Watershed Protection
Development Review

Some Water Quality Threats to the Barton Springs Salamander at Low Flows

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Abstract

An evaluation of salamander counts, spring flowrates, and dissolved oxygen concentrations was completed to recommend a pumping limit for sustainable yield to the Barton Springs Edwards Aquifer Conservation District. The primary purpose of the evaluation was to find correlations between flow, dissolved oxygen, and surface count data of the endangered Barton Springs salamander. If such correlation were significant, it would provide the statistical basis for setting thresholds for Barton Springs flows related to a water quality parameter commonly used in aquatic life support. In addition, this parameter was shown to be decreasing in baseflow spring water quality data (Turner, 2000). The relevance of dissolved oxygen levels to maintenance of this aquatic endangered species is also evaluated. It was determined that salamander counts decline when dissolved oxygen (DO) concentrations fall below 5 mg/L and when flow from Barton Springs falls below 30 cfs. Flows equal to or below the drought of record low flow of 10 cfs were found to be potentially harmful to the Barton Springs salamander. Dissolved oxygen levels at the same flow rates could be lower than they were in the 1950s during the drought of record in the 1950's.

Introduction

Droughts are a normal part of Central Texas weather cycles and will recur periodically in the future, causing hydrological responses in water table elevations and spring discharges. The drought of record occurred during the 1950's with a minimum discharge of 9.6 cubic feet per second (cfs) from Barton Springs. Droughts since 1990 have resulted in spring discharges of between 15 and 20 cfs several times between January and December 1990, as low as 17 cfs in August 1996, and between 18 and 20 cfs from April through September 2000.

Current permitted and non-regulated pumping from the BSEA (Barton Springs Edwards Aquifer) is equivalent to approximately 10.5 cfs, approximately 10 cfs from permitted wells and approximately 0.5 cfs from exempt wells (private domestic or livestock wells incapable of pumping greater than 10,000 gallons per day). During a drought equivalent to the drought of record (minimum discharge of 9.6 cfs with pumpage of 0.66 cfs), the BSEACD anticipates that a low flow of 3 cfs from Barton Springs will still be available. However, this flow depends on achieving a 30% reduction in pumping through conservation measures.

The impact of this low flow on the Barton Springs salamander is uncertain. Extrapolating from the historical dissolved oxygen (DO) to flow relationships, and using available laboratory testing on similar salamanders, significant Barton Springs salamander mortality could be expected at this flow.

The historical relationship between flow, dissolved oxygen and salamander abundance is discussed below. The emphasis in the discussion will be on Barton Springs, but consequences of low flow, such as anoxic sediment and loss of habitat in Upper Barton, Eliza and Old Mill Springs will also be presented. Effects of other water quality problems at low flow were also noted although detailed evaluation of these parameters has not been completed.

Dissolved Oxygen and Barton Springs Discharge

The relationship between flow and DO at Barton Springs can be observed in the plots of data from the summers of 1996 and 2000. The average concentration of DO during the non-drought period 1997-1999 was 6.5 mg/L. During the droughts of 1996 and 2000 the DO dropped below 5 mg/L, and the low DO corresponded to periods of low spring flow. The Texas Commission on Environmental Quality has designated Barton Springs Pool as a high aquatic life use water body and therefore, to meet the Texas Surface Water Quality Standards, average DO should be greater than 5 mg/L with minimum DO of no less than 3 mg/L for the protection of aquatic life. (30 TAC 307.9).

Figure 1
Dissolved Oxygen and Flow at Barton Springs during the 1996 Drought

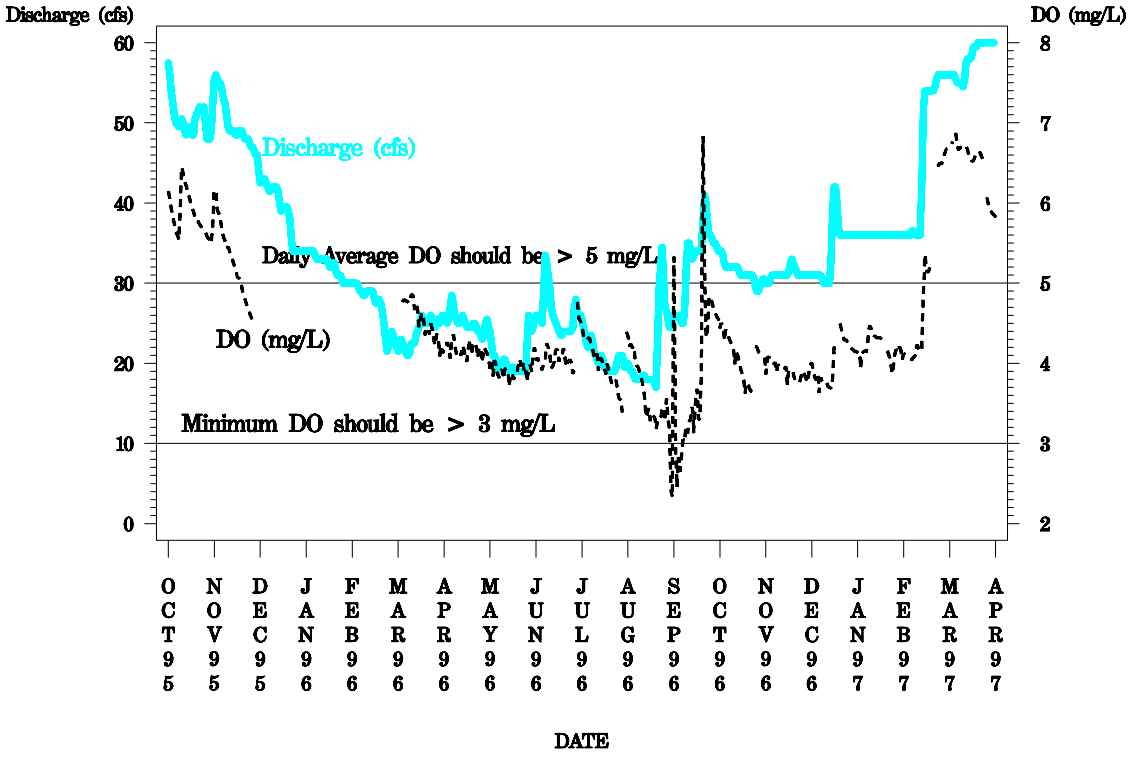
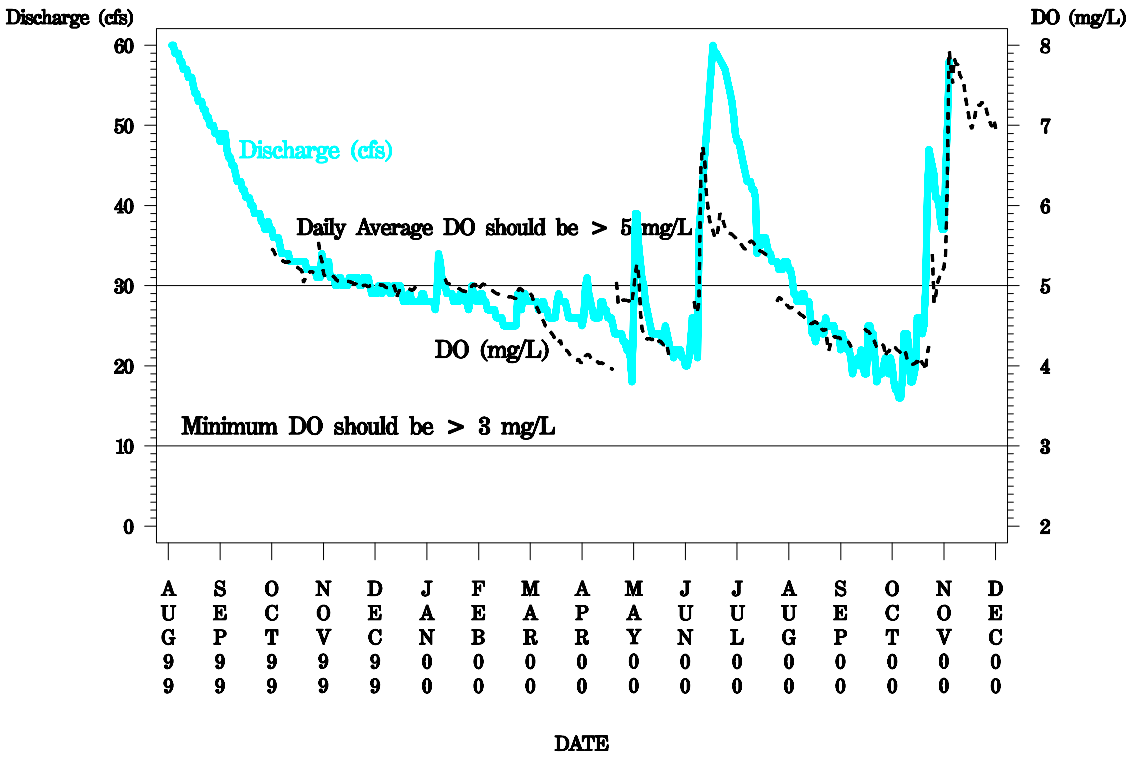


Figure 2
Dissolved Oxygen and Flow at Barton Springs during the 2000 Drought



The plotted relationship of flow to DO is confirmed by statistical analysis on both grab samples and data from Datasonde water quality probe data-loggers from 1993 through 2003. The best model of the data is a logarithmic, rather than a linear, relationship and a relatively good correlation is found or this model with R^2 values of 0.65 for the grab samples and 0.75 for the time series Datasonde data (Figures 3 and 4).

While the average DO levels are below 5 mg/L at drought flows, it has been suggested that the Barton Springs salamander can tolerate low DO concentrations because the salamander population survived the drought of the 1950's. Whereas tolerance of similar salamander species to low DO has been measured (Norris et al., 1963), the ability of the Barton Springs salamander to tolerate low DO has not been tested. However it should be noted that dissolved oxygen levels decreased by approximately 1 mg/L during the period from 1975through 2000 (Figure 5). This decline is statistically significant [$Pr>F < 0.0001$, $R^2=0.59$] (Turner, 2000). When increased pumping leads to decreased flow, the resulting dissolved oxygen levels will be lower than during the drought of the 1950's due to the decrease in oxygen levels over time. The resultant levels could be lower than the salamander requires for survival and reproduction. Table 1 shows the predicted mean dissolved oxygen for several flow levels based on the regression equation from Figure 4. No data were available below 17 cfs of discharge; therefore, the level of confidence in the predicted DO values for 14, 8, and 5 cfs is less than confidence levels at higher flows.

Figure 3
DO Data and Fitted Regression Line for 1993-2003 Grab Samples, Including an Estimate of the Average DO Levels in the 1950's.

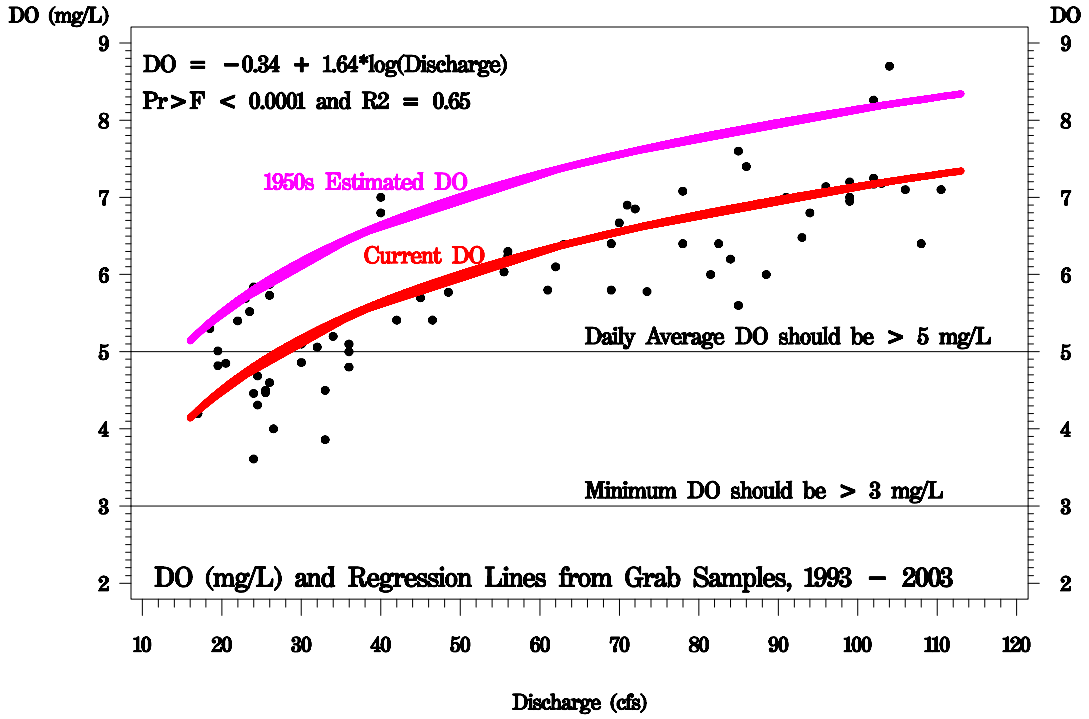


Figure 4
DO Data and Fitted Regression Line for 1993-2003 Datasonde Measurements, Including an Estimate of the Average DO Levels in the 1950's.

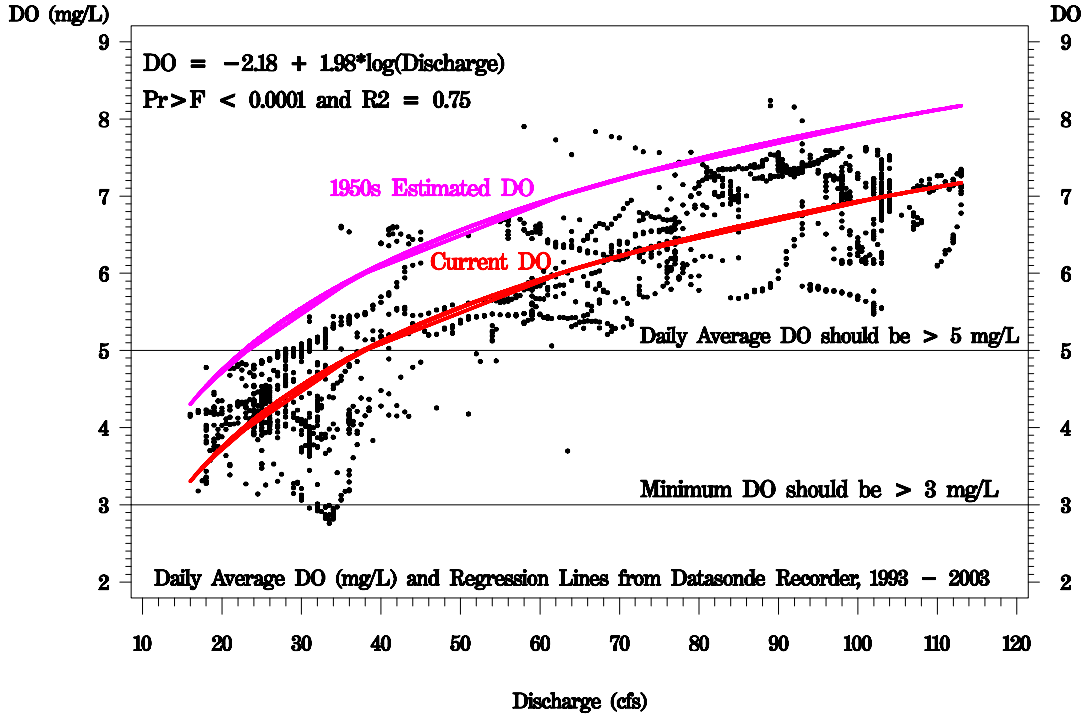
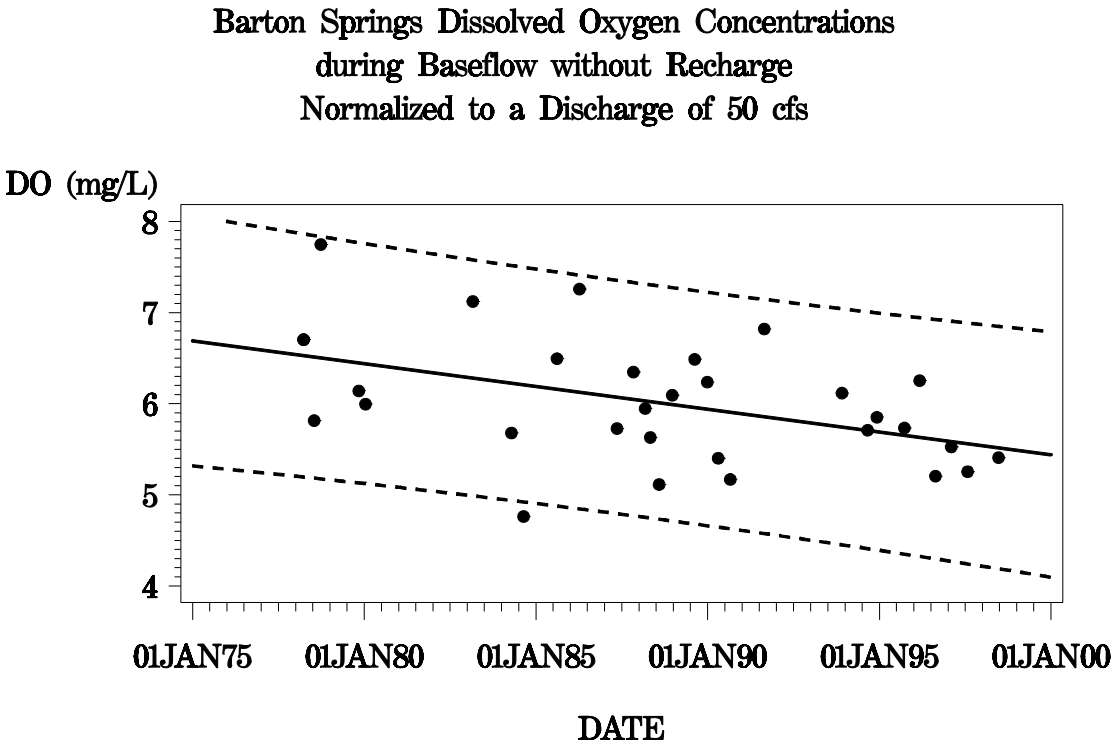


Table 1
Predicted Dissolved Oxygen for 5 Discharge Levels where DO = -2.18 + 1.98* $\log_e$(Discharge)

Discharge at Barton springs (cfs)	Predicted Dissolved Oxygen (mg/L)
38	5
23	4
14	3
8	2
5	1

Figure 5
Decrease of Dissolved Oxygen by 1 mg/L in Barton Springs since 1975.



Dissolved Oxygen and Salamander Counts at Barton Springs

Although the relationship between flow and DO is straightforward, the relationship between DO levels and salamander counts in Barton Springs Pool is more complicated. There appears to be a lag of about 6 months from periods of low DO to periods of low salamander counts. The linear relationship between salamander abundance and the DO measurements 6 months earlier is significant (Figure 6). While the regression is significant, the data may be better explained by a threshold model (Figure 7). Dissolved oxygen levels below 5 mg/L correspond to salamander counts of less than 20 individuals 6 months later. If DO levels are greater than 5 mg/L then the counts vary from 6 to over 80 individuals 6 months later, with most of the counts greater than 10 individuals. This variability is also dependent on other factors not captured in these simple comparisons.

Figure 8 shows the relationship between DO and mean salamander abundance 6 months later. Flow levels specified on the graph are from Table 1, and are intended to give a simple estimate of the expected range of flows for low DO levels. The data show a steady increase in mean number of salamanders as DO levels 6 months earlier increase. A possible reason for the lagged relationship is that when DO is low, reproduction falls off (Duellman and Trueb, 1986, Pianka, 1983), and the effects of decreased reproduction are not apparent until several months later. The percent of small salamanders in the total salamander count is the lowest for DO between 3 and 4 mg/L. This may support the hypothesis of decreases in reproduction when the adult salamanders are stressed by low DO levels, or it may be that juvenile salamanders are more sensitive to the low DO levels.

Figure 6
Relationship Between Dissolved Oxygen Levels and Barton Springs Salamander Abundance 6 Months Later

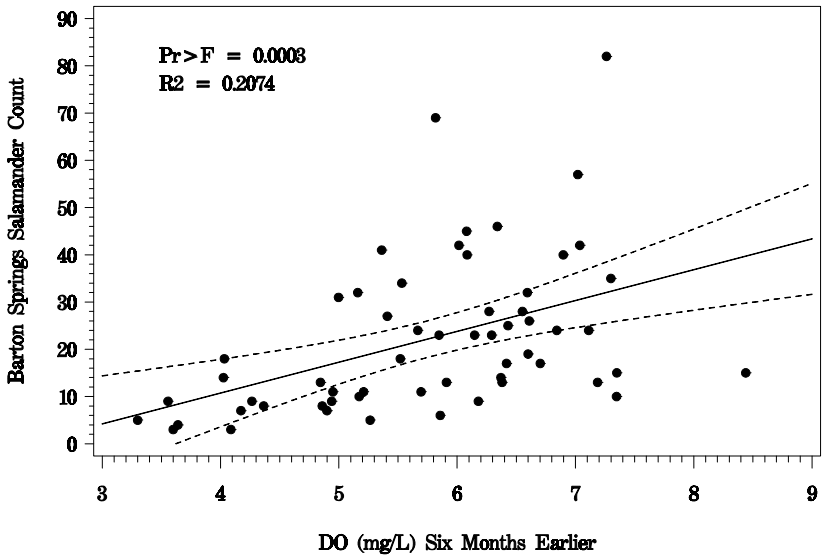


Figure7
Dissolved Oxygen Levels and Barton Springs Salamander Abundance 6 Months Later

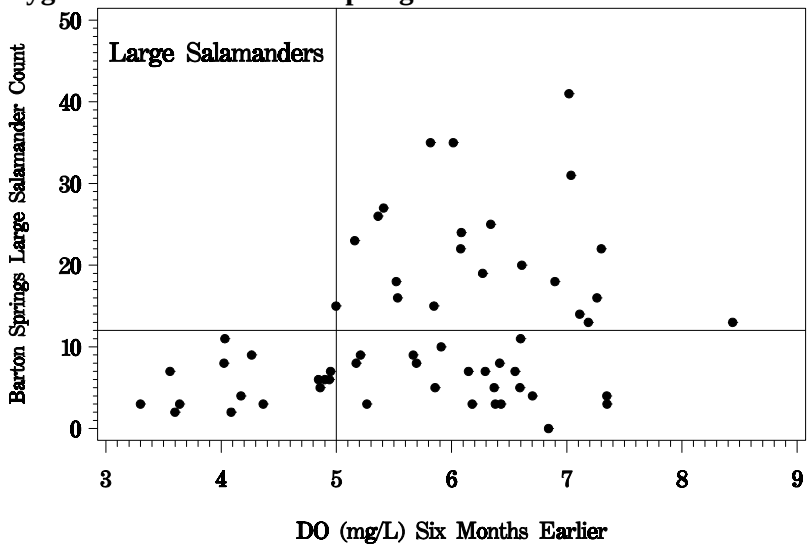


Figure 7 (continued)

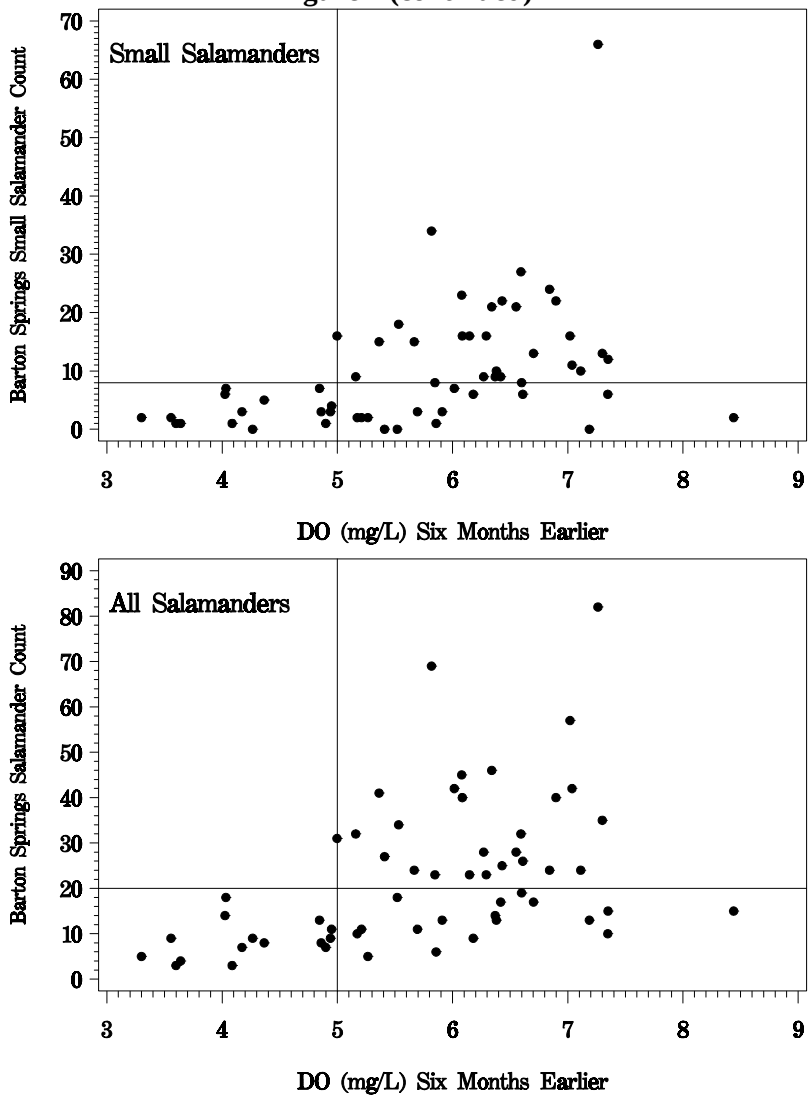
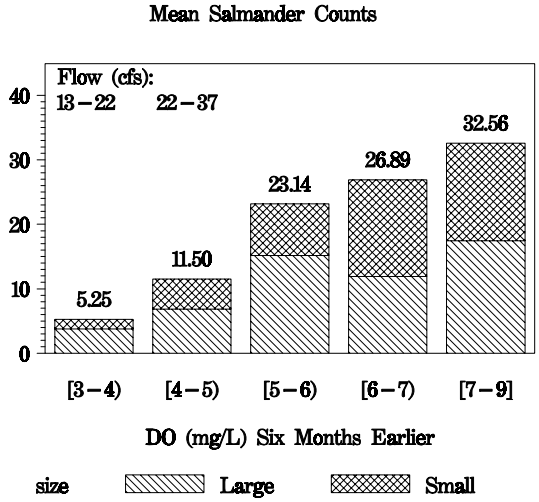


Figure 8
Grouped Dissolved Oxygen Levels and Mean Barton Springs Salamander Counts 6 Months Later



Salamander Counts during Low Flow Conditions at Eliza, Old Mill and Upper Barton Springs

Plots of water flow at Barton Springs and salamander counts at Eliza, Old Mill and Upper Barton Springs suggest a strong relationship (Figure 9). Flows below approximately 30 cfs at Barton Springs are associated with low counts at the smaller springs, which sometimes are completely or partially dry. This loss of habitat may be a serious threat to the salamander. Dissolved oxygen data from these springs are insufficient to allow direct comparisons of salamander counts to DO levels. However, anoxic sediment was observed at Eliza Spring during a low flow period. Table 2 shows apparent threshold flows below which counts are substantially lower than normal for these three springs and for Main (Parthenia) Barton Springs as well.

While it is clear that salamander counts drop at these three springs during low flow conditions it is unknown if the salamanders die, remain in the springs below where counted, or migrate to the main Barton Springs where stronger flow is present. DNA analysis currently underway may be able to answer this question by determining the genetic similarity of the populations among the springs.

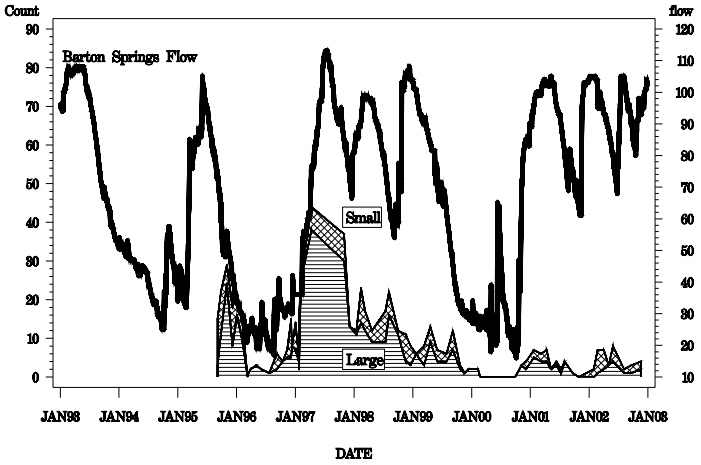
Regardless of responses at the smaller springs, the counts at the main Barton Spring also drop under low flow conditions. Therefore, the ability to migrate may not be enough to prevent major loss of salamanders during low flow conditions.

Table 2
Threshold Flows Below Which Salamander Counts are Low

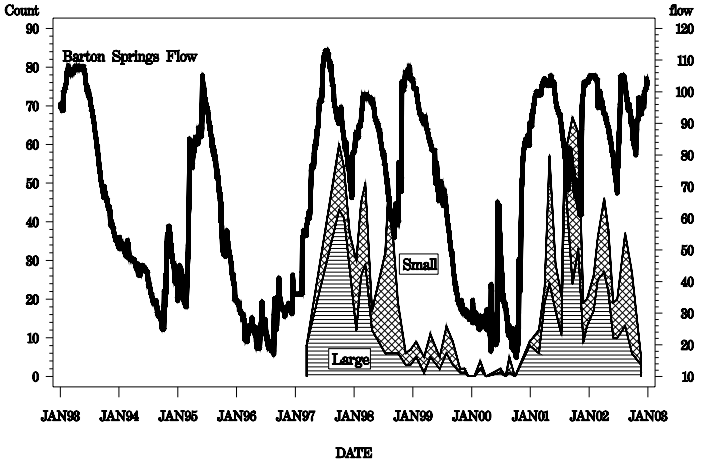
Spring	Threshold Flow	Maximum Number of Large Salamanders at flows below the threshold flow	Maximum Number of Small Salamanders at flows below the threshold flow	Number of Samples (1996-2002)	Comments	Maximum Number of Large Salamanders at all flows	Maximum Number of Small Salamanders at all flows
Eliza	<= 25 cfs	3	0	8		38	13
Old Mill	<=33 cfs	2	4	9	No samples at 34-45 cfs.	53	45
Upper Barton	40 cfs	0	0	0	Completely dry when Barton Springs is at 40 cfs.	14	4
	Threshold Flow 6 Months Earlier						
Barton	<30	11	7	17		41	66

Figure 9
Large and Small Salamander Counts at Eliza, Old Mill, and Upper Barton Springs and Barton Springs Flow vs. Time

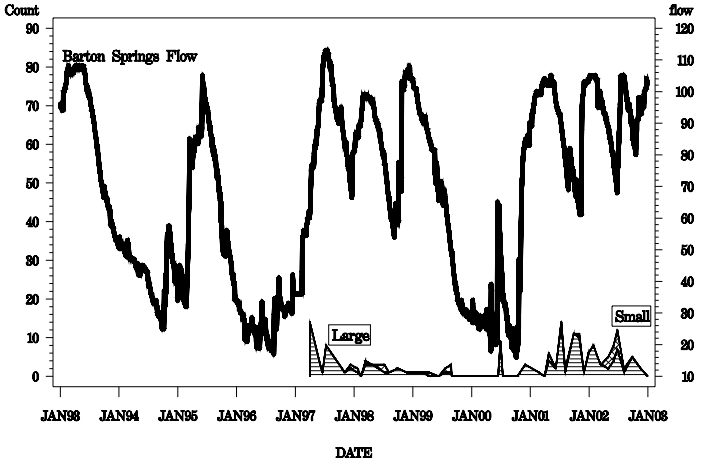
Eliza Spring



Old Mill Spring



Upper Barton Spring



Other Potential Water Quality Problems at Low Flows

Concentrations of sodium, chloride, sulfate and nitrogen increase when spring flows drop below 40 cfs and have been observed to double during recent droughts (David Johns, COA, in press). Increases in dissolved sodium and chloride generally represent leakage from the Saline or "Bad-Water" Zone, whereas increases in sulfate and strontium are generally attributed to greater leakage from the underlying Trinity aquifer (Senger and Kreitler, 1984). Aerated water from a bad water zone well has been shown to be toxic to *Eurycea nana* (San Marcos salamander), a surrogate for the Barton Springs salamander (COA 1999). The No Observed Effect Concentration (NOEC) for *Eurycea nana* was observed to be less than 6.25% of the aerated bad water zone well water. It is unknown at what flow level these water quality constituents may pose a threat to the Barton Springs salamander.

If flow levels drop significantly, water temperatures in the pool as a whole will also increase. A preliminary heat budget analysis of Barton Springs Pool, using the BSEACD proposed minimum flow of 3 cfs, shows that the pool water temperatures would increase to 25 degrees C. This is assuming no increase in the water temperature entering the pool at the spring. This temperature level may not threaten the salamanders if they are concentrated in areas where the spring flow is strong. However, temperatures any higher than 25 degrees C could be a concern due to the relationship between temperature and salamander heat tolerance, oxygen consumption, and metabolism. (Berkhouse and Fries, 1995; Feder 1978; Norris, 1963; Whitford, 1973)

Conclusions

The following conclusions were developed from the analyses discussed above:

- DO levels during future droughts will be worse than DO levels during equivalent flow periods in the past.
- DO of 5 mg/L is an apparent threshold below which salamander abundance declines.
- Flows of less than 30 cfs result in an average DO less than 5 mg/L.
- The predicted DO level of < 1 mg/L at the BSEACD-assumed low flow of 3 cfs during a drought as severe as the drought of record (1950's) could result in significant salamander mortality.
- Apparent threshold flows for Barton, Eliza, Old Mill, and Upper Barton are 30, 25, 33, and 40 cfs, respectively, below which salamander abundance declines.
- Extended periods of flow below recent drought levels (approximately 20 cfs) could result in declines in water quality could harm the Barton Springs salamander.

Recommendations

- Testing should be done to determine the sensitivity of the salamander *Eurycea nana* to low levels of dissolved oxygen
- Permitted pumpage from the aquifer is already at levels that could be detrimental to the Barton Springs salamander during critical conditions; therefore, future expansion of existing permits or approval of new permits is not recommended.
- Monitoring and periodic reassessment of both water quality trends and salamander counts is warranted annually.
- Strategies to address the decline in flow and dissolved oxygen should be formulated in both the Barton Springs Regional Water Quality Protection Plan and the Habitat Conservation Plan for the Barton Springs Salamander.

References

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