Comparison of water quality data at Testudo Tube Cave before and after construction.

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Testudo Tube Cave is located in an undeveloped area of Austin, TX. No previous information had been collected at this site, and road construction was scheduled to begin in 2005 that could affect the cave. A two part study was designed to obtain background information about the cave's water chemistry and to determine if the construction would affect the cave's water quality. During 2005, water samples were collected every two to three months beginning on February 17, 2005 until four samples were collected. A second set of samples was to be collected in April 2006 and January 2008 after the road construction. The samples collected in 2005 were Phase I samples, while the 2006 and 2008 samples were Phase II samples. The samples in Phase I were compared to Phase II in order to see any change that might have occurred. Temporal trends in water chemistry were investigated to determine if significant impacts had occurred. Samples were also compared to deionized water. Results show that nickel, calcium, and nitrate/nitrite increased over the study time. Nickel also increased significantly from Phase I to Phase II, while calcium and nitrate/nitrite have a marginal increase from Phase I to Phase II. Overall, the water chemistry parameters of Testudo Tube Cave were not significantly different from that of deionized water. The construction might have had an effect on the cave; however, the area seems to still have a high water quality.

Introduction

Testudo Tube Cave (site #3574) is located on a small undeveloped water quality protection land tract owned by the City of Austin (Austin Water Utility) near Lime Creek Road. Large limestone quarries are located in the surrounding areas of the cave. Improvements to Lime Creek Road began in 2005 and new home construction followed. It appeared as though the construction of the road was in such a location that the water quality of the cave may be affected by it; however, the location of the housing development was not expected to have an impact.

Road construction may cause the addition of nutrients and metals into nearby waterways from leaching and sediment runoff. As Testudo Tube Cave is home to Jollyville salamanders, *Eurycea* sp., and karst invertebrate species of concern, it was important to obtain a baseline for water chemistry while the area was still undeveloped and compare that with the water chemistry after any development to examine changes. This study compares the water quality of Testudo Tube Cave while the area is undeveloped to the quality of water in the cave after the construction that began in 2005 took place.

Methods

The study was conducted in two phases. In Phase I, background samples were collected before the construction in order to form a baseline of water quality in the cave. Phase I samples were collected from Testudo Tube Cave starting on 17 February 2005 through 2 November 2005 at intervals of two to three months. Although the Quality Assurance Program Plan (QAPP) calls for six samples during this phase, only four samples were collected before construction began. Phase II samples were collected to examine any effect the construction might have had on the cave's water chemistry. Follow up (Phase II) samples were collected on 19 April 2006, 25 April 2006, and 9 January 2008. Blanks were collected on 18 August 2005 and 2 November 2005. Due to poor sampling conditions the blank was the only sample gathered for 2 November 2005. The sample collected on 17 February 2005 was analyzed for a large suite of organic parameters, hardness, oil and grease content, cadmium, mercury, and water depth in addition to parameters that were analyzed in all subsequent sampling events (Table 1). With the exception of Bis(2-ethylhexyl)Phthalate, Di-N-Butyl Phthalate, Hardness, and water depth, all of the parameters that were collected just on 17 February 2005 were below detection levels.

Hardness and water depth are just measurements of the system and are not of much concern. BisS(2-ethylhexyl)Phthalate (or DEHP) is a common substance found in the environment due to its use in the creation of plastics and PVC. DEHP can be detrimental to aquatic life at high levels, but at 2.36µg/L it is unlikely to be very harmful to the water system. DI-N-Butyl Phthalate is another common substance found in the environment because of its use in plastics. This form of phthalate has not been shown to be as toxic as DEHP. The 3.79µg/L present in the water is not expected to have an effect on the ecosystem.

Table 1: List of parameters collected only on 17 February 2005 and those collected for every sampling event.

Parameters collected only on 17 FEB 2005 (measured parameter value)	**Parameters collected for every sample**
1_1_1-TRICHLOROETHANE (<1µg/L)	Alkalinity (mg/L)
1_1_2_2-TETRACHLOROETHANE (<1µg/L)	Ammonia-Nitrogen (mg/L)
1_1_2-TRICHLOROETHANE (<1µg/L)	Arsenic (µg/L)
1_1-DICHLOROETHANE (<1µg/L)	Calcium (µg/L)
1_1-DICHLOROETHYLENE (<1µg/L)	Chloride (mg/L)
1_2_4_5-TETRACHLOROBENZENE (<1µg/L)	Conductivity (uS/cm)
1_2_4-TRICHLOROBENZENE (<1µg/L)	Copper (µg/L)
1_2-DIBROMOETHANE (<1µg/L)	Dissolved Oxygen (DO) (mg/L)
1_2-DICHLOROBENZENE (<1µg/L)	*Escherichia coli* (cfu/100mL)
1_2-DICHLOROETHANE (<1µg/L)	Flouride (mg/L)
1_2-DICHLOROPROPANE (<1µg/L)	Iron (µg/L)
1_3-DICHLOROBENZENE (<1µg/L)	Lead (µg/L)
1_4-DICHLOROBENZENE (<1µg/L)	Magnesium (µg/L)
2_4_5-TP (SILVEX) (<0.5µg/L)	Nickel (µg/L)
2_4_5-TRICHLOROPHENOL (<1µg/L)	Nitrate+Nitrite-Nitrogen (mg/L)

Table 1 (continued)

Parameters collected only on 17 FEB 2005 (measured parameter value)	Parameters collected for every sample
2_4-DICHLOROPHENOL (<1µg/L)	Orthophosphorus (mg/L)
2_4-DICHLOROPHENOXYACETIC ACID (<0.5µg/L)	pH
2_4-DIMETHYLPHENOL (<1µg/L)	Potassium (µg/L)
2_4-DINITROPHENOL (<1µg/L)	Sodium (µg/L)
2_4-DINITROTOLUENE (<1µg/L)	Sulfate (mg/L)
2_6-DINITROTOLUENE (<1µg/L)	Total Suspended Solids (mg/L)
2-CHLOROETHYL VINYL ETHER (<1µg/L)	Water Temperature (°C)
2-CHLORONAPHTHALENE (<1µg/L)	Zinc (µg/L)
2-CHLOROPHENOL (<1µg/L)	
2-NITROPHENOL (<1µg/L)	
3_3'-DICHLOROBENZIDINE (<1µg/L)	
4_6-DINITRO-2-METHYLPHENOL (4_6-DINITRO-O-CRESOL) (<1µg/L)	
4-BROMOPHENYL PHENYL ETHER (<1µg/L)	
4-CHLOROPHENYL PHENYL ETHER (<1µg/L)	
4-NITROPHENOL (<1µg/L)	
ACENAPHTHENE (<1µg/L)	
ACENAPHTHYLENE (<1µg/L)	
ACROLEIN (<3µg/L)	
ACRYLONITRILE (<1µg/L)	
ANTHRACENE (<1µg/L)	
AZINPHOS METHYL (GUTHION) (<0.05µg/L)	
AZOBENZENE (<1µg/L)	
BENZENE (<1µg/L)	
BENZIDINE (<1µg/L)	
BENZO(A)ANTHRACENE (<1µg/L)	
BENZO(A)PYRENE (<1µg/L)	
BENZO(B)FLUORANTHENE (<1µg/L)	
BENZO(GHI)PERYLENE (<1µg/L)	
BENZO(K)FLUORANTHENE (<1µg/L)	
BIS(2-CHLOROETHOXY)METHANE (<1µg/L)	
BIS(2-CHLOROETHYL)ETHER (<1µg/L)	
BIS(2-CHLOROISOPROPYL)ETHER (<1µg/L)	
BIS(2-ETHYLHEXYL)PHTHALATE (2.36µg/L)	
BOLSTAR (SULPROFOS) (<0.05µg/L)	
BROMACIL (<0.05µg/L)	
BROMOCHLOROMETHANE (<1µg/L)	
BROMODICHLOROMETHANE (<1µg/L)	
BROMOFORM (<1µg/L)	
BUTYL BENZYL PHTHALATE (<1µg/L)	
CADMIUM (<1µg/L)	
CARBON TETRACHLORIDE (<1µg/L)	
CHLOROBENZENE (<1µg/L)	
CHLOROETHANE (<1µg/L)	
CHLOROFORM (<1µg/L)	
CHLORPYRIFOS (DURSBAN) (<0.05µg/L)	
CHROMIUM (<1µg/L)	
CHRYSENE (<1µg/L)	
CIS-1_2-DICHLOROETHENE (<1µg/L)	

Table 1 (continued)

Parameters collected only on 17 FEB 2005 (measured parameter value)	**Parameters collected for every sample**
CIS-1_3-DICHLOROPROPENE (<1µg/L)	
DEMETON (<0.05µg/L)	
DIAZINON (<0.05µg/L)	
DIBENZ(AH)ANTHRACENE (<1µg/L)	
DIBROMOCHLOROMETHANE (<1µg/L)	
DIBROMOMETHANE (<1µg/L)	
DICHLORVOS (<0.05µg/L)	
DIETHYL PHTHALATE (<1µg/L)	
DIMETHOATE (<0.05µg/L)	
DIMETHYL PHTHALATE (<1µg/L)	
DI-N-BUTYL PHTHALATE (3.79µg/L)	
DI-N-OCTYL PHTHALATE (<1µg/L)	
DISULFOTON (DISYSTON) (<0.05µg/L)	
EPN (SANTOX) (<0.05µg/L)	
ETHOPROPHOS (ETHOPROP) (<0.05µg/L)	
ETHYLBENZENE (<1µg/L)	
FENSULFOTHION (<0.05µg/L)	
FENTHION (BAYTEX) (<0.05µg/L)	
FLUORANTHENE (<1µg/L)	
FLUORENE (9H-FLUORENE) (<1µg/L)	
HARDNESS (AS CACO3) (368 mg/L)	
HEXACHLOROBENZENE (HCB) (<1µg/L)	
HEXACHLOROBUTADIENE (<1µg/L)	
HEXACHLOROCYCLOPENTADIENE (<1µg/L)	
HEXACHLOROETHANE (<1µg/L)	
INDENO(1_2_3-CD)PYRENE (<1µg/L)	
ISOPHORONE (<1µg/L)	
MERCURY (<0.15µg/L)	
METHYL CHLORIDE (CHLOROMETHANE) (<1µg/L)	
METHYL ETHYL KETONE (BUTANONE) (<5µg/L)	
METHYL PARATHION (<0.05µg/L)	
METHYLENE CHLORIDE (<1µg/L)	
MEVINPHOS (PHOSDRIN) (<0.05µg/L)	
MONOCROTOPHOS (<0.05µg/L)	
NALED (DIBROM) (<0.05µg/L)	
NAPHTHALENE (<1µg/L)	
NITROBENZENE (<1µg/L)	
N-NITROSODIETHYLAMINE (<1µg/L)	
N-NITROSODIMETHYLAMINE (<1µg/L)	
N-NITROSO-DI-N-BUTYLAMINE (<1µg/L)	
N-NITROSO-DI-N-PROPYLAMINE (<1µg/L)	
N-NITROSODIPHENYLAMINE (<1µg/L)	
OIL AND GREASE (<5mg/L)	
PAH (POLYCYCLIC AROMATIC HYDROCARBONS) (<0.016mg/L)	
PARATHION (PARATHION ETHYL) (<0.05µg/L)	
P-CHLORO-M-CRESOL (<1µg/L)	
PENTACHLOROBENZENE (<1µg/L)	
PENTACHLOROPHENOL (<1µg/L)	

Table 1 (continued)

Parameters collected only on 17 FEB 2005 (measured parameter value)	Parameters collected for every sample
PHENOL (<1µg/L)	
PHORATE (THIMET) (<0.05µg/L)	
PYRENE (<1µg/L)	
PYRIDINE (<1µg/L)	
RONNEL (FENCHLORPHOS) (<0.05µg/L)	
SILVER (<1µg/L)	
SULFOTEPP (BLADAFUME) (<0.05µg/L)	
TETRACHLOROETHYLENE (TETRACHLOROETHENE) (<1µg/L)	
TETRACHLOROVINPHOS (STIROPHOS) (<0.05µg/L)	
TOKUTHION (PROTOTHIOFOS) (<0.05µg/L)	
TOLUENE (<1µg/L)	
TOTAL CRESOLS (<1µg/L)	
TRANS-1_2-DICHLOROETHENE (TRANS-1_2-DICHLOROETHYLENE) (<1µg/L)	
TRANS-1_3-DICHLOROPROPENE (<1µg/L)	
TRICHLOROETHYLENE (TCE) (<1µg/L)	
TRICHLORONATE (<0.05µg/L)	
VINYL CHLORIDE (<1µg/L)	
WATER DEPTH (14.34 cm)	

Parameters collected were compared to the Environmental Protection Agency's (EPA's) criteria for aquatic life in order to verify that their was no expected chronic or acute toxicity. The information collected from the cave was also compared to water quality data collected for the Jollyville Plateau Water Quality and Salamander Assessment (City of Austin, 2001) to see if the water chemistry in Testudo Tube Cave was similar to water chemistry of other known locations of the Jollyville salamander.

Differences between parameters collected during Phase I and Phase II were analyzed by either the t-test in SAS using TTEST or the Wilcoxon test in SAS using NPAR1WAY. The t-test was used for parameters that met the proper assumptions for parametric tests while the Wilcoxon test was used for the parameters that did not meet the criteria. Comparisons between parameters in Phase I and Phase II with censored data (data below detection level) were done by non-parametric survival analysis using STRATA in SAS under PROC LIFETEST (Allison, 1995). Summary statistics for censored data were computed by Kaplan-Meier estimation methods.

The water quality of Testudo Tube Cave has not been previously described, so a statistical comparison between deionized water and the cave's water was performed. Non-parametric survival analysis was performed using STRATA in SAS PROC LIFETEST, with the option of using the Peto and Peto test to compensate for unequal sample sizes (Latta 1981).

Temporal trends were analyzed using least-square linear regression in SAS by PROC REG. Parameters with censored data were analyzed by Cox's proportional hazards

regression in SAS PROC PHREG (Allison, 1995). The Wald test was used to calculate all p-values except nickel, where the likelihood ratio test was used because the Wald test produced no response. All trends were verified by visual inspection. All tests used a critical value (α) of 0.05 to test for significance.

Finally, a Piper diagram was created to classify the water chemistry in the cave and to determine temporal differences. The samples collected in June 2005 and November 2005 were not used in the Piper diagram. The sample collected in June did not have all of the parameters needed for the diagram, and the sample collected in November was collected as strictly blank samples.

Results

All parameters analyzed were in an acceptable range for supporting aquatic life according to the EPA's water quality criteria. When compared to the sites used in the Jollyville salamander assessment, the means of all the parameters measured at Testudo Tube Cave were close to the lower readings collected at rural assessment sites except for alkalinity, calcium, and iron (City of Austin, 2001). The means of these three parameters were closer to levels in the sites designated as urban rather than rural. When the data for Testudo Tube Cave was broken into two phases, the means of alkalinity, calcium, and iron were still in the higher range of the assessment sites. Therefore, these parameters were at a higher level before the subject road and subdivision construction took place.

While all of the measurements collected for calcium and alkalinity are in this high range, iron was measured to be low at all but two dates. The samples collected on 18 August 2005 and 25 April 2006, both have elevated measurements of iron in the water. The other samples taken had low levels of iron when compared to the sites tested in the Jollyville assessment.

Table 2: Minimums/Maximums and Means of parameters in Phase I and Phase II at Testudo Tube Cave and the test comparison between phases for each parameter.

Parameter	**Analysis**	**Min/Max Phase I**	**Phase I (N=3)**	**Min/Max Phase II**	**Phase II (N=3)**	**P-value**
Alkalinity (mg/L)	t-test	365/384	372	356/378	367	0.5716
Ammonia-N (mg/L)	Survival	<0.02/0.03	0.030	<0.02/0.036	0.036	0.9767
Arsenic (ug/L)	Survival	<6/<6	< 6**	<6/<6	< 6**	---
Calcium (mg/L)	t-test	139.38/144.04	141.71	148.00/158.00	152.33	0.0855
Chloride (mg/L)	t-test	10.7/12.6	11.9	11.5/13.5	12.4	0.5480
Conductivity (uS/cm)	t-test	715/737	724	685/721	702	0.1566
Copper (ug/L)	Survival	<6/<6	< 6**	<6/<6	< 6**	---
DO (mg/L)	Wilcoxon	4.59/7.72	5.93	4.70/7.46	6.53	0.5000
E. coli (mpn/100ml)	t-test	15/84	50	1/90	34	0.7464
Fluoride (mg/L)	Survival	<0.02/0.21	0.19	0.11/0.33	0.252	0.2675

*Iron is represented by the median of the data and not the mean.
**100% censored data.

Table 2 (continued)

Parameter	Analysis	Min/Max Phase I	Phase I (N=3)	Min/Max Phase II	Phase II (N=3)	P-value
Iron (ug/L)	Survival	<20/247	20*	<20/306	27*	0.4928
Lead (ug/L)	Survival	<3/<3	< 3**	<5/<5	< 5.00**	---
Magnesium (ug/L)	t-test	3101/3129	3115	2820/3490	3180	0.8131
Nickel (ug/L)	Survival	<3.00/<3.00	< 3.00**	3.41/5.83	4.307	0.0360
Nitrate/Nitrite (mg/L)	Wilcoxon	0.35/0.36	0.36	0.38/0.41	0.40	0.1000
Organic Carbon (mg/L)	t-test	1.39/2.07	1.65	1.06/5.69	3.2433	0.3579
Orthophosphorus (mg/L)	Survival	<0.02/0.03	0.03	<0.02/<0.02	<0.02**	0.3173
pH	t-test	6.97/7.07	7.03	6.76/7.28	7.02	0.9188
Potassium (ug/L)	t-test	471/731	601	500/657	586	0.9012
Sodium (ug/L)	t-test	9997/11919	10958	6730/8740	8020	0.0756
Sulfate (mg/L)	t-test	9.33/10.50	10.01	9.88/11.10	10.43	0.4525
Total Suspended Solids (mg/L)	Survival	<4/13	8.267	<4/14.6	12.067	0.6445
Water Temperature (°C)	t-test	19.23/20.1	19.56	19.56/20.01	19.75	0.5654
Zinc (ug/L)	Survival	<6.0/29.5	29.5	<6/28.7	10.4	0.2522

*Iron is represented by the median of the data and not the mean.
**100% censored data.

T-tests, Wilcoxon tests, and survival analysis methods were used to compare the water chemistry of samples collected in Phase I of the study to that of the samples collected in Phase II. The only parameter that showed a significant difference between Phase I and Phase II was nickel (Table 2). Calcium, nitrate/nitrite, and sodium were marginally different ($p \leq 0.1$). Some other parameters of interest were zinc, chloride, and fluoride. While none of these parameters had a significant or marginal difference between Phase I and Phase II, the mean of chloride and fluoride did increase. When Zinc was detected it was much higher than detection level but was not detected often. No analysis could be performed on arsenic, copper, or lead as the majority of the readings were censored (i.e. below detection level). All of the values for arsenic, copper, lead, Phase I nickel, and Phase II orthophosphorus were below detection levels. Iron is represented by the median as the mean for iron is slightly biased due to position of censored data points.

The water chemistry of Testudo Tube Cave was compared to that of deionized water by non-parametric survival analysis. Conductivity, dissolved oxygen, pH, and water temperature were not included in this analysis because no readings were collected for these parameters in deionized water. No parameter in Testudo Tube Cave samples was significantly different from the parameter in deionized water (Table 3). Alkalinity, arsenic, calcium, chloride, magnesium, nitrate/nitrite, potassium, sodium, and sulfate in Testudo Tube Cave are marginally different from deionized water ($p \leq 0.1$). It may be of concern that the mean for arsenic was somewhat high in the blank sample. Copper and lead could not be compared because there were too many censored values. Many of the parameters in deionized water are below detection level, thus the data is highly censored.

Table 3: Means of parameters in Testudo Tube Cave and distilled water (blank) with comparison (LIFETEST) results.

Parameter	Blank (N=2)	Testudo Tube Cave (N=6)	P-value
Alkalinity (mg/L)	7.8	369.7	0.0716
Ammonia-N (mg/L)	0.02	0.031	0.6350
Arsenic (ug/L)	2.8	0.7	0.0833
Calcium (mg/L)	0.2	148.1	0.0751
Chloride (mg/L)	<0.5*	12.1	0.0716
Copper (ug/L)	<6*	<6	---
E. coli (mpn/100ml)	0*	40	0.2930
Fluoride (mg/L)	<0.02*	0.2	0.2729
Iron (ug/L)	7.8	103.9	0.2227
Lead (ug/L)	<3*	<5	---
Magnesium (ug/L)	38.2	3154.0	0.0751
Nickel (ug/L)	<3.0*	3.9	0.2745
Nitrate/Nitrite (mg/L)	<0.02*	0.4	0.0633
Organic Carbon (mg/L)	1.1	2.4	0.2340
Orthophosphorus (mg/L)	<0.02*	<0.02	0.5637
Potassium (ug/L)	23.5	591.8	0.0751
Sodium (ug/L)	<1000.0*	9195.2	0.0751
Sulfate (mg/L)	<0.5*	10.2	0.0716
Total Suspended Solids (mg/L)	<0.5*	8.7	0.1025
Zinc (ug/L)	<6.0*	29.0	0.2596

*100% censored data.

Temporal trends of the parameters collected in Testudo Tube Cave were performed to further analyze any change in water chemistry. Calcium, nickel, and nitrate/nitrite all had significantly increasing trends (Table 4). Nickel had a significant increasing trend according to the likelihood ratio test and the score test, but the parameter had no response from the Wald test. No other parameter had a significant temporal trend. Arsenic, copper, and lead were not analyzed because of too many censored data points.

Table 4: Temporal trends (REG for non-censored data, PHREG for censored data) for parameters in Testudo Tube Cave with appropriate regression line description (R^2 for REG, Hazard ration for PHREG) for significant trends.

Parameter	Analysis	P-value (R^2/Hazard ratio)
Alkalinity (mg/L)	REG	0.2614
Ammonia-N (mg/L)	PHREG	0.2832
Arsenic (ug/L)	PHREG	---
Calcium (mg/L)	REG	0.0396 (0.7372)
Chloride (mg/L)	REG	0.6309
Conductivity (uS/cm)	REG	0.0727
Copper (ug/L)	PHREG	---
DO (mg/L)	REG	0.6650
E. coli (mpn/100ml)	REG	0.2224
Fluoride (mg/L)	PHREG	0.9423

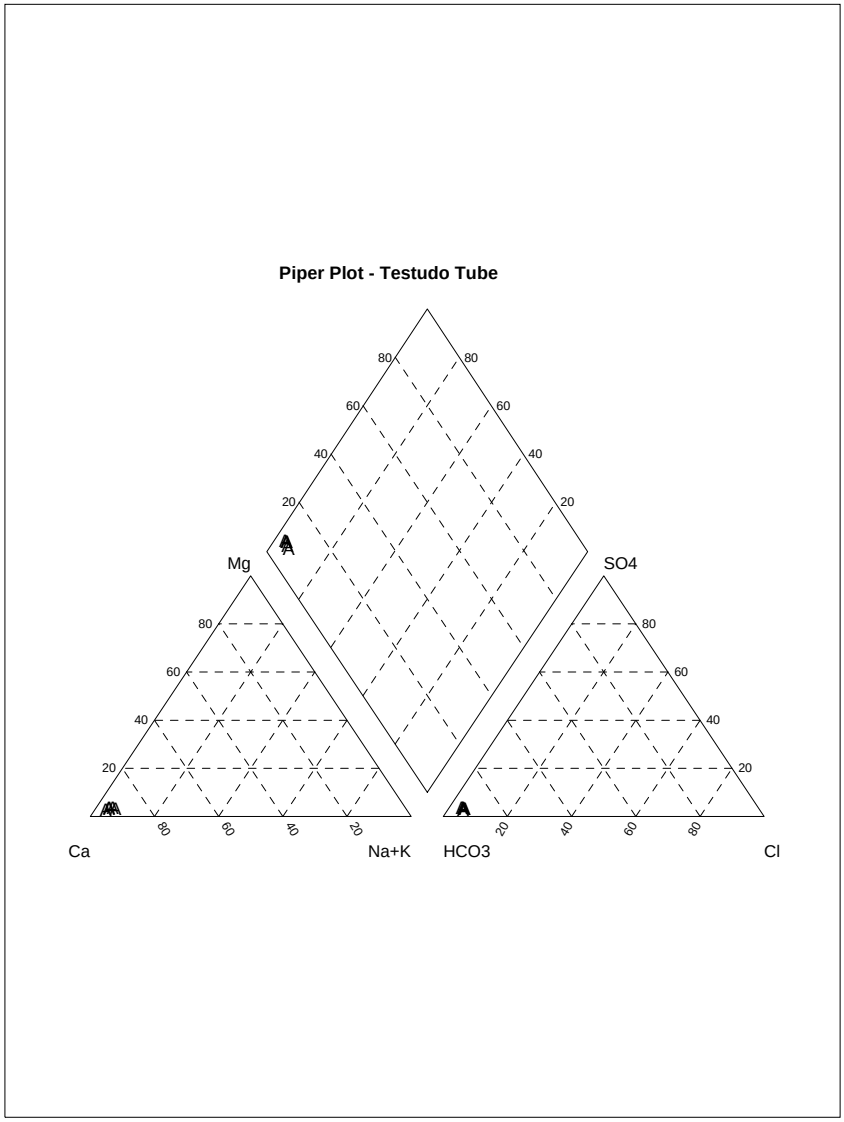
Table 4 (continued)

Parameter	Analysis	P-value (R^2/Hazard ratio)
Iron (ug/L)	PHREG	0.9854
Lead (ug/L)	PHREG	---
Magnesium (ug/L)	REG	0.7988
Nickel (ug/L)	PHREG	0.0020*
Nitrate/Nitrite (mg/L)	REG	0.0338 (0.6446)
Organic Carbon (mg/L)	REG	0.9878
Orthophosphorus (mg/L)	PHREG	1.0000
pH	REG	0.9549
Potassium (ug/L)	REG	0.9167
Sodium (ug/L)	REG	0.3463
Sulfate (mg/L)	REG	0.8600
Total Suspended Solids (mg/L)	PHREG	0.2741
Water Temperature (°C)	REG	0.4742
Zinc (ug/L)	PHREG	0.1958

* Likelihood ratio test used to calculate the p-value, since the Wald test produced no response.

Based on the ionic chemistry, the ground water in Testudo Tube Cave was classified as calcium/bicarbonate (Figure 1). The grouping of the five samples over the time period indicates that the dominant ion concentrations have very little variation. This suggests that the factors affecting the ionic composition of the water did not change over time.

Figure 1: Piper Plot of Ion Data from Testudo Tube Cave.



Conclusions

The original sampling of the cave showed low levels of organics, metals, and other ions. Most parameters collected for only the first sample were below detection level. Only DEHP and Di-N-Butyl Phthalate were available in trace amounts, which is common in water bodies because they are used in plastics. From the parameters collected throughout the study period only alkalinity, calcium, iron, and total suspended solids seem to be in a high range when compared to other sites where Jollyville salamanders are located. However, the parameters that seem to be of most concern in the study are calcium, nickel, and nitrate/nitrite.

The significant difference for nickel between phase one and two implies that the some source of nickel fed into the cave's system during the time of the study. One possible

cause of this increase could be the road construction that began in the latter portion of 2005, as trace amounts of nickel are common in asphalt. The trend of nickel to increase over time may be due to ongoing construction around the cave that continues to add the metal to the system. Eventually, this increase of nickel could become a problem for the aquatic life in Testudo Tube Cave; however, currently the amount of nickel in the system is comparable to deionized water.

Although nitrate/nitrite and calcium are only marginally different between phase one and phase two, the parameters increased significantly over the time period of the study suggesting that something was adding nitrate/nitrite and calcium to this water system. There are many ways to add nitrate/nitrite to the system. Possibilities include sediment runoff or leaching from a construction source. The road improvements could be one source of nitrogen entering the cave as nitrogen is a key component of asphalt, which is used to build most roadways.

Possible causes for the increase in calcium could be sediment runoff. The surrounding area is known to be a limestone quarry, and some amount of calcium would be present in soil that could support such a quarry. Construction is known to produce large amounts of sediment runoff to waterways, so it is possible that the construction was one source of calcium input into the system. The change in calcium was not matched by the other ions in the water body. Therefore, the overall water chemistry does not appear to be impacted by the road construction.

Like nickel, both nitrate/nitrite and calcium are still at low levels in the cave. Neither are significantly different from that present in deionized water. The low levels support a healthy groundwater system; however, the significant increase of nitrate/nitrite, nickel, and calcium may suggest a need to observe Testudo Tube Cave in the future as increasing levels of these substances may eventually affect cave fauna. While these measurements are low, nitrate at extreme levels (10 mg/L) has been associated with deformities in aquatic life.

No runoff from road construction was observed to enter Testudo Tube Cave; however, it is possible that the construction did have some effect on the area. Prior to the construction the water chemistry of the cave consisted of low levels of organics and metals. During the time period of the construction nickel, calcium, and nitrate/nitrite all increased in the cave. However, most of the parameters measured are still at low levels after the period of the study and meet surface water quality criteria; therefore, the water quality of Testudo Tube Cave does not appear to be significantly degraded..

References

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