The Nitrogen Balance of the Barton Springs Segment of the Edwards Aquifer. Changes since Barrett and Charbeneau (1996) balance.

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Abstract

Revisions to two factors affecting the nitrogen balance in the aquifer, creek recharge and infiltration of rainfall, resulted in a reduction in previous estimates of nitrogen loading to Barton Springs. The removal of water flowing to Cold Spring combined with the addition of Blanco River water flow to Barton Springs based on dye studies resulted in a net loss in nitrogen loading in comparison to that provided in a 1996 study by Barrett and Charbeneau . The recent data collected on nitrogen concentrations in cave drips also resulted in a substantial drop in the estimated nitrogen loading from rainfall infiltration. New estimates of loading from fertilizer application over the recharge zone indicated that it is a substantial source of nitrogen loading to the aquifer which was not previously documented. The estimated incoming load of nitrogen is still less than the observed outflow of nitrogen from the Barton Springs segment of the Edwards Aquifer, indicating missing sources or inaccurate estimates of load from the known sources.

Introduction

With revised aquifer flow paths based on recent dye studies, improved estimates of creek recharge, and data on upland infiltration concentrations, a review of the nitrogen balance developed by Barrett and Charbeneau (1996) is in order. The sources of nitrogen considered in the 1996 study were creek recharge, rainfall infiltration and septic systems. These are revisited and two other sources, irrigation with tap water and leachate from fertilizer, are included in this assessment of the nitrogen balance in the Barton Springs segment of the Edwards Aquifer.

The estimated load to the land surface from rain, from irrigation with tap water, and from fertilizer is presented first. Then, the loading to the aquifer, and thus to Barton Springs, from runoff into creeks, from rainfall infiltration or runoff into local features, from septic systems, and from fertilizer plus irrigation water is evaluated.

The outgoing load of total nitrogen from the Barton Springs segment of the Edwards Aquifer via Barton Springs and well pumping was not re-evaluated in this analysis. Previous estimates from Barrett and Charbeneau 1996 were used as calculated from an average concentration of 1.48 mg/L of total nitrogen in the discharge from Barton Springs (53 ft^3/s) and in pumped water (5 ft^3/s).

While the nitrogen loading numbers presented here are necessarily gross estimates with many sources of uncertainty, the relative contributions of the sources of nitrogen is based on sound methods and data. Improvements to the loading calculations based on new information, methods, and data should be of interest to those trying to preserve or improve water quality at Barton Springs.

Loads to the Land Surface

Rain water load to surface

The long term historical average rain fall has been calculated to be 32.5 inches of rain per year and the average concentration of total nitrogen in the rainfall over Austin is 1.5 mg/L (Barrett and Charbeneau 1996). Thus the annual nitrogen load to the land surface of the recharge zone is 5.01 kg/acre. No reduction is made for the percent of impervious cover in the recharge zone. Calculation details are shown in Appendix E. Rainfall concentration data for total nitrogen in the Austin area was taken between April and November of 1995 at one urban location, the St. Elmo Wet Pond (Appendix B). Additional local data is needed, especially in the more rural areas of the Barton Springs recharge zone. Nitrogen rainfall concentrations are frequently lower in rural areas and have been observed to be lower in other Texas locations (Ockerman and Fernandez 2010).

Fertilizer load to surface: A typical suburban application rate

Fertilizer bag size makes it hard to apply fertilizer at the recommended rate of ½ lb per 1,000 ft^2 for the typical suburban yard. As a typical example, consider a bag of Scotts Turf builder (N:P:K), a well-known brand available at a competitive price. The blend was 27-3-4 and it came in a 37 pound bag (from a January 2005 Austin Area Fertilizer Products Survey – see Appendix C). A 100 pound bag of 27-3-4 contains 27 pounds of N, so a 37 pound bag contains 10 pounds of N. If it was applied at the COA recommended rate of ½ lb per 1000 ft^2 it would cover 20,000 ft^2. However, a typical lot size (small lot single family) is around 5,000 ft^2 with 50% impervious cover, or likely 2,500 ft^2 of landscape. This means that if you spread one bag you would be applying 4 lbs per 1000 ft^2 or eight times the recommended rate. If you fertilized twice a year, which many homeowners do, you would have applied 8 pounds per 1000 ft^2 annually.

Some of the expected fertilizer application rates for Austin area home or business owners are shown in Table 1.

Table 1. Annual load from some likely fertilizer application rates

Application Type	Annual Load in kg/acre
none	0
once or twice per year @ ½ lb/1000 ft^2 **(recommended)**	20 (twice per year)
once or twice per year at 2 lb/1000 ft^2	80 (twice per year)
twice a year at 4 lb/1000 ft^2 **(likely for typical lot – see above)**	160
3 times per year at 2 lb/1000 ft^2	120
6 times per year at 2 lb/1000 ft^2 **(yard service)**	240

We estimated the area in the recharge zone where fertilizer would be applied as 4,386 acres. Single family small lot, commercial, office and government/church/hospital/ meeting hall land uses from the 2006 land use data were included. It was assumed that ½ of the total land in these land use categories was fertilized. Fertilizer applied to agricultural areas was assumed to be minimal and was not included.

Converting pounds per square foot to kilograms per acre for the recommended and likely application rates results in 20 to 160 kg/acre of nitrogen applied annually for the acres which are fertilized.

Irrigation load to surface from tap water (water from Ulrich Treatment Plant)

The average total nitrogen (TN) concentration in tap water from Ulrich is 0.49 mg/L. One inch of water adds 0.0504 kg of nitrogen to an acre (calculation same as for rainfall). If a homeowner irrigates 20 times per year with one inch of water, then the annual nitrogen load is 1 kg/acre over irrigated land. Twenty times per year is a rough estimate and assumes that there are twenty periods without rainfall lasting about a week within the growing season or when irrigation is needed for plant health. If the season is April – October there are 30 weeks total. Thus an estimate of load based on irrigating 20 of 30 weeks might be high in wet years. The irrigation area is most likely the same area where fertilizer would be applied or 4,386 acres.

Irrigation with well water would be withdrawing nitrogen from the aquifer and then returning the proportion that was not used by plants. Well water would be used primarily on large single family lots or ranches, and irrigation with well water is not considered in this report.

Summary of surface loading

The major sources of nitrogen loading to the surface are listed in Table 2. Note that this just shows relative loading to the surface and does not indicate the amount of the nitrogen that reaches the aquifer. Plant uptake and other losses are not discussed in this section. The load per acre from fertilizer is much larger than the load from either rainfall or tap water irrigation. However the number of acres which are fertilized and irrigated must be considered. The total annual load from irrigation is small. The load from rainfall is likely less than or equal to the load from fertilizer, unless everyone is following City of Austin fertilizer recommendations.

Table 2. Annual surface loads per acre from rainfall, irrigation and fertilizer

Load type to surface	Annual Load (kg) of N per acre	Acres *	Total Annual Load (kg)	Comments
Rainfall @ 1.50 mg/L TN @ 32.5 in/yr	5	57,715	288,575	The concentration may be high – more local non-urban data is needed
Irrigation water @ 20 in/yr @ 0.5 mg/L TN (COA tap water)	1.7	4,386**	7,456	1" applied 20 times per year may be high.
Fertilizer @ 1 lb/1000 sq. ft. per year	20	4,386**	87,720	Recommended application rate
Fertilizer @ 8 lb/1000 sq. ft. per year***	160	4,386**	701,760	likely application rate

*details in Appendix A
** ½ of single family, commercial, office, Government/church/hospital/meeting hall
*** apply one typical bag twice per year on typical single family lot

Loads to the Aquifer

While the surface loads of nitrogen are of interest, of primary importance for Barton Springs are the nitrogen loads to the aquifer. We investigated the load which enters the aquifer in the creek beds, the load from rainfall which infiltrates through soils or enters the aquifer through local karst features, and the load from fertilizer. The estimated load from on-site sewage facilities (OSSF) was also included from Barrett and Charbeneau (1996).

Load from water which enters the aquifer through creek beds

The cumulative cubic feet of flow from Nico Hauwert's water balance results for 5/31/2003 – 9/19/2007 (Hauwert 2011, in press) was used. This period covered two cycles of high flow to average flow over 1,572 days. Flow was converted to an annual average for comparison purposes. The average discharge at Barton Springs during this period was 66 ft^3/s which is 25% above the long term average of 53 ft^3/s. Thus annual creek bed and rainfall loads determined from this period are 25% higher than average.

The storm and baseflow concentrations and the percent of the creek recharge that is storm or base flow were taken from Barrett and Charbeneau 1996. Concentration of total nitrogen from Onion Creek was used for the Blanco River because water quality monitoring data from the Blanco River was not available.

Table 3 summarizes the annual loading to the aquifer from major creek channels. The nitrogen concentrations that are used for Barton Creek may be low. These are calculated using stations over the entire length of Barton Creek, including data from the gage just below Little Barton. The flow that is used is from the Barton Creek at Loop 360 gage. From dye tracing performed since Barrett and Charbeneau 1996 flow upstream of the Loop 360 gage travels to Cold Spring rather than Barton Springs. The nitrogen concentrations below Loop 360 would be expected to be higher than the averages of the entire creek, since this part of the watershed is significantly more urbanized.

Table 3. Annual Average Creek Runoff Load to Barton Springs.

Creek	Water 1573 days cubic feet	% of discharge + pumping	Water (annual average ft^3)	Storm TN mg/L	% storm flow	Base conc, mg/L	% base flow	Mean Conc. Mg/L	Annual Load (kg)
Barton	5.4E+08	6%	1.2E+08	1.29*	10%	0.5*	90%	0.58*	2,036*
Bear	6.2E+08	7%	1.4E+08	0.92	8%	0.61	92%	0.63	2,605
Little Bear	3.6E+08	4%	8.3E+07	1.66	8%	1.26	92%	1.29	3,029
Onion	3.4E+09	38%	7.9E+08	0.68	6%	0.55	94%	0.56	12,425
Slaughter	7.1E+08	8%	1.7E+08	1.39	20%	0.59	80%	0.75	3,517
Williamson	8.9E+07	1%	2.1E+07	2.79	25%	0.88	75%	1.36	796
Blanco	3.6E+08	4%	8.3E+07	0.68	6%	0.55	94%	0.56	1,308
Total Creek Recharge	6.1E+09	68%	1.4E+09						**25,716**

*Shaded concentrations and loads may be low since Barton below Loop 360 is more urban in character than the rest of the watershed.

Load from rain which infiltrates through soils or runs off into local recharge features (diffuse recharge)

The diffuse infiltration volume is calculated from the most recent water balance prepared for the aquifer (Hauwert 2011). In Hauwert's water balance, diffuse infiltration is composed of discrete recharge to sinkholes and tributary features and rainfall infiltration, and is labeled "intervening area recharge". The diffuse infiltration is approximately equal to the discharge at Barton Springs minus the creek recharge. During the 5/31/2003 – 9/19/2007 period, the calculated diffuse infiltration amounts to about 30% of the Barton Springs discharge. Pumping is not included in the calculation (Hauwert 2011).

At first, rainfall was considered rather than Barton Springs discharge to estimate the volume of infiltrated and locally recharged water. Hauwert indicates that the recharge from the intervening area is about 30% of the rainfall (Hauwert 2009). The basis for this estimate was a study done at Flint Ridge cave during a wet period of 17 months from April 2004 – August 2005. The average annual rainfall was 41.7 inches or 28% above the long term average of 32.5 inches. The average percent of the rainfall that was infiltrated was 29% and the resulting average percent of the rainfall as discrete recharge (sinkhole/tributary feature recharge) was 3%. Thus, of the intervening area recharge, discrete recharge was 9% and diffuse infiltration was 91%. However, when this is extrapolated to the entire recharge zone and over the 52 month period where rainfall is less than the 04-05 study, (although still 12% above average), too much water is predicted to enter the aquifer. Until further investigation into the percent of rainfall that infiltrates is completed, the superior approach appears to be use of the difference in the creek recharge estimate and the springs discharge for the amount of infiltrated water rather than a percent of the rainfall.

In an alternative water balance analysis focusing on dry periods, creek recharge + 30% of creek recharge as upland infiltration is less than the amount of water discharging from the Barton Springs segment of the Edwards Aquifer (spring discharge + pumping) (Turner 2012). The Barrett water balance estimated diffuse infiltration from 1979-1995 at about 15% of Barton Springs discharge with 84% from creek recharge vs. Hauwert's 30% from intervening area recharge and 69% from creek recharge (Barrett and Charbeneau 1996, Hauwert 2011). Clearly more work is needed on the water balance of the aquifer; therefore, the nitrogen loading estimates based on the water balance are preliminary

The concentration of total nitrogen in the rainfall runoff which enters sinkholes or recharges through tributary features before reaching the main channel is set to the average concentration (0.65 mg/L TN, Barrett 1996) for stormflow for all the creeks. We assumed rainwater travels overland before entering the local recharge features just as creek water does.

The nitrogen concentration for rainfall which has infiltrated is taken from the data for cave drips. (Hauwert 2011) The average TKN is added to the average NO2/NO3 for a concentration of 0.94 mg/L TN. This is very different from the number estimated previously of 5.3 mg/L (Barrett and Charbeneau 1996). Barrett used the GLEAMS model to get a total load and a volume and thus the concentration (Leonard 1987). Of course cave drip concentrations in drier years are unknown, but additional cave drip data will be available in the near future. The average annual load from diffuse recharge, infiltrated rainfall and runoff into local features, is shown in Table 4.

Table 4. Annual load from infiltrated rainfall and runoff into local features

Source	Water 1573 days ft^3	% of discharge + pumping	Water (annual average ft^3)	TN conc. mg/L	TN Load (kg)
rainfall infiltration (diffuse) = 91% of total intervening area recharge or 27% of Barton Springs discharge	2.44E+09	27%	5.65E+08	0.94	15,042
sinkhole/trib recharge (not mainstem) = 9% of total intervening are recharge or 3% of Barton Springs discharge	2.41E+08	3%	5.59E+07	0.65	1,029
Total Intervening Area Recharge = 30% of Barton Springs Discharge	2.68E+09	30%	6.21E+08		**16,071**

Load from fertilizer to aquifer

The load of total nitrogen to the aquifer from fertilizer was estimated from data collected during a two year study of leachate from fertilizer at the Wildflower Center in 2006 and 2007 (COA 2008). Lysimeters were placed an average of 12" below the surface of small grass plots. Fertilizer was applied at an average annual rate of 1 lb.N/1000 ft^2 per year (COA recommended rate). Rainfall was measured over the course of the experiment. If no rain occurred during the week, the plots were irrigated with an inch of tap water. The volume that accumulated in the lysimeter and the total nitrogen concentration were measured. The load relative to the surface area of the lysimeters was calculated from the volume and the concentration (for details see Appendix D). The proportion of the load that was from rainfall/irrigation water alone was estimated at 2% for rainfall and 2% for irrigation or 4% of the total load. This load was considered to be negligible in subsequent calculations. The average concentration of TN was 2.51 mg/L and the average annual load was 1.21 kg/acre.

There are many factors which contribute to the uncertainty of the fertilizer load estimate from this study. The leachate was collected during the growing season when more nutrients would be taken up by the plants resulting in a lower load. Some of the fertilizers were slow release varieties. Leachate from the slow release fertilizers during other non or low growing seasons might be higher. However, rapid release fertilizers were also used and they would have provided more nitrogen leachate during this period. Rainfall during the first fall season of the study was very low and not much higher during the second. Leachate volume was higher during the second season of the study as rainfall increased. Since some of the unknown factors would be expected to result in greater or lesser loads, the unavoidable errors in load estimates may balance out and the results be more accurate than previously calculated.

Unfortunately, the load determined from the application of 1 lb.N/1000 ft^2 per year is expected to be underestimated, since many homeowners and commercial yard services apply fertilizers at much higher levels than the City's guidelines. In Table 5, three more likely scenarios of fertilizer application are also listed. .

The calculated load for additional fertilizer above the recommended rate is a multiple of the amount that leached for 1 lb.N/1000 ft^2 per year. However, this also is an underestimate. If 1 lb/1000 ft^2 / year of fertilizer contains appropriate nutrients for turf growth then less of the additional fertilizer will be taken up by the plants and more will leach. Basically, there is a limit to how the uptake rate and amount will increase as the nutrient loading increases from fertilizer application.

Table 5. Estimates of annual aquifer nitrogen loads per acre based on fertilizing practices

Load Type to aquifer	Annual Load of N per acre (kg)	Acres *	Total Annual N Load (kg)	Comment
Fertilizer @ 1 lb/1000 sq. ft./yr (applied to ½ of single family, commercial/office/ government/church/hospital/meeting hall landuses)	1.21	4,386	5,307	Dry fall, growing season, slow release fertilizer, only 1.16% of surface load to lysimeters
1/3 apply no fertilizer, 1/3 apply recommended amount., 1/3 apply 2 bags per year on typical lot	3.62	4,386	15,888	
Same as above 2 bags/yr. Assume twice as much leaches per lb. of fertilizer since overall plant uptake is lower	6.84	4,386	30,001	
Intensively managed turfgrass with fertilizer @ 8 lb/1000 sq. ft. per year	8.96	4,386	42,456	Under estimate – assumes no increase in leachate rate when excess fertilizer is applied

*details in Appendix A

Summary of nitrogen aquifer loading from all sources

Table 6 shows the estimated annual loads to the aquifer from creek bed recharge, infiltrated rainfall, runoff into local features, septic systems (OSSFs) and fertilizer leachate. Irrigation with tap water is included in the fertilizer estimates. The OSSF contribution was determined using the GLEAMS model. Barrett also used the GLEAMS model to estimate the concentration of infiltrated rainwater (Barrett and Charbeneau 1996). Since the rainfall estimate was higher than observed data, it is possible that the septic contribution is high also. The loads for both the lowest and highest rates of fertilizer application are included on the theory that they will bracket the actual load of nitrogen to the aquifer. With the lowest fertilizer load the most important source is creek bed recharge with 45% of the load. Fertilizer is the least important with 9% of the load but it is still contributing a sizable amount. At the highest estimated fertilizer load, fertilizer becomes the largest source of nitrogen to the aquifer, higher even than creek bed recharge. For the other two fertilizer scenarios, the percent of the load attributable to fertilizer is 23% or 37%. In both cases, fertilizer is a substantial source for nitrogen in the aquifer. Also, as development increases, the number of acres to which fertilizer is applied will grow and the contribution from fertilizer leachate will grow faster than increases in the other sources. An additional potential major new source of nitrogen loading to the aquifer is the direct discharge of treated wastewater to contributing zone creeks which enter the recharge zone such as Hays County Water Control and Improvement District No. 1 (Belterra subdivision) in the Bear Creek watershed.

Loads of nitrogen leaving the aquifer
The loads of nitrogen leaving the aquifer are estimated based on an average concentration of 1.5 mg/L of total nitrogen and volume of water which discharging from the Barton Springs segment of the Edwards Aquifer.

Table 6. Annual aquifer loads of total nitrogen per acre to the Barton Springs segment of the Edwards Aquifer with the lowest and the highest estimate fertilizer loads

Load Type to aquifer, Recharge from:	Annual Load of N per acre	Acres *	Total Annual Load (kg) to the aquifer	% of total annual load with either low or high fertilizer
Water via Creek beds	0.446	57,715	25,716	45% or 27%
Rainfall (diffuse and discrete) calculated from cave drips and NH infiltration volume of 6.21E+08	0.278	57,715	16,071	28% or 17%
OSSF (from Barrett, 1996)			10,000	18% or 11%
Fertilizer applied to ½ of single family, commercial, office, gov, church, hospital, meeting hall landuses**	1.21 – 8.96	4,386	5,307 to 42,456	9% or 45%

*details in Appendix A

**includes load from irrigation with tap water

Comparison of the 1996 water and nitrogen balance with the data collected in recent years

In Barrett's 1996 study, he developed a nitrogen balance for the Barton Springs segment of the Edwards Aquifer. Barrett's values for the volume of water recharged and discharged as well as the total nitrogen concentrations and loads are shown in Table 7. More than ½ of the load of nitrogen to the aquifer was posited to come from rainfall. Additional information has since become available on direction of ground water flow, the volume of rainfall infiltrated and the concentration of infiltrated rainfall.

In a more recent study (Hauwert 2011) progress has been made on refining our understanding of what recharged water flows to Barton Springs and how much rainfall infiltrates. Hauwert's values for the volume of water recharged and discharged are also shown in Table 7. The volume of discharged water is taken from Table 3 in his report and the volume of infiltration is calculated using 33% of the discharge as specified in his Figure 26 (Hauwert 2011). Unlike Barrett, Hauwert includes recharge from the Blanco River if Barton Springs discharge is < 40 cfs and subtracts out the recharge from Barton and Williamson Creeks which flows toward Cold Spring. He does not discuss nitrogen concentrations or load. However the resulting water balance identifies the need to assess additional sources of nitrate loading to the aquifer. For the present work, we used preliminary water balance for a four year period developed by Hauwert, combined with creek nitrogen concentrations and the septic system information from the 1996 study, recent fertilizer leachate information, and the cave drip data to arrive at an overall nitrogen balance for the aquifer.

Table 7. New Nitrogen Balance Compared with Barrett's 1996 Balance.

	Recharge annual average (ft^3)		Average Nitrogen Concentration (mg/L)		Annual Nitrogen Load (kg)	
Source	Barrett, 1996**	Hauwert, 2011#	Barrett, 1996**	2011 (this report)	Barrett, 1996**	2011 (this report)
Creek	2.1E+09	1.6E+09#	0.69	0.69	41,000	26,000
Septic**	0.027E+09	0.027E+09**	13	13	10,000	10,000
Infiltration	0.37E+09	0.8E+00#	5.3	0.94	55,000	16,000
Fertilizer				2.5		25,000*
IN (Sum)	2.5E+09	2.4E+09	1.5##	1.13##	106,000	77,000
	Annual Average Barton Springs Discharge + Pumping ft^3					
OUT	2.5E+09	2.4E+09	1.5##	1.5	106,000	102,000^

*25,000 kg from fertilizer is approx. avg of high and low estimates in Table 5
** from Table 4.5
# from Table 3 with results converted to average annual values
calculated from volume and load
^ calculated from volume and concentration

There is a major difference in the nitrogen entering and leaving the system if the concentrations of the cave drips are used rather than the GLEAMS model estimates (Table 7). A moderate estimate of the amount of nitrogen coming from fertilizer improves the balance but there is still more nitrogen leaving the system then entering it. Even using the maximum load from fertilizer listed in Table 5 does not result in enough nitrogen to entering the aquifer to match the outflow. Another potential source is nitrogen from blasting materials used in quarries. The estimates from OSSF could be refined and leakage from WW pipes investigated. More recent studies than Barrett have been performed to improve these estimates in general; however, their validity in making aquifer load estimates has not been documented (Herrington 2005,Garcia-Fresca 2004). Additional information is definitely needed, but from the body of evidence available, it appears that fertilizer is a major source of nitrogen in the system.

Summary and Conclusions

Changes from the 1996 nitrogen mass balance include:

- From dye tracing studies it was shown that recharge from Barton Creek flows mostly to Cold Spring. Only flow downstream of Loop 360 travels to Barton Springs. Some flow from the Blanco River is added in to the water balance under low flow conditions. However, the net change in mass of nitrogen recharged is negative.
- The concentration of nitrogen in infiltrated rainwater is now estimated (from cave drip data) at 0.94 mg/L rather than 5.3 mg/L. This is a major decrease in nitrogen loading.

- Estimates of nitrogen loading from fertilizer indicate that it is a substantial contributor to the total aquifer nitrogen load.
- Nitrogen from irrigation with tap water is included in the fertilizer estimates.
- The current loading estimates, with a moderate scenario for fertilizer, are not enough to match the nitrogen output from the aquifer.
- Additional sources to investigate include nitrogen loading from blasting in quarries, and from leaking wastewater lines. OSSF contribution to the load could also be reassessed.

Recommendations for future study to improve accuracy of N balance:

- Well concentrations should be assessed to improve the estimate of the load removed from the aquifer by pumping. In addition, the distribution of nitrogen loads across the aquifer could be evaluated
- Additional data on nitrogen and oxygen isotopes should be used to assess sources
- Urban leakage should be investigated as a potential source of nitrogen
- Septic loading should be reassessed, since there has been some large lot development in the recharge zone since 1996.
- Additional rain data should be collected particularly in rural area. Investigation of cave drips in more urban areas would also be useful. The cave drip concentrations might be higher if the rainfall concentrations were higher.
- Concentrations of nitrogen in wells near quarries should be assessed following rainstorms after blasting events

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Appendix A. Land use and Area over which rain infiltrates into the Barton Springs Segment of the Edwards Aquifer (GIS analysis by Rob Clayton with advice from Nico Hauwert)

Table1: Total area = shaded area in figure, recharge area = area inside the official (squiggly line) recharge zone

BASIN	Total area in square miles	Recharge area in square miles
COLD SPRING	11.99	11.78
SUNSET	10.92	9.83
MANCHACA	122.04	66.40
NON COLD SPRING	132.96	76.23

Table 2.

BASIN	AQUIFER	Total area in square miles	Recharge area in square miles
NON COLD SPRING	Artesian	41.44	0.06
NON COLD SPRING	Contributing	2.84	0.07
NON COLD SPRING	Drainage	12.04	7.56
NON COLD SPRING	Outcrop	74.81	68.49
NON COLD SPRING	Potential Outcrop	0.49	0.05
NON COLD SPRING	Saline	1.57	0.00
MANCHACA	Artesian	40.70	0.00
MANCHACA	Contributing	2.84	0.07
MANCHACA	Drainage	10.01	5.88
MANCHACA	Outcrop	66.68	60.40
MANCHACA	Potential Outcrop	0.49	0.05
MANCHACA	Saline	1.57	0.00
COLD SPRING	Contributing	0.07	0.04
COLD SPRING	Drainage	1.29	1.29
COLD SPRING	Outcrop	10.53	10.45
SUNSET	Artesian	0.76	0.06
SUNSET	Drainage	2.04	1.68
SUNSET	Outcrop	8.13	8.09

Rainfall infiltrates on total area minus artesian and saline locations. The contributing area in this table is land over which rainfall cannot infiltrate directly. The rain that falls on it infiltrates shallowly and travels horizontally to then enter the Edwards Aquifer. Notice that this is a relatively small area. Rainfall that travels to Barton Springs falls on the Non- Cold Springs total area minus artesian and saline areas or on 90.18 square miles (shaded cells).

Land use in the Recharge Zone calculated from 2006 data

		Recharge Zone Total			Cold Spring Recharge			Barton Spring Recharge		
GENLU2006	DESC	Parcel Ct	Area FT2	Area Ac	Parcel Ct	Area FT2	Area Ac	Parcel Ct	Area FT2	Area Ac
100	Single Family	24,058	432,694,619	9,933	5,802	96,852,394	2,223	18,339	335,842,225	7,710
113	Mobile Home	65	5,160,244	118	7	440,491	10	58	4,719,753	108
160	Large Lot Single Family (lot 10ac +)	90	107,276,157	2,463	1	374,872	9	89	106,901,285	2,454
200	Three/Fourplex	295	42,990,394	987	114	20,978,464	482	188	22,011,929	505
300	Commercial	230	45,946,135	1,055	102	19,579,919	449	136	26,366,217	605
400	Office	167	24,256,198	557	132	19,351,162	444	41	4,905,035	113
500	Manufacturing/industrial	17	1,720,954	40	6	792,253	18	11	928,701	21
560	Resource Extraction	8	8,693,411	200				8	8,693,411	200
600	Govt Church Hospital Meeting Hall	100	32,345,923	743	57	17,371,114	399	43	14,974,809	344
700	Park/Greenbelt	468	639,086,030	14,671	139	75,139,601	1,725	352	563,946,429	12,946
800	Rail/Transport Hubs	6	726,170	17	3	656,646	15	3	69,525	2
860	Streets/Road	249	171,510,101	3,937	63	52,829,858	1,213	197	118,680,243	2,725
870	Utilities	30	4,229,963	97	13	3,056,545	70	17	1,173,417	27
900	Undeveloped	1,770	945,387,351	21,703	259	26,249,122	603	1,514	919,138,229	21,101
940	Water	5	136,190	3	4	128,934	3	1	7,257	0
999	Unknown	2	4,016,296	92				2	4,016,296	92
		Total	2,466,176,136	56,616		333,801,376	5,407		2,132,374,760	48,953
		Zone Area	2,466,176,237	56,616		333,801,375	7,663		2,132,374,862	48,890
	Zone Area - Total of Parcel Data		101			-0.43917			102	

Appendix B. Rainwater Nitrogen Concentrations from the COA Field Sample Database

SITE#	DATE	SITE	MEDIUM	NO2/NO3	UNITS	TKN	TN
541	4/20/1995	St Elmo Wet Pond	Rain Water	0.34	MG/L	1.24	1.58
541	4/22/1995	St Elmo Wet Pond	Rain Water	0.88	MG/L	1.66	2.54
541	5/8/1995	St Elmo Wet Pond	Rain Water	0.26	MG/L	1.36	1.62
541	5/18/1995	St Elmo Wet Pond	Rain Water	0.53	MG/L	1.99	2.52
541	6/11/1995	St Elmo Wet Pond	Rain Water	0.46	MG/L	0.66	1.12
541	6/29/1995	St Elmo Wet Pond	Rain Water	0.33	MG/L	0.94	1.27
541	7/6/1995	St Elmo Wet Pond	Rain Water	0.44	MG/L	0.57	1.01
541	7/30/1995	St Elmo Wet Pond	Rain Water	0.54	MG/L	0.11	0.65
541	9/13/1995	St Elmo Wet Pond	Rain Water	2.65	MG/L	0.93	3.58
541	9/20/1995	St Elmo Wet Pond	Rain Water	0.26	MG/L	0.23	0.49
541	10/2/1995	St Elmo Wet Pond	Rain Water	1.28	MG/L	1.88	3.16
541	5/30/1995	St Elmo Wet Pond	Rain Water	0.28	MG/L	0.46	0.74
541	9/7/1995	St Elmo Wet Pond	Rain Water	0.81	MG/L	2.05	2.86
541	11/1/1995	St Elmo Wet Pond	Rain Water	0.18	MG/L	0.11	0.29
541	11/17/1995	St Elmo Wet Pond	Rain Water	1.66	MG/L	0.27	1.93
4340	5/23/2008	UT Geology Building Rainwater Catchment	Rain Water	0.36	MG/L	.	

Appendix C. Austin Area Fertilizer Products – January 2005

Austin Area Fertilizer Products Survey– January 2005

Blend	Brand	Bag Size	Price	Garden Center
46-0-0	(Urea)	50#	$26	Howard's
29-3-4	Vigoro	48#	$18	Home Depot
27-3-4	Scotts Turf Builder	37#	$16	Home Depot
22-3-14	Scotts	42#	$24	Home Depot
19-5-9	Easy Grow Lawn ???(may not stock this yr)	40# 40#	$22 $15	Howard's Red Barn
18-6-4	Easy Grow Lawn	40#	$14	Howard's
18-0-18	Lesco	50#	$14	Home Depot
15-5-10	Austin Nurseryman ???	40# 50#	$15 $12	Howard's Home Depot
21-0-0	(Ammonium Sulfate)	#40	$13	Howard's
9-1-1	Gardenville	40#	$33	Howard's
9-0-0	(Corn Gluten)	40#	$22	Natural Gardener
8-2-4	Ladybug	35#	$22 $19 $28 $31 ??	Natural Gardener Home Depot Red Barn Howard's Barton Springs Nursery
8-2-4	Concern All Natural Weed Prevention Plus (82% Corn Gluten)	25#	$18	Home Depot
8-1-1	Austin Nurseryman	30#	$15	Howard's
6-2-4	Bluebonnet Farms Premium Organic	40#	$19	Home Depot
6-3-0	Hou-Actinite	??#	$??	Barton Springs Nursery
6-2-2	Gardenville Soil Food	40#	$30	Howard's
6-2-0	Milorganite	40# ??#	$14 $??	Howard's Barton Springs Nursery
6-1-1	Beauty Grows Tx Friendly (from biosolids)	??#	$??	Home Depot Barton Springs Nursery
3-1-5	Bradfield	35#	$20	Pots & Plants
1-1-1	Hu More	40#	$10	Natural Gardener

Appendix D. Fertilizer Load Calculations

Wildflower Center Data	fertilizer application rates of 0, 1/2, or 2 lbs N per 1000 sq. ft., weighted average = 1 lb/1000 sq ft		Average
year	2006	2007	
dates	9/6 - 10/18 10/26 - 11/29	9/12 - 11/17	
# of days	78	67	approx 20% of year
volume (ml)	160,910	54,255	
surface area =0 .45 ft^2 per lysimeter * 80 lysimeters=35.9 ft^2	35.9	35.9	
average concentration of nitrate in mg/L as N	1.12	3.89	2.51
mass of N (kg)	1.80E-04	2.11E-04	1.96E-04
kilograms of N per day per ft^2	6.44E-08	8.77E-08	
average annual load (kg) per ft^2	2.35E-05	3.20E-05	
average annual load to aquifer (kg) per acre	1.02	1.39	1.21
irrigation inches	7	8	
rain in inches during dates Fews gage 1190	4.49	0.84	
expected vol of water from rainfall and irrigation in lysimeters is in/12 * 0.29*35.9 ft2*28.32 l/ft3*1000 ml/l	282,309	217,198	
expected load (kg) from rainfall on surface above lysimeters=5.01kg/acre*year*(4.49 rain in/32.5 rain in/year)*(35.9 ft2/43560 ft2/acre) in kg	5.70E-04	1.07E-04	
expected load (kg) from fertilizer on surface above lysimeters = 19.76*(35.9/43560)	1.63E-02	1.63E-02	
ratio of rainfall load to fertilizer load	3.50%	0.66%	2%
ratio of irrigation load to fertilizer load	1.78%	2.05%	2%
irrigation (tap) load: approximate inches 2006: 7", 2007: 8"	2.90E-04	3.34E-04	
total load (tap+fertilizer+rain) during period on surface	1.71E-02	1.67E-02	1.69E-02

Appendix E. Calculation Details

Useful conversions:

- 1 lb = 0.4536 kg
- 1 acre = 43,560 sq. ft.
- 1 cubic foot = 28.32 liters
- 1 lb/1000 sq ft of N is 19.76 kg of N per acre

Rain water

One inch of water over an acre = 1/12 ft* 43,560 ft^2 * 28.32 L/ft^3 = 102,801.6 Liters;

102,801.6 Liters/acre* 1.5 mg/L of N (rain concentration) / 1,000,000 mg/kg = 0.1542 kg/acre.

32.5 annual inches of rain * 0.1543kg/acre/inch of rain = 5.01kg/acre

Thus if we have 32.5 inches of rain per year (long term historical average - Barrett 2006) the annual N load from rainfall is 5.01 kg/acre.