Appendix E:
Data Analysis Methods

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APPENDIX E – DATA ANALYSIS METHODS

This section 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 (e.g., petroleum hydrocarbons [TPH-Dx], polycyclic aromatic hydrocarbons [PAHs] and polychlorinated biphenyls [PCBs]). Data analysis methods are also described, which include calculating percent reduction and statistical tests. Statistical test results are also presented.

E.1 Laboratory and Field Replicates

Laboratory and field replicates were considered quality control samples and were not used in data analysis, but rather as part of the data validation and quality control assessments.

E.2 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). In these cases, the value has higher uncertainty and is 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.

E.3 Summation for TPH-Dx, PAH, and PCB Totals

Diesel-range and lube oil-range petroleum hydrocarbon results were summed for TPH-Dx. Total PAHs are the sum of 16 PAH compounds (Table E-1). Total PCBs are the sum of all detected concentrations of the 209 congeners. Results deemed non-detect by the laboratory or through data validation were not included in these sums. Some samples did not have any detected petroleum hydrocarbons or PAHs. In these cases, the highest MDL of the summed compounds was used as the level of detection.

Table E-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

E.4 Use of Non-detect Result Values

Non-detect results were included in summary statistics, 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. In most cases, parameters were detected in the influent, but not the effluent. This suggests that high bias may be introduced to the effluent results,

but not the influent results. Therefore, percent reductions and statistically significant decreases calculated from this dataset provide a conservative estimate of stormwater treatment. However, to help mitigate this uncertainty, parameters were included in statistical analyses only if frequency of detection was greater than 75%.

E.5 Statistical Analysis

This section describes the methods used for statistical analysis presented in the main report and appendices.

Differences between Influent and Effluent Chemical Concentrations – Data Preparation

All representative sample results for samples collected from the bioretention planter boxes (BPBs), the Filterra®, and the detention tank system (DTS) were included in the following analyses. However, one influent sample at the DTS (L65650-1) was deemed "not representative" as described in Section G1.6 of Appendix G. Data for the influent and effluent sample pair (L65650-1 and -3, sampled 6/23/2016) are not included in the sample summary table (Table 1 in the main report) and were not retained for any data analyses associated with this report. However, these sample results were included in the data validation (Appendix G) and full list of validated results (Appendix F).

Differences between Influent and Effluent – Paired Permutation Tests

Statistically significant reductions in concentration between influent and effluent were determined for individual BPBs (BPB1, BPB2, and BPB3), the Filterra, and the DTS using a one-sided paired permutation test (Sections 2.1 and 2.2 in the main report). This test was conducted in R (version 3.2.1; R Core Team 2017). The code is included on page E-5. The test determines whether decreases in concentration (between influent and effluent) are greater than would be expected by chance. This is accomplished by calculating signed differences between influent and effluent pairs, then generating many permutations of this dataset by randomly assigning a positive or negative difference (i.e., multiplying by 1 or -1). The mean difference in concentration is then recalculated for each permutation. The mean difference calculated with the original dataset is then compared to those generated by the permutations. If the observed mean difference is within the top 5% of the permutation results, then the decrease is greater than would be expected by chance – the mean reduction in concentration is statistically significant with p-value <0.05 (Figure E-1).

This test is similar to a paired 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 one-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 E-2.

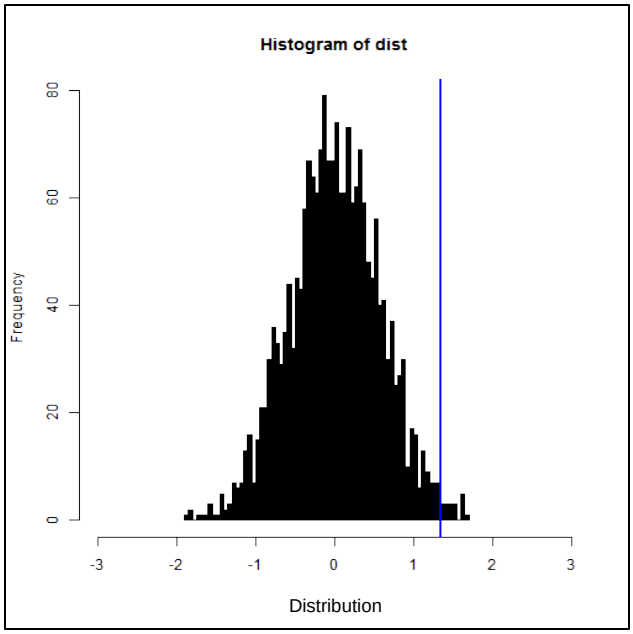

Figure E-1. Example of permutation results. Black bars indicate frequency of permutated difference and blue line signifies the observed difference.

Mean Percent Reductions with 95% Confidence Intervals - Bootstrapping

The 95% confidence intervals around mean percent reductions were calculated using R for individual BPBs (BPB1, BPB2, and BPB3), all BPBs combined (including BPB4), the Filterra, and the DTS using bootstrapping as described in TAPE (Ecology 2011). The "boot" function in the "boot" package for R was used (Canty and Ripley 2017). This test was first performed for the complete dataset for each parameter and then again for parameters included in TAPE using only the sample pairs for which influent concentrations were within the TAPE-specified influent range (Table 2 in Ecology 2011). Results for these analyses are presented in Table E-3 and Table E-4, respectively. Table 2 in the main report summarizes the mean percent reductions based on the lowest 95% confidence interval for each parameter and site (Table E-3).

Toxicity Test Results – CETIS Statistical Analysis

Toxicity tests were conducted to address Objective 1 described in the main report (Section 2.1). Appendix H2 includes a brief summary of the results with full reports included in Appendix F3).

The KCEL Aquatic Toxicology Unit uses the Comprehensive Environmental Toxicity Information System (CETIS) statistical package to assess toxicity (CETIS V1.8.7.16). This program compares the 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, these statistical comparisons were repeated between the influent and effluent sample pairs for each sample event.

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

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).

Relationships between Parameters – Linear Regression

Appendix H3 describes the use of linear regressions to describe how certain parameters may be related. Linear regressions were conducted using Microsoft Excel 2010, which uses least-squares fit. The R^2 values are presented on the scatter plots included in Appendix H3.

Echo Lake Water Quality Monitoring Summary – Data Preparation

Appendix H6 describes the data analysis conducted on the Echo Lake water quality monitoring data. For most analyses the data were grouped by year and were not differentiated between months. Data collection included samples for nutrient data collected in April during some years, but for most years, nutrient data were collected only from May through October. To maintain data comparability across years, the April results were not included in the data analysis. Additionally, in 2014 fecal coliform was analyzed only in samples collected in May and June; therefore, 2014 data were not included in the analyses. Fecal coliform results for three samples were less than the method detection limit; the MDL of 1 was used for these results. Finally, the bacteria dataset used for this analysis included only the samples collected as part of the weekly monitoring effort.

Echo Lake Water Quality Monitoring Summary – Wilcoxon Rank-Sum Test

Wilcoxon Rank-Sum Tests (or Mann-Whitney U tests) were conducted using Sigma Plot v12.5 to compare median nutrient concentrations and bacteria counts between pre- and post-retrofit years. This is a non-parametric test that estimates whether the difference in medians between two groups is greater than would be expected by chance. Two-sided p-values less than 0.05 were used to indicate statistically significant differences. Table E-5 lists these results.

R Code for Paired Permutations

```
#permutation Test, paired -
#datafile format:
#Site2 = monitoring stations (e.g., Filterra, bioswale)
#Type = influent to or effluent from facility
#Date = date of sampling (both influent and effluent sampled)
#Cu = Copper concentration
#.....

results<-data.frame(Site2=unique(data$Site2),Alt_Reduce=NA,Alt_Increase=NA,Alt_Diff=NA)
#setting up a blank data frame to fill with permutation test results

for (j in unique(data$Site2)){ #loop through each site
  sides<-merge(subset(data,Site2==j&Type=='Influent'),subset(data,Site2==j&Type=='Effluent'),by='Date',
            suffixes = c(".Influent",".Effluent")) #create data frame where influent and effluent are side-by-side

 sample<-sides$CuD.Influent-sides$CuD.Effluent #determine difference between influent and effluent level ###change parameter name for each
  length_sample<-length(sample) #n
  possibilities <-unique(t(combn(c(-1,1)*(rep(1,length_sample*2)),length_sample))) #determine number of possible combinations for permutation
  out<-rep(NA,nrow(possibilities)) #permutation test output vector

  for(i in 1:nrow(possibilities)){
    out[i]<-mean(sample*possibilities[i,]) #calculate mean for each possible permutation
  }
  plot(density(out)) #plot distribution of permutated means
  abline(v=mean(sample)) #what was the observed mean difference
  #calculate p-values based on permutated output
  results$Alt_Reduce[results$Site2==j]<-length(which(out>mean(sample)))/length(out) #alternative hypothesis: Influent > Effluent
  results$Alt_Increase[results$Site2==j]<-length(which(out<mean(sample)))/length(out) #alternative hypothesis: Influent < Effluent
  results$Alt_Diff[results$Site2==j]<-length(which(abs(out)>abs(mean(sample))))/length(out) #alternative hypothesis: Influent =/= Effluent
}
```

Code written by Tim Clark, King County Water and Land Resources, April 2017.

Appendix E References

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King County. 2015. Quality Assurance Project Plan For Monitoring Stormwater Retrofit in the Echo Lake Drainage Basin – RSMP Effectiveness Study. Prepared by Carly Greyell, Water and Land Resources Division. Seattle, Washington.

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.

Table E-2. Paired permutation test results for influent and effluent concentrations.

Parameter	Site	one-sided p-value*
Ammonia Nitrogen	BPB1	0.000
Ammonia Nitrogen	BPB2	0.000
Ammonia Nitrogen	BPB3	0.000
Ammonia Nitrogen	Filterra	0.000
Ammonia Nitrogen	DTS	0.813
Conductivity	BPB1	0.973
Conductivity	BPB2	0.992
Conductivity	BPB3	0.992
Conductivity	Filterra	0.813
Conductivity	DTS	0.375
Dissolved Copper	BPB1	0.004
Dissolved Copper	BPB2	0.320
Dissolved Copper	BPB3	0.516
Dissolved Copper	Filterra	0.781
Dissolved Copper	DTS	0.375
Dissolved Oxygen	BPB1	0.723
Dissolved Oxygen	BPB2	0.219
Dissolved Oxygen	BPB3	0.000
Dissolved Oxygen	Filterra	0.000
Dissolved Oxygen	DTS	0.250
Dissolved Zinc	BPB1	0.000
Dissolved Zinc	BPB2	0.000
Dissolved Zinc	BPB3	0.000
Dissolved Zinc	Filterra	0.906
Dissolved Zinc	DTS	0.531
Hardness	BPB1	0.176
Hardness	BPB2	0.508
Hardness	BPB3	0.617
Hardness	Filterra	0.000
Hardness	DTS	0.375
Petroleum Hydrocarbons	BPB1	0.000
Petroleum Hydrocarbons	BPB2	0.000
Petroleum Hydrocarbons	BPB3	0.000
Petroleum Hydrocarbons	Filterra	0.000
Petroleum Hydrocarbons	DTS	0.875
Nitrate/nitrite Nitrogen	BPB1	0.996
Nitrate/nitrite Nitrogen	BPB2	0.992
Nitrate/nitrite Nitrogen	BPB3	0.992
Nitrate/nitrite Nitrogen	Filterra	0.594
Nitrate/nitrite Nitrogen	DTS	0.250
Othrophosphate Phosphorus	BPB1	0.996
Othrophosphate Phosphorus	BPB2	0.992
Othrophosphate Phosphorus	BPB3	0.992
Othrophosphate Phosphorus	Filterra	0.406
Othrophosphate Phosphorus	DTS	0.625
pH	BPB1	0.000
pH	BPB2	0.000
pH	BPB3	0.000
pH	Filterra	0.000
pH	DTS	0.375
Temperature	BPB1	0.008
Temperature	BPB2	0.031
Temperature	BPB3	0.250
Temperature	Filterra	0.500
Temperature	DTS	0.625
Total Cadmium	BPB1	0.000
Total Cadmium	BPB2	0.000

Table E-2. Paired permutation test results for influent and effluent concentrations.

Parameter	Site	one-sided p-value*
Total Cadmium	Filterra	0.000
Total Cadmium	DTS	0.469
Total Copper	BPB1	0.000
Total Copper	BPB2	0.000
Total Copper	BPB3	0.000
Total Copper	Filterra	0.000
Total Copper	DTS	0.250
Total Lead	BPB1	0.000
Total Lead	BPB2	0.000
Total Lead	BPB3	0.000
Total Lead	Filterra	0.000
Total Lead	DTS	0.250
Total Nitrogen	BPB1	0.008
Total Nitrogen	BPB2	0.195
Total Nitrogen	BPB3	0.828
Total Nitrogen	Filterra	0.000
Total Nitrogen	DTS	0.188
Total PAHs	BPB1	0.000
Total PAHs	BPB2	0.000
Total PAHs	BPB3	0.000
Total PAHs	Filterra	0.000
Total PAHs	DTS	0.125
Total Phosphorus	BPB1	0.992
Total Phosphorus	BPB2	0.992
Total Phosphorus	BPB3	0.977
Total Phosphorus	Filterra	0.000
Total Phosphorus	DTS	0.188
Total Suspended Solids	BPB1	0.000
Total Suspended Solids	BPB2	0.000
Total Suspended Solids	BPB3	0.000
Total Suspended Solids	Filterra	0.000
Total Suspended Solids	DTS	0.031
Total Zinc	BPB1	0.000
Total Zinc	BPB2	0.000
Total Zinc	BPB3	0.000
Total Zinc	Filterra	0.000
Total Zinc	DTS	0.031
Turbidity	BPB1	0.000
Turbidity	BPB2	0.000
Turbidity	BPB3	0.000
Turbidity	Filterra	0.063
Turbidity	DTS	0.750

* Shaded cells indicate statistically significant decrease in mean concentration from influent to effluent ($p<0.05$).

Table E-3. 95% confidence intervals for percent reduction in concentration by site.

Parameter	Site	95% Lower Confidence Interval	95% Upper Confidence Interval
Ammonia Nitrogen	All BPB	89%	95%
Ammonia Nitrogen	BPB1	80%	94%
Ammonia Nitrogen	BPB2	97%	99%
Ammonia Nitrogen	BPB3	93%	96%
Ammonia Nitrogen	FLT1	86%	92%
Ammonia Nitrogen	DTS	-27%	14%
Dissolved Copper	All BPB	-43%	16%
Dissolved Copper	BPB1	13%	40%
Dissolved Copper	BPB2	-22%	24%
Dissolved Copper	BPB3	-114%	32%
Dissolved Copper	FLT1	-65%	19%
Dissolved Copper	DTS	-8%	5%
Dissolved Lead	All BPB	NDs	NDs
Dissolved Lead	BPB1	NDs	NDs
Dissolved Lead	BPB2	NDs	NDs
Dissolved Lead	BPB3	NDs	NDs
Dissolved Lead	FLT1	NDs	NDs
Dissolved Lead	DTS	-57%	12%
Dissolved Zinc	All BPB	60%	75%
Dissolved Zinc	BPB1	63%	69%
Dissolved Zinc	BPB2	76%	83%
Dissolved Zinc	BPB3	65%	78%
Dissolved Zinc	FLT1	-100%	3%
Dissolved Zinc	DTS	-2%	2%
Petroleum Hydrocarbons	All BPB	81%	89%
Petroleum Hydrocarbons	BPB1	75%	90%
Petroleum Hydrocarbons	BPB2	78%	91%
Petroleum Hydrocarbons	BPB3	79%	94%
Petroleum Hydrocarbons	FLT1	68%	85%
Petroleum Hydrocarbons	DTS	-23%	-5%
Nitrate/nitrite Nitrogen	All BPB	-534%	-217%
Nitrate/nitrite Nitrogen	BPB1	-346%	-106%
Nitrate/nitrite Nitrogen	BPB2	-596%	-216%
Nitrate/nitrite Nitrogen	BPB3	-1021%	-209%
Nitrate/nitrite Nitrogen	FLT1	-107%	31%
Nitrate/nitrite Nitrogen	DTS	-7%	20%
Othrophosphate Phosphorus	All BPB	-8045%	-2891%
Othrophosphate Phosphorus	BPB1	-3212%	-1490%
Othrophosphate Phosphorus	BPB2	-9822%	-3968%
Othrophosphate Phosphorus	BPB3	-16323%	-1286%
Othrophosphate Phosphorus	FLT1	-130%	43%
Othrophosphate Phosphorus	DTS	-5%	5%
Total Cadmium	All BPB	24%	44%
Total Cadmium	BPB1	13%	47%
Total Cadmium	BPB2	18%	50%
Total Cadmium	BPB3	NDs	NDs
Total Cadmium	FLT1	16%	62%
Total Cadmium	DTS	-15%	14%
Total Copper	All BPB	74%	84%
Total Copper	BPB1	78%	85%
Total Copper	BPB2	77%	87%
Total Copper	BPB3	76%	86%
Total Copper	FLT1	56%	67%
Total Copper	DTS	-9%	10%
Total Lead	All BPB	66%	88%
Total Lead	BPB1	49%	75%

Table E-3. 95% confidence intervals for percent reduction in concentration by site.

Parameter	Site	95% Lower Confidence Interval	95% Upper Confidence Interval
Total Lead	BPB2	93%	95%
Total Lead	BPB3	87%	95%
Total Lead	FLT1	67%	83%
Total Lead	DTS	-8%	20%
Total Nitrogen	All BPB	-1%	21%
Total Nitrogen	BPB1	10%	34%
Total Nitrogen	BPB2	-8%	36%
Total Nitrogen	BPB3	-29%	8%
Total Nitrogen	FLT1	44%	54%
Total Nitrogen	DTS	-4%	9%
Total PAHs	All BPB	71%	95%
Total PAHs	BPB1	97%	98%
Total PAHs	BPB2	98%	99%
Total PAHs	BPB3	98%	99%
Total PAHs	FLT1	86%	98%
Total PAHs	DTS	0%	21%
Total PCBs	All BPB	82%	95%
Total PCBs	BPB1	83%	92%
Total PCBs	BPB2	98%	99%
Total PCBs	BPB3	65%	100%
Total PCBs	FLT1	82%	95%
Total PCBs	DTS	-52%	35%
Total Phosphorus	All BPB	-249%	-122%
Total Phosphorus	BPB1	-121%	-42%
Total Phosphorus	BPB2	-453%	-249%
Total Phosphorus	BPB3	-252%	-90%
Total Phosphorus	FLT1	37%	63%
Total Phosphorus	DTS	-4%	8%
Total Suspended Solids	All BPB	83%	95%
Total Suspended Solids	BPB1	75%	89%
Total Suspended Solids	BPB2	97%	99%
Total Suspended Solids	BPB3	96%	98%
Total Suspended Solids	FLT1	58%	87%
Total Suspended Solids	DTS	4%	22%
Total Zinc	All BPB	86%	92%
Total Zinc	BPB1	83%	89%
Total Zinc	BPB2	92%	96%
Total Zinc	BPB3	90%	95%
Total Zinc	FLT1	64%	78%
Total Zinc	DTS	0%	11%

Table E-4. 95% confidence intervals to compare to TAPE criteria.

Parameter	Influent Range	Criteria	Site	N	Lower 95% CI	Upper 95% CI	Units	Meets Criteria?*
Total Suspended Solids	20 to 100 mg/L	≤ 20 mg/L effluent	All BPB	16	3.49	10.7	mg/L effluent	**Yes**
			BPB1	5	8.78	16.8		**Yes**
			BPB2	5	0.69	1.55		**Yes**
			BPB3	4	1.01	2.13		**Yes**
			FLT1	4	6.39	30.4		No
	100 to 200 mg/L	≥ 80% removal	All BPB	8	92%	98%	% reduction in concentration	**Yes**
			BPB1	3	89%	92%		**Yes**
			BPB2	2	NA	NA		NA
			BPB3	3	97%	99%		**Yes**
			FLT1	1	NA	NA		NA
Dissolved Copper	5 to 20 µg/L	> 30 % removal	All BPB	6	24%	46%	% reduction in concentration	No
			BPB1	2	NA	NA		NA
			BPB2	1	NA	NA		NA
			BPB3	3	30%	51%		**Yes**
			FLT1	2	NA	NA		NA
Dissolved Zinc	20 to 300 µg/L	> 60% removal	All BPB	1	NA	NA	% reduction in concentration	NA
			BPB1	0	NA	NA		NA
			BPB2	0	NA	NA		NA
			BPB3	1	NA	NA		NA
			FLT1	1	NA	NA		NA
Total Phosphorus	0.1 to 0.5 mg/L	≥ 50% removal	FLT1	3	36%	72%	% reduction in concentration	No

* This analysis is based on an extremely limited number of samples (N). Additionally, these are based on concentration reduction, not mass reduction, even though volume reductions were likely, particularly at the BPB. There is high uncertainty in these estimates.

NA - not analyzed due to sample size (N) less than 3.

Table E-5. Wilcoxon Rank-Sum Test (Mann-Whitney U test) results for Echo Lake monitoring data 2001-2011 (pre-retrofit) versus 2012 to 2016.

Parameter	Mann-Whitney U Statistic	two-sided p-value
Total Phosphorus 1-m depth (May through October)	2124	<0.001
Total Nitrogen 1-m depth (May through October)	2468	<0.001
Fecal coliform (May through September)	3746	0.002