspen Drive = 0.10 ft^3/s for nitrogen only	Headwater flow only for one tributary (most upstream tributary, 0.01 ft^3/s)
Ambient DO: mainstem and tributaries = 6.06 mg/L	Ambient DO: mainstem = 5 mg/L, tributaries = 6 mg/L
Ambient organic nitrogen = 0.50 mg/L	Ambient organic nitrogen = 0.31 mg/L
Ambient ammonia = 0.05 mg/L	Ambient ammonia = 0.029 mg/L
Ambient NO3+NO2 = 0.20 mg/L	Ambient NO3+NO2: mainstem = 0.20 mg/L, tributaries = 0.15 mg/L
No ambient (headwater) total N or total P	Ambient total P: mainstem = 0.0, tributaries = 0.021 mg/L
Total N in discharge = 20 mg/L; Total N in headwaters = 0.75 mg/L	Total N modeled by individual nitrogen components
Total P in discharge = 0.10 mg/L; total P in headwaters = 0.021 mg/L	Total P in discharge = 1.0 mg/L
Total P decay rate = 0.08 day^{-1}	Total P decay rate = 0.16 day^{-1}

Methods

Using the identical reach definitions and advective hydraulic characteristics of the TCEQ model, a single input file was compiled for the entire 12.5 km reach of Bear Creek from the discharge to the upper recharge zone boundary and evaluated using LA-QUAL version 8.0. The model consisted of 39 reaches and 469 computational elements.

The TCEQ model included total nitrogen as a separate non-conservative material with a decay rate that was not compatible with the decay rate specified for organic nitrogen and ammonia. If nitrate values are calculated from the TCEQ model output as total nitrogen minus the sum of ammonia and organic nitrogen, nitrate values become negative and thus unrealistic considering the total nitrogen concentrations remain elevated in this stream reach (nitrate = -0.02 mg/L, total nitrogen = 0.42 mg/L). Thus, loss coefficients utilized in this model for nitrate (nitrate plus nitrite), ammonia and organic nitrogen were specified individually and the resulting total nitrogen was calculated by LA-QUAL following the methodology of Miertschin and Obenour (2006). As done with both the Miertschin and Obenour (2006) and TCEQ models, total phosphorus was evaluated separately as a non-conservative material. The limitations of this method are both the absence of any rigorous representation of nutrient dynamics with biological functions, and the inability to determine more appropriate coefficients without calibration data over a range of seasons and hydrological conditions.

Output from the TCEQ model was compared to this LA-QUAL version using identical first-order kinetics except using the total nitrogen loss rate from the TCEQ model as the denitrification rate in the LA-QUAL model. The TCEQ model yielded general agreement with this LA-QUAL model, with only minor differences observed for some constituents (Figure 1). Based on this qualitative graphical comparison, the LA-QUAL model structure was assumed to be comparable to the TCEQ version. Graphs depicted in this report present concentrations versus stream kilometers from the discharge point (27.83 km) to the recharge zone boundary (15.31 km).

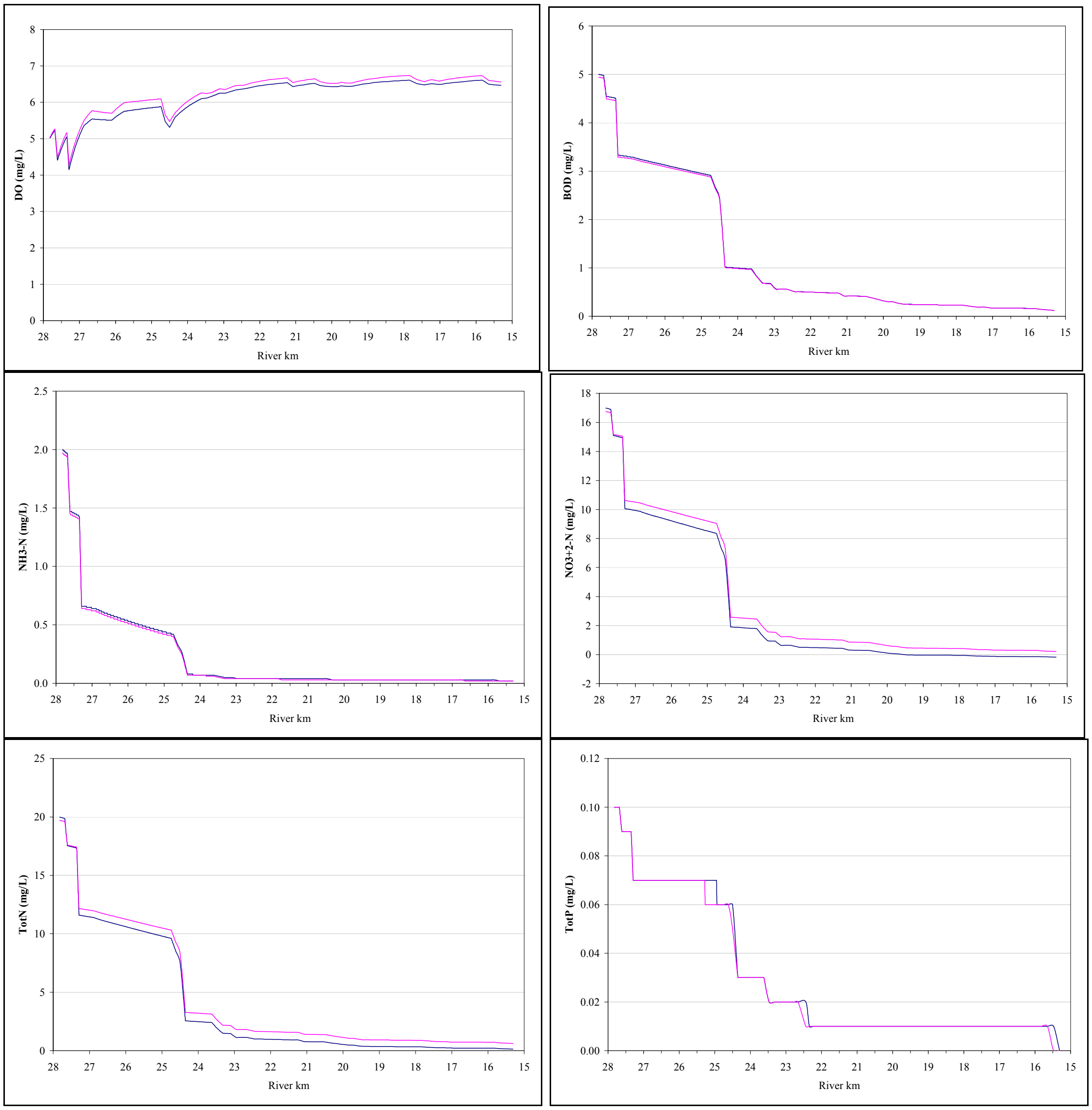

Figure 1. Comparison of TCEQ (blue) version LA-QUAL (red) model outputs for dissolved oxygen (DO), carbonaceous biochemical oxygen 5-day demand (BOD5), ammonia (NH3), nitrate plus nitrite nitrogen (NO3), total nitrogen and total phosphorus. TCEQ values for nitrate were calculated as total nitrogen minus sum of organic nitrogen and ammonia.

This LA-QUAL model was used to analyze the impacts of the proposed discharge on Bear Creek water quality under a variety of flow and temperature conditions (Table 3). Ambient water temperature effects on temperature-dependent loss rates were assessed at 29.7 ºC as used in the original TCEQ summer temperature model, at a moderate temperature of 21ºC and at a winter temperature of 10 ºC as used by Miertschin and Obenour (2006).

Table 3. Identification of model scenarios evaluated with LA-QUAL.

#	Scenario Name	Water temperature (ºC)	Flow (ft^3/s)	Discharge Concentrations (mg/L)	Decay rates (1/day)
0	(TCEQ original) summer temp, low flow, daily averages with low TP	29.7	Headwater = 0.0 Discharge = 0.77	BOD5 = 5.0 DO = 5.0 Org-N = 1.0 NH3 = 2.0 NO3 = 17.0 TP = 0.10	Org-N = 0.03 NH3 = 0.30 NO3 = 0.14 TP = 0.08
1	Winter, low flow, daily averages with low TP	10.0	Headwater = 0.0 Discharge = 0.77	BOD5 = 5.0 DO = 5.0 Org-N = 1.0 NH3 = 2.0 NO3 = 17.0 TP = 0.10	Org-N = 0.03 NH3 = 0.30 NO3 = 0.14 TP = 0.08
2	Moderate temp, low flow, daily averages with low TP	21.0	Headwater = 0.0 Discharge = 0.77	BOD5 = 5.0 DO = 5.0 Org-N = 1.0 NH3 = 2.0 NO3 = 17.0 TP = 0.10	Org-N = 0.03 NH3 = 0.30 NO3 = 0.14 TP = 0.08
3	Summer temp, low flow, daily averages with high TP	29.7	Headwater = 0.0 Discharge = 0.77	BOD5 = 5.0 DO = 5.0 Org-N = 1.0 NH3 = 2.0 NO3 = 17.0 TP = 0.30	Org-N = 0.03 NH3 = 0.30 NO3 = 0.14 TP = 0.08
4	Moderate temp, low flow, daily averages with high TP	21.0	Headwater = 0.0 Discharge = 0.77	BOD5 = 5.0 DO = 5.0 Org-N = 1.0 NH3 = 2.0 NO3 = 17.0 TP = 0.30	Org-N = 0.03 NH3 = 0.30 NO3 = 0.14 TP = 0.08
5	Low temp, low flow, daily averages with high TP	10.0	Headwater = 0.0 Discharge = 0.77	BOD5 = 5.0 DO = 5.0 Org-N = 1.0 NH3 = 2.0 NO3 = 17.0 TP = 0.30	Org-N = 0.03 NH3 = 0.30 NO3 = 0.14 TP = 0.08
6	Critical k***, low flow, high TP	21.0	Headwater = 0.0 Discharge = 0.77	BOD5 = 5.0 DO = 5.0 Org-N = 1.0 NH3 = 2.0 NO3 = 17.0 TP = 0.30	Org-N = ?*** NH3 = ? NO3 = ? TP = ?
7	Moderate temp, median flow at USGS gage*	21.0	Ambient flow at USGS gage = 1.1 Discharge = 0.77	BOD5 = 5.0 DO = 5.0 Org-N = 1.0 NH3 = 2.0 NO3 = 17.0 TP = 0.30	Org-N = 0.03 NH3 = 0.30 NO3 = 0.14 TP = 0.08
8	Critical flow**	21.0	Discharge = 0.77, ambient flow varied	BOD5 = 5.0 DO = 5.0 Org-N = 1.0 NH3 = 2.0 NO3 = 17.0 TP = 0.30	Org-N = 0.03 NH3 = 0.30 NO3 = 0.14 TP = 0.08

*ambient concentrations at long-term non-storm flow averages ** ambient concentrations at long-term storm flow averages
***critical rates determined through iterative model runs to meet background at RZ

Total phosphorus in the discharge was varied but all other discharge concentrations of other constituents utilized permit daily average limits (Table 1). The total phosphorus concentration in the discharge was modeled using both a daily average of 0.10 mg/L as used in the TCEQ model and as a daily average of 0.30 mg/L which may be obtained while still meeting all permit requirements.

Predicted nutrient concentrations were found to be highly sensitive to selected decay rates (COA 2006). Decay rates for an oligotrophic stream may decrease over time under the influence of a high nutrient point source discharge as the stream becomes nutrient saturated (Marti et al 2004). The change in decay rate over time is not considered by the steady-state LA-QUAL model. Using the moderate (average) ambient water temperature of 21 ºC scenario, critical decay rates were determined to yield predicted nutrient concentrations exactly at background levels immediately at the upper recharge zone boundary in low flow conditions (no Bear Creek headwater flow). These decay rate values may be used in comparison to literature values to qualitatively assess potential water quality impacts to the Edwards Aquifer.

Dilution effects were considered using the moderate temperature scenario and the higher 0.30 mg/L phosphorus daily average from the proposed discharge. Incremental inflow quality was set to long-term average constituent concentrations for all tributaries (Table 5). Incremental inflow quantity was roughly approximated for each tributary based on cumulative drainage area by linear regression of the exponentially-transformed median of the daily flow rates at the USGS (1.1 ft^3/s, drainage area = 7,864 acres) and City of Austin (1.06 ft^3/s, drainage area = 3,524 acres) flow gages versus drainage area. The resulting regression equation was then used to estimate the incremental increase in flow at each tributary junction so that the resulting flow at the mainstem Bear Creek flow at the USGS gage was approximately equivalent to the median of the mean daily values (Table 4) without the proposed discharge. This method most likely over-estimates tributary flow for smaller drainage area tributaries and thus dilution might actually occur over longer distances. Previous comparisons (Miertschin and Obenour 2006) of data from these gages have identified some discrepancies which may be the result of either gains or losses in the reach between the gages or due to measurement error, although gage readings and resulting median flow rates were presumed accurate for this analysis.

Table 4. Tributary junctions and incremental inflows used in baseflow dilution scenario. The USGS gage falls within reach #31.

Reach #	Reach ID	Drainage Area (acres)	Incremental Inflow (ft^3/s)	Cumulative Flow* (ft^3/s)
1	headwaters	0.0	0.00	0.00
9	unknown trib	1,021.3	0.48	0.48
24	spring creek	6,479.1	0.60	1.08
30	friday mtn	6,981.8	0.05	1.13
36	north fork	11,483.2	0.30	1.43

*ambient flow, excluding proposed discharge

To facilitate the evaluation of the dilution of any additional conservative material in the proposed discharge including pharmaceuticals that may not be removed by the wastewater treatment process, a surrogate conservative substance was included in the dilution model with a concentration of 1.00 mg/L in the discharge, an ambient concentration of 0.00 mg/L and a loss rate of 0.00 day^{-1}. Thus, predicted concentrations may represent the fraction remaining conservative material after dilution.

Finally, a critical dilution flow was determined by iterative evaluation using the moderate temperature scenario with a daily average 0.3 mg/L total phosphorus in the discharge so that the minimum amount of ambient flow could be identified where all constituents were diluted (and subject to decay) resulting in concentrations at background levels at the upper end of the recharge zone boundary. Ambient constituent concentrations were set to long-term historical averages from measurements at the USGS gage in storm-influenced conditions. Incremental inflows were added at tributary junctions (similar to median flow scenario) and were estimated using a two-part regression method. First, concurrent values of flow measurements from the USGS and COA gages were plotted and a linear regression value used to predict the flow at the COA gage when the flow at the USGS gage was known. Using the predicted COA gage value and the known USGS value, a linear regression of flow versus drainage area was used to predict Bear Creek flow at the tributary junctions. Again, this method is a reasonable estimate but is likely to over-estimate flow values at the most upstream junctions. The estimated critical flow may be useful in evaluating the feasibility of a flow-conditional discharge permit.

Model outputs were compared to TCEQ surface water quality screening levels for freshwater streams and to long-term (1978-2007) non-storm ambient water quality monitoring results from the USGS gage 08158810 near the Bear Creek Pass road crossing over Bear Creek (Table 5).

Table 5. TCEQ (2008) screening levels and long-term (1978-2007) average water quality concentrations in mg/L based on USGS and COA monitoring at the USGS gage 08158810.

Parameter (mg/L)	**TCEQ Screening Level**	**Long-Term Ambient Average**
BOD5	n/a	0.63
NH3-N	0.33	0.04
NO3+NO2-N	1.95	0.16
TP	0.69	0.03

Results

Constituent concentrations at the recharge zone boundaries were evaluated for all scenarios (Table 6). These concentrations may be input to the Edwards Aquifer model (Barrett and Charbeneau 1996) to predict potential impacts of the discharge under varying conditions at Barton Springs. The variability in the predicted concentrations at the recharge zone boundaries demonstrate the sensitivity of the model to user-selected input conditions.

Table 6. Predicted concentrations at upper recharge zone boundary by scenario.

#	**Scenario**	**Temp (°C)**	**DO (mg/L)**	**BOD5 (mg/L)**	**Org-N (mg/L)**	**NH3-N (mg/L)**	**Total N (mg/L)**	**NO3+2-N (mg/L)**	**Total P (mg/L)**
0	TCEQ original, summer temp, low TP	29.7	6.56	0.12	0.38	0.02	0.62	0.22	0.00
1	winter temp, low TP	10.0	10.68	0.97	0.51	0.19	3.05	2.36	0.03
2	moderate temp, low TP	21.0	8.16	0.37	0.43	0.05	1.21	0.73	0.01
3	summer temp, high P	29.7	6.56	0.12	0.38	0.02	0.62	0.22	0.01
4	moderate temp, high P	21.0	8.16	0.37	0.43	0.05	1.21	0.73	0.04
5	winter temp, high P	10.0	10.68	0.97	0.51	0.19	3.05	2.36	0.08
6	critical k, moderate temp, low flow	21.0	8.16	0.37	0.43	0.04	0.59	0.12	0.03
7	median flow	21.0	8.05	0.57	0.48	0.06	1.39	0.86	0.04
8	critical dilution flow	21.0	6.90	1.64	0.50	0.05	0.92	0.37	0.06

Sensitivity to Ambient Water Temperature

Predicted values are highly sensitive to ambient water temperature input as loss rates are temperature-dependent. The TCEQ original (scenario 0) summer low flow results were compared to average (scenario 2) and winter low flow results (scenario 1), varying only ambient water temperature. Predicted concentrations at the recharge zone boundary increased approximately 8 times for BOD5, 9 times for ammonia and 10 times for nitrate between the low and high temperature scenarios (Figure 2). During winter low flow conditions, concentrations of nitrate are predicted to be above TCEQ (2008) screening levels for the entire reach of upper Bear Creek to the recharge zone and concentrations of BOD_5, ammonia and nitrate are above long-term averages.

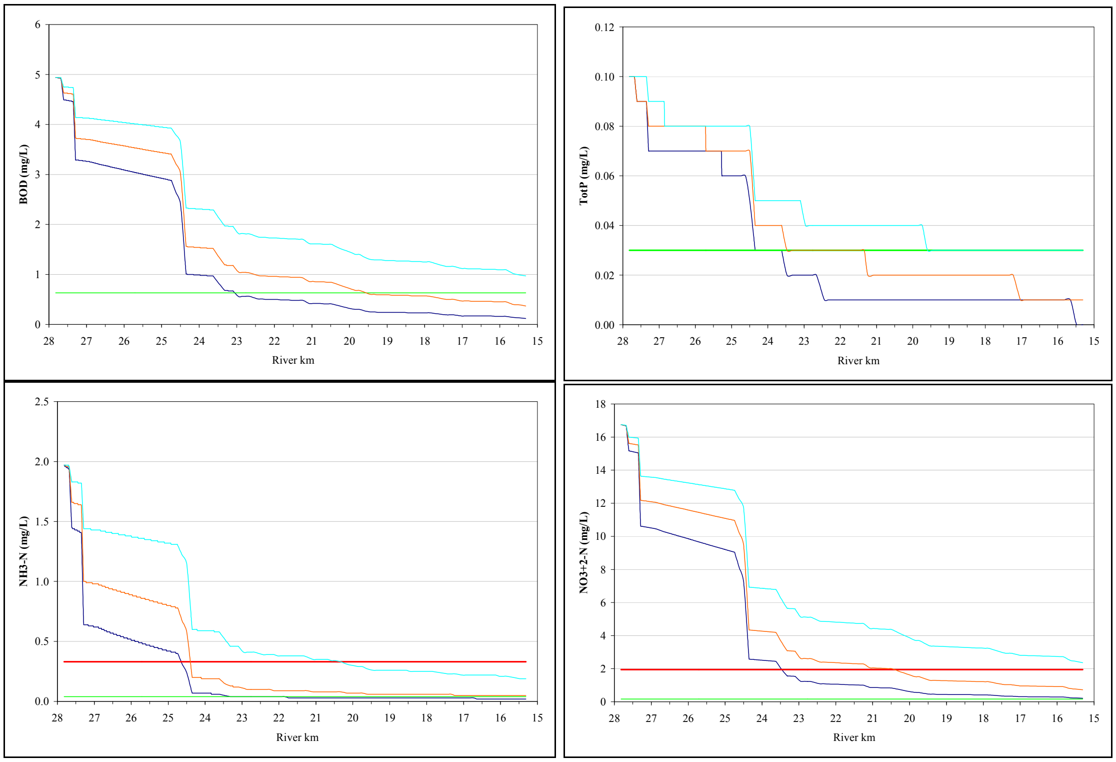

Figure 2. Low (turquoise), moderate (orange) and high (blue) temperature scenario output versus TCEQ screening levels (red) and long-term averages (green) for BOD5, total P, NH3 and NO_3+NO_2.

Discharge concentrations

The concentration of total phosphorus was evaluated using original TCEQ decay rates at the varying ambient water temperatures but using the daily average discharge concentration of 0.30 mg/L (Figure 3). As there is no restriction in the permit requiring the daily average total phosphorus to be 0.10 mg/L and the 0.30 mg/L daily average is possible while still meeting all permit requirements, this is a reasonable scenario. Predicted ammonia and nitrate concentrations are above long-term averages for both moderate and low temperature scenarios at the recharge zone boundary.

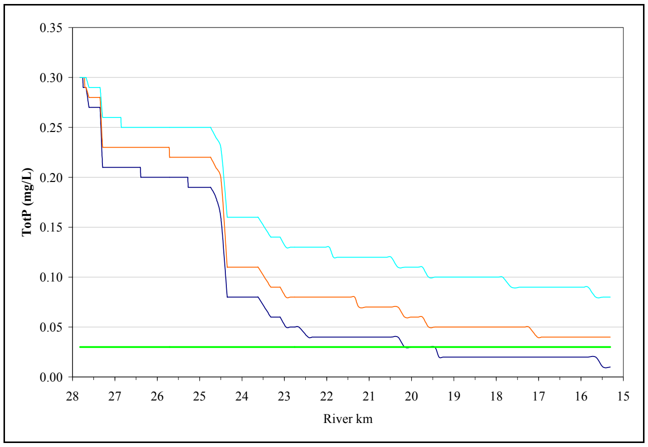

Figure 3. Low (turquoise), moderate (orange) and high (blue) temperature scenario output versus long-term Bear Creek average (green) for total phosphorus with a 0.30 mg/L daily average in the proposed discharge.

Critical decay rates

Critical decay rates for nutrient parameters to yield long-term average concentrations at the upper boundary of the recharge zone were determined at average temperatures and low flow (Table 7). Significant portions of Bear Creek remain above TCEQ screening levels at these decay rates (Figure 4). A 2004 study on the Bosque River (Miertschin and Obenour 2006) yielded decay rates for ammonia (Bosque River NH_3 = 0.10 day^{-1}), nitrate (Bosque River NO_3 = 0.19 day^{-1}) and total phosphorus (Bosque River TP = 0.055 day^{-1}) all lower than the estimated critical low flow decay rates for Bear Creek. Additional studies (EPA 1985) have yielded even lower decay rates for ammonia (EPA = 0.04 day^{-1}) and nitrate (EPA = 0.09 day^{-1}).

Table 7. Critical decay rates (day^{-1}) to yield nutrient concentrations at long-term averages at upper boundary of recharge zone during low flow conditions.

Flow Condition	**NH3-N (day^{-1})**	**NO3+2-N (day^{-1})**	**Total P (day^{-1})**
No headwater flow, moderate temp (scenario 6)	0.35	0.255	0.085

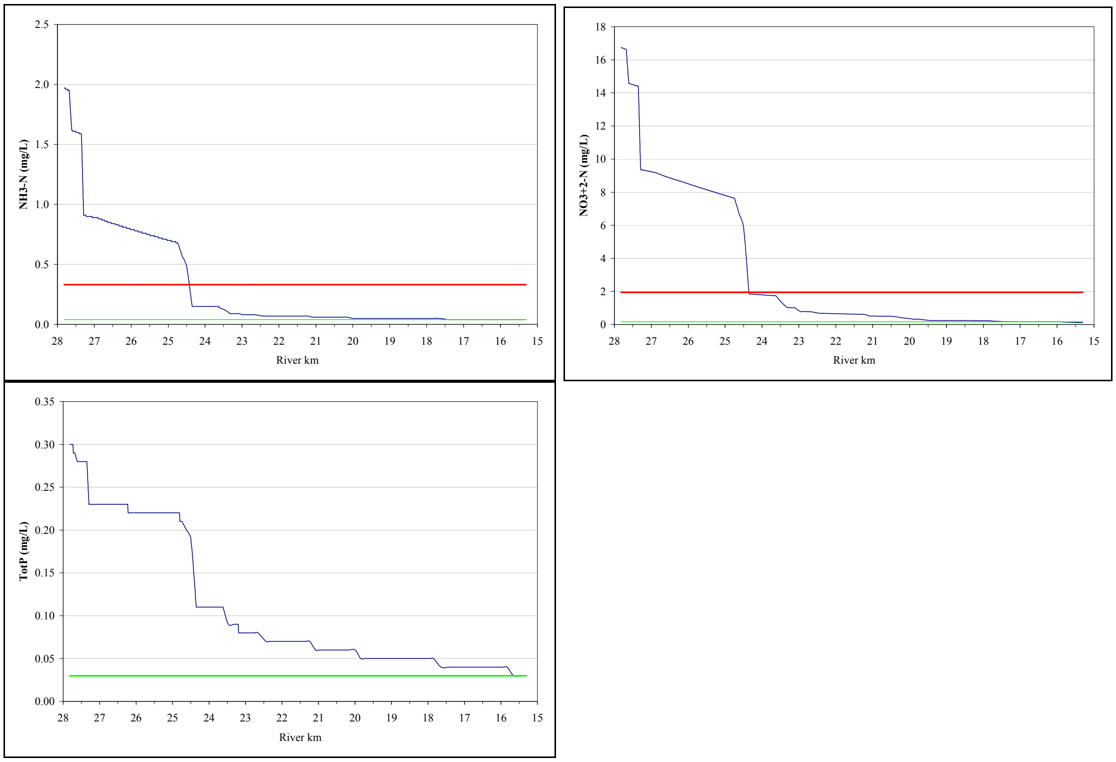

Figure 4. Predicted concentrations (blue) at critical decay rates in low flow conditions versus TCEQ screening levels (red) and long-term averages (green) for ammonia, nitrate and total phosphorus.

Dilution with Ambient Bear Creek Flow at Median Discharge

With the incremental tributary inflows, travel times from the proposed discharge location to the recharge zone boundary decrease from approximately 28 days (scenario 4, discharge as only source of flow in Bear Creek) to approximately 17 days. Although ambient Bear Creek inflows act to dilute waste load concentrations from the proposed discharge, the decreased travel time results in nearly equivalent concentrations at the recharge zone boundary under average ambient water temperatures between the median creek flow scenario and the comparable low flow discharge only scenario (Figure 5). Nitrate and total phosphorus remain above long-term averages at the upper recharge zone boundary.

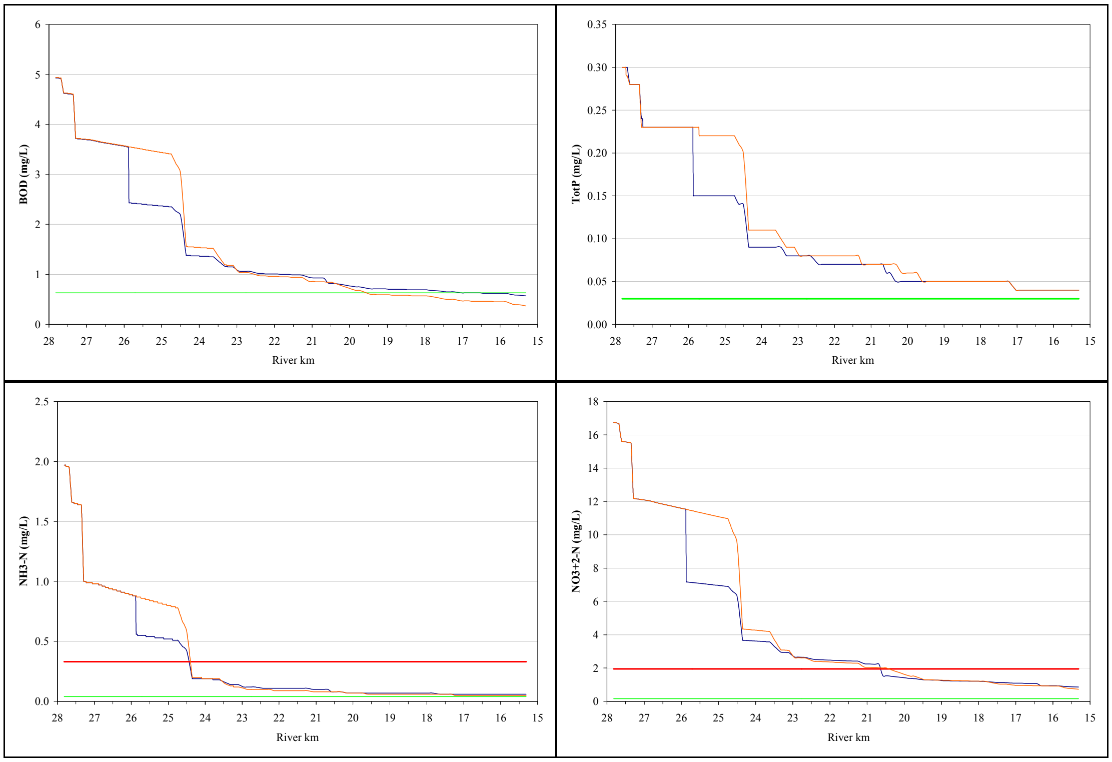

Figure 5. Predicted concentrations with median Bear Creek flows (blue) and with the discharge as the only source of flow (orange) versus TCEQ screening levels (red) and long-term averages (green).

Conservative Material Dilution

In the absence of any ambient headwater or incremental flows, the concentration of the conservative material was 1.0 in all reaches. Concentration of conservative material at varying ambient headwater flow rates may be simply estimated by conservative mass balance calculations. Conservative material concentration change with dilution was estimated for the dilution scenario (scenario 7) when the natural Bear Creek flows approximate the median of the mean daily average at the USGS gage (Figure 6). As expected by mass balance, the concentration of the conservative material was reduced 70% by dilution at the upper recharge zone boundary.

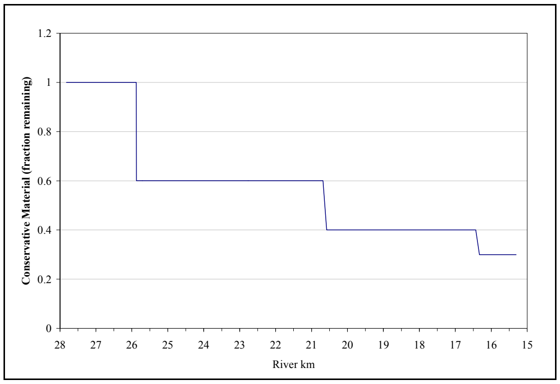

Figure 7. Predicted concentration of conservative material from the proposed discharge in median Bear Creek flow.

Critical Dilution Flow

Travel times decrease with increasing Bear Creek ambient flow values. Although additional Bear Creek ambient flow dilutes pollutants from the proposed discharge, decreasing travel times may result in decreased decay. When ambient flow (excluding the discharge) at the USGS gage is 21.75 ft^3/s, all constituents except nitrate are diluted to current average storm flow concentrations. This flow is approximately equivalent to the 94th percentile of flow based on the period of record at the USGS gage. Concentrations of nitrate remain 1.6 times higher than long-term average storm flow concentrations at this flow. Because of the high concentration of nitrate in the discharge relative to average storm flow levels, increasing dilution (>50 ft^3/s) results in reduced travel times that do not allow for sufficient predicted nitrate levels to decrease to average storm flow values at the upper end of the recharge zone. The conservative material is diluted to less than 10% of it's original concentration at this flow value.

Conclusions

Concentration of conservative materials may be simply estimated by mass balance calculations, and may be expected to decrease 70% in conditions when daily Bear Creek flow approaches median values.

Predicted concentrations of non-conservative pollutants are sensitive to ambient temperatures if loss rates are temperature-dependent. During cold low flow conditions, predicted concentrations for nitrate are above the TCEQ screening level for the entire 12.52 km reach of upper Bear Creek from the discharge to the recharge zone with TCEQ loss rates. Total phosphorus concentrations are predicted to be above the long-term average at the upper boundary of the recharge zone if natural Bear Creek discharge is near median values and under moderate and low temperature scenarios if total phosphorus in the discharge has a daily mean value of 0.30 mg/L.

Increased Bear Creek natural flow may dilute waste load concentrations from the proposed discharge, but up to some critical Bear Creek natural flow at least greater than the median the decrease in travel time results in reduced losses to decay resulting in reasonably equivalent concentrations at the upper recharge zone boundaries.

No predicted total phosphorus concentrations are expected to exceed the TCEQ screening level under the conditions evaluated here. However, concentrations of nitrate and ammonia are predicted to exceed TCEQ screening levels for some conditions (Table 8). **In winter low flow conditions, nitrate concentrations are predicted to exceed TCEQ (2008) screening levels for the entire reach of Bear Creek from the proposed discharge to the upper recharge zone boundaries.** At least 24% of Bear Creek from the discharge to the recharge zone will exceed the TCEQ ammonia screening level and at least 26% of Bear Creek will exceed the TCEQ nitrate screening level under all conditions assessed here. Even with dilution of the wastewater with ambient creek flows at current median values, predicted concentrations at the recharge zone for total nitrogen and total phosphorus are more than 5 times higher than reference conditions from least-disturbed streams in the Edwards Plateau (EPA 2001, USGS 2007). A flow conditional discharge may dilute concentrations of BOD_5, ammonia and total phosphorus to background levels but is predicted to increase nitrate loading to the Edwards Aquifer relative to current conditions.

Table 8. Summary of LA-QUAL output under varying conditions expressed as length of stream in kilometers from discharge to upper recharge zone boundaries exceeding TCEQ screening levels for nitrogen. Percentage of stream length exceeding screening levels from discharge to upper recharge zone boundary in parentheses.

#	**Scenario**	**Stream reach in km exceeding NH3 screening levels**	**Stream reach in km exceeding NO3+2 screening levels**
0	TCEQ original (high temp, low flow, low TP, original k)	3.09 km (24.7%)	4.36 km (34.8%)
1	Winter (low temp, low flow, low TP, original k)	7.35 km (58.7%)	**12.52 km (100%)**
2	Moderate temp (low flow, low TP, original k)	3.33 km (26.6%)	7.35 km (58.7%)
3	High temp, low flow, high TP	3.09 km (24.7%)	4.36 km (34.8%)
4	Mod temp, low flow, high TP	3.33 km (26.6%)	7.35 km (58.7%)
5	Low temp, low flow, high TP	7.35 km (58.7%)	**12.52 km (100%)**
6	Critical k, low flow	3.33 km (26.6%)	3.33 km (26.6%)
7	Dilution at median flow	3.33 km (26.6%)	7.15 km (57.1%)
8	Critical dilution flow	1.95 km (15.6%)	**12.52 km (100%)**

Predicted DO concentrations do not fall below the minimum 4 mg/L required for aquatic life use support under the conditions evaluated here. However, DO concentrations drop as low as 4.28 mg/L in the original TCEQ scenario (high temperature, low flow) in one pond reach. Actual DO concentrations are expected to decrease below predicted values since LA-QUAL models do not consider any algal respiration or decay of algal biomass even though that is the presumed mechanism for ultimate nutrient removal. If Bear Creek DO levels fall below long-term averages or if BOD loading from Bear Creek to the recharge zone is increased, DO concentrations at Barton Springs may fall below critical levels for the federally-endangered Barton Springs salamander (COA 2006).

Comparison of predicted concentrations to long-term water quality averages at the USGS gage near Bear Creek Pass (08158810) may be used to determine if the proposed discharge will have more than a *de minimus* impact on Bear Creek. Length of creek reaches exceeding long-term averages were estimated (Table 9). At low water temperatures and when the discharge is the only flow in Bear Creek, predicted concentrations of BOD5, ammonia and nitrate are above long-term averages for the entire reach of Bear Creek from the discharge to the upper recharge zone boundary. Total phosphorus at both average and low water temperatures and in both low flow and median flow conditions exceeds long-term historical average for the entire reach of Bear Creek when the total phosphorus in the effluent is modeled at the 0.30 mg/L daily average. Increases in total phosphorus loading from Bear Creek to the recharge zone may result in the exacerbation of a pre-existing nuisance algal problem at Barton Springs Pool (Herrington and Scoggins 2006).

Table 9. Summary of LA-QUAL output under varying conditions expressed as length of stream in kilometers from discharge to upper recharge zone boundaries exceeding long-term average concentrations. Percentage of stream length exceeding long-term average concentrations from discharge to upper recharge zone boundary in parentheses.

#	Scenario	BOD5	NH3-N	NO3+2-N	TP
0	TCEQ original (high temp, low flow, low TP, original k)	4.73 km (37.8%)	4.36 km (34.8%)	**12.52 km (100%)**	3.33 km (26.6%)
1	Winter (low temp, low flow, low TP, original k)	**12.52 km (100%)**	**12.52 km (100%)**	**12.52 km (100%)**	8.09 km (64.6%)
2	Mod temp (low flow, low TP, original k)	8.235 km (65.8%)	**12.52 km (100%)**	**12.52 km (100%)**	4.21 km (33.6%)
3	High temp, low flow, high TP	4.73 km (37.8%)	4.36 km (34.8%)	**12.52 km (100%)**	7.51 km (60%)
4	Mod temp, low flow, high TP	8.235 km (65.8%)	**12.52 km (100%)**	**12.52 km (100%)**	**12.52 km (100%)**
5	Low temp, low flow, high TP	**12.52 km (100%)**	**12.52 km (100%)**	**12.52 km (100%)**	**12.52 km (100%)**
6	critical k, low flow	8.235 km (65.8%)	10.19 km (81.4%)	10.9 km (87.1%)	12 km (95.8%)
7	dilution at median flow	10.6 km (84.7%)	**12.52 km (100%)**	**12.52 km (100%)**	**12.52 km (100%)**
8	critical dilution flow	3.33 km (26.6%)	12.35 km (98.6%)	**12.52 km (100%)**	7.15 km (57.1%)

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