Refined Impervious Cover Analysis for the Four Central Texas Salamanders

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Introduction

Impervious cover is any surface material, such as roads, rooftops, sidewalks, patios, paved surfaces, or compacted soil, that prevents water from filtering into the soil (Arnold and Gibbons 1996, p. 244). Once natural vegetation in the area draining into a stream (watershed) is replaced with impervious cover, rainfall is converted to surface runoff instead of filtering through the ground (Schueler 1991, p. 114). Large-scale changes in how water moves within a watershed can have significant impacts on streams and the organisms that rely on those streams.

As urbanization increases due to human population growth within watersheds, levels of impervious cover will likely rise. For this reason, impervious cover is often used as a surrogate for urbanization (Schueler *et al.* 2009, p. 309). A vast amount of literature indicates that increases in impervious cover cause measurable stream degradation (for example, Klein 1979, p. 959; Bannerman *et al.* 1993, pp. 251–254, 256–258; Schueler 1994, p. 104; Center for Watershed Protection 2003, p. 91; Schueler *et al.* 2009, pp. 312-313; Coles *et al.* 2012, p. 4). This decline in aquatic habitat quality has demonstrable impacts on biological communities within streams. For example, an analysis of nine regions across the United States found considerable losses of algal, invertebrate, and fish species in response to stressors brought about by urban development (Coles *et al.* 2012, p. 58). Impervious cover degrades stream habitat in three ways: (1) introducing and concentrating contaminants in surface runoff, (2) increasing the rate at which sediment is deposited into a stream, and (3) altering the natural flow regime of streams.

In our August 22, 2012, proposed rule (77 FR 50768), we presented impervious cover calculations within the watersheds occupied by the four central Texas salamander species to identify the extent and magnitude of the current impervious cover threat on these species. The four salamander species are the Austin blind salamander (*Eurycea waterlooensis*), Jollyville Plateau salamander (*Eurycea tonkawae*), Georgetown salamander (*Eurycea naufragia*), and Salado salamander (*Eurycea chisholmensis*). This analysis used the nationally consistent Watershed Boundary Dataset to delineate 15 watersheds occupied by the four central Texas salamander species. Although the data for this impervious cover analysis were derived using the finest scale hydrologic units that we were aware of in the Watershed Boundary Dataset (12-digit HUCs), they were too large to offer any reference to the location of salamander-occupied spring sites in relation to the location of impervious cover within the watersheds. In other words, impervious cover occurring within each 12-digit HUC may not necessarily be an indicator of how much impervious cover is impacting water quality within known salamander sites because this analysis did not take into account whether the salamander sites are found upstream or downstream of impervious surfaces associated with developed areas in the HUC.

The goal of the analysis presented here is to calculate impervious cover within the watersheds occupied by the four central Texas salamander species currently proposed for listing at a finer scale. This analysis will identify the surface areas that drain into surface salamander sites and which of these sites may be experiencing habitat quality degradation as a result. We believe the results give a more accurate description of the status of the salamander sites than the analysis performed with the larger 12-digit HUC. We also compare the results of our refined impervious cover analysis with two additional impervious cover analyses conducted by SWCA Environmental Consultants (SWCA) and the City of Austin (COA).

Methods

Watershed delineation

To calculate impervious cover within the watersheds occupied by the four central Texas salamander species, we used a combination of the NHDPlus dataset (http://www.horizon-systems.com/NHDPlus/NHDPlusV1_12.php) and a digital elevation layer developed by the U.S. Geological Survey (USGS) (http://seamless.usgs.gov/ned13.php) to delineate the watersheds of each surface site where these species are known to occur. Because we only delineated the area of land draining into surface habitat, cave locations for each salamander were omitted from the analysis. NHDPlus is a nationally consistent watershed dataset developed by the U.S. Environmental Protection Agency and USGS, based on the National Hydrography Dataset (NHD). NHDPlus integrates the NHD with the National Elevation Dataset (NED) and the Watershed Boundary Dataset (WBD) to produce the smallest (or finest scale) of hydrologic units available: the 14-digit HUC (USGS 2011, pp. 7-8). We used ESRI software to create an aspect map and a set of 5-foot contour lines to help guide creation of even smaller watersheds that specifically drain into salamander spring sites. In the proposed rule, we cited that salamanders have been found up to 164 feet (ft) [50 meters (m)] from a spring opening (Pierce *et al.* 2011a, p. 4), so watersheds were originally delineated based upon the point 164 ft (50 m) downstream from a salamander site. Spring sites were grouped together if they were located 164 ft (50 m) or less downstream from another site. Ten spring sites total were grouped, including eight for the Jollyville Plateau salamander and two for the Salado salamander.

In the final listing and critical habitat rule, we cite a recent study completed by the COA (COA 2013, pers. comm.) that demonstrates salamanders can occupy stream habitat up to 262 ft (80 m) downstream of a spring opening. This information was received after our original watershed delineation. We subsequently delineated watersheds using a point 262 ft (80 m) downstream from a salamander site (Appendix A) and compared the resulting impervious cover values to values from our original watersheds. The values were similar for the most part, and differences that we did observe were the result of larger watersheds for the analysis based on the 262 ft (80 m) downstream point. Because *Eurycea* salamanders are rarely found more than 66 ft (20 m) from a spring source (TPWD 2011, p. 3), we felt that these larger watersheds that drained into areas farther downstream of a spring source would not affect the majority of habitat that is used by the salamander species. Therefore, we continued to use our original watershed delineations for the analysis.

We also calculated the impervious cover levels for the contributing and recharge zones of the Barton Springs Segment of the Edwards Aquifer. Unlike the known locations for the Jollyville Plateau, Georgetown, and Salado salamanders, subsurface water feeding the sites of Austin blind salamander (Barton Springs complex) are fairly well-delineated. Barton Springs is the principal discharge point for the Barton Springs Segment of the Edwards Aquifer, and recharge throughout most of the aquifer converges to this discharge point (Slade *et al.* 1986, p.

28; Johnson *et al.* p. 2). Most of the water recharging the Barton Springs Segment of the Edwards Aquifer was believed to be derived from percolation through six creeks that cross the recharge zone (Slade *et al.* 1986, pp. 43, 51), but more recent work shows that a significant amount of recharge occurs in the upland areas (Hauwert 2009, pp. 212-213).

<u>Impervious cover layer</u>

For the impervious cover layer, we used the 2006 National Land Cover Dataset (MRLC 2012, p. 1). The 2006 National Land Cover Dataset (the most recent of the national land cover datasets) was developed by the Multi-Resolution Land Characteristics Consortium to provide 98 ft^2 (30 m^2) spatial resolution estimates for tree cover and impervious cover percentages within the contiguous United States. An impervious cover value (0 to 100 percent) is assigned for each 98 ft^2 (30 m^2) pixel within the 2006 National Land Cover Dataset. Using these values, we calculated the overall average impervious cover value (percentage) for each watershed identified. This analysis is most likely an underestimation of current impervious cover because small areas of impervious cover may have gone undetected at the resolution of our analysis and additional areas of impervious cover have been added within some watersheds since 2006 (the year the dataset was generated).

<u>Impervious cover categories</u>

The impervious cover categories were chosen partly based on ecological thresholds reported in the literature. An ecological threshold is the point at which there is an abrupt shift in the quality of an ecosystem, or where small changes in an environmental driver produce large responses in an ecosystem (Groffman *et al.* 2006, p. 1). In our analysis, the ecosystem is a spring-fed stream and the environmental driver is the level of impervious cover within the watershed. The point at which a certain level of impervious cover begins to negatively affect the stream ecosystem is a valuable tool for aquatic species management (Hilderbrand *et al.* 2010, pp. 1010, 1014).

Table 1 presents a summary of studies that report watershed impervious cover thresholds based on a variety of degradation measurements. Most studies examined biological responses to impervious cover (for example, aquatic invertebrate and fish diversity), but several studies measured chemical and physical responses as well (for example, water quality parameters and stream channel modification). Ten percent was the most commonly reported threshold, with more recent studies trending towards thresholds 10 percent and lower. Recent studies in the eastern U.S. have reported large declines in aquatic macroinvertebrates (the prey base of salamanders) at impervious cover levels as low as 0.5 percent (King and Baker 2010, p. 1002; King *et al.* 2011, p. 1664). Perhaps the most relevant study to this analysis, Bowles *et al.* (2006, pp. 113, 117-118), found lower Jollyville Plateau salamander densities in watersheds with more than 10 percent impervious cover. To our knowledge, this is the only peer-reviewed study that examined watershed impervious cover effects on salamanders in our study area.

Various levels of impervious cover within watersheds have been cited as having

Table 1: Watershed impervious cover thresholds cited in the literature

Author(s)	Year	Page number(s)	Measure of degradation	Region	Range of impervious cover thresholds cited (%)																			
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dunne and Leopold	1978	699-700	channel dimensions	New Mexico				■																
Klein	1979	959	fish diversity	Maryland										■		■								
Morisawa and LaFlure	1979	345-348	channel enlargement	New York		■																		
Jones and Clark	1987	1051-1054	aquatic invertebrate diversity	northern Virginia															■					
Steedman	1988	498	fish diversity	Ontario										■	■	■								
Schueler and Galli	1992	170-171	fish diversity (10-12% IC), insect diversity (15% IC)	Maryland										■	■	■			■					
Booth and Reinelt	1993	549-550	channel morphology, fish and amphibian populations, vegetation succession, and water chemistry	western Washington										■										
Shaver et al.	1995	451	aquatic macroinvertes	Delaware								■	■	■	■	■	■	■	■					
Maxted and Shaver	1997	500	aquatic invertebrate community	Delaware										■	■	■	■	■	■					
Booth and Jackson	1997	1084	channel stability, bankfull discharge	western Washington										■										
Wang et al.	1997	9	fish community quality	Wisconsin										■	■	■	■	■	■	■	■	■	■	■
Horner et al.	1997	267	aquatic invertebrate diversity, amphibian richness, aquatic plant species richness, woody debris, dissolved oxygen, zinc	Washington					■	■	■	■												
May	1997	86	riparian buffer, woody debris, streamback erosion, salmoniod community, benthic macroinvertebrates	Washington					■	■	■	■	■	■										
Yoder et al.	1999	20	aquatic invertebrate diversity, sensitive fish species	Ohio								■												
Wang et al.	2001	264	fish community quality and baseflow	southeastern Wisconsin								■	■	■	■	■								
Beach	2001	10-11	fish diversity	coastal streams										■										
Stepenuck et al.	2002	1044	aquatic invertebrate community structure	Wisconsin								■	■	■	■	■								
Morse et al.	2003	120-121	aquatic invertebrate community structure	Maine						■														
Bowles et al.	2006	113, 117-118	Jollyville Plateau salamander density and conductivity	Austin										■										
Olivera and DeFee	2007	178-179	stormwater flow and depth	North of Houston, Texas										■										
Conway	2007	312-313	pH, conductivity	New Jersey		■	■	■	■															
Stranko et al.	2008	1227	brook trout abundance	Maryland				■																
Randhir and Ekness	2009	93	amphibian species richness	Massachusetts												■	■							
Utz et al.	2009	562-563	aquatic invertebrate richness	east and southeast USA		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
King and Baker	2010	1002	aquatic invertebrate community + individual taxa	Maryland	■																			
Hilderbrand et al.	2010	1013	aquatic invertebrate taxa	Maryland					■	■	■	■	■	■										
King et al.	2011	1664	aquatic invertebrate taxa	Maryland	■	■																		

detrimental effects to water quality and biological communities within streams (Schueler *et al.* 2009, pp. 312-313; Coles *et al.* 2012, p. 65). An impervious cover model generated using data from relevant literature by Schueler *et al.* (2009, p. 313) indicates that stream degradation generally increases as impervious cover increases, and occurs at impervious cover of 5 to 10 percent. This model predicts streams transition from an "impacted" status (clear signs of declining stream health) to a "nonsupporting" status (no longer support their designated uses in terms of hydrology, channel stability, habitat, water quality, or biological diversity) at impervious cover levels from 20 to 25 percent. However, a recent national-scale investigation of the effects of urban development on stream ecosystems revealed that degradation of invertebrate communities can begin at the earliest levels of urban development (Coles *et al.* 2012, p. 64), thereby contradicting the resistance thresholds described by Schueler (1994, pp. 100-102). Therefore, the lack of a resistance threshold in biological responses indicates that no assumptions can be made with regard to a "safe zone" of impervious cover less than 10 percent (Coles *et al.* 2012, p. 64). In light of these studies, we created the following impervious cover categories:

- None: 0 percent impervious cover in the watershed
- Low: >0 to 10 percent impervious cover in the watershed
- Medium: >10 to 20 percent impervious cover in the watershed
- High: Greater than 20 percent impervious cover in the watershed

Sites in the Low category may be experiencing impacts from urbanization, as cited in studies such as Coles *et al.* (2012, p. 64), King *et al.* (2011, p. 1664), and King and Baker (2010, p. 1002). In accordance with the findings of Bowles *et al.* (2006, pp. 113, 117-118), sites in the Medium category are likely experiencing impacts from urbanization that are negatively impacting salamander densities. Sites in the High category are so degraded that habitat recovery will either be impossible or very difficult (Schueler *et al.* 2009, pp. 310, 313).

<u>SWCA Analysis</u>

We received data from an impervious cover analysis conducted by SWCA Environmental Consultants for Williamson County, Texas (SWCA 2012). This impervious cover analysis was conducted on watersheds for 9 Jollyville Plateau salamander sites, 11 Georgetown salamander sites, and 1 Salado salamander site. Although these watersheds are similar to the watersheds that we delineated, there are some differences in the total number of acres analyzed per watershed due to different methods of delineation. For example, while our analysis delineated watersheds based upon the point 164 ft (50 m) downstream from a salamander site, SWCA delineated watersheds based upon the salamander site (spring opening) itself.

For a base set of data, SWCA obtained images from 2010 from the Texas Natural Resource Information System (TNRIS) website (http://www.tnris.org/get-data?quicktabs_maps_data=1). To process the images and perform classification, ESRI's ArcInfo 10 was used. Image classification was performed using to two different methods, namely Iso Cluster Unsupervised Classification and Interactive Supervised Classification. The best method of classification was determined through trial and error for each image set and used the best end result which approximated impervious ground cover. SWCA also incorporated the

Strategic Mapping Program's (StratMap) file of Texas road centerlines into the final result to correct for shadows cast by tree cover in the images. More details on the methods of this analysis are presented in SWCA's final report (2012, p. 29-30).

We compared maps of SWCA analysis with maps of our analysis and noted visual differences in watersheds and estimated impervious cover within the watersheds. In one case, we could not match a SWCA site (Tributary 7) with any known Jollyville Plateau salamander sites in our database, so this site was not comparable. We also compared our maps to 2010 aerial photos to determine if differences between our data and SWCA's data could be explained by recent development not captured in our 2006 dataset.

<u>COA Analysis</u>

To compare our impervious analysis to COA, we provided them our delineated watersheds for the Jollyville Plateau salamander, which they used to cut out the overlapping parts of their impervious cover data layer. They then provided us with their calculation of impervious cover for each watershed. Because we received new locations for the Jollyville Plateau salamander after we received the impervious cover calculations from COA, there are several spring sites for which we do not have COA data. COA's impervious cover data layer was derived from three sources:

1) Impervious Cover Planimetrics: Building and transportation footprints were digitized using aerial imagery. This planimetric data (generated by a consultant) is from 2006 and only available within the COA limits. It excludes sidewalks and residential driveways.
2) Sidewalk and Driveway Assumptions: COA added a factor to the planimetrics to account for the missing sidewalks and driveways. This is based on GIS analysis of single-family residential areas.
3) Land Use Assumptions: For areas where planimetrics are not available (that is, outside City jurisdiction), COA relied on impervious cover assumptions based on different types of land use (also 2006 data).

Land use impervious cover assumptions are used when direct measurements of impervious cover are not available. Assumptions were based on the COA 2006 land use and planimetric data. Land use assignments (for example, single family and multi-family residential, commercial, office, or civic) were made using tax parcels from county appraisal district information. In contrast, planimetric data collected by a consultant for the COA provide a direct measure of impervious cover and consist of building footprints, roads, parking lots, and other features of the built environment.

Parcels representing each land use and their planimetric data were analyzed using common statistical measures to develop the impervious cover assumptions. Measures included the mean, standard deviation, standard error, and confidence intervals. These statistical measures were used when all parcels representing a specific land use could be analyzed. If all parcels within a land use category could not be analyzed, COA used statistics from a set of randomly selected parcels representing that use and applied those sample statistics to the unanalyzed parcels.

Sidewalks and driveways can add significantly to total impervious cover; however, planimetric data collection methods do not account for them on smaller parcels. Direct sidewalk and driveway measurements were made to a set of randomly selected one-half acre or smaller, single-family parcels (LU Code = 120 or 130). These single-family, sub-classes were chosen because of their large size (in total number and area) compared to other land use classes. As before, the mean, standard deviation, standard error, and confidence intervals were calculated.

Maps of COA's data were not available to visually compare to our data (COA provided us with acres of impervious cover only). Because both our set of data and COA's set of data were based on 2006 data, we could not reliably attribute differences in impervious cover percentages to new development. It should be noted that all three analyses are estimations of impervious cover and do not reflect an exact accounting of every impervious surface within the watersheds.

Results

Our estimated impervious cover percentages for each watershed analyzed are presented in Table 2. A total of 114 watersheds were analyzed, encompassing a total of 543,269 acres (ac) (219,854 hectares (ha)). A map of each individual watershed is located in Appendix B.

Table 2: Estimated impervious cover percentages by watershed from our analysis. Omitted cave locations are shown in gray. Summary statistics for each salamander species are presented in blue. Impervious cover percentages were shaded a color based on the following impervious cover categories: High=red, Medium=orange, Low=yellow, and None=green. The sums of acres and hectares analyzed do not add up to the species total because some watersheds overlapped with each other.

Watershed	Acres Analyzed	Hectares Analyzed	Percent Impervious
Austin blind salamander	76,616	31,005	
Parthenia (Main) Spring	76,597	30,998	3.37
Eliza Spring	76,615	31,005	3.37
Sunken Garden (Old Mill) Spring	2	1	2.86
Georgetown salamander	275,069	111,317	
Avant's (Capitol Aggregates) Spring	8,993	3,639	0.70
Bat Well			
Buford Hollow Springs	417	169	0.16

Watershed	Acres Analyzed	Hectares Analyzed	Percent Impervious
Cedar Breaks Hiking Trail Spring	207	84	0.16
Cedar Hollow Spring	121	49	0.08
Cobbs Springs	535	216	0.01
Cobbs Well			
Cowan Creek Spring	6,660	2,695	0.92
Knight (Crockett Garden) Spring	7	3	0.00
San Gabriel Spring	258,017	104,416	0.78
Shadow Canyon Spring	25	10	0.74
Swinbank Spring	9	4	6.90
Twin Spring	78	32	3.45
Walnut Spring	1	0	0.00
Water Tank Cave			
Jollyville Plateau salamander	104,731	42,383	
1	1,736	703	7.14
2	1,659	671	7.48
3, Lanier Spring	1,604	649	7.73
4	1,688	683	7.35
5	648	262	9.45
6	243	98	15.99
9	215	87	20.27
10	235	95	18.50
12	293	119	14.84
13	411	166	10.58
14, Lower Ribelin	520	210	8.37
15	17	7	0.00
16	15	6	0.00
17	788	319	19.16
20	11	5	0.28
21	188	76	26.93
22	31	13	40.60
24	74	30	4.95
25	467	189	0.00
Audubon Spring	23	9	0.00
Avery Deer Spring	246	100	17.66
Avery Springhouse Spring	24	10	45.60
Baker Spring	79	32	0.41

Watershed	Acres Analyzed	Hectares Analyzed	Percent Impervious
Balcones District Park Spring	2,256	913	33.50
Barrow Hollow Spring	183	74	12.19
Barrow Preserve Tributary	124	50	10.76
Blizzard 2, Blizzard 3	6	3	0.00
Blizzard (R-Bar-B) Spring	1,538	622	10.36
Bluewater Cave No. 1			
Bluewater Cave No. 2			
Broken Bridge Spring	270	109	22.87
Brushy Creek Spring	49,784	20,147	14.00
Bull Creek at Lanier Tract	660	267	6.59
Bull Creek Spring Pool	1,743	705	7.12
Bull Creek Tributary 5 (2), Bull Creek Tributary 5 (3)	773	313	19.23
Buttercup Creek Cave			
Canyon Creek, Bull Creek Tributary 6 (3)	1,186	480	20.11
Canyon Creek Hog Wallow Spring	726	294	8.43
Canyon Creek Pope and Hiers	851	344	19.67
Cistern (Pipe) Spring	3	1	0.00
Concordia Spring X	17	7	13.53
Concordia Spring Y	322	130	12.89
Downstream of Small Sylvia Spring 1	1,369	554	21.88
Downstream of Small Sylvia Spring 2	1,364	552	21.94
Fern Gully	151	61	26.93
Flea Cave			
Franklin, Franklin Tract 3	1,829	740	6.78
Franklin Tract 2	1,832	742	6.77
Gardens of Bull Creek	2,099	849	18.76
Gaas Spring	24	10	0.15
Godzilla Cave			
Hamilton Reserve West	554	224	14.55
Hearth Spring	719	291	22.58
Hideaway Cave			
Hill Marsh Spring	146	59	10.21
Horsethief, 18	7	3	0.00
House Spring	93	38	25.96
Ilex Cave			
Indian Spring	111	45	11.13

Watershed	Acres Analyzed	Hectares Analyzed	Percent Impervious
Ivanhoe Spring 2	11	5	0.00
Kelly Hollow Springs	254	103	23.23
Kretschmarr Salamander Cave			
Krienke Spring	3,235	1,309	8.74
Lanier 90-foot Riffle	814	329	9.89
Little Stillhouse Hollow Spring	26	11	20.46
Long Hog Hollow Trib. Below Fireoak Spring	191	77	24.78
MacDonald Well	535	217	7.82
Moss Gully Spring	26	11	0.00
PC Spring	1,630	660	11.68
Pit Spring	1,823	738	6.80
Ribelin Spring	12	5	0.00
Ribelin 2	416	168	10.46
Ribelin / Lanier	578	234	7.53
Salamander Squeeze Cave			
SAS Canyon	68	28	11.64
Schlumberger Spring #1, 19	58	24	27.03
Schlumberger Spring #2	86	35	19.82
Sierra Spring	347	140	19.96
Small Sylvia Spring	1,241	502	22.09
Spicewood Spring (USGS), Spicewood Tributary	377	152	30.75
Spicewood Park Dam	259	105	17.96
Spicewood Valley Park Spring, Sylvia Spring Area 4	855	346	21.03
Stillhouse Hollow	44	18	25.20
Stillhouse Hollow Spring	9	4	11.26
Stillhouse Hollow Tributary	67	27	19.83
Stillhouse Tributary	63	25	20.96
Sylvia Spring Area 2, Sylvia Spring Area 3	839	340	20.83
Tanglewood 2	64	26	32.05
Tanglewood Spring, Tanglewood 3	141	57	30.03
Testudo Tube			
Three Hole Spring	645	261	9.49
Treehouse Cave			

Watershed	Acres Analyzed	Hectares Analyzed	Percent Impervious
Tributary Downstream of Grandview	101	41	7.89
Tributary No. 3	640	259	21.34
Tributary 4 shaft - upstream	1,445	585	21.75
Tributary 4 shaft - downstream	1,595	646	21.11
Tributary No. 5	794	321	19.00
Tributary No. 6, Bull Creek Tributary 6 (2)	1,190	482	20.04
Tributary 6 at Sewage Line	1,178	477	20.22
Troll Spring	129	52	48.29
Tubb Spring	9	4	28.55
TWASA Cave			
Two Hole Cave			
Upper Ribelin	284	115	15.34
Wheless 2	283	115	0.00
Wheless Springs	411	166	0.00
Whitewater Cave			
Salado salamander	86,853	35,148	
Big Boiling Spring, Lil' Bubbly Spring	86,681	35,079	0.41
Cistern Spring	4,480	1,813	0.04
Lazy Days Fish Farm (Critchfield Spring)	172	69	6.42
Hog Hollow Spring	89	36	0.00
Robertson Spring	86,500	35,005	0.38
Solana Spring	67	27	0.01

The Austin blind salamander had three watersheds delineated, one for each of the springs where the species is found. Eliza and Parthenia Springs had nearly identical large surface drainage areas, while the watershed of Sunken Garden (Old Mill) was found to be a much smaller area to the south (Figure 1). While the level of impervious cover was Low in Eliza and Parthenia watersheds, most of the impervious cover occurs within five miles (eight kilometers) of the springs (Figure 1). The recharge and contributing zones for the Barton Springs segment of the Edwards Aquifer had low amounts of impervious cover (6.88 and 1.81 percent, respectively).

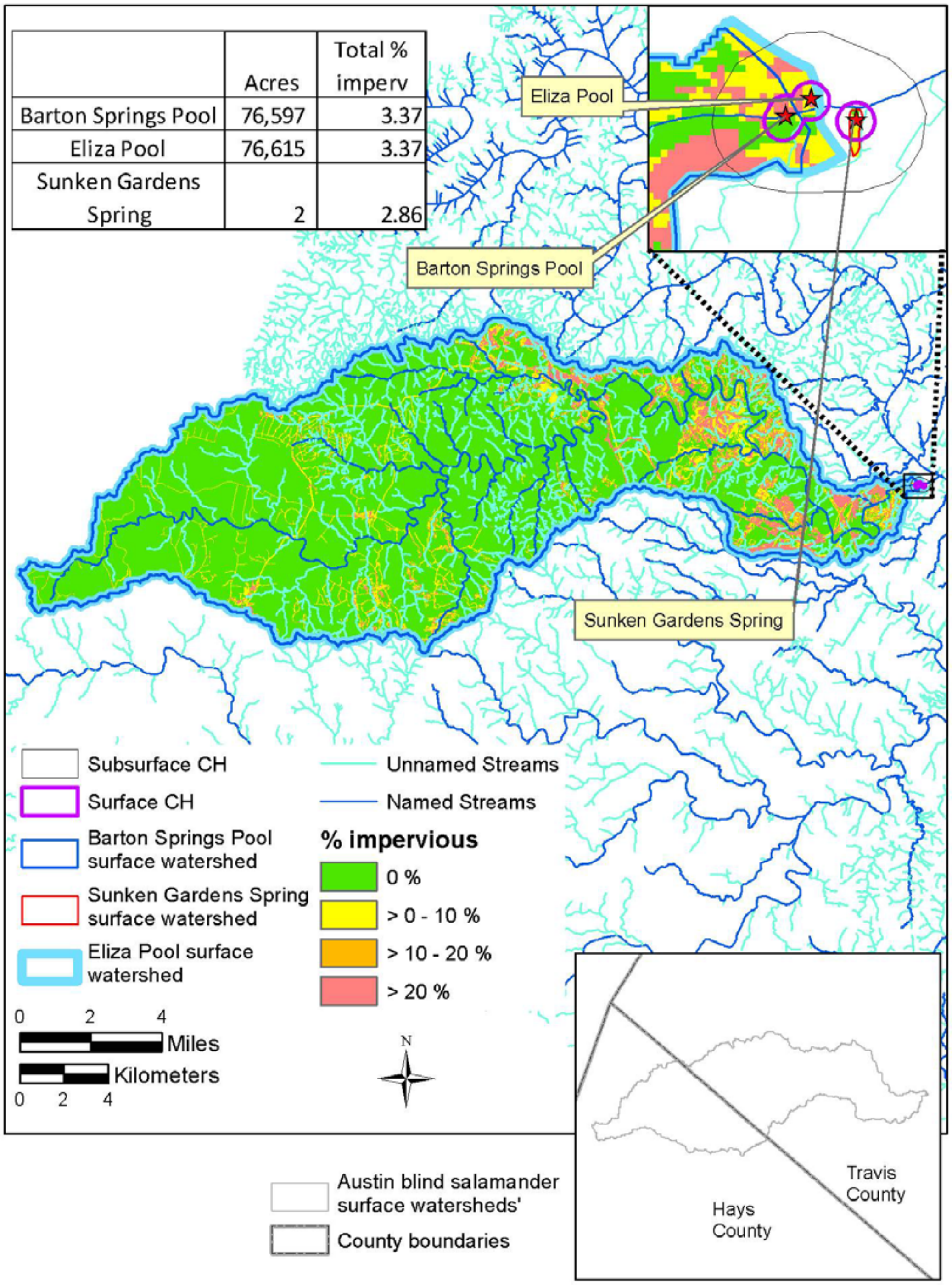


Figure 1: Austin blind salamander watersheds with impervious cover.

For the Georgetown salamander, a total of 12 watersheds were delineated, representing 12 spring sites. The watersheds varied greatly in size, ranging from the 1 ac (0.4 ha) watershed of Walnut Spring to the 258,017 ac (104,416 ha) watershed of San Gabriel Spring. The impervious cover within each watershed had generally lower variation, and most watersheds (10 out of 12) were categorized as Low. Two watersheds had no impervious cover (Knight Spring and Walnut Spring) and Swinbank Spring had the highest amount of impervious cover at 6.9 percent. The largest watershed, San Gabriel Spring, had a low proportion of impervious cover overall. However, Figure 2 reveals that most of the impervious cover is in the area immediately surrounding the spring site.

For the Jollyville Plateau salamander, a total of 93 watersheds were delineated, representing 106 spring sites. The watersheds varied greatly in size, ranging from the 3 ac (1 ha) watershed of Cistern (Pipe) Spring to 49,784 ac (20,147 ha) watershed of Brushy Creek Spring. Impervious cover also varied greatly among watersheds. Twelve watersheds had no impervious cover. Eighty-one of the 93 watersheds had some level of impervious cover, with 31 watersheds categorized as High, 26 as Medium, and 21 as Low. The highest level of impervious cover (48 percent) was found in the watershed of Troll Spring.

The Salado salamander had a total of six watersheds delineated, representing seven different spring sites. The watersheds ranged in size from the 67 ac (27 ha) watershed of Solana Spring to 86,681 ac (35,079 ha) watershed of Big Boiling and Lil' Bubbly Springs. Five of the six watersheds were categorized as Low, and the watershed of Hog Hollow had no impervious cover. Although the largest watershed (Big Boiling and Lil' Bubbly Springs) has a low amount of impervious cover (0.41 percent), almost all of that impervious cover is located within the Village of Salado surrounding the spring site (Figure 3).

<u>Comparison to SWCA Analysis</u>

A comparison of SWCA, COA, and our data is presented in Appendix C. This table contains the amount of area analyzed (in acres and hectares), the amount of that analyzed area that was categorized as impervious (in acres and hectares), and the percentage of impervious cover for all of the watersheds. The majority of SWCA watersheds were similar in size and shape to the watersheds that we delineated. The remaining SWCA watersheds differed from ours mostly due to our decision to start the delineation 164 ft (50 m) downstream of the site, whereas SWCA started delineation at the site itself. Nonetheless, these watersheds were generally close enough to our own to facilitate comparison in impervious cover data. However, there were two watersheds that were not comparable in terms of impervious cover because SWCA's watersheds were very different from our own (Walnut Spring and Baker Spring).

Impervious cover percentage of each watershed often differed a great deal between our data and SWCA data. Except for one watershed (Audubon Spring), SWCA's percentages were always higher than our own. On 16 occasions, SWCA's percentages were placed in one or two higher impervious cover categories than percentages from our analysis. Of the 11 Georgetown salamander watersheds SWCA analyzed, 2 were categorized as High, 2 were Medium, and 7 were Low. Of the 19 Jollyville Plateau salamander watersheds analyzed by SWCA, 12 watersheds were categorized as High, 4 were Medium, 2 were Low, and one was None. By examining 2010 aerial photos in ArcGIS, we were able to attribute some of this increase in impervious cover to recent development that our 2006-based analysis did not consider. For

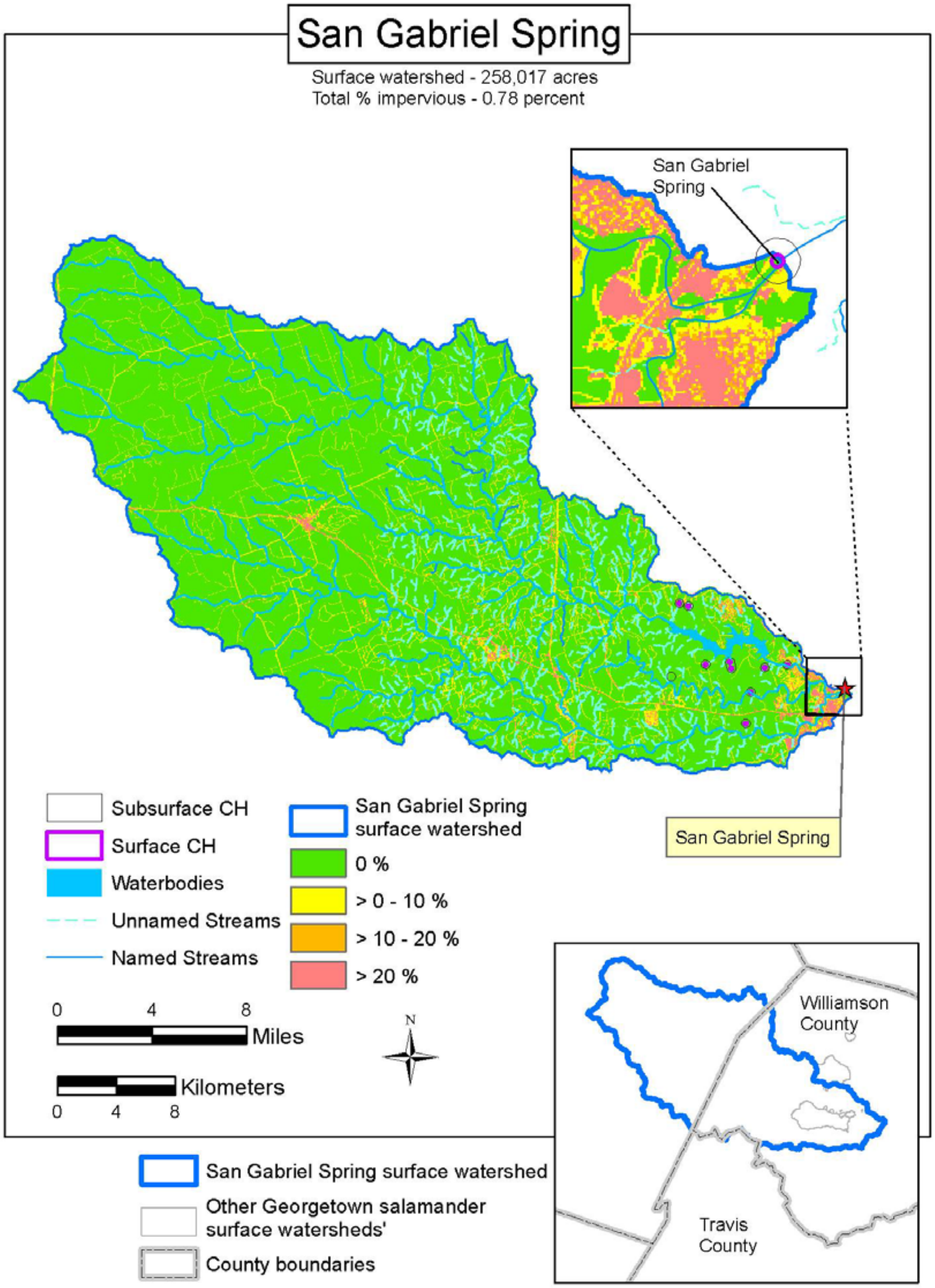
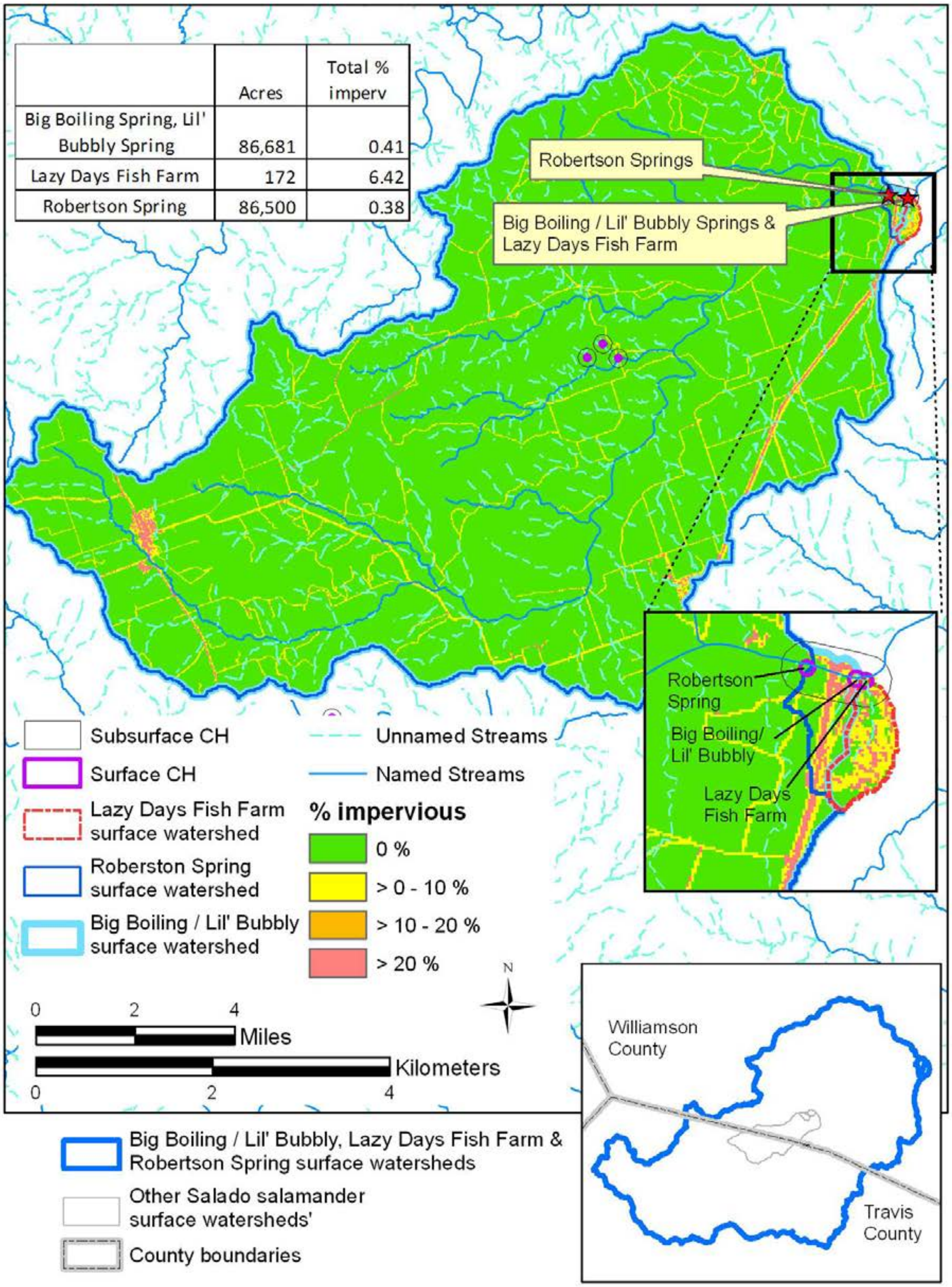


Figure 2: San Gabriel Spring watershed with impervious cover



	Acres	Total % imperv
Big Boiling Spring, Lil' Bubbly Spring	86,681	0.41
Lazy Days Fish Farm	172	6.42
Robertson Spring	86,500	0.38

Figure 3: Big Boiling and Lil' Bubbly Springs watershed with impervious cover

example, in the Buford Hollow watershed, we saw a road and part of a quarry in the 2010 aerial photo and the SWCA data layer that was not present in our impervious cover data layer. We measured the area of the road and the quarry and concluded that these features explained about 28 ac (11 ha) of the 37.9 ac (16 ha) difference in impervious area between our data and SWCA's data. Other watersheds that had unaccounted for development include Avant Spring, Cedar Breaks Hiking Trail Spring, Cedar Hollow Spring, Cowan Creek Spring, 3/Lanier Spring, 14/Lower Ribelin, PC Spring, Tributary No. 5, and Upper Ribelin.

Recent development did not explain all of the difference in impervious area between the two datasets. Besides slight differences in watersheds, we attributed the remainder of the impervious area difference to differences in our analysis methods. For example, the impervious cover data that we used attempted to estimate impervious cover in 98 ft (30 m) pixels of land, whereas SWCA's analysis was able to more finely categorize features as impervious using vector data. We noticed that our analysis tended to underestimate the amount of impervious cover compared to SWCA due to this difference in methodology, especially in small watersheds. Upon examination of aerial photos and SWCA impervious cover maps, we also noticed that the SWCA analysis tended to categorize land features such as bare ground, dirt roads, and dry stream beds as impervious where our analysis did not. This was particularly apparent in the watershed of Big Boiling and Lil' Bubbly Springs. As these features are typically not considered 100 percent impervious, we concluded that SWCA's figures tend to overestimate the amount of impervious cover in a watershed.

<u>Comparison to COA Analysis</u>

Because we provided COA with our watersheds, almost all of COA's watersheds have the same size and shape as our own. However, after COA provided us with their impervious cover analysis of our delineated watersheds, we incorporated new Jollyville Plateau salamander sites based on new information and subsequently modified one watershed (Tanglewood Spring/Tanglewood 3). We also added 12 watersheds that COA did not analyze.

COA's impervious cover percentage of each watershed was generally closer to our percentages than SWCA's. COA's percentages were generally higher than our own, and 14 watersheds were placed in a higher impervious cover category than percentages from our analysis. There were 10 watersheds where our percentages were higher, and only one was placed in a lower category as a result of this percentage difference (Blizzard Spring). Because we did not have maps of COA's impervious cover, we could not attribute differences in impervious cover to development that our data did not capture. Because our dataset and COA's dataset were both from 2006, we did not attribute differences to additional development built over time. Overall, COA analyzed 81 watersheds. 35 watersheds were categorized as High, 22 were Medium, 16 were Low, and 8 were None.

Discussion

Based on our analysis of impervious cover levels in land draining across the surface into salamander habitat (Table 2), the Jollyville Plateau salamander had the highest proportion of watersheds with Medium and High levels of impervious cover. Conversely, the watersheds encompassing Austin blind, Georgetown, and Salado salamander habitat were relatively low in impervious cover. No watersheds for Austin blind, Georgetown, and Salado salamanders were classified as Medium or High (that is, greater than 10 percent). Most watersheds for all four species had some level of impervious cover—only 15 of the 114 watersheds had none. In addition, the recharge and contributing zones of the Barton Springs segment of the Edwards Aquifer were classified as Low. Therefore, most spring sites for all four species may be experiencing impacts from urbanization. The analyses completed by SWCA and COA confirmed our results and broadly followed this species-level pattern, although impervious cover percentages at individual sites were generally higher than our own (Appendix C).

Although Table 2 and Appendix C are helpful in determining the general level of impervious cover within watersheds, it does not tell the complete story of how urbanization may be affecting salamanders or their habitat. Understanding how a salamander might be affected by water quality degradation within its habitat requires an examination of where the impervious cover occurs and what other threats to water quality (for example, non-point source runoff, highways and other sources of hazardous materials, livestock and feral hogs, and gravel and limestone mining) are present within the watershed. For example, San Gabriel Spring's watershed (a Georgetown salamander site) has an impervious cover of only 1.2 percent (Table 2), but the salamander site is in the middle of a highly urbanized area: the City of Georgetown (Figure 2). The habitat is in poor condition and Georgetown salamanders have not been observed here since 1991 (Chippindale *et al.* 2000, p. 40; Pierce 2011b, pers. comm.).

Other studies have demonstrated that the spatial arrangement of impervious cover has impacts on aquatic ecosystems. An analysis of 42 watersheds in Washington found that the spatial configuration of impervious cover is important in predicting aquatic macroinvertebrate communities (Alberti *et al.* 2007, pp. 355-359). King *et al.* (2005, p. 146-147) found that the closer developed land was to a stream in the Chesapeake Bay watershed, the larger the effect it had on stream macroinvertebrates. On a national scale, watersheds with development clustered in one large area (versus being interspersed throughout the watershed) and development located closer to streams had a higher frequency of high-flow events (Steuer *et al.* 2010, p. 47-48, 52). Based on these studies, it is likely that the way development is situated in the landscape of a watershed of a salamander spring site plays a large role in how that development impacts salamander habitat. Taking into account the spatial configuration of impervious cover within a watershed is a crucial step in future analyses of these salamander sites.

Although most of the watersheds were classified as Low, it is important to note that low levels of impervious cover (that is, less than 10 percent) may degrade salamander habitat. Recent studies in the eastern U.S. have reported large declines in aquatic macroinvertebrates (the prey base of salamanders) at impervious cover levels as low as 0.5 percent (King and Baker 2010, p. 1002; King *et al.* 2011, p. 1664). Several authors have argued that impervious cover has a mostly linear effect on aquatic habitat; that is, negative effects to stream ecosystems are seen at low levels of impervious cover and gradually increase as impervious cover increases (Booth *et al.* 2002, p. 838; Groffman *et al.* 2006, pp. 5-6; Schueler *et al.* 2009, p. 313; Coles *et al.* 2012, pp. 4, 64).

Because we used the 2006 National Land Cover Dataset to calculate impervious cover, impervious cover values within the watersheds of the four salamander species may be higher at the time of this report than those reported here. Between 2006 and 2009, the human population in Travis County increased from 928,037 (Texas State Data Center 2006, p. 6), to 1,012,789 (Texas State Data Center 2009, p. 7), representing an increase of 9.1 percent. Williamson County population increased from 349,982 in 2006 (Texas State Data Center 2006, p. 7) to 408,128 in 2009, a 16.6 percent increase (Texas State Data Center 2009, p. 8). Bell County population increased from 269,073 in 2006 (Texas State Data Center 2006, p. 1) to 284,408 in 2009, a 5.7 percent increase (Texas State Data Center 2009, p. 1). Development in the area likely also increased to accommodate the growth in these areas. At the time of this report, the Texas State Data Center only has annual population estimates up to 2009. We saw evidence of impervious cover growth within the watersheds by comparing our data to SWCA's data, which was based on 2010 aerial photography. SWCA also examined impervious cover changes from 1996 to 2010 and found increases in 11 of the 12 Georgetown salamander sites (SWCA 2012, p. 31). Future analyses should attempt to use more current impervious cover estimates and compare them to the values presented in this analysis to understand how threats to the salamander species are changing over time.

One major limitation of this analysis is that we only examined surface drainage areas (watersheds) for each spring site for the Georgetown, Jollyville, and Salado salamanders. In addition to the surface habitat, these three salamanders use the subsurface habitat. Moreover, the base flow of water discharging from the springs on the surface comes from groundwater sources, which are in turn replenished by recharge features on the surface. As Shade *et al.* (2008, p. 3-4) point out ". . . little is known of how water recharges and flows through the subsurface in the Northern Segment of the Edwards Aquifer. Groundwater flow in karst is often not controlled by surface topography and crosses beneath surface water drainage boundaries, so the sources and movements of groundwater to springs and caves inhabited by the Jollyville Plateau salamander are poorly understood. Such information is critical to evaluating the degree to which Jollyville Plateau salamander sites can be protected from urbanization." So, a recharge area for a spring may occur within the surface watershed, or it could occur many miles away in a completely different watershed. A site completely surrounded by development may still contain unexpectedly high water quality because that spring's base flow is coming from a distant recharge area that is free from impervious cover stressors. While some dye tracer work has been done in the Northern Segment (Shade *et al.* 2008, p. 4), clearly-delineated recharge areas that flow to specific springs in the Northern Segment have not been identified for any of these spring sites; therefore, we could not examine impervious cover levels on recharge areas to better understand how development in those areas may impact salamander habitat.

Another limitation of this analysis is that we did not account for riparian (stream edge) buffers or stormwater runoff control measures, both of which have the potential to mitigate some of the effects of impervious cover on streams. Research studies consistently demonstrate that streams with higher levels of riparian vegetation have higher habitat and biological scores (Schueler *et al.* 2009, pp. 312-313). Vegetated riparian areas are effective at buffering streams against the detrimental effects of impervious cover at lower levels, but this buffering quality tends to decrease in effectiveness when impervious cover levels rise above 10 to 15 percent (Schueler *et al.* 2009, p. 313).

In contrast, the effectiveness of stormwater runoff control measures, such as passive filtering systems, is largely unknown in terms of mitigating the effects of watershed-scale urbanization (O'Driscoll *et al.* 2010, p. 614, 616-617; Schueler *et al.* 2009, p. 313). In a survey and information gathering workshop of more than 100 stream ecologists (Wenger *et al.* 2009, p. 1083-1085), key unanswered research questions were formulated, including the following two questions:

> 1) Can retrofitted, dispersed stormwater treatment measures in existing urban areas mimic some of the important ecological and hydrological processes previously performed by headwater streams?
> 2) Which management actions are likely to achieve improved ecological condition under different levels of impervious cover and different current stream conditions?

Schueler *et al.* (2009, p. 313) notes that the Center for Watershed Protection's impervious cover model has been tested in areas where some degree of stormwater regulation has existed for several decades. Booth *et al.* (2002, pp. 835-836) also point out that a focus on the conservation of aquatic species has highlighted ineffectual stormwater mitigation efforts around the country.

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