Jollyville Plateau Salamander Monitoring Report 2008

Nathan Bendik
Watershed Protection & Development Review Department
City of Austin
SR-09-09. January 2009

Direct count data for Eurycea tonkawae, *the Jollyville Plateau Salamander, were evaluated for the years 1996-2008. Previous analyses solely addressed population trends in terms of direct linear relationships through time. Here the same data is evaluated (with the addition of 2008) using methods commonly referred to as population viability analysis (PVA) and the survey results for 2008 are summarized. Additionally, new impervious cover estimates were calculated for each monitoring site's drainage basin for 2006, 2003, and 1997 based on building and transportation footprints. Three populations at urban sites are identified as under the most threat of extirpation, as their population numbers are very low with a trend of decreasing population size. These sites, Trib 5, Trib 3, and Spicewood Springs, all exhibit high or greatly increasing influence of impervious cover in each respective watershed basin. Future directions for the salamander monitoring plan are also discussed.*

INTRODUCTION

The goals of this project, as outlined in the associated Quality Assurance Program Plan (QAPP), are to: (1) assess long-term trends of Jollyville Plateau Salamander populations; (2) document the species distribution and identify its range of habitat; (3) identify what management activities can be accomplished and (4) what we can expect to gain from those activities to improve the status of *E. tonkawae* populations in the City of Austin. The primary focus of this report is to address item (1) and briefly discuss its implications for (3) and (4).

This project originated with a monitoring program started in 1996 that intensively surveyed *E. tonkawae* populations at nine sites for two consecutive years (Davis et al. 2001; Bowles et al. 2006). Since then several modifications to the project have been implemented, including the addition of new monitoring sites, a change in survey frequency (from monthly to quarterly; although some sites less frequently), and the elimination of water chemistry sampling.

Previous reports summarizing available count data have examined salamander population trends via linear relationships through time (O'Donnell et al. 2005; O'Donnell et al. 2006). While this is a commonly used analysis, other methods (under the general umbrella of a suite of methods known as population viability analyses, or PVA's) are available that use count data to evaluate the status of a population in terms of its risk of extinction. Here the direct count data is analyzed for seven monitoring sites from 1996-2008 using a simple count-based PVA density-independent model following Morris and Doak (2002; pp 51-97) and the advantages and disadvantages of this method are evaluated.

In addition to PVA analysis of all monitoring data, survey results for 2008 are summarized and briefly discussed. New land-use maps were also generated for each sample site basin, and impervious cover was estimated using the Travis County Appraisal District's building and transportation planimetrics.

METHODS

Surveys and Water Quality

Surveys for 2008 were conducted quarterly at 12 sites (with some exceptions- see Results). Water quality data (pH, DO, temp, and SpC) were collected as well. These data were combined with data from previous years to test whether any trends existed between water quality parameters and salamander counts at each site. More detailed information on surveys and water quality data can be found in previous reports (Davis et al. 2001; O'Donnell et al. 2005; O'Donnell et al. 2006), Water Resources Evaluation standard operating procedures, and the QAPP for this project.

Population Viability Analysis

To prepare for computation of PVA statistics, count surveys were summarized by site and date in SAS 9.1. (SAS Institute Inc. 2002). Raw count data from each site are divided into sections, although the sections surveyed were not always consistent between years. For example, sites in the initial study may have included a section where surveys were discontinued in later years. To achieve more comparable results between years, count data from sections that currently are not surveyed were removed before summing the total salamander counts from each site. A summary of the sections included are listed in Table 1.

Counts by size class (<1", 1-2", >2") were combined to yield a single value for each survey. Once counts were summarized by site and survey date, μ and σ^2 were calculated for two different time frames: whole year and partial-year (March-July). The values of μ (average population growth, or mathematically, the natural logarithm of the geometric mean of the population growth rates) and σ^2 (variance in the natural log of population growth rate caused by environmental stochasticity) "describe the changing probability that the log population size will lie within a given range" (Morris and Doak 2002).

To calculate μ and σ^2, a linear regression is performed for $y_i = x_i$, where t is time, and N is the population size (represented here by the count data):

$$x_i = \sqrt{t_{i+1} - t_i}$$

$$y_i = \ln(N_{i+1} / N_i) / x_i$$

The intercept is forced to zero so that no change in population size can occur if no time has elapsed. The regression slope gives the estimate of μ and the residual mean square is the estimate of σ^2 (Morris and Doak 2002).

Whole and part year count data were averaged to produce a single value each year (μ hat and σ^2 hat). Because these counts represent repeated measures, estimates of σ^2 must be corrected for observation error. Estimates of raw σ^2 are greatly biased upwards as sampling variance increases, leading to pessimistic assessments of population viability if uncorrected (μ hat is a nearly unbiased estimator of true μ). To correct for observation error, the average of the variances as an overall measure of the mean variance in log λ (λ =population growth rate) due to sampling variation was calculated as:

$$\overline{Var(\ln \lambda)} = \frac{1}{q}\sum_{t=1}^{q}\left[\frac{s_t^2}{n_t \overline{N}_t^2} + \frac{s_{t+1}^2}{n_{t+1}\overline{N}_{t+1}^2}\right]$$

Subtracting this variance from the raw estimates of σ^2 yields the corrected σ^2:

$$\sigma_{corr}^2 = \hat{\sigma}^2 - \overline{Var(\ln \lambda)}$$

Unfortunately, when sampling variance is high (as is suspected with this data set), a large number of samples are required to precisely estimate σ^2 (Morris and Doak 2002).

By averaging the counts by year (as opposed to partial year, or even monthly), more surveys can be used to generate a data point for a given year. However, there is potential that increased seasonal variation is introduced by incorporating surveys taken at many different times of the year. Seasonal variation, by definition, is not variation in actual population size, but rather variation in behavior, movement, and other factors that would affect the estimate of population size. Conversely, summarizing the counts for only a portion of the year in the late spring and early summer is more likely to reduce seasonal variation in the counts, however sample sizes are reduced (sometimes to one) thereby increasing the effects of sample variation. The net effect of high sampling variation (even with yearly averaging) is that σ^2_{corr} can be negative or zero. However a PVA cannot be calculated using the methods described above with a value of zero for σ^2_{corr}, so the resulting PVA without corrected σ^2 are considered worst case scenarios because higher σ^2 result in more pessimistic extinction predictions.

Outliers were identified as observations with studentized residuals greater than 2 and Dffits (a statistic that measures the influence each data point has on the regression parameter estimates) greater than $2\sqrt{(1/q)}$. Durbin-Watson statistics were computed to test for the presence of auto-correlation (absence of auto-correlation is an assumption of estimating μ and σ^2). Outliers were detected in six of the seven populations (one each); however, there did not appear to be any pattern or biological explanation for the outliers so they were not removed from the dataset.

These estimates of μ and σ^2 can be used to estimate the probability of extinction within a given time-frame and extinction threshold using a cumulative distribution function,

$$G(T \mid \mu, \sigma^2, d) = \Phi\left(\frac{-d-\mu T}{\sqrt{\sigma^2 T}}\right) + \exp(-2\mu d / \sigma^2)\Phi\left(\frac{-d+\mu T}{\sqrt{\sigma^2 T}}\right)$$
$$\Phi(z) = \frac{1}{2\pi}\int_{-\infty}^{z} \exp(-y^2/2)dy$$

where T is a future time of interest, $d = \log N_c - \log N_e$ (log = natural logarithm; N_c = current population size; N_e = user defined extinction threshold), and $\Phi(z)$ is the standard normal cumulative distribution function with a mean of zero and a variance of one.

The cumulative probability of extinction was calculated for a tmax (time in future of interest) of 50 years, which represents the probability that a population will go extinct at some point during that time span. Population sizes (N_c) used in the calculation were taken from the raw averages of

2008 and adjusted upwards to represent an average capture probability of 0.35 (the average capture probability of all surveys conducted during the 2007 mark-recapture project; O'Donnell et al., 2008). An extinction threshold of N_e=1 was used due to the very low estimated average population sizes at some of the sites. Ideally a larger N_e is used because once population sizes become small, demographic stochasticity begins to have a large effect on the fate of the population (as opposed to environmental stochasticity, an assumption of this PVA). Demographic stochasticity is defined as "temporal variation in population growth driven by chance variation in the actual fates of different individuals within a year, and is strongly depended on population size" (Morris and Doak 2002). This potentially violates the assumption of no demographic stochasticity (μ and σ^2 are assumed to be constant; these parameters will change when individual variation in vital rates have a large influence on the fate of the population).

Impervious Cover

Drainage basins were calculated using a flow direction grid (based on a topographic map) from each sample site location in ArcMap 9.2 (ESRI 2008). This created, for each site, a polygon representing all theoretical upstream areas of surface water influence. It is important to note, however, that this does not necessarily represent or reflect the path of groundwater.

For each basin, impervious cover estimates were calculated from available planimetric layers containing building and transportation footprints obtained from COA GIS resources for the following years: 1997, 2003, and 2006. Because these layers did not contain driveway or sidewalk polygons, an additional 10.97% or 10.44% impervious covers were added to land use codes 120 and 130 (small and medium sized single family homes), respectively.

RESULTS

Surveys

Surveys were conducted quarterly at all sites with the exception of those listed in Table 1a. Average rainfall was approximately 15 inches in the Jollyville Plateau region for the year 2008, less than half of the average annual rainfall in the Austin area. The result of this lack of rain was that many sites were partially or entirely dry through the second half of the year. In fact, the only sites that remained flowing in all survey sections were urban sites that likely are heavily influenced by urban leakage (Balcones District Park and Spicewood Springs).

Table 1a. Monitoring sites and surveys completed in 2008. Quarterly survey periods for 2008 are as follows: **I** Jan-Feb; **II** April-May; **III** July-Aug; **IV** Oct-Nov.

Site Name	Shorthand used in this report	Sample Site Number	Land Use	Sections Surveyed	Quarterly Surveys Conducted
Bull Creek Tributary 6 (BCP Hanks Tract)	Trib 6	151	Urban – recent development	1,2/3,6	all
Bull Creek Franklin on Trib 7 (BCP Franklin Tract)	Franklin	349	Rural (preserve)	2,3,4,7	all
Balcones District Park (Walnut Creek) Spring	BDS	445	Urban- old development	1	all
Bull Creek Tributary 3 (Great Hills CC)	Trib 3	926	Urban – recent development	1-4	**II**
Stillhouse Hollow	Stillhouse	927	Urban- old development	1-5,7-8	all
Tanglewood Spring	Tanglewood	928	Urban- recent development	1-13	all
Barrow Preserve Tributary	Barrow	929	Urban- old development	1-3	all
Spicewood Springs Tributary	Spicewood	930	Urban- old development	1-4	**II,III,IV**
Bull Creek Tributary 5 (BCP Hanks Tract)	Trib 5	1164	Urban – recent development	1,2,4,5,6	**I,II**
Baker Spring (Audubon Preserve)	Baker	3959	Rural (preserve)	1-7	**I,II**
Lower Ribelin	Lower Ribelin	4035	Rural- newly developing	1	**I,II**
Upper Ribelin	Upper Ribelin	4184	Rural- newly developing	1-3	**I,II**

Table 1b. Dry sections (not surveyed) at all surface count monitoring sites during 2008. na= site not visited; dash = no unsurveyed sections due to lack of water; # = the section number of the dry, unsurveyed sections.

Site Name	Sample Site Number	Sections Surveyed	Dry Sections (not surveyed) by quarter			
			I	II	III	IV
Bull Creek Tributary 6 (BCP Hanks Tract)	151	1,2/3,6	-	-	1	1
Bull Creek Franklin on Trib 7 (BCP Franklin Tract)	349	2,3,4,7	-	-	7	7
Balcones District Park (Walnut Creek) Spring	445	1	-	-	-	-
Bull Creek Tributary 3 (Great Hills CC)	926	1-4	na	-	na	na
Stillhouse Hollow	927	1-5,7-8	-	-	1	-
Tanglewood Spring	928	1,4-13	-	-	4-8	4-9
Barrow Preserve Tributary	929	1-3	-	-	1	1
Spicewood Springs Tributary	930	1-4	-	-	-	-
Bull Creek Tributary 5 (BCP Hanks Tract)	1164	1,2,4,5,6	-	-	all	all
Baker Spring (Audubon Preserve)	3959	1-7	-	-	all	all
Lower Ribelin	4035	1	-	-	all	all
Upper Ribelin	4184	1-3	-	-	all	all

Population Viability Analysis

Population viability "growth" estimates (μ) were positive for only two populations (Stillhouse Hollow and Franklin; Figure 1). However, 95 % confidence intervals were very large for all estimates of μ (Table 2), so the possibility of all populations having a negative (or positive, for that matter) growth trend cannot be ruled out. Estimates of σ^2 also have wide confidence limits, and corrected σ^2 values are negative for many sites (Figure 2), indicating high observational error and variation of counts within years. Durbin-Watson test did not reveal any positive autocorrelation of count data (Table 2) for either data treatment.

Cumulative probabilities of extinction within 50 years were very high, approaching 1.0, for all sites except Stillhouse Hollow and Franklin, both of which had moderate probabilities of extinction (Figure 3). These high probabilities of extinction are likely influenced most by extremely low estimated population sizes, as low as 6 in some cases. As with estimates of μ and σ^2, probabilities computed from March-July count data did not exhibit a consistent trend compared to those from entire year data. Cumulative probability of extinction graphs for entire year count data are shown in Figure 4. While confidence intervals (CI) are wide here as well (they depend upon CI for μ and σ^2), some inferences can still be drawn. Spicewood Springs, Trib 3 and Trib 5 exhibit the highest probabilities of extinction, with higher CI than any of the other sites, and upper CI reaching 1.0 within as little as 3-6 years. This is not surprising given the very low numbers of salamanders found at these sites recently, even when adjusted for low capture probability (Figure 3).

Impervious Cover

Land use and impervious cover estimates for each site's drainage basins are shown in Figure 5. Total impervious cover estimates range from less than 1% (Baker Spring, 5a) to 46% (Spicewood Springs, 5d).

Table 2. PVA statistics for seven Jollyville Plateau Salamander monitoring sites calculated from average yearly counts for whole year and partial (March-July) year data. DW is the Durbin-Watson statistic and ProbDW is the probability of auto-correlation of μ among years. *na= not calculated.

Entire Year

Site	Observations	μ	StdErr	μ LowerCL	μ UpperCL	σ^2	σ^2 LowerCL	σ^2 UpperCL	σ^2_{corr}	DW	ProbDW
Trib 6	12	-0.128	0.177	-0.521	0.266	0.374	0.187863	1.0792	0.069	2.882	0.946
Franklin	13	0.022	0.165	-0.342	0.385	0.327	0.168029	0.89042	-0.051	2.216	0.651
Trib 3	7	-0.253	0.234	-0.855	0.348	0.602	0.250126	2.9209	-0.007	3.532	0.997
Stillhouse	12	0.084	0.186	-0.330	0.498	0.414	0.207961	1.19466	0.235	1.649	0.272
Tanglewood	7	-0.029	0.108	-0.306	0.248	0.139	0.057893	0.67606	-0.238	1.766	0.412
Spicewood	9	-0.092	0.278	-0.749	0.566	0.927	0.423083	3.40343	0.408	1.208	0.110
Trib 5	11	-0.215	0.210	-0.690	0.260	0.485	0.236828	1.49401	0.192	1.651	0.282

Mar-July

Site	Observations	μ	StdErr	μ LowerCL	μ UpperCL	σ^2	σ^2 LowerCL	σ^2 UpperCL	σ^2_{corr}	DW	ProbDW
Trib 6	11	-0.148	0.146	-0.479	0.184	0.236	0.115177	0.72658	-0.208	2.799	0.916
Franklin	10	0.006	0.224	-0.510	0.521	0.550	0.260252	1.83334	0.405	2.795	0.908
Trib 3	6	-0.286	0.149	-0.699	0.127	0.243	0.094861	1.46449	-0.252	2.162	0.645
Stillhouse	9	0.174	0.205	-0.310	0.658	0.461	0.210227	1.69114	0.322	1.994	0.507
Tanglewood	6	-0.100	0.069	-0.291	0.091	0.052	0.020281	0.3131	-0.365	2.060	0.591
Spicewood	7	-0.218	0.232	-0.815	0.379	0.594	0.246447	2.87794	na	2.594	0.808
Trib 5	11	-0.233	0.342	-1.007	0.541	1.287	0.628389	3.96412	1.139	3.305	0.993

DISCUSSION

Population Viability Analysis

Wide confidence intervals for PVA statistics suggest that there is a large source of variation in the count data that is not attributable to real population dynamics. It is clear that these data have a large amount of observational error because σ^2 corrected values are negative in several instances (Table 2). This is a reflection of the high amount of within-year variation in surface counts, likely due to a combination of several factors. Within-year variation in migration from the surface to the subsurface, and vice-versa, likely play a large role in this apparent fluctuation of population size. This may occur because of variation in spring flow, seasonality, or biological factors such as reproduction (which is poorly understood). In addition, other unknown or unpredictable factors may also influence salamander detection probabilities (the probability of observing a salamander when it is present), which in turn affect the direct count results. Thus, future surveys should be conducted to minimize the variation in apparent population size due to these effects. Two ways to deal with this problem are: (1) sample enough times so that the true signal is not overcome by sample variation; or (2) schedule surveys so that seasonality and flow patterns are consistent between years for the same time frame. Also, mark-recapture studies, such as O'Donnell et al. (2008), may provide insight into the factors that influence detection probabilities, which can then be used to improve the direct count study design.

Based on the PVA results, it is unclear how seasonal variation affects the surface counts. The assumption that excluding months with the largest temperature extremes on average (August and January) and including the months with the highest precipitation on average (May and June) would reduce variability in the data (particularly with respect to σ^2), did not hold true. There were no consistent patterns of whole-year vs. partial-year (March through July) data groupings for confidence intervals or magnitude of μ and σ^2. Future analyses designed to explore differences in seasons of the year may help tease apart within-year variation from between year variation, especially if sources of observation error can be reduced. However, this may be difficult given the small sample sizes available and the fact that rainfall and flow are not necessarily consistent from year to year for a given season. Currently, surveys are scheduled on a quarterly basis. The spring months of April through June tend to have higher salamander counts than any other quarter on average, although this relationship is not statistically significant. It may be prudent, therefore, to focus more effort on surveying during these months (for example, doing two surveys for that quarter).

Although sources of error ultimately bias the count results as an index of the true abundance and variability of the populations, we do know the direction of the bias gives a pessimistic (more likely to lead towards extinction) answer about viability (Morris and Doak 2002). Thus the estimates of μ and σ^2 given are likely worse than the actual values. However, the intent here is to use the estimates of extinction time for comparison among the different populations surveyed, not to provide an absolute answer about the total probability of extinction. Many authors have cautioned against the use of these extinction estimates when confidence intervals for estimated parameters are wide or not estimated at all (Taylor 1995; Reed et al. 1998). However, they are not without value, as we know the direction of bias for the estimates of extinction and they can still be compared among different monitoring sites.

Spicewood Springs, Trib 3 and Trib 5 all exhibit the greatest risk of extinction based on both their high calculated probability of extinction within 50 years, but also their lower confidence limits for cumulative probability of extinction all reach above 10^{-2} within 10 years, plateauing at its maximum value more quickly than for any of the other sites (Figures 4d, e, f). Correspondingly, these sites also exhibit the most negative values for μ (Figure 1) and the smallest current estimated population sizes (Figure 3). Any consideration of Jollyville Plateau Salamander site remediation (including improvements to water quality) should focus on these sites as a priority.

Somewhat surprising is the relative stability of the population at Stillhouse Hollow, having the second lowest probability of extinction, and one of two sites with a positive μ estimate (Franklin is the other). This is of note because of previous issues at this locality including salamander spinal deformities and much higher than normal concentrations of nitrate/nitrites (O'Donnell et al. 2006).

Annual Survey Results Summary

Raw counts for 2008 at all survey sites are reported in Figure 6. Balcones Canyonland Preserve sites on Bull Creek main stem continue to exhibit higher population sizes than urban populations (Upper Ribelin, Lower Ribelin, and Franklin). For example, 119 salamanders were observed in April at Franklin (site 349). Populations in closer proximity to urban development do not appear to harbor large salamander populations, and data are consistent with previous conclusions regarding population declines in these areas (O'Donnell et al. 2006). No salamanders have been observed at Balcones District Spring (site 445) since 2005, and this trend continues (no plot shown). Among sites where samples were able to be conducted at least twice, survey period II continues to yield the highest salamander counts. This is consistent with previous survey data where late spring tends towards higher salamander numbers, as stated above.

Habitat Restoration

In September 2007, WPDRD removed a low-water crossing just downstream of our Trib 5 monitoring site (Hanks tract COA BCP) in order to eliminate the impounded water behind the concrete crossing and restore the stream channel to a more natural state. Although this ponded water only directly affected a small portion of potential habitat, the indirect affects potentially included increased predatory fish presence and inhibition of dispersal. The Trib 5 site has experienced declines in population size (based on count data) over the past decade with a corresponding increase in upstream residential development, despite the fact that this site is within a preserve. These declines are attributed to effects of the increased development and impervious cover, which has increased from 4% in 1997 to over 18% in 2006. However it is still not known what is directly causing these declines in salamander counts, except that there is a clear inverse relationship between low population size and urbanization. Water quality is typically worse at these urban sites (Davis et al. 2001). For example, specific conductivity (SpC) at reference rural sites (< 10% impervious cover, IC) is often far below that of urban (>10% IC) and developing sites (Figure 7). Unlike other urban sites, however, Trib 5 has exhibited the largest increase in impervious cover over the last 12 years among the monitoring sites (Figure 6), and this corresponds to increasing levels of sodium, chloride and SpC since 2004 (Perry 2008). Furthermore, scouring of the creek bottom had occurred at this site in early 2000's, permanently altering the habitat (M. Sanders, *pers. comm.*) which also may have had an impact on the apparent decline in population size.

Bull Creek Tributary 5 represents, perhaps, the best location where habitat improvements can be made for the Jollyville Plateau Salamander. Despite the decreasing water quality at this site (Perry 2008), there are several impoundments within the preserve that, if removed, could drastically improve habitat conditions along this tributary. It is possible that each impoundment is located on top, or just downstream, of springs which in the past may have harbored large numbers of salamanders, as are found in the adjacent tributaries. Although these areas have not been surveyed methodically, they represent very poor salamander habitat: sediment deposits are deep, there is low flow velocity, and predatory centrachid fish have a more permanent presence where they would otherwise be uncommon or absent.

Another possible but less beneficial target for restoration is the removal of the well house at Spicewood Springs. While removal of debris from the well house may improve the microhabitat of that small area (less than 1m^2), it is doubtful that much improvement can be made to this site without instituting measures to increase water quality across the entire basin. Only two salamanders during 2008 were found at this site, out of three surveys. This is despite steady spring flow during a time of drought. One possible explanation for such low salamander numbers, beyond poor water quality, could be reduced natural spring flow supplanted by artificial flow, or urban leakage. High impervious cover in the Spicewood Springs basin (46% in 2006) results in less recharge to groundwater, yet leaking water transmission and sewer lines and landscape irrigation may make up for natural recharge in terms of volume. It is unknown how much leakage occurs in this area, however one estimate is that 12% of water is lost city-wide (Garcia-Fresca and Sharp 2005). The artificial recharge that occurs as a result may not cover the same area as natural recharge would inside the aquifer, a net result being that there is much less available subterranean salamander habitat despite there being ample spring flow. In addition, the artificial recharge water is significantly different chemistry that natural rainwater. While this is speculative, and very little is known about the subterranean habitat of *E. tonkawae* in this region, it is important to consider the role of decreasing habitat quantity in addition to degraded habitat quality.

Future Directions

Population viability analysis, as used here, can be a useful tool to compare the threat of extirpation among different Jollyville Plateau Salamander populations. However, it is not without limitations. When counts are as low as they are at several of our monitoring sites (less than 20), the utility of PVA declines due to violations in assumptions (e.g. no demographic stochasticity) and also the fact that analysis is not required for one to know that such low population sizes are unsustainable in nature. Since the high variance in within-year counts is likely attributed to natural fluctuations in the movement and behavior of salamanders (with respect to surface vs. subsurface presence), it would be useful to further investigate whether these cycles can be predicted and how analyses can be adjusted to account for them. If these cycles occur on a greater than yearly basis, analyses would need to be adjusted to account for this. If fluctuations are cyclical in nature, it likely occurs in relation to rainfall and flow, which is a topic for future analysis. In the meantime, the PVA shown here at least gives a better idea of the relative severity of threat to population survival, something that previous analyses failed to do.

Two other possible projects that will help improve our understanding of this species and the suspected population declines it has endured are an analysis of urban leakage contribution to spring flow and research on the seasonal macroinvertebrate communities that inhabit both urban and rural salamander spring localities.

Macroinvertebrate surveys have been ongoing at three salamander sites as part of a separate Bull Creek study (Perry 2008). This study will be merged with the salamander monitoring plan, and more frequent invertebrate surveys will be conducted. This additional information should allow us to get a clearer picture of prey species available for salamanders during different times of the year and at different sites.

Urban leakage can be examined by comparing strontium isotope ratios ($^{87}Sr/^{86}Sr$) found in spring water to those found in treated water. This method is currently being used by researchers to examine the influence of urban leakage on Barton Springs discharge (N. Hauwert, *pers. comm.*) and has been used in other systems for detection of leaking water mains into groundwater (Leung and Jiao 2006).

Ongoing projects include the continuation of the direct count surveys, mark-recapture research at the Lanier and Wheless sites, and searching for new salamander populations.

REFERENCES

Bowles, B., M. Sanders, R. Hansen. 2006. Ecology of the Jollyville Plateau salamander (*Eurycea tonkawae*: Plethodontidae) with an assessment of the potential effects of urbanization. Hydrobiologia 553:111-120.

Davis, B., R. Hansen, N. L. McClintock, E. D. Peacock, M. Turner, C. Herrington, D. Johns, D. A. Chamberlain, D. Cerda, T. Pennington, L. Leopold, A. Vaughan, and D. Nuffer. 2001. Jollyville Plateau water quality and salamander assessment. CM-01-04. City of Austin, Austin, Texas.

Garcia-Fresca, B., and J. M. Sharp, Jr. 2005. Hydrogeologic considerations of urban development: Urban-induced recharge. In J. Ehlen, W. C. Haneberg, and R. A. Larson (eds.), Humans as Geologic Agents pp. 123-136. The Geologic Society of America, Boulder, Colorado.

Leung, C., and J. J. Jiao. 2006. Use of strontium isotopes to identify buried water main leakage into groundwater in a highly urbanized coastal area. Environmental Science & Technology 40:6575-6579.

Morris, W. F., and D. F. Doak. 2002. Quantitative Conservation Biology: Theory and Practice of Population Viability Analysis. Sinauer Associates Inc., Sunderland, MA.

O'Donnell, L., M. Turner, E. Geismar, M. Sanders. 2005. Summary of Jollyville Plateau salamander data (1997 – 2005) and status. SR-06-06. City of Austin, Austin, Texas.

O'Donnell, L., M., Turner, M. Sanders, E. Geismar, S. Heilman, L. Zebehazy. 2006. Summary of Jollyville Plateau salamander data (1997 – 2006) and status. SR-07-02. City of Austin, Austin, Texas.

O'Donnell, L., A. G. Gluesenkamp, C. Herrington, M. Schlaepfer, N. F. Bendik. 2008. Estimation of Jollyville Plateau Salamander (*Eurycea tonkawae*) Populations
Using Surface Counts and Mark-Recapture. City of Austin Report. Austin, Texas.

Perry, H. 2008. Bull Creek water quality, benthic macroinvertebrate and stream habitat survey 2008. City of Austin Report. Austin, Texas.

Reed, J. M., D. D. Murphy, and P. F. Brussard. 1998. Efficacy of population viability analysis. Wildlife Society Bulletin 26:244-251.

Taylor, B. L. 1995. The reliability of using population viability analysis for risk classification of species. Conservation Biology 9:551-558.

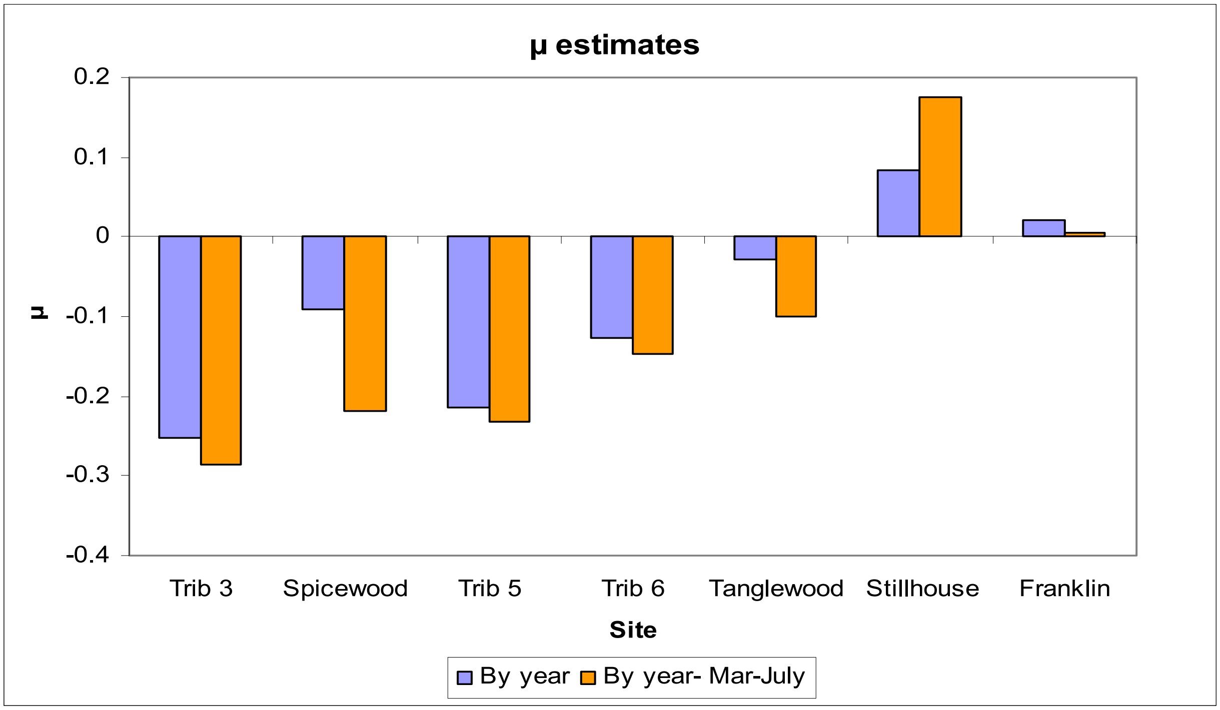


Figure 1. Estimates of μ calculated by yearly averages of the entire year and partial years from March through July. Estimates of μ are positive only for the Franklin and Stillhouse sites. See Table 2 for confidence intervals.

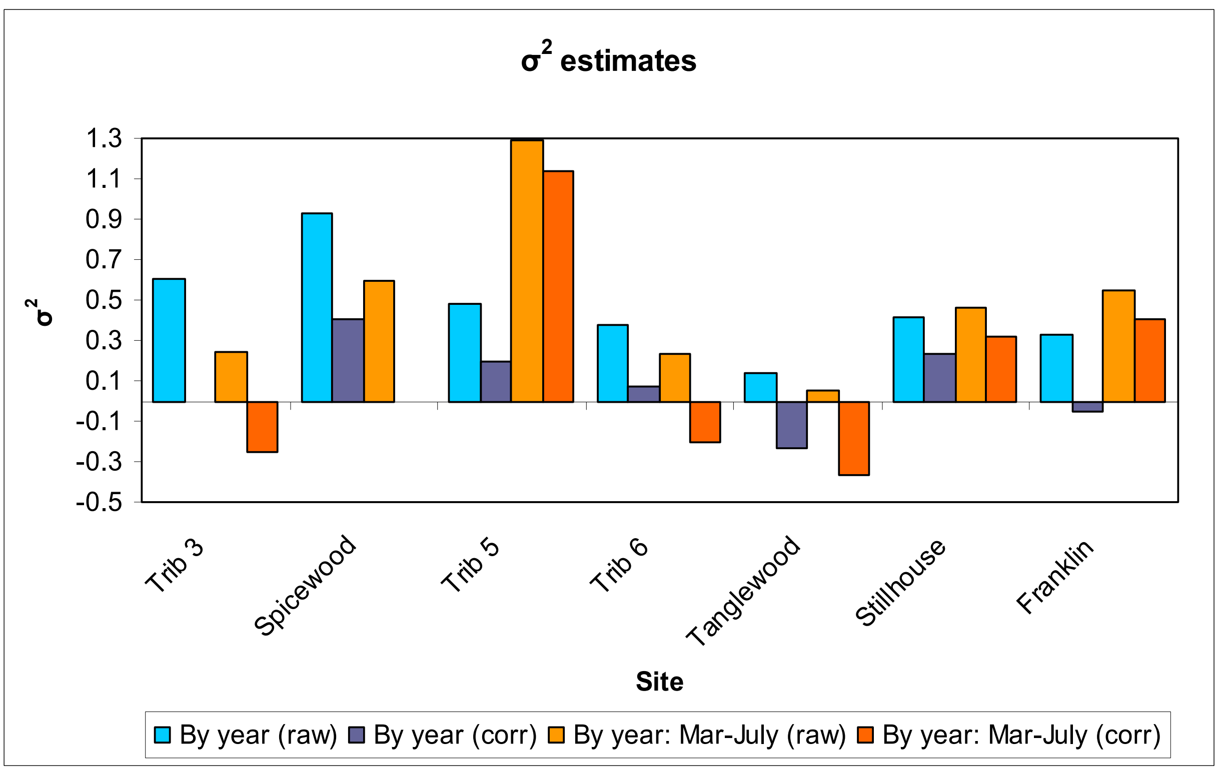


Figure 2. Raw and corrected estimates of σ^2 calculated by yearly averages of the entire year and partial years from March through July. Negative corrected values indicate high observational error and we cannot rule out the possibility that σ^2 has a value of zero in those instances (zero instead of a negative because there is no such thing as a negative variance). See Table 2 for confidence intervals.

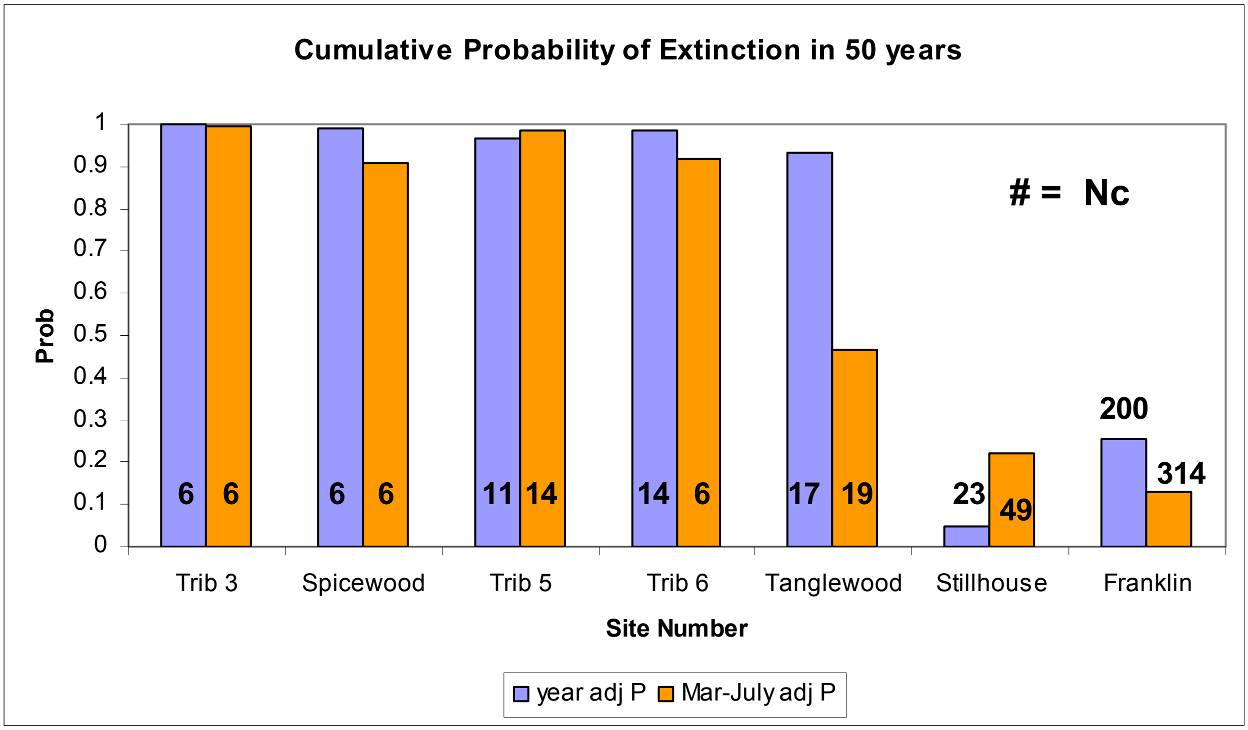
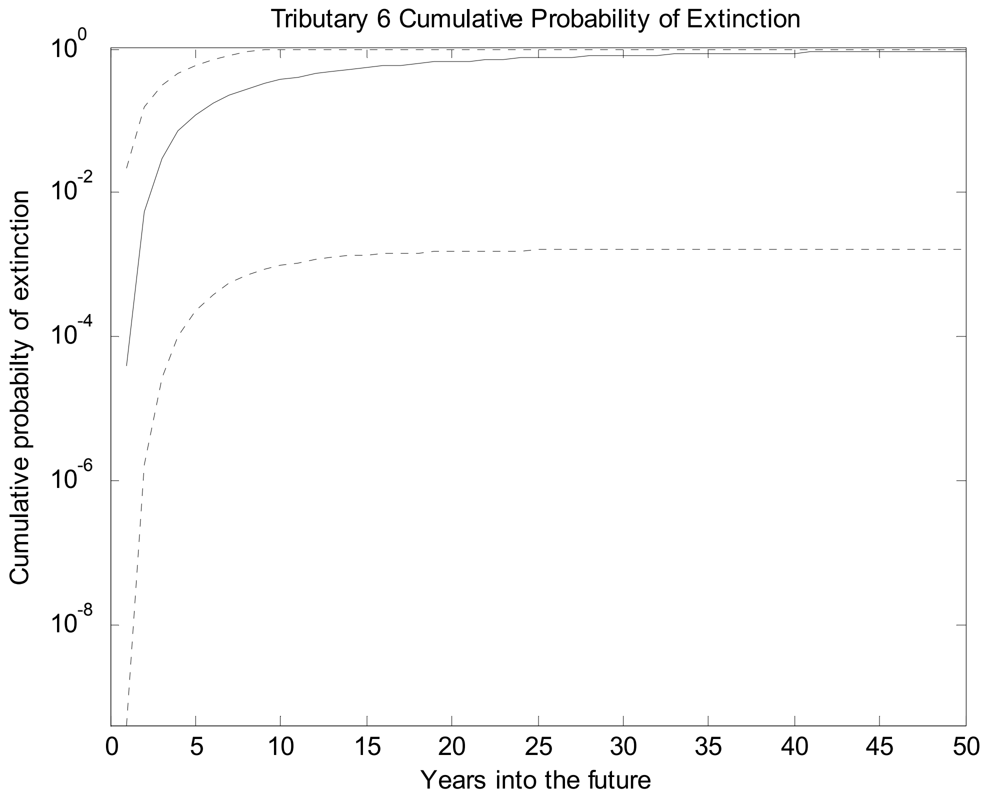


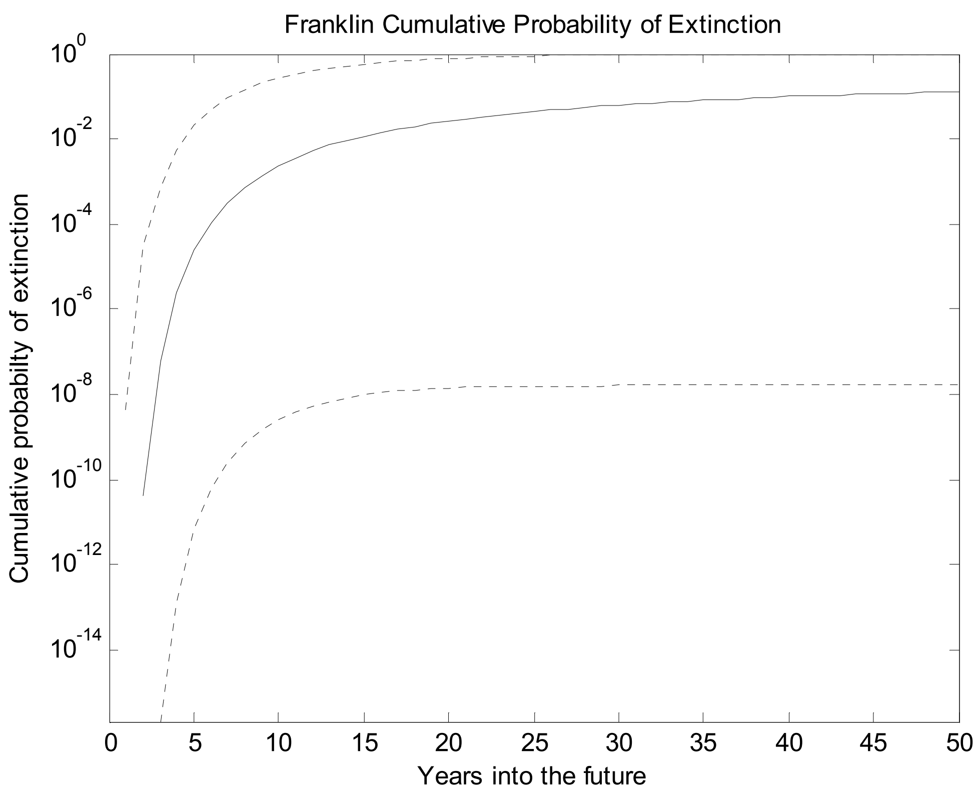
Figure 3. Cumulative probability of extinction among sites in 50 years. Numbers at the base of each bar indicate N_c, the current population size adjusted for an assumed capture probability of 0.35.

Figure 4. Cumulative distribution function plots for the probability of extinction at each monitoring site. Plots shown are for whole year data treatment (solid line) with upper and lower confidence limits (dotted lines) for t_{max}=50, N_c=N /0.35 (based on average capture probability from O'Donnell et al. 2008), N_e=1. Raw σ^2 values were used in lieu of corrected values because the cumulative distribution function could not be computed using a negative or zero value of σ^2.

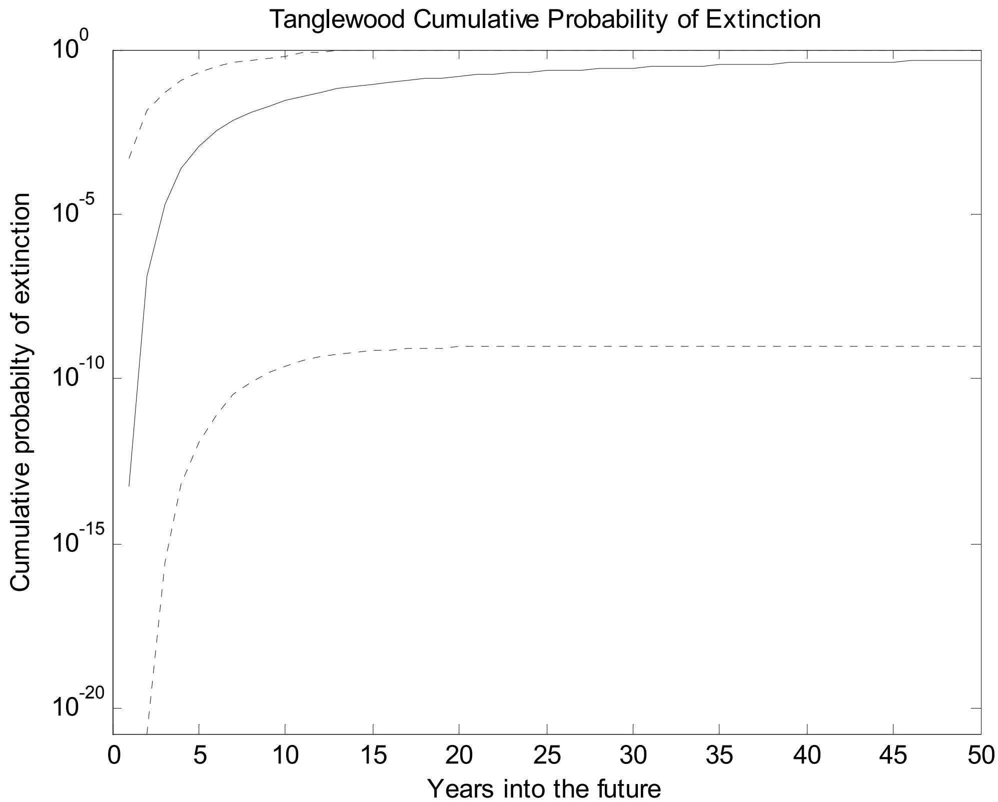
a.



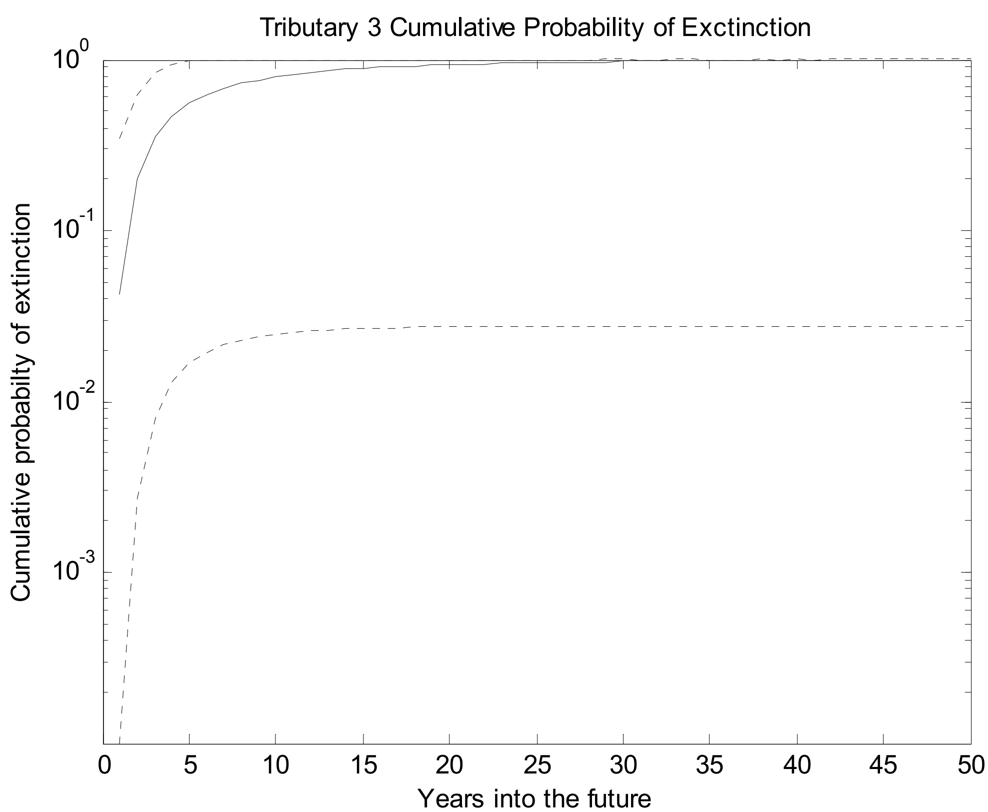
b.



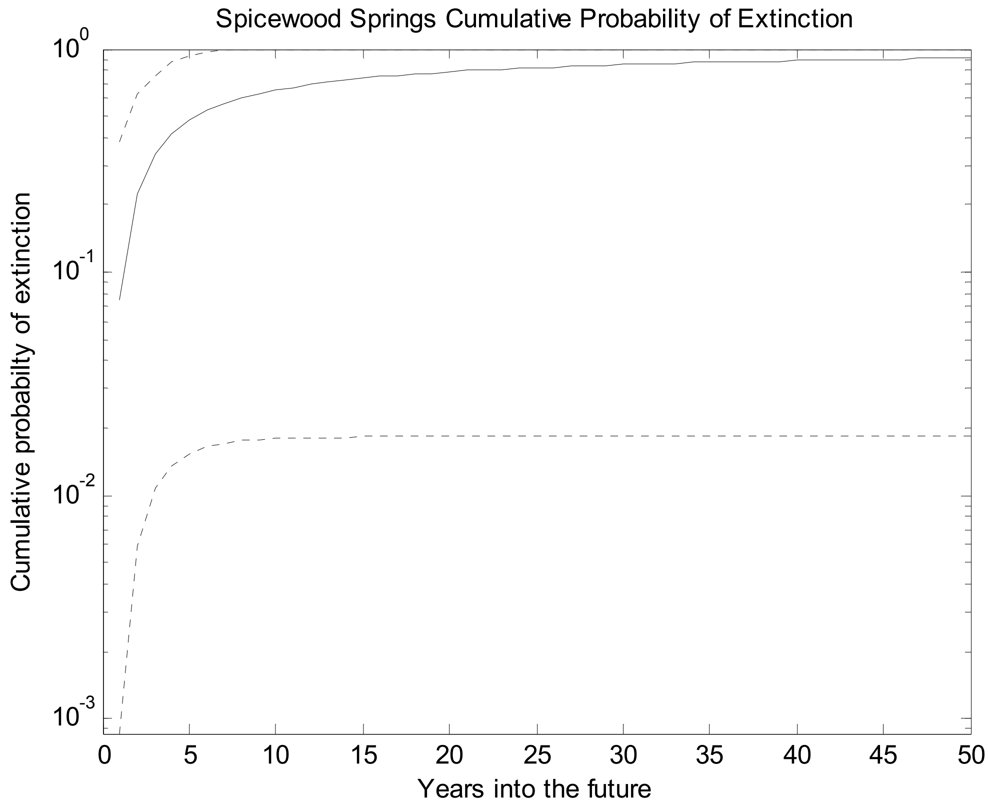
c.


Tanglewood Cumulative Probability of Extinction
Cumulative probabilty of extinction
Years into the future

d.

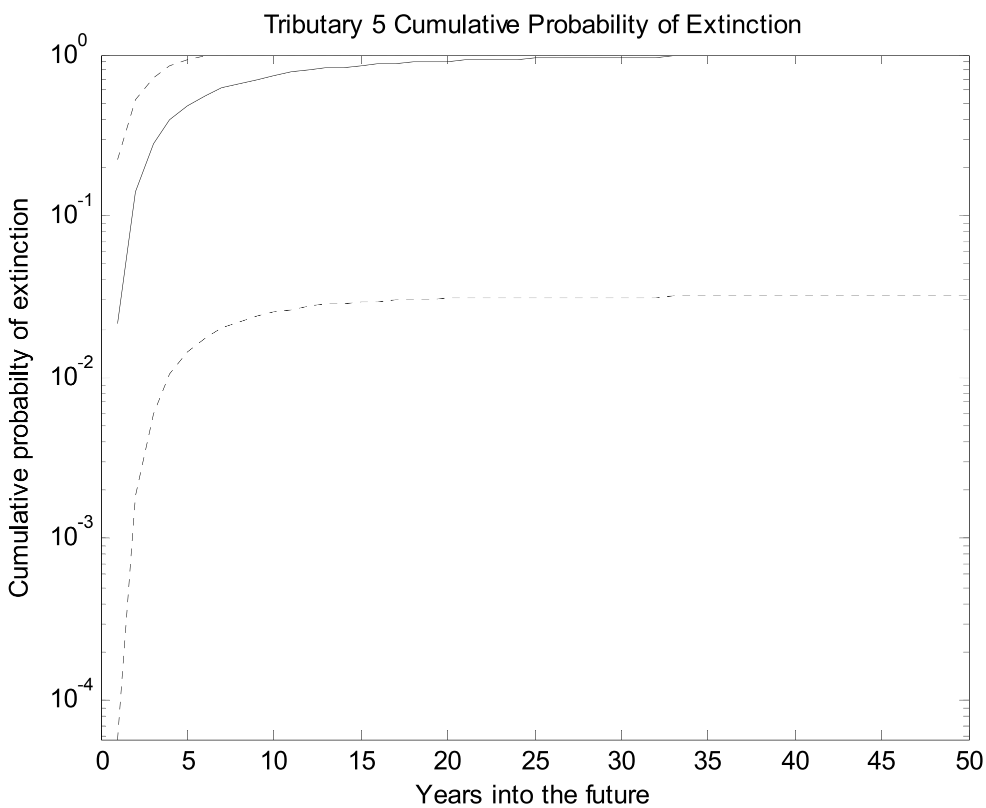

Tributary 3 Cumulative Probability of Exctinction
Cumulative probabilty of extinction
Years into the future

e.



Spicewood Springs Cumulative Probability of Extinction
10^0
10^{-1}
10^{-2}
10^{-3}
Cumulative probabilty of extinction
0
5
10
15
20
25
30
35
40
45
50
Years into the future

f.



Tributary 5 Cumulative Probability of Extinction
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Cumulative probabilty of extinction
0
5
10
15
20
25
30
35
40
45
50
Years into the future

g.

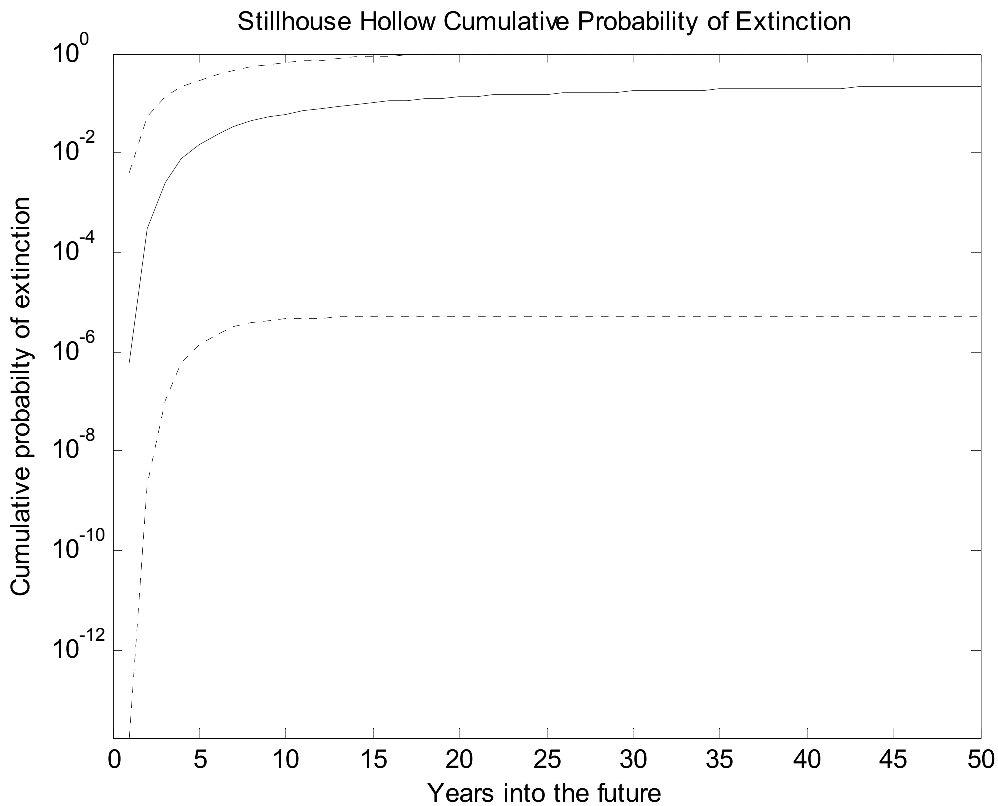
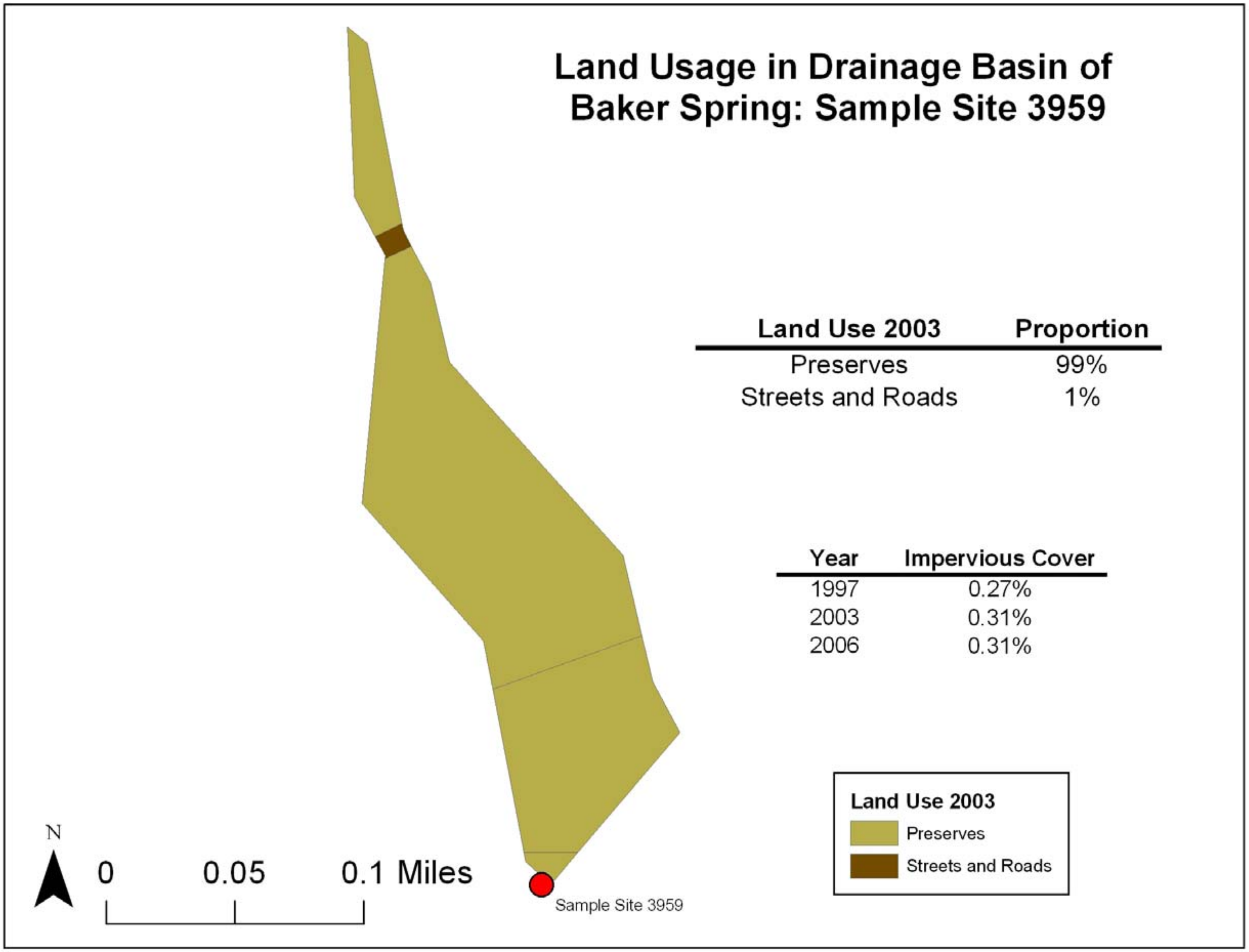
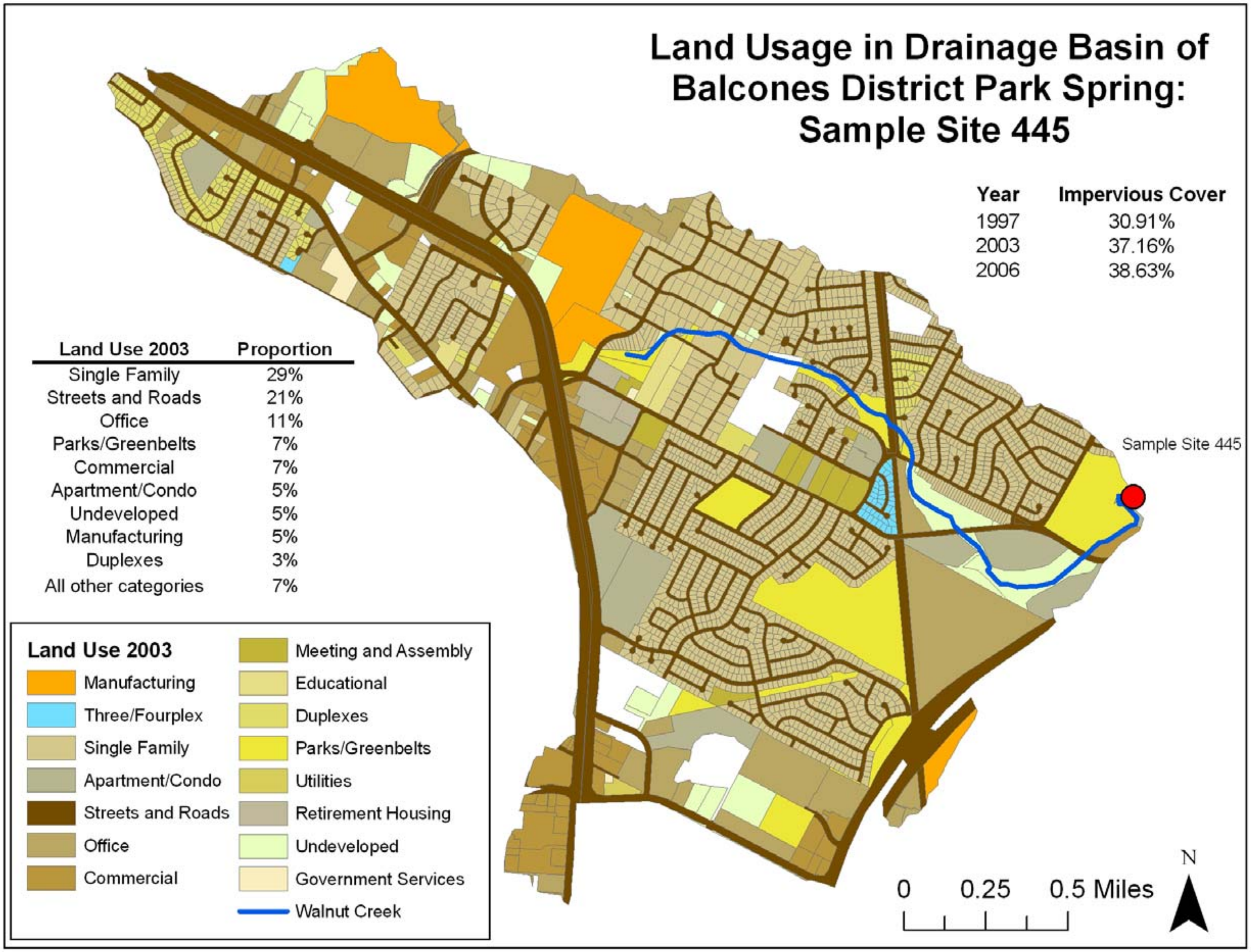

Stillhouse Hollow Cumulative Probability of Extinction
Cumulative probabilty of extinction
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
0
5
10
15
20
25
30
35
40
45
50
Years into the future

Figure 5 (a-i). Land use maps and impervious cover estimates for drainage basins at all Jollyville Plateau Monitoring Sites.

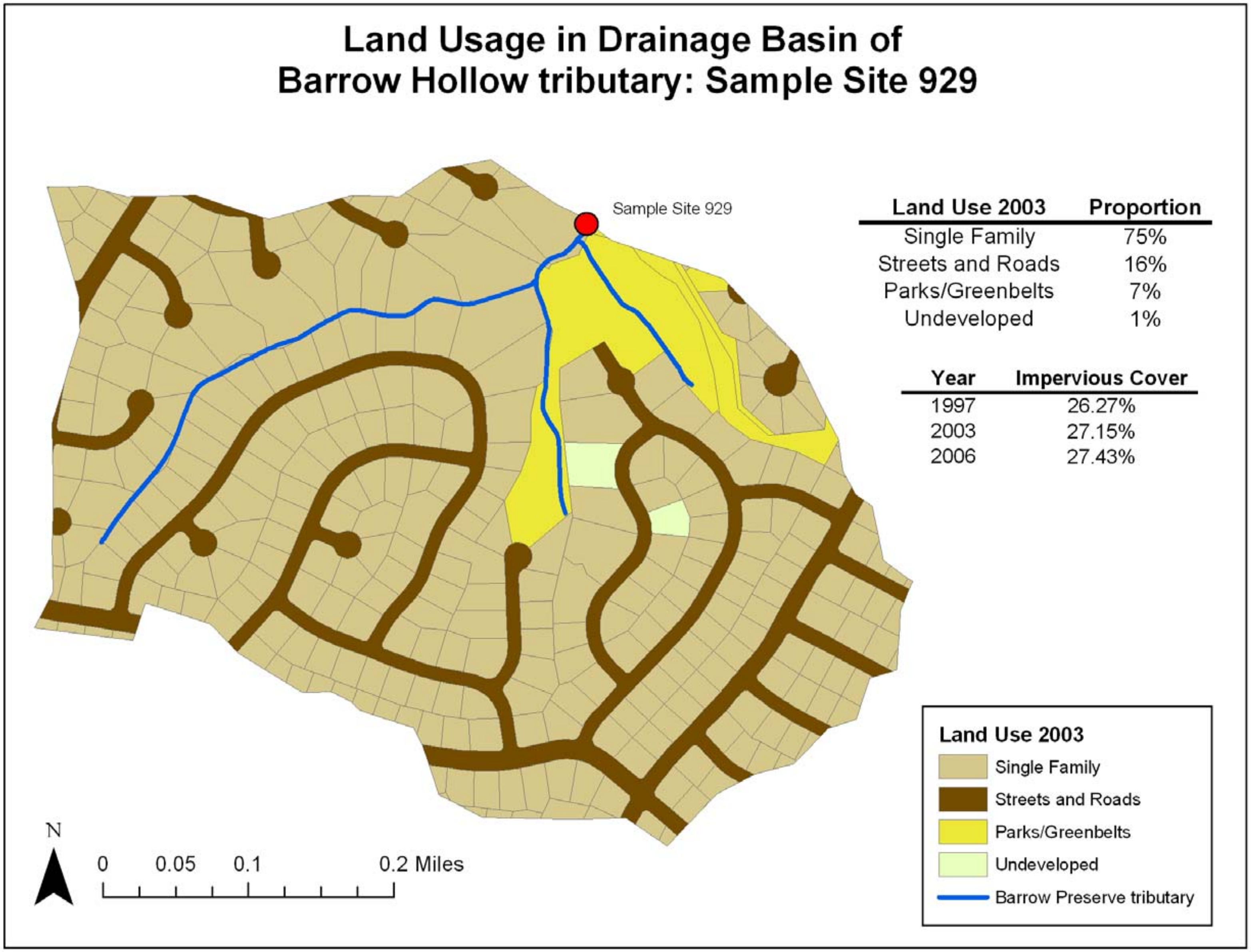
a.



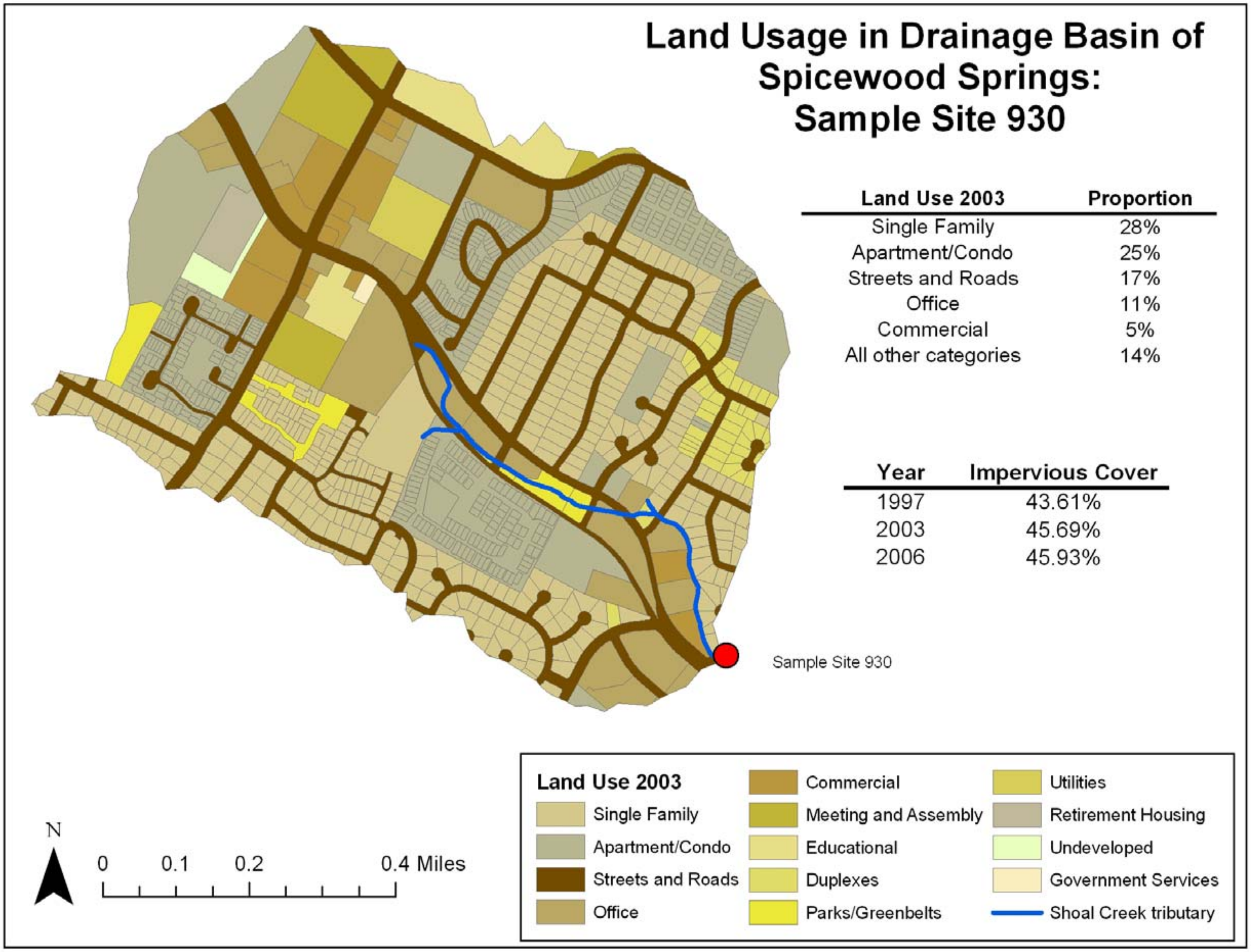
b.


Land Usage in Drainage Basin of Balcones District Park Spring: Sample Site 445
Year | Impervious Cover
1997 | 30.91%
2003 | 37.16%
2006 | 38.63%
Land Use 2003 | Proportion
Single Family | 29%
Streets and Roads | 21%
Office | 11%
Parks/Greenbelts | 7%
Commercial | 7%
Apartment/Condo | 5%
Undeveloped | 5%
Manufacturing | 5%
Duplexes | 3%
All other categories | 7%
Sample Site 445
Land Use 2003
Manufacturing
Three/Fourplex
Single Family
Apartment/Condo
Streets and Roads
Office
Commercial
Meeting and Assembly
Educational
Duplexes
Parks/Greenbelts
Utilities
Retirement Housing
Undeveloped
Government Services
Walnut Creek
0 0.25 0.5 Miles
N

c.

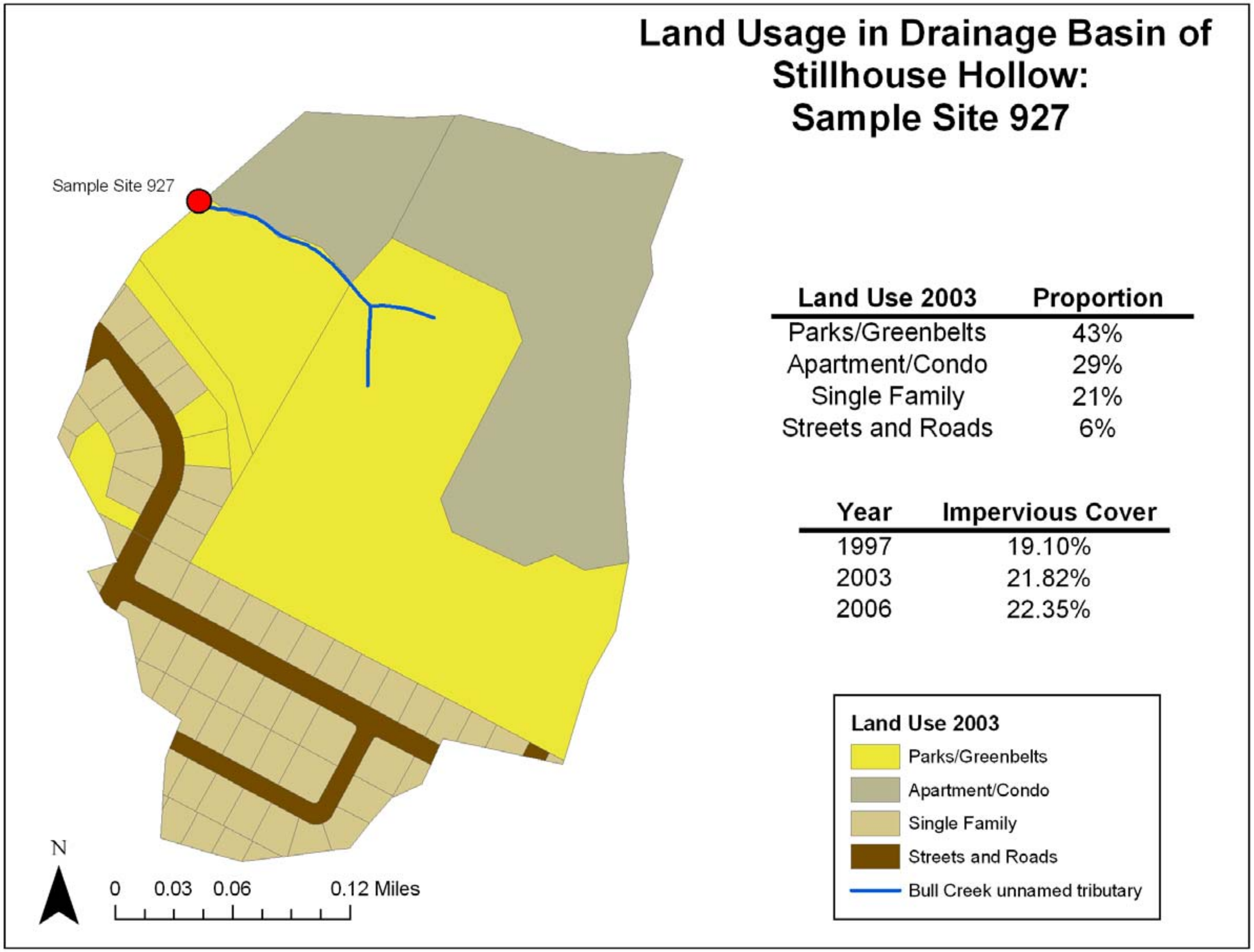

Land Usage in Drainage Basin of
Barrow Hollow tributary: Sample Site 929
Sample Site 929
Land Use 2003 | Proportion
Single Family | 75%
Streets and Roads | 16%
Parks/Greenbelts | 7%
Undeveloped | 1%
Year | Impervious Cover
1997 | 26.27%
2003 | 27.15%
2006 | 27.43%
Land Use 2003
Single Family
Streets and Roads
Parks/Greenbelts
Undeveloped
Barrow Preserve tributary
N
0 0.05 0.1 0.2 Miles

d.



Land Usage in Drainage Basin of Spicewood Springs: Sample Site 930
Land Use 2003 | Proportion
Single Family 28%
Apartment/Condo 25%
Streets and Roads 17%
Office 11%
Commercial 5%
All other categories 14%
Year | Impervious Cover
1997 43.61%
2003 45.69%
2006 45.93%
Sample Site 930
N
0 0.1 0.2 0.4 Miles
Land Use 2003
Single Family
Apartment/Condo
Streets and Roads
Office
Commercial
Meeting and Assembly
Educational
Duplexes
Parks/Greenbelts
Utilities
Retirement Housing
Undeveloped
Government Services
Shoal Creek tributary

e.



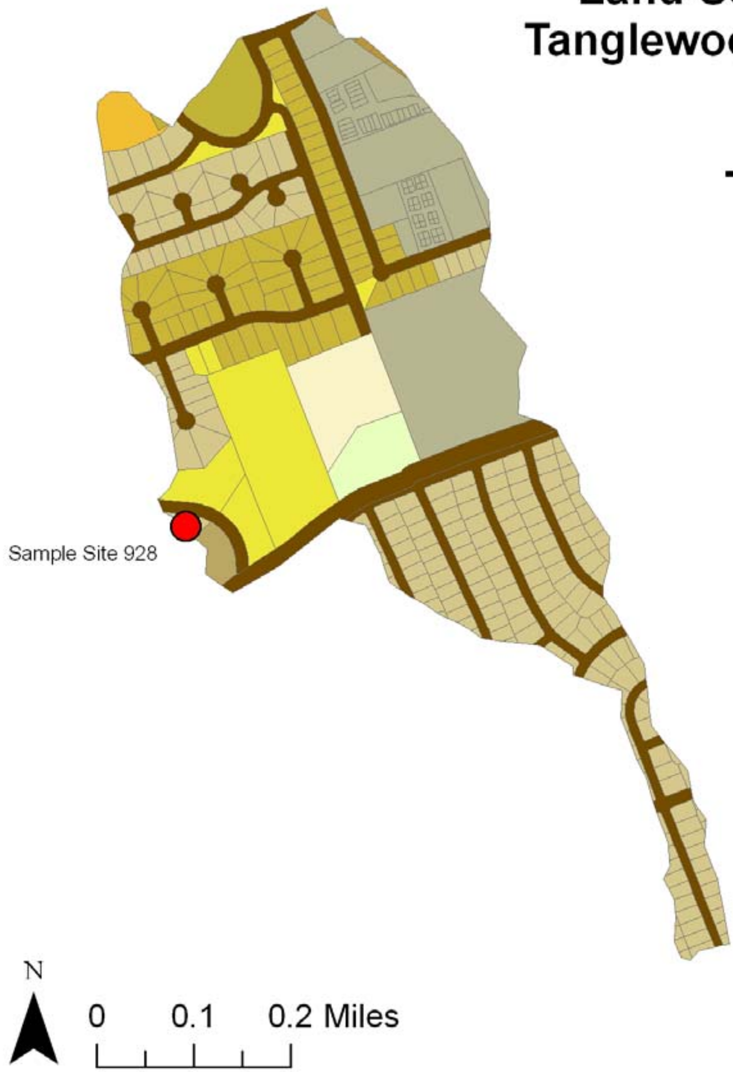
Land Usage in Drainage Basin of
Stillhouse Hollow:
Sample Site 927
Sample Site 927
Land Use 2003 Proportion
Parks/Greenbelts 43%
Apartment/Condo 29%
Single Family 21%
Streets and Roads 6%
Year Impervious Cover
1997 19.10%
2003 21.82%
2006 22.35%
Land Use 2003
Parks/Greenbelts
Apartment/Condo
Single Family
Streets and Roads
Bull Creek unnamed tributary
N
0 0.03 0.06 0.12 Miles

f.

Land Usage in Drainage Basin of Tanglewood tributary: Sample Site 928

Land Use 2003	Proportion
Single Family	29%
Apartment/Condo	20%
Streets and Roads	18%
Duplexes	13%
Parks/Greenbelts	10%
Retirement Housing	4%
All other categories	7%

Year	Impervious Cover
1997	29.65%
2003	32.94%
2006	33.82%

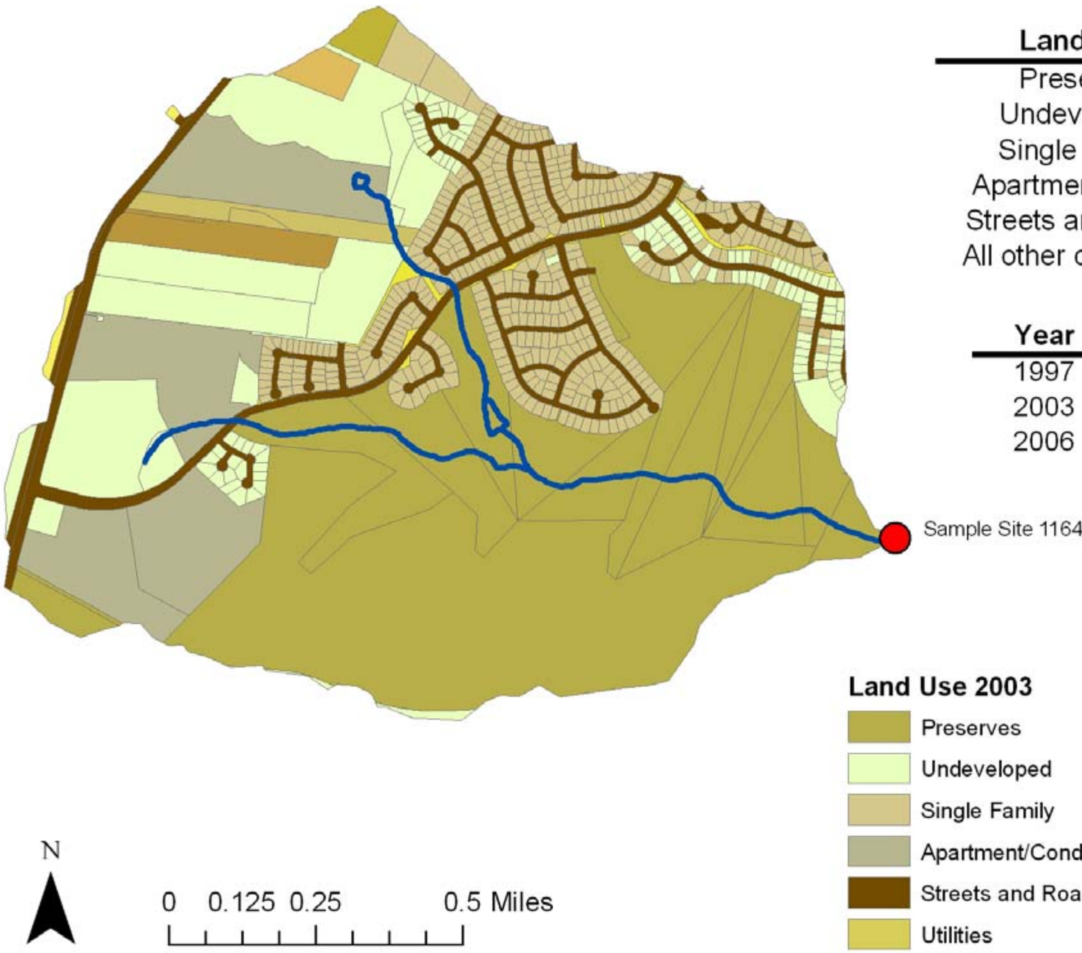


Land Use 2003

- Single Family
- Apartment/Condo
- Streets and Roads
- Duplexes
- Parks/Greenbelts
- Retirement Housing
- Meeting and Assembly
- Undeveloped
- Golf Courses
- Office
- Commercial

g.

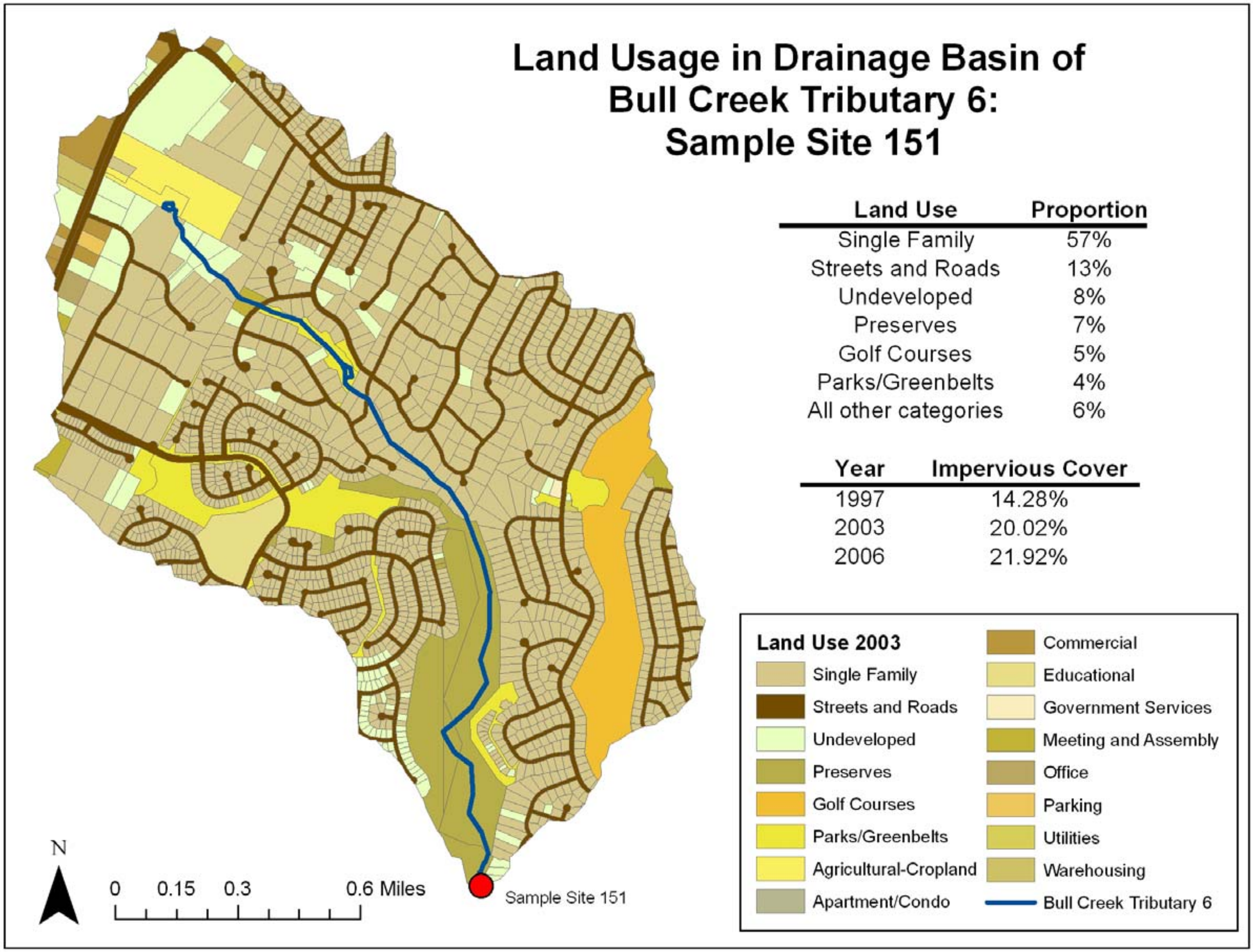
Land Usage in Drainage Basin of Bull Creek Tributary 5: Sample Site 1164



Land Use	Proportion
Preserves	44%
Undeveloped	17%
Single Family	13%
Apartment/Condo	13%
Streets and Roads	7%
All other categories	5%

Year	Impervious Cover
1997	4.64%
2003	14.46%
2006	18.03%

h.


Land Usage in Drainage Basin of
Bull Creek Tributary 6:
Sample Site 151
Land Use
Proportion
Single Family
57%
Streets and Roads
13%
Undeveloped
8%
Preserves
7%
Golf Courses
5%
Parks/Greenbelts
4%
All other categories
6%
Year
Impervious Cover
1997
14.28%
2003
20.02%
2006
21.92%
Land Use 2003
Single Family
Streets and Roads
Undeveloped
Preserves
Golf Courses
Parks/Greenbelts
Agricultural-Cropland
Apartment/Condo
Commercial
Educational
Government Services
Meeting and Assembly
Office
Parking
Utilities
Warehousing
Bull Creek Tributary 6
N
0
0.15
0.3
0.6 Miles
Sample Site 151

i.

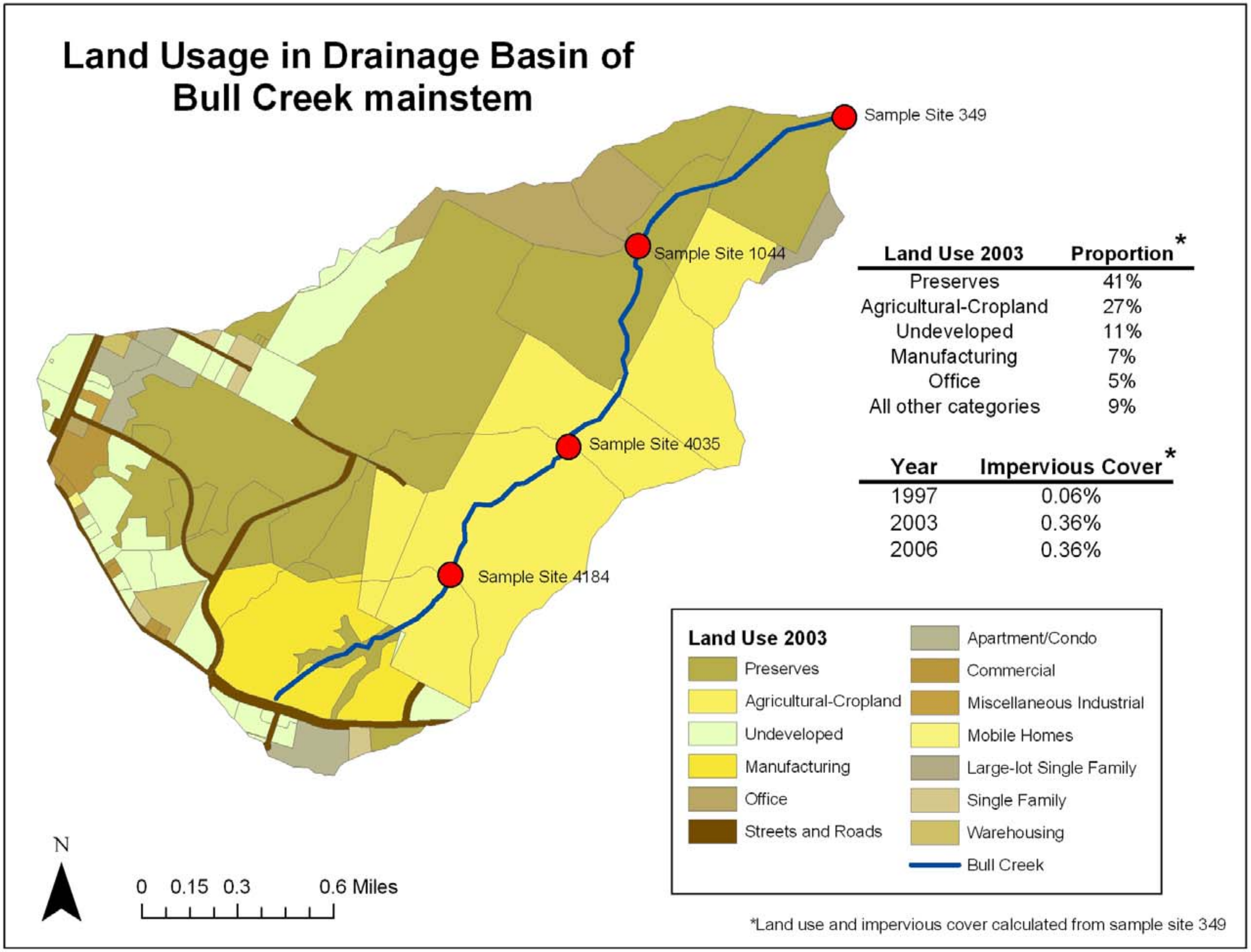
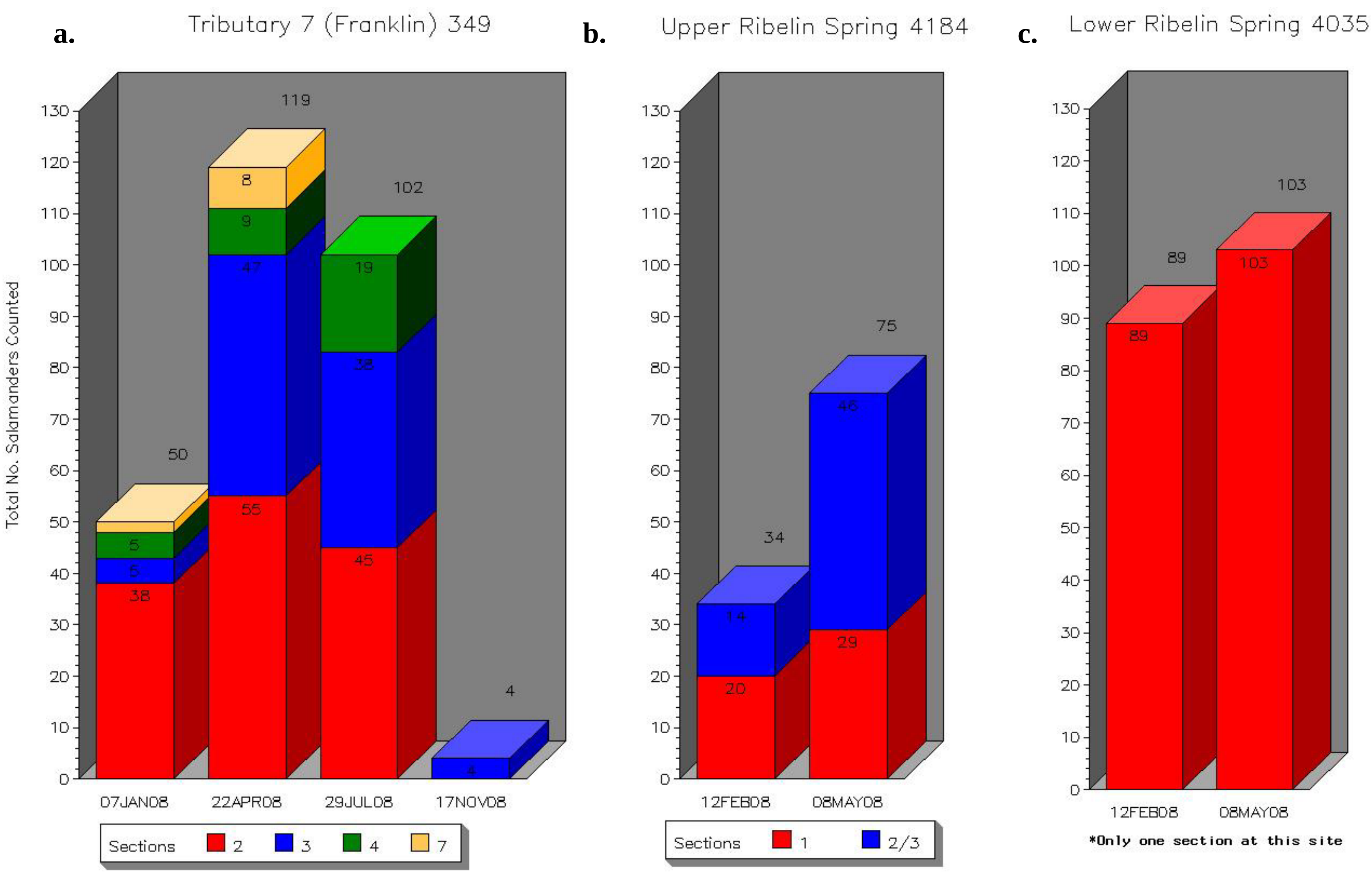
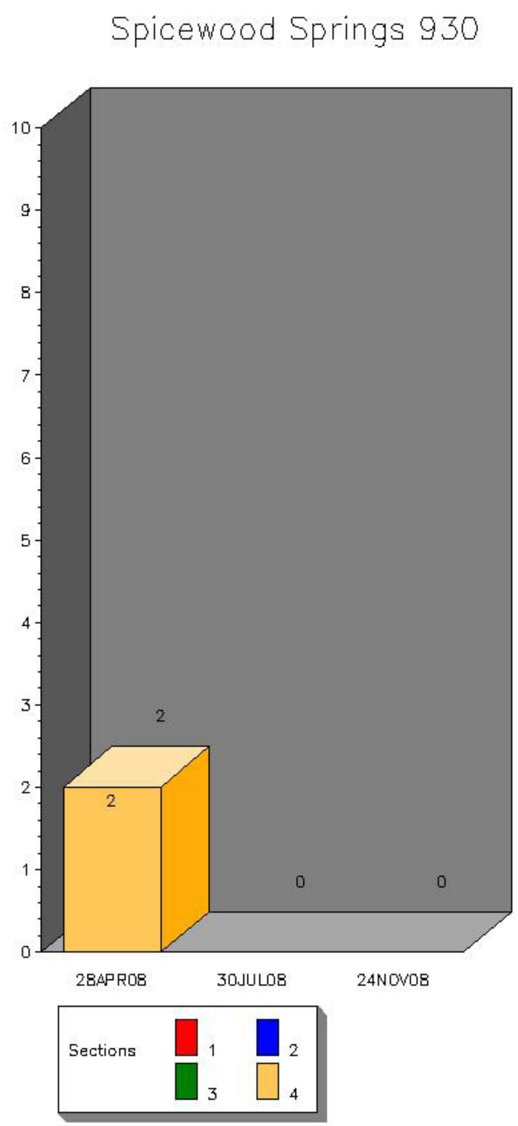

Land Usage in Drainage Basin of Bull Creek mainstem
Sample Site 349
Sample Site 1044
Sample Site 4035
Sample Site 4184
Land Use 2003 Proportion*
Preserves 41%
Agricultural-Cropland 27%
Undeveloped 11%
Manufacturing 7%
Office 5%
All other categories 9%
Year Impervious Cover*
1997 0.06%
2003 0.36%
2006 0.36%
Land Use 2003
Preserves
Agricultural-Cropland
Undeveloped
Manufacturing
Office
Streets and Roads
Apartment/Condo
Commercial
Miscellaneous Industrial
Mobile Homes
Large-lot Single Family
Single Family
Warehousing
Bull Creek
N
0 0.15 0.3 0.6 Miles
*Land use and impervious cover calculated from sample site 349

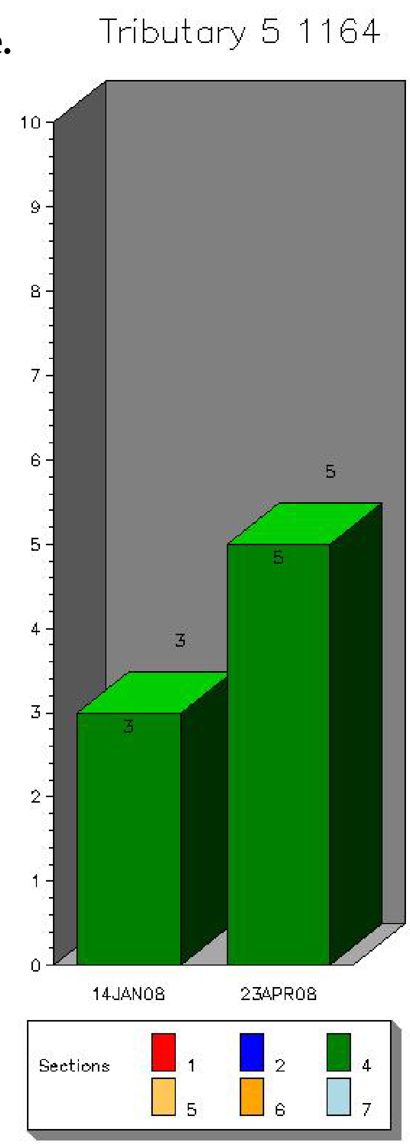
Figure 6 (a-k). Direct count survey results for 2008: Total number of salamanders counted vs. survey date by section. Common site name and site number are indicated in title. See table 1b for wet and dry status of sites by section.



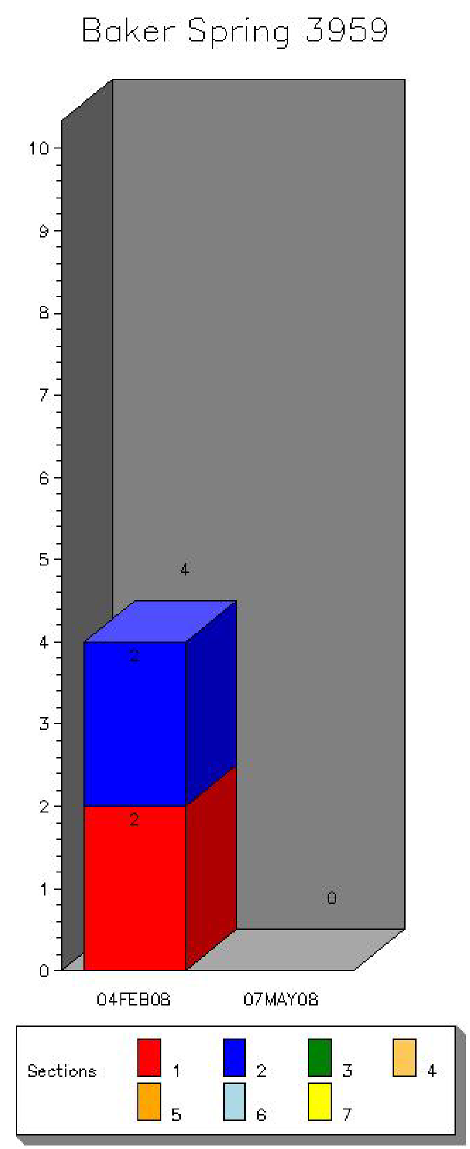
d.


Spicewood Springs 930
10
9
8
7
6
5
4
3
2
1
0
2
2
0
0
28APR08
30JUL08
24NOV08
Sections
1
2
3
4

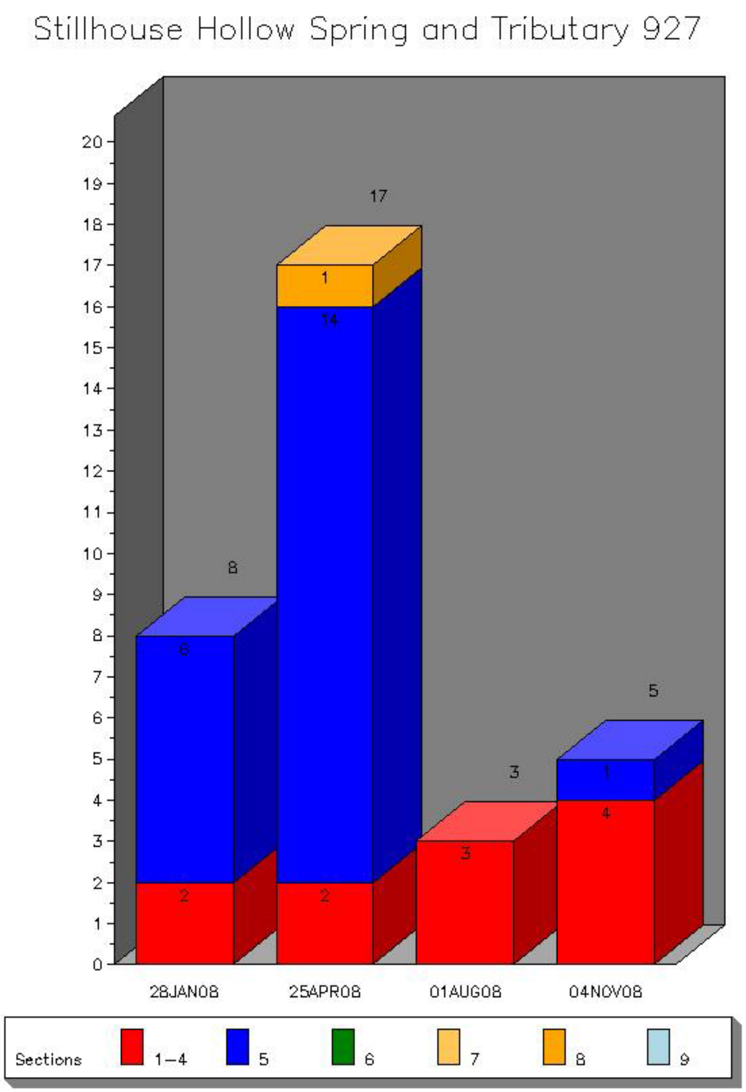
e.


Tributary 5 1164
10
9
8
7
6
5
4
3
2
1
0
3
3
5
5
14JAN08
23APR08
Sections
1
2
4
5
6
7

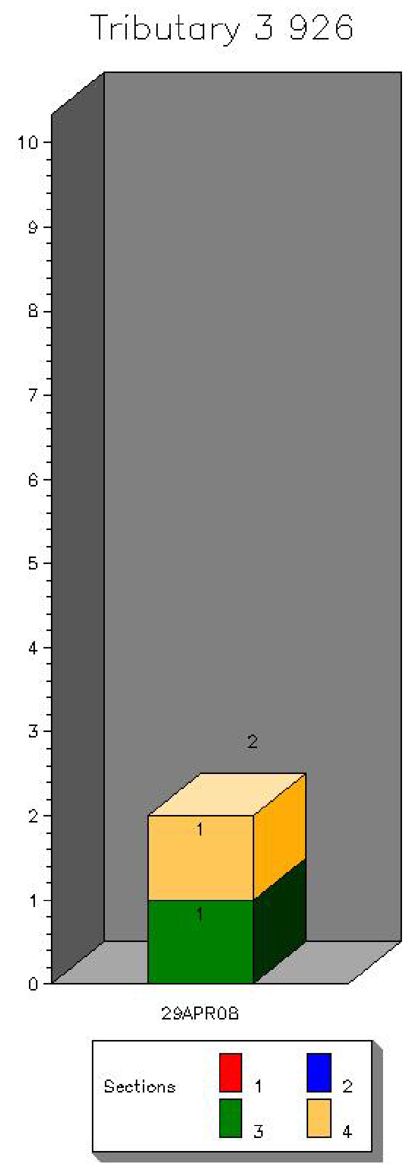
f.


Baker Spring 3959
10
9
8
7
6
5
4
3
2
1
0
4
2
2
0
04FEB08
07MAY08
Sections
1
2
3
4
5
6
7

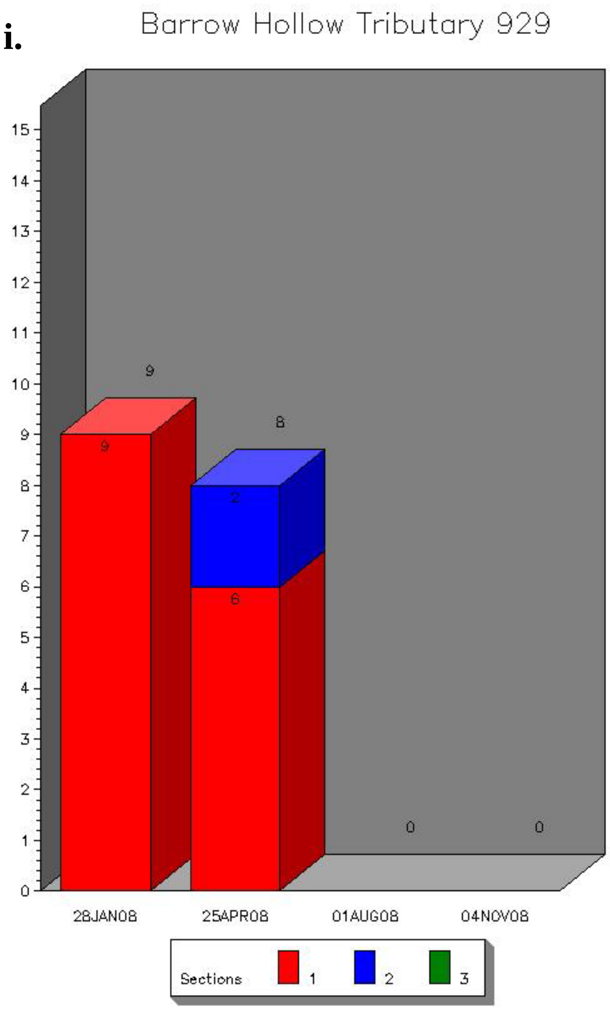
g.


Stillhouse Hollow Spring and Tributary 927
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
8
6
2
17
1
14
2
3
3
5
1
4
28JAN08
25APR08
01AUG08
04NOV08
Sections
1–4
5
6
7
8
9

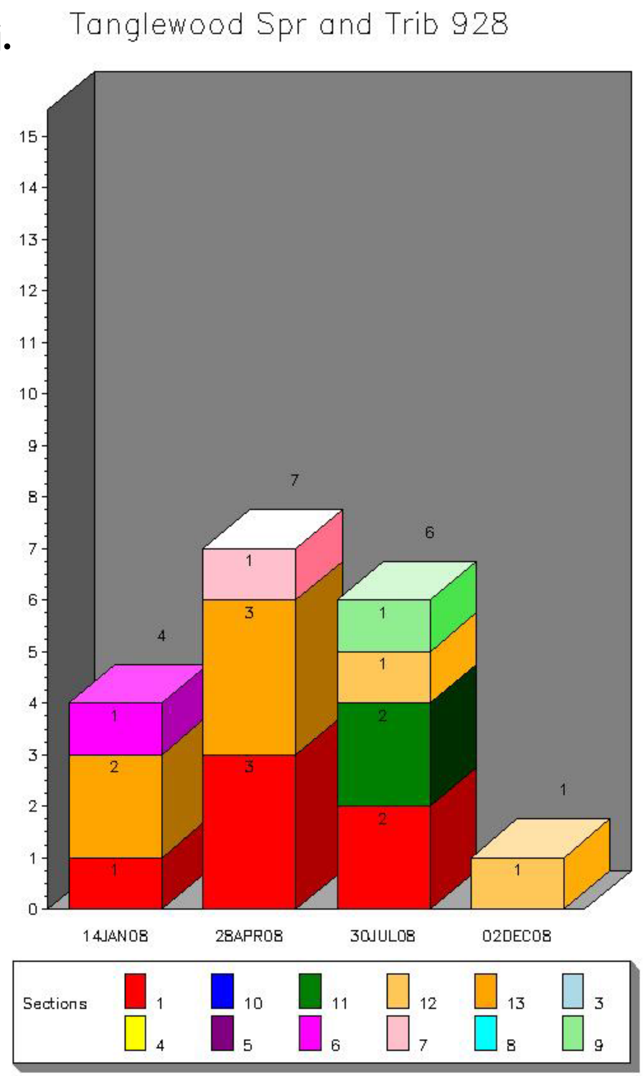
h.


Tributary 3 926
10
9
8
7
6
5
4
3
2
1
0
2
1
1
29APR08
Sections
1
2
3
4

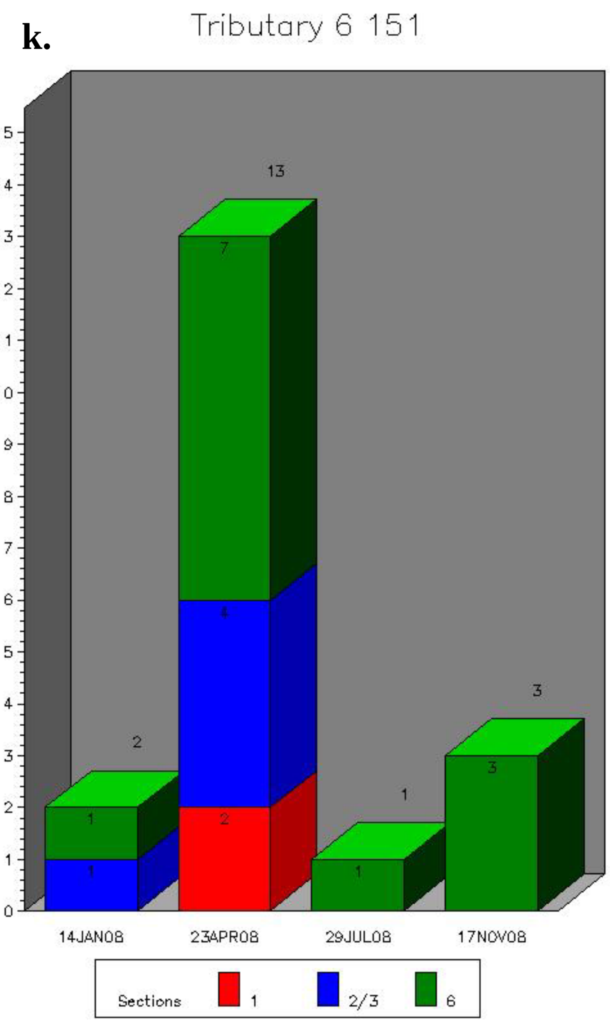
i.


Barrow Hollow Tributary 929
28JAN08
25APR08
01AUG08
04NOV08
Sections
1
2
3

j.


Tanglewood Spr and Trib 928
14JAN08
28APR08
30JUL08
02DEC08
Sections
1
10
11
12
13
3
4
5
6
7
8
9

k.


Tributary 6 151
14JAN08
23APR08
29JUL08
17NOV08
Sections
1
2/3
6

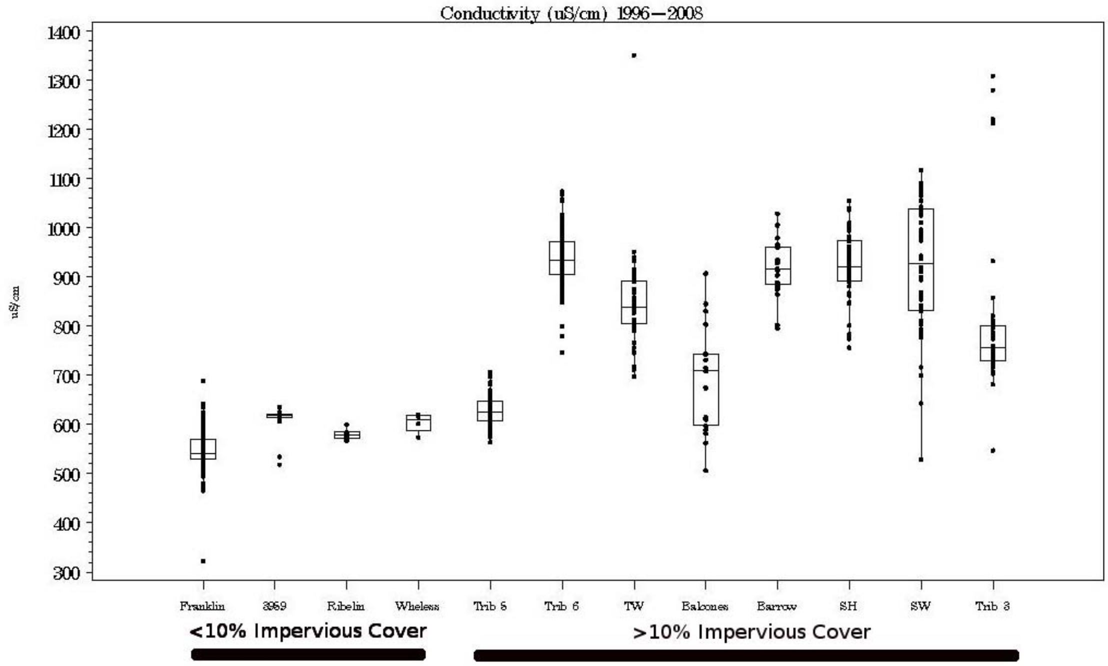


Figure 7. Box plots of specific conductivity measured from 12 monitoring sites over the course of 12 years (1996-2008). Sites with higher impervious cover tend towards higher average specific conductivity.