A Summary of Previous Water Quality Studies of Arboretum Creek: FOAC Technical Memorandum #1

— Dave Galvin[1] 8/13/2018

PURPOSE:

Friends of Arboretum Creek (FOAC) intends to document water quality and sediment quality issues related to Arboretum Creek as well as inputs to the creek and adjacent, potential water sources, in order to better evaluate options for enhancing flows into Arboretum Creek in the future. To this end, an early step is to compile available data from recent studies and from comparable nearby streams.

SUMMARY:

Four reports containing recent water or sediment data from the vicinity of Arboretum Creek were located; a fifth document mapped sub-watersheds within the Arboretum Creek drainage but did not provide any additional data; a sixth report documented a temporary flood within the Japanese Garden pond. Petroleum hydrocarbons (such as lube oils), trace metals (such as copper and zinc) and a few legacy pesticides were identified in sediments from the Japanese Garden pond. Nitrogen levels were high in a few samples within the Arboretum, and some trace metals were also found at relatively high levels in various locations. Other results tended to show levels of nutrients, trace metals and old, chlorinated pesticides at what might be considered "background" concentrations within an urban watershed. More sampling will likely be needed to better assess the significance of these findings. Recent water samples of upstream flows did not indicate any unusual contamination. Comparisons with water and sediment data from nearby urban watersheds around Seattle help to put these findings into greater perspective. The assembled data provide a baseline for FOAC's intended sampling and analyses of upper parts of the current Arboretum Creek watershed.

Friends of Arboretum Creek

SEATTLE PARKS FOUNDATION

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King County
Department of Natural Resources and Parks
Wastewater Treatment Division

INTRODUCTION:

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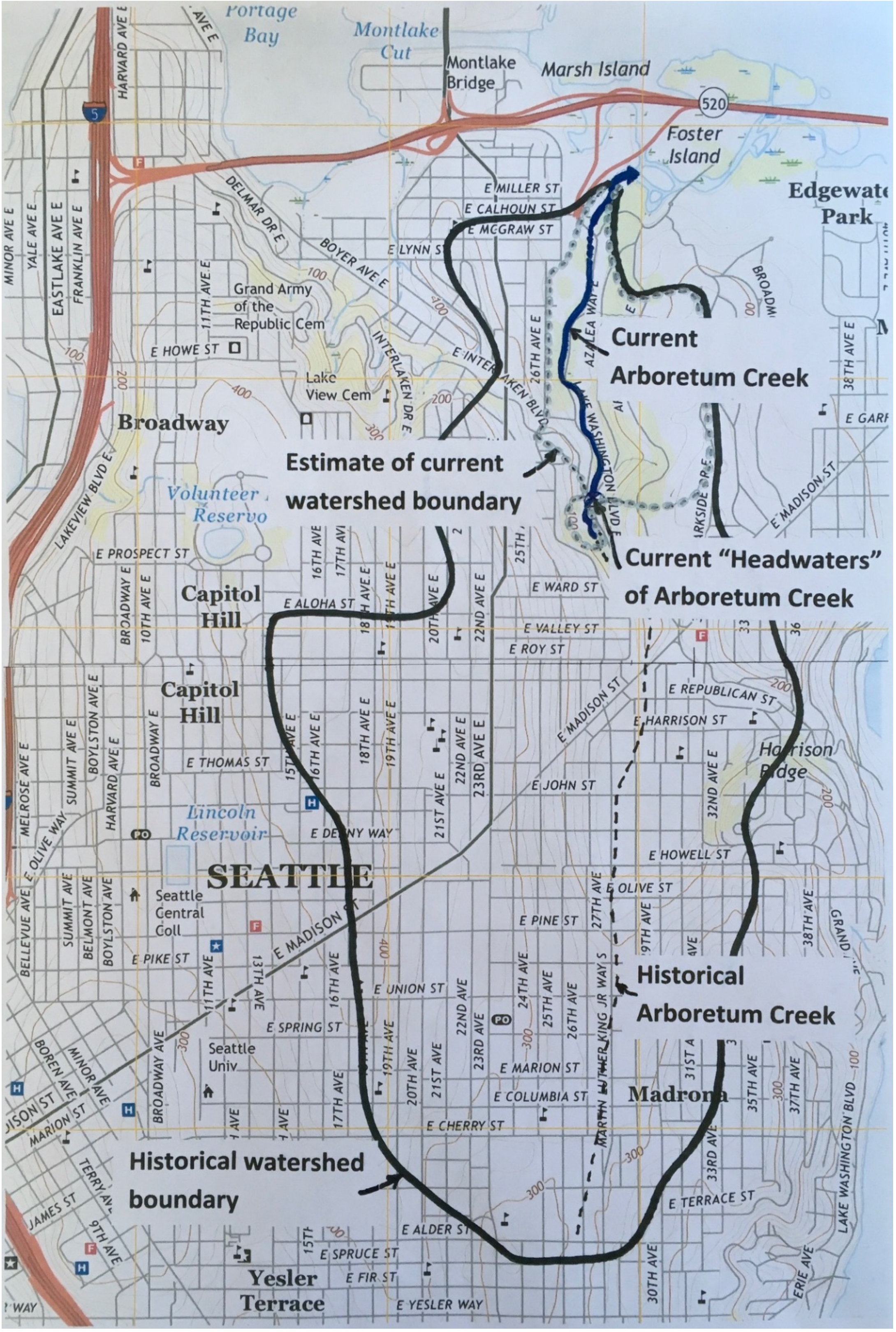
The environmental quality of urban watersheds is challenged by many factors, including extensive development, impervious surfaces, changes to surface drainage flows, shifts of drainage into combined sewers, scouring peak flows during storms, dwindling low flows during dry periods, traffic on roadways with resulting contaminants, runoff from over-fertilized lawns, use of pesticides (legacy and current), and many other issues.

The Arboretum Creek watershed in Seattle is no different from other urban watersheds, and faces all of the challenges noted above. As just one example, the map in Figure 1 shows the historical watershed draining much of east Capitol Hill and the Central District from Garfield High School north, compared to the approximate boundary of the current watershed immediately around the Washington Park Arboretum and adjacent Broadmoor Golf Course. The current "headwaters" are shown as a small X at the southern-most point of the current creek; any drainage immediately south of that point (as indicated by a "?") is still in question as to where it comes from and where it flows. The city's massive sewer and drainage engineering efforts going back more than a century diverted most of the surface water flows from the historical watershed into combined sewers, which carry both wastewater and stormwater in the same pipes, either for treatment at the West Point facility in Discovery Park or, by design, to overflow during storms into the Montlake Cut. (We will prepare a separate technical memorandum that will provide more detail about these engineering changes and possible locations where history might be changed in the future to return some flows to the creek.)

DATA SOURCES:

To our knowledge, the following six reports capture all recent data related to Arboretum Creek. This Technical Memorandum attempts to summarize what we learned from these recent studies. The sources are as follows, in chronological order:

- **Knight, Erica, Megan McPherson and Betsy Vance. 2011.** ***Washington Park Arboretum Saturated Soil Study.*** **University of Washington: Student paper**. A student team from the School of Forest Resources tested soil pits in the Holly garden on the west side of the Arboretum to determine sources of wet soils; their tests included *E.coli* bacteria.
- **Orth, Mark. 2012.** ***Technical Memo: Japanese Garden Park Damages from SPU Water Main Failure*****. Seattle Parks and Recreation: internal report.** A pipe failure uphill of the Japanese Garden flooded the koi pond with eroded sediment; special treatment had to be used to return turbidity and pH levels to standards.
- **O'Brien, Kevin/Otak, Inc. 2015.** ***Technical Memo: Arboretum Water Quality Sampling and Analysis*****. Seattle Parks and Recreation: internal report.** Turbidity and WQ data (nutrients, copper, zinc, chlorinated pesticides) were analyzed from samples collected in March 2015).
- **Watson, Christopher. 2016.** ***Master's Thesis: Watershed and Stormwater Drainage Assessment of the Washington Park Arboretum*****. U.W. Master's Thesis, School of Environment and Forest Sciences.** No new WQ data were collected, but reference is made to O'Brien data. The focus is on identifying sub-watersheds within the Arboretum.



Current Arboretum Creek

Estimate of current watershed boundary

Current "Headwaters" of Arboretum Creek

Historical Arboretum Creek

Historical watershed boundary

Figure 1. The Arboretum Creek watershed, then and now.

— **Bottem, Kelly/Analytical Resources, Inc. 2017. *Technical Memo: Solids [Sediment sample results from Japanese Garden]*. Seattle Parks and Recreation: internal report.** Grab samples were taken of sediment in August 2017; analyses included petroleum hydrocarbons, chlorinated pesticides and metals. Raw data are reported; no attempt was made to interpret the results.

— **Frodge, Jonathan. 2018. *Technical Memo: Arboretum Creek Preliminary Water Quality Data*. Seattle Public Utilities: internal report.** Grab samples of water were taken in February 2018; they were analyzed for nutrients, fecal coliform, turbidity and alkalinity.

In addition, I reference King County data for nearby streams as well as locally available sediment and stormwater values, in order to put the above results in context.

MEASUREMENTS:

In order to characterize environmental samples for their relative health or for contamination concerns, analyses are typically divided into the following categories:

— **Conventional** parameters such as temperature, turbidity, total suspended solids, alkalinity and pH;

— **Biological** parameters such as different measures of bacteria, the most common being fecal coliform counts;

— **Nutrients** such as nitrogen and phosphorus (and various subsets of nutrient compounds);

— **Trace metals** such as cadmium, copper, chromium, lead, mercury and zinc;

— **Trace organic compounds** such as old, chlorinated pesticides like DDT, plasticizers called phthalates or soot particles known as PAHs.

Appendix A provides a brief description of these measures and how they can be used to assess the quality of a body of water.

WHAT WE LEARNED:

1. **Knight et al. (2011)** used previously-dug soil pits (Amico, 2010) to assess sources of water in the Holly garden on the west edge of the Arboretum between Interlaken Blvd. and Boyer Ave. They determined that the very wet soil in this part of the park was most likely from groundwater seepage rather than surface water flows. To check for the possibility that the water could be coming from cracks in up-hill sewer lines, the students employed a simple bacterial test on three samples, with inconclusive results but no obvious *E.coli* findings.

2. **Orth (2012)** documented an emergency clean-up within the Japanese Garden pond due to a ruptured water main up-hill, which deposited eroded sediment and debris within the pond. Initial turbidity measures within the flooded pond were in the range of 154.6-162.7 NTUs (see Appendix A for definitions of measures), while final measures after clean-up, 3.25-4.86 NTUs, were well within the "background" range of 1-10. Acidity measures (pH) were reported as 7.1 to 7.2 after clean-up, well within the state standard of 6.5 to 8.5 for the protection of aquatic life.

3. **O'Brien (2015)** reported results of sampling at 11 sites within the Arboretum for turbidity during storm events, plus at two of these sites for water quality analyses (nutrients, metals and chlorinated pesticides).

   The general map of sampling sites is shown in Figure 2 (with turbidity results). Sampling was done in the Stone Garden sub-watershed (farthest south), the Rhododendron Glen sub-watershed (middle/east side of the Arboretum) and the Woodland Garden sub-watershed (northern/east side of the Arboretum). WQ samples were analyzed from site 2 in the Woodland Garden drainage and site 11 in the Stone Garden drainage (although the document refers repeatedly to these sites as 1 and 10).

   The O'Brien results showed high **turbidity** in the flows coming out of the Broadmoor Golf Course in the northern Woodland Garden drainage (see map image in Figure 2), with levels measured as high as 290 NTUs (higher than the pond-flooding incident of 2012). This turbidity likely originated off-site and is consistent with the large volume of sediments received in the downstream ornamental ponds which require periodic clean-out. Almost all other sites sampled within the Arboretum were at background levels (1-10 NTUs). Turbidity may just be a localized issue, but is still a significant factor for downstream Arboretum Creek and one we should watch for in future sampling.

   Nutrients (measured as nitrate+nitrite Nitrogen) were found to be within standards based on O'Brien's comparison to a British Columbian criterion. However, it appears that the southern Stone Cottage drainage might be impacted by excess nutrients from adjacent lands (e.g., the Broadmoor golf course) or from fertilizer use within the Arboretum. The level recorded there is higher than most urban stream measurements or even local stormwater runoff, as shown in comparison tables in Appendices C and D. The northern drainage had low Nitrogen levels.

Sampling sites	**Nutrient levels (nitrate+nitrite Nitrogen)**	**Reference "standard"**
Stone Cottage (#10 or 11)	3.07 mg/L	40.02 mg/L (B.C. aquatic criteria)
Woodland Garden (#1 or 2)	0.237 mg/L	"

   Copper and zinc trace metal levels were found to exceed threshold levels (derived based on water hardness) for both acute and chronic criteria. (<u>Acute</u> toxicity is the level that causes immediate or short-term adverse effects, such as lethal poisoning; <u>chronic</u> toxicity is the level shown to cause long-term adverse effects such as reproductive anomalies or cancer; see Appendix A for more discussion of acute vs. chronic.) These may reflect toxicity within surface water runoff which originates from general urban sources as well as particular sources such as the golf course. More data will be needed to explore this potential toxicity, as well as to put it in context with other urban watersheds within Seattle.

Sampling Sites	**Metal levels**	**References/"standards"***

Stone Cottage (#10 or 11)	Copper = 7 ug/L Zinc = 20 ug/L	Cu acute freshwater conc. = 7-12 ug/L Cu chronic freshwater conc. = 5-8 ug/L Zn acute freshwater conc. = 53-85 ug/L Zn chronic freshwater conc. = 48-77 ug/L
Woodland Garden (#1 or 2)	Copper = 37 ug/L Zinc = 80 ug/L	See above.

*Calculated using formulae from the WAC based on average local water hardness.

Figure 2. Sampling locations within the Arboretum reported in O'Brien (2015).

As shown in Appendix C, the levels of copper and zinc seen in the Stone Cottage drainage are very similar to "background" urban streams. However, the Woodland drainage levels are noticeably higher, close to stormwater runoff levels as shown in Appendix D. More scrutiny will be needed to assess the significance of trace metals in the local area.

A few **chlorinated pesticides** were found at levels exceeding chronic criteria. Dieldrin, a DDT compatriot from the 1940s to the 1970s, was found at both sites within the park. In addition, chlordane (used for termites and ants) was found at levels above chronic criteria at site #1 (Woodland Gardens). These legacy pesticides are not supposed to be used today (dieldrin was banned in 1985, chlordane in 1988); they continue to linger in the environment for many decades.

Sampling Sites	**Pesticide levels**	**Reference/"standards"**
Stone Cottage (#10 or 11)	Dieldrin = 0.058 ug/L Chlordane = Not detected	WAC: dieldrin acute = 2.5 ug/L WAC: dieldrin chronic = 0.0019 ug/L WAC: chlordane acute = 2.4 ug/L WAC: chlordane chronic = 0.0043 ug/L
Woodland Garden (#1 or 2)	Dieldrin = 0.13 ug/L Chlordane = 0.130 ug/L	See above.

Summary of O'Brien data: There were high turbidity readings in the northern-sampled drainage, which is not a surprise given the ongoing sedimentation observed in the ornamental ponds in this drainage; otherwise there were no findings of significance for turbidity in the other samples. Nitrogen levels were high in the Stone Cottage drainage. High copper and zinc levels, especially in the northern drainage, show that surface runoff might present an ongoing challenge to aquatic creatures downstream; much more research is needed to flesh this out. High dieldrin and chlordane pesticide residues show either continued use (after these products were taken off the market in the 1980s) or, more likely, ongoing legacy levels in the soil from previous use. How all of this affects downstream levels in Arboretum Creek is unknown.

4. **Watson (2016)** primarily focused on watershed delineation, and provided no new data regarding water quality. He referenced the O'Brien data. He recommended additional water quality testing throughout the calendar year in order to better evaluate challenges which might be seasonal within the watershed.

   Watson identified eight sub-watersheds to Arboretum Creek. See map in Figure 3. In addition, he identified six minor watersheds in the northeast corner of the Arboretum that flow directly into Union Bay.

   Watson based his watershed delineation on Lidar topographic assessment, without taking into account the reality over the last 100+ years of the city's combined sewers which divert much of the identified watershed areas outside of the park away from Arboretum Creek (see Figure 1). He mentions this diversion in his text, but the sub-watershed boundaries he identifies are significantly larger than the areas that actually drain into Arboretum Creek today. They represent the maximum possible drainage areas if all surface flows were separated back out of the combined sewers. Watson does acknowledge the huge diversion of all flows south of Madison Street into the combined sewers and the recent MVSP (Madison Valley Stormwater Project), which includes the large storage tank in the southern portion of the park next to Madison Street; all of these flows from the MVSP go directly into the large King County combined sewer pipe that runs under the west side of the Arboretum and which flows toward the Montlake Cut.

A more accurate assessment of current flows within the current watershed is needed.

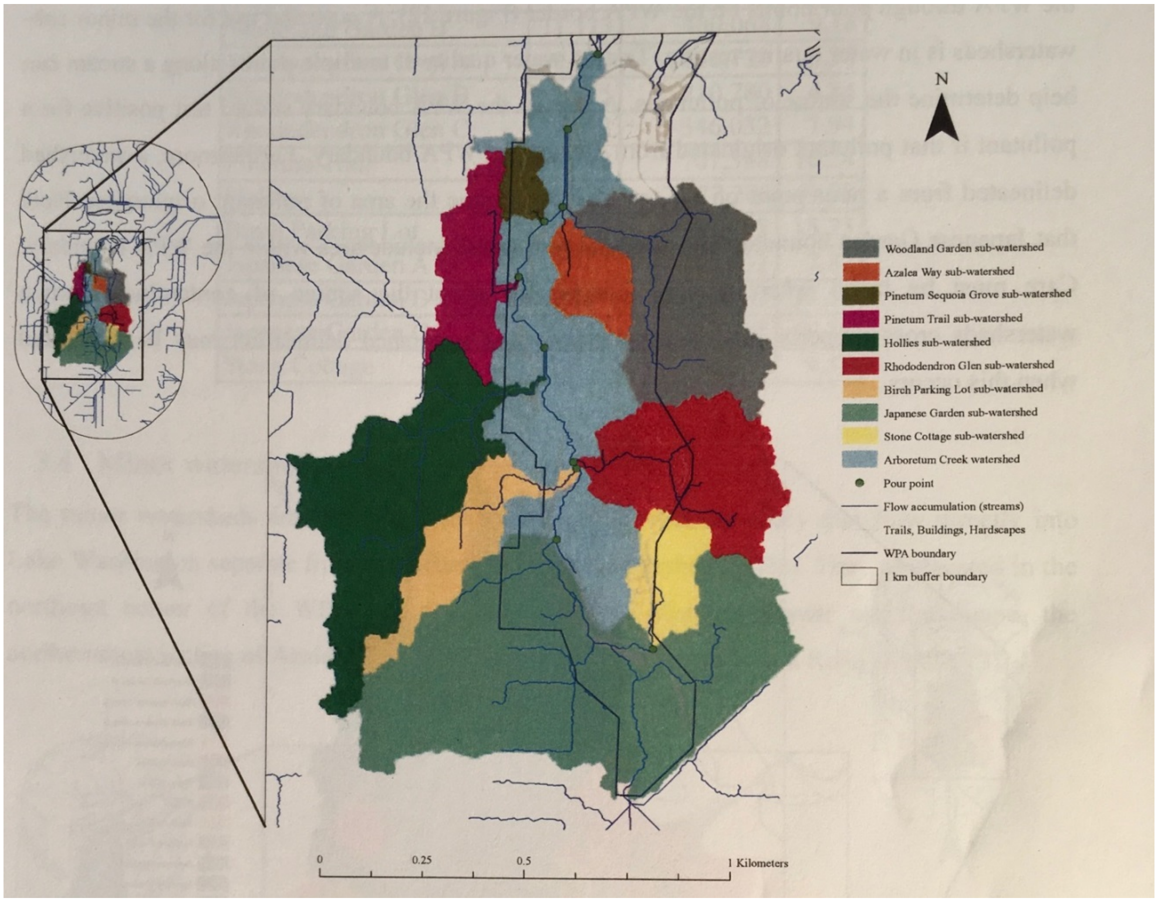


Figure 3. Topography-based sub-watersheds to Arboretum Creek, from Watson (2016).

5. **Kelley Bottem of Analytical Resources, Inc.** analyzed four sediment samples collected by park staff from within the Japanese Garden pond in August 2017. The samples were analyzed for diesel/heavy oil hydrocarbons, chlorinated pesticides and trace metals. (Results were reported in wet weight. In order to compare these values to Washington State's Model Toxics Control Act sediment clean-up standards and other comparison data, we converted these data into dry weight values.)

Results for **hydrocarbons** showed contamination within the pond's sediments. For **"light-weight" organics in the range of diesel fuel** (carbon chains from around 12 to 24 carbons), levels were higher than Washington state's sediment clean-up standards. These results indicate some petroleum/oil sources into the pond, such as from street surface or parking lot runoff.

Diesel organics (C12-C24)	**Results in wet weight mg/kg Median (Range)**	**Results converted to dry weight in mg/kg Median (Range)**	**Comparison to standards SCUM II***	**MTCA** (Both in dry weight)**
4 Samples	337 (193-1230)	1380 (586-6579)	340	510

* Sediment cleanup objective, from Washington Administrative Code 173-204-563

** Model Toxics Control Act cleanup screening level, also from WAC " .

For **heavier organic hydrocarbons, in the motor oil range** of 24 to 38 carbons, levels were again higher than state clean-up standards for at least two of the samples. This confirms to me that there must be some street or parking lot runoff that has gotten or is getting into the Japanese Garden pond.

Motor oil organics (C24-C38)	**Results in wet weight in mg/kg Median (Range)**	**Results converted to dry weight in mg/kg Median (Range)**	**Comparison to standards: total petroleum hydrocarbon (residual) SCUM II**	**MTCA (Both in dry weight)**
4 Samples	685 (429-1390)	3010 (1043-7457)	3600	4400

Pond sediment samples were also analyzed for **chlorinated pesticides**. A few of the old DDT relatives were found, which are common in sediment samples as legacies of use 50+ years ago. These included dieldrin, DDE and DDD. Hexachlorobenzene (a fungicide banned in 1966) and chlordane (an ant- and termite-icide, banned in 1988) were also found. Dieldrin and DDE exceeded reference standards; DDD did not; the others are in question without standards to compare to. We need to seek other local sediment data in the urban area in order to help to put these findings into perspective; they likely represent "background" legacies.

Detected Pesticides in 4 samples: Upper 1-2 and Lower 1-2	**Results for chlorinated pesticides in ug/kg wet weight (ranges in 4 samples)**	**Results for chlorinated pesticides converted to dry weight in ug/kg (ranges in 4 samples)**	**Comparison to standards SCUM II**	**MCTA (Both in dry weight)**
Dieldrin	1.89 – 13.5 (2 of 4)	4.6 – 60.2	4.9	9.3
DDE (a DDT breakdown	9.97 – 19.5 (4 of 4)	24.3 – 104.6	21	33

DDD	9.51 – 13.1 (2 of 4)	23.1 – 56.2	310	860
Hexachlorobenzene	0.61 – 2.67 (2 of 4)	1.5 – 11.9	—	—
Chlordane	6.59 – 10.1 (2 of 4)	29.4 – 54.2	—	—

Trace metals were also analyzed for in the pond mud. Cadmium was detected in a single sample, at a high level when compared to both state clean-up standards and nearby comparison sediments (as shown in Appendix C); but with a detection of only one out of four samples, it is difficult to put this single observed level into context. Chromium exceeded sediment standards significantly in three of the four samples, and was higher than most comparison sediment results (Appendix C). Lead, while not exceeding clean-up standards, was still at levels fairly high in comparison to other local data (see Appendix C). Mercury also exceeded standards in two of the four samples. These results, especially for chromium, are puzzling and will require further analyses to sort out. If, for example, pressure-treated wood might be a source of chromium in the sediments, one would expect to also find high levels of arsenic, which was analyzed for but not detected in any of the four samples. Could the chromium have been introduced inadvertently with the pond treatment for turbidity in 2012?

Detected trace elements (heavy metals) in 4 samples	**Results in mg/kg wet weight Median (Range)**	**Results converted to dry weight in mg/kg Median (Range)**	**Comparison to standards**	
			SCUM II	**MCTA**
			(Both in dry weight) mg/kg	
Cadmium	1.07*	5.6*	2.1	5.4
Chromium	59.4 (27.8 – 71.7)	336 (71 — 435)	72	88
Lead	43.7 (23.9 – 49.5)	230 (61 — 344)	360	1300
Mercury	0.19 (0.02 – 0.28)	0.8 (0.13 – 2.0)	0.66	0.8

* Cadmium was detected in only one sample, at level shown.

Summary of Bottem/ARI data: Sediments in the Japanese Garden pond appear to be contaminated by sources outside of the garden, and/or by legacy sources left over in the bottom sediments. Petroleum hydrocarbon levels were high, signaling potential stormwater runoff sources. Some legacy pesticides linger there, and trace metal levels were significantly higher than expected. More sampling will be needed here and in sources to the pond in order to better assess the significance of these findings.

6. **Jonathan Frodge, Ph.D.**, staff scientist at SPU, took a few grab samples of water in and near Arboretum Creek in February 2018 in order to get an initial indication of WQ concerns in areas of

interest to FOAC. Comparison was made to recent results from Mapes Creek in south Seattle, Thornton Creek in north Seattle and Juanita Creek in Kirkland.

Sampling sites are shown in Figure 4, next page. One site was at the current headwaters of Arboretum Creek. Two other sites were up-hill to the west of the Japanese Garden, where

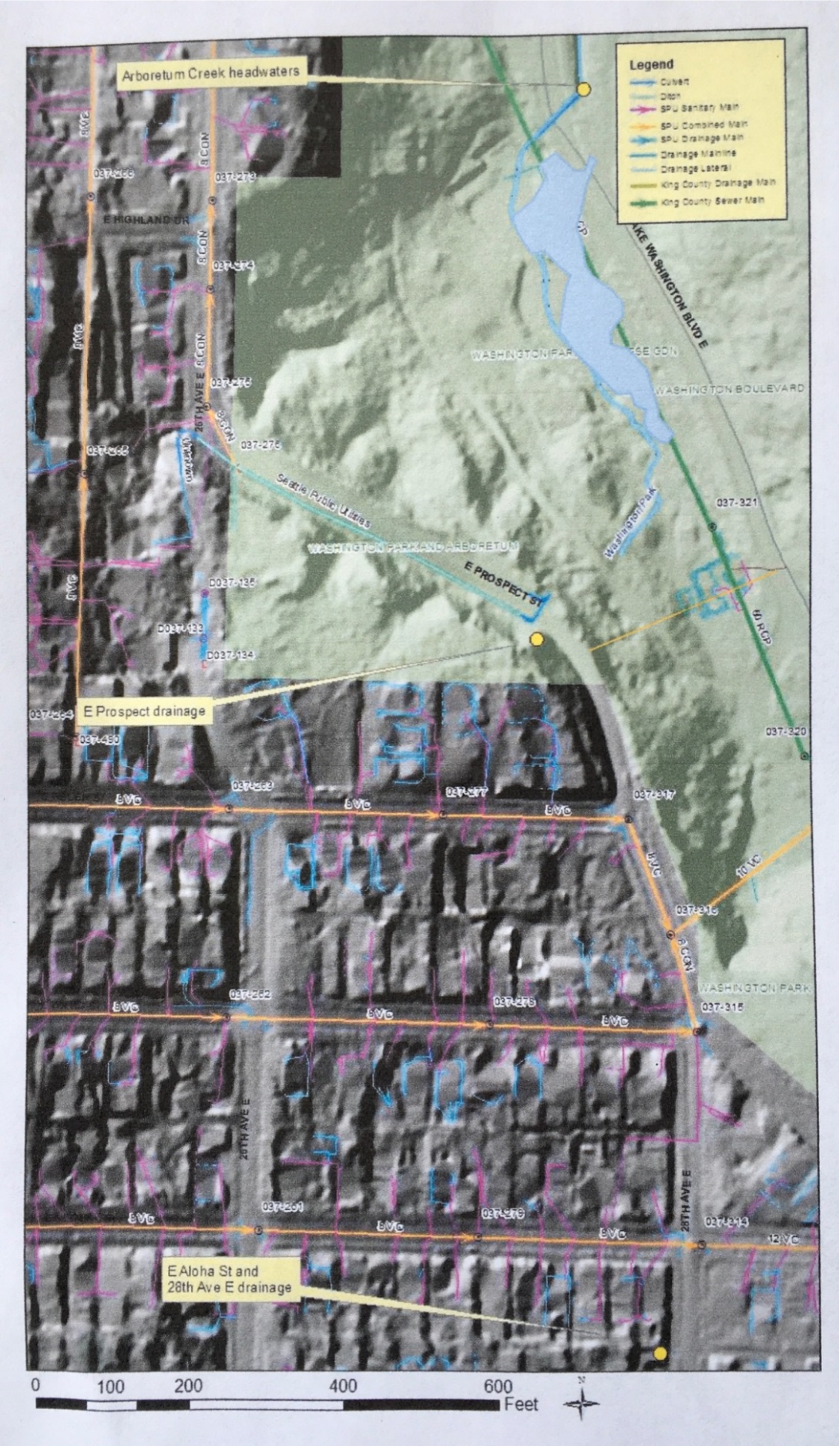


Figure 4. Sites near the Japanese Garden where Frodge (2018) took water samples.

springs and other surface flows drain out of the side of Capitol Hill — one at the bottom of the hill at E. Prospect, the other where regular puddles are seen at 28th Ave. E. and E. Aloha.

Nutrients were divided into Total Nitrogen, Nitrite+Nitrate, Ammonia Nitrogen, Total Phosphorus and Orthophosphate Phosphorus. All results were within normal levels — no signs of unusually high fertilizer use or other sources were detected. Only Total N and Total P results are shown here:

Samples	**Total nitrogen in mg/L**	**Comparison with nearby streams*** **Mapes Thornton Juanita**
Arboretum Creek hdwtrs.	0.60	2.9 1.2 1.1
E. Prospect St.	1.89	Same
28th Ave. E. & E. Aloha St.	1.86	Same

* Further comparison data are available in Appendix B.

Samples	**Total phosphorus in mg/L**	**Comparison with nearby streams*** **Mapes Thornton Juanita**
Arboretum Creek hdwtrs.	0.060	0.08-0.2 0.059 0.051
E. Prospect St.	0.049	Same
28th Ave. E. & E. Aloha St.	0.073	Same

* Further comparison data are available in Appendix B.

Fecal coliform bacteria were analyzed in order to assess potential for sewage contamination. Some low levels of bacteria are found in all urban water samples, from pet wastes, birds and other sources. While the result at 28th and Aloha was somewhat higher than others, it was still within the normal range for urban water samples as shown by the comparison to levels observed in the same time period in Thornton and Juanita creeks – considered "background" levels. Typical sewage contamination would add orders-of-magnitude greater counts.

Samples	**Fecal Coliform Bacteria in CFU/100 ml**	**Comparison with nearby streams*** **Mapes Thornton Juanita**
Arboretum Creek hdwtr.	Less than 1	1-2 360 410
E. Prospect St.	12	Same
28th Ave. E. & E. Aloha St.	210	Same

* Further comparison data are available in Appendix B.

Alkalinity was also measured, as a way to assess the water's capacity to buffer against changes in pH. All levels were within a normal range for the water found in the glacial till of the Puget Sound area.

Samples	Total Alkalinity (mg CaCO3/L)	Comparison with nearby streams		
		Mapes	**Thornton**	**Juanita**
Arboretum Creek hdwtr.	67	103	58	51
E. Prospect St.	91	Same		
28th Ave. E. & E. Aloha St.	105	Same		

Summary of Frodge (2018) data: "No smoking guns," as Frodge described to us directly. All sample results were within expected urban water levels. No obvious contamination from sewage was detected from the locations sampled.

ADDITIONAL COMPARISON DATA FOR URBAN WATERSHEDS:

In order to more fully evaluate what we see in the Arboretum Creek watershed, it is useful to look at data from nearby watersheds, both for water and sediment quality. King County provides a great repository of such information at its website, "Streams Data," at http://green2.kingcounty.gov . **Appendix B** provides **summary water quality data** from three Seattle watersheds: Thornton Creek, Pipers Creek and Longfellow Creek, as well as for Lake Washington water at the Montlake Cut. While each creek has its own unique issues, a general view of levels and trends across multiple local watersheds can help to put specific data from Arboretum Creek into context.

In addition, I have sought out **local sediment data** from Lake Washington, Lake Union and other nearby locations in order to compare values and specific chemicals found in Arboretum Creek sediments with comparable results. **Appendix C** provides a few useful comparisons.

I have also located some **local stormwater runoff data** in order to provide another comparison which might be handy as we assess potential street runoff sources into the creek. **Appendix D** provides a summary of what I found from useful local studies done about ten years ago in the Broadview/Carkeek area in NW Seattle and in the Delridge area in SW Seattle.

I have not included **local drinking water data** (available from Seattle Public Utilities) here since these comparison appendices are already getting to be larger than my direct report. Of most interest would be fluoride levels in drinking water (typically 0.6 – 0.9 ppm) which could be used as an indicator of drinking water sources if, for example, we suspected that some of the seeps along 28th Ave. E were from cracked or broken distribution pipes.

NEXT STEPS:

The results we have found from recent studies paint a mixed picture. Frodge's recent grab samples of sites near the current "headwaters" of Arboretum Creek all look relatively clean, showing no signs of contaminants from leaking sewage or stormwater sources. However, Frodge did not analyze for petroleum hydrocarbons, trace metals or chlorinated pesticides. The O'Brien and Bottem/ARI data showed some contaminants of concern that will require further assessment.

Based on the data summarized above, FOAC will develop a proposed sampling plan to explore water and sediment quality further within the upper parts of Arboretum Creek as well as in potential sources to the creek. Issues related to contaminant sources within the Japanese Garden pond will also be explored. Due to limited funds, we will focus our efforts initially on basic water quality parameters that are relatively inexpensive to analyze for, similar to those used by Frodge (2018), with the addition of some general petroleum hydrocarbon measures (indicators of stormwater runoff) and some sediment samples to complement water grabs. We will begin to collect routine temperature data for Arboretum Creek in order to establish a baseline understanding of that important parameter, and will explore use of a portable turbidity meter in order to collect more on-site data for that parameter-of-interest. Further analyses of trace metals and chlorinated organic compounds will await a clearer overall picture of drainage in this area as well as additional dedicated funds to run these relatively expensive analyses.

We will continue to explore data and trends from other urban watersheds and nearby monitoring sites in order to keep locally-collected results in context with urban "background" conditions as well as official quality standards.

We expect to update this compilation of background data periodically as new information surfaces.

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Appendix A. Environmental Quality Measures Explained.

In order to help readers interpret all of the data summarized in this report, I provide the following brief definitions for various parameters used to assess water and sediment quality, as well as some discussion about how we use these measures to understand environmental conditions. Many of these definitions are adapted from King County's excellent on-line resources at http://green2.kingcounty.gov .

1. **Units of measure:**
    a. **Concentrations in water** are measures of one substance in a given amount of another (water), usually shown in milligrams per liter (mg/L) which is often reported as parts per million (ppm). (For comparison, one part per hundred = a percentage.) Smaller concentrations are shown in micrograms per liter (ug/L) which is often reported as parts per billion (ppb). 1 ppm = 1000 ppb.

    b. **Concentrations in sediment** are similar measurements of a substance within a solid matrix, shown in milligrams per kilogram (mg/kg or ppm) or micrograms per kilogram (ug/kg or ppb). Results are often reported as "wet weight," which includes the amount of moisture in the solid sample. Conversion to "dry weight" is important in order to compare with available standards.

    c. **Stormwater data** are often reported as **"Event Mean Concentration"** or **EMC.** This unit represents the median concentration of a parameter in stormwater taking into account the storm flow as well as the incidental grab samples measured for storm quality.

    d. **Other units** are defined with the measures below.

2. **Conventional measures** of water quality include:

    a. **Temperature** – a key measure for environmental conditions, water temperature affects the amount of oxygen able to remain dissolved and thus is significant to fish and other critters. Results are usually reported in degrees Celcius ("C"). Washington state fresh water standards set an upper threshold of 13 degrees C (55 degrees Fahrenheit ("F")) in fall-winter-spring when salmonids are spawning and fry are emerging. An upper threshold of 16 degrees C (61 degrees F) is set for summer (June 15—September 15). State standards define a maximum temperature for salmon spawning, rearing and migration at 17.5 C (63.5 F). Temperatures above 23 degrees C (73 F) are lethal to salmonid fish; temperatures above 17.5 C (63.5 F) are lethal to developing salmonid embryos.

    b. **pH** – a measure of acidity of water, on a scale of 0 (extremely acidic) to 14 (extremely basic), with 7 as the neutral mid-point. Most of our local streams measure just slightly above neutral, in an average range of 7.2 to 7.8. Median pH at the Montlake Cut over many decades has been measured at 7.7 (Clark et al., 2017). Washington fresh water standards allow a range between 6.5 and 8.5. Seattle's drinking water enters the distribution pipes at pH 8.0-8.6.

    c. **Turbidity** – a measure of cloudiness of the water, which can be caused by suspended dirt particles or other things like algae. It is reported in Nephelometric Turbidity Units ("NTUs") – the measure uses light scatter off of suspended solids as a beam of light passes through the water sample. Background can be considered anything less than 50 NTUs, while measures of 10 or less are considered quite low for surface waters. Seattle's drinking water enters the pipes (after treatment) at 0.15-0.3 NTUs – super clear!

d. **Suspended Solids** – a way to quantify the solids suspended in water (related to turbidity), by a filtration method. It is reported in mg/L. Turbidity and Total Suspended Solids (TSS) can be correlated in site-specific areas, so as to use the easier method to achieve both results. The TSS method is dependent on the mesh of the filter used in the analyses, usually 1.5 microns.

e. **Alkalinity** – a measure of the carbonates and bicarbonates dissolved in water, which is an indicator of the water's ability to buffer against too much acidity. It is similar to hardness, but measures the carbonate part of the calcium- or magnesium-carbonate compounds. Waters with alkalinity values of 50 mg/L or greater usually have a neutral to slightly basic pH and the ability to buffer pH changes (which is a good thing). In the soft-water of the Western Cascades, urban environments tend to add alkalinity due to the extent of concrete surfaces and pipes that react with surface water flows. Seattle's drinking water measures 19-21 mg/L. Lakes Washington and Union have reported consistent median values over many decades at 39 mg/L (Clark et al., 2017).

f. **Hardness** – a measure related to alkalinity, which focuses on the total dissolved minerals calcium and magnesium; thus it measures the dissolved, elemental portions of calcium- and magnesium-carbonate. It is sometimes expressed as grains per gallon, where each "grain" is equivalent to 17.1 ppm of dissolved calcium and magnesium. Measures from 0 to 60 mg/L (ppm) or 3.5 grains are considered "soft" water, while measures above 120 ppm or 7 grains are considered "hard" water. Seattle's drinking water measures 1.3-1.6 grains/gal (22-27 mg/L).

g. **Conductivity** – a measure of electrical current through a water sample. It is often used as a surrogate for salinity, such as to measure the movement of the salt-water wedge into and through the Ship Canal, sneaking in at the bottom of the water column from the locks.

h. **Dissolved Oxygen** – a classic measure of water quality due to its importance to aquatic life. Low DO can indicate problems for fish and other aquatic species. Levels will vary daily, by season, and as algae levels rise and fall; typical levels can range from less than 1 mg/L to greater than 20; DO levels tend to be higher in colder water (up to 14 mg/L on average at freezing temps), and lower in the summer months (around 8-10 mg/L) since warmer water cannot hold as much DO.

   DO levels in streams are more consistent based on mixing, but still seasonal based on algal productivity and temperatures. Washington's standard for streams is a minimum of 8 mg/L for salmonid spawning and rearing, and 6.5 for rearing only (downstream of spawning, one would assume); core summer salmonid habitat is listed as requiring a minimum of 9.5. DO concentrations less than 2 mg/L are lethal to salmonid fish.

3. **Biological measures** of water quality include algal levels in lake water, macroinvertebrates (aquatic insect larvae) in streams, and various types of bacteria. We will only focus on one here:

a. **Fecal coliform bacteria** – a classic measure of bacteria from warm-blooded animals (humans, mammals, birds, etc.), it is still the standard measure used in water quality monitoring even while more detailed bacterial measures (such as specifically for *E. coli*, a type of fecal coliform) have been derived which are more specific to human sources or human health concerns. Pets, local animals such as birds and beavers, as well as human wastes from illegal or broken connections, sewer leaks or combined sewer overflows can all contribute to this indicator. As a result, fecal coliform bacteria are routinely present in urban waters at low ("background") levels.

   Measurements of fecal coliform bacteria are reported as Colony Forming Units per 100 ml of water (CFU/100 ml).

   Washington state standards are based on water-contact recreation: for "extraordinary" contact such as drinking water sources, the maximum is 50 CFU; for "secondary" water contact at designated public swimming beaches, the maximum is 200 CFU (as a geometric mean of multiple samples, with no one sample exceeding 1000). Urban streams often have background levels as high as 400-500 CFU. Levels above 500 CFU, including extreme spikes well over 1000, clearly indicate sewage contamination from a combined sewer overflow, a broken sewer line or a malfunctioning on-site septic system.

4. **Nutrients** are substances that are required by plants and animals for growth and reproduction. The dominant nutrients in aquatic systems (fresh water as well as marine) are **nitrogen** and **phosphorus**. A "limiting nutrient" is the substance that is in least supply, thus limiting the growth of algae, for example; adding more of a limiting nutrient to a body of water will cause an increase in growth, which can present problems of eutrophication if left unchecked. In marine waters, nitrogen is often the limiting nutrient, while in freshwater, phosphorus is usually the culprit.

   a. **Total Nitrogen** – this measure quantifies all nitrogen in a water sample: nitrate (NO3), nitrite (NO2), organic N and ammonia (NH3). No fresh water standards exist for nitrogen in Washington; O'Brien (2015) referenced the British Columbia aquatic criterion of 40 mg/L for nitrogen (nitrate + nitrite).

   b. **Total Kjeldahl Nitrogen** – a measure used in wastewater treatment monitoring that combines organic N and ammonia.

   c. **Nitrate + Nitrite** – a subset of Total N that measures the combination of NO3 + NO2.

   d. **Ammonia** – NH3 can serve as an indicator of decomposition, including waste sources such as sewage, manure, landfill leachate, or recently decomposed natural material.

   e. **Total Phosphorus** – a measure of all P within a water sample, suspended as well as dissolved.

   f. **Orthophosphate P** – a measure of the dissolved portion of phosphorus-containing molecules.

[Note that c, d and f are typically analyzed in the dissolved form since dissolved nutrients are more readily taken up by plants and algae.]

5. **Trace metals (often referred to as "heavy metals")** are essential elements for all living organisms in tiny amounts, but which morph into toxic substances when found at levels too high for certain organisms to tolerate. All of these elements are found in natural soil and rocks, at "background" levels. The most commonly analyzed elements are the following seven:

    a. **Arsenic** – This element has been used in pesticides and in various electronic semi-conductors. It is found naturally in local soils at trace amounts. As a result of fallout from the plume of the old Asarco copper smelter near Tacoma, western King County soils (all the way through the city of Seattle) contain extra arsenic over background conditions. Most occurrences of arsenic locally have to do with historical pesticide use, including most likely the wood preservative Chromated Copper Arsenate ("CCA") which was widely used from the 1970s to the 2000s before it was phased out beginning in 2003; tons of CCA-treated wood products are still in wide use locally. Other legacy uses included pesticides for apples and other crop trees.

    b. **Cadmium –** This element is toxic at fairly minute levels. Sources locally include plating on steel and in pigments used for red, orange and yellow paints (including striping on roads).

    c. **Chromium** – This element has been used in stainless steel production and chrome plating. It is not (or much less) toxic in its elemental form, but rather is most toxic in its ionic Cr +3 form. Thus, measurements of total Chromium are somewhat difficult to interpret in environmental samples. Widespread use of CCA-treated wood is likely to have dispersed chromium in local soils.

    d. **Copper** – Copper has a wide variety of uses in electrical conductivity (wires, machines, motors, etc.), in paint pigments as well as in pesticides. It is most prevalent in environmental samples from brake pads and antifouling paints on boats as well as from wood treatment and other pesticidal uses. Copper-based chemicals are now the most widely-used products for treated wood after the phase-out of CCA.

    e. **Lead** – This element was widely used in plumbing, batteries, bullets and shot, solders, white paint and gasoline. Its uses have been greatly reduced, such as its ban as an additive in gasoline in the U.S. as of 1995 and its elimination from paint in 1978, with resulting reductions in its levels seen in environmental samples. Still, it is high toxic and continues to be a concern due to legacy uses.

    f. **Mercury** – Mercury is the "mad hatter" substance immortalized in *Alice in Wonderland*. It is a very toxic element commonly used until recently in thermometers and other gauges, in switches, in thermostats and in fluorescent lighting. It's uses have now been greatly reduced. Local levels in the environment are likely due to legacy uses in pesticides.

    g. **Zinc** – This element is quite common, used in galvanized pipes and metals as well as in batteries and alloys such as brass. It is the element found in highest concentrations in stormwater runoff now that lead levels have been reduced since the advent of lead-free gasoline in 1995. Its current sources are most likely from galvanized pipes, gutters and other metal surfaces.

Toxicity of heavy metals is divided into **acute** exposures (those resulting in immediate adverse effects, such as lethal poisonings) and **chronic** exposures (those usually of lower, non-acute levels that result in long-term health effects such as cancers or birth defects). Water quality standards are based on these different exposure levels, which makes interpretation of local results very challenging.

6. **Organic (petroleum) and Trace Organic Compounds** include most compounds based on carbon (except things like CO2), from methane (CH4) to complex carbon chains and aromatic ring structures based on benzene. The focus for environmental concerns is on a wide range of chemicals that have toxic properties: everything from gasoline, diesel fuel, motor oil, and other "simple" (aliphatic) carbon-chains; to chlorinated compounds such as carbon tetrachloride (CCl4); to complex chlorinated pesticides; to incomplete combustion products such as polycyclic aromatic hydrocarbons (PAHs); to chemicals that make plastics more flexible, called phthalate esters; to many others in between. Organic chemists have created analytical tools that can find these trace organics at the part per trillion level in the environment; toxicologists are decades behind in their ability to assess relevance of such detected levels. Other than for gross levels of petroleum, the cost per sample to analyze for specific trace organics is quite high compared to conventionals, nutrients or trace metals. We have water and sediment standards for a few of the trace organic substances while we still scratch our heads about many others as to their toxicity levels in the environment.

    a. **Gasoline** – a mixture of relatively short-chain aliphatic hydrocarbons such as octane (8 carbons in the chain) derived from petroleum, typically a mix of hydrocarbons between 4 and 12 carbon atoms per molecule. Because it is volatile, gasoline mixtures tend to evaporate quickly and not persist in the environment.

    b. **Diesel** – a mixture of medium-chain aliphatic hydrocarbons, most commonly from petroleum but also from "biodiesel" sources such as plant oils. Diesel typically includes carbon chains containing 8-12 to 21-24 carbon atoms per molecule. It tends to show up in soil samples where contamination has occurred from spills or from stormwater runoff.

    c. **Motor oil** – a heavier mixture of longer-chain aliphatic hydrocarbons derived from petroleum. Carbons range from 16-24 to 38 atoms per molecule. The viscosity of this heavy petroleum is its key property. Leaking oil as well as the exhaust of un-broken-down oil represents a significant source of pollution in stormwater runoff.

    d. **Chlorinated Hydrocarbon Pesticides** – The classic bad-actors such as DDT and its breakdown products (DDE and DDD), as well as other pesticides including dieldrin, chlordane, hexachlorocyclohexane, pentachlorophenol and a variety of other nasty actors. All of these products have been banned, some as long as 50 years ago, yet they are so persistent in the environment that we still find them regularly in water and sediments, especially sediments where they adhere to tiny particles. They represent a toxic background level in urban sediments that is difficult to interpret: are they a threat or simply part of today's background exposure for all urban aquatic creatures?

e. **Other organic compounds** – Most other organic compounds are analyzed via a combined technique known as gas chromatography/mass spectroscopy (GC/MS). We can find chlorinated solvents, PAHs, plasticizers and many other compounds via this process. In the late 1970s, the U.S. EPA developed a list of "priority pollutants" that could be analyzed for using this and related technology. Most environmental samples (water or sediment) are subject to protocols that search for these selected compounds among the many thousands of other organics found in environmental matrices.

Acute-versus-chronic toxicity is a challenge for all of these organic chemicals similar to the discussion above under trace metals. Exposure to high levels might induce direct poisoning, while exposure to lower, on-going levels might result in chronic maladies such as cancer. Some standards are available, but most are lacking as current toxicology is far behind our current ability to analyze for chemicals in the environment. We really don't know what 20 parts per billion in a sediment sample means for DDE, or for most other chemicals we analyze for. The best we can do is to compare with available standards, and compare with other local sites in order to gauge relative levels of concern.

Appendix B. Comparison Water Quality Data from other Seattle Urban Streams and Lake Washington

Decades of data are available for three watersheds within the City of Seattle: Thornton Creek in NE Seattle and the City of Shoreline; Pipers Creek in NW Seattle; and Longfellow Creek in the Delridge area of SW Seattle. Mapes Creek data (representing only two recent samples) from SE Seattle are also included here. Data are also available for King County's routine monitoring site in the Montlake Cut, as well as other nearby lake stations; I include a summary of the Montlake data here. Data are posted and summarized at King County's website, "Streams Data" and "Major Lakes Data" at http://green2.kingcounty.gov . The captured summary tables below were taken from King County's website on June 3, 2018.

1. Summary Table for Conventionals, Nutrients and Bacteria:

Summary of Comparable Conventionals' Data from Nearby Urban Streams[2]

Measures	**Thornton Cr.**		**Pipers Cr.**		**Longfellow Cr.**		**Mapes Cr.**
(units)	Base-flow median (range)	Storm-flow median (range)	Base-flow median (range)	Storm-flow median (range)	Base-flow median (range)	Storm-flow median (range)	Base-flow data as reported
Turbidity (NTUs)	3.00 (0.1-43)	13.9 (3.4-117)	1.9 (0.1-160)	15.7 (2.2-925)	4.01 (0.6-122)	70.4 (46-105)	13.8
Total N (mg/L)	1.4 (0.8-2.4)	1.2 (0.8-2.9)	1.7 (0.5-3.5)	1.5 (0.8-4.7)	1.2 (0.8-3.2)	--	2.9
Nitrate + Nitrite N (mg/L)	1.1 (0.3-2.0)	0.6 (0.3-1.4)	1.5 (0.3-2.9)	0.9 (0.3-2.5)	0.9 (0.4-2.6)	0.7 (0.5-0.8)	2.4
Ammonia N (mg/L)	0.03 (0.001-0.2)	0.06 (0.01-0.24)	0.02 (0.005-0.27)	0.05 (0.01-0.3)	0.03 (0.003-0.6)	0.03 (0.02-0.1)	0.001
Total P (mg/L)	0.07 (0.007-0.4)	0.1 (0.05-0.6)	0.07 (0.02-0.7)	0.1 (0.06-1.4)	0.07 (0.005-0.1)	0.18 (0.16-0.3)	0.08-0.22
Ortho P (mg/L)	0.03 (0.005-0.1)	0.03 (0.006-0.08)	0.06 (0.006-0.2)	0.04 (0.03-0.1)	0.04 (0.005-0.1)	0.05 (0.03-0.07)	0.04-0.05
Fecal Coliform Bacteria (CFUs/100 ml)	430 (14-12,000)	3200 (150-41,000)	133 (5-40,000)	2400 (44-38,000)	210 (9-19,000)	--	1-2

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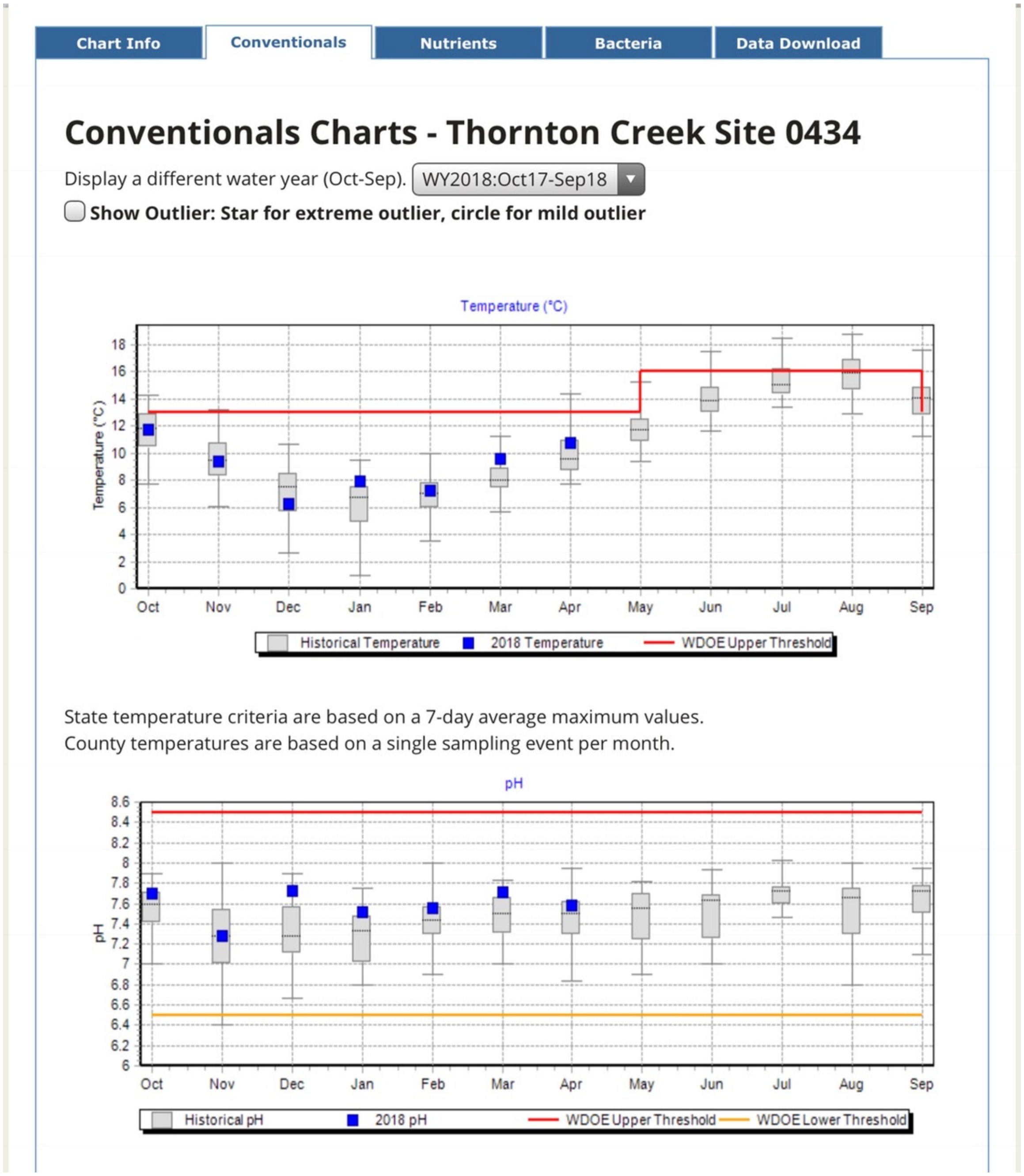
[2] I have tried to summarize a ton of data here, showing the median value and the range for each parameter.

Appendix B. (continued)

2. Conventional, Nutrient and Bacterial data graphs for Thornton Creek:



Conventionals Charts - Thornton Creek Site 0434

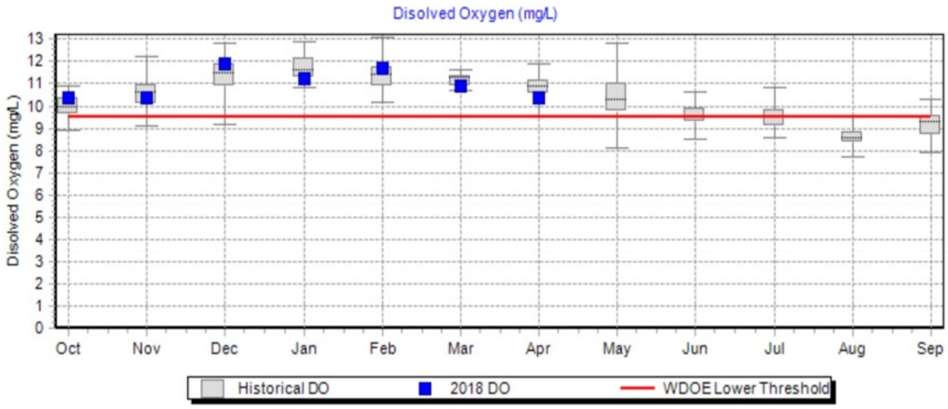
Display a different water year (Oct-Sep). WY2018:Oct17-Sep18 ▾

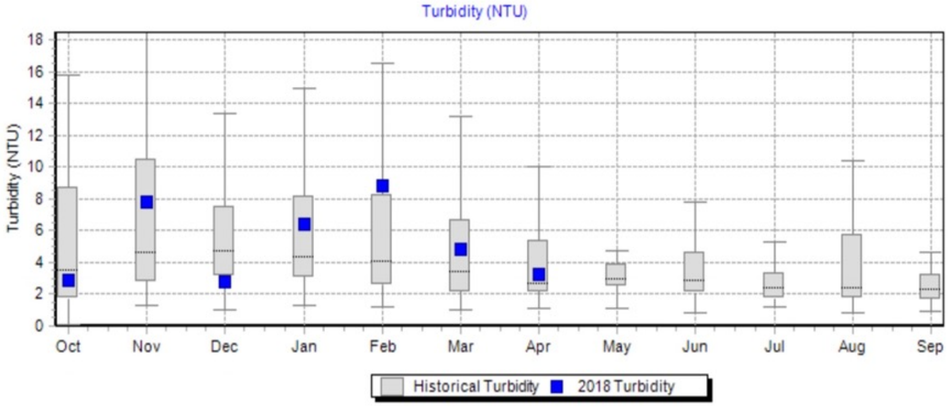
☐ **Show Outlier: Star for extreme outlier, circle for mild outlier**

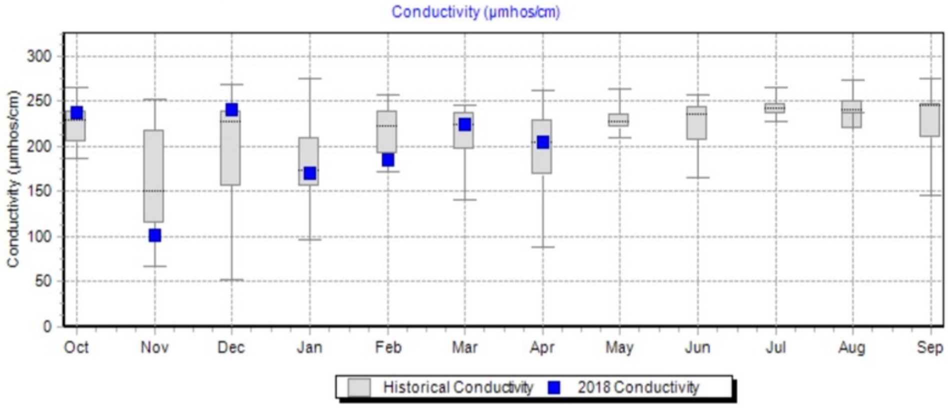
State temperature criteria are based on a 7-day average maximum values.
County temperatures are based on a single sampling event per month.

Appendix B. (continued)

Water quality graphs for **Thornton Creek**, continued…

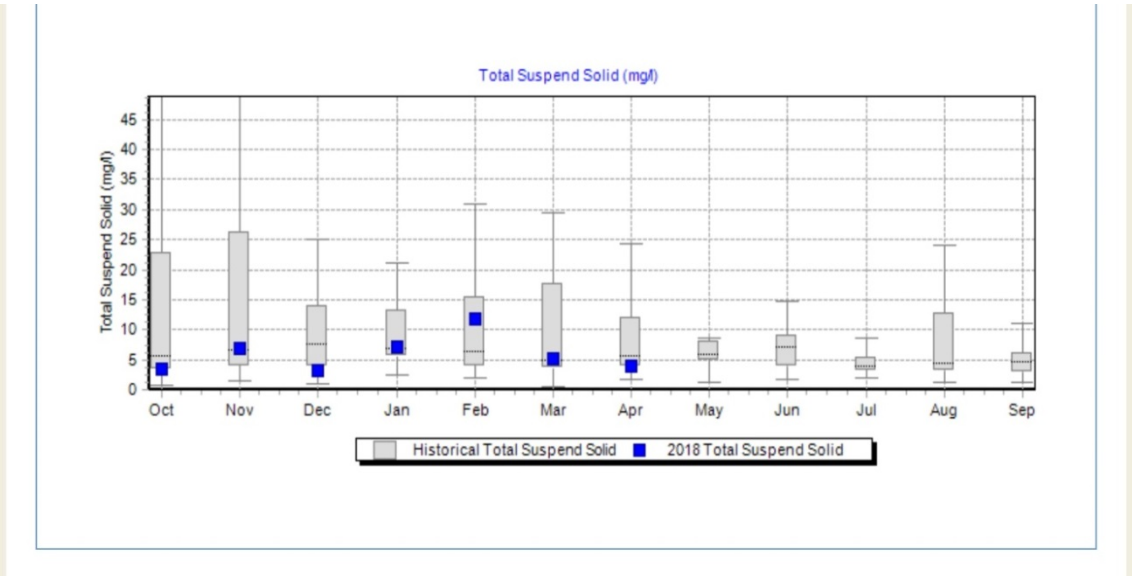


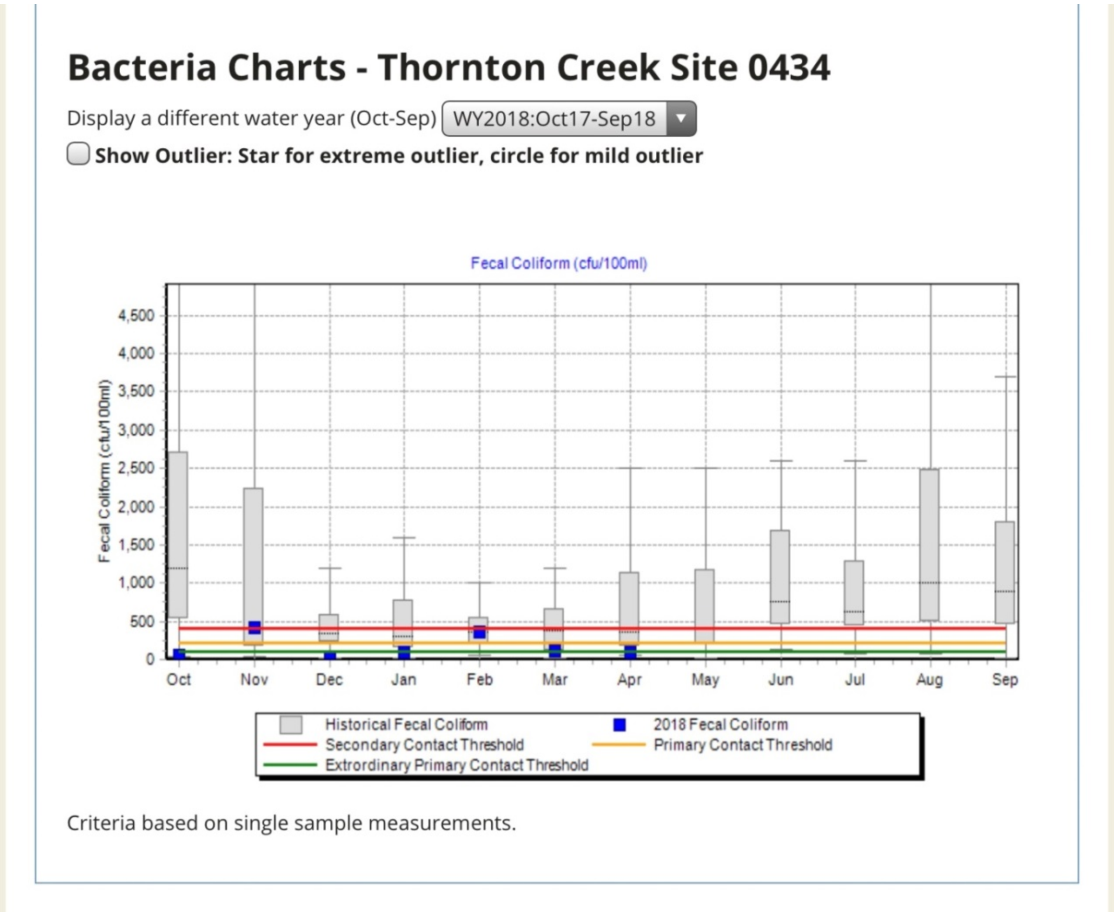




Appendix B. (continued)

Water quality graphs for **Thornton Creek**, continued…





Bacteria Charts - Thornton Creek Site 0434

Display a different water year (Oct-Sep) WY2018:Oct17-Sep18 ▾

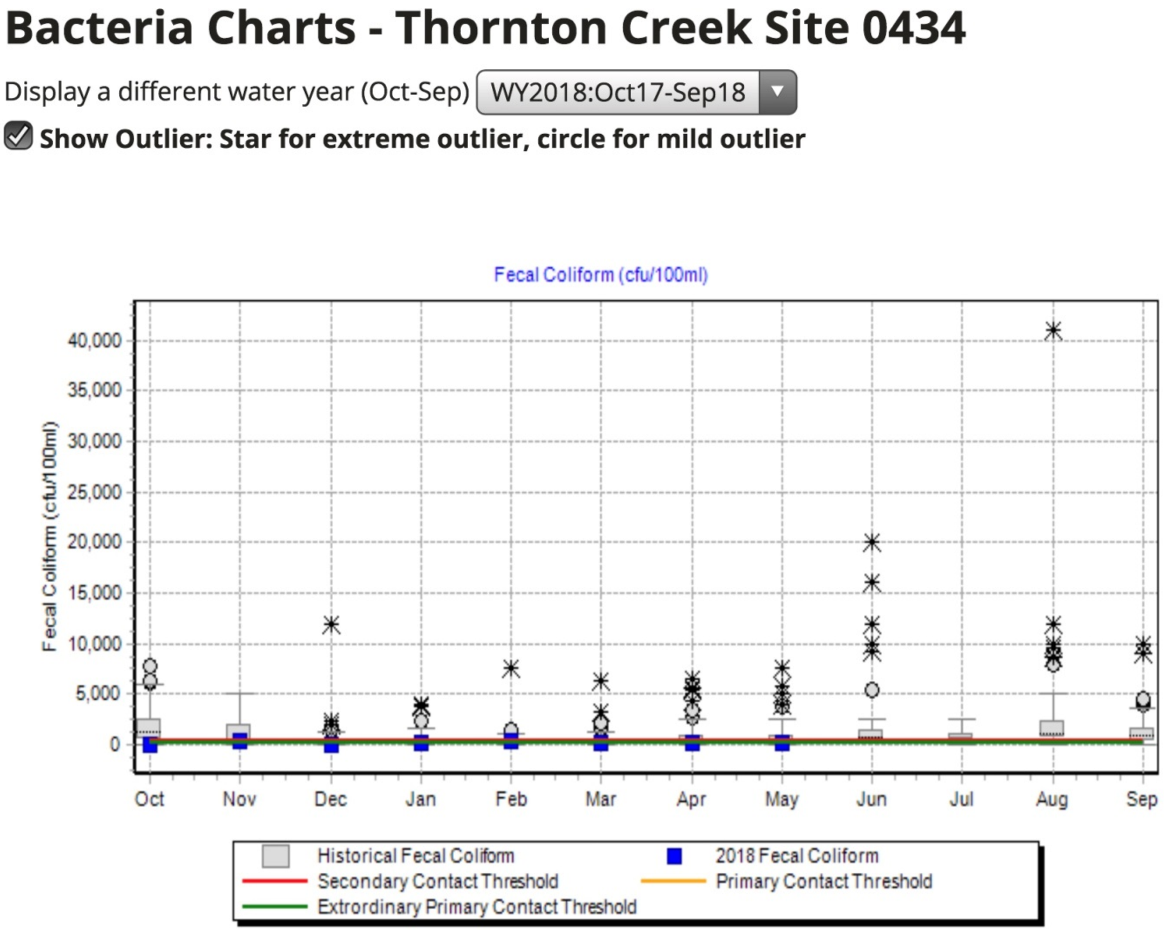
☐ **Show Outlier: Star for extreme outlier, circle for mild outlier**

Criteria based on single sample measurements.

Appendix B. (continued)

Water quality graphs for **Thornton Creek**, continued…

- Bacteria graph with “outlier” data, to illustrate how high some samples can be:

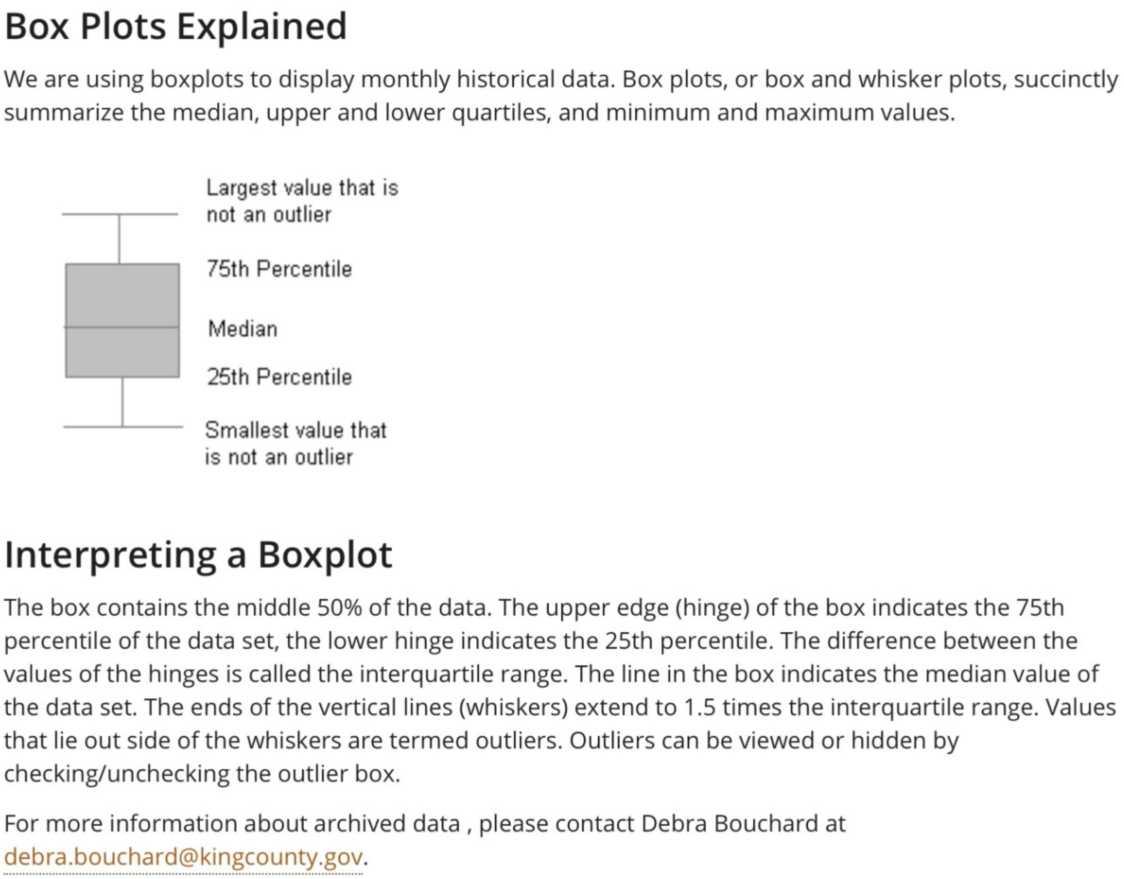


Bacteria Charts - Thornton Creek Site 0434

Display a different water year (Oct-Sep) WY2018:Oct17-Sep18

☑ **Show Outlier: Star for extreme outlier, circle for mild outlier**

Water quality graphs from King County: **how to read the “box plot”**:



Box Plots Explained

We are using boxplots to display monthly historical data. Box plots, or box and whisker plots, succinctly summarize the median, upper and lower quartiles, and minimum and maximum values.

Interpreting a Boxplot

The box contains the middle 50% of the data. The upper edge (hinge) of the box indicates the 75th percentile of the data set, the lower hinge indicates the 25th percentile. The difference between the values of the hinges is called the interquartile range. The line in the box indicates the median value of the data set. The ends of the vertical lines (whiskers) extend to 1.5 times the interquartile range. Values that lie out side of the whiskers are termed outliers. Outliers can be viewed or hidden by checking/unchecking the outlier box.

For more information about archived data , please contact Debra Bouchard at debra.bouchard@kingcounty.gov.

Appendix B. (continued)

3. Summary Table for Trace Metals in Local Streams:

Between 1993 and 2008, King County analyzed for a suite of trace elements in local creek samples. I have tried to summarize this extensive data set here in order to use as a tool to compare values we might see in results in or close to Arboretum Creek.

Summary of Comparable Trace Metal Data from Nearby Urban Streams[3]

Total Metals (ug/L or ppb)	**Thornton Creek** Median (Range)	**Pipers Creek** Median (Range)
Arsenic	2.26 (1.3 - 8.0)	2.54 (1.9 - 19.3)
Cadmium	0.140 (0.012 - 0.330)	0.205 (0.018 - 0.678)
Chromium	3.9 (0.640 – 20.9)	3.78 (0.961 – 91.3)
Copper	7.02 (0.86 – 23.4)	7.02 (0.670 – 85.6)
Lead	10.8 (0.78 – 69.0)	6.09 (0.302 – 80.2)
Mercury	0.031 (0.008 – 0.050)	--
Nickel	3.41 (1.04 – 114.0)	4.22 (0.993 – 132.0)
Zinc	31.9 (3.63 – 132.0)	24.0 (2.81 – 235.0)

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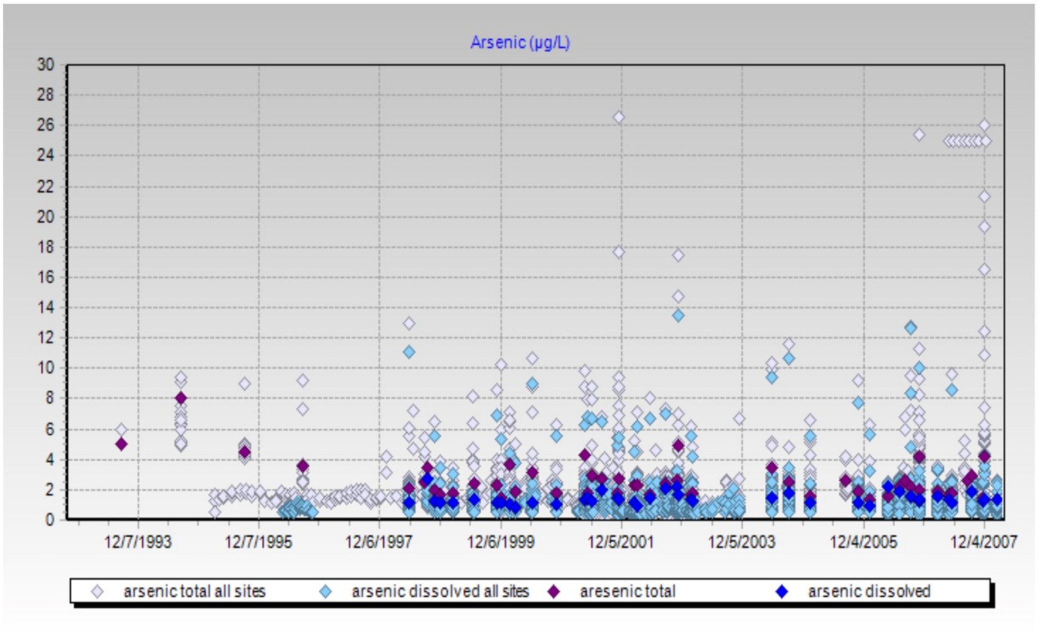
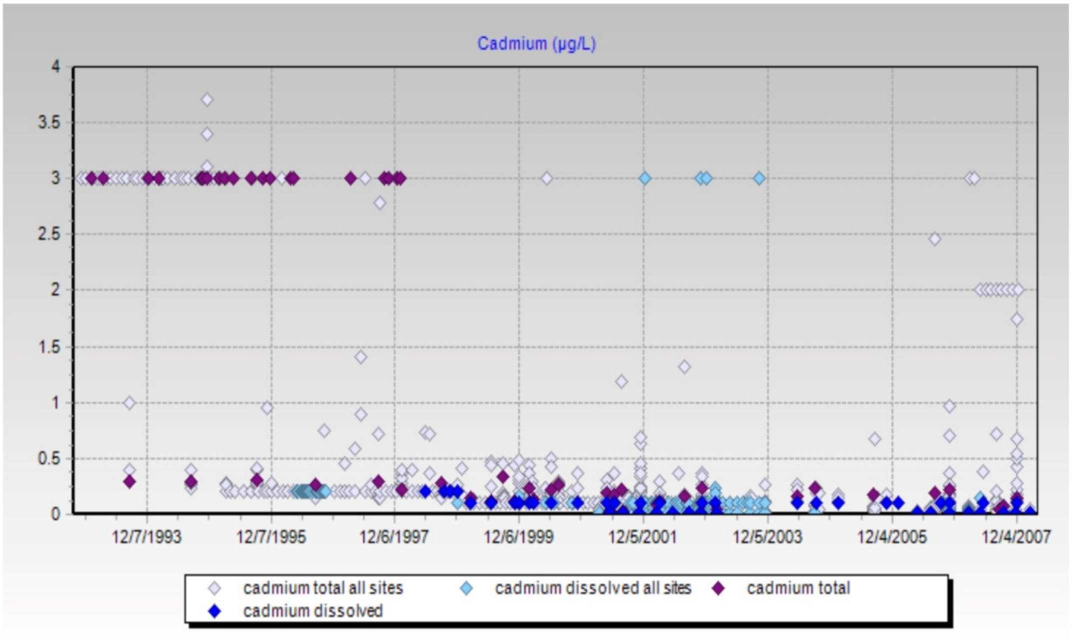
[3] I have summarized a ton of metals' data here, showing median value and the range for each element.

Appendix B. (continued)

4. Trace Metal data graphs for Thornton Creek:

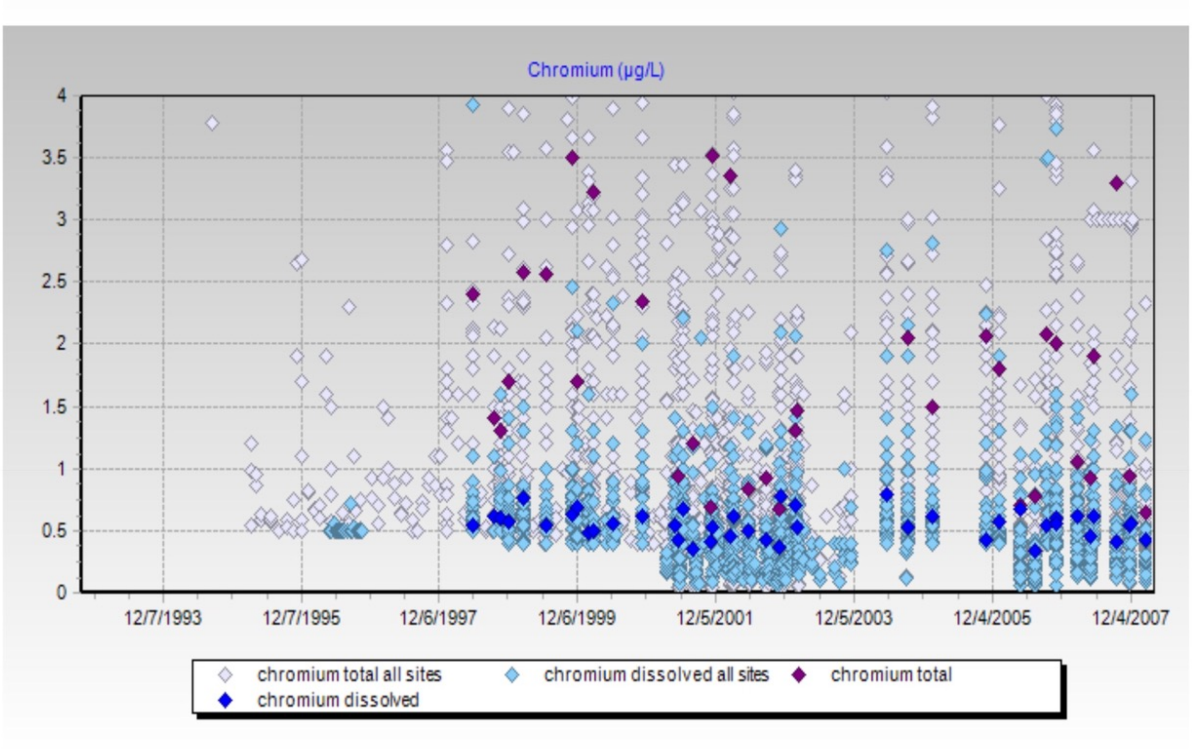
These graphs include all sites across King County (clear and light blue diamonds) as well as data for Thornton Creek in red and dark blue diamonds). [Note: the graphs for cadmium, mercury, lead and nickel show odd Method Detection Limits in the early years – pay attention only to recent years on these charts.]

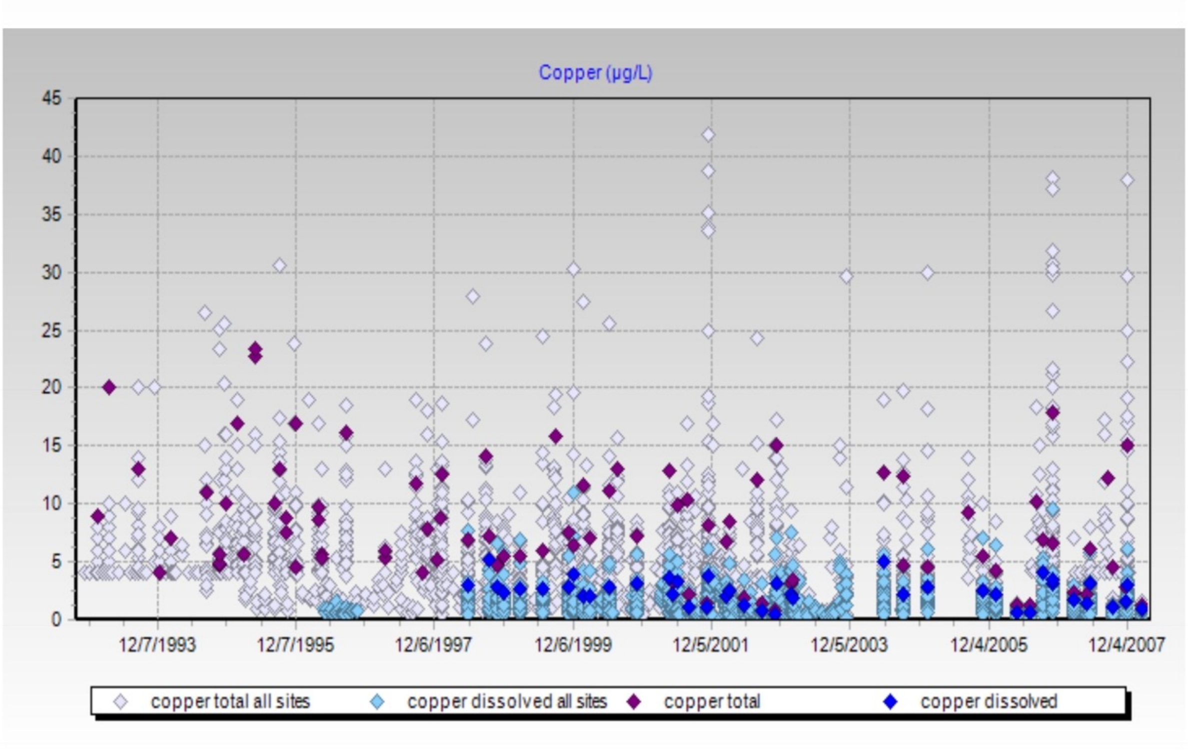



Cadmium (µg/L)
4
3.5
3
2.5
2
1.5
1
0.5
0
12/7/1993
12/7/1995
12/6/1997
12/6/1999
12/5/2001
12/5/2003
12/4/2005
12/4/2007
◇ cadmium total all sites
◆ cadmium dissolved all sites
◆ cadmium total
◆ cadmium dissolved

Appendix B. (continued)

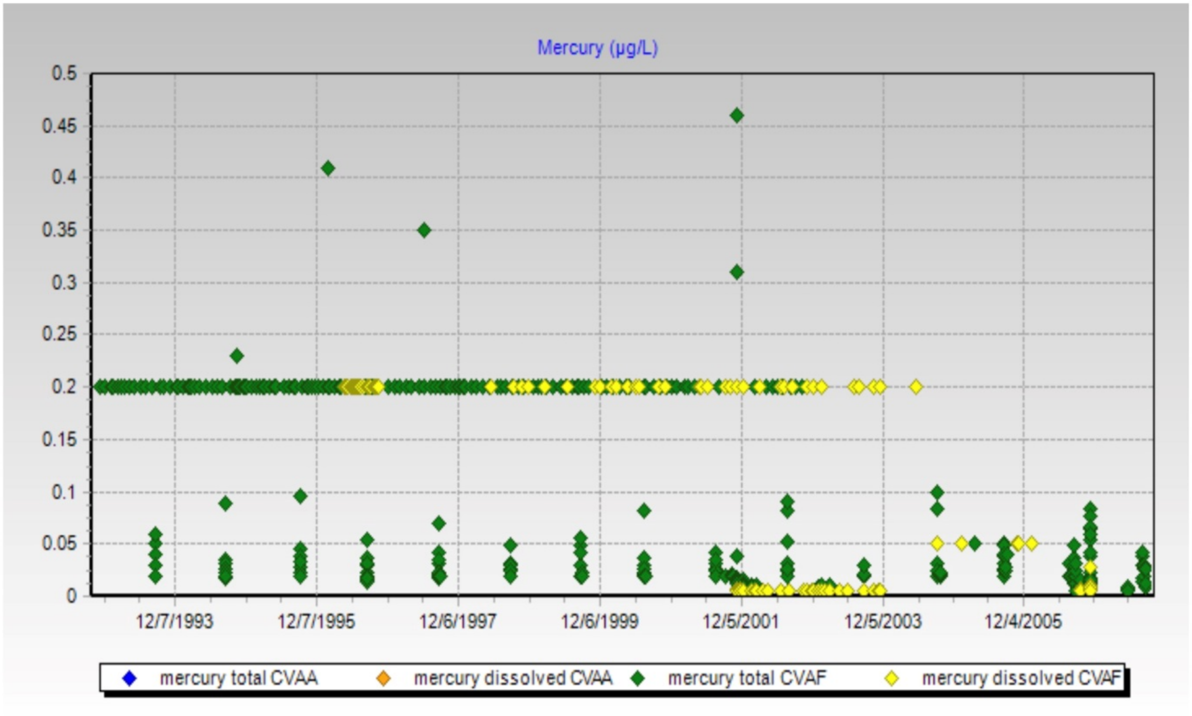
Water quality graphs for **Thornton Creek**, continued…

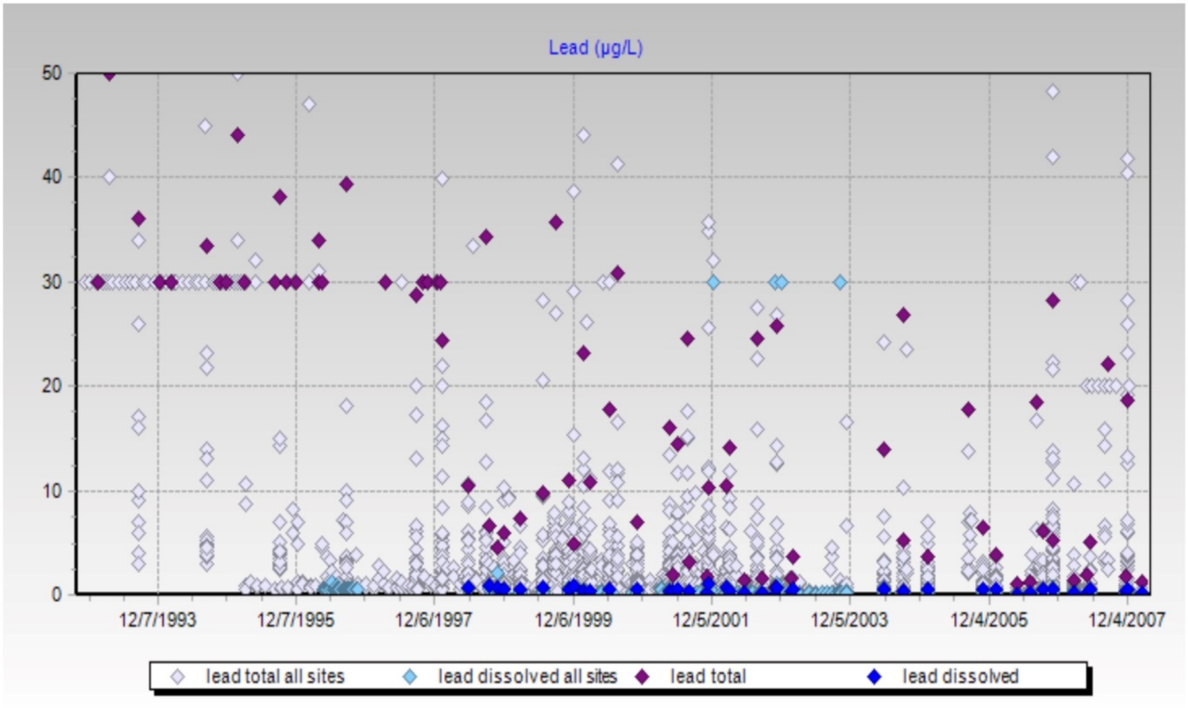




Appendix B. (continued)

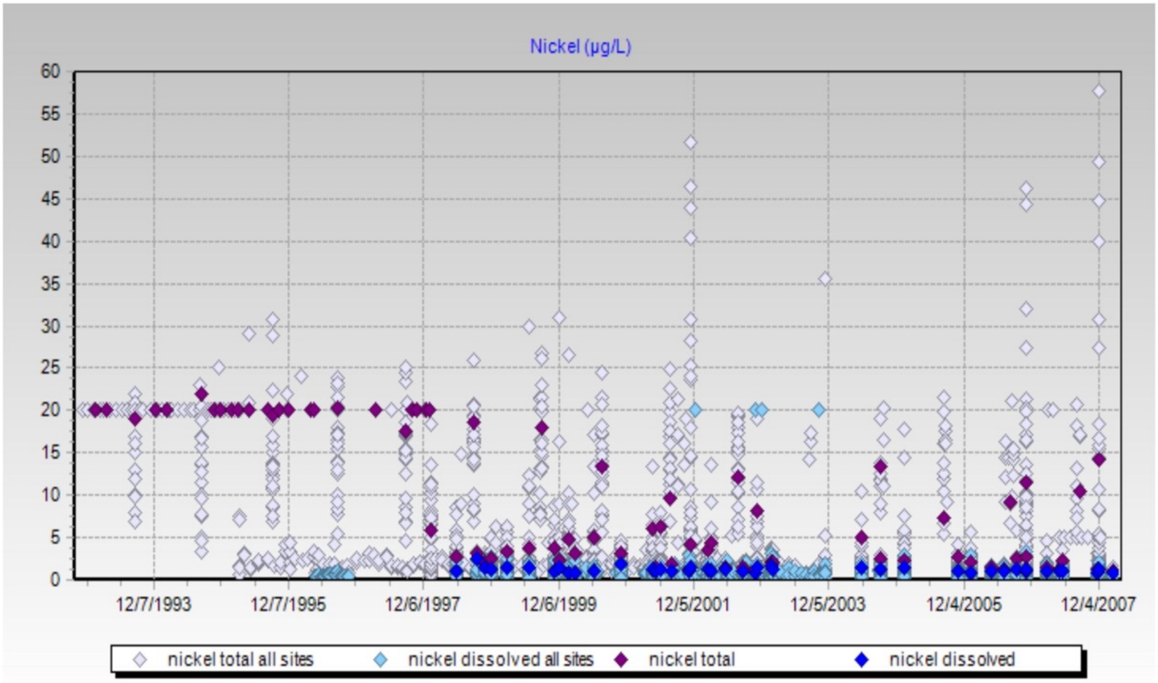
Water quality graphs for **Thornton Creek**, continued…

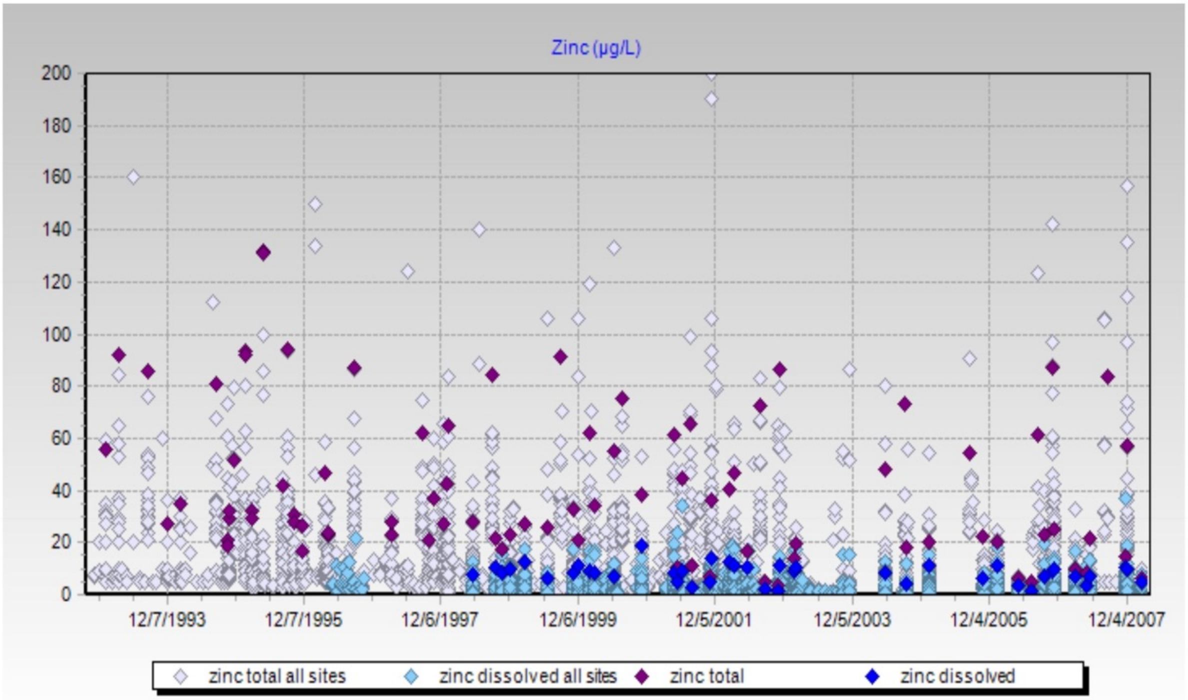




Appendix B. (continued)

Water quality graphs for **Thornton Creek**, continued…





Appendix B. (continued)

5. Lake Washington Water Quality Data from the Montlake Cut:

- **Temperature** ranges from 7 degrees C in winter to 22 in summer
- **Dissolved Oxygen** ranges from 7 to 12 mg/L
- **pH** ranges from 7.2 to 8.5
- **Total Alkalinity** ranges from 37 to 42 mg/L
- **Total Nitrogen** ranges from 0.2 to 0.45 mg/L
- **Nitrate+Nitrite** ranges from 0.0 to 0.25 mg/L
- **Ammonia Nitrogen** ranges from 0.005 to 0.35 mg/L (spikes above 0.02 are probably related to Combined Sewer Overflows)
- **Total Phosphorus** ranges from 0.005 to 0.02 mg/L
- **Ortho Phosphorus** ranges from 0.001 to 0.008 mg/L

Appendix C. Comparison Sediment Data from Other Seattle Urban Waters

Some local stream and lake sediments as well as some soil samples have been analyzed for metals and a few trace organic compounds. Interpreting the results can be tricky because sediments are not uniform in composition and in fact vary widely in sand-to-silt ratios as well as organic matter. The finer the sediment and the more organic content, the more likely it will be to have higher levels of metals and organic contaminants, all other factors being equal (which they never are). The "availability" of these chemicals (a measure of what form they are in and how tightly attached they are to sediment particles) is yet another factor to weigh in interpreting levels found. Also, some local data reflect highly contaminated spots such as the sediments in north Lake Union adjacent to Gas Works Park, a Superfund site. I have included below a sampling of available data that might help us to broadly compare local levels of metals and trace organics with any results we glean from the Arboretum Creek area.

Summary of Nearby Sediment and Soil Samples

Total Metal (mg/kg or ppm dry weight)	**Lake Washington reference site**	**Montlake Cut**	**Freshwater Sediments across Washington** (28-161 samples)	**Recent Lake Union Nearshore** (range of 3 samples)	**Lake Union Shoreline Soil** (range of 6 samples)	**Lake Washington in early 1980s** (57 samples)
Arsenic	--	--	8.7 (0.8-80)	17.3-78.9	1.9-30	33.8
Cadmium	--	0.6	0.4 (0.1-2.6)	--	--	0.69
Chromium	19.7	27.4	21 (0.0-740)	19.4-32.2	9.9-19.3	39.6
Copper	11	30	36 (1-4870)	91.4-273	9.3-57.0	35.7
Lead	26	91	18.9 (0.0-900)	56-149	8.1-35.2	137.2
Mercury	0.04	0.16	0.04 (0.0-0.70)	--	--	0.22
Nickel	22.6	26.8	25 (5.8-154)	--	--	34.2
Zinc	40	84	104 (47-813)	219-381	23.7-117.0	131.7

Appendix D. Comparison Data for Seattle-Area Urban Stormwater

Summary of Comparable Nearby Stormwater Runoff Data[4]

Measure (all units mg/L, except bacteria)	**NW 110th St** mean* (range)	**Venema drainage** mean* (range)	**Broadview** no means avail. (range)	**High Point/ Delridge** mean* (range)	**520 Bridge** median (range)	**N.U.R.P. National Results** mean* (range)
Total Suspended Solids (TSS)	94 (34-324)	41 (4-215)	-- (13-204)	25 (17-31)	71 (5-440)	101
Total N	1.2 (0.5-3.5)	1.1 (0.5-5.5)	-- (0.6-4.9)	--	--	--
Total P	0.2 (0.07-0.6)	0.2 (0.06-0.5)	-- (0.1-0.4)	0.1 (0.14-0.22)	--	0.38
Fecal Coliform Bacteria (CFUs/100 ml)	1220	1620	--	1180 (160-2200)	*E.coli* 505 (40-7600)	-- (3,500-63,000)
Total Copper	0.016 (0.007-0.042)	0.008 (0.005-0.045)	-- (0.01-0.042)	0.009 (0.003-0.010)	0.058 (0.036-0.179)	0.033 (0.001-0.100)
Total Zinc	0.094 (0.047-0.465)	0.042 (0.030-0.298)	-- (0.06-0.314)	0.035 (0.001-0.035)	1.140 (0.427-3.020)	0.035 (0.010-2.4)
Total Petroleum Hydrocarbons/	-- (0.08-3.5)	-- (0.15-2.7)	-- (2.2-5.4)	--	"Lube Oil" 3.6 (1.4-11)	--
Total Arsenic	--	--	--	--	0.0024 (0.0014-0.0057)	--

*Event Mean Concentration (see Appendix A, Section 1C, for definition).

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[4] The first four columns of data are from within the City of Seattle, summarized from studies of Green Stormwater Infrastructure and "Natural Drainage Systems" sponsored by Seattle Public Utilities (find references at http://www.seattle.gov/util/EnvironmentConservation/Projects/GreenStormwaterInfrastructure/CompletedGSIProjects/MeasuringSuccess/index.htm .)