



Watershed Protection Development Review

PREDICTING PHOSPHORUS WITH THE PARSIMONIOUS MODEL.

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Abstract

A lumped parameter flow and water quality model was developed for the Barton Springs Segment of the Edwards Aquifer in 1996 by the Center for Resources in Water Resources. Initial use of the model was for simulations of total nitrogen in the aquifer and discharge at Barton Springs under various scenarios of watershed development. As an extension of this model, the total phosphorous concentrations were simulated for the same time period and calibration and verification was completed using the available data. Baseflow and stormflow TP concentrations were determined for recharging creeks, and a mass balance calculated for the model using discharge TP concentrations at Parthenia (Main Barton) Springs. The model predicted increase of phosphorous in the aquifer associated with development could impact Barton Springs Pool and Town Lake. Potential biological impacts from increased TP might be increased algae blooms, decreased dissolved oxygen levels during algal senescence and decay, and a decrease in the desirability of recreational activity in the springs. Eutrophication may occur when phosphorous levels exceed 0.04 mg/L. Therefore, algae blooms could impact the Pool and Lake at phosphorous concentrations between current and moderate development conditions.

Introduction

The objectives of this project were to calculate a mass balance for total phosphorous (TP) in the Barton Springs segment of the Edwards Aquifer and to use the Parsimonious Model developed by Barrett and Charbeneau (1996) to predict impacts of development on aquifer TP. Well data was obtained from Michael Barrett at the University of Texas Center for Research in Water Resources. Creek and Barton Spring data were downloaded from the United States Geological Survey water quality database (txwww.cr.usgs.gov). These data were analyzed to estimate the volume of phosphorous entering the aquifer via creek and diffuse recharge and the volume of phosphorous discharging from Barton Spring. The same study area, hydraulic model, development scenarios, and input files used by Barrett and Charbeneau (1996) apply to this project. The only modification made to the Parsimonious Model for this project was the substitution of phosphorous data in the place of the nitrogen data. Technical Report CRWR 269 (Barrett and Charbeneau, 1996) can be used for a detailed description of the hydraulic and water quality model development.

Phosphorous Mass Balance Calculation

A mass balance of total phosphorous (TP) in the Barton Springs segment of the Edwards Aquifer (BSEA) was performed. The amount of phosphorous recharging the aquifer was compared to the amount discharging from Barton Spring. The primary phosphorus sources are assumed to be creek recharge, rainfall infiltration, and septic tank effluent.

Spring Discharge

USGS water quality data collected from 1984 to 1996 was analyzed for Barton Springs and for five creeks crossing the recharge zone of the BSEA. Data from earlier years were ignored to avoid the uncertainty associated with the use of different analytical methods and detection limits. Also, a sewer line break, which may have affected water quality in the Barton watershed, reportedly occurred in the early 1980s. TP levels in Barton Spring are historically very low with most reported concentrations near or below the detection limit of 0.01 mg/L (Figure 1).

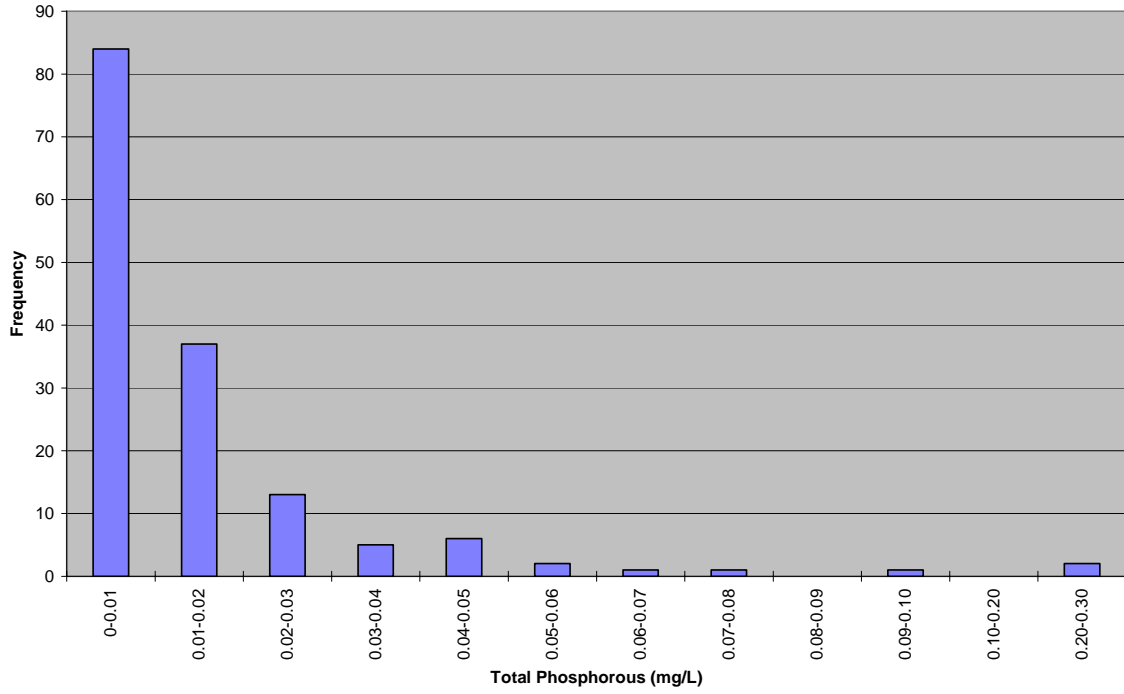
Creek Recharge

The water quality data for Onion, Slaughter, Bear, and Barton creeks was collected at USGS gauging stations located in or above the recharge zone. The concentrations from Bear were used for both Bear and Little Bear creeks due to the small amount of data available from the Little Bear station. The frequency plots for the five creeks (Figures 2 through 6) show the number of times a TP value falls within a given range. The majority of surface water TP concentrations measured in the creeks are equal to or less than 0.01 mg/L. The majority of values measured in Williamson creek lie between 0.1 and 0.2 mg/L TP. A relatively large number of values in Barton Creek also lie between 0.1 and 0.2 mg/L which is the range of stormflow TP.

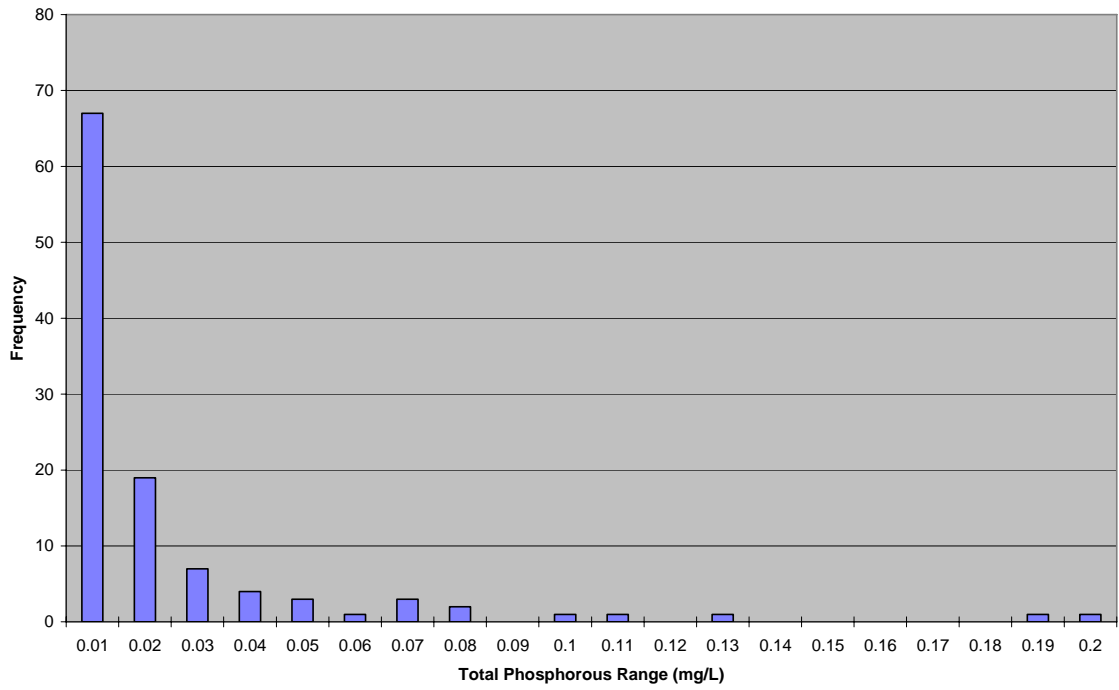
Mean TP concentrations in storm flow and base flow were determined for Onion, Bear, Slaughter, Williamson, and Barton creeks. TP values below the detection limit of 0.01 mg/L were set equal to zero for the purpose of data analysis. This is justified by the observation that phosphorous levels in stormwater collected by the COA drop very rapidly to the detection limit. Phosphorus is thought to be the limiting nutrient in local aquatic systems and is therefore subject to very rapid uptake. The separation baseflow TP was calculated of baseflow from stormflow was based on the concentration of total suspended solids (TSS). Mean by averaging the concentrations at TSS concentrations less than 10 mg/L. Mean storm flow TP was calculated by averaging the concentrations with TSS greater than 20 mg/L. This method was used to reduce the uncertainty about whether the intermediate TSS concentrations (10 mg/L < TSS < 20 mg/L) are storm flow or base flow (Table 1). The TSS ranges for stormflow and baseflow were chosen based on the observations of historical data by COA hydrogeologists.

The same base flow and storm flow concentrations were used for Bear and Little Bear creeks due to the minimal data available from the Little Bear Station. Any differences are offset by the small contribution of the Little Bear watershed to aquifer recharge.

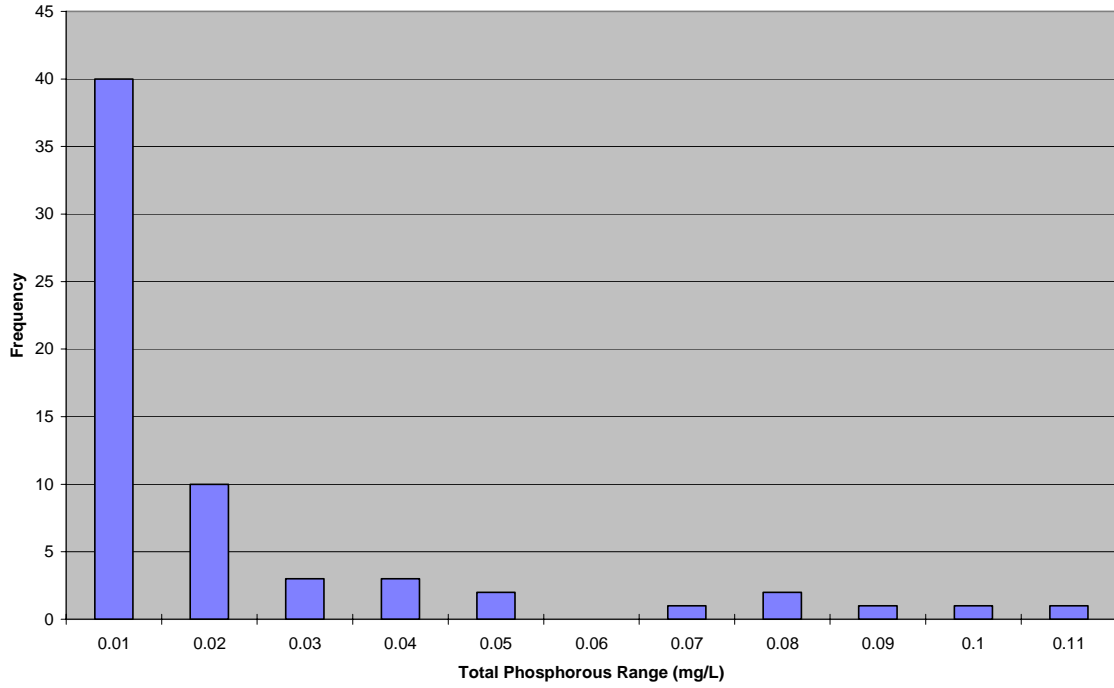
**Figure 1. TP Frequency Diagram
Barton Spring (USGS Station 08155500)**



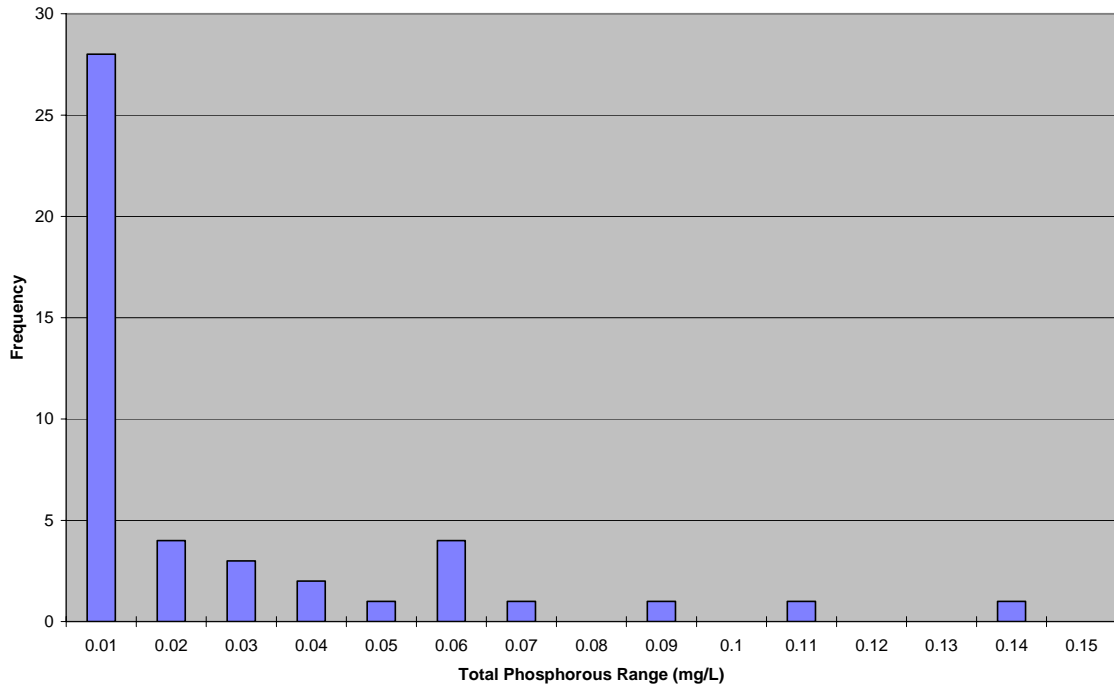
**Figure 2. TP Frequency Diagram
Onion Creek (USGS Station 08158700)**



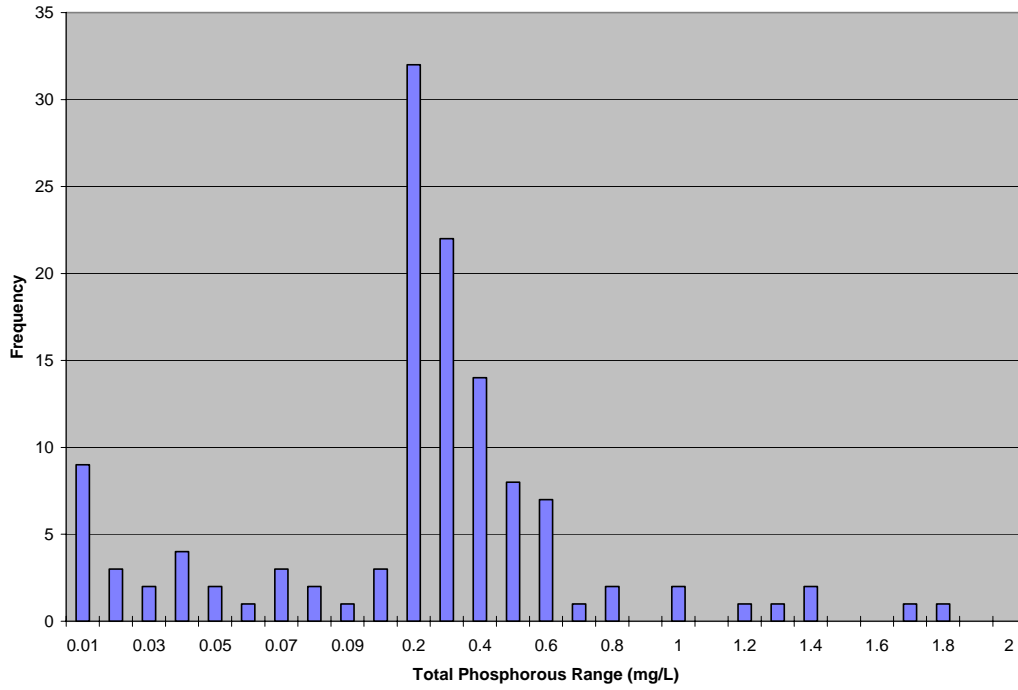
**Figure 3. TP Frequency Diagram
Bear Creek (USGS Station 08158810)**



**Figure 4. TP Frequency Diagram
Slaughter Creek (USGS Station 08158840)**



**Figure 5. TP Frequency Diagram
Williamson Creek (USGS Station 08158920)**



**Figure 6. TP Frequency Diagram
Barton Creek (USGS Station 08155300)**

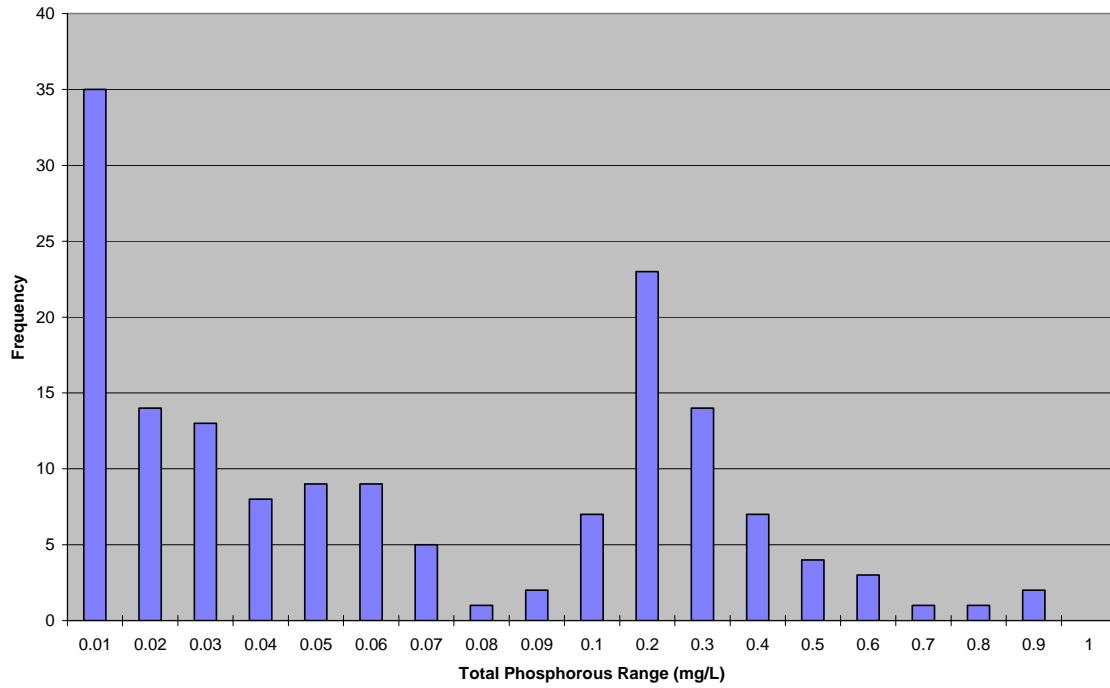


Table 1. Average Total Phosphorus Concentrations for the Creeks

Creek	Mean Baseflow Total Phosphorus (mg/L)	Mean Stormflow Total Phosphorus (mg/L)
Barton	0.009	0.170
Williamson	0.110	0.430
Slaughter	0.007	0.071
Bear (and Little Bear)	0.009	0.043
Onion	0.011	0.141

Appendix A contains tables for each creek showing the separation of storm and baseflow. Average TP was calculated for data collected between 1984 and 1996.

Table 2 shows the calculation for the mean TP input from each creek to the aquifer using the fraction of creek recharge specified in the Parsimonious Model.

Table 2. Mean Phosphorous Concentration Derived from Creeks

Creek	USGS Station	Flow Type	n	TP (mg/L)	Fraction Creek Recharge	Weighted Average
Barton	8155300	Base	19	0.009	0.267	0.002
		Storm	70	0.170	0.043	0.007
Williamson	8158920	Base	18	0.110	0.021	0.002
		Storm	61	0.430	0.007	0.003
Slaughter	8158840	Base	26	0.007	0.046	0.000
		Storm	10	0.071	0.014	0.001
Bear	8158810	Base	30	0.009	0.062	0.001
		Storm	6	0.043	0.008	0.0003
Little Bear	8158810	Base	30	0.009	0.062	0.001
		Storm	6	0.043	0.008	0.0003
Onion	8158700	Base	38	0.011	0.434	0.004
		Storm	11	0.141	0.038	0.005
Average from Creeks						0.028

Barton Spring Mean Total Phosphorous

1984-96 0.018

Note:

TP values from USGS (1984-1996)

*Non-detect TP values were set = 0

*Base flow: Used TP @ TSS < 10 mg/L

*Storm flow: Used TP @ TSS >20 mg/L

The weighted average TP input from the creeks is 0.028 mg/L whereas the mean TP discharging from Barton Springs is 0.018 mg/L. This difference may reflect a difference in the percentages of dissolved and suspended phosphorous in the creeks versus Barton Springs. These differences are accounted for to achieve a better mass balance of phosphorous.

Total phosphorous is a combination of dissolved and suspended phosphorous. The analysis of proportions of dissolved and suspended phosphorous in base flow and storm flow is presented in Appendix B. Storm flow in the creeks appears to have approximately equal proportions of dissolved and suspended phosphorous. However, Barton Spring discharge contains primarily dissolved phosphorous. The percentages of DP and SP were not calculated for baseflow because the majority of the values were

below the detection limit. The phosphorous mass balance was re-calculated with the assumption that all of the SP in stormflow will settle out within the aquifer and only DP will reach Barton Spring. Table 3 shows the new calculation for the mean phosphorous input from the creeks.

Table 3. Mean Phosphorous Derived from Creeks, Accounting for SP in Stormflow

Creek	USGS Station	Flow Type	n	Mean TP (mg/L)	Stormflow TP x 0.50	Fraction Creek Recharge	Weighted Average (mg/L)
Barton	8155300	Base	19	0.009		0.267	0.002
		Storm	70	0.17	0.083	0.043	0.004
Williamson	8158920	Base	18	0.110		0.021	0.002
		Storm	61	0.43	0.214	0.007	0.001
Slaughter	8158840	Base	26	0.007		0.046	0.000
		Storm	10	0.071	0.036	0.014	0.000
Bear	8158810	Base	30	0.009		0.062	0.001
		Storm	6	0.043	0.022	0.008	0.000
Little Bear	8158810	Base	30	0.009		0.062	0.001
		Storm	6	0.043	0.022	0.008	0.000
Onion	8158700	Base	38	0.011		0.434	0.005
		Storm	11	0.141	0.071	0.038	0.003
Average from Creeks							0.019

Note

- TP values from USGS (1984-1996)
- *Non-detect TP values were set = 0
- *Base flow: Used TP @ TSS < 10 mg/L
- *Storm flow: Used TP @ TSS >20 mg/L

**Barton Spring Mean Total Phosphorous
1984-96 0.018**

The mean concentration of total phosphorous in storm flow is multiplied by a factor of 0.5 to account for the settling of SP. Next, the mean phosphorous is multiplied by the fraction of creek recharge to obtain a weighted average for each creek. The weighted averages are summed to obtain the total input from the creeks. The mean total phosphorous input from the creeks is 0.019 mg/L. The mean total phosphorous discharging from Barton Springs (1984 - 1996) is 0.018 mg/L.

Septic Tank Effluent

The assumptions made by Barrett and Charbeneau (1996) apply regarding the number of septic tanks and the volume of septic tank effluent. Septic tank effluent is given an initial concentration of 12 mg/L. This value is in the range of the mean phosphorous concentration for septic tank effluent reported by Viraraghavan and Warnock (1976) and the concentrations reported in a local study by Espey, Huston and Associates (1985). A study reported in Canter and Knox (1986) states that phosphorous in effluent from septic systems is not usually transported through the soil to groundwater. Phosphorous is retained in the soils by both chemical precipitation of hydroxyapatite and chemisorption to Ca, Fe, and Al minerals (Canter and Knox, 1986). Uptake by plants may also be a mechanism of phosphorous removal. We don't know the amount of phosphorous that reaches groundwater from septic tanks but for the purpose of this model, it is assumed that the amount contributed by septic tank effluent is minimal and 99% of the phosphorus concentration is attenuated before reaching groundwater.

Rainfall Infiltration

Diffuse recharge is given an initial concentration of 0.08 mg/L which is the mean total phosphorous concentration measured in rainwater collected from St. Elmo and Windago Way wet ponds by the City of Austin (Table 4).

Table 4 . Mean Phosphorous in Rainwater

SITE	DATE	DP (mg/L)	TP (mg/L)
St. Elmo Pond	4/20/95		0.14
St. Elmo Pond	4/22/95	0.03	0.1
St. Elmo Pond	5/8/95		0.07
St. Elmo Pond	5/18/95	0.06	0.08
St. Elmo Pond	5/30/95	0.02	< 0.02
St. Elmo Pond	6/11/95	0.06	0.21
St. Elmo Pond	6/29/95	0.02	< 0.02
St. Elmo Pond	7/6/95	0.02	0.03
St. Elmo Pond	9/7/95	0.11	0.06
St. Elmo Pond	9/14/95	0.12	0.08
St. Elmo Pond	9/20/95	0.16	0.18
Windago Way Pond	9/21/95		0.02
Windago Way Pond	11/1/95	0.04	< 0.02
St. Elmo Pond	11/1/95		0.02
Windago Way Pond	11/17/95	0.03	0.12
St. Elmo Pond	11/17/95	0.03	0.03
Windago Way Pond	3/26/96	0.04	0.09
St. Elmo Pond	3/26/96	0.13	0.13
Windago Way Pond	7/22/96	0.16	0.16
AVERAGE		0.07	0.08

The attenuation factor of 99% that is applied to septic effluent is also applied to diffuse recharge.

The Mass Balance

The average phosphorous concentration is multiplied by the volume of recharge (cubic feet) and a conversion factor to obtain a phosphorous mass in kilograms. The phosphorous mass balance calculation is shown in Table 5 assuming septic TP at 12 mg/L and 99% attenuation with rainwater at 0.08 mg/L.

Table 5. Phosphorous Mass Balance

	recharge (ft3)	conversion factor	Average P (mg/L)	Mass (kg)	% of total mass
Creek Recharge	2.10E+09	2.83E-05	0.019	1130	92
Septic Systems	2.70E+07	2.83E-05	0.12	92	7
Diffuse Recharge	3.70E+08	2.83E-05	0.0008	8	1
Total Mass Recharging				1230	97
Total Mass Discharging	2.50E+09	2.83E-05	0.018	1274	

The mass of phosphorous supplied to the aquifer by the creeks, septic systems, and diffuse recharge totals 1230 kg/year. The total mass of phosphorous discharging from Barton Spring is 1274 kg/year. This is a

mass balance of 97%. An uncertainty associated with the mass balance calculation is the degree of attenuation of phosphorous before reaching groundwater. Another uncertainty lies in the calculation of the average phosphorous recharging from the creeks. It is assumed that 50% of the stormflow TP reaches Barton Spring as DP and that the remaining 50% of the TP is SP which settles out within the aquifer. It is uncertain how much local storm SP (Barton Creek recharge zone) reaches the springs. The model therefore assumes that there is no SP in creek baseflow (See explanation in Appendix B). However baseflow probably does contain some SP but we don't know how much reaches Barton Spring.

Model Inputs

The model input files created by Michael Barrett (Barrett and Charbeneau, 1996) for the simulation of nitrogen transport were modified to simulate the transport of phosphorous in the BSEA. Initial constituent concentrations in each cell were changed to a reflect median phosphorous concentrations in the creeks. The creek data files (onion.txt., bear.txt, slauter.txt, will.txt, barton.txt) were modified by replacing the baseflow and stormflow nitrogen values with baseflow and stormflow phosphorous concentrations. Flow rates were not changed. Pumping volumes for each cell (pump.txt) were unchanged. The simulation parameter file was modified by changing the initial constituent concentration in each cell to median TP. Initial water volume of each cell, rate of diffuse infiltration, and longitudinal dispersivity were kept the same. The concentration of TP in diffuse recharge for each cell was determined by calculating the weighted average TP in septic systems and diffuse recharge (Table 6). The same assumptions used by Barrett and Charbeneau (1996) for the volume of recharge provided by septic systems and diffuse recharge during moderate and intense development apply. It is assumed that during moderate development, the number of septic systems doubles and diffuse recharge is reduced by 20% (due to increased impervious cover). During intense development, the number of septic systems quadruples and diffuse recharge is reduced by 40%.

Table 6. Weighted Average TP from Septic Systems and Diffuse Recharge

Current Conditions	Recharge volume (ft3)	Phosphorus (mg/L)
Septic Systems	2.70E+07	0.12
Diffuse Recharge	3.70E+08	0.0008
Weighted Average		0.009
Moderate Development	Recharge volume (ft3)	Phosphorus (mg/L)
Septic Systems x 2	5.40E+07	0.12
Diffuse Recharge x 0.8	2.96E+08	0.0008
Weighted Average		0.019
Intense Development	Recharge volume (ft3)	Phosphorus (mg/L)
Septic Systems x 4	1.08E+08	0.12
Diffuse Recharge x 0.6	2.22E+08	0.0008
Weighted Average		0.040

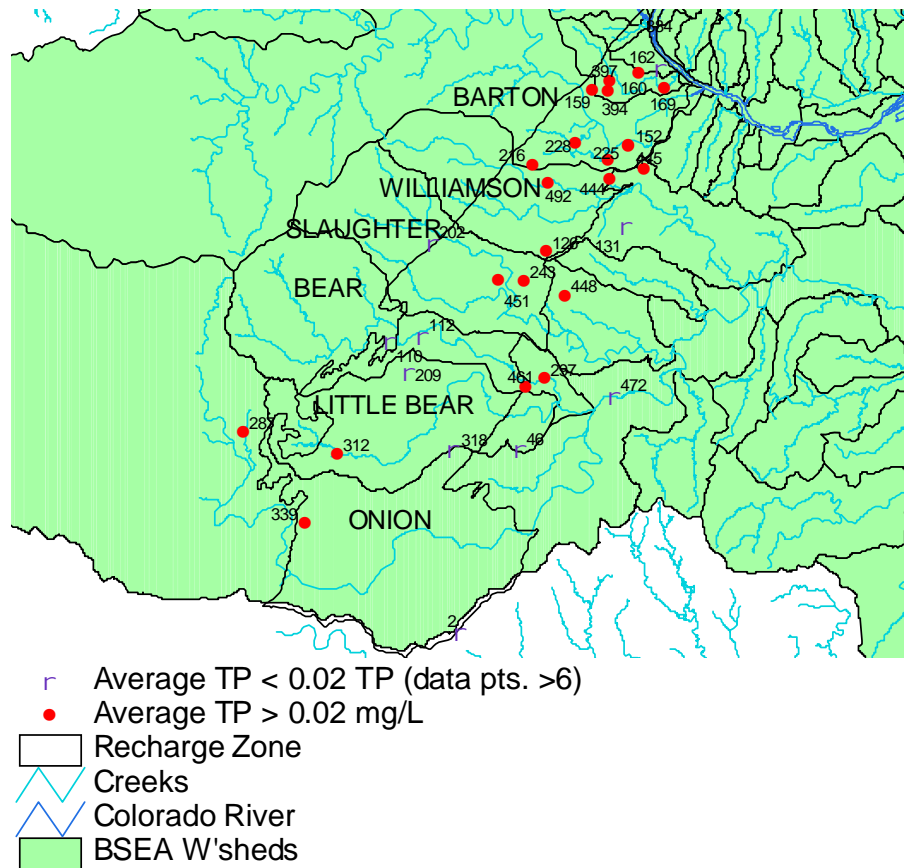
Current Conditions: Observed versus Predicted Phosphorous

Groundwater data from 30 wells in the BSEA (Figure 7) was used to compare observed TP concentrations in the aquifer to the concentrations predicted by the model (Figures 8 through 12). Generally, average phosphorous concentrations are low in the aquifer, less than 0.02 mg/L. The detection limit for TP is 0.01 mg/L. The predicted groundwater values in each cell fall within the range of observed values with the exception of the Williamson Creek cell (Table 7).

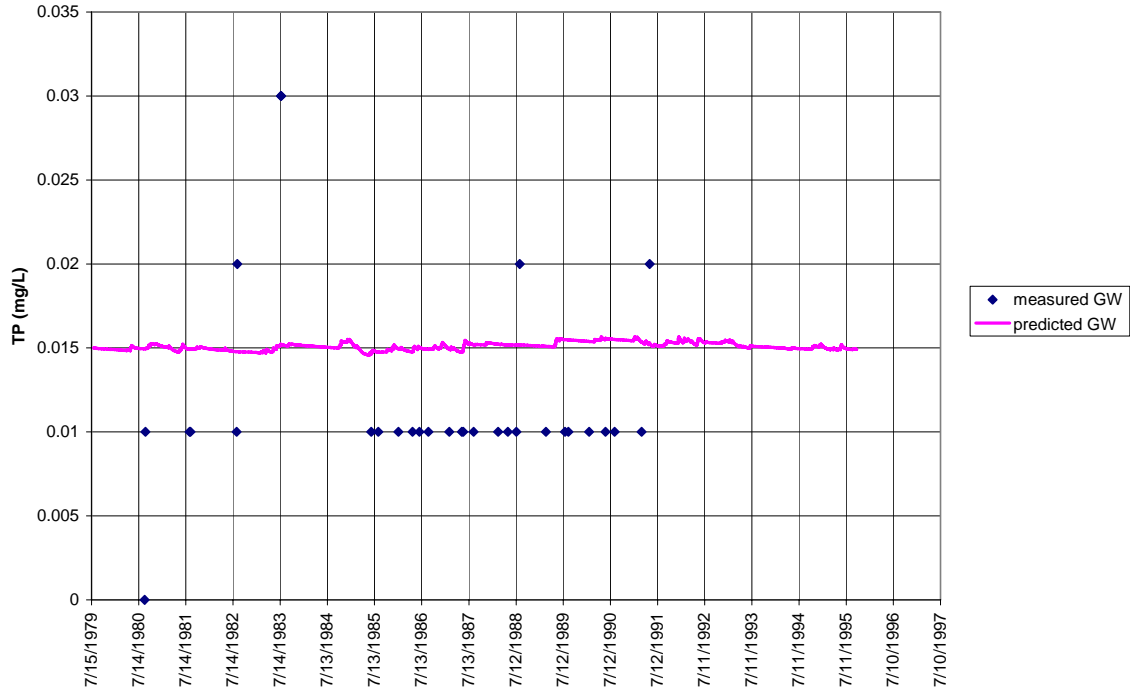
Table 7. Current Conditions, Measured vs. Predicted Average Total Phosphorous

Watershed	Onion	Bear	Slaughter	Williamson	Barton	Barton Spring
Creeks measured (base/storm)	0.011 / 0.141	0.009 / 0.043	0.007 / 0.071	0.11 / 0.43	0.009 / 0.17	
GW measured	0.012	0.018	0.016	0.04	0.017	0.018
GW predicted	0.015	0.014	0.014	0.018	0.018	0.018

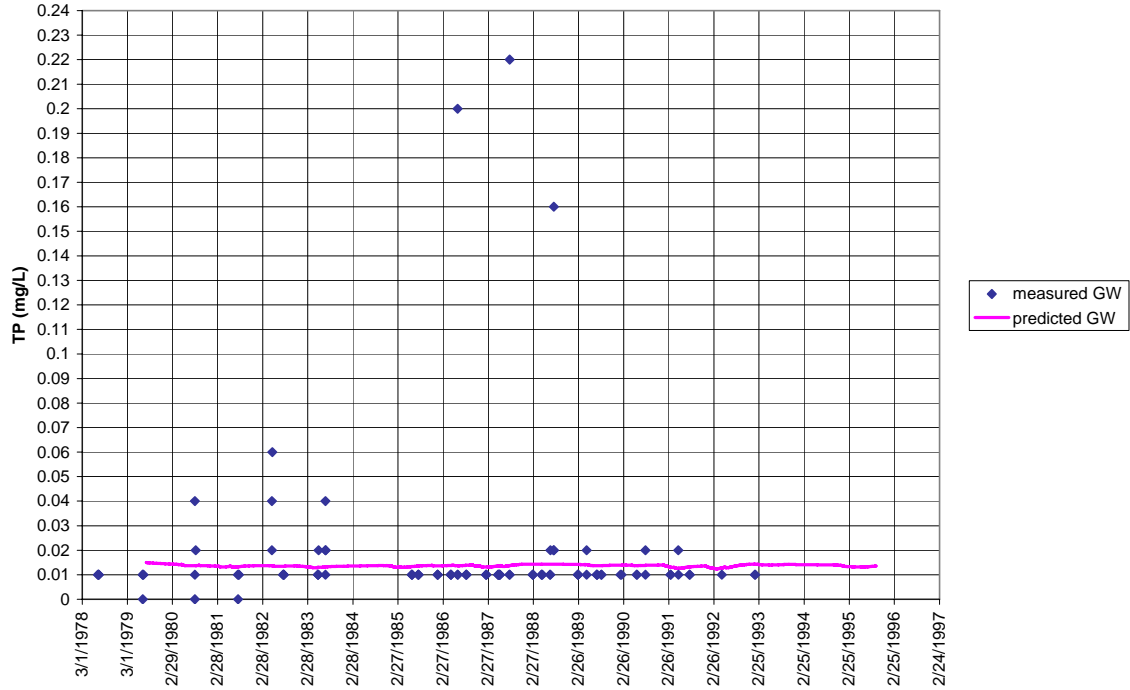
Figure 7. Well Locations in the Barton springs Segment of the Edwards Aquifer



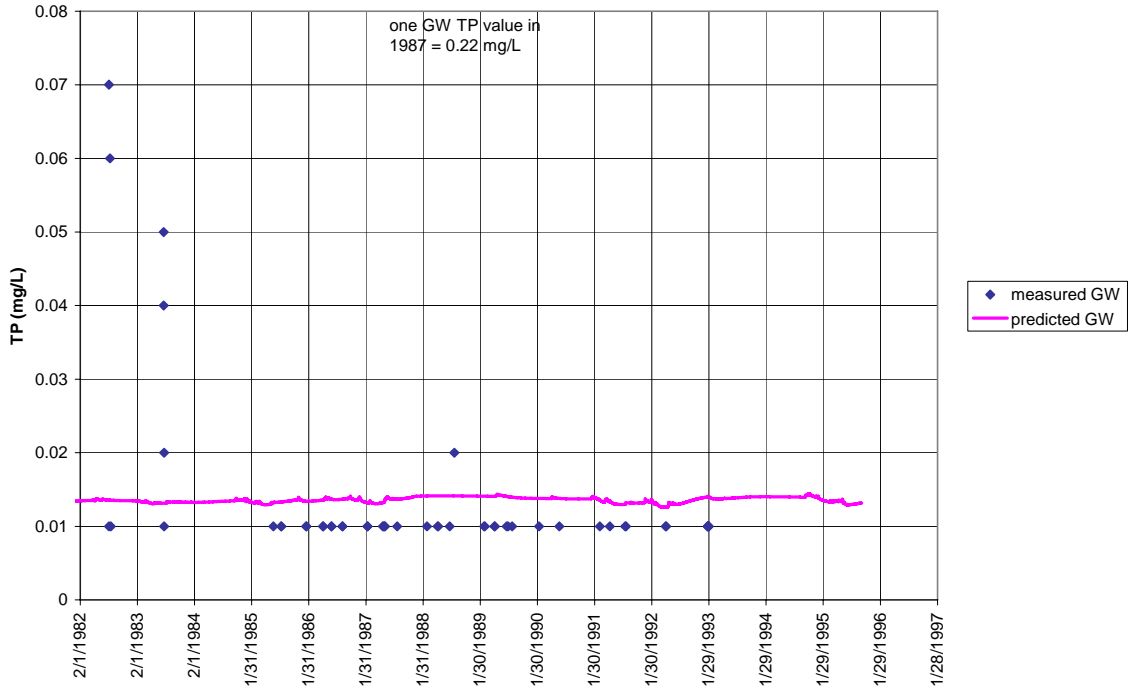
**Figure 8. Current Conditions
Onion Total Phosphorous**



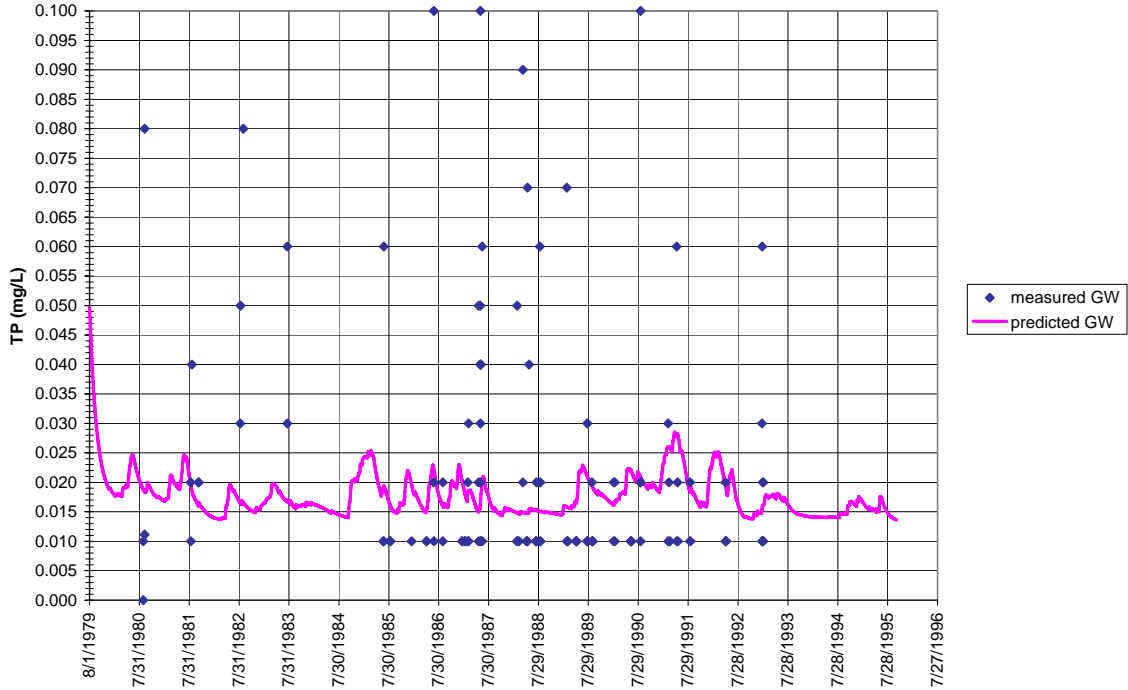
**Figure 9. Current Conditions
Bear Total Phosphorous**



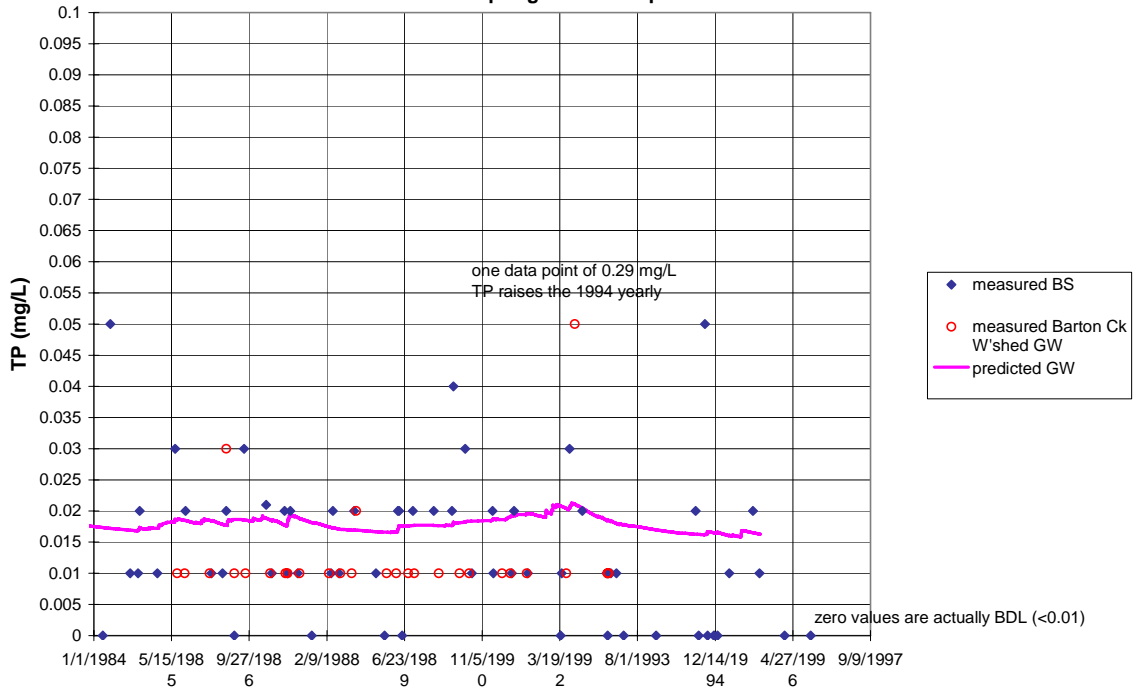
**Figure 10. Current Conditions
Slaughter Total Phosphorous**



**Figure 11. Current Conditions
Williamson Total Phosphorous**



**Figure 12. Current Conditions
Barton Spring Total Phosphorous**



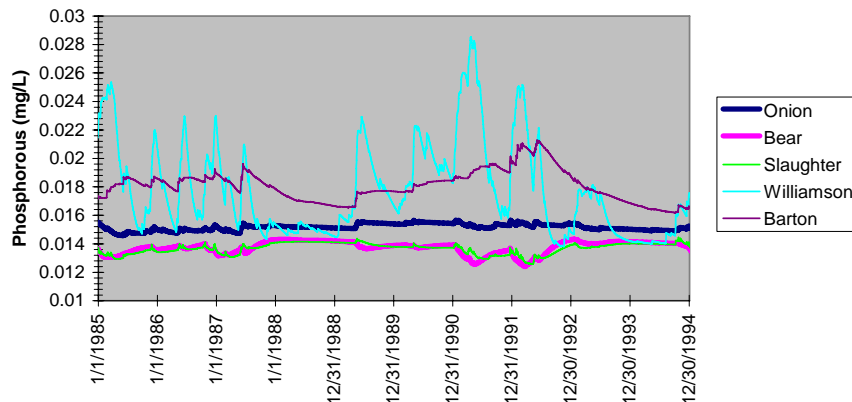
The high average TP observed in the Williamson cell may be a result of a localized source of phosphorous near the observation wells. The average TP in the Williamson cell predicted by the model is lowered by the input of dilute groundwater from the Onion, Bear, and Slaughter cells.

Figure 13 is a time series comparison of groundwater TP predicted by the model for current development conditions. The Williamson and Barton cells have the highest TP concentrations. Williamson cell shows the largest variance in TP between stormflow and baseflow. Onion, Bear, and Slaughter cells have lower TP concentrations and show less variance in concentrations.

The Effects of Urbanization

The effect of moderate development on the watersheds was modeled by assuming that all the creeks contributing recharge to the aquifer would have the same flow pattern and water quality currently observed in Williamson Creek. The effect of intense development was modeled by assuming the creeks

Figure 13. Current Development Conditions



would have the same flow pattern and water quality currently observed in Shoal Creek. Impervious cover for current conditions in the contributing and recharge zone is assumed to account for 5-8% of the total area. Impervious cover is expected to increase to approximately 20% of the total area for moderate development and 40-50% of the area for intense development (Barrett and Charbeneau, 1986). Phosphorous concentrations used for the development scenarios are presented in Table 8.

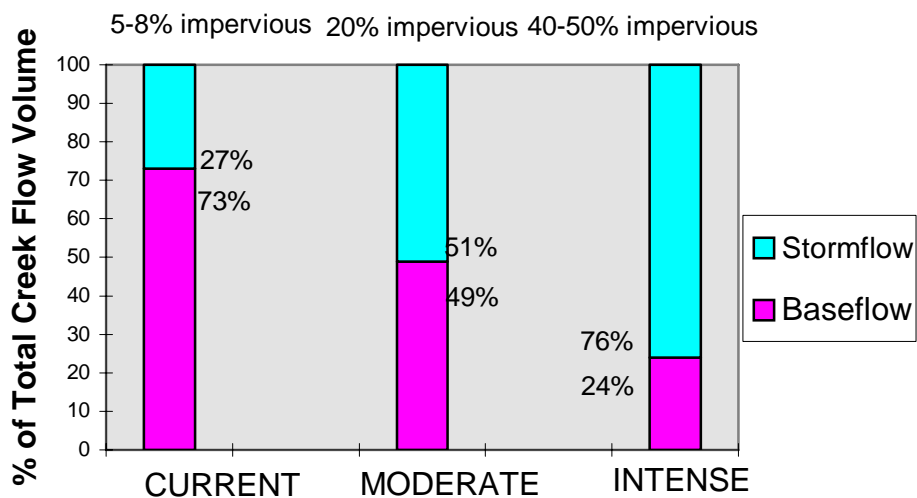
Table 8. Phosphorous Concentrations Used for Development Scenarios

Moderate Development (Williamson Creek)	(mg/L)	Intense Development (Shoal Creek)	(mg/L)
Baseflow TP	0.11	Baseflow TP	0.05
Stormflow TP	0.43	Stormflow TP	1.09
Transported Stormflow DP	0.21	Transported Stormflow DP	0.54

Note: SP in stormflow is assumed to settle out within the aquifer (see Appendix B)

A comparison of volumes of total base flow and storm flow during current, moderate, and intense development model scenarios is shown in Figure 14.

Figure 14. Effect of Development on Creek Flow.



The percentage of stormflow of the total flow volume increases from current to intense development. The percentage of baseflow decreases from current to intense development. The increase in impervious cover prevents diffuse infiltration, lowers baseflow, and increases stormwater runoff to the creeks.

If a larger proportion of recharge from the creeks is derived from stormwater runoff, lower water quality would be expected. Figures 15 and 16 compare the predicted water quality changes during moderate and intense development. Barton and Onion cells have the highest phosphorous concentrations during moderate development conditions but show less of a response to rainfall than the three smaller cells. During moderate development, phosphorous concentrations vary between 0.105 mg/L and 0.130 mg/L. During intense development conditions, the model predicts that Barton will have the highest phosphorous concentrations, followed by Slaughter and Williamson, during intense development conditions. Bear and Onion cells have the lowest predicted phosphorous during intense development. The phosphorous concentrations vary between 0.25 mg/L and 0.35 mg/L.

Figure 15

Moderate Development Conditions

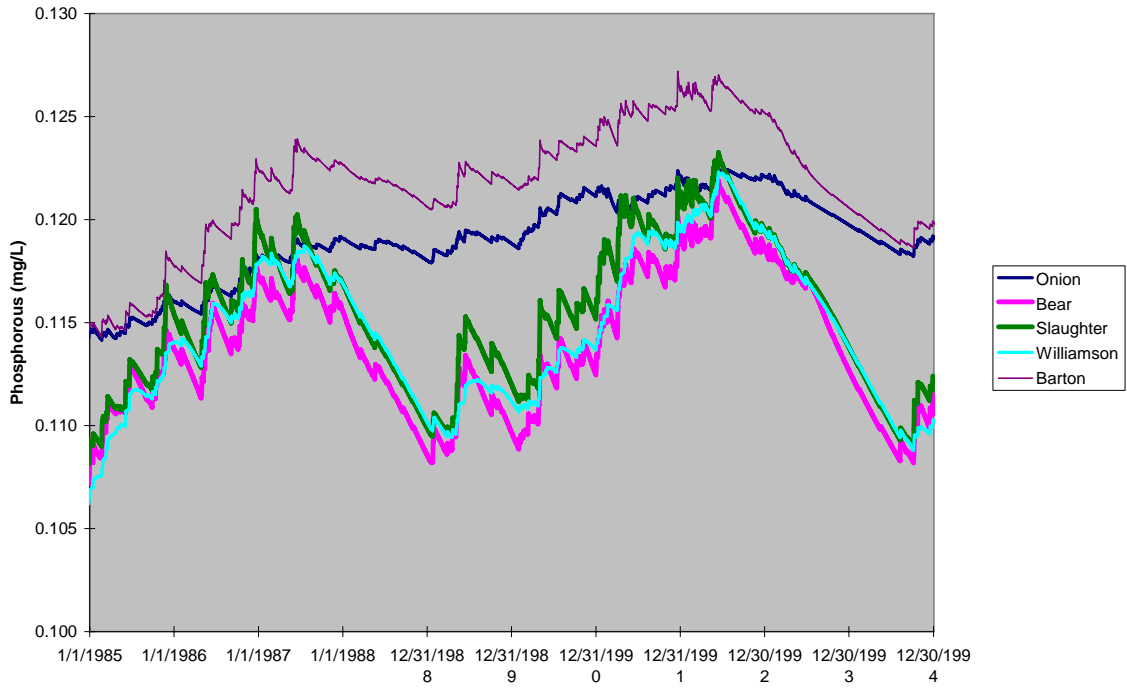
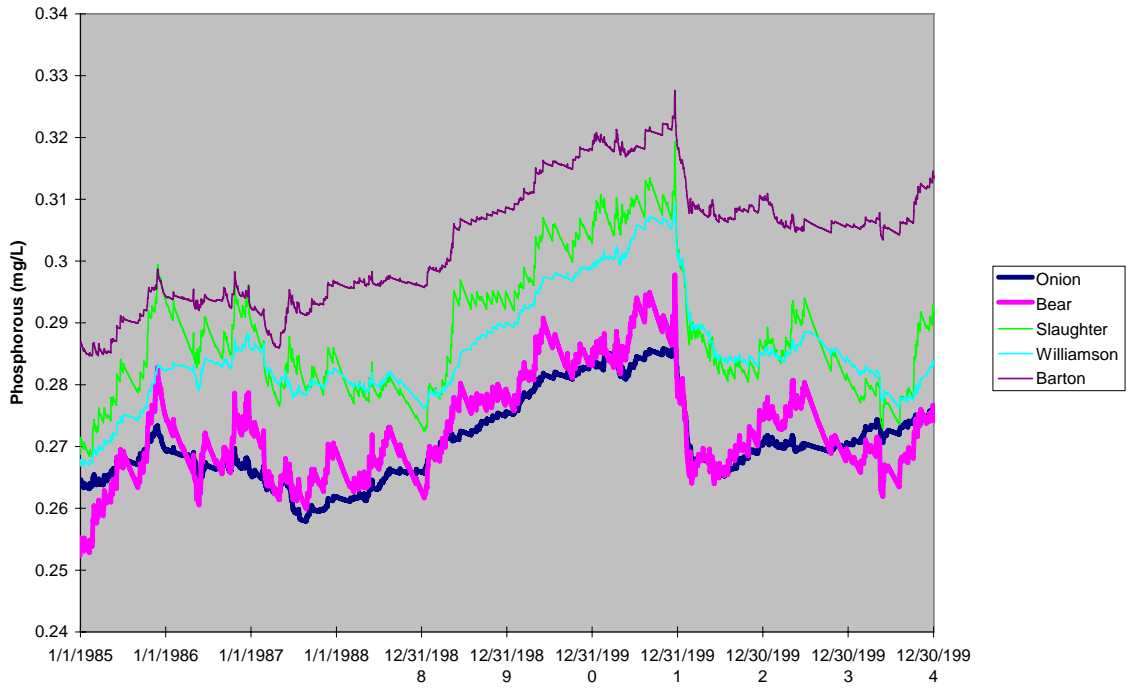


Figure 16. Intense Development



Figures 17 through 21 compare the effects of development on water quality in the individual cells. The Barton cell reflects the phosphorous level expected in Barton Springs discharge. The model predicts

phosphorus increasing in the Barton cell (Figure 21) from approximately 0.02 mg/L to 0.12 mg/L under moderate development and to approximately 0.30 mg/L under intense development. City of Austin planners predict a level of development between the current and moderate scenarios with approximately 10-15% impervious cover by the year 2040.

Figure 17. Effect of Development on Onion Cell

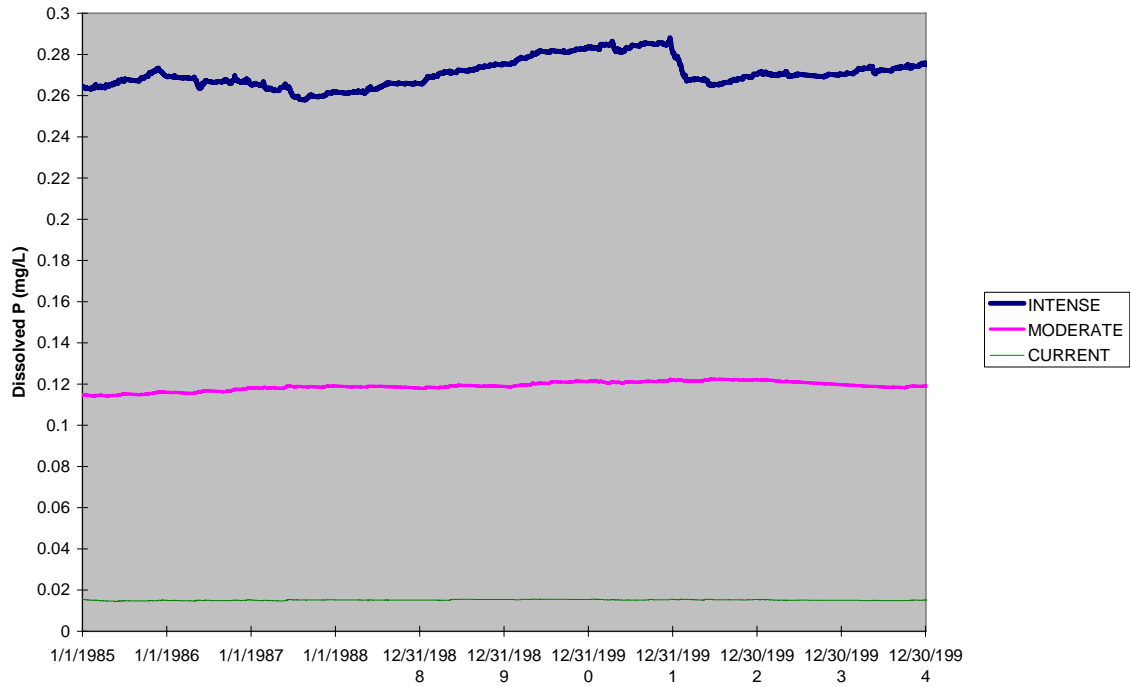


Figure 18. Effect of Development on Bear Cell

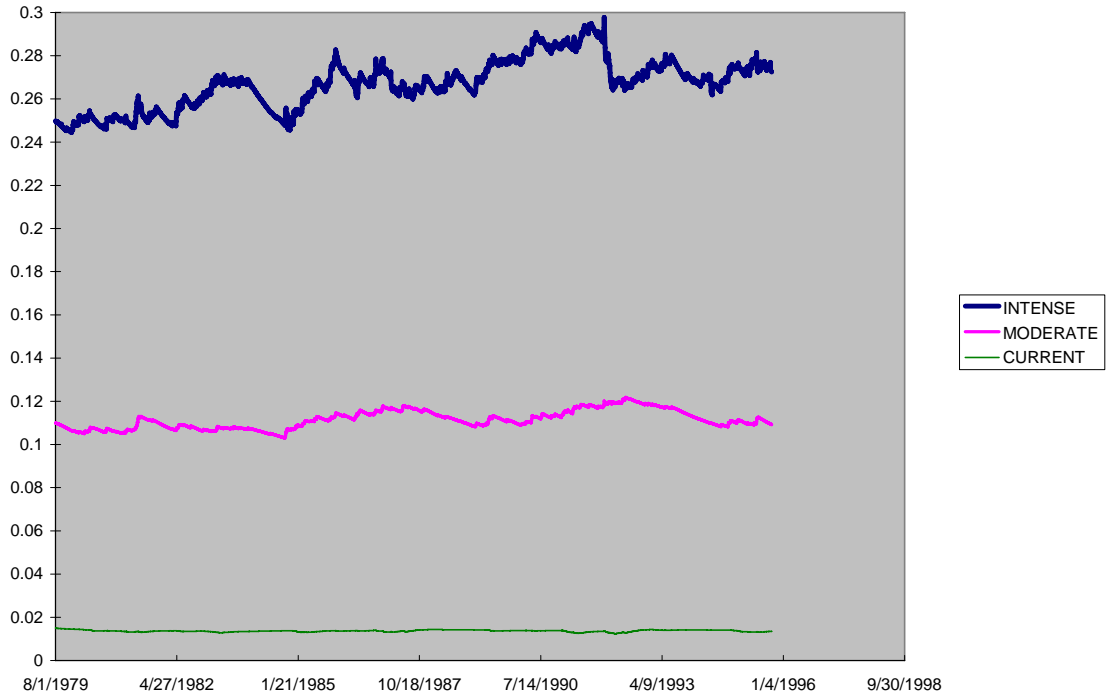


Figure 19. Effect of Development on Slaughter Cell

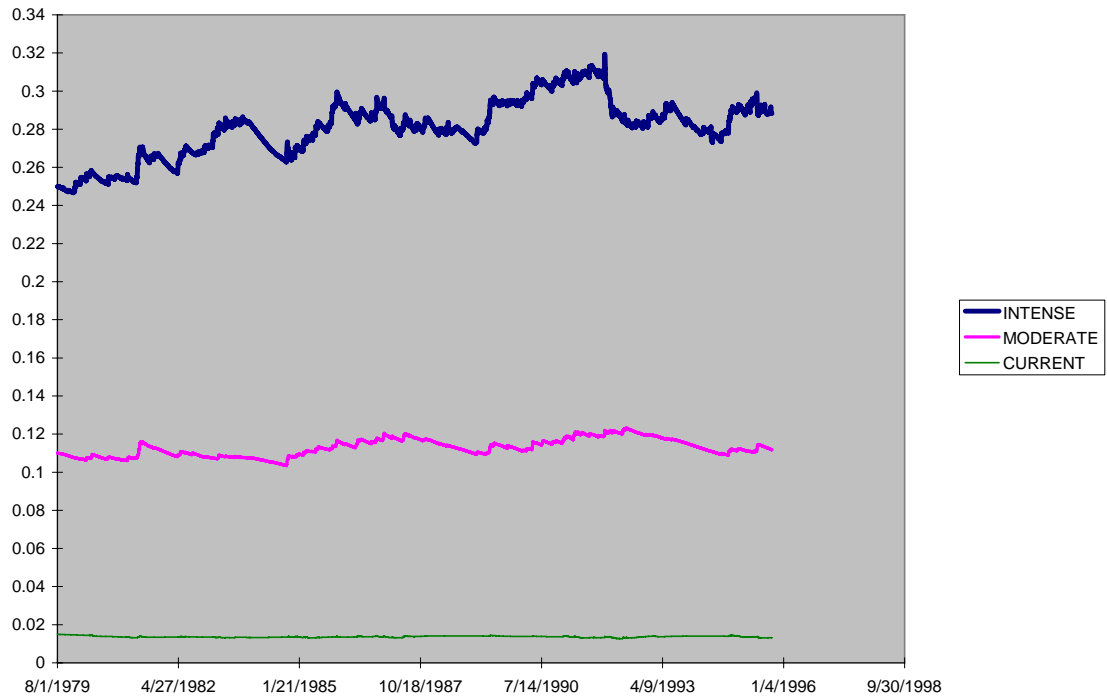


Figure 20. Effect of Development on Williamson Cell

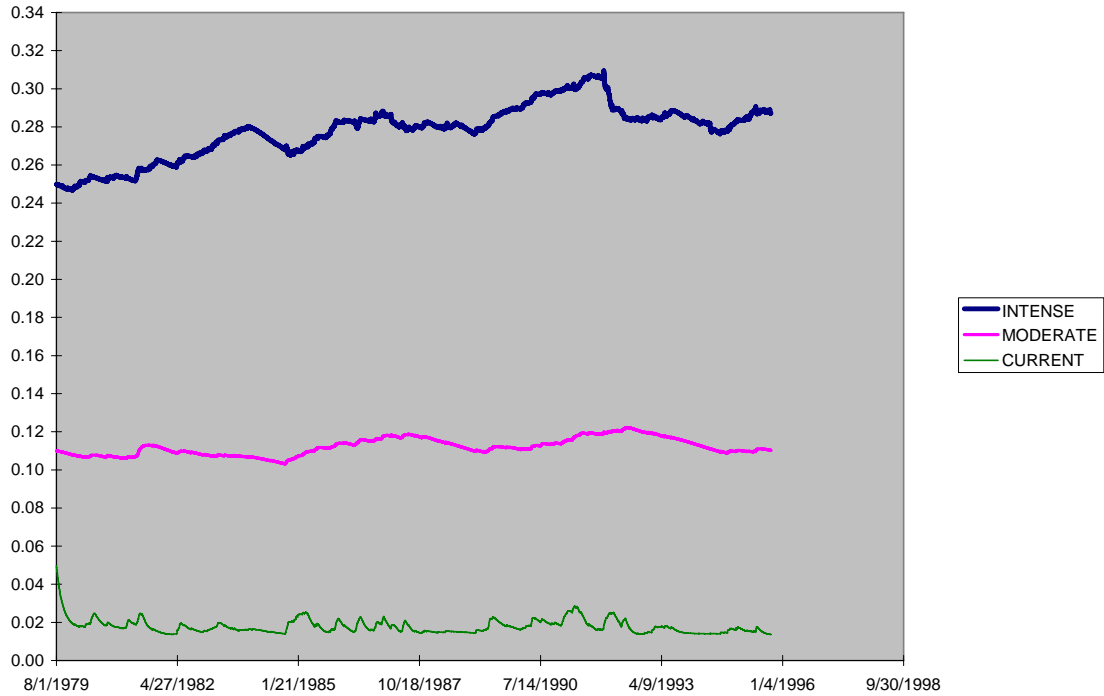
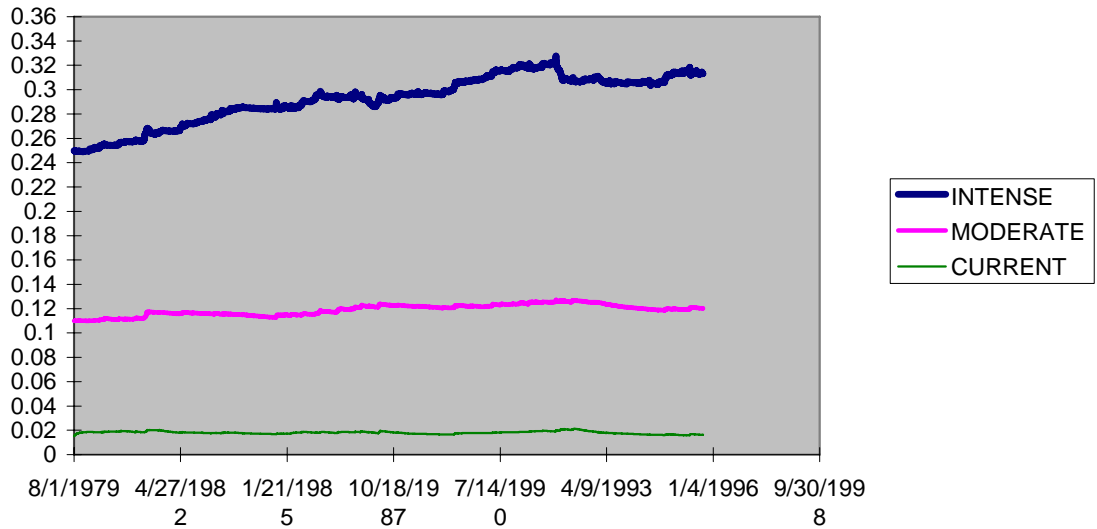


Figure 21. Effect of Development on Barton Cell



Conclusions

The predicted increase of phosphorous in the aquifer associated with development could impact Barton Springs Pool and Town Lake. Potential biological impacts from increased TP might be increased algae blooms, decreased dissolved oxygen levels during algal senescence and decay, and a decrease in the

desirability of recreational activity in the springs. Eutrophication may occur when phosphorous levels exceed 0.04 mg/L. Therefore, algae blooms could impact the Pool and Lake at phosphorous concentrations between current and moderate development conditions. City planners predict development conditions between current and moderate development to occur by the year 2040.

References

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APPENDIX A
STORMFLOW/BASEFLOW SEPARATION

Table A-1. Baseflow & Stormflow Mean TP in Onion Creek				
STATION 08158700, ONION CREEK NEAR DRIFTWOOD, TEXAS				
1984-96	TSS	TSS	TP	TP
date	mg/L	DL=0	mg/L	DL=0
1/13/1987	< 1.0000	0	< 0.01000	0
5/11/1987	< 1.0000	0	0.01	0.01
2/16/1988	< 1.0000	0	< 0.01000	0
4/25/1988	< 1.0000	0	< 0.01000	0
6/6/1989	< 1.0000	0	0.01	0.01
4/23/1990	< 1.0000	0	< 0.01000	0
9/5/1990	< 1.0000	0	< 0.01000	0
2/26/1991	< 1.0000	0	< 0.01000	0
5/28/1991	< 1.0000	0	< 0.01000	0
8/13/1991	< 1.0000	0	< 0.01000	0
4/5/1992	< 1.0000	0	< 0.01000	0
4/6/1992	< 1.0000	0	< 0.01000	0
7/29/1992	< 1.0000	0	0.05	0.05
12/5/1994	< 1.0000	0	< 0.01000	0
3/4/1996	< 1.0000	0	< 0.01000	0
7/15/1996	< 1.0000	0	< 0.01000	0
2/20/1985	1	1	0.07	0.07
1/29/1986	1	1	< 0.01000	0
4/8/1986	1	1	< 0.01000	0
8/21/1986	1	1	0.01	0.01
2/18/1987	1	1	< 0.01000	0
8/13/1985	2	2	0.1	0.1
8/16/1989	2	2	< 0.01000	0
4/5/1992	2	2	< 0.01000	0
6/23/1986	3	3	0.01	0.01
8/5/1987	3	3	< 0.01000	0
4/17/1984	4	4	0.08	0.08
11/3/1987	4	4	< 0.01000	0
5/15/1989	4	4	< 0.01000	0
7/31/1995	4	4	< 0.01000	0
8/22/1984	5	5	0.02	0.02
2/13/1989	5	5	< 0.01000	0
12/12/1989	5	5	< 0.01000	0
2/12/1992	5	5	< 0.01000	0
7/17/1987	6	6	0.04	0.04
2/28/1984	7	7	< 0.01000	0
8/2/1988	7	7	0.02	0.02
7/19/1990	8	8	< 0.01000	0
12/20/1988	11	11	< 0.01000	0
8/15/1991	11	11	0.02	0.02
6/19/1992	11	11	0.02	0.02
2/4/1991	19	19	< 0.01000	0
1/10/1991	27	27	0.04	0.04
5/29/1987	34	34	0.05	0.05
5/17/1989	100	100	0.03	0.03
6/17/1986	128	128	0.07	0.07
6/4/1987	147	147	0.08	0.08
10/25/1994	554	554	0.17	0.17
10/25/1994	612	612	0.06	0.06
10/25/1994	764	764	0.36	0.36
10/25/1994	852	852	0.35	0.35
6/6/1985	1380	1380	0.21	0.21
10/11/1984	1620	1620	0.13	0.13
BASEFLOW				
MEAN TP@TSS<10				
0.011				
n= 38				
STORMFLOW				
MEAN TP@TSS>20				
0.141				
n= 11				

Table A-2. Baseflow & Stormflow Mean TP in Bear Creek							
STATION 08158810, BEAR CREEK BELOW FM ROAD 1826 NEAR DRIFTWOOD, TEXAS							
1984-'95	TSS	TSS	TP	TP			
date	mg/L	DL=0	mg/L	DL=0			
4/17/1984	< 2.0000	0	0.01	0.01			
1/13/1987	< 1.0000	0	< 0.01000	0			
5/11/1987	< 1.0000	0	0.01	0.01			
4/25/1988	< 1.0000	0	< 0.01000	0			
5/17/1989	< 1.0000	0	0.01	0.01			
2/26/1991	< 1.0000	0	< 0.01000	0			
5/29/1991	< 1.0000	0	< 0.01000	0			
8/13/1991	< 1.0000	0	< 0.01000	0			
7/29/1992	< 1.0000	0	< 0.01000	0			
6/7/1995	< 1.0000	0	< 0.01000	0			
2/20/1985	1	1	0.01	0.01			
4/9/1986	1	1	< 0.01000	0			
6/23/1986	1	1	0.08	0.08			
8/21/1986	1	1	0.02	0.02			
7/17/1987	1	1	0.1	0.1			
6/6/1989	1	1	< 0.01000	0			
8/5/1987	2	2	< 0.01000	0			
4/23/1990	2	2	< 0.01000	0			
2/18/1987	3	3	< 0.01000	0			
8/16/1989	3	3	< 0.01000	0			
12/5/1994	3	3	< 0.01000	0			
11/3/1987	4	4	< 0.01000	0			
2/16/1988	4	4	< 0.01000	0			
4/6/1992	4	4	< 0.01000	0			
8/13/1985	5	5	0.02	0.02			
7/19/1990	5	5	< 0.01000	0			
4/5/1992	5	5	< 0.01000	0			
4/5/1992	5	5	< 0.01000	0	BASEFLOW		
2/28/1984	6	6	< 0.20000	< 0.20000	MEAN TP @ TSS<10		
2/12/1992	6	6	< 0.01000	0	0.009		
1/29/1986	7	7	< 0.01000	0	n= 30		
6/19/1992	11	11	0.01	0.01			
5/17/1989	12	12	0.02	0.02			
5/1/1986	14	14	0.02	0.02			
8/15/1991	15	15	0.07	0.07			
5/29/1987	19	19	0.03	0.03			
2/4/1991	20	20	< 0.01000	0			
3/4/1996	22	22	0.02	0.02	STORMFLOW		
1/10/1991	27	27	0.03	0.03	MEAN TP@ TSS>=20		
5/1/1986	28	28	0.03	0.03	0.043		
5/17/1989	40	40	0.02	0.02	n= 6		
6/4/1987	44	44	0.05	0.05			
6/6/1985	146	146	0.11	0.11			

Table A-3. Baseflow & Stormflow Mean TP in Slaughter Creek						
STATION 08158840, SLAUGHTER CREEK AT FM ROAD 1826 NEAR AUSTIN, TEXAS						
1984-95	TSS	TSS	TP	TP		
date	mg/L	DL=0	mg/L	DL=0		
1/13/1987	< 1.0000	0	< 0.01000	0		
5/11/1987	< 1.0000	0	0.01	0.01		
2/16/1988	< 1.0000	0	< 0.01000	0		
4/25/1988	< 1.0000	0	0.01	0.01		
4/23/1990	< 1.0000	0	< 0.01000	0		
4/26/1990	< 1.0000	0	0.01	0.01		
2/26/1991	< 1.0000	0	< 0.01000	0		
5/28/1991	< 1.0000	0	< 0.01000	0		
1/29/1986	1	1	0.01	0.01		
8/13/1991	1	1	0.01	0.01		
5/1/1986	2	2	0.02	0.02		
8/5/1987	2	2	0.01	0.01		
12/5/1994	2	2	< 0.01000	0		
8/13/1985	3	3	0.06	0.06		
2/18/1987	3	3	< 0.01000	0		
7/29/1992	3	3	< 0.01000	0		
4/17/1984	4	4	0.01	0.01		
6/6/1989	4	4	0.02	0.02		
4/5/1992	4	4	< 0.01000	0		
2/27/1995	4	4	< 0.01000	0		
2/20/1985	5	5	< 0.01000	0		
4/8/1986	5	5	0.01	0.01		
4/5/1992	5	5	< 0.01000	0	BASEFLOW	
1/18/1995	6	6	< 0.01000	0	MEAN TP@TSS<10	
4/6/1992	7	7	< 0.01000	0	0.007	
1/11/1988	8	8	< 0.01000	0	n= 26	
6/18/1987	10	10	0.03	0.03		
2/12/1992	10	10	< 0.01000	0		
6/19/1992	10	10	0.02	0.02		
6/16/1986	14	14	0.01	0.01		
6/18/1987	15	15	0.04	0.04		
8/15/1991	22	22	0.06	0.06	STORMFLOW	
1/10/1991	25	25	0.05	0.05	MEAN TP@TSS>20	
2/4/1991	26	26	0.03	0.03	0.071	
6/4/1987	44	44	0.07	0.07	n= 10	
10/8/1994	47	47	0.06	0.06		
5/29/1987	55	55	0.06	0.06		
10/8/1994	66	66	0.09	0.09		
10/21/1984	133	133	0.11	0.11		
6/6/1985	218	218	0.14	0.14		
5/17/1989	313	313	0.04	0.04		

Table A-4. Baseflow & Stormflow Mean TP in Williamson Creek					
STATION 08158920, WILLIAMSON CREEK AT OAK HILL, TEXAS					
1984-'95	TSS	TSS	TP	TP	
date	mg/L	DL=0	mg/L	DL=0	
12/31/1984	0	0	0	0	
2/23/1985	0	0	0	0	
1/13/1987	< 1.0000	0	0.12	0.12	
5/11/1987	< 1.0000	0	0.23	0.23	
6/6/1989	< 1.0000	0	0.05	0.05	
5/28/1991	< 1.0000	0	< 0.01000	0	
2/20/1985	1	1	0.24	0.24	
1/27/1986	1	1	0.19	0.19	
3/28/1986	2	2	0.21	0.21	
6/16/1986	2	2	0.15	0.15	
4/17/1984	3	3	0.11	0.11	
3/9/1988	3	3	0.1	0.1	
2/28/1984	4	4	0.13	0.13	
1/11/1988	4	4	0.17	0.17	
2/18/1987	5	5	0.12	0.12	BASEFLOW
2/13/1989	7	7	0.02	0.02	MEAN TP@TSS<10
7/20/1990	7	7	0.07	0.07	0.11
2/25/1991	9	9	0.05	0.05	n= 18
8/4/1987	10	10	0.03	0.03	
6/18/1987	12	12	0.07	0.07	
2/11/1992	12	12	< 0.01000	0	
8/14/1991	22	22	0.38	0.38	STORMFLOW
8/14/1991	30	30	0.58	0.58	MEAN TP@TSS>20
11/8/1987	31	31	0.18	0.18	0.43
5/21/1988	61	61	0.26	0.26	n= 61
11/8/1990	64	64	0.13	0.13	
6/18/1987	67	67	0.08	0.08	
8/14/1991	69	69	0.32	0.32	
11/8/1990	71	71	0.11	0.11	
5/29/1987	76	76	0.16	0.16	
6/4/1987	81	81	0.1	0.1	
8/14/1991	97	97	0.26	0.26	
11/8/1987	100	100	0.2	0.2	
6/18/1987	102	102	0.15	0.15	
4/26/1990	126	126	0.16	0.16	
11/8/1990	136	136	0.27	0.27	
4/26/1990	193	193	0.54	0.54	
10/21/1984	195	195	0.17	0.17	
5/21/1988	210	210	0.22	0.22	
4/26/1990	226	226	0.22	0.22	
3/17/1988	246	246	0.18	0.18	
11/8/1987	251	251	0.21	0.21	
2/9/1990	265	265	1.4	1.4	
2/9/1990	275	275	0.54	0.54	
11/8/1987	282	282	0.39	0.39	
6/6/1985	292	292	0.3	0.3	
1/26/1989	292	292	0.29	0.29	
3/28/1989	332	332	0.41	0.41	

STATION 08158920, WILLIAMSON CREEK AT OAK HILL, TEXAS					
1984-'95	TSS	TSS	TP	TP	
date	mg/L	DL=0	mg/L	DL=0	
1/26/1989	344	344	0.22	0.22	
5/9/1986	370	370	0.59	0.59	
3/20/1985	374	374	0.35	0.35	
5/21/1988	378	378	0.38	0.38	
9/6/1986	392	392	0.43	0.43	
5/1/1986	480	480	0.97	0.97	
3/28/1989	495	495	0.5	0.5	
11/24/1985	536	536	0.34	0.34	
3/20/1985	566	566	0.51	0.51	
2/3/1986	634	634	0.18	0.18	
11/24/1985	644	644	0.51	0.51	
1/26/1989	648	648	0.29	0.29	
11/19/1985	830	830	0.8	0.8	
1/26/1989	848	848	0.44	0.44	
5/21/1988	908	908	0.25	0.25	
5/9/1986	1040	1040	0.26	0.26	
2/9/1990	1050	1050	1.2	1.2	
2/3/1986	1070	1070	0.19	0.19	
11/19/1985	1330	1330	0.47	0.47	
3/20/1985	2000	2000	0.78	0.78	
12/31/1984	4380	4380	0	0	
2/23/1985	4550	4550	1.7	1.7	
2/23/1985	4680	4680	1.8	1.8	

**Table A-5. Baseflow & Stormflow Mean TP in Barton Creek
STATION 08155300, BARTON CREEK AT LOOP 360, AUSTIN, TEX**

1984-'95 date	TSS mg/L	TSS DL=0	TP mg/L	TP DL=0	
6/18/1992	< 1.0000	0	< 0.01000	0	
5/17/1993	< 1.0000	0	< 0.01000	0	
4/11/1995	< 1.0000	0	< 0.01000	0	
1/14/1987	1	1	0.01	0.01	
12/26/1991	1	1	< 0.01000	0	
3/16/1993	1	1	< 0.01000	0	
1/27/1986	2	2	0.01	0.01	
2/20/1985	3	3	0.01	0.01	
3/27/1986	3	3	0.01	0.01	
1/16/1991	3	3	0.02	0.02	
7/14/1992	3	3	< 0.01000	0	
10/25/1994	3	3	0.01	0.01	
6/7/1995	3	3	0.03	0.03	
2/19/1987	4	4	< 0.01000	0	
1/11/1988	7	7	< 0.01000	0	
6/16/1986	8	8	0.01	0.01	BASEFLOW
5/29/1991	8	8	0.01	0.01	MEAN TP @TSS<10
10/25/1994	8	8	< 0.01000	0	0.009
1/19/1993	9	9	0.05	0.05	n= 19
6/5/1989	10	10	< 0.01000	0	
8/15/1991	10	10	0.27	0.27	
2/13/1992	10	10	< 0.01000	0	
11/20/1992	10	10	0.04	0.04	
12/28/1994	10	10	0.02	0.02	
1/20/1993	11	11	< 0.01000	0	
1/25/1993	13	13	< 0.01000	0	
10/26/1994	13	13	< 0.01000	0	
1/11/1991	16	16	0.01	0.01	
1/19/1993	17	17	0.05	0.05	
5/29/1995	17	17	< 0.01000	0	
8/4/1987	18	18	0.01	0.01	
1/19/1993	19	19	0.04	0.04	
10/26/1994	21	21	0.01	0.01	STORMFLOW
1/19/1993	24	24	0.02	0.02	MEAN TP@TSS>20
10/25/1994	24	24	0.03	0.03	0.17
1/19/1993	26	26	0.05	0.05	n= 70
5/29/1995	26	26	0.02	0.02	
12/29/1994	29	29	0.01	0.01	
5/11/1989	32	32	0.03	0.03	
5/15/1989	33	33	0.01	0.01	
10/25/1994	33	33	0.06	0.06	
5/29/1995	35	35	0.03	0.03	
12/28/1994	37	37	0.02	0.02	
3/5/1992	38	38	< 0.01000	0	
12/28/1994	48	48	0.05	0.05	
1/9/1991	54	54	0.1	0.1	
12/29/1994	62	62	0.01	0.01	
6/18/1987	75	75	0.03	0.03	
5/29/1995	81	81	0.06	0.06	
6/18/1987	93	93	0.04	0.04	
1/10/1991	96	96	0.03	0.03	
12/28/1994	98	98	0.04	0.04	
6/18/1987	106	106	0.7	0.7	

STATION 08155300, BARTON CREEK AT LOOP 360, AUSTIN, TEX

1984-'95	TSS	TSS	TP	TP		
date	mg/L	DL=0	mg/L	DL=0		
8/9/1994	114	114	0.2	0.2		
2/4/1986	128	128	0.02	0.02		
5/17/1989	143	143	0.07	0.07		
8/9/1994	192	192	0.19	0.19		
3/4/1992	228	228	0.05	0.05		
10/8/1994	230	230	0.09	0.09		
10/22/1984	240	240	0.07	0.07		
8/9/1994	244	244	0.27	0.27		
3/4/1992	264	264	0.07	0.07		
5/17/1989	293	293	0.04	0.04		
12/21/1991	298	298	0.1	0.1		
10/11/1984	324	324	0.11	0.11		
10/8/1994	338	338	0.12	0.12		
10/11/1984	380	380	0.11	0.11		
2/4/1986	382	382	0.05	0.05		
8/9/1994	402	402	0.24	0.24		
5/29/1987	409	409	0.1	0.1		
10/8/1994	420	420	0.14	0.14		
6/6/1985	428	428	0.19	0.19		
5/1/1986	452	452	0.08	0.08		
5/3/1990	474	474	0.03	0.03		
10/21/1984	508	508	0.21	0.21		
5/3/1990	524	524	0.05	0.05		
10/8/1994	534	534	0.27	0.27		
12/22/1991	576	576	0.07	0.07		
8/9/1994	588	588	0.22	0.22		
5/9/1986	620	620	0.49	0.49		
12/21/1991	648	648	0.28	0.28		
5/1/1986	664	664	0.14	0.14		
10/8/1994	672	672	0.2	0.2		
1/9/1991	818	818	0.06	0.06		
3/4/1992	830	830	0.11	0.11		
5/3/1990	839	839	0.03	0.03		
10/21/1984	840	840	0.41	0.41		
10/21/1984	888	888	0.23	0.23		
5/10/1986	928	928	0.19	0.19		
1/9/1991	942	942	0.12	0.12		
5/29/1987	1040	1040	0.26	0.26		
8/9/1994	1090	1090	0.33	0.33		
5/10/1986	1240	1240	0.09	0.09		
3/4/1992	1260	1260	0.04	0.04		
6/6/1985	1390	1390	0.88	0.88		
2/23/1985	1480	1480	0.33	0.33		
2/23/1985	1820	1820	0.34	0.34		
6/6/1985	1850	1850	0.51	0.51		
12/20/1991	1980	1980	0.49	0.49		
10/7/1994	2150	2150	0.18	0.18		
2/23/1985	2250	2250	0.6	0.6		
2/23/1985	3020	3020	0.82	0.82		

Table A-6. Baseflow & Stormflow Mean TP in Shoal Creek					
STATION 08156800, SHOAL CREEK AT WEST 12TH STREET, AUSTIN, TEXAS					
1984-95	TSS	TSS	TP	TP	
date	mg/L	DL=0	mg/L	DL=0	
5/12/1987	< 1.0000	0	0.25	0.25	
1/10/1993	< 1.0000	0	0.03	0.03	
1/14/1987	1	1	0.01	0.01	
2/28/1984	2	2	0.01	0.01	
2/12/1985	2	2	0.03	0.03	
4/5/1993	2	2	0.01	0.01	
2/27/1995	2	2	< 0.01000	0	
12/28/1989	3	3	0.07	0.07	
7/19/1990	3	3	0.03	0.03	
2/25/1991	3	3	0.03	0.03	
6/16/1986	4	4	0.02	0.02	
9/1/1987	4	4	0.03	0.03	
8/24/1995	4	4	0.03	0.03	
5/31/1996	4	4	0.05	0.05	BASEFLOW
5/1/1990	5	5	0.02	0.02	MEAN TP@TSS<10
4/30/1994	7	7	0.04	0.04	0.05
8/10/1994	9	9	0.08	0.08	n= 17
5/28/1996	9	9	0.11	0.11	
2/11/1992	11	11	< 0.01000	0	
2/17/1987	18	18	0.01	0.01	
8/15/1991	42	42	0.22	0.22	STORMFLOW
2/22/1994	45	45	0.11	0.11	MEAN TP@TSS>20
12/14/1992	76	76	0.08	0.08	1.09
11/8/1990	81	81	0.15	0.15	n= 78
11/8/1990	84	84	0.17	0.17	
11/8/1990	128	128	0.14	0.14	
3/28/1992	137	137	0.23	0.23	
2/22/1994	176	176	0.21	0.21	
12/14/1992	280	280	0.43	0.43	
2/22/1994	320	320	0.35	0.35	
7/12/1988	393	393	0.28	0.28	
3/28/1992	428	428	0.17	0.17	
12/14/1992	438	438	0.61	0.61	
4/13/1985	444	444	0.68	0.68	
4/19/1989	456	456	0.16	0.16	
2/22/1994	458	458	0.51	0.51	
12/14/1992	545	545	0.35	0.35	
10/7/1989	548	548	0.52	0.52	
4/29/1988	563	563	0.2	0.2	
3/28/1992	568	568	0.29	0.29	
3/14/1990	592	592	0.81	0.81	
10/14/1985	620	620	0.97	0.97	
8/14/1991	627	627	0.24	0.24	
4/19/1989	640	640	0.17	0.17	
1/8/1984	660	660	2.1	2.1	
5/27/1996	690	690	0.31	0.31	
8/14/1991	758	758	0.22	0.22	
3/20/1985	768	768	0.9	0.9	

STATION 08156800, SHOAL CREEK AT WEST 12TH STREET, AUSTIN, TEXAS

1984-95	TSS	TSS	TP	TP			
date	mg/L	DL=0	mg/L	DL=0			
5/9/1986	796	796	0.52	0.52			
2/22/1994	924	924	0.78	0.78			
10/8/1994	926	926	0.83	0.83			
6/6/1985	944	944	0.39	0.39			
3/28/1992	960	960	0.26	0.26			
1/8/1984	1040	1040	3.1	3.1			
3/20/1985	1040	1040	0.89	0.89			
5/27/1996	1040	1040	0.98	0.98			
3/14/1990	1090	1090	1	1			
12/14/1992	1090	1090	0.75	0.75			
4/13/1985	1200	1200	1.2	1.2			
3/28/1992	1230	1230	1	1			
3/14/1990	1300	1300	1.1	1.1			
4/13/1985	1370	1370	1	1			
4/19/1989	1400	1400	0.19	0.19			
3/28/1992	1420	1420	0.68	0.68			
3/20/1985	1450	1450	1.8	1.8			
4/29/1988	1510	1510	0.2	0.2			
4/13/1985	1520	1520	1.1	1.1			
10/7/1994	1550	1550	1.3	1.3			
10/7/1989	1590	1590	0.24	0.24			
10/7/1994	1600	1600	1.4	1.4			
5/8/1987	1640	1640	1.6	1.6			
6/1/1986	1700	1700	0.75	0.75			
3/17/1987	1720	1720	1.2	1.2			
6/12/1984	1910	1910	1	1			
6/6/1985	1960	1960	0.77	0.77			
3/17/1987	2090	2090	0.82	0.82			
6/12/1984	2140	2140	1.5	1.5			
10/7/1994	2200	2200	1.7	1.7			
5/27/1996	2200	2200	0.88	0.88			
6/1/1986	2480	2480	0.17	0.17			
10/7/1984	2660	2660	2.1	2.1			
7/24/1984	2880	2880	3.1	3.1			
5/27/1996	2940	2940	3	3			
7/24/1984	3130	3130	2.5	2.5			
2/22/1985	3130	3130	3.2	3.2			
3/1/1989	3290	3290	1.1	1.1			
3/1/1989	3360	3360	1	1			
5/27/1996	3590	3590	2	2			
5/8/1987	3740	3740	3.1	3.1			
10/7/1989	3820	3820	0.25	0.25			
5/8/1987	3900	3900	3.9	3.9			
4/19/1989	4010	4010	0.28	0.28			
10/7/1984	4440	4440	3.4	3.4			
10/7/1994	4680	4680	1.3	1.3			
3/1/1989	5100	5100	1.2	1.2			
5/8/1987	5280	5280	5.7	5.7			
5/21/1988	5610	5610	0.47	0.47			

STATION 08156800, SHOAL CREEK AT WEST 12TH STREET, AUSTIN, TEXAS

1984-'95	TSS	TSS	TP	TP			
date	mg/L	DL=0	mg/L	DL=0			
10/7/1994	9090	9090	4.5	4.5			

APPENDIX B

Comparison of Total, Dissolved, and Suspended Phosphorous Concentrations

Phosphorous analyses require steps involving digestion and colorimetric methods. Determination of total phosphorous is performed on unfiltered samples. Filtration through a 0.45-um-pore-diam membrane filter separates dissolved phosphorous from suspended phosphorous (Greenberg et. al., 1992). Total phosphorous (TP) and dissolved phosphorous (DP) results are available from the USGS Water Resources Office for creeks in the Barton Springs section of the Edwards Aquifer (BSEA) and for Barton Springs (available via Internet at <http://txwww.cr.usgs.gov>).

Suspended phosphorous (SP) may be estimated by subtracting DP from TP. The TP analyzed in water collected from Barton Spring (Station 8155500) appears to be primarily DP. DP is occasionally higher than TP, which may be a result of both values being very close to the detection limit.

Unlike the other creeks used in the model, Barton Creek and Shoal Creek have several years worth of TP and DP data from which SP can be determined. The following Tables contain TP and DP data for Barton Creek and Shoal Creek. The data is sorted by total suspended solids. SP is calculated by subtracting DP from TP. SP is not calculated when either DP or SP is below the detection limit. The mean DP and SP in stormflow (TSS > 20 mg/L) is determined. During stormflow, the creeks have approximately 50% SP and 50% DP. The exception is Barton Creek at Loop 360 (Station 08155300), the farthest downstream gauge, which has approximately 60% DP and 40% SP during stormflow. For the phosphorous mass balance calculation, 50% of the mean total phosphorous during stormflow is input from each creek into the aquifer as dissolved phosphorous which can move through the system. Thus the model assumes that all of the SP in stormflow will settle out within the aquifer before reaching Barton Spring. The percentage of SP is not calculated for creek baseflow or for Barton Spring discharge because a large percentage of the phosphorus analyses are below the detection limit.