Appendix E:
Data Analysis Methods

APPENDIX E – DATA ANALYSIS METHODS

This appendix presents the methods used to prepare data for analysis, including the rules for: use of replicate data, significant figures, non-detect results, and determining sums for chemical groups (i.e., polycyclic aromatic hydrocarbons [PAHs] and polychlorinated biphenyls [PCBs]). Data analysis methods are also described, which include calculating the percent reduction between influent and effluent and associated statistical tests. Statistical test results are also presented.

Laboratory and Field Replicates

Laboratory and field replicate sample results were considered quality control data. These data were used as part of the data validation process and to assess quality control.

Significant Figures

Chemical data generated by the King County Environmental Laboratory (KCEL) are reported to three significant figures, unless the value is below the reporting detection limit (RDL). Results below the RDL have higher uncertainty and are reported to only two significant figures. Pacific Rim Laboratories reports PCB congener results to three significant figures. PCB congener sums were also rounded to three significant figures. Appendix F presents the concentration data with appropriate significant figures.

Summation for PAH and PCB Totals

Total PAHs are the sum of 16 PAH compounds (Table 1). Results for individual PAHs deemed non-detect by the laboratory or through the data validation process were not included in the sums. Some samples did not have any detected PAHs. In these cases, the highest MDL of the summed compounds was used as the level of detection and this value is reported as the total.

Total PCBs are the sum of all detected concentrations of the 209 congeners. Results for individual PCB congeners deemed non-detect by the laboratory or through the data validation process were not included in the sums. All samples had at least one PCB congener detected, and therefore sums were based only on detected levels.

Table 1. PAH compounds included in total PAH sums.

PAH Compounds			
2-Methylnaphthalene	Benzo(a)anthracene	Chrysene	Indeno(1,2,3-Cd)Pyrene
Acenaphthene	Benzo(a)pyrene	Dibenzo(a,h)anthracene	Naphthalene
Acenaphthylene	Benzo(b,j,k)fluoranthene	Fluoranthene	Phenanthrene
Anthracene	Benzo(g,h,i)perylene	Fluorene	Pyrene

Use of Non-detect Result Values

For each parameter, non-detect results were included in calculation of summary statistics (e.g., minimum, maximum, mean), report figures, percent reduction calculations, and statistical tests using the MDL as the sample value. This method results in a high bias for data summaries with non-detects and increases uncertainty in other calculations and statistical tests. All statistical tests for parameters with non-detects were repeated using

half the MDL as the substituted value to determine the impact on statistical results. Statistical differences remained the same, except for total cadmium at WB where use of half the MDL resulted in statistical differences between influent and effluent concentrations, but substituting at the full MDL did not. Statistical tests were conducted for all parameters except dissolved cadmium for which there were very few detections in both influent and effluent at all sites.

Data Preparation

Sufficient sample volume for all planned analytical tests was collected during most events. However, in a few cases there was insufficient sample volume to analyze both an influent and effluent sample. These unpaired results were not used in the paired comparisons between influent and effluent results (i.e., the performance summary tables in Section 2.1 of the main report and the scatter plots in Appendix H, Section H1). All sample results (including unpaired samples) were included in the statistical comparison of influent and effluent concentrations, and the data summary tables and box plots in Appendix H1.

Testing for Differences between Influent and Effluent – Paired Permutation Tests

A permutation test was used to assess if differences between influent and effluent concentrations, across storms at individual sites (i.e., EB, WB, and WC), were significant (Sections 2.1 and 2.2 in the main report). This test was conducted in R (version 3.2.1; R Core Team 2017) using "oneway_test" from the "coin" package. The p-values generated for the one-way test were then multiplied by two to approximate a two-way test. The two-way test determines whether the difference in mean concentration (between influent and effluent) is less than or greater than would be expected by chance. This is accomplished by calculating many permutations of the dataset by randomly assigning an influent or effluent designation to each sample result and recalculating the difference between the means for each permutation. The observed difference between the means (calculated using the original data) is then compared to the distribution of mean differences generated by the permutations. If the observed mean difference is within the top or bottom 2.5% of the permutation results, then the difference is greater than would be expected by chance – the difference in mean influent and effluent concentrations is statistically significant with p-value <0.05 (Figure 1).

This test is similar to a two-tailed t-test, except it is does not require the assumption of normal distribution. Instead, it uses the sampled distribution by resampling from the actual dataset. This test is also favorable because it tests on means, unlike the two-tailed Wilcoxon signed-rank test, which is used to determine if population mean ranks differ (recommended in Technology Assessment Protocol – Ecology [TAPE]; Ecology 2011). Permutation test results are presented in Table 2.

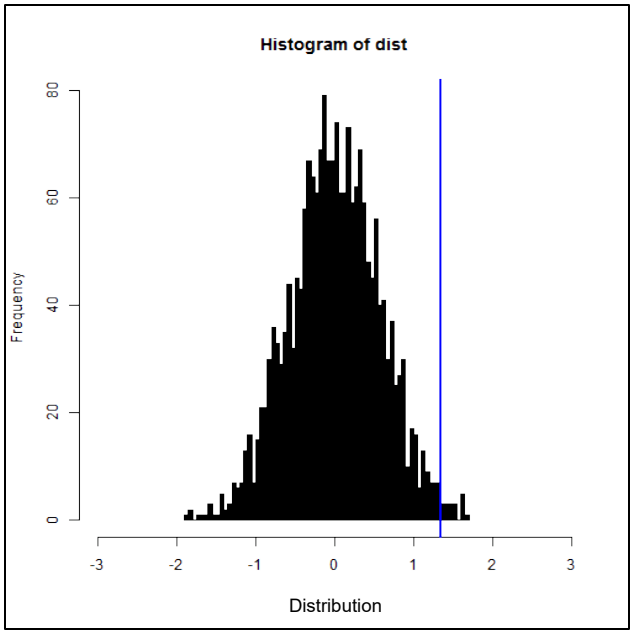

Figure 1. Example of permutation results. Black bars indicate frequency of permutated difference and blue line signifies the observed difference.

Table 2. Results of permutation tests to analyze differences between inlet and outlet concentrations of sampled parameters at the east (EB) and west (WB) bioretention facilities and the wetland complex (WC). Green check next to the z value indicates the difference between the inlet and outlet concentration is in the desired direction; red x indicates difference is in the undesired direction. Green shading = p<0.01; yellow shading = p<0.05.

Asymptotic Two-Sample Fisher-Pitman Permutation Test							
		Non-detect = MDL			Non-detect = 0.5MDL		
Parameter	Site	z	one way p-value	two way p-value	z	one way p-value	two way p-value
Turbidity	EB	✓ -2.00	4.60E-02	0.09204			
	WB	✓ -0.45	6.56E-01	1.3114			
	WC	✓ -3.09	0.001986	0.003972			
TSS	EB	✓ -3.08	0.002066	0.004132			
	WB	✓ -0.79	0.4321	0.8642	✓ -0.81	0.4205	0.841
	WC	✓ -4.63	3.59E-06	0.00000717			
Conductivity	EB	✗ 1.74	8.20E-02	0.16398			
	WB	✗ 3.26	1.12E-03	0.00223			
	WC	✗ 2.00	0.04512	0.09024			
Total Phosphorus	EB	✗ 5.27	1.39E-07	0.000000277			
	WB	✗ 5.38	7.34E-08	1.4686E-07			
	WC	✓ -0.53	0.5934	1.1868			
Ortho-phosphate	EB	✗ 5.35	8.60E-08	1.7202E-07			
	WB	✗ 5.51	3.55E-08	7.098E-08			
	WC	✗ 5.22	1.82E-07	3.646E-07			
Total Nitrogen	EB	✗ 4.72	2.41E-06	0.000004826			
	WB	✗ 4.89	1.03E-06	0.000002058			
	WC	✓ -3.59	0.0003368	0.0006736			
Nitrate + Nitrite	EB	✗ 4.42	9.74E-06	0.000019478			
	WB	✗ 3.62	0.0002981	0.0005962			
	WC	✓ -1.38	0.1662	0.3324			
Ammonia	EB	✗ 2.33	0.02003	0.04006	✗ 2.33	0.01993	0.03986
	WB	✗ 4.66	3.14E-06	0.000006278	✗ 4.66	3.14E-06	0.000006272
	WC	✓ -3.66	0.0002536	0.0005072			
Fecal Coliforms	EB	✓ -1.48	0.138	0.276			
	WB	✓ -1.39	0.1655	0.331			
	WC	✓ -2.14	0.03208	0.06416			

Asymptotic Two-Sample Fisher-Pitman Permutation Test, continued							
		Non-detect = MDL			Non-detect = 0.5MDL		
Parameter	Site	z	one way p-value	two way p-value	z	one way p-value	two way p-value
Total Cadmium	EB	✗ 1.18	0.2382	0.4764	✗ 1.37	0.171	0.342
	WB	✗ 1.87	0.06146	0.12292	✗ 2.31	0.02091	0.04182
	WC	✓ -2.29	0.02182	0.04364	✓ -2.78	0.005496	0.010992
Total Copper	EB	✗ 1.22	0.2215	0.443			
	WB	✗ 2.59	0.009494	0.018988			
	WC	✓ -4.35	1.34E-05	0.00002684			
Dissolved Copper	EB	✗ 2.84	0.004528	0.009056			
	WB	✗ 3.45	0.0005634	0.0011268			
	WC	✗ 0.46	0.6445	1.289			
Total Lead	EB	✓ -2.27	0.02338	0.04676			
	WB	✗ 2.03	0.0422	0.0844			
	WC	✓ -4.46	8.22E-06	0.000016434			
Dissolved Lead	EB	✗ 3.87	0.0001094	0.0002188	✗ 4.18	0.00002921	0.00005842
	WB	✗ 4.89	1.00E-06	0.000002	✗ 5.01	5.58E-07	1.1158E-06
	WC	✗ 1.01	0.3108	0.6216	✗ 1.19	0.2355	0.471
Total Zinc	EB	✓ -5.57	2.55E-08	5.106E-08			
	WB	✓ -5.35	8.59E-08	1.7184E-07			
	WC	✓ -3.64	0.0002771	0.0005542			
Dissolved Zinc	EB	✓ -5.63	1.81E-08	3.626E-08			
	WB	✓ -5.30	1.13E-07	2.256E-07			
	WC	✗ 2.28	0.02282	0.04564			
PAHs	EB	✓ -1.78	0.07489	0.14978	✓ -2.17	0.03024	0.06048
	WB	✓ -2.24	0.0248	0.0496	✓ -2.63	0.008488	0.016976
	WC	✓ -4.42	1.01E-05	0.00002018	✓ -4.43	9.53E-06	0.000019066
PCBs (not including samples impacted by method blank issue)	EB	✓ -1.77	7.62E-02	0.15246			
	WB	✓ -2.80	0.005115	0.01023			
	WC	✓ -3.01	2.58E-03	0.00515			
PCBs (all samples included)	EB	✓ -1.71	0.08785	0.1757			
	WB	✓ -2.71	6.76E-03	0.013518			
	WC	✓ -3.03	0.002452	0.004904			

Asymptotic Two-Sample Fisher-Pitman Permutation Test, continued							
		Non-detect = MDL			Non-detect = 0.5MDL		
Parameter	Site	z	one way p-value	two way p-value	z	one way p-value	two way p-value
Dissolved organic carbon	EB	4.44	9.06E-06	0.00001812			
	WB	5.17	2.31E-07	4.624E-07			
	WC	1.42	0.156	0.312			
Total organic carbon	EB	4.42	1.01E-05	0.00002012			
	WB	5.00	5.64E-07	0.000001128			
	WC	-3.41	0.0006521	0.0013042			
Hardness	EB	3.90	9.70E-05	0.00019402			
	WB	4.48	7.60E-06	0.000015192			
	WC	2.89	0.003802	0.007604			
pH	EB	-2.16	3.10E-02	0.06192			
	WB	-2.46	1.40E-02	0.02806			
	WC	0.24	0.8085	1.617			

Testing for Mean Percent Reductions with 95% Confidence Intervals - Bootstrapping

The 95% confidence intervals around mean percent reductions were calculated using R for EB, WB and WC using bootstrapping as described in TAPE (Ecology 2011) (Table 3). The "boot" function in the "boot" package for R was used (Canty and Ripley 2017). This test was performed for parameters included in TAPE (Table 2 in Ecology 2011).

Table 3. Bootstrapped confidence intervals for average percent reduction by each facility.

Parameter	Site	95% Lower Confidence Interval	95% Upper Confidence Interval
Dissolved Zinc	EB (all samples)	0.80	0.84
	EB (only including EBI samples >20 ug/L)	0.83	0.88
	WB (all samples)	0.52	0.67
	WB (only including WBI samples >20 ug/L)	0.67	0.74
	WC	-0.27	-0.13
Total Suspended Solids	EB	-0.14	0.70
	WB	-0.72	0.37
	WC	0.66	0.77

Toxicity Test Results – CETIS Statistical Analysis

Toxicity tests were conducted to address Goal 1 described in the main report (Section 2.1). Appendix H3 includes a brief summary of the results with full reports included in Appendix F3.

The King County Environmental Laboratory Aquatic Toxicology Unit uses the Comprehensive Environmental Toxicity Information System (CETIS) statistical package to assess toxicity (CETIS V1.8.7.16). This program compares toxicity endpoints[1] between environmental samples and negative control samples for each toxicity test. When available, the low hardness negative control was used for this comparison. To meet the project objectives, statistical comparisons were run between influent and effluent sample pairs for each sample event and then between the control and the creek site.

The specific statistical tests used for these data were based on dataset characteristics such as normal-distribution, equal variance, and equal number of replicates. The United States Environmental Protection Agency (EPA) methods for interpreting toxicity data provide flow charts to determine which statistical test to use (acute test: Figure 12 in EPA 2002a, and chronic test: Figure 2 in EPA 2002b). Appendix A of the CETIS User's Guide describes the statistical tests used by the program (Tidepool Scientific 2011). The statistical results are presented in the reports for each toxicity test (Appendix F3).

Appendix E References

Angelo Canty and Brian Ripley (2017). Boot: Bootstrap R (S-Plus) Functions. R package version 1.3-20.

Ecology. 2011. Guidance for Evaluating Emerging Stormwater Treatment Technologies. Technology Assessment Protocol – Ecology. Publication No. 11-10-061.

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EPA. 2002b. Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms, Fourth Edition. United States Environmental Protection Agency, Office of Water, Washington D.C. EPA-821-R-02-013.

King County. 2016. Quality Assurance Project Plan: Effectiveness Monitoring of the South 356th Street Retrofit and Expansion Project, Federal Way. Prepared by Kate Macneale, Water and Land Resources Division. Seattle, Washington.

[1] Percent survival is the acute toxicity test endpoint (*Daphnia pulex*), while both percent survival and mean reproduction are used as chronic toxicity tests endpoints (*Ceriodaphnia dubia*).

R Core Team. (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Tidepool Scientific, LLC. 2011. CETIS-Comprehensive Environmental Toxicity Information System: User's Guide.