Differential changes in groundwater quality due to urbanization under varying environmental regulations in Austin, Texas.

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Abstract

Karst springs in the Canyon Creek and Avery Ranch subdivisions were monitored before, during and after construction of residential homes with some commercial development. The objective of the monitoring program was to track trends in spring chemistry with changing land use in source area and compare the water quality impact of different water quality regulations after development. Groundwater chemistry, particularly ions, changed in correlation with increasing development. The data seems to suggest that with the exception of one spring, the enhanced water quality controls at Avery Ranch had some success in limiting nitrate enrichment of ground water during the construction of the subdivision. Ion concentrations including strontium are generally higher in Canyon Creek Subdivision springs than Avery Ranch, suggesting a potential difference in source water composition. Piper plots indicate few differences between sites that could identify source waters. A comparison was made between the spring chemistry data collected from a newly developing subdivision that was permitted under enhanced development agreement Planned Unit Development (PUD) and an older subdivision that was built-out under less restrictive Municipal Utility District (MUD) agreement to determine if differences in water chemistry could be seen. Spring data collected seems to indicate that only slight difference was seen in groundwater chemistry results between the two subdivisions. This suggests that water quality benefits provided by surface water quality controls had little effect on groundwater quality within subdivisions. Additional data is needed to test this hypothesis.

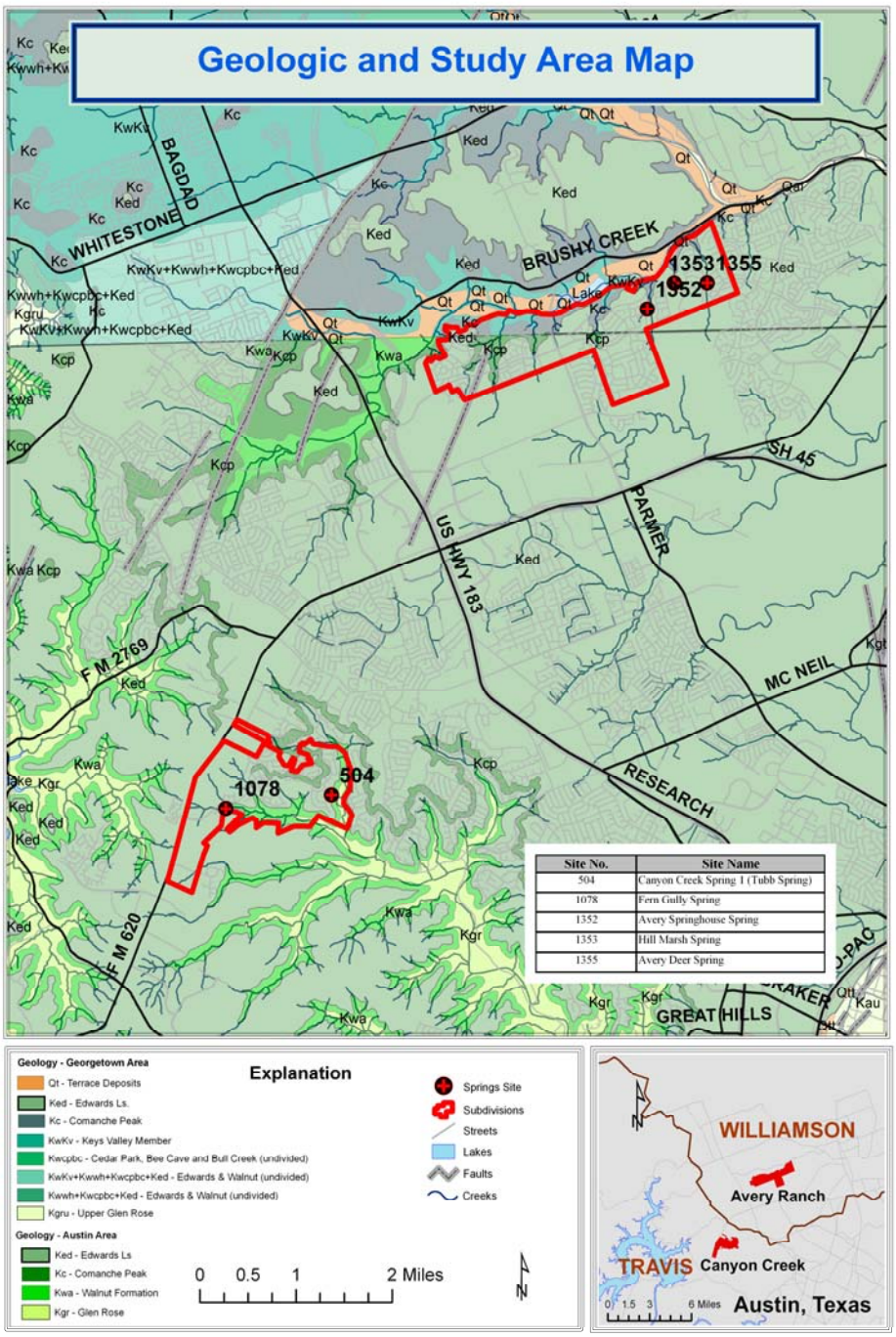
Introduction

The effects of urbanization on water quality of surface and groundwater resources are well documented in the scientific literature. In general, as impervious cover increases water quality decreases. As development of land and water resources increase, it is apparent that development of either of these resources affects the quantity and quality of the other, because of the connectivity and interaction between surface-water features such as streams, lakes, reservoirs, and wetlands with groundwater. In the Austin area, these interactions take the form of surface water recharging the karst aquifer. As a result, the loss of wetland habitat and degradation of surface water quality has an effect on groundwater resources. Thus, effective land and water management requires a clear understanding of the linkage between the ground and surface water.

Over the years, the City of Austin has created polices governing the management and protection of aquifers and watersheds. These development ordinances have been modified over the years as our understanding of the interaction and interdependency between surface water and groundwater has increased to where we no longer view surface water and groundwater as not simply two independent resources, but as integrated resources. The goal of this study is to measure the effectiveness of development policies and management practices by monitoring the rate and degree of water chemistry changes at karst springs located in two subdivisions within the Northern Segment of the Edwards Aquifer on the Jollyville Plateau in Central Texas.

Spring sites within the Avery Ranch and Canyon Creek subdivisions were monitored during and after construction of residential subdivisions (Table 1). Prior to development, the Canyon Creek and Avery Ranch areas were primarily hunting and ranching areas. The Canyon Creek subdivision was developed as a municipal utility district (MUD) and construction started in the early 1980s and most of the subdivision was built out by 2005. Avery Ranch subdivision began construction early in 2000 and there is current

Figure 1



Source: City of Austin GIS based on Collins, E.W. , 2005, Geologic Map of West half of the Taylor, Texas 30x 60 Minute Quadrangle and Trippet, A.R. and Garner, L.E., 1986, Geologic Map of Austin, Texas 1:62,500 scale.

development underway. The Avery Ranch subdivision includes an 18-hole golf course and amenity center and was developed as a Planned Unit Development (PUD) district.

Municipal Utility Districts (MUD) are a special purpose governmental entity of the State of Texas. Regulated by the Texas Commission on Environmental Quality (TCEQ), the MUD's primary function is to provide water, wastewater and stormwater drainage service within its boundaries. A MUD may sell bonds, levy and collect taxes, provide and charge for water and sewer services, build infrastructure, condemn property, enforce restrictive covenants and make regulations to accomplish its purposes. All Municipal Utility Districts are managed by an elected Board of Directors. Each Director on the Board is a resident or a property owner within the boundaries of the District. The Board of Directors conducts a meeting, usually every month to transact the business of the District.

A Planned Unit Development (PUD) district is the designation for a large or complex single or multi-use development that is planned as a single contiguous project and that is under unified control. The purpose of a PUD district designation is to preserve the natural environment, encourage high quality development and innovative design, and ensure adequate public facilities and services for development within a PUD. A PUD district designation provides greater design flexibility by permitting modifications of site development regulations. Development under the site development regulations applicable to a PUD must be superior to the development that would occur under conventional zoning and subdivision regulations. A PUD district must include at least 10 acres of land, unless the property is characterized by special circumstances, including unique topographic constraints.

Development within the two subdivisions occurred under different water quality ordinances. The Canyon Creek subdivision was initially developed in accordance with the City of Austin's Comprehensive Watershed Ordinance and later sections were permitted in accordance with the Save Our Springs Ordinance. The Avery Ranch Subdivision was developed as a PUD and provided water quality controls "superior" to the development that would occur under the conventional Save Our Springs Ordinance. The water quality controls for Avery Ranch are mainly wet ponds, compared to the standard sedimentation/filtration ponds constructed in the Canyon Creek Subdivision. To determine if there are differential changes in groundwater quality due to urbanization under varying environmental regulations, springs within each watershed were monitored for a period of five years from 2002 to 2007. Five karst springs; two springs in Canyon Creek and three in Avery Ranch Subdivision were selected for this study (Table 1). All five springs discharge at or near the same geologic contact between the Edwards Limestone and Walnut Formation and have similar discharges rates and springshed sizes (Figure 1). Groundwater movement within the Northern Edwards in the Jollyville Plateau is typically controlled by primary porosity flow through fractures, bedding planes, and conduits. Spring recharge occurs in upland areas where karst recharge features allow for surface water to infiltrate into the Edwards and migrate to the Walnut Formation through a network of voids, fracture, bedding plans and conduits. An example of this is the cave stream intercepted upstream of Avery Deer Spring during trenching activities for construction of a wastewater line. However, spring development occurs mostly in the underlying Walnut Formation where groundwater movement is more diffuse via secondary porosity, or water moving within the rock matrix.

Table 1. Spring sites

Site #	Site Name	Subdivision
504	Canyon Creek Spring 1 (Tubb Spring)	Canyon Creek
1078	Fern Gully Spring	Canyon Creek
1352	Avery Springhouse Spring	Avery Ranch
1353	Hill Marsh Spring	Avery Ranch
1355	Avery Deer Spring	Avery Ranch

Except for site 504, Jollyville salamanders have been observed by City staff at all the springs (City of Austin field data, 1999-2006). Spring sites were sampled quarterly beginning in 2002, although some historical data collected prior to 2002 was considered for temporal trend analyses. Metals were only analyzed once annually at all sites.

The contributing drainage area to each spring was estimated using surface topography derived from City of Austin Geographic Information Systems (GIS), see Figure 2. Impervious cover for each area was estimated from GIS landuse information and corresponding average percent of impervious cover (Figure 3). Impervious cover within the Avery Springhouse and Fern Gully springs rapidly increased over the 1997-2006 time period. Impervious cover has consistently been higher at Tubb Spring partially due to the fact that development occurred earlier than at Avery Springhouse or Fern Gully springs.

The Canyon Creek subdivisions consists of a higher percentage of residential land use and a lower percentage of undeveloped land and parks based on 2003 aerial photography analysis (Table 2).

Table 2. 2003 Landuse in the two subdivisions.

Landuse	**Avery**	**Canyon Creek**
Single Family Residential	16.6	19.6
Multi-family Residential	0.0	13.9
Commercial	0.1	1.5
Office	0.0	0.3
Industrial	0.0	2.0
Civic	5.1	0.4
Parks/Open Space	15.4	37.0
Transportation	12.5	8.2
Undeveloped	50.3	17.2

Figure 2: Changes in the amount of Impervious Cover within the springshed 1997 to 2006

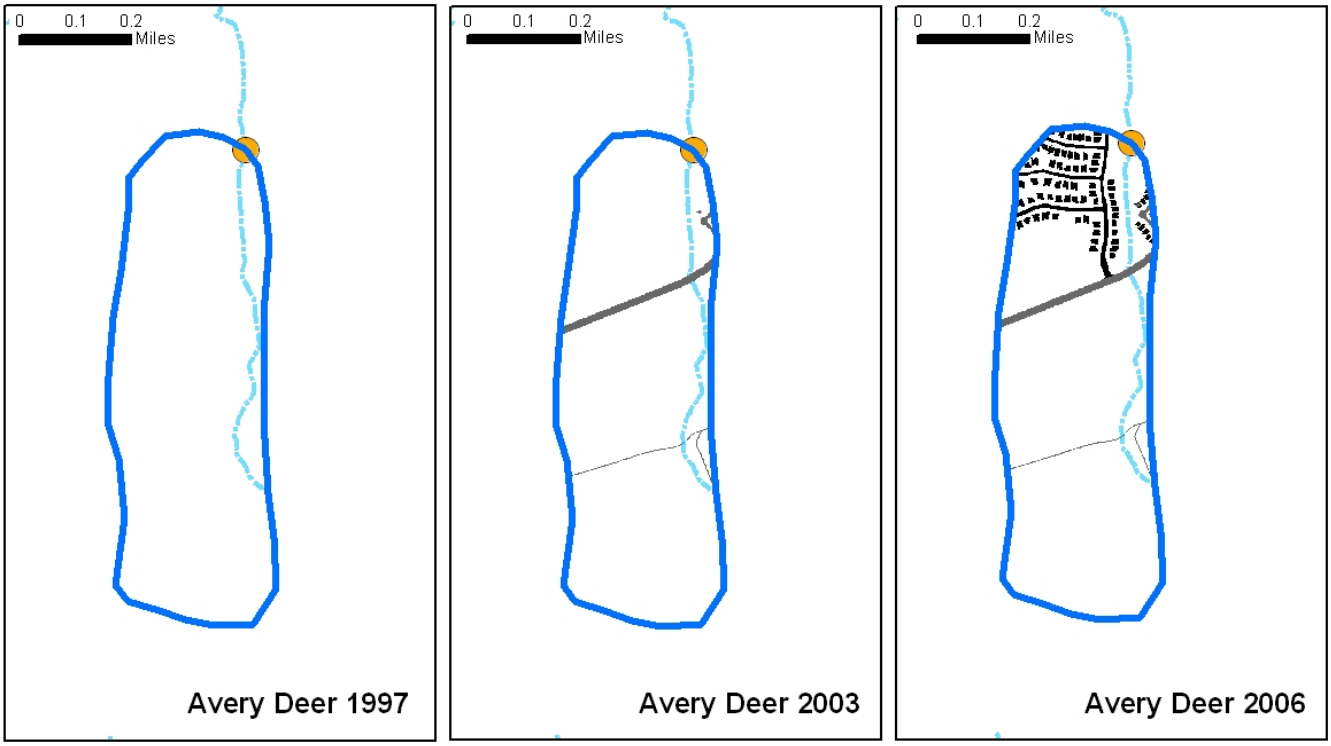
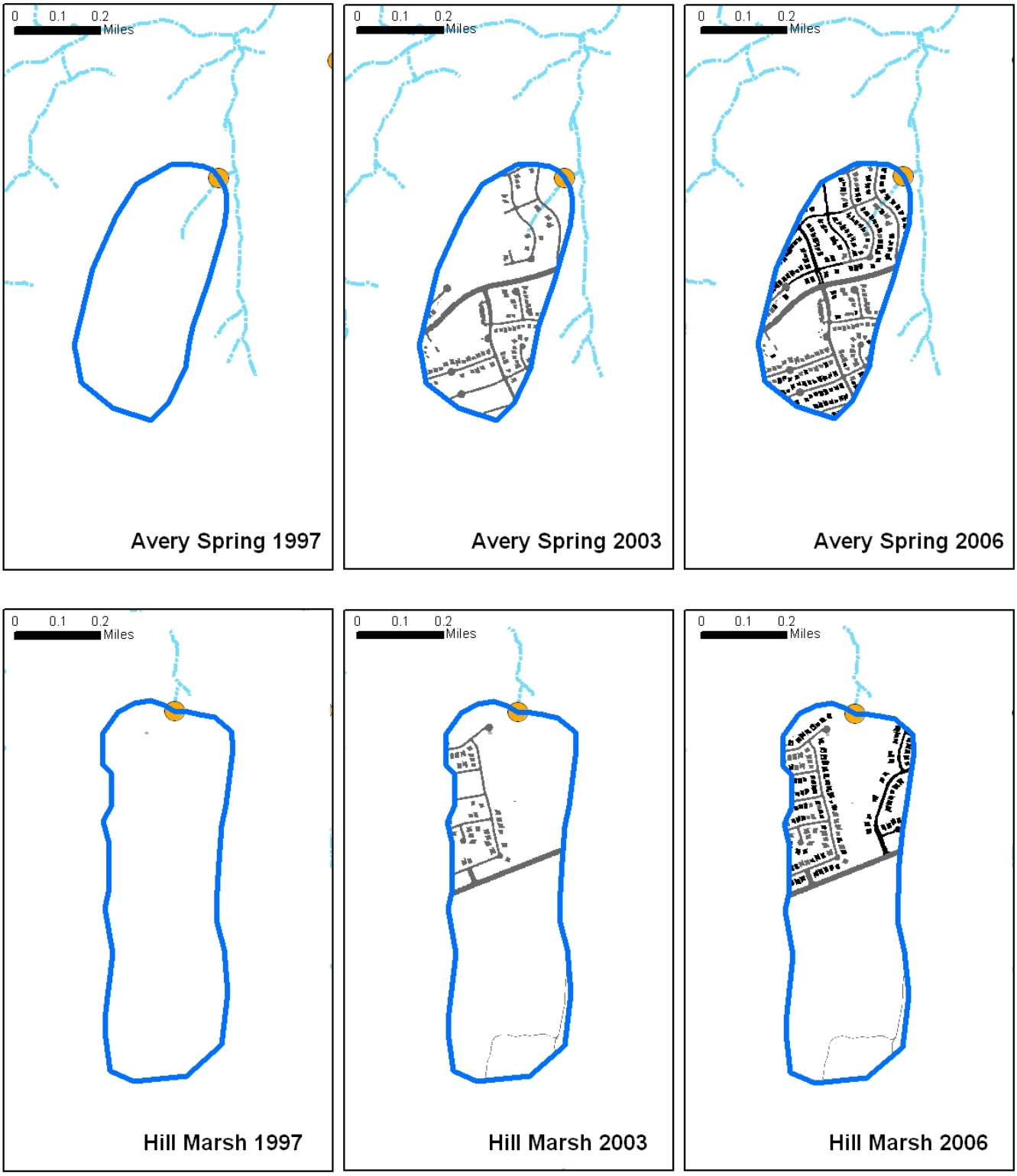
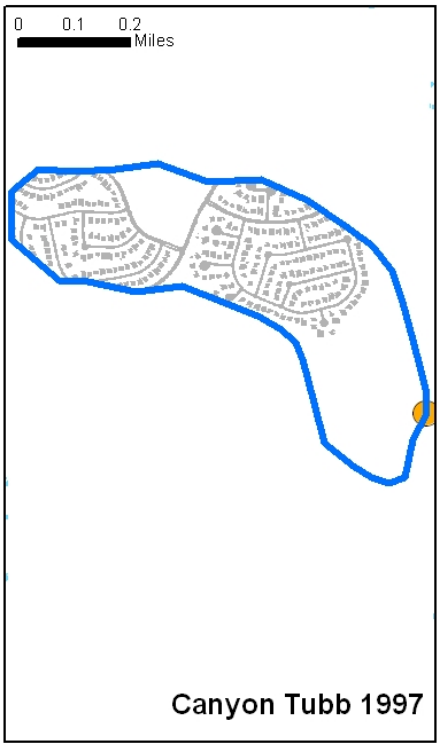


Figure 2 (continued)

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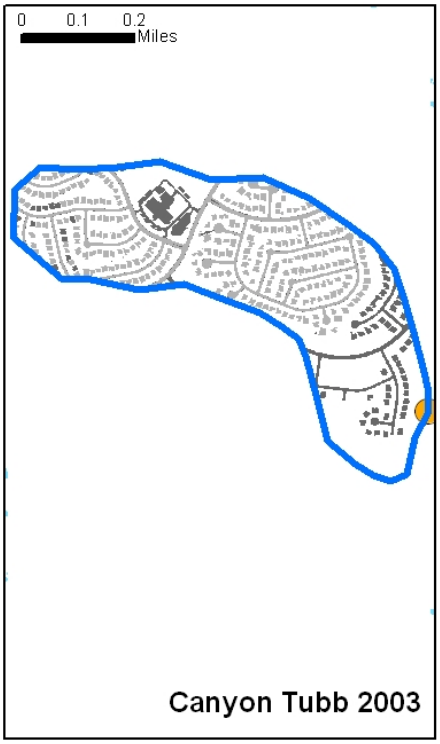
Miles
Canyon Tubb 1997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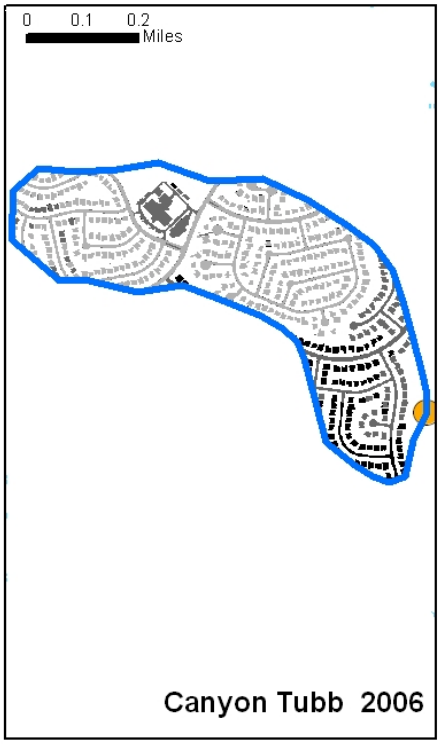
Miles
Canyon Tubb 2003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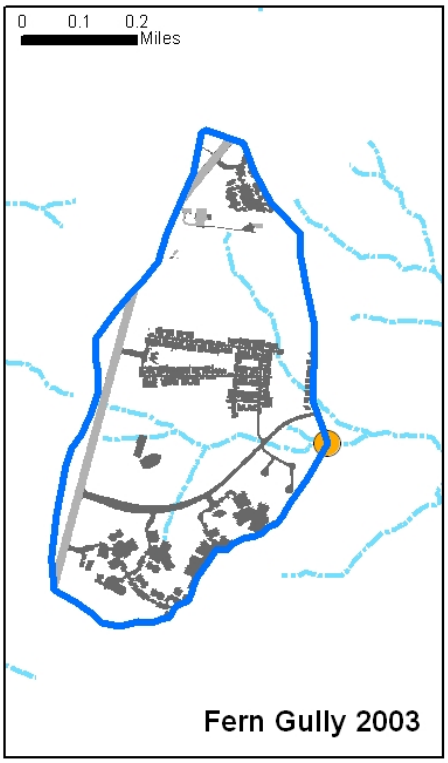
Miles
Canyon Tubb 2006

0 0.1 0.2
Miles
Fern Gully 1997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Fern Gully 2003

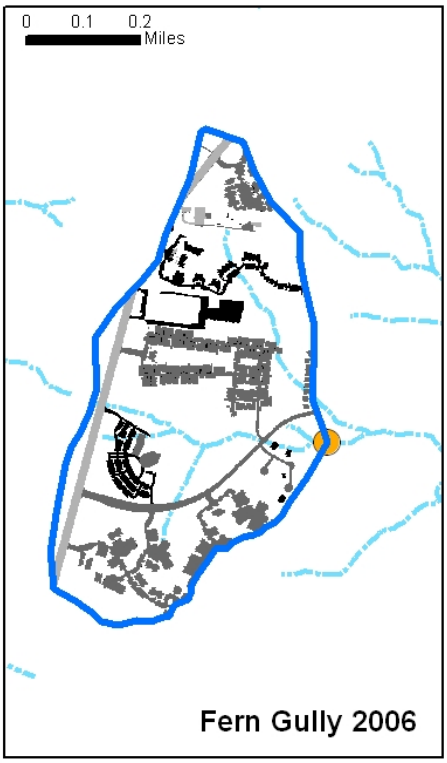

0 0.1 0.2
Miles
Fern Gully 2006

Figure 3

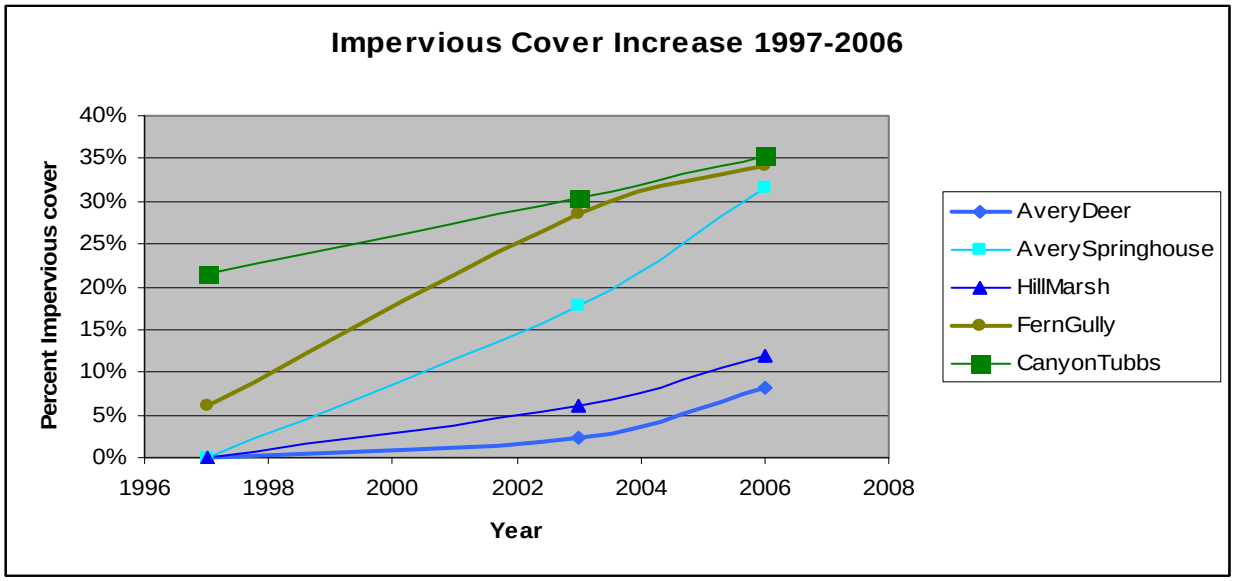


Figure 3. Percent impervious cover by springshed based on City of Austin GIS land use information.

Methods

Outliers were identified and removed from the analysis. These datapoints included all potassium and sodium data collected on 6 March 2002. Iron data collected on 5 October 2005 were also removed. One unusual ammonia value (0.7 mg/L) at Hill Marsh Spring on 12 December 2007 was excluded from the analysis.

Differences within and between subdivisions were analyzed by the non-parametric Wilcoxon rank-sum test in SAS using PROC NPAR1WAY and confirmed by Ryan-Einot-Gabriel-Welsch multiple range test (SAS PROC GLM).

Temporal trends were assessed using least-square linear regression in SAS (SAS Institute, version 9.1) by PROC GLM. For datasets with censored values (i.e., less than detection limit), temporal trends were assessed by Cox proportional hazards regression (Allison 1995) using SAS PROC PHREG. All temporal trends were verified graphically.

Water quality measurements were compared to impervious cover by linear regression analyses. Because impervious cover information is currently available only for three years, impervious cover change over time was assumed to be a linear function and the change in impervious cover in intervening years (without actual impervious cover measures) was estimated by linear regression. Negative values for impervious cover were censored at zero. This method is likely to over-estimate impervious cover in more recent years. More frequent annual estimates of impervious cover, as can be derived from local county appraisal district records, would be more realistic to use in this type of analysis. (check to see if GIS aerial photo analysis updated the i.c. estimates or to see if TCAD and WCAD records were used)

Piper plots were used to compare groundwater chemistry between sites. Unless specified otherwise, a critical value (α) of 0.05 was used to determine statistical significance.

Results

Temporal trend analysis yields significant change over time for most ion parameters at the majority of sites (Table 3). Nitrate increased in Canyon Creek sites but yields conflicting results for sites in Avery Ranch as seen in nitrate values at the different Avery springs showing no change, increasing and decreasing trends in concentrations (Figure 4). The data seems to suggest that the enhanced water quality controls at Avery Ranch had some success in limiting nitrate enrichment of ground water during the construction of the subdivision with the exception of one spring; Avery Deer, where nitrate levels increased. The decreasing nitrate trend at Avery Hill Marsh is surprising and seems to indicate a change in the source water recharging the springs. Perhaps, the drop in nitrate concentrations is related to the enhanced Integrated Pest Management Plan that limits fertilizer application and irrigation practices used for the Golf Course. Additional studies are needed to confirm this hypothesis. Development practices appear to result in differential water quality degradation in nitrate.

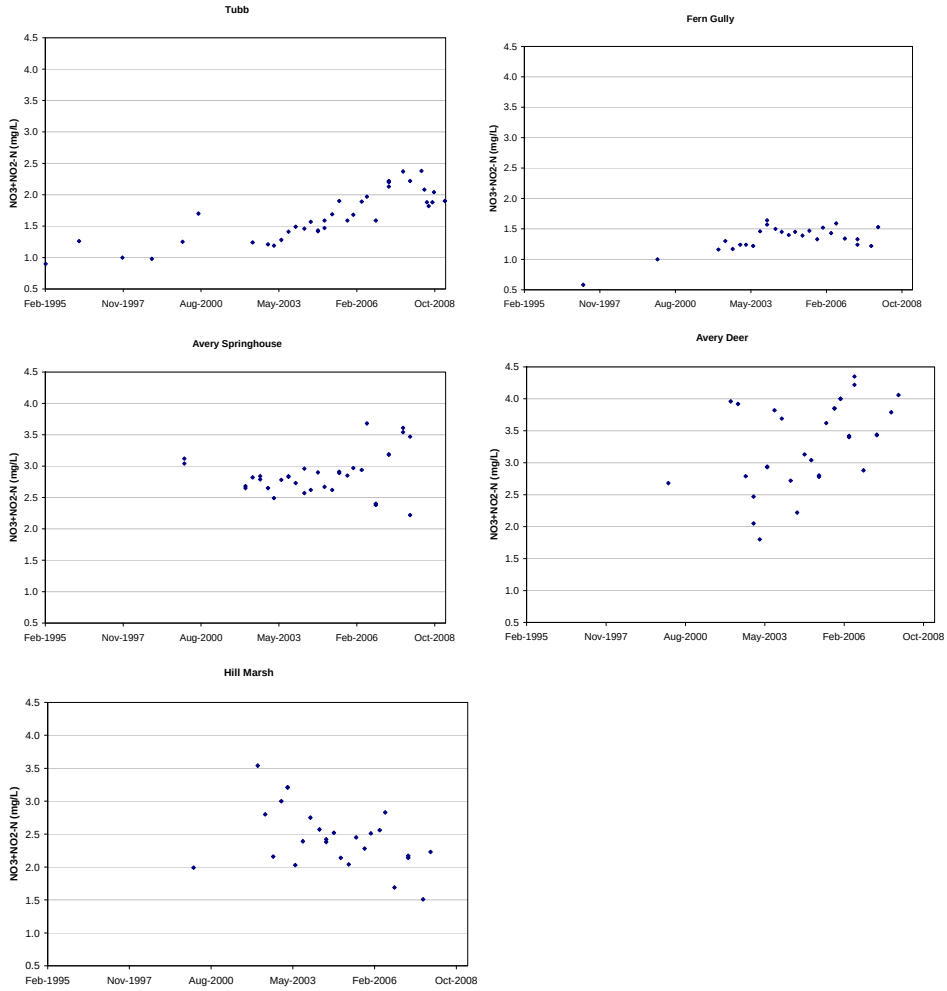


Figure 4. Nitrate plus nitrite as nitrogen (mg/L) over time for all five study springs with consistent axes.

The temporal trend analysis indicates significant increasing cation and anion concentrations are occurring at all sites. Figure 5 shows a piper plot on cation and anion values over time. The piper plots, used to describe the hydrochemical facies of an aquifer, indicate that the groundwater is calcium /bicarbonate type, as anticipated for groundwater in limestone lithology. The calcium, magnesium and bicarbonate are the dominant ions, as indicated in the plot of average dominant ion concentrations. However, a plot of all the major ion data indicates the hydrochemical facies in the springsheds is slowly shifting to magnesium/chloride type because of changes in the solution kinetics, flow patterns, or source recharge in the springsheds. Despite observed differences in long-term mean concentrations of ions between

subdivisions, piper plots indicate few differences between sites. However, groundwater chemistry, particularly ions, changed in correlation with increasing development.

Temporal trend analysis yields significant change over time for three metals; iron, nickel and lead. Iron values spiked in 2003, and then appeared to slightly decrease over the remainder of the period of record. Observed temporal trends in metals may be due to laboratory analytical problems or from the use of contaminated acid for sample preservation as indicated by metals values peaking in approximately 2003. An internal investigation of metal results by Water Resources Evaluation Section revealed that some type of preservation or analytical laboratory error resulting elevated metal concentrations through 2004?. However, the more recent samples have been all nondetect or at low levels.

Canyon Creek springs typically maintain higher ion concentrations than Avery Ranch springs (table 4), although nitrogen appears to be higher in Avery Ranch springs. Metals show no differences between subdivisions.

Table 3. Summary of temporal trend analysis results over the period of record.

* = no trend	Canyon Creek		Avery Ranch		
	Tubb	**Fern**	**Deer**	**Springhouse**	**Hill Marsh**
Ions					
ALKALINITY	Increasing	Decreasing	*	Increasing	Increasing
CALCIUM	Increasing	*	Increasing	Increasing	*
CHLORIDE	Increasing	Increasing	*	Increasing	Increasing
CONDUCTIVITY	Increasing	*	Increasing	Increasing	Increasing
FLUORIDE	*	*	*	*	*
MAGNESIUM	*	Decreasing	Increasing	Increasing	Increasing
POTASSIUM	Increasing1	Increasing1	Increasing	Increasing	*
SODIUM	Increasing	Increasing	Increasing	Increasing	Increasing
SULFATE	Increasing	*	Increasing	Increasing	Increasing
Nutrients					
AMMONIA	*	*	Decreasing1	*	*
NITRATE/NITRITE	Increasing	Increasing	Increasing	*	Decreasing
ORTHOPHOSPHORUS	*	*	*	*	Decreasing
Metals					
ARSENIC	*	*	*	*	*
COPPER	*	*	*	*	*
IRON	*	*	Decreasing	Decreasing	Decreasing1
LEAD	*	Decreasing1	Decreasing	Decreasing	Decreasing
NICKEL	Increasing	Increasing	Increasing	Increasing	Increasing
STRONTIUM	*	*	*	*	*
ZINC	*	*	*	*	*
Conventionals					
DISSOLVED OXYGEN	*	Decreasing1	*	*	*
E COLI BACTERIA	Increasing	*	*	*	*
FECAL COLIFORM	*	*	*	*	*
FLOW	*	*	*	*	*
ORGANIC CARBON	Increasing	*	Increasing	Increasing	*
PH	*	*	*	Increasing	*
TURBIDITY	*	Decreasing	*	Decreasing	Decreasing
TEMPERATURE	*	Increasing	*	*	*

1. Only significant at the α=0.10 level

Table 4. Differences between site groups by Wilcoxon rank-sum test and site group means.

Parameter	Units	Mean		Wilcoxon Rank-Sum	Notes
		Avery	**CC**	**Pr > |z|**	
Ions					
ALKALINITY-CaCO3	MG/L	332.184	329.434	0.4292	*
CALCIUM	MG/L	101.648	113.406	0.0000	CC>Avery
CHLORIDE	MG/L	14.802	21.684	0.0000	CC>Avery
CONDUCTIVITY	µS/cm	690.722	739.027	0.0107	CC>Avery
FLUORIDE	MG/L	0.155	0.185	0.9263	*
MAGNESIUM	MG/L	27.860	19.192	0.0000	Avery>CC
POTASSIUM	MG/L	1.085	1.006	0.0354	Avery>CC
SODIUM	MG/L	7.931	11.938	0.0000	CC>Avery
STRONTIUM	UG/L	106.917	379.833	0.0037	CC>Avery
SULFATE	MG/L	17.529	21.015	0.0001	CC>Avery
Nutrients					
AMMONIA AS N	MG/L	0.013	0.012	0.0460	Avery>CC
NITRATE/NITRITE-N	MG/L	2.893	1.535	0.0000	Avery>CC
ORTHOPHOSPHORUS-P	MG/L	0.009	0.009	0.1176	*
Metals					
ARSENIC	UG/L	0.654	1.195	0.8680	*
COPPER	UG/L	0.833	0.681	0.3727	*
LEAD	UG/L	5.601	5.531	0.8878	*
NICKEL	UG/L	2.161	2.206	0.7379	*
ZINC	UG/L	4.109	4.147	0.8985	*
Conventionals					
DISSOLVED OXYGEN	MG/L	6.200	6.885	0.0006	CC>Avery
E COLI BACTERIA	MPN/dL	66.020	15.426	0.0001	Avery>CC
FECAL COLIFORM	Colonies/dL	207.839	33.833	0.0656	*
FLOW	CFS	0.036	0.038	0.0114	CC>Avery
IRON	UG/L	45.566	42.716	0.1910	*
ORGANIC CARBON	MG/L	2.290	2.865	0.3954	*
PH	Std Units	7.025	7.020	0.6745	*
TEMPERATURE	Deg. C	20.757	20.676	0.7293	*
TURBIDITY	NTU	2.851	2.937	0.5867	*

* = indicates no significant difference between site groups
CC = Canyon Creek

Sites within each subdivision were also assessed for potential differences. Avery Ranch sites yield higher concentrations of nutrients than springs in Canyon Creek (Table 5). There were no statistically significant differences between sites for metals. Within Canyon Creek, Tubb Spring (site 504) had generally higher concentrations of ions than Fern Gully (site 1078). Strontium values in Canyon Creek are significantly higher than Avery Ranch, suggesting a potential difference in source water composition.

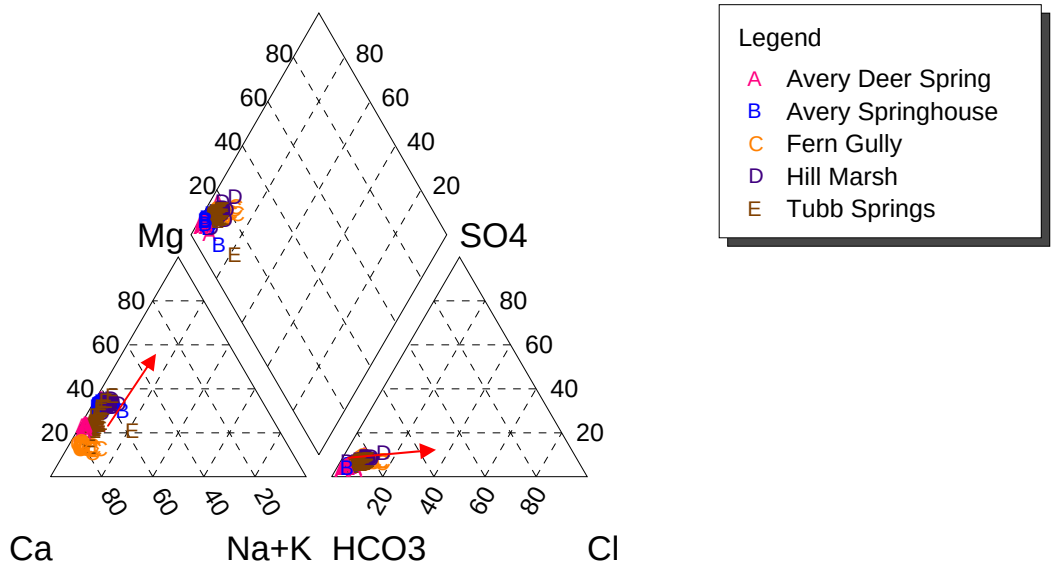
Table 5. Site means and differences between sites for each subdivision by Wilcoxon rank-sum test (p-values < 0.05 indicate significant difference within site groups).

Parameter	Unit	Canyon Creek			Avery Ranch			
		Tubb	Fern	Pr>|z|	Deer	Spg. House	Hill Marsh	Pr>|z|
Ions								
ALKALINITY-CaCO3	MG/L	367.857	286.400	0.0000	307.433	339.844	352.080	0.0000
CALCIUM	MG/L	117.915	108.175	0.0295	103.550	99.174	102.688	0.0612
CHLORIDE	MG/L	23.000	20.209	0.0236	9.610	14.145	21.872	0.0000
CONDUCTIVITY	µS/cm	802.693	632.917	0.0000	627.120	694.042	756.391	0.0000
FLUORIDE	MG/L	0.240	0.124	0.0044	0.129	0.166	0.171	0.1839
MAGNESIUM	MG/L	26.224	11.035	0.0000	19.162	31.139	33.275	0.0000
POTASSIUM	MG/L	1.045	0.987	0.6231	0.765	0.685	1.967	0.0000
SODIUM	MG/L	12.593	11.173	0.0844	5.334	7.749	11.178	0.0000
STRONTIUM	UG/L	501.667	258.000	0.0495	55.933	145.633	80.467	0.0222
SULFATE	MG/L	22.411	19.452	0.0020	12.436	16.119	25.444	0.0000
Nutrients								
AMMONIA AS N	MG/L	0.011	0.013	0.1880	0.013	0.015	0.015	0.2167
NITRATE/NITRITE-N	MG/L	1.671	1.337	0.0007	3.292	2.874	2.443	0.0000
ORTHOPHOSPHORUS-P	MG/L	0.010	0.021	0.1338	0.030	0.008	0.012	0.8245
Metals								
ARSENIC	UG/L	0.657	3.934	0.3851	0.481	8.240	1.241	0.7167
COPPER	UG/L	0.610	0.720	0.6264	0.328	1.030	1.282	0.5444
IRON	UG/L	48.493	36.486	0.9342	39.107	48.382	49.335	0.8922
LEAD	UG/L	4.602	6.706	0.5165	7.311	6.223	8.074	0.8992
NICKEL	UG/L	2.320	2.149	0.2661	2.108	2.260	2.370	0.5161
ZINC	UG/L	4.788	3.537	0.9372	3.725	4.620	3.933	0.9032
Conventionals								
DISSOLVED OXYGEN	MG/L	6.651	7.257	0.0232	6.114	5.496	7.027	0.0000
E COLI BACTERIA	MPN/dL	25.819	3.969	0.8331	103.250	17.450	81.000	0.9088
FECAL COLIFORM	Col./dL	26.889	41.667	0.0759	472.100	59.250	114.222	0.7470
FLOW	cfs	0.021	0.059	0.4428	0.023	0.041	0.044	0.0693
ORGANIC CARBON	MG/L	2.486	3.320	0.4851	2.040	2.169	2.834	0.0138
PH	Std Unit	7.042	6.983	0.2020	7.054	6.937	7.086	0.0430
TEMPERATURE	Deg C	20.865	20.361	0.2413	20.537	20.928	20.807	0.8437
TURBIDITY	NTU	3.792	1.919	0.0976	3.482	2.133	2.910	0.4528

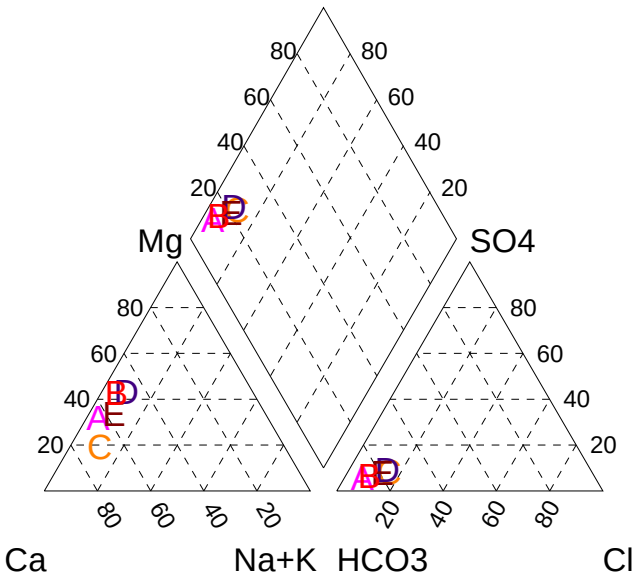
Piper plots indicate few differences between sites or subdivisions (figure 3).

Figure 5. Piper plots using site mean parameter concentrations.

All Ion Concentrations



Average Ion Concentrations



Water quality data was compared to impervious cover by linear regression analysis. Ions and nitrate generally increased with increasing impervious cover. Trends in metals may be affected by change in analytical laboratories and sample preservation methods as discussed previously.

Table 6. Summary of regression analysis with impervious cover by site.

* = no trend	Canyon Creek		Avery Ranch		
	Tubb	**Fern**	**Deer**	**Springhouse**	**Hill Marsh**
Ions					
ALKALINITY-CaCO3	Increasing	Decreasing1	*	Increasing	Increasing
CALCIUM	Increasing	*	Increasing	Increasing	Increasing
CHLORIDE	Increasing	Increasing	Increasing1	Increasing	Increasing
CONDUCTIVITY	Increasing	*	Increasing	Increasing	Increasing
FLUORIDE	*	*	*	*	*
MAGNESIUM	*	Decreasing	Increasing	Increasing	Increasing
POTASSIUM	Increasing1	Increasing1	*	Increasing	*
SODIUM	Increasing	Increasing	Increasing	Increasing	Increasing
STRONTIUM	*	*	*	*	*
SULFATE	Increasing	*	Increasing	Increasing	Increasing
Nutrients					
AMMONIA-N	*	*	Decreasing1	*	*
NITRATE/NITRITE-N	Increasing	Increasing	Increasing	Increasing1	Decreasing
ORTHOPHOSPHORUS-P	*	*	*	*	Decreasing
Metals					
ARSENIC	*	*	*	*	*
COPPER	*	*	*	*	*
IRON	*	*	Decreasing	Decreasing	Decreasing1
LEAD	*	Decreasing1	Decreasing	Decreasing	Decreasing
NICKEL	Increasing	Increasing	Increasing	Increasing	Increasing
ZINC	*	*	*	*	*
Metals					
DISSOLVED OXYGEN	*	Decreasing1	*	*	*
E COLI BACTERIA	Increasing	*	*	*	*
FECAL COLIFORM	*	*	*	*	*
FLOW	*	*	*	*	*
ORGANIC CARBON	Increasing	*	Increasing	Increasing	*
PH	*	*	*	Increasing	*
TURBIDITY	*	*	*	Decreasing	Decreasing
TEMPERATURE	*	Increasing1	*	*	*

1. Only significant at the α=0.10 level

Conclusions

Since the late 1980's, the City of Austin has created development ordinances and polices governing development within its city limits and extraterritorial jurisdiction area to help protect the local environmental resources. As our understanding of the interaction and interdependency between surface water and groundwater has increased over the years to no longer view surface water and groundwater as not simply two independent resources, but as integrated resources, ordinances were modified with goal of improving the City protection of surface water resources. Although the effect of impervious cover on surface water and groundwater are well documented, the goal of this study was to determine if measures difference in groundwater chemistry can detected at spring within subdivision development under different and changing development ordinances and increases in impervious cover over time. The Avery

Ranch Subdivision was developed as a PUD and provided "superior" water quality controls to the development that would occur under the conventional Save Our Springs Ordinance. Water quality controls are mainly wet ponds, compared to the standard sedimentation/filtration ponds constructed in the Canyon Creek Subdivision.

A comparison was made between the groundwater chemistry data collected from springs in a newly developing subdivision that was permitted under enhanced development agreement Planned Unit Development (PUD) and an older subdivision that was completely built-out under less restrictive Municipal Utility District (MUD) agreement. The comparison was to determine if differences in water chemistry could be seen. Although surface water quality might have benefited greatly improved water quality measures, the groundwater data collected seems to indicate that only slight differences were seen in groundwater chemistry results between the two subdivisions. This suggests that water quality benefits provided by surface water quality controls had little effect on groundwater quality within subdivisions. Additional data is needed to test this hypothesis.

Groundwater chemistry, particularly ions, changed in correlation with increasing development. These data seem to suggest that the enhanced water quality controls at Avery Ranch had some success in limiting nitrate enrichment of ground water during the construction of the subdivision with the exception of one spring; Avery Deer, where nitrate levels increased. Ion concentrations including strontium are generally higher at Canyon Creek Subdivision than Avery Ranch, suggesting a potential difference in source water composition. Despite observed differences in long-term mean concentrations of ions between subdivisions, piper plots indicate few differences between sites.

Water quality data was compared to impervious cover by linear regression analysis. Ions and nitrate generally increased with increasing impervious cover. Trends noted in metals data may have been affected by change in analytical laboratories and sample preservation methods.

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