Monitoring DDT and PAHs in Barton Springs Sediment
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Abstract

Barton Springs is an environmentally-sensitive area which provides habitat for two endangered aquatic salamander species, supplies water to Barton Springs pool, and represents the primary discharge point for the Barton Springs segment of the Edwards Aquifer, a sole-source aquifer for the Austin area. DDT, DDD, DDE, and a list of polycyclic aromatic hydrocarbons (PAH) are toxic pollutants that have been monitored in the sediment at Barton Springs for at least 15 years. Trends of these pollutants over time were analyzed at Barton Springs and current concentrations of the pollutants present within the springs were compared to concentrations of the pollutants in sediment samples collected throughout Austin in 2013 and 2014. DDT, DDD, and DDE were not pollutants of concern for Barton Springs; however, PAH including benzo(a)anthracene, benzo(a)pyrene, benzo(e)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, phenanthrene, and pyrene have risen in concentration beginning in approximately 2006. While many samples at Barton Springs have not contained samples above probable effect concentration levels, investigation is warranted to determine why the PAH concentrations increased. The initial concern of this report was to address sediment pollution at Barton Springs but additional sites of concern were identified upon comparison of pollutant concentrations at Barton Springs to concentrations throughout Austin in 2013 and 2014. Most notably, sediment samples collected within the Harper's Branch watershed indicate chronically toxic sediments and an investigation for a source should be conducted.

Introduction

Barton Springs is an environmentally-sensitive area consisting of four springs, Main, Eliza, Old Mill (Sunken Garden), and Upper Barton (Brune 1981, Hauwert et al. 2004a), which are the primary discharge points for the Barton Springs segment of the Edwards Aquifer (Hauwert et al. 2004b). Water quality in the springs is of interest because the spring flow provides habitat for the Barton Springs salamander (*Eurycea sosorum*) and Austin Blind salamander (*Eurycea waterlooensis*), two federally listed endangered species (US Fish and Wildlife Service 1997; US Fish and Wildlife Service 2013), supplies water to Barton Springs pool (municipal swimming facility), and represents water from a Safe Drinking Water Act sole source aquifer for the Austin area (US EPA 2006). The City of Austin (COA) monitors the springs in order to track any water quality degradation that may occur due to anthropogenic sources in the contributing and recharge zones of the Barton Springs segment of the Edwards Aquifer. Part of the monitoring includes analyzing the metals, pesticides/herbicides, and polycyclic aromatic hydrocarbons (PAH) in the sediments around the springs. DDT was detected for the first time since 2005 in the sediment samples of Main Barton Springs collected in May and October 2014. This prompted this analysis to detect any trends over time for DDT (and its metabolites) and PAH in Main, Eliza, Sunken Garden, and Upper Barton springs. In addition, the concentrations of these pollutants present at the springs were compared to concentrations present in the most recent sediment samples collected throughout Austin.

DDT (1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane) is an insecticide previously used in the United States to control insects on agricultural crops and to kill insects that carried diseases such as malaria and typhus. DDD (1,1-dichloro-2,2-bis(p-chlorophenyl)ethane) and DDE (1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene) are breakdown products (metabolites) of DDT. Both DDD and DDE are present in the environment as a result of the breakdown of DDT; however, DDD was also used as a pesticide but to a far less extent when compared to DDT. Human and animal exposure to DDT/DDD/DDE affects the nervous system and can cause tremors or convulsions, causes cancer in animals (primarily in the liver), has been assigned as probable human carcinogens by the Environmental Protection Agency (EPA), and alters the development of reproductive organs in animals (ATSDR 2002, US EPA 2015). The EPA banned the use of DDT in 1972, except for public health emergencies. Today, DDT cannot be legally sold or distributed inside the United States; however, it is still used in other countries to control insect populations that might spread disease. DDT has a long half-life and is not readily degraded through hydrolysis, oxidation, or direct photolysis which leads to the pollutant being very persistent in the environment (US EPA 1979). In fact, the half-life of DDT in soil has been estimated at 15 years or longer. While the use of DDT in the United States has been banned since the 1970s, DDT continues to be detected in sediment and aquatic biota across the United States (Nowell et al. 1999). Current sediment sources of DDT in the United States are thought to include short and long distance atmospheric transport followed by wet and dry atmospheric deposition and erosion of soils that have been contaminated from past use (Rapaport et al. 1985, Nowell et al. 1999, US HHS 2002, Gioia et al. 2005).

PAH are a group of chemical compounds consisting of three or more fused benzene rings. The number of rings and the shape of the ring structure both play a role in the chemical properties of the different PAH. These compounds are currently on the Toxic Pollutants and Priority Pollutants lists of the Code of Federal Regulations at 40 CFR 401.15 and 40 CFR 423 Appendix A, respectively. PAH are considered Toxic Pollutants because they persist in the environment; several are toxic, carcinogenic, mutagenic, and/or teratogenic (causing birth defects) to aquatic life; and seven are probable human carcinogens (US EPA 2015). PAH are able to persist in the environment because they generally have a low volatility and a high resistance to biodegradation (McElroy et al. 1989). While PAH occur naturally at low concentrations from combustion of organic matter, problems tend to occur in urban environments where the concentrations of PAH are higher due to an increased number of anthropogenic sources (Stout et al. 2004). Anthropogenic sources include the combustion of fossil fuels in heat and power generation, gasoline based vehicle emissions, and the combustion of waste incineration (Ramdahl et al. 1983, Wild and Jones 1995).

Research conducted by the US Geological Survey (USGS) in cooperation with the City of Austin identified coal-tar based pavement sealant as a significant anthropogenic source of PAH in urban environments (Mahler et al. 2005). The City of Austin prohibited the use of coal-tar based pavement sealants in Austin in 2006. PAH concentrations may be decreasing over time for some constituents in Austin creek sediments, and total PAH significantly decreased in Barton Creek sediments upstream of Barton Springs from 1996 to 2010 (Richter 2012). Recent USGS studies found that average PAH concentrations in the downstream basin of Lady Bird Lake (Austin, Texas) have declined 58% since the ban, reversing a 40-year increasing trend (Van Metre and Mahler 2014).

DDT (and its metabolites) and PAH are hydrophobic and tend to sorb to particulates in the water column, eventually settling to the substrate of water bodies as sediment. Thus, concentrations in the sediment tend to be much higher than concentrations in the water column (Moore and Ramamoorthy 1984). The accumulation in the sediment can lead to toxic effects to the surrounding biological communities. State of Texas regulations in 30 Texas Administrative Code 307.6 and associated guidance protect aquatic life from toxic conditions in both the water column and the sediment (TCEQ 2012). MacDonald et al. (2000) developed consensus-based sediment quality guideline concentrations for 28 chemicals of concern which included metals, PAH, polychlorinated biphenyls, and pesticides. The threshold effect concentration (TEC) was developed as the concentration under which adverse effects are not expected to occur and the probable effect concentration (PEC) was developed as the concentration above which adverse impacts are expected to occur (McDonald et al. 2000). Currently the Texas Commission on Environmental Quality (TCEQ) identifies a concern for aquatic life if more than 20% of sediment samples collected contain contaminants exceeding the PEC using the binomial method for ten PAH (TCEQ 2012). The TCEQ has also included acenaphthene and acenaphthylene as PAH of concern if concentrations are above the probable effect level (PEL) noted from the Canadian Council of Ministers of the Environment (1999). The threshold effect level (TEL) is thought to be the concentration below which it is rare to see adverse impacts to aquatic life while the PEL is the concentration where adverse impacts to aquatic life are probable. In addition to a trend analysis for sediment contaminants at the springs, recent contaminant concentrations throughout Austin were compared to the TEC and PEC levels developed by MacDonald et al. (2000) or the TEL and PEL noted from the Canadian Council of Ministers of the Environment (1999) to identify potential sites of concern for sediment toxicity.

Methods

The four individual springs where sediment samples were obtained are aligned upstream to downstream along Barton Creek in the order of Upper Barton Spring, Main Barton Spring, Eliza Spring, and Old Mill (Sunken Garden) with a span of approximately 1,800 ft between Upper Barton Spring and Sunken Garden. Other sediment locations considered in comparison were mouth sites of Austin watersheds included in the Environmental Integrity Index (EII), a program which monitors Austin creeks on a biannual rotation (Figure 1, Table 1).

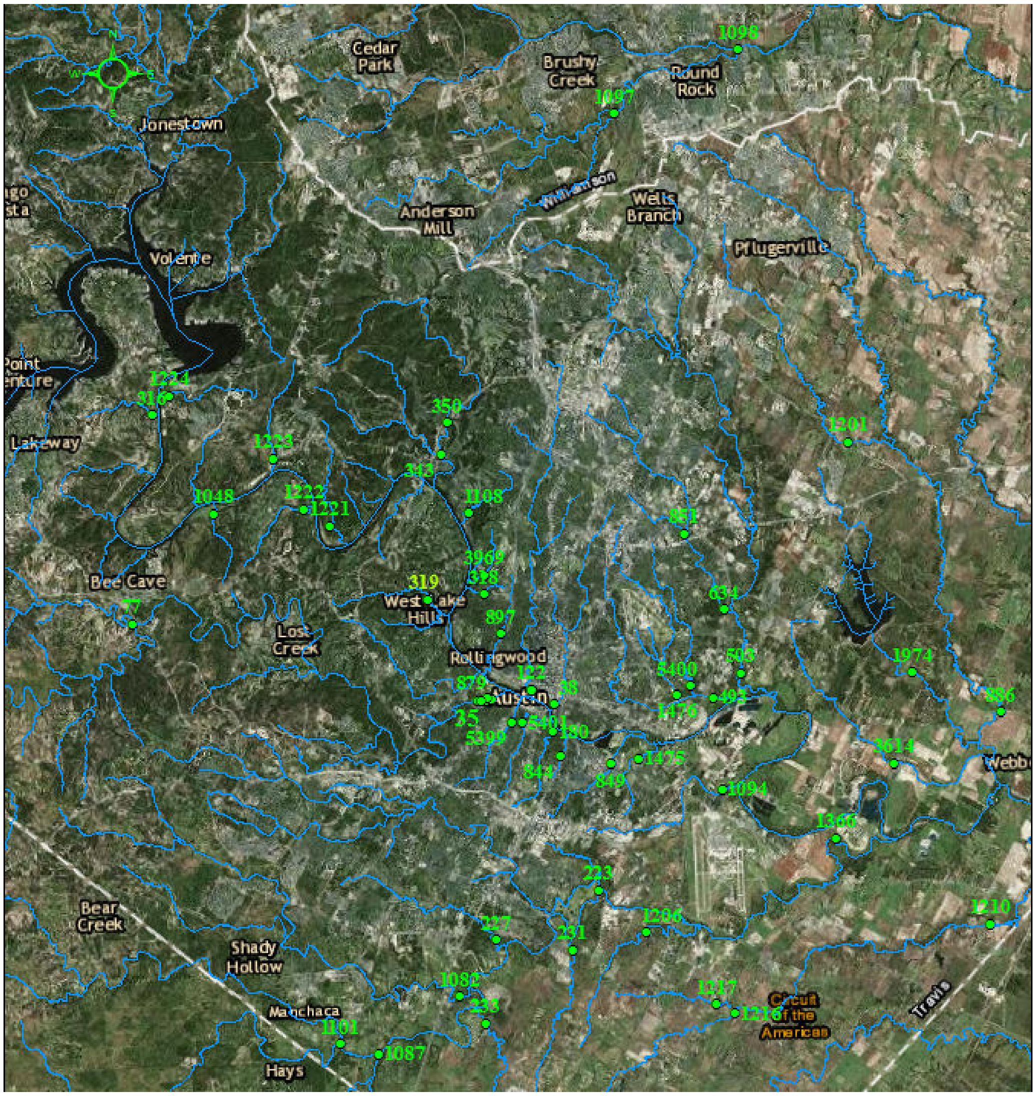

Figure 1: Map of sediment sample locations.

Table 1: Site name, longitude, and latitude of sediment sample locations.

Site Name	Map Label	Longitude	Latitude
Barton Creek Between Dams Upstream of Pool	879	-97.77247	30.26363
Barton Springs	35	-97.77098	30.26354
Bear Creek at Twin Creeks Rd	1087	-97.82190	30.12742
Bear Creek (West) at Fritz Hughes Park Rd	1224	-97.90938	30.38450
Bee Creek at Lake Austin	319	-97.79541	30.30313
Blunn Creek at Riverside Dr	180	-97.74088	30.25058
North Boggy Creek at Delwau Ln	493	-97.66878	30.26269
Bull Creek at Loop 360	350	-97.78493	30.37167
Buttermilk Creek at Little Walnut Creek	851	-97.68015	30.32643
Carson Creek at Shady Spring Subdivision	1094	-97.66590	30.22672
Cottonmouth Creek at Dee Gabriel Collins Rd	1206	-97.70112	30.17212
East Country Club at ACC	1475	-97.70261	30.23937
West Country Club at Crossing Place Dr	849	-97.71505	30.23759
Decker Creek at Gilbert Rd	1974	-97.57982	30.27042
Dry Creek at Wolf Ln	1210	-97.54761	30.17210
Dry Creek (North) at Mt Bonnel Rd	1108	-97.77643	30.33639
East Bouldin Creek at Christopher	5401	-97.75434	30.25460
Elm Creek at Austins Colony	3614	-97.58883	30.23545
Fort Branch at Tura Ln	5400	-97.67876	30.26712
Gilleland Creek at FM 969	886	-97.54019	30.25406
Harper’s Branch Creek at Woodland Ave	844	-97.73808	30.24117
Harris Branch Creek at Boyce Ln	1201	-97.60603	30.36037
Johnson Creek at Woodmont Ave	897	-97.76335	30.28910
Common Ford Trib in Common Ford Metro Park	1048	-97.89050	30.33835
Cuernavaca Creek at River Hills Rd	1222	-97.84999	30.33935
Deer at Running Deer Trail	316	-97.91679	30.37712
Lake Creek at Sugar Berry Cove	1098	-97.65059	30.51386
Little Barton Creek at Barton Creek	77	-97.92775	30.29618
Little Bear Creek at Bear Creek	1101	-97.83929	30.13142
Little Walnut Creek at US 183	634	-97.66288	30.29673
Marble Creek at William Cannon Dr	231	-97.73409	30.16582
North Fork Dry Creek at FM 812	1217	-97.67064	30.14353
Onion Creek at South Austin Regional WWTP	1366	-97.61559	30.20693
Panther Hollow Creek at Big View Rd	1223	-97.86358	30.35922
Rattan Creek at Shadowbrook Circle	1097	-97.70680	30.49001
Rinard Creek at Bradshaw Rd	233	-97.77395	30.13811
Shoal Creek Upstream of 1st St	122	-97.75031	30.26728
Slaughter Creek at Pine Valley Dr	1082	-97.78555	30.14872
South Boggy Creek at Bluff Springs Rd	227	-97.76861	30.17051
South Fork Dry Creek at FM 812	1216	-97.66277	30.13984
Tannehill Creek at Desirable Dr	1476	-97.68536	30.26390
Taylor Slough North at Mayfield Park	3969	-97.77018	30.31232
Taylor Slough South at Reed Park	318	-97.77053	30.30484
Turkey Creek at City Park Rd	1221	-97.83896	30.33264
Waller Creek Downstream of Cesar Chavez	38	-97.74023	30.26143
Walnut Creek Upstream of Freescale	503	-97.65625	30.27176
West Bouldin Creek at Treadwell	5399	-97.75946	30.25496
West Bull Creek Upstream of Bull Creek	343	-97.78830	30.35942
Williamson Creek at McKinney Falls	223	-97.72230	30.18886

Data for analysis was taken from COA monitoring data collected for EII and the City's Texas Pollutant Discharge Elimination System (TPDES) Municipal Separate Storm Sewer System (MS4) permit issued by the Texas Commission on Environmental Quality (TCEQ). Sampling was conducted in accordance with Water Resource Evaluation Standard Operating Procedures (COA 2013), where by a minimum of three sediment subsamples are deposited into a clean glass bowl and fully mixed before being composited into a clean, properly labeled glass jar. As a part of the City's Storm Water Management Program to stay in compliance with the MS4 permit, sediment samples have been collected from Main Barton Springs four times a year since 2000, while samples have been collected from the other springs once per year since 2000. Samples from other sites were collected on a three year rotation from 2000 to 2009, and on a two year rotation from 2009 to present. Sediment samples were analyzed for metals, pesticides, PAH, and total organic carbon. Pollutants discussed in this report include DDT, DDD, DDE, and the 15 most commonly grouped PAH (acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, ideno(1,2,3-cd)pyrene, phenanthrene, and pyrene) with one bicyclic aromatic hydrocarbon (naphthalene).

Pollutant concentrations were often below the detection limit of the laboratory analysis. These values often cause problems in statistical analysis so a number of methodologies have been developed to handle values below detection (Zhang et al. 2009). When all or almost all of the data is below a detection limit, the only applicable method for handling these values is to substitute in a single value or a value from a distribution. Single value substitution reduces the sample variance and can bias estimates of precision and therefore, was not used. Substituting values from a distribution can partially compensate for this reduced variance (Lin and Niu 1998). For all values below a detection limit, a value was generated from a uniform distribution developed between the detection limit value and zero. The generated value was then substituted in for the detection limit value for the remainder of the analyses.

Dynamic linear models, or state space models, were developed to analyze the trend over time for DDT, DDD, DDE, and PAH separately at each of the four springs. The data represent an irregular time series which are not handled well by ordinary linear regression or classical time series analysis. However, state space models are equipped to model univariate time series data with structural change, non-stationarity, and irregular patterns such as these data (Petris et al. 2009). DDT, DDD, DDE, and PAH were normalized by the organic carbon content in the sediment samples and the normalized values were log transformed prior to trend analysis. Normalization to organic carbon content was done because the pollutants will partition onto particulate matter proportional to the organic carbon content of the particulate matter (Karickhoff et al. 1979). Transformations brought the data distribution closer to Normal distribution which is an assumption necessary to Gaussian linear state space models. Analysis was done using the dlm package in R, more specifically the dlmFilter() function was used for estimating a solution using the Kalman filter (Kalman 1960).

Logistic regression was performed to determine if the frequency of DDT, DDD, DDE, or PAH concentrations above the threshold effects (TEC or TEL) or probable effects (PEC or PEL) concentrations has increased over time. Raw values of DDT, DDD, DDE, anthracene, benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, naphthalene, phenanthrene, and pyrene concentrations were compared to the TEC and PEC while acenaphtene and acenaphthylene concentrations were compared to the TEL and PEL. For the threshold effects regression, data were assigned a zero if the value of the pollutant was below detection limit or if the value was below the TEC (TEL). Data were assigned a value of one if the value was above the detection limit and above the TEC (TEL). A similar data structure was developed using the PEC (PEL). Logistic regression was then run on each pollutant independently for both sets of data using the glm() function in the R statistics program.

Bar charts were developed to visually compare the raw values and normalized values of DDT, DDD, DDE, and PAH at the four springs with data collected throughout Austin. Only data collected in 2013 and 2014 were used in these charts so that a recent comparison could be done. The raw data values were also compared to the TEC (TEL) and PEC (PEL) for each applicable pollutant to determine if there were any sites that were above these thresholds.

Results

DDT (1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane)

While there was no significant trend over time for DDT at Barton Springs, there was an increase in the variance for DDT at Main Barton Spring and Eliza Spring (Figure 2). The mean trend and the upper confidence interval for DDT at Main Barton Spring and Eliza Spring increased over time from 2010 to 2014; however, the lower confidence interval remained flat resulting in no significant trend over time for DDT. At Main Barton Spring, this was due to the last two data points being above the detection limit with values much higher than previous concentrations. At Eliza Spring, the last two data points (12 August 2013 and 22 May 2014) had higher concentrations than previous samples but only the 22 May 2014 sample was above the detection limit. The detection limit for sediment samples can be affected by the sensitivity of the instrument used in analysis, sample weight or volume, the extraction procedure used, and the moisture content of the sample. Due to one of these factors, the detection limit for the 12 August 2013 sample collected at Eliza Spring was higher than previous detection limits and this abnormally high detection limit coupled with the detected value obtained in the 22 May 2014 sample caused the variation of DDT to increase at Eliza Spring.

Monitoring and examination of DDT results at Barton Springs is important as continued detection of DDT may give rise to a significant increase in sediment DDT concentrations which would justify upstream investigation for a DDT source. However, the amount soil organic material in the last two sediment samples collected at Main Barton Spring were high compared to the majority past samples and it is possible that the sediment load was so large in the 2014 samples that the DDT bound to the sediment was detectable. If this is the case, then future data points of DDT at Main Barton Spring may return to levels below detection when the soil organic material in the sediment also decreases to normal concentrations. However, this is not absolutely the case as a few samples collected at Main Barton Springs have contained similar levels of soil organic material but still contained concentrations of DDT lower than the detection limit suggesting that not all large sediments loads contain contaminated sediment.

Values of DDT collected throughout Austin in 2013 and 2014 were above detection levels in about half of the samples. When normalized to total organic carbon, the detectable values of DDT at Barton Springs were at similar concentrations to the majority of detectable values throughout Austin (Figure 3). Bear Creek (West) at Fritz Hughes Park Rd was the only site to have DDT levels above the PEC level (Figure 3); however, past concentrations of DDT at this site have always been below the detection limit. The recent high value on Bear Creek (West) may indicate a concern at this site or increased erosion in the watershed could have washed contaminated soil downstream to the collection site. Monitoring and examination of DDT results for this site location is important and subsequent actions may include a source identification study if concentrations remain elevated in future samples.

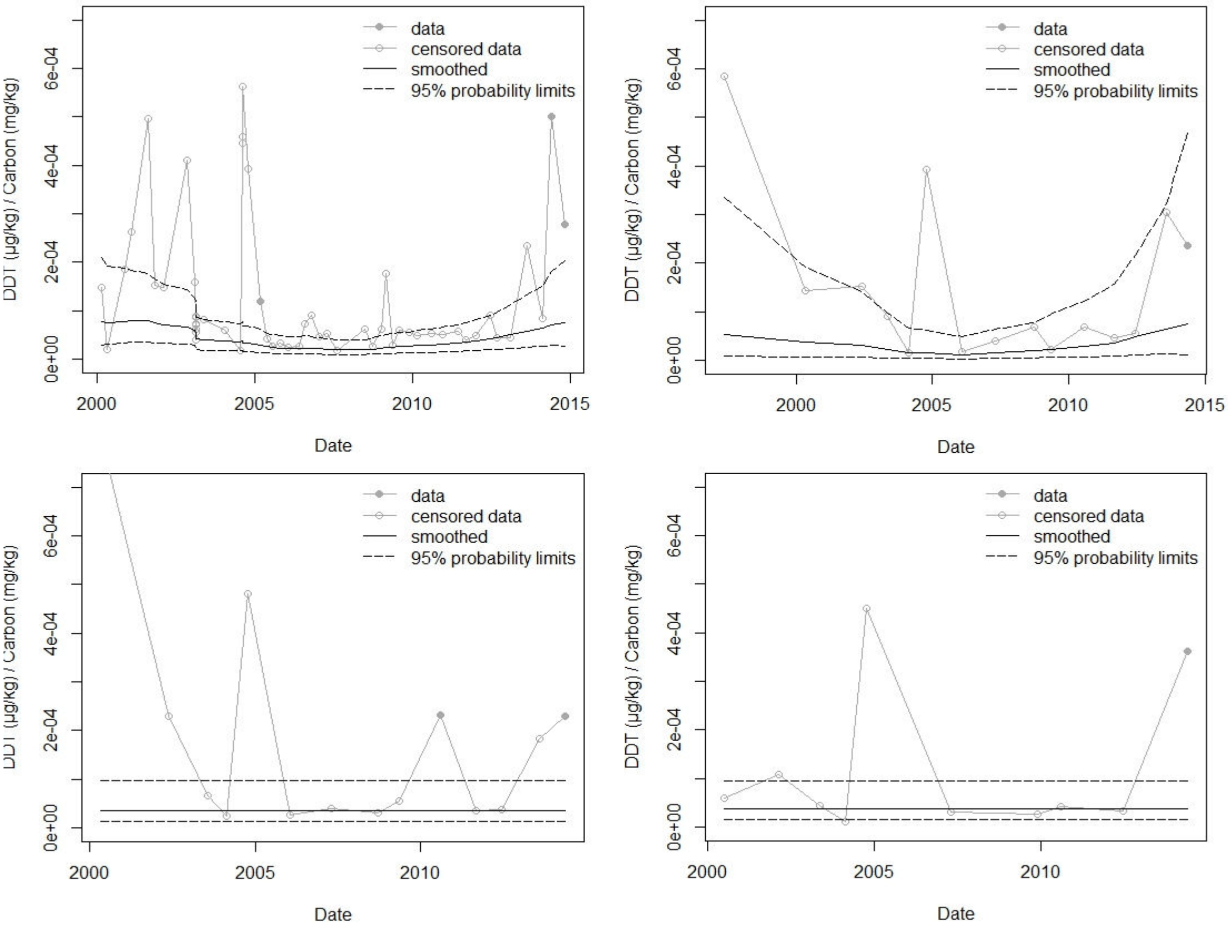

Figure 2: DDT (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

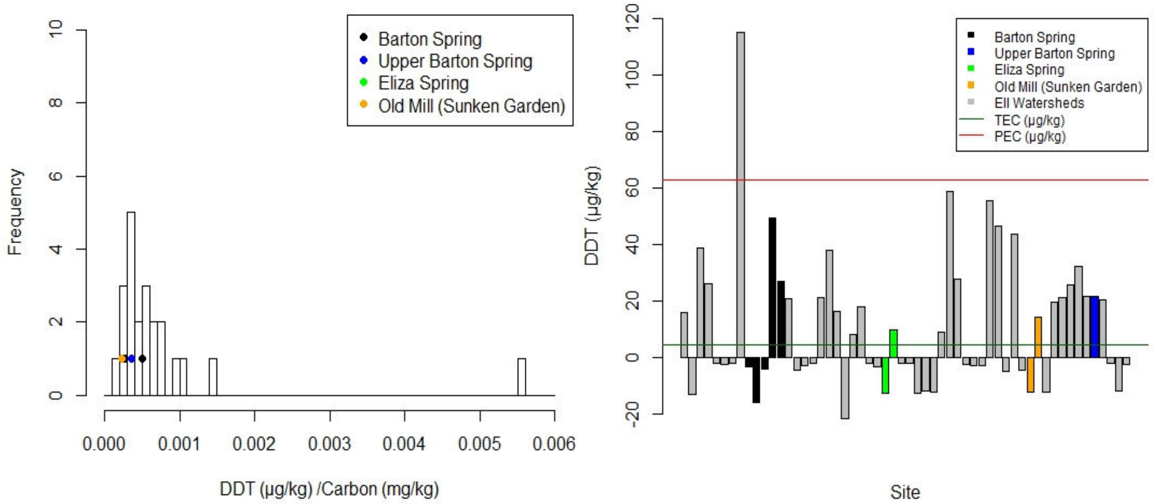

Figure 3: Histogram of DDT (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

DDD (1,1-dichloro-2,2-bis(p-chlorophenyl)ethane)

Similarly, there was no significant trend over time for DDD at Barton Springs. The variation increased over time at Main Barton Spring and Eliza Spring due to high detection limits and one detected value of DDD at Eliza Spring on 01 September 2011 and one detected value of DDD at Main Barton Spring on 22 May 2014 (Figure 4). Throughout Austin there were only 12 sites where concentrations of DDD were above the detection limit in 2013 and 2014, and the detectable concentration collected at Main Barton Spring was similar to the concentration at the majority of these 12 sites (Figure 5). East Country Club at ACC was the only site with a DDD concentration above the PEC. DDD concentrations collected at this site were below the detection limit in 2003 and 2006; however, the concentration collected in 2009 was 4.31 μg/kg and the latest data point in 2013 was 30.6 μg/kg.

DDE (1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene)

There was no significant trend over time for DDE at Barton Springs. Variation in DDE increased over time at Eliza Spring, Old Mill Spring, and Upper Barton Spring entirely due to the increased variation in the detection limits of DDE in the sediment samples (Figure 6). Throughout Austin there were only eight sites where concentrations of DDE were above the detection limit in 2013 and 2014, and the concentrations at Barton Springs were all below the detection limit (Figure 7). Waller Creek Downstream of Cesar Chavez was the only site with a DDE concentration above the PEC. DDE concentrations collected at this site were below the detection limit in 2003 and 2011; however, the concentrations in 2006, 2009, and 2013 were all around the PEC. High values of DDE seem to be persistent in Waller Creek sediment but do not seem to be increasing over time.

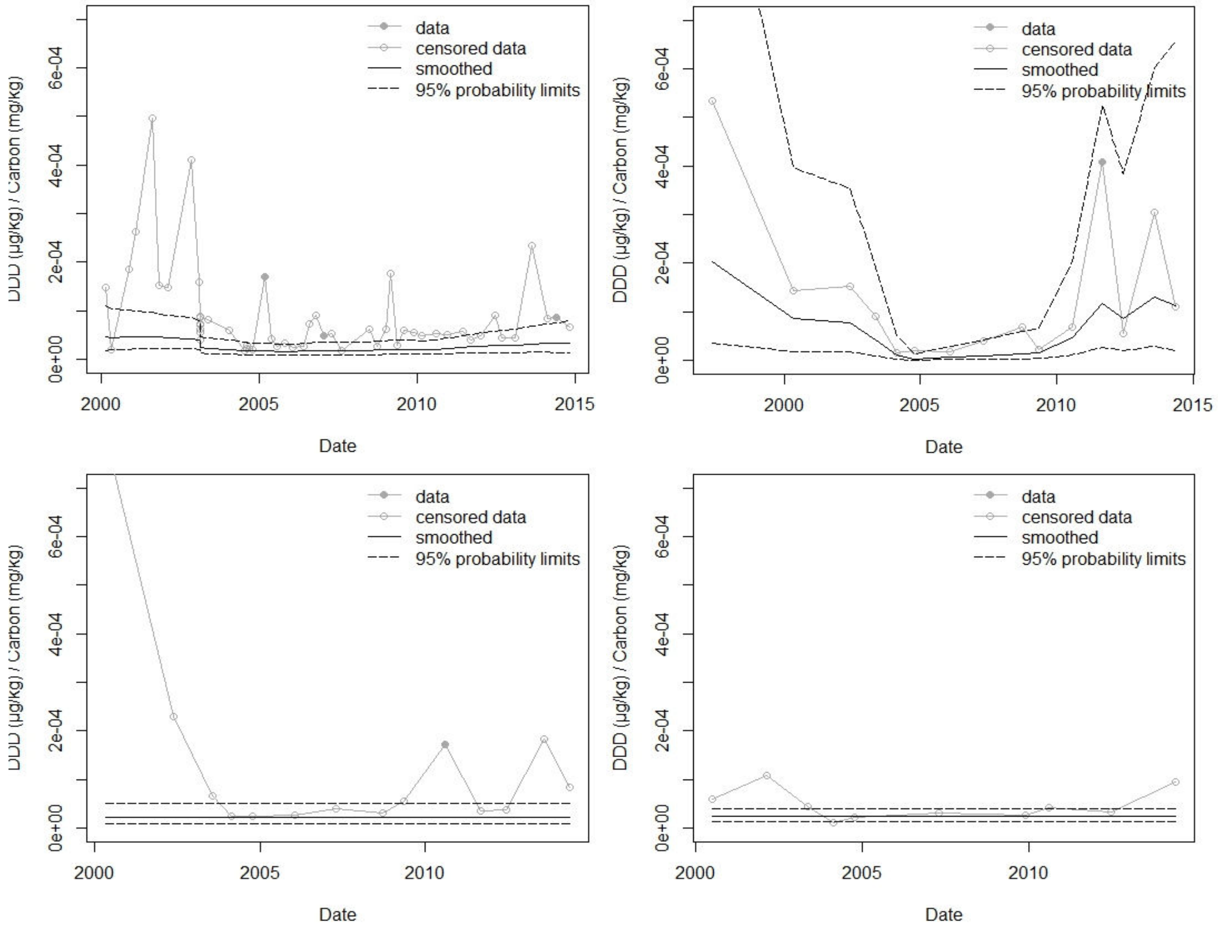

Figure 4: DDD (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

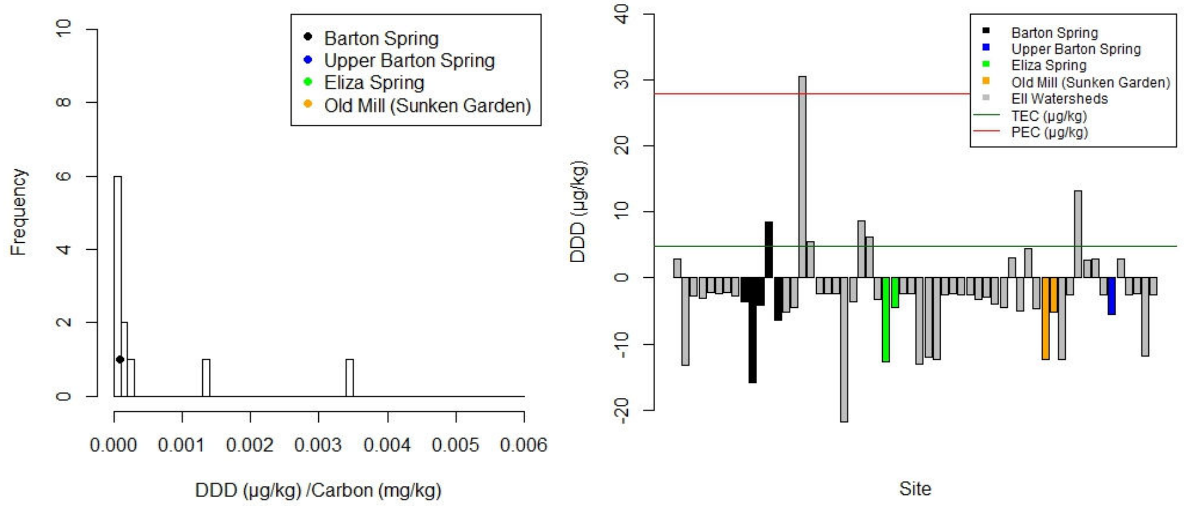

Figure 5: Histogram of DDD (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

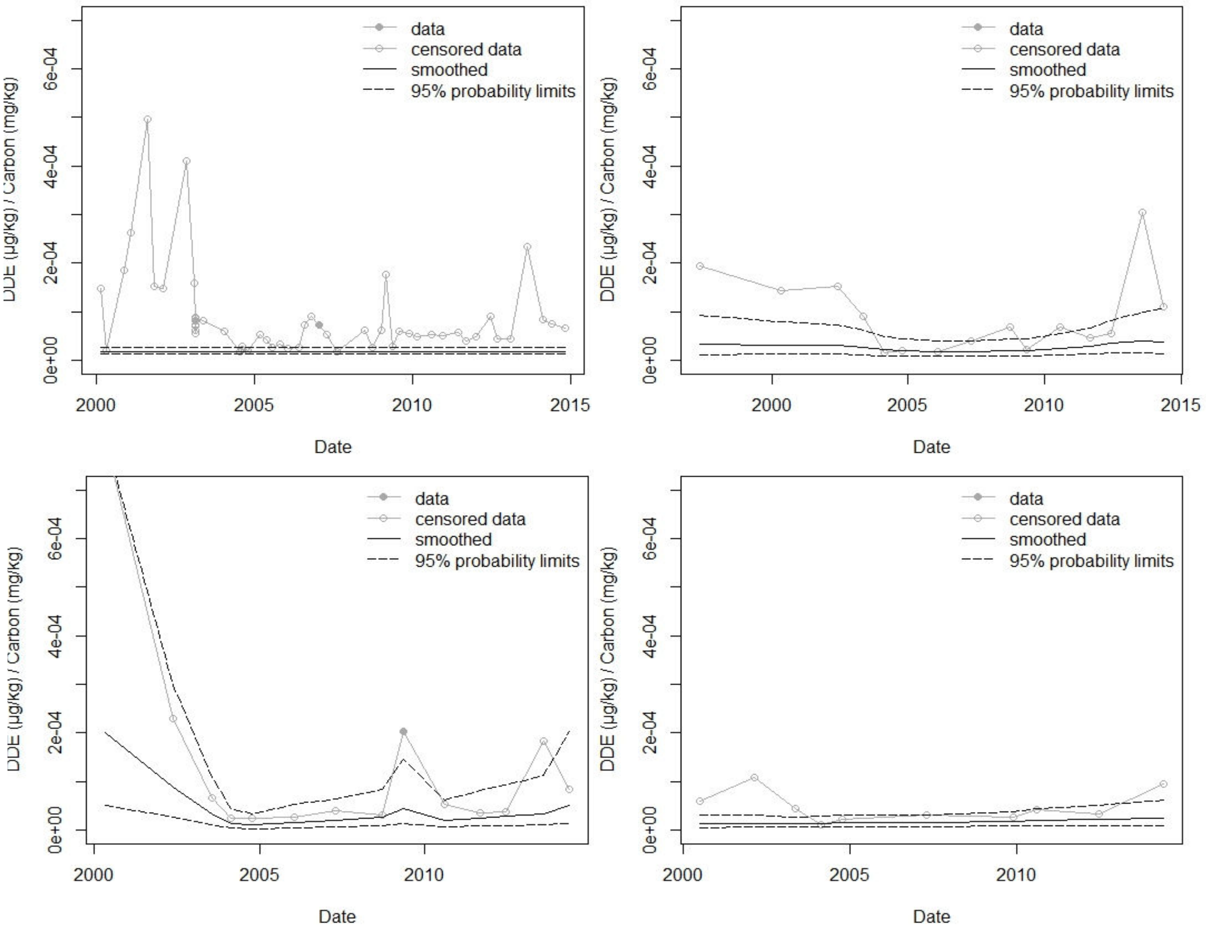

Figure 6: DDE (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

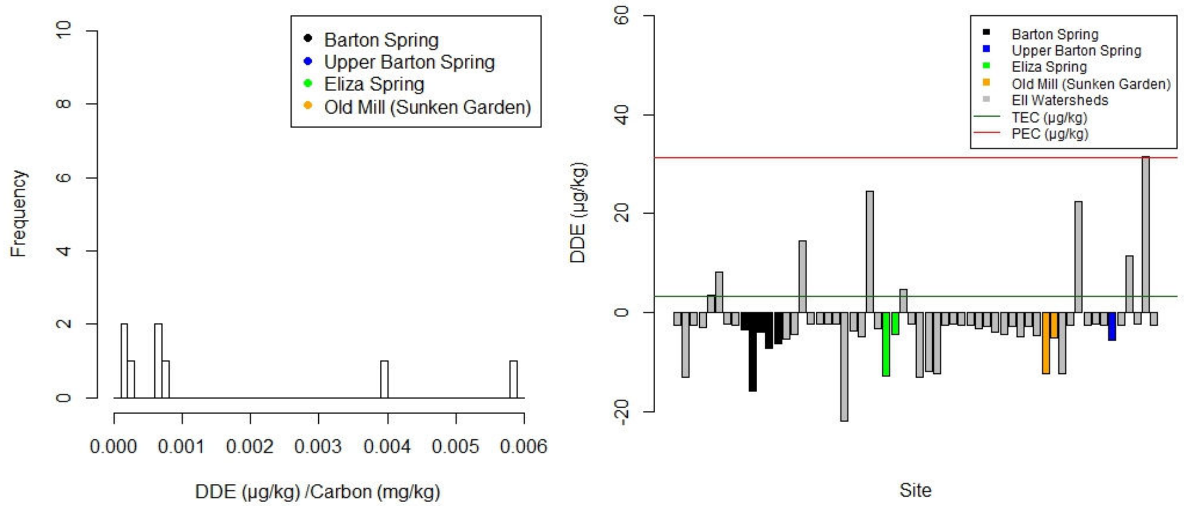

Figure 7: Histogram of DDE (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

Only three samples collected through the period of record at Main Barton Springs have contained detectable levels of DDT, with two of those samples being collected in 2014. The only sample with a detectable level of DDT at both Upper Barton Spring and Eliza Spring occurred in 2014, while detectable levels of DDT have been collected in 2010 and 2014 at Sunken Garden (Table 2). If a value of DDT was above the detection limit at Barton Springs then it was also above the TEC threshold. Even though the 2014 sediment samples contained concentrations of DDT above the detection limit and the TEC threshold, there was no significant trend in frequency of concentrations above the TEC or PEC at the four springs.

DDD concentrations have also been above the detection limit in three sampling events at Main Barton Springs but only one of these samples occurred in 2014. Samples collected from the other three springs have not contained concentrations of DDD higher than the detection limit since 2011. The concentration of DDE in sediment samples collected at any spring within Barton Springs has not been above the detection limit since 2009. If a value of DDD or DDE was above the detection limit at Barton Springs, the value was also above the TEC threshold. There was no significant trend in frequency of concentrations above the TEC or PEC at any of the four springs for DDD or DDE.

Table 2: Number of DDT, DDD, and DDE values above detection limit, TEC level, and PEC level at Barton Springs.

	Above Detection/ Total Samples	**Above TEC**	**Above PEC**	**Frequency above TEC increasing**	**Frequency above PEC increasing**
DDT		4.16 μg/kg	62.9 μg/kg		
Barton Spring	3/60	3	0	No	No
Upper Barton Spring	1/12	1	0	No	No
Eliza Spring	1/17	1	0	No	No
Sunken Garden	2/16	2	0	No	No
DDD		4.88 μg/kg	28.0 μg/kg		
Barton Spring	3/60	3	0	No	No
Upper Barton Spring	0/11	0	0	No	No
Eliza Spring	1/16	1	0	No	No
Sunken Garden	1/15	1	0	No	No
DDE		3.16 μg/kg	31.3 μg/kg		
Barton Spring	2/61	2	0	No	No
Upper Barton Spring	0/12	0	0	No	No
Eliza Spring	0/17	0	0	No	No
Sunken Garden	1/16	1	0	No	No

Polycyclic aromatic hydrocarbons (PAH)

PAH including acenaphthene, acenaphthylene, anthracene, dibenz(a,h)anthracene, fluorene, and naphthalene shared similar trends over time at Barton Springs and high concentrations of the pollutants were found at the same sites (Figure 8-19). Mean trends along with lower and upper confidence intervals for acenaphthene (Figure 8), acenaphthylene (Figure 10), anthracene (Figure 12), dibenz(a,h)anthracene (Figure 14), fluorene (Figure 16), and naphthalene (Figure 18) showed no increase in concentration over time at Barton Springs.

Throughout Austin there were only five sites where concentrations of acenaphthene were above the detection limit in 2013 and 2014, and the concentrations at Barton Springs were all below the detection limit (Figure 9). Eleven sites contained concentrations of acenaphthylene above the detection limit including Eliza Spring (Figure 11), 16 sites contained concentrations of anthracene above the detection limit including Main Barton Spring and Eliza Spring (Figure 13), 16 sites contained concentrations of dibenz(a,h)anthracene above the detection limit including Main Barton Spring and Eliza Spring (Figure 15), eight sites contained concentrations of fluorene above the detection limit including Main Barton Spring (Figure 17), and only two sites contained concentrations of naphthalene above the detection limit (Figure 19). Detectable values of each pollutant at Barton Springs were similar to the majority of detectable values throughout Austin.

Harpers Branch Creek at Woodland Ave sediment contained high concentrations for acenaphthene (129 µg/kg), acenaphthylene (152 µg/kg), anthracene (438 µg/kg), dibenz(a,h)anthracene (398 µg/kg), and fluorene (135 µg/kg). Concentrations of acenaphthene and acenaphthylene were above the PEL at this site and the concentrations of anthracene and fluorene were above the TEC. Concentrations of acenaphthene and fluorene have increased every sampling event since 2006, while concentrations of acenaphthylene have typically been about one third of the current concentration, concentrations of anthracene have typically been about one half of the current concentration, and concentrations of dibenz(a,h)anthracene have typically been much higher than the current concentration.

Shoal Creek Upstream of 1st St. sediment contained high concentrations of acenaphthylene (57.8 µg/kg), anthracene (116 µg/kg), and dibenz(a,h)anthracene (435 µg/kg). The acenaphthylene concentration was above the TEL and the anthracene concentration was above the TEC. Concentrations of the above pollutants at this site vary through time and no clear pattern exists but current concentrations were not higher than what has been documented in the past.

Waller Creek Downstream of Cesar Chavez sediment contained high concentrations for acenaphthene (1840 µg/kg), acenaphthylene (79 µg/kg), anthracene (3310 µg/kg), dibenz(a,h)anthracene (997 µg/kg), fluorene (2180 µg/kg), and naphthalene (1150 µg/kg). Anthracene, fluorene, and naphthalene were all above the PEC at this site while acenaphthene was above the PEL and acenaphthylene was above the TEL. Each of these pollutants has typically been much lower at this site if not below detection limit.

It is uncommon for sediment samples collected at Barton Springs to contain concentrations of acenaphthene, acenaphthylene, anthracene, dibenz(a,h)anthracene, fluorene, or naphthalene and even rarer for the concentrations to be above the TEC (TEL). These pollutants have never been above the PEC (PEL) at Barton Springs. No significant trend exists for the frequency of concentrations above the TEC (TEC) or PEC (PEL) for any of these pollutants at Barton Springs (Table 3). Therefore, concentrations of acenaphthene, acenaphthylene, anthracene, dibenz(a,h)anthracene, fluorene, and naphthalene are not currently a concern at Barton Springs.

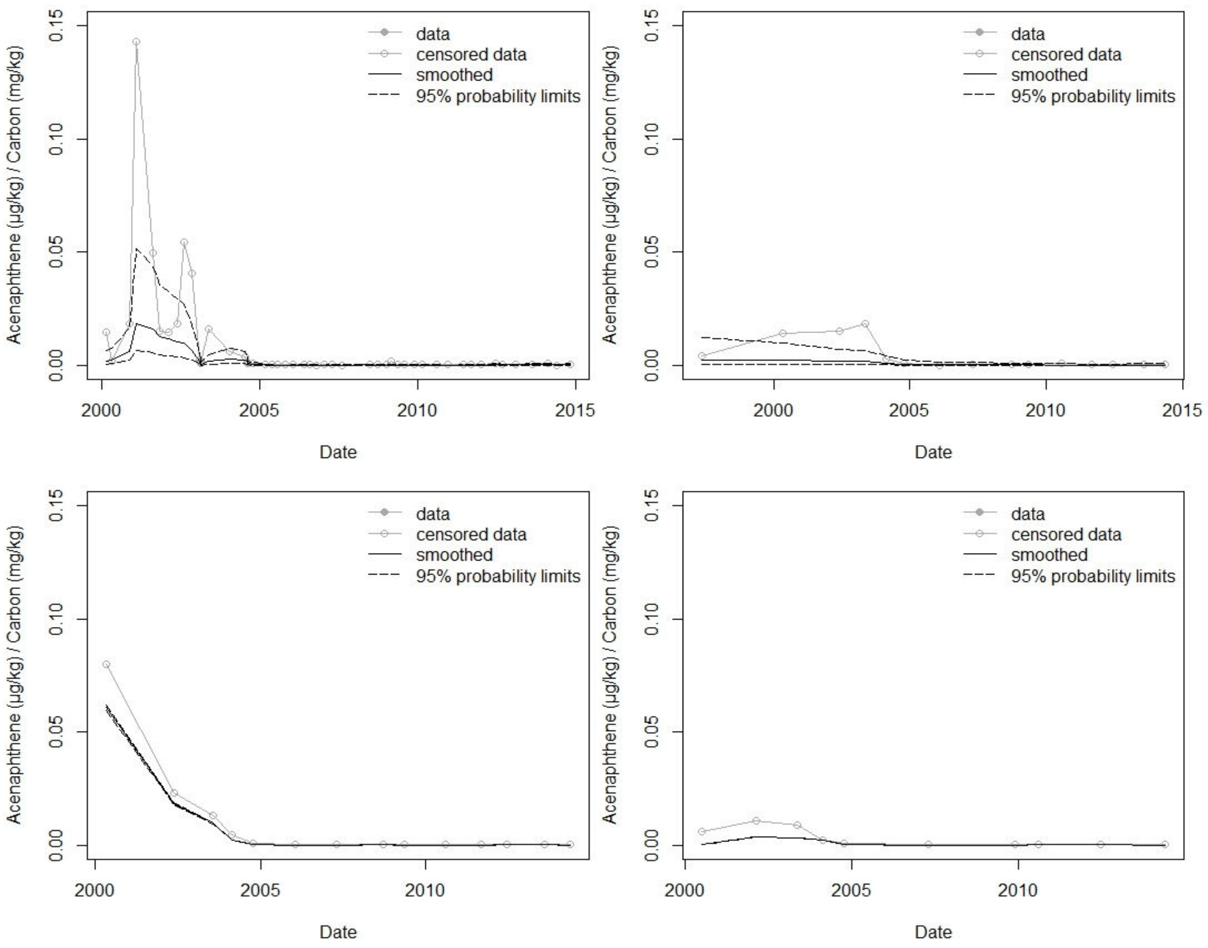

Figure 8: Acenaphthene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

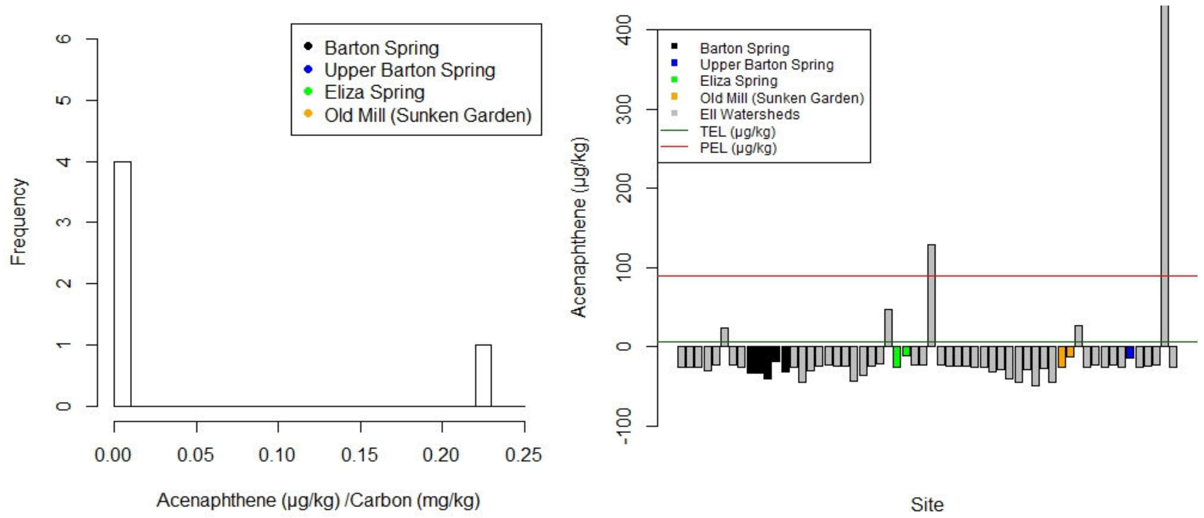

Figure 9: Histogram of acenaphthene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

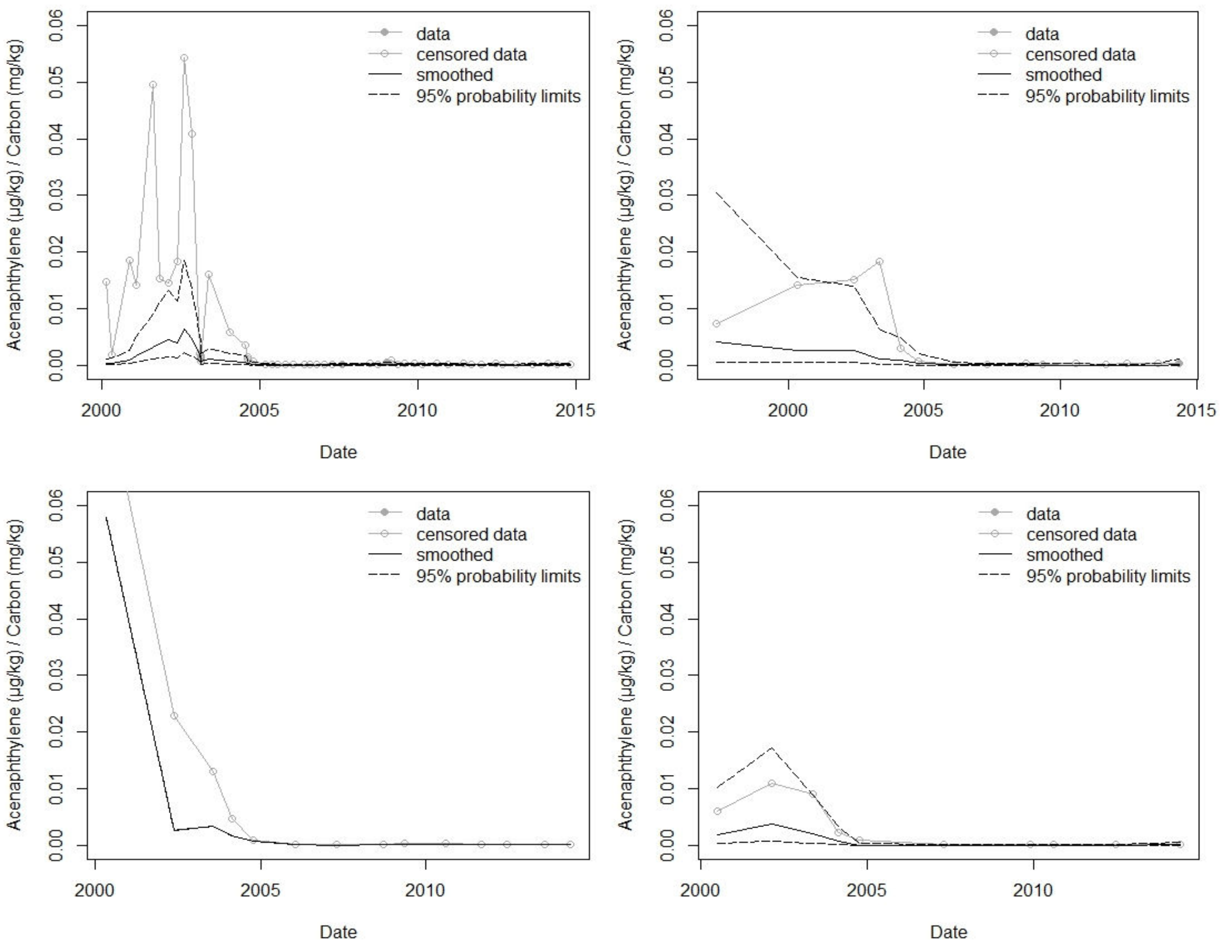

Figure 10: Acenaphthylene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

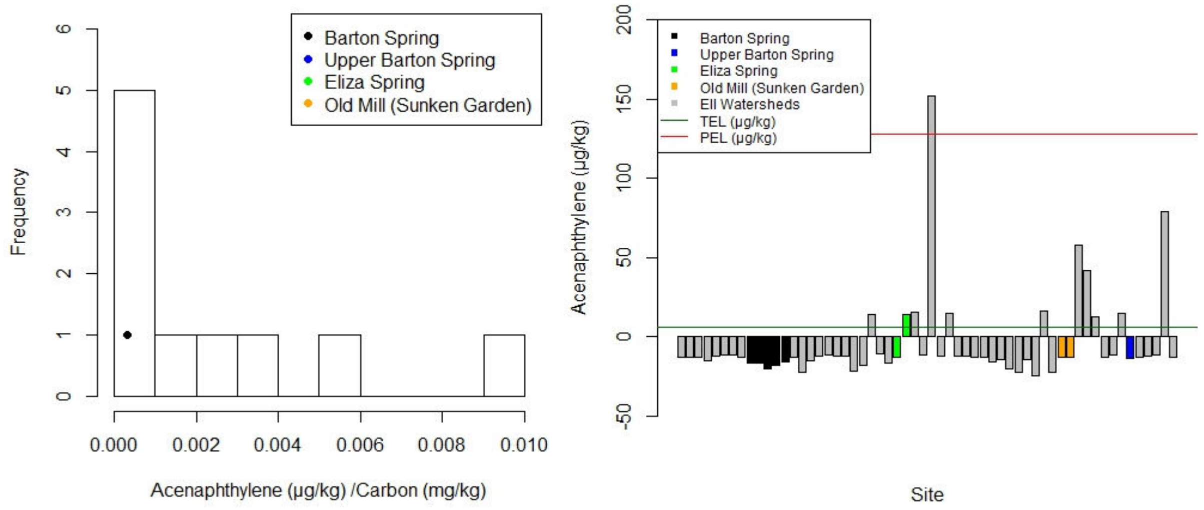

Figure 11: Histogram of acenaphthylene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

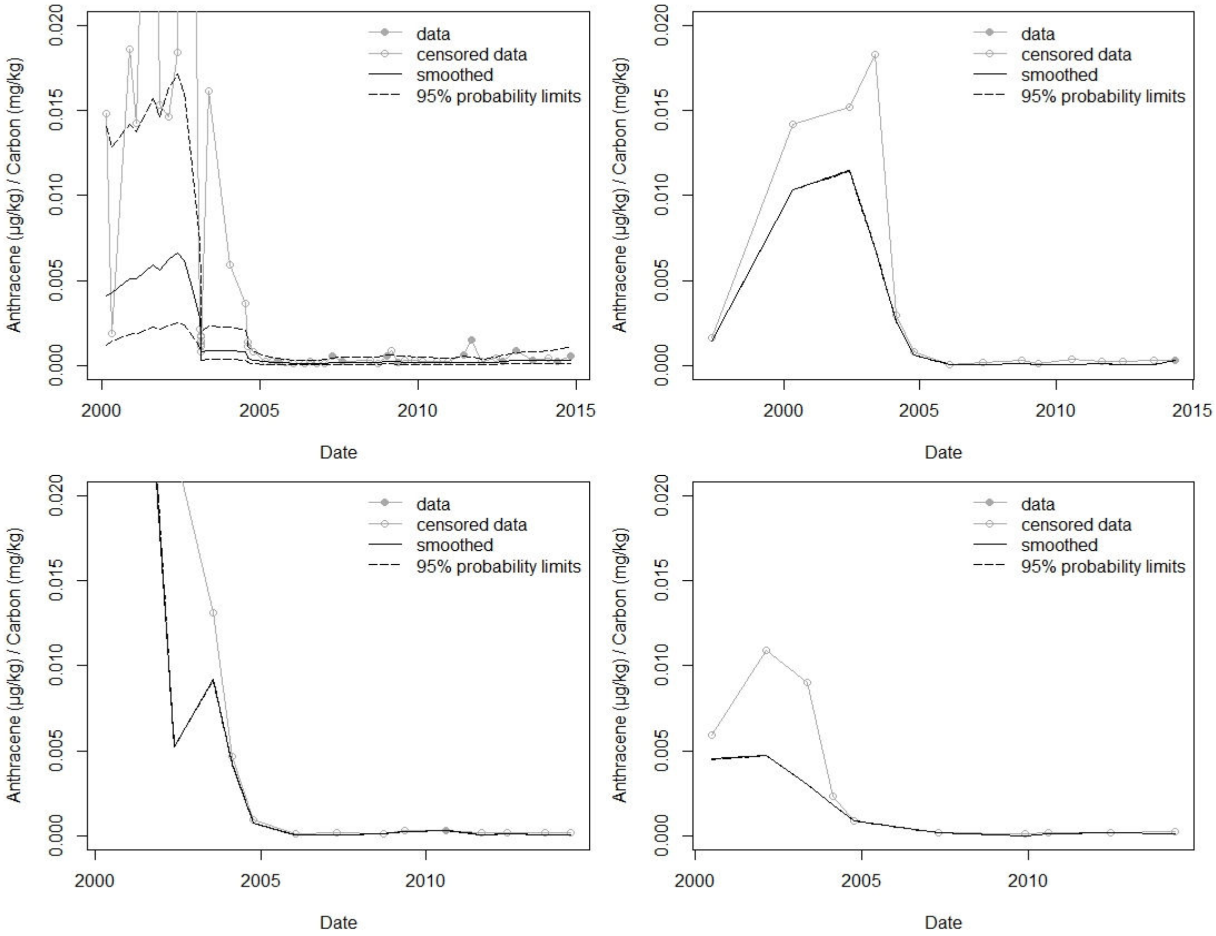

Figure 12: Anthracene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

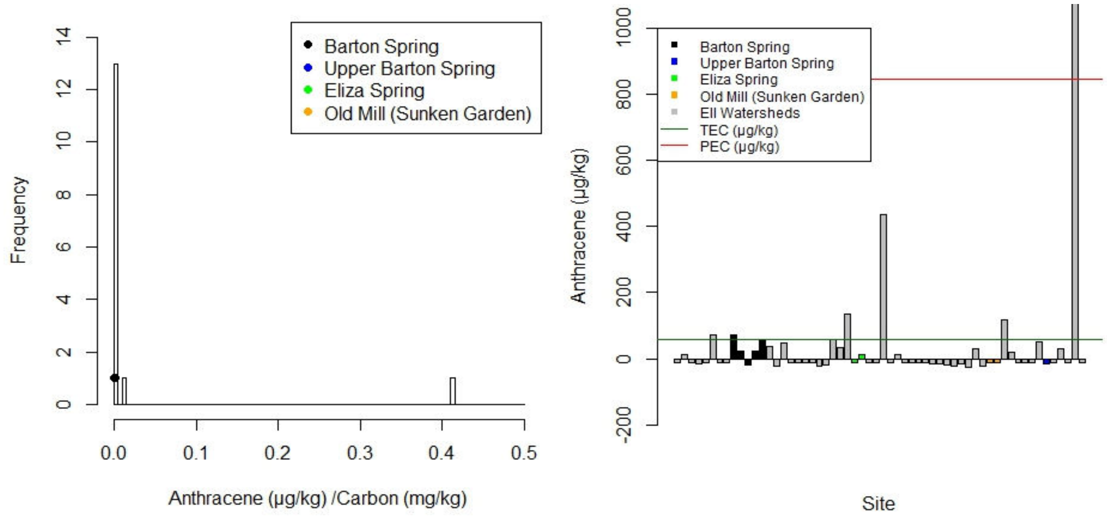

Figure 13: Histogram of anthracene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

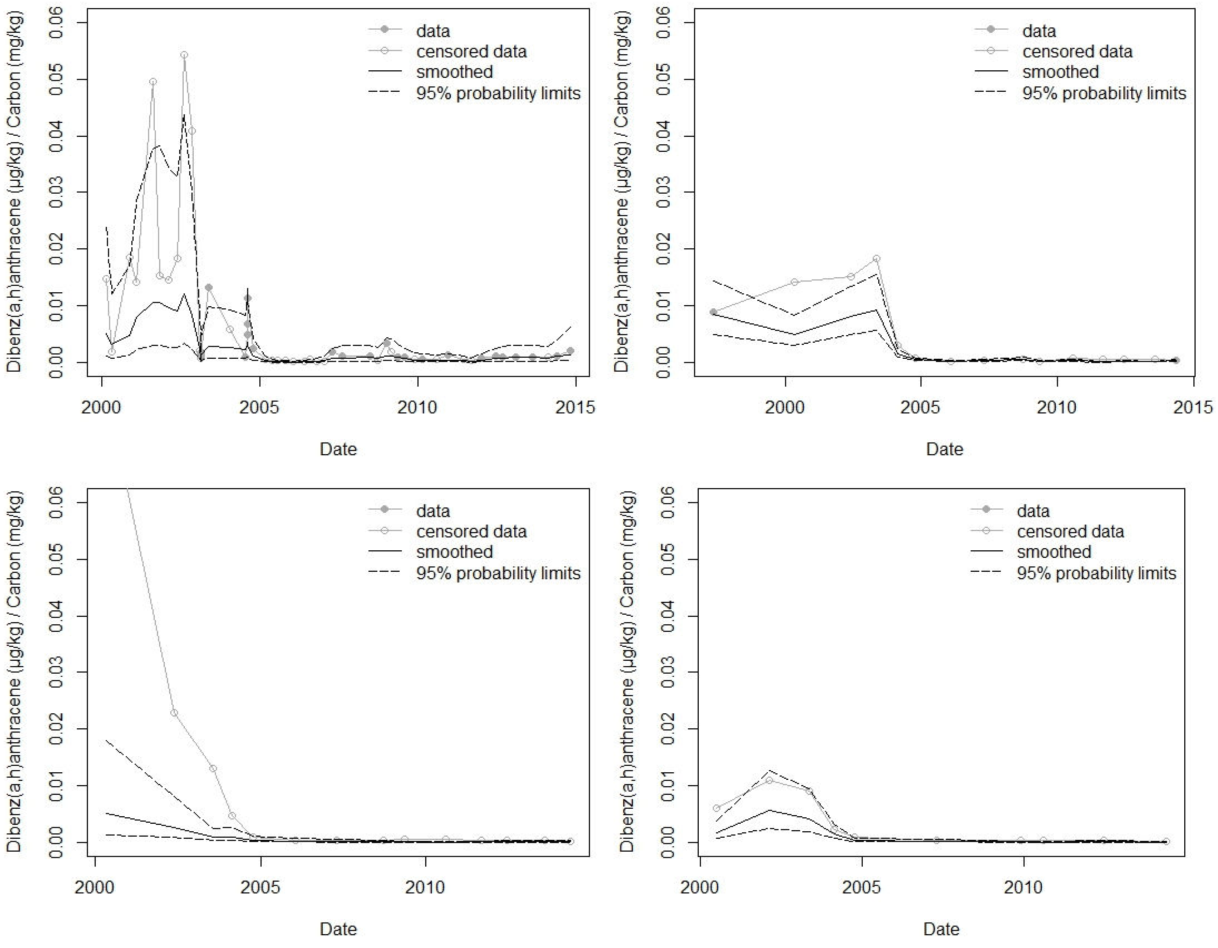

Figure 14: Dibenz(a,h)anthracene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

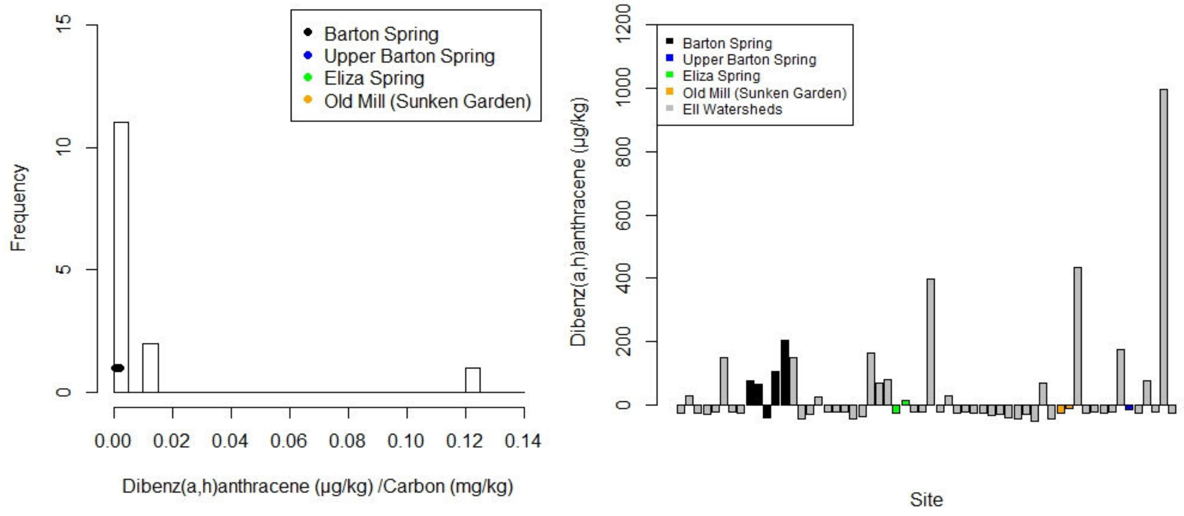

Figure 15: Histogram of dibenz(a,h)anthracene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

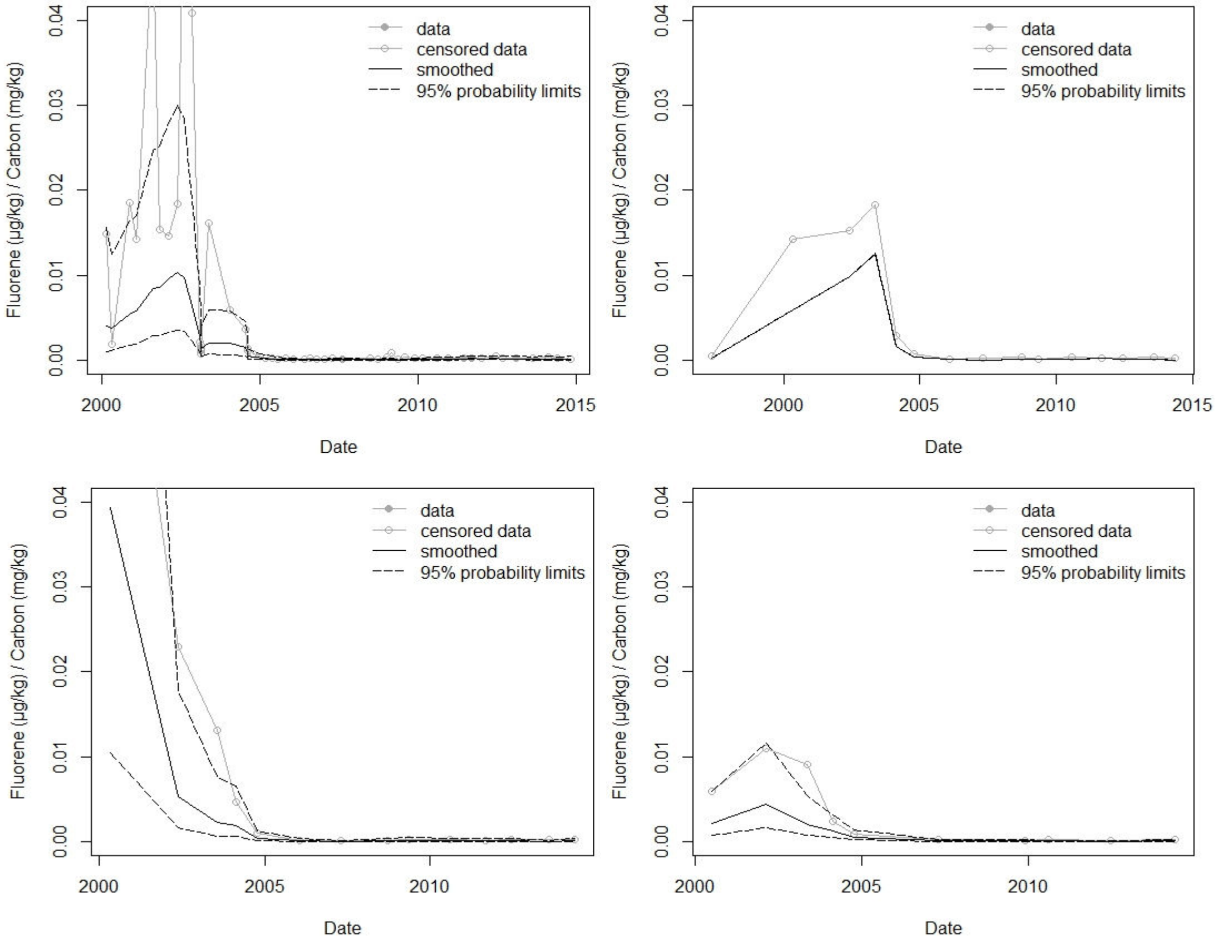

Figure 16: Fluorene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

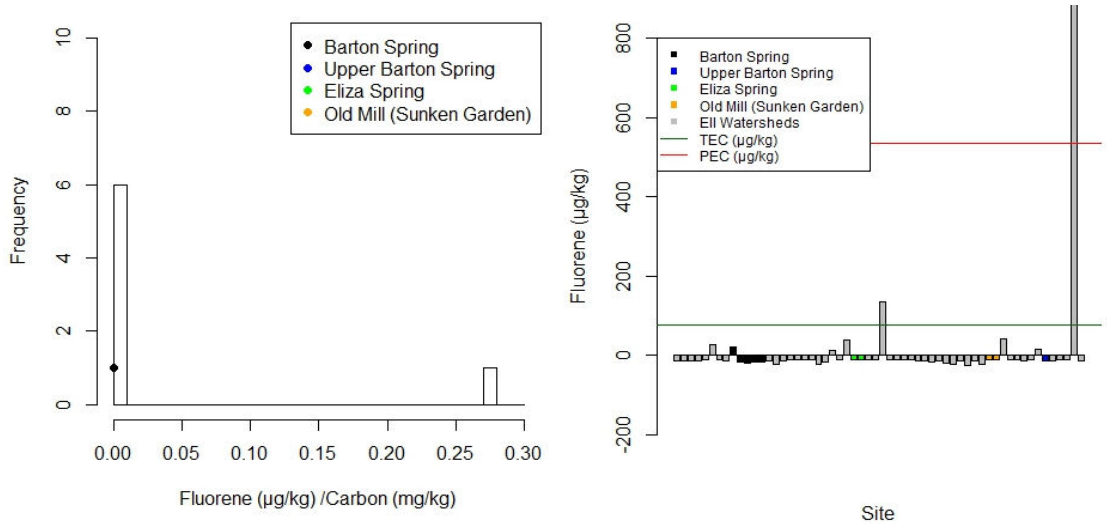

Figure 17: Histogram of fluorene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

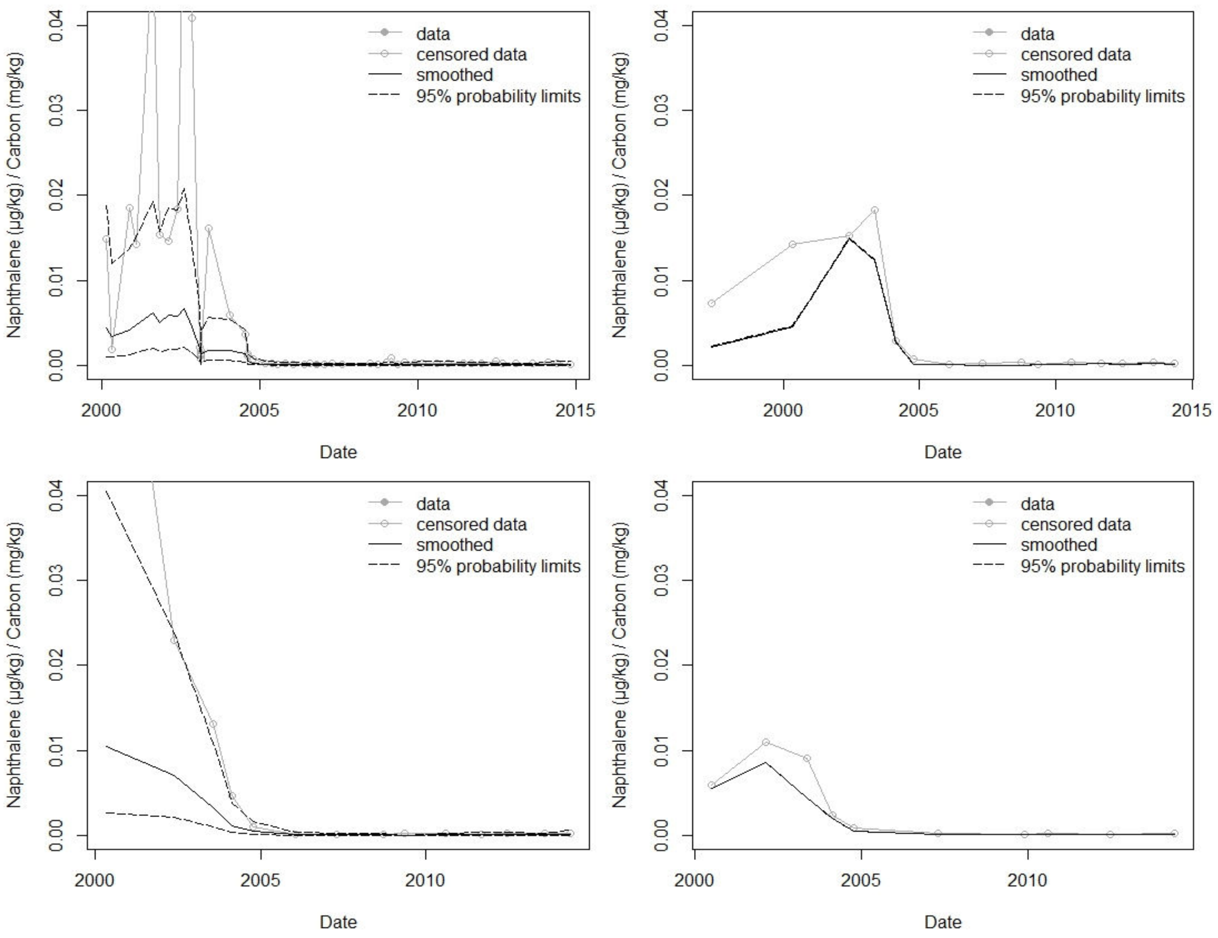

Figure 18: Naphthalene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

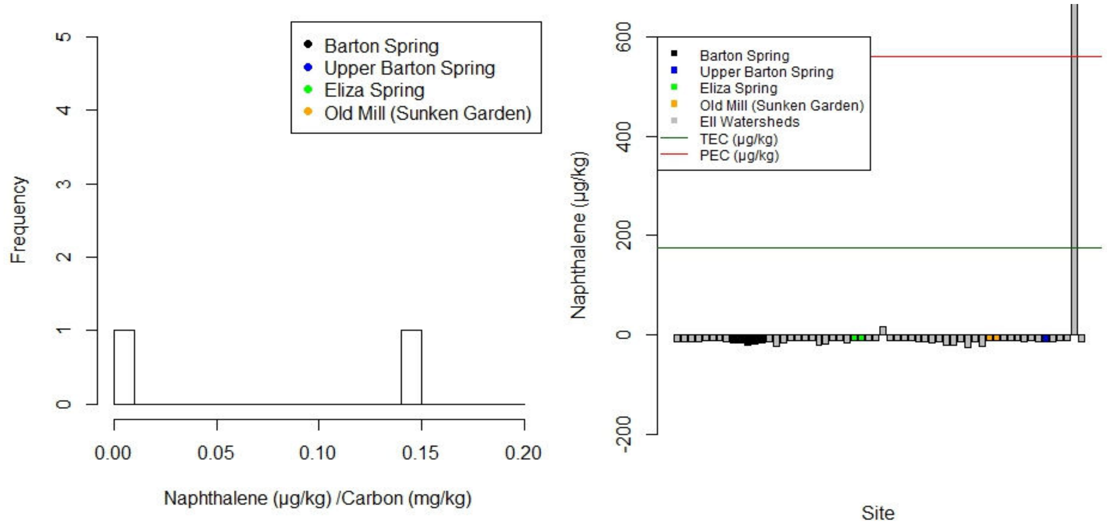

Figure 19: Histogram of naphthalene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

Table 3: Number of acenaphthene, acenaphthylene, anthracene, fluorene, and naphthalene concentrations above detection limit, TEC (TEL), and PEC (PEL) at Barton Springs. Acenaphthene and acenaphthylene are compared to TEL and PEL while other pollutants are compared to TEC and PEC.

	Above Detection/ Total Samples	**Above TEC (TEL)**	**Above PEC (PEL)**	**Frequency above TEC (TEL) increasing**	**Frequency above PEC (PEL) increasing**
Acenaphthene		6.71 µg/kg	88.9 µg/kg		
Barton Spring	0/64	0	0	No	No
Upper Barton Spring	0/13	0	0	No	No
Eliza Spring	0/17	0	0	No	No
Sunken Garden	0/16	0	0	No	No
Acenaphthylene		5.87 µg/kg	128 µg/kg		
Barton Spring	2/64	2	0	No	No
Upper Barton Spring	0/13	0	0	No	No
Eliza Spring	1/17	1	0	No	No
Sunken Garden	0/16	0	0	No	No
Anthracene		57.2 µg/kg	845 µg/kg		
Barton Spring	13/64	3	0	No	No
Upper Barton Spring	0/13	0	0	No	No
Eliza Spring	1/17	0	0	No	No
Sunken Garden	1/16	0	0	No	No
Fluorene		77.4 µg/kg	536 µg/kg		
Barton Spring	4/64	0	0	No	No
Upper Barton Spring	0/13	0	0	No	No
Eliza Spring	0/17	0	0	No	No
Sunken Garden	0/16	0	0	No	No
Naphthalene		176 µg/kg	561 µg/kg		
Barton Spring	1/64	0	0	No	No
Upper Barton Spring	0/13	0	0	No	No
Eliza Spring	0/17	0	0	No	No
Sunken Garden	0/16	0	0	No	No

PAH including benzo(a)anthracene, benzo(a)pyrene, benzo(e)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, phenanthrene, and pyrene shared similar trends over time at Barton Springs and high concentrations of the pollutants were found at the same locations (Figure 20-41). Mean trends along with lower and upper confidence intervals for benzo(a)anthracene (Figure 20), benzo(a)pyrene (Figure 22), benzo(e)pyrene (Figure 24), benzo(b)fluoranthene (Figure 26), benzo(k)fluoranthene (Figure 28), benzo(g,h,i)perylene (Figure 30), chrysene (Figure 32), fluoranthene (Figure 34), indeno(1,2,3-cd)pyrene (Figure 36), phenanthrene (Figure 38), and pyrene (Figure 40) showed low concentrations and variability around 2005-2006 followed by a slow increase in pollutant concentration and variability through 2010 when pollutant concentrations seemed to stop increasing at Main Barton Spring. No significant long term trends existed for any of these pollutants at any of the other three springs.

Throughout Austin 25 sites contained concentrations of benzo(a)anthracene, benzo(k)fluoranthene, or phenanthrene above the detection limit in 2013 and 2014, including Main Barton Spring and Eliza Spring. Twenty-seven sites contained concentrations of benzo(a)pyrene above the detection limit and 26 sites contained concentrations of benzo(e)pyrene above the detection limit, including Main Barton Spring, Eliza Spring, and Upper Barton Spring. Over 30 sites contained concentrations of benzo(b)fluoranthene, benzo(g,h,i)perylene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, or pyrene above the detection limit, including Main Barton Spring, Eliza Spring, and Upper Barton Spring. Detectable concentrations at Main Barton Spring, Eliza Spring, and Upper Barton Spring were similar to the majority of detectable concentrations at other sites for each pollutant; however, concentrations at Main Barton Spring were much higher than concentrations present at Eliza Spring or Upper Barton Spring. In fact, concentrations of each pollutant were always under the TEC (if available) at Eliza Spring and Upper Barton Spring. Concentrations in Main Barton Spring were always above the TEC (if available). The latest sediment sample at Main Barton Spring contained concentrations of chrysene and fluoranthene near the PEC and the concentration of pyrene was over the PEC.

Harpers Branch Creek at Woodland Ave sediment contained high concentrations for benzo(a)anthracene, benzo(a)pyrene, benzo(e)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, phenanthrene, and pyrene. Concentrations of pollutants at this site were above the PEC for each pollutant where a PEC exists. Past sediment samples collected at this site have typically had high concentrations of these pollutants with values above the PEC in most samples.

Shoal Creek Upstream of 1st St. sediment contained high concentrations for benzo(a)anthracene, benzo(a)pyrene, benzo(e)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene. Concentrations at this site were higher than the PEC for each pollutant where a PEC exists except phenanthrene for which concentrations were higher than the TEC. Past sediment samples collected at this site have typically contained concentrations much lower than the current concentrations with values well under the PEC for each pollutant.

Waller Creek Downstream of Cesar Chavez sediment also contained high concentrations for all of the above pollutants with values above the PEC for each pollutant where a PEC exists. Past sediment samples do not support the extremely high concentrations documented in the most current sample with typical values well under the PEC for each pollutant.

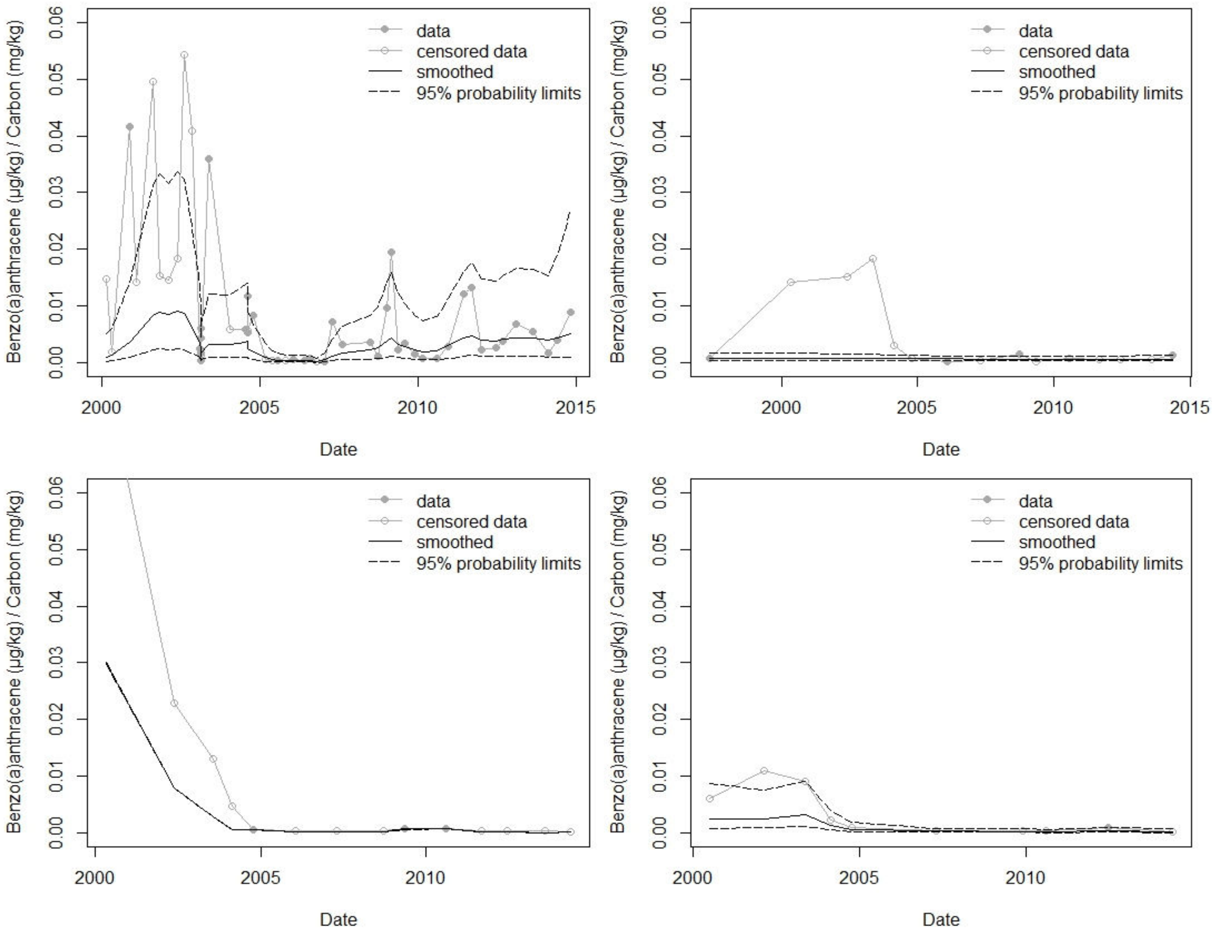

Figure 20: Benzo(a)anthracene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

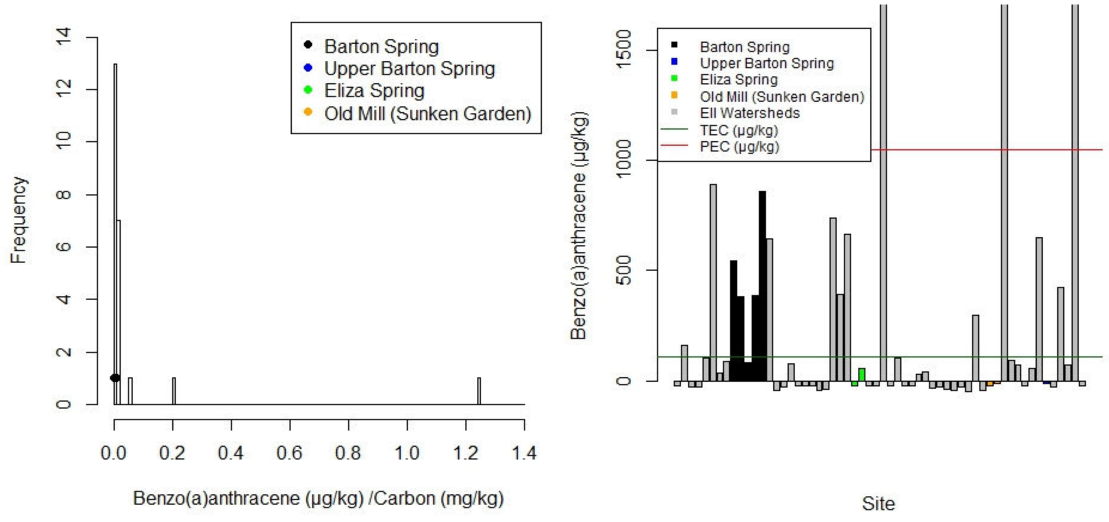

Figure 21: Histogram of benzo(a)anthracene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

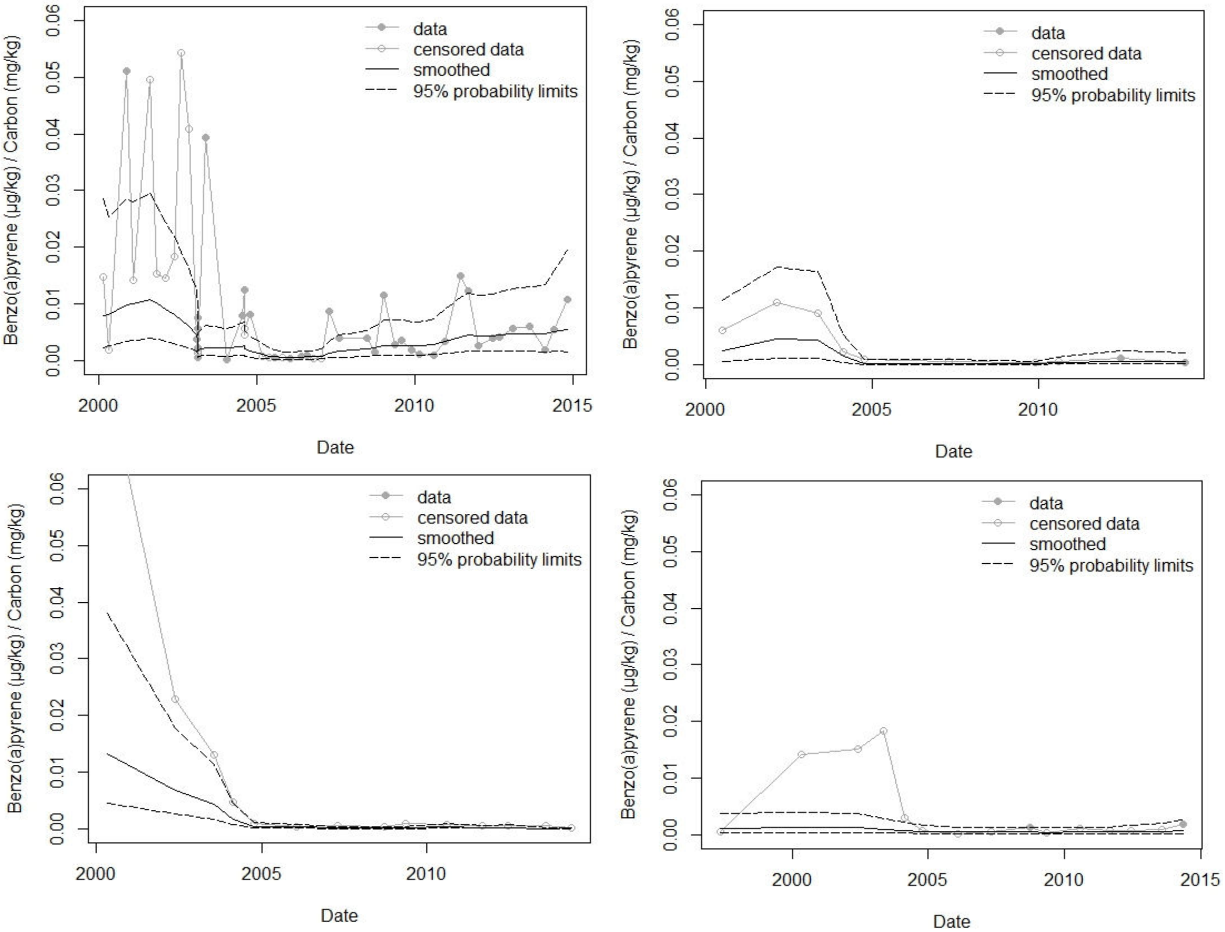

Figure 22: Benzo(a)pyrene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

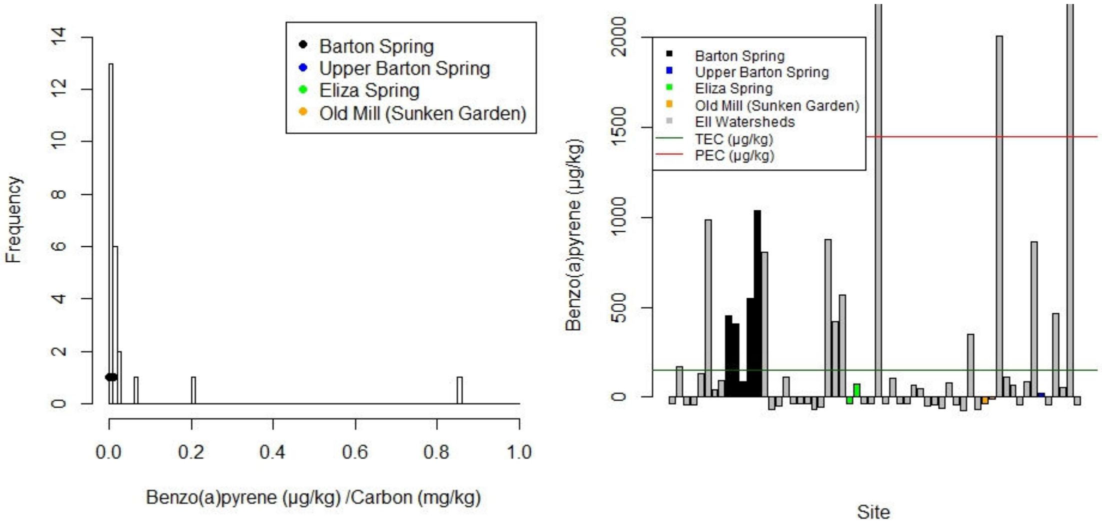

Figure 23: Histogram of benzo(a)pyrene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

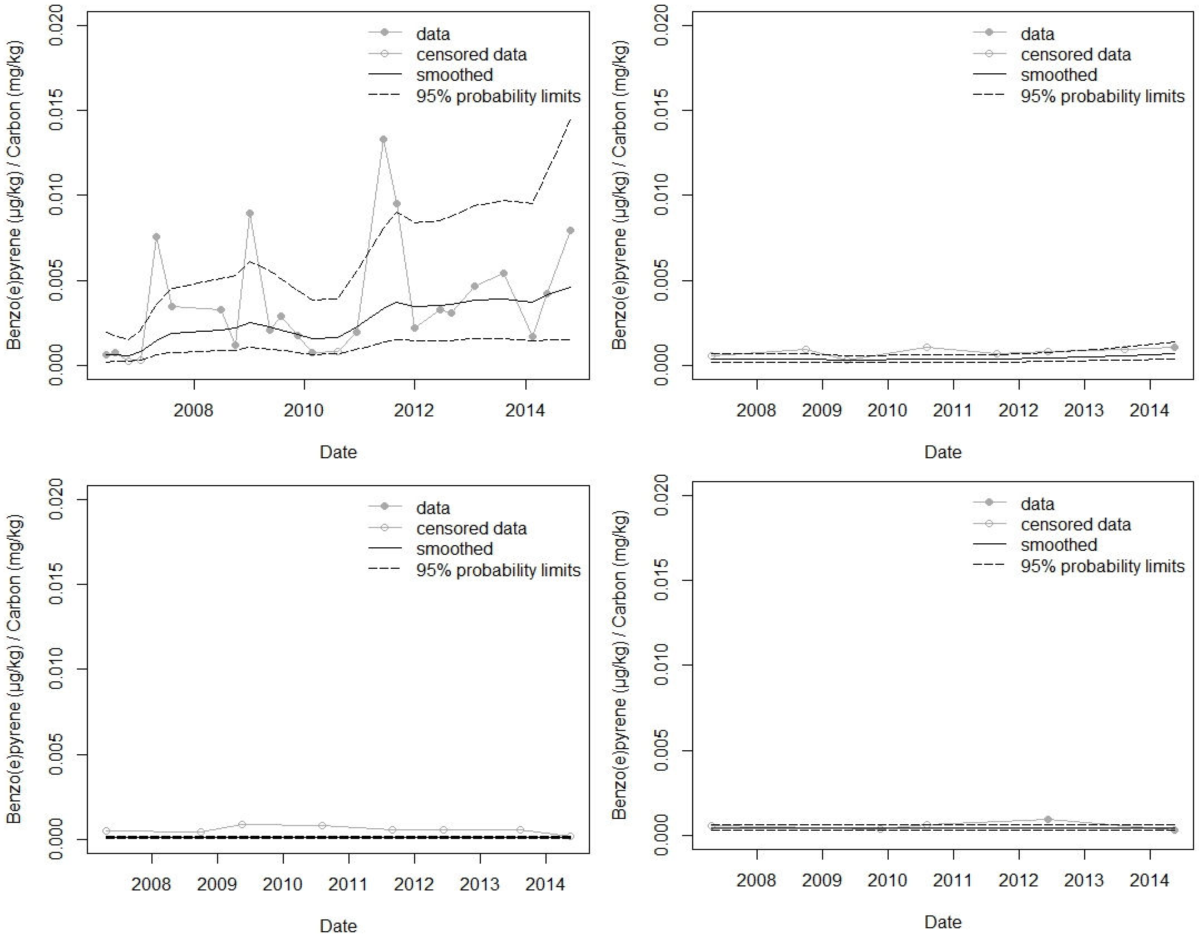

Figure 24: Benzo(e)pyrene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

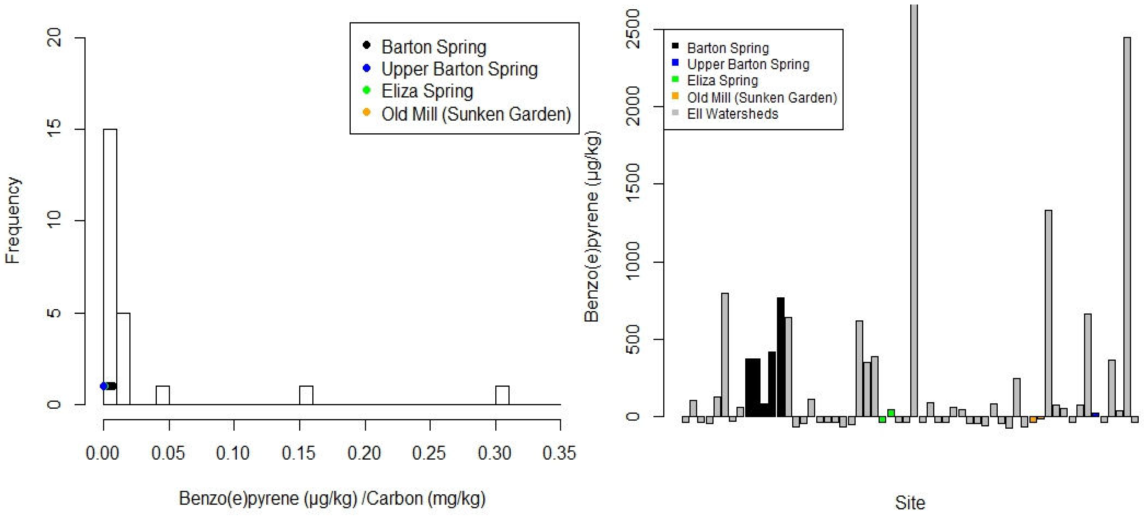

Figure 25: Histogram of benzo(e)pyrene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

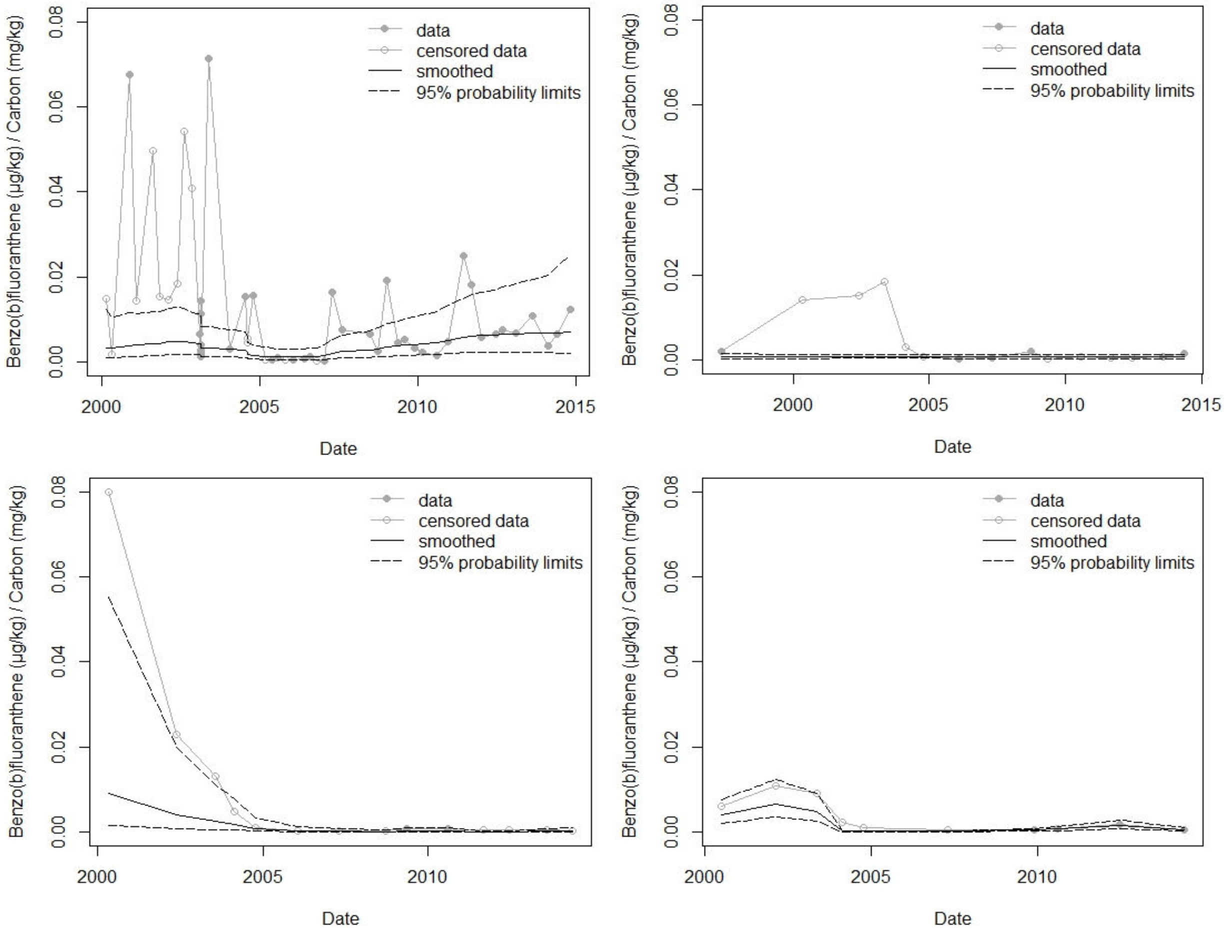

Figure 26: Benzo(b)fluoranthene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

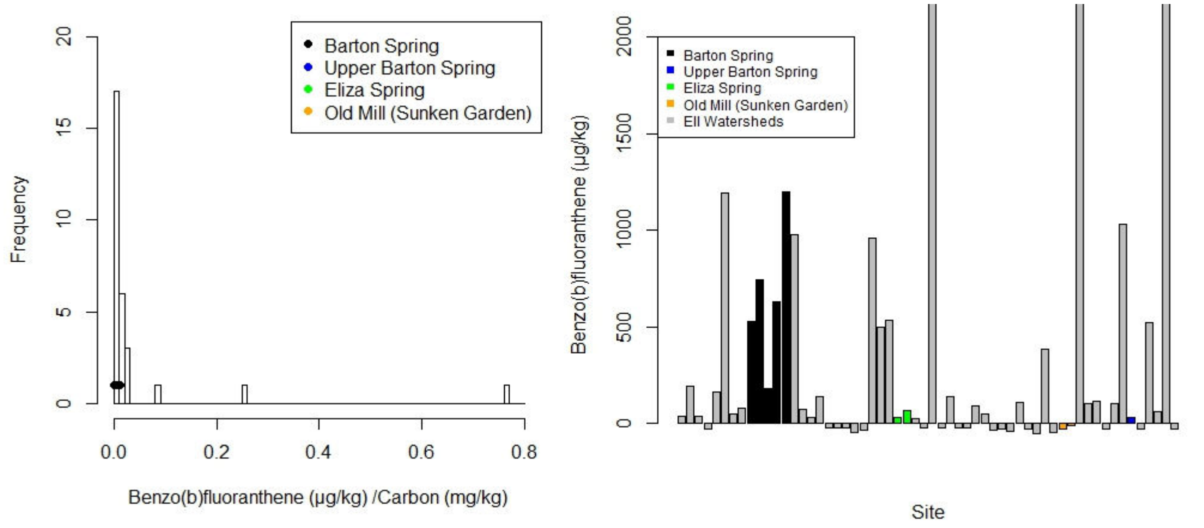

Figure 27: Histogram of benzo(b)fluoranthene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

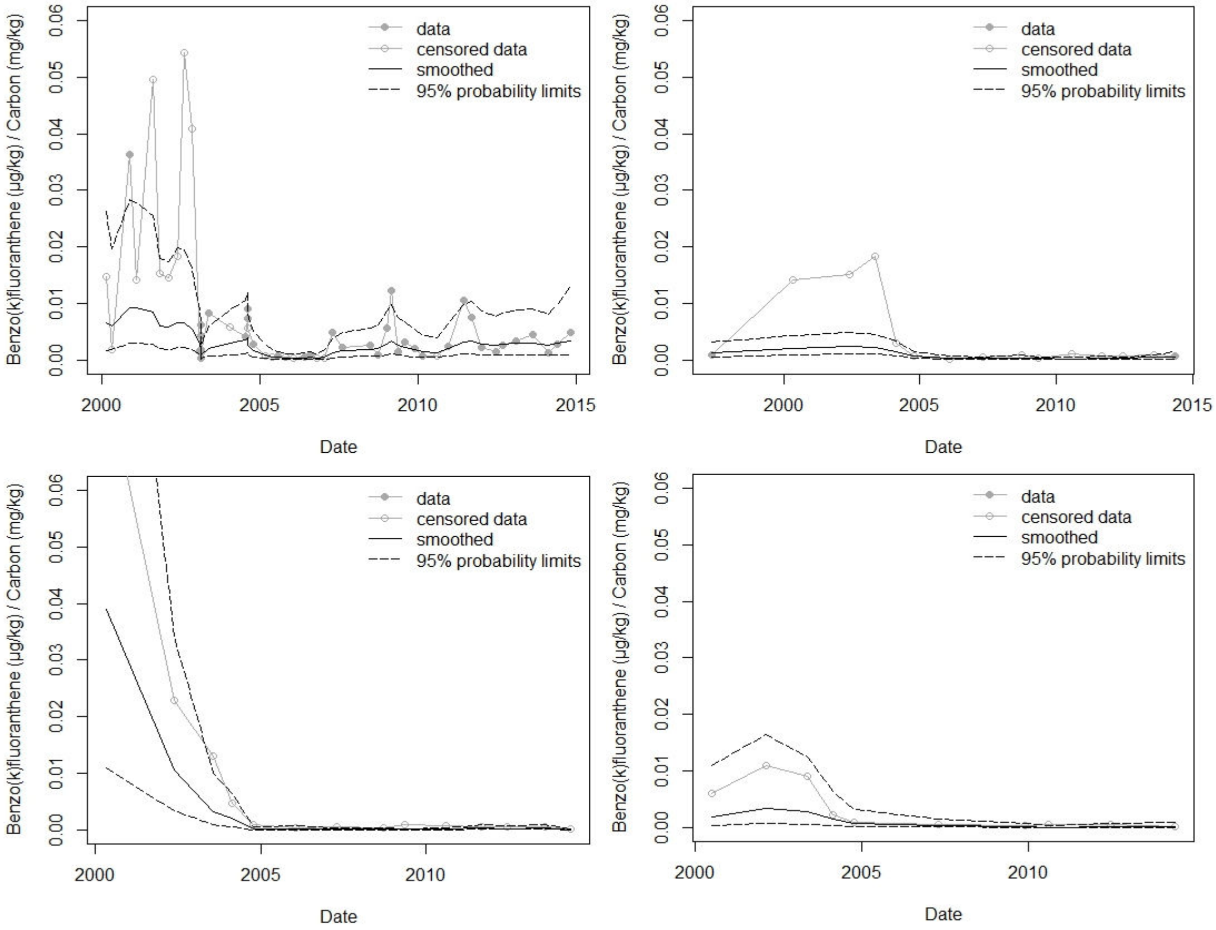

Figure 28: Benzo(k)fluoranthene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

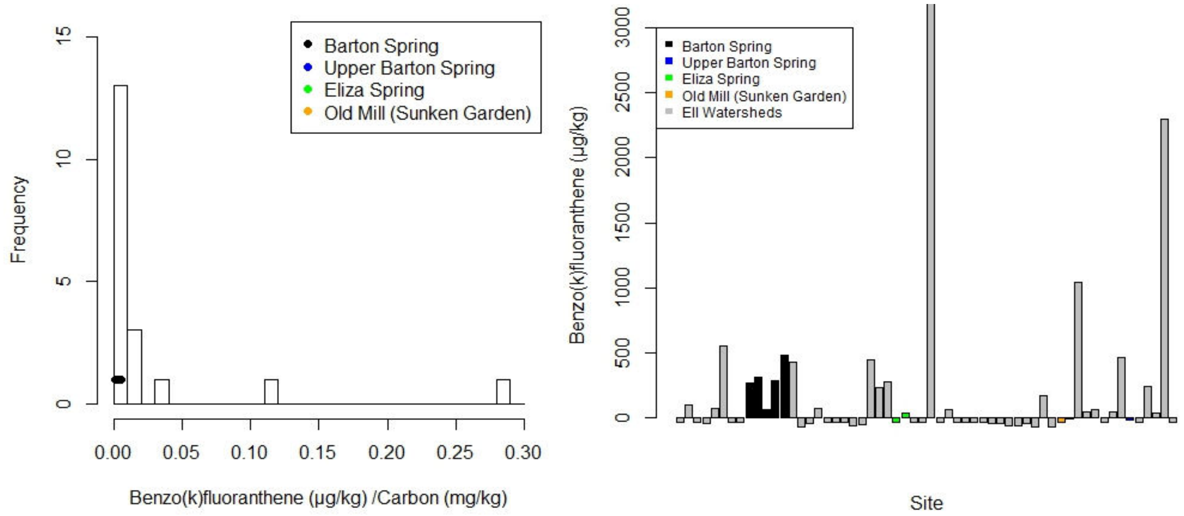

Figure 29: Histogram of benzo(k)fluoranthene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

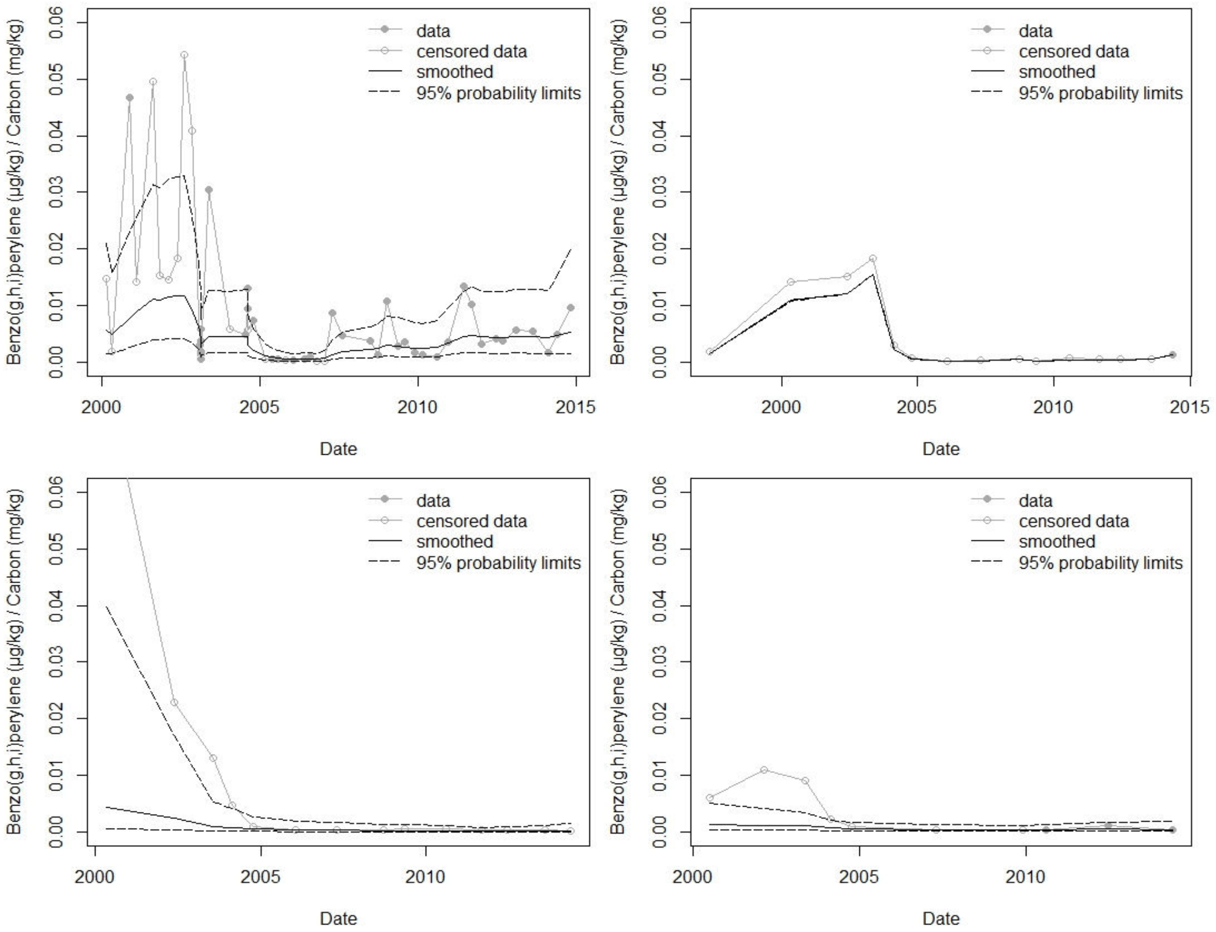

Figure 30: Benzo(g,h,i)perylene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

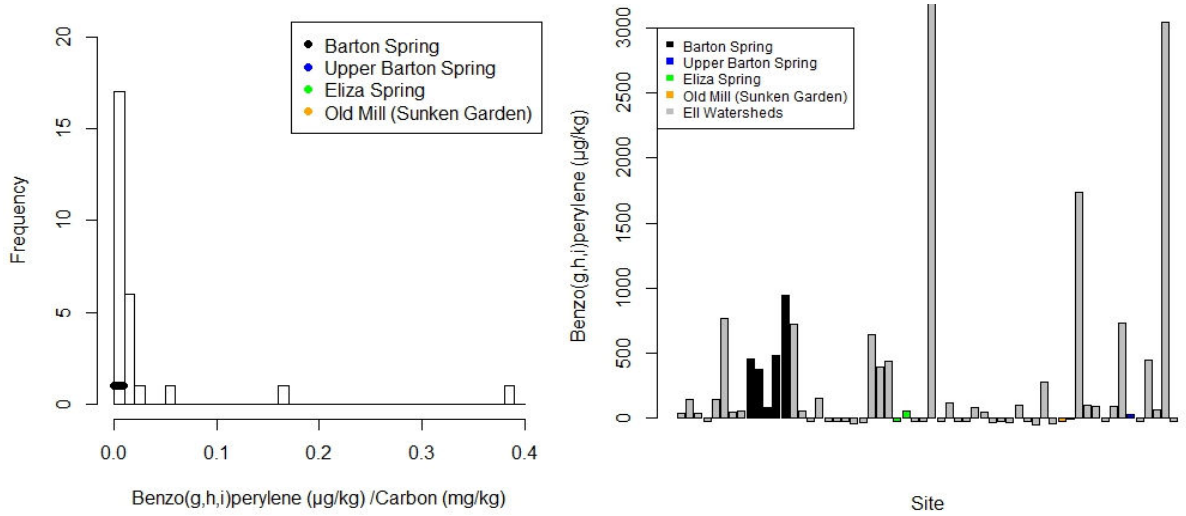

Figure 31: Histogram of benzo(g,h,i)perylene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

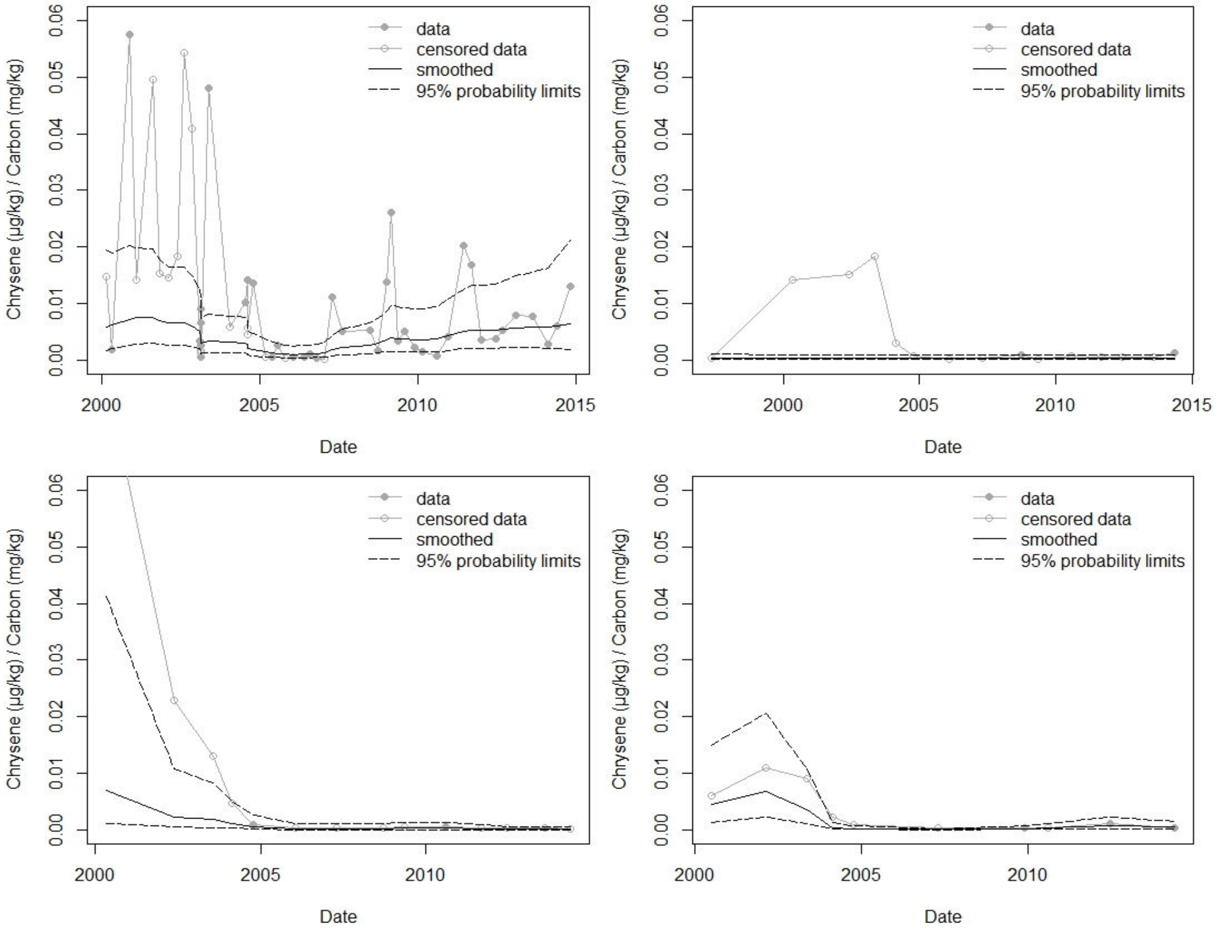

Figure 32: Chrysene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

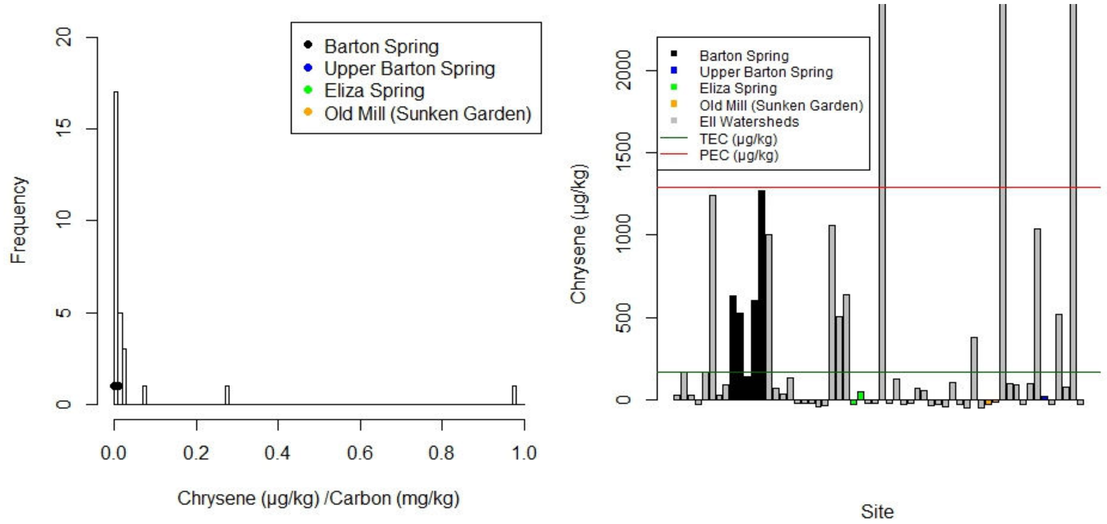

Figure 33: Histogram of chrysene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

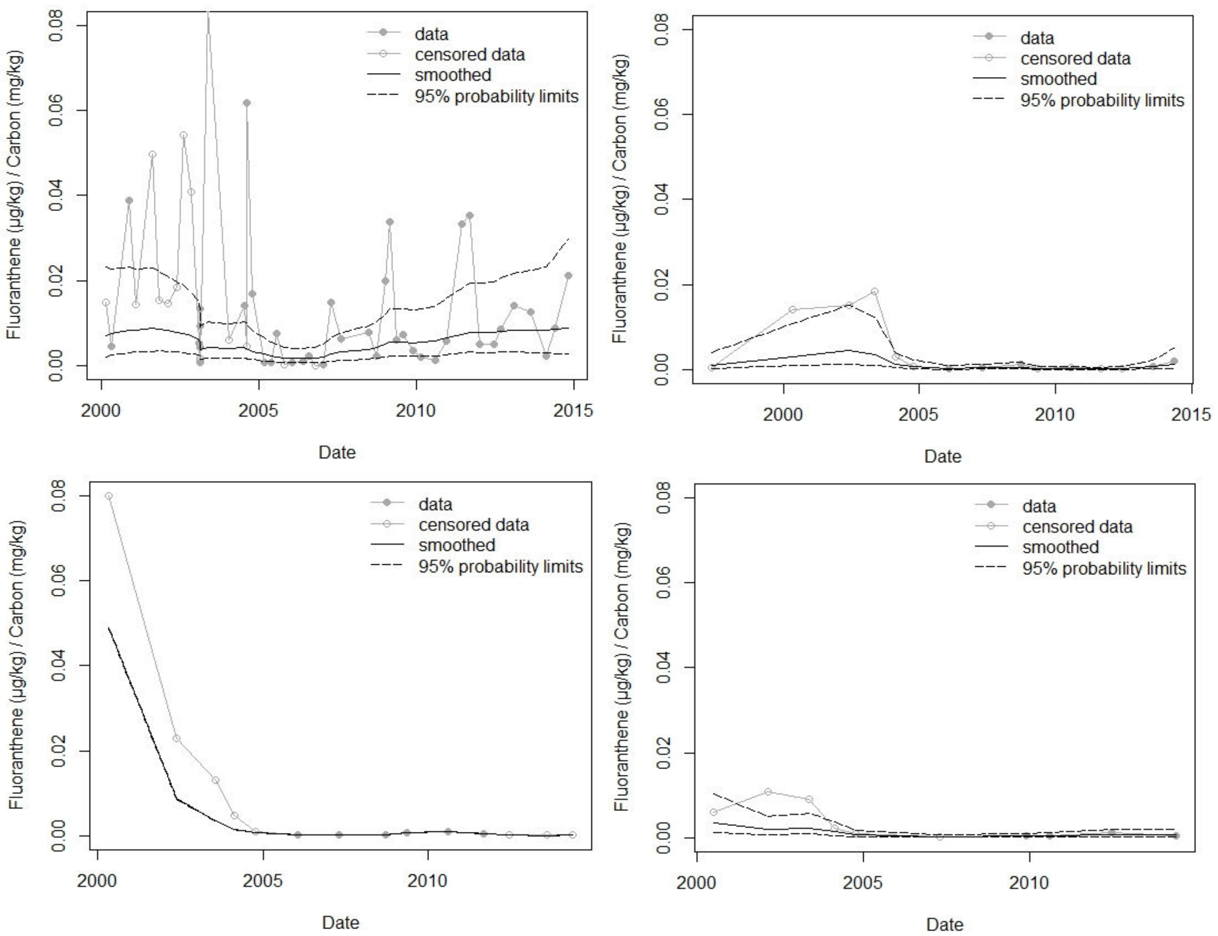

Figure 34: Fluoranthene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

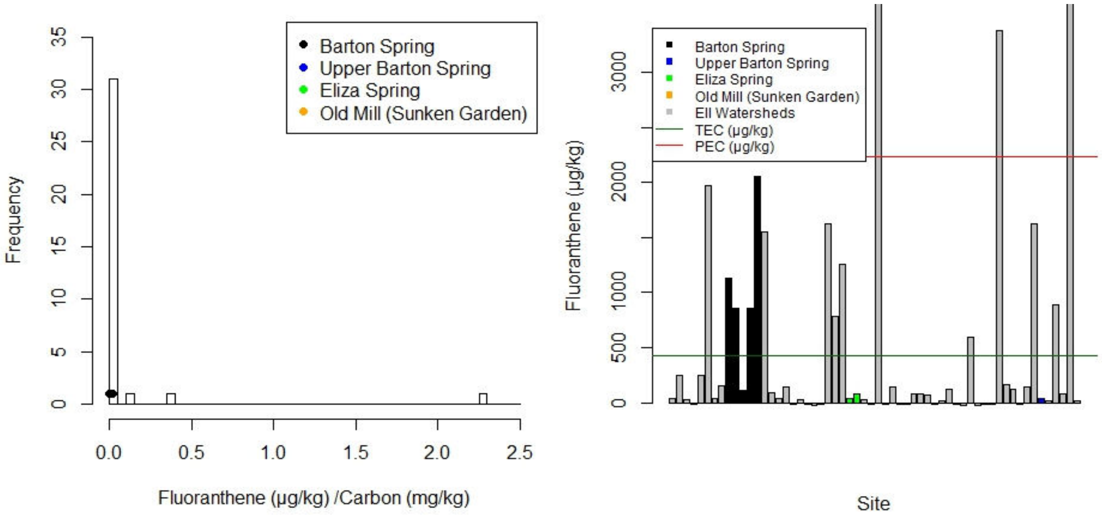

Figure 35: Histogram of fluoranthene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

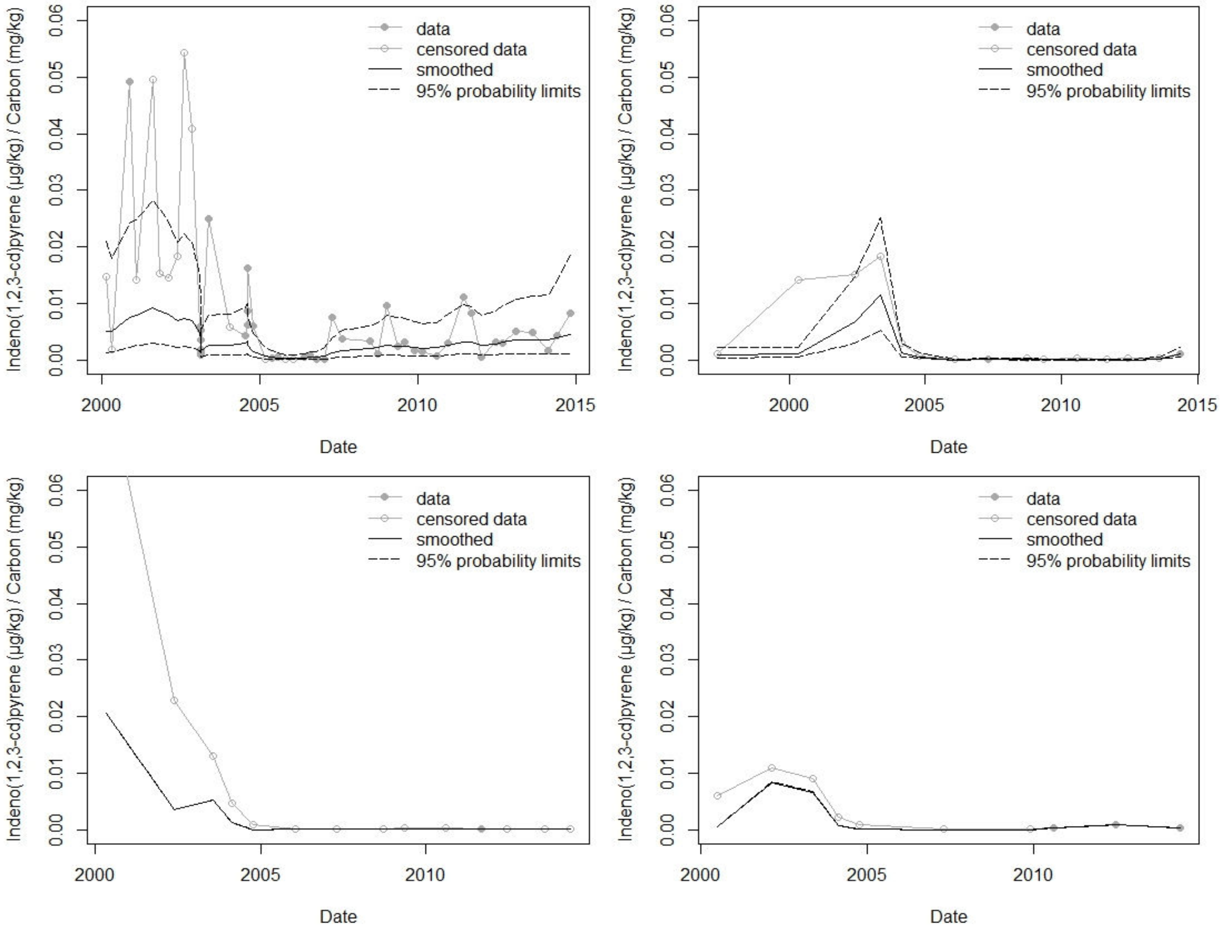

Figure 36: Indeno(1,2,3-cd)pyrene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

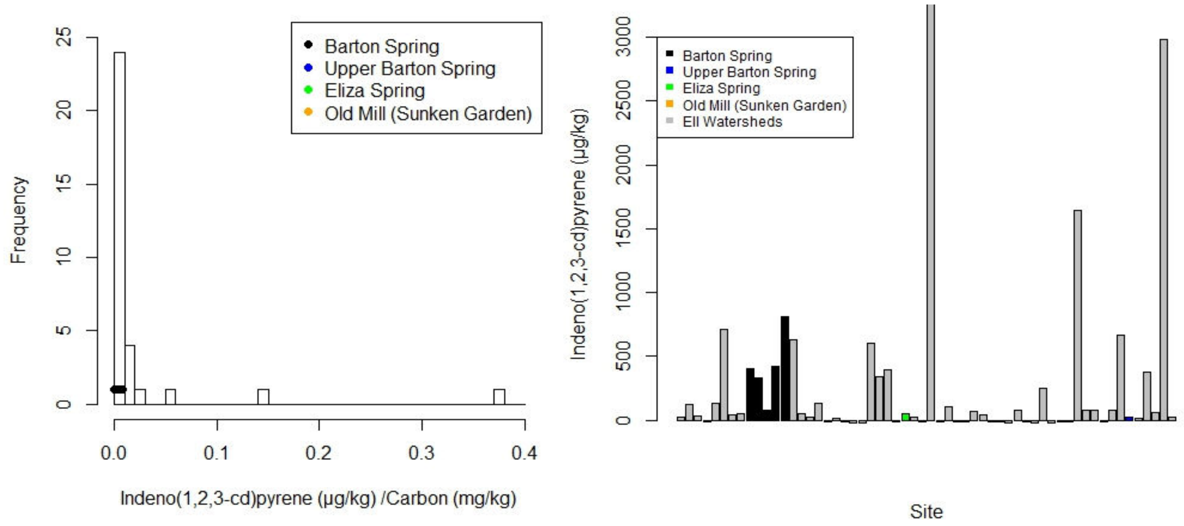

Figure 37: Histogram of indeno(1,2,3-cd)pyrene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

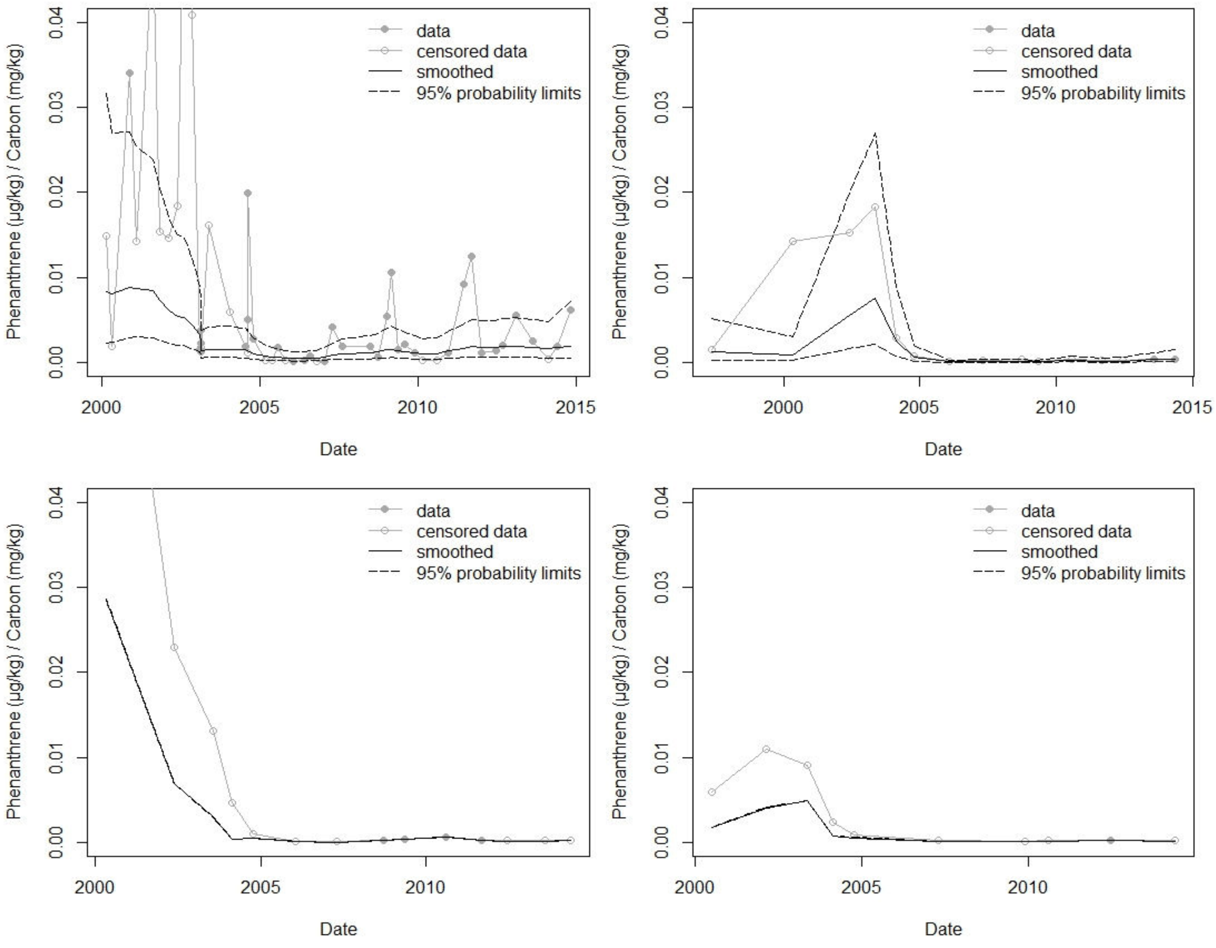

Figure 38: Phenanthrene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

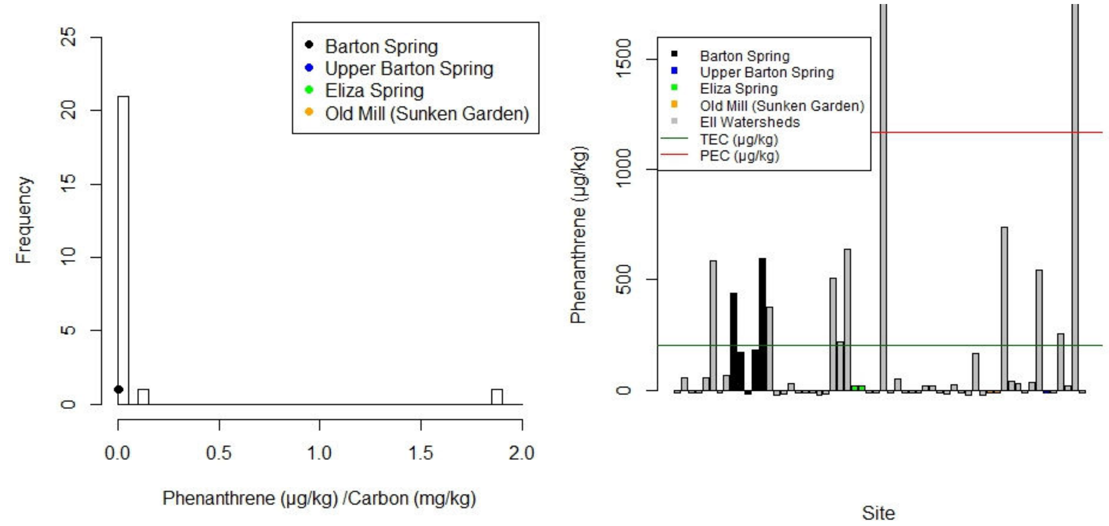

Figure 39: Histogram of phenanthrene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

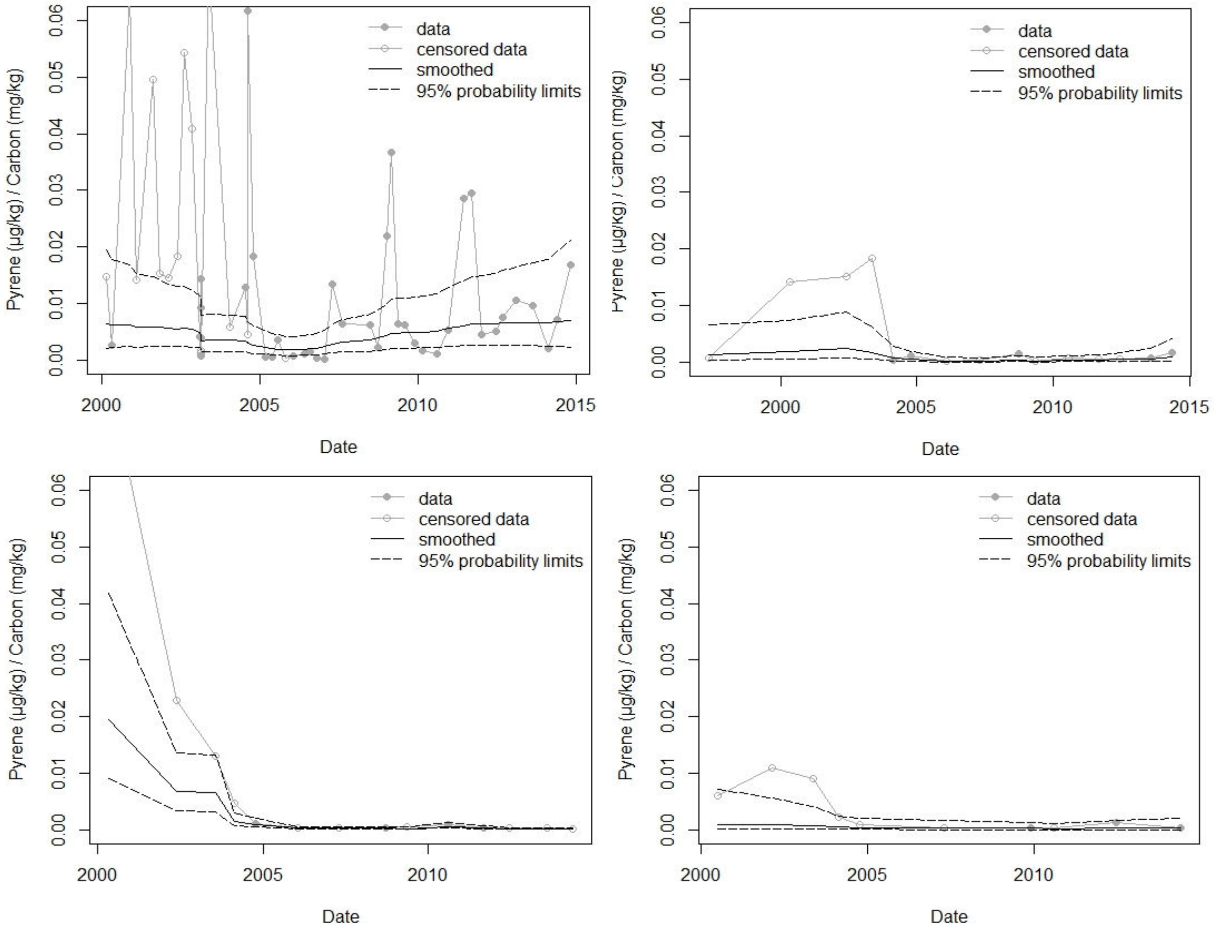

Figure 40: Pyrene (µg/kg) normalized to total organic carbon (mg/kg) in sediment at Main Barton Spring (up-left), Eliza Spring (up-right), Sunken Garden (low-left), and Upper Barton Spring (low-right).

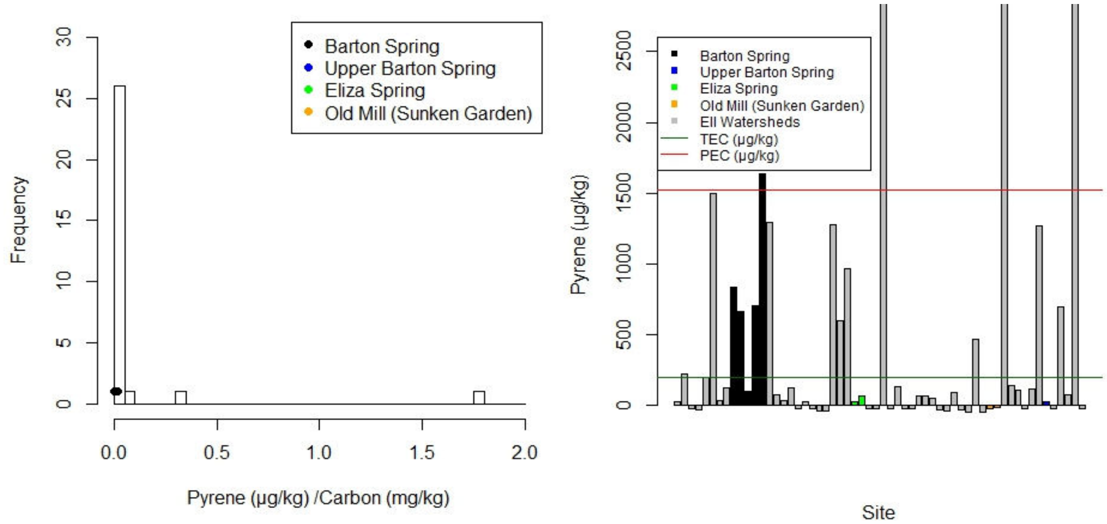

Figure 41: Histogram of pyrene (µg/kg) throughout Austin in 2013-2014, normalized to total organic carbon (mg/kg) above detection limit (left) and non-normalized (right). Non-normalized values below detection limit appear as negative values.

There have been a substantial number of samples collected at Main Barton Spring with concentrations above the TEC for benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, and pyrene (Table 4). In addition, the frequency of collecting sediment samples at Main Barton Spring with concentrations of benzo(a)anthracene, benzo(a)pyrene, chrysene, and pyrene above the TEC has increased over time. Few samples collected at Main Barton Spring have had concentrations higher than the PEC. No samples collected at Eliza Spring, Upper Barton Spring, or Sunken Garden have ever contained concentrations above the TEC for these pollutants. Main Barton Springs differs from the other springs of the Barton Springs Complex in that it is more likely to be inundated during flood events than Eliza and Sunken Garden springs, which are not within the main channel of Barton Creek, and is more likely to accumulate sediment than Upper Barton Springs because of the presence of the downstream dam to impound Barton Springs Pool.

Table 4: Number of benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, and pyrene values above detection limit, TEC, and PEC at Barton Springs.

	Above Detection/ Total Samples	**Above TEC**	**Above PEC**	**Frequency above TEC increasing**	**Frequency above PEC increasing**
Benzo(a)anthracene		108 µg/kg	1050 µg/kg		
Barton Spring	39/62	29	3	Yes	No
Upper Barton Spring	1/13	0	0	No	No
Eliza Spring	4/17	0	0	No	No
Sunken Garden	3/16	0	0	No	No
Benzo(a)pyrene		150 µg/kg	1450 µg/kg		
Barton Spring	40/63	29	2	Yes	No
Upper Barton Spring	2/13	0	0	No	No
Eliza Spring	2/17	0	0	No	No
Sunken Garden	0/16	0	0	No	No
Chrysene		166 µg/kg	1290 µg/kg		
Barton Spring	43/64	32	5	Yes	No
Upper Barton Spring	3/13	0	0	No	No
Eliza Spring	2/17	0	0	No	No
Sunken Garden	2/16	0	0	No	No
Fluoranthene		423 µg/kg	2230 µg/kg		
Barton Spring	44/64	26	5	No	No
Upper Barton Spring	5/13	0	0	No	No
Eliza Spring	5/17	0	0	No	No
Sunken Garden	6/16	0	0	No	No
Phenanthrene		204 µg/kg	1170 µg/kg		
Barton Spring	36/64	18	5	No	No
Upper Barton Spring	1/13	0	0	No	No
Eliza Spring	2/17	0	0	No	No
Sunken Garden	4/16	0	0	No	No
Pyrene		195 µg/kg	1520 µg/kg		
Barton Spring	45/64	33	21	Yes	No
Upper Barton Spring	3/13	0	0	No	No
Eliza Spring	5/17	0	0	No	No
Sunken Garden	4/16	0	0	No	No

Conclusions

Barton Springs

DDT, DDD, DDE
The recent detected values of DDT in sediment samples collected at Main Barton Spring and Eliza Spring and the resulting increase in variation raises some concern for sediment quality at Barton Springs. However, the lack of a significant trend for DDT at the springs quells some of the concern. The two detected values at Main Barton Springs is not sufficient evidence to classify the site as a problem, especially since the detected values are still below the PEC. The same is true for the one detected value at Eliza Spring. The values of DDT above detection could be the result of an influx of previously contaminated sediment brought into the spring from a large storm event. Continued monitoring will allow the City of Austin to evaluate DDT concentrations at all four springs. If values continue to be above the detection limit for DDT then further investigation for a point source is warranted and subsequent actions may include a source identification study around the springs and in streams that would contribute recharge of the aquifer along with increased frequency of sampling at Upper Barton Spring, Eliza Spring, and Old Mill Spring.

Currently, DDD and DDE concentrations do not indicate levels of sediment contamination at Barton Springs for these pollutants. As metabolites of DDT, concentrations of DDD and DDE could increase as DDT eventually breaks down. The City of Austin should continue to monitor for these pollutants in the sediments of Barton Springs in order to ensure that these pollutants to not emerge as concerns to sediment.

PAH
While DDT has only been detected recently in two samples at Main Barton Spring, the concentrations of PAH found historically in the sediment are of more concern. Due to the historical elevated PAH concentration in sediments of Barton Springs several studies have been conducted around the springs to determine the toxicity of the sediments and trace an upstream source of the pollutants. In 2003, the Texas Department of Health conducted a study to determine the human health impacts of the pollutants which concluded that there was no apparent public health hazard to swimmers (ATSDR 2003). Also in 2003, TCEQ conducted a study in Barton Springs Pool and Barton Creek that concluded that elevated PAH concentrations in Barton Creek above the pool were most likely the result of runoff of coal-tar based parking lot sealants based on elevated levels of PAH along a dry tributary which increased upstream to the proximity of an apartment complex parking lot (TCEQ 2003). This would also be a source for Main Barton Springs as the sediment from Barton Creek could be introduced to the area around the spring during major storm events when water and sediment could wash over the dam separating the creek and the spring.

Based on the findings of the study the TCEQ recommended engineering controls be built at the Barton Hills Park Place Apartments to prevent future contamination, an assessment be done for the possibility of removal of contaminated soil and sediment from the dry tributary leading to Barton Creek from the Barton Hills Park Place Apartments, monitoring of the area continue, and an assessment be done for potential aquatic impacts to Barton Creek and Barton Springs Pool. The City of Austin Watershed Protection Department responded by installing a full sedimentation/sand filtration pond, which was completed in July 2007, to treat water entering Barton Creek from this location and re-route runoff from large storm events downstream of Barton Springs. Prior to the construction, contaminated rubble and debris was removed from site. Monitoring of Barton Springs sediment continues as the City of Austin collects quarterly sediment samples from Main Barton Springs with annual sediment samples from Upper

Barton Springs, Eliza Spring, and Sunken Garden, which is reported to the TCEQ in compliance with the City's TPDES MS4 permit. The City of Austin continues to assess potential aquatic impacts to Barton Creek and Barton Springs Pool through the annual reporting to TCEQ and reports such as this one.

For a two year span in 2005-2006, PAH concentrations in Main Barton Springs sediment were very low and have increased slightly from that time period; however, concentrations of PAH do not seem to be currently increasing at the spring. Current PAH concentrations at the springs are not as high as concentrations seen in sediments collected prior to 2005 at the springs. In fact, total PAH (the sum of selected constituent PAH) sediment concentrations in Barton Creek above the dam separating the creek and the springs have decreased over time (Richter 2012). However, individual PAH continue to have intermittent concentrations near or above the PEC threshold. Concentrations of benzo(a)pyrene, chrysene, and other of the probable human carcinogens have frequently been above the detection limit, with the most recent sample containing pyrene at a concentration above the PEC. Additional source locations may be contributing to sediment contamination at Barton Creek and Main Barton Springs and it is recommended that the sampling frequency be increased from quarterly to every other month to better estimate how often the sediment contains concentrations of PAH that are likely to negatively impact aquatic life.

Sediment sampling at the other three springs should continue at the current frequency as there is no evidence of sediment contamination at these springs. If sediment sources of contamination are found for Main Barton Spring in the future that could affect the sediment at the other springs then sampling frequency should increase.

Other Locations of Concern

Sediment DDT concentration collected in 2014 for Bear Creek (West) at Fritz Hughes Park Rd was above the PEC threshold and sediment DDD concentration collected in 2013 for East Country Club at Austin Community College (ACC) was above the PEC threshold. In addition, sediment PAH concentrations collected in 2013 for Shoal Creek upstream of 1st Street were above the PEC for the majority of PAH where a PEC exists. The City of Austin has been routinely sampling sediment in the Bear Creek (West), East Country Club, and Shoal Creek watersheds since 1999, 1996, and 1994, respectively. DDT concentrations have never been above the detection limit in Bear Creek (West) at Fritz Hughes Park Rd. Similarly, DDD has typically been below the detection limit in East Country Club Creek and has not been above the PEC threshold previously. PAH concentrations for Shoal Creek are also typically much lower than the current sample and have been below the PEC threshold. A single high concentration collected from the routine monitoring at these sites is not sufficient evidence to indicate a sediment concern within these watersheds but the City of Austin will continue to monitor these locations every other year to ensure that DDT, DDD, DDE, or PAH are not emerging pollutants. In the next scheduled monitoring events for these locations, analysis results from the lab should be flagged for immediate examination of PAH within Shoal Creek or DDT, DDD, and DDE concentrations within Bear Creek (West) and East Country Club. If levels of pollutants are above the PEC threshold then further investigation is warranted and subsequent actions may include increased sampling frequency at these locations followed by source identification studies.

Sediment DDE concentration collected in 2013 for Waller Creek downstream of Cesar Chavez was above the PEC threshold. The City of Austin has routinely sampled sediment in Waller Creek since 1996. In 2006, 2009, and 2013, the concentrations of DDE were near the PEC threshold while concentrations of DDT and DDD were only above the TEC threshold. Sediment samples collected in 2011 at this location contained no concentrations above the detection limit for DDT, DDD, or DDE. High values of DDE seem to be persistent in Waller Creek sediment but do not seem to be increasing over time. The most recent samples collected at Waller Creek downstream of Cesar Chavez also contained high PAH concentrations. Recent construction of the Waller Creek tunnel may fundamentally alter the quality of the sediment collected at this location. Thus continued monitoring is needed to determine if DDE concerns will persist at this location and if high PAH concentrations will emerge as an issue for this location.

Sediment PAH concentrations collected in 2013 for Harper's Branch at Woodland Avenue was above the PEC threshold for the majority of PAH. The City of Austin has routinely sampled sediment in Harper's Branch since 1996 and the sediment has typically contained sediment with PAH concentrations well above the PEC thresholds. More data does not need to be collected at this site and investigation for a local or upstream source of sediment contamination should be conducted soon for this site.

Recommendations

Increase monitoring of sediment at Main Barton Springs to six events per year. Maintain annual monitoring of sediment at Upper Barton Spring, Eliza Spring, and Old Mill. Additional assessment following the one year of increased monitoring at Main Barton Springs should be conducted. If DDT, DDD, or DDE values continue to be above the detection limit than the sampling frequency at Upper Barton Spring, Eliza Spring, and Old Mill should increase to quarterly sampling in addition to a source identification study. If PAH concentrations are above the PEC for benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, and pyrene in two of the six samples then a source identification study should follow.

Continue biennial monitoring of sediment at Bear Creek (West) at Fritz Hughes Park Rd and East Country Club at ACC. Samples should be flagged for examination upon receipt from the lab. If DDT, DDD, or DDE are above the PEC threshold then frequency of sediment sampling should increase at these locations followed by source identification studies.

Continue biennial monitoring of sediment at Shoal Creek upstream of 1st Street. Samples should be flagged for examination upon receipt from the lab. If PAH (anthracene, fluorene, naphthalene, benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, and pyrene) are above the PEC threshold then frequency of sediment sampling should increase at this location followed by a source identification study.

Continue biennial monitoring of sediment at Waller Creek downstream of Cesar Chavez. Samples should be flagged for examination upon receipt from the lab. If DDT, DDD, DDE, or PAH (anthracene, fluorene, naphthalene, benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, phenanthrene, and pyrene) are above the PEC threshold then frequency of sediment sampling should increase at this location followed by a source identification study.

Biennial monitoring should continue as part of the EII monitoring effort for Harper's Branch at Woodland Avenue; however, a source identification study should be conducted at this location which should include increased frequency of sediment collection.

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