Science + Planning + Design

TECHNICAL MEMORANDUM

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Subject: WQBE Phase 3 Water Quality Performance Parameter Data Compilation (Appendix D to 439-TM1)

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Introduction

The King County Wastewater Treatment Division (WTD) is developing the Water Quality Benefits Evaluation (WQBE) toolkit to inform King County (County) decision-making processes for selecting cost-effective water quality investments, reducing pollutant load and improving ecological and human health outcomes. The WQBE Toolkit will include a set of computational models:

- Integrated pollutant loading models, which estimate pollutant loads for major King County waterbodies taking into account major pollutant pathways and sources. Included in the suite of integrated pollutant loading models is a watershed model for estimating runoff volumes and pollutant loads that are delivered via stormwater and baseflow.
- System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) models, which identify cost-effective combinations of potential water quality improvement investments for reduction of pollutant loads or stormwater volumes.
- Qualitative causal models, which define relationships between potential water quality projects and programs and five ecological/human health endpoints (southern resident orca population trends, Chinook salmon population trends, toxics in fish, toxics and pathogens in shellfish, and algal toxins and pathogens at swimming beaches).

The WQBE Toolkit provides information that will be used in planning and prioritization of water quality investments. However, it is not the only information that informs these decisions. These efforts will also consider information not provided by the WQBE Toolkit, including how well different actions would advance equity and social justice, meet regulatory requirements, impact the cost of wastewater rates, and reflect other regional priorities (e.g., sustainability, community well-being, and more).

Part of this effort has involved the development of model inputs for “Actions” composed of structural or nonstructural stormwater controls that improve water quality and/or provide flow control. These Actions provide the unit building blocks (or “unit Actions”) that are aggregated and combined to develop "Programs,” or groups of Actions that can be implemented to achieve a stormwater management target over a broad geographic area. SUSTAIN models are then developed for each Program to evaluate cost effectiveness combinations of Actions, or “Packages,” for improving water quality or providing flow control.

The WQBE Toolkit is being developed in three phases over a period extending from 2020 through 2024.

- Phase 1 (2020): Assumptions for a preliminary set of nineteen Actions and three Programs focused on improving water quality were developed to be modeled with the WQBE Toolkit.
- Phase 2 (2021-2022): Preliminary Actions and Programs from Phase 1 were refined to improve their representation in SUSTAIN (Herrera 2022a). The three water quality Programs from Phase 1 were subsequently modeled with SUSTAIN (Paradigm and Herrera 2022).

- **Phase 3 (2023-2024)**: An additional five Actions and four Programs focused on providing flow control were developed and the Phase 2 Action costs were refined using a simplified approach that allows for more direct comparison to similar planning level cost estimates in the region.

This memorandum documents the technical basis for pollutant removal performance parameter (performance parameter) data for the Actions developed in Phase 2 and Phase 3. It begins with a description of the methods that were used to compile and review these data. It then documents the approach used to fill gaps where existing data were not available for specific combinations of Actions and pollutants. Finally, the performance parameter data that are recommended as input for SUSTAIN models and included in the Action Fact Sheets are summarized.

Methodology

The Actions in the WQBE toolkit were developed in two Phases. The following Actions were developed in Phase 2.

- Bioretention
- Raingarden
- Bioretention planter
- Bioswale
- Media Filter Drain
- Drywell
- Deep underground injection control (UIC) well
- Permeable pavement
- Depaving
- Detention vault
- Detention pond
- Infiltration vault
- Infiltration pond
- Cistern
- Stormwater treatment wetland
- Wetpond
- Wetvault
- High rate underground filter system (underground filter system)

- Regional vegetated media filtration stormwater facility [Stormwater park (water quality treatment)]
- The following Actions were developed in Phase 3:
- Sports field and park detention
- Compost amendment
- Blue roof
- Reforest High Density Development
- Reforest Pervious Area

See Appendix B and Appendix C of Herrera (2024) for the design details of the Actions developed in Phase 2 and Phase 3, respectively.

The SUSTAIN model simulates Action performance through the following three treatment pathways:

- Untreated bypass. Any water that overflows an Action or exceeds the capacity of an Action results in bypass. This water receives no treatment and retains the influent concentration.
- Retention, detention and filtration. Water that receives treatment through retention, detention and filtration that also discharges through a pipe to receiving waters is assigned a percent removal down to a minimum effluent concentration, or irreducible concentration. This reduction is applied to the water discharging through an orifice or an underdrain.
- Infiltration to groundwater. Runoff that infiltrates to groundwater is lost from SUSTAIN, the surface water model. SUSTAIN model results can be put back into the watershed model where the increased volume from infiltration to subsurface flow and groundwater can be assigned a pollutant concentration.

This section presents the methods used to compile and review the performance parameter data for each Action needed to model their performance using the SUSTAIN model. Also discussed are methods used to fill gaps when no data could be found for an Action and pollutant combination.

Data Compilation

The Actions were screened and categorized into one of four groups to determine if performance parameter data would be needed to support SUSTAIN model development:

1. Actions that are expected to provide negligible water quality benefit. Actions in this category include:
   - Cistern
   - Blue roof

2. Actions that will not require compilation of performance parameter data for representation in SUSTAIN models. Actions in this category include:
   - Depaving
   - Reforest high density development
   - Reforest pervious area
3. Actions that provide pollutant removal through infiltration. All water that infiltrates is lost from the SUSTAIN model to groundwater, so the associated pollutants are 100 percent removed from the surface water model. Actions in this category include:
   - Raingarden
   - Drywell
   - Deep UIC well
   - Permeable pavement
   - Infiltration vault
   - Infiltration pond
   - Compost amendment
4. Actions that provide treatment via a combination of unit processes (e.g., filtration, sedimentation, sorption, etc.) and have the potential for a direct discharge to a receiving water via an outlet or underdrain pipe; hence, the associated influent and effluent pollutants will be included in the surface water model. Actions in this category include:
   - Bioretention
   - Bioretention planter
   - Bioswale
   - Media filter drain
   - Stormwater treatment wetland
   - Detention vault
   - Detention pond
   - Wetpond
   - Wetvault
   - Underground filter system
   - Stormwater park (water quality treatment)
   - Sports field and park detention

Attachment A presents a matrix that documents the results from this screening process with explanations for why Actions were categorized in specific groups.

No performance parameter data are required for Actions categorized in the first, second, and third groups based on their representation in the SUSTAIN models. Performance parameter data are required for Actions categorized in the fourth group to allow their representation in these models in one of two ways depending on their physical configuration:

- For Actions with an underdrain, the influent flow concentration is assigned a percent removal and an irreducible concentration for each pollutant.
- Water that flows through a pond or vault outlet is assigned a percent removal to the influent flow concentration and an irreducible concentration for each pollutant.

For Actions falling in category 4, Herrera (2022b) performed a literature review for the following suite of pollutants for the WQBE Toolkit:

- Total copper
- Dissolved copper
- Total zinc
- Dissolved zinc
- Total phosphorus
- Total nitrogen
- Total suspended solids (TSS)
- Total polychlorinated biphenyls (total PCB)
- Total polybrominated diphenyl ethers (total PBDE)
- Total polycyclic aromatic hydrocarbons (total PAH)
- Bis(2-ethylhexyl) phthalate (BEHP)
- Fecal Coliform

This literature review specifically focused on obtaining measured percent removal and effluent concentration (used as a surrogate for irreducible concentration) data for each Action using the following stepwise process:

- The International Stormwater Best Management Practices Database (ISBMPD) was queried on May 13, 2020 (ISBMPD 2019) to obtain all available influent and effluent data for each Action and pollutant combination. Because the ISBMPD is considered a highly consistent and complete source for these data, results from this query were prioritized in the compilation of performance parameter data for each Action. If no data were identified for a specific Action and pollutant combination through this query, the following additional step was performed.

- Additional sources for performance parameter data were identified using online literature search engines (Web of Science, UW library, internet searches) and knowledge of local/regional studies. These sources included peer reviewed papers, consultant reports, white papers, and agency reports. The additional data sources identified through this process are documented in Attachment A for specific Action and pollutant combinations where relevant.

In all cases, the following criteria were used to guide the compilation of performance parameter data during the literature review:

- Data must represent the performance of each Action individually (i.e., not in a treatment train).
- Data from both laboratory and field studies were included in the review.
- Data ideally consisted of influent and effluent concentrations from individual sampling events.

The data obtained from this literature review were subsequently compiled in a database for additional processing. Influent and effluent concentration data from individual sampling events were specifically processed as follows:

1. Influent and effluent concentration data from individual sampling events were excluded from subsequent analysis if the influent concentration was below the applicable reporting limit for the pollutant. These data were excluded because they cannot provide a meaningful assessment of treatment performance.
2. For each Action and pollutant combination, the influent and effluent concentration data from individual sampling events were analyzed to compute the median percent removal to represent the typical performance of an Action. The 25th percentile effluent concentration was calculated to represent the irreducible concentration for each Action and pollutant combination. In these computations, the reporting limit was used when the effluent concentration was below the applicable reporting limit for the pollutant. This resulted in a conservative estimate of performance in relation to using other substitution methods (e.g., 1/2 the reporting limit) in these computations.

The number of sampling events with influent and effluent concentration data for these computations is documented in Table 1 for each Action and pollutant combination; this table also identifies where significant data gaps exist for these combinations. The following section describes the process that was used to fill these data gaps where feasible.

Table 1. Number of Sampling Events with Influent and Effluent Concentration Data for each Action and Pollutant Combination.

Parameter	Bioretention/ Bioretention Planter[a]	Bioswale	Media Filter Drain[b]	Stormwater Treatment Wetland	Detention Pond	Detention Vault	Wetpond	Wetvault	Under Ground Filter Systems/Stormwater Park[c]	Sports Field and Park Detention
Copper, Dissolved	30	139	27	51	179	NF	287	NF	39	NF
Copper, Total	28	243	27	270	249	NF	712	NF	49	NF
BEHP	NF	NF	NF	NF	NF	NF	NF	NF	NF	NF
Fecal Coliform	15	84	NF	82	145	NF	163	NF	3	NF
Nitrogen, Total	10	204	NF	539	153	NF	533	NF	38	NF
PBDE	NF	NF	NF	NF	NF	1	NF	NF	NF	NF
Total PAHs	15	NF	NF	18	NF	6	NF	NF	NF	NF
Total PCBs	NF	NF	NF	15	NF	NF	NF	NF	4	NF
Total Phosphorus	44	364	39	714	414	NF	911	NF	109	NF
Total Suspended Solids	14	377	39	632	432	NF	967	NF	107	NF
Zinc, Dissolved	29	132	39	81	128	NF	238	NF	39	NF
Zinc, Total	29	281	39	327	269	NF	778	NF	54	NF

[a] Bioretention and bioretention planters are assumed to have equivalent performance (see assumptions in Attachment A).

[b] Media filter drain data Includes samples with unpaired influent and effluent concentrations from WSDOT (2013). Median percent removal was calculated for paired data only. 13 paired influent and effluent concentration data were available for total copper and dissolved copper, and 25 paired influent and effluent concentration data were available for total phosphorus, total suspended solids, total zinc, and dissolved zinc.

[c] Underground filter systems and stormwater parks (water quality treatment) are assumed to have equivalent performance (see assumptions in Attachment A).

NF = No data found

Data Gaps

This section describes the processes used to fill data gaps when performance parameter data were not identified through the literature review described in the previous section for a given Action and pollutant combination. These processes involved filling data gaps based on data obtained from surrogate Actions or surrogate pollutants.

Surrogate Actions

Where feasible, data gaps for specific Action and pollutant combinations were filled based on data obtained from surrogate Actions that are expected to provide equivalent treatment based on their unit processes (i.e., pollutant removal mechanisms). The surrogate Actions that were used to fill data gaps were discussed with King County and are presented below.

Detention Pond, Detention Vault, and Sports Field and Park Detention: Sedimentation is the primary unit process for pollutant removal in a detention pond. The ISBMPD contains a substantial amount of data for this Action, but data were unavailable for detention vaults and sports field and park detention, which also use sedimentation as their primary unit process for pollutant removal and have as similar structural geometry to detention ponds. Therefore, detention pond performance parameter data obtained from the ISBMPD for the following pollutants were also used for detention vaults and stormwater field and park detention:

- Total copper
- Dissolved copper
- Total zinc
- Dissolved zinc
- Total phosphorus
- Total nitrogen
- TSS

It is likely that the performance of detention vaults and sports field and park detention may be overestimated based on this approach due to these Actions lacking all of the unit processes present in a detention pond.

Similarly, performance parameter data for total PBDEs and total PAHs were summarized in Sebastian et al. (2014) for detention vaults but not detention ponds or sport fields and parks detention. Hence, these data were also used for detention ponds and sports fields and parks detention.

Wetpond and Wetvault: The primary unit processes for pollutant removal in a wetpond are sedimentation and biological uptake. Biological uptake is only an important unit process for those wetponds with abundant vegetation in the littoral zone. Many ponds lack this biologically active area and rely primarily on sedimentation for treatment; this makes them similar to wetvaults. Wetpond performance parameter data obtained from the ISBMPD for the following pollutants were also used for wetvaults:

- Total copper
- Dissolved copper
- Total zinc
- Dissolved zinc
- Total phosphorus
- Total nitrogen
- TSS
- Fecal coliform bacteria

It is likely that the performance of wetvaults may be overestimated based on this approach due to wetvaults lacking all of the unit processes present in a wetpond.

Surrogate Parameters

As Table 1 demonstrates, performance parameter data were identified for most of the Actions through the literature review described above for TSS, most nutrients, and metals. However, data were not identified through this effort for most of the following organic pollutants:

- Total PCBs
- Total PAHs
- Total PBDE
- BEHP

In addition, performance parameter data were also not identified for some of the following additional pollutants:

- Total nitrogen
- Fecal coliform bacteria.

The sections below describe the methods used to fill these data gaps where possible.

Organic Chemicals

Because the organic pollutants identified above are all strongly associated with suspended solids in stormwater due to their hydrophobic properties (Schueler and Youngk 2015), TSS was considered as a suitable surrogate for estimating their removal via treatment with the various Actions. Table 2 summarizes results from research on the affinity of the organic pollutants identified above for sediments. As is apparent, the fraction of organic pollutants associated with suspended sediments ranges from 78 to 86 percent. This implies that the removal of a large percentage of suspended sediment from stormwater by an Action will also result in the effective removal of these organic chemicals.

Given this consideration, the results in Table 2 were used to develop equations for estimating effluent organic pollutant concentrations (total PCBs, total PAHs, total PBDEs and BEHP) based on the effluent TSS concentrations obtained from the literature review described above. Specifically, the 25th percentile effluent TSS concentration (in mg/L) for each Action was multiplied by the estimated concentration of the organic pollutant in the associated sediment from Table 2. This resulted in an estimate of the organic chemical associated with the TSS. However, not all the organic pollutant will be associated with the sediment, a smaller fraction will also be in solution. Using data from Table 2 that quantifies the partitioning of the organic pollutant between the solid and aqueous phase in stormwater, the following correction factor was therefore applied to derive a final estimate of the effluent organic pollutant concentration from the Action:

RatioTD = 1 + (1- % in Sed/100). The % in Sed values are derived from Table 2.

The resultant equations are as follows:

Action effluent total PCB concentration (pg/L) =

$$\mathrm{TSS}\left(\frac{\mathrm{mg}}{\mathrm{L}}\right) \times \mathrm{Sed_C} \times \mathrm{Ratio_{TD}}$$

Where:

$\mathrm{Sed_C}$ = 21.8 ug/kg. The estimated total PCB concentration in the suspended solids (Table 2)

$\mathrm{Ratio_{TD}} = 1.22$. The ratio of total PCB associated with the liquid versus the solid phase.

Action effluent total PAH concentration (µg/L) =

$$\mathrm{TSS}\left(\frac{\mathrm{mg}}{\mathrm{L}}\right) \times \mathrm{Sed_C} \times \mathrm{Ratio_{TD}}$$

Where:

$\mathrm{Sed_C}$ = 108 ug/kg. The estimated total PAH concentration in the suspended solids (Table 2)

$\mathrm{Ratio_{TD}} = 1.15 \times 10^{-6}$. The ratio of total PAH associated with the liquid versus the solid phase, with unit adjustment.

Action effluent PBDE concentration (ng/L) =

$$\mathrm{TSS}\left(\frac{\mathrm{mg}}{\mathrm{L}}\right) \times \mathrm{Sed_C} \times \mathrm{Ratio_{TD}}$$

Where:

$\mathrm{Sed_C}$ = 2.2 ug/kg. The estimated PBDE concentration in the suspended solids (Table 2)

$\mathrm{Ratio_{TD}} = 1.14 \times 10^{-3}$. The ratio of PBDE associated with the liquid versus the solid phase, with unit adjustment.

Action effluent BEHP concentration (µg/L) =

$$\mathrm{TSS}\left(\frac{\mathrm{mg}}{\mathrm{L}}\right) \times \mathrm{Sed_C} \times \mathrm{Ratio_{TD}}$$

Where:

$\mathrm{Sed_C}$ = 2,743 ug/kg. The estimated BEHP concentration in the suspended solids (Table 2)

$\mathrm{Ratio_{TD}} = 1.19 \times 10^{-6}$. The ratio of BEHP associated with the liquid versus the solid phase, with unit adjustment.

Table 2. Organic Chemical Associations with Suspended Solids.

Study	Source	Total PCBs (ug/kg)[a]	Total PCBs % in Sed[b]	Total PAHs (ug/kg)	Total PAHs % in Sed	PBDE (ug/kg)	PBDE % in Sed	BEHP (ug/kg)	BEHP % in Sed
Ecology (2009)	Lower Duwamish stormwater	14.5	–	143.5	–	–	–	–	–
CSN (2015)	Norway sediment traps (PCB), Wisconsin stormwater suspended sediment (PAH), France urban and river sediment (PBDE and BEHP)	29	–	72.85	–	2.2	–	1,230	–
Ko and Baker (2004)	Major tributaries to Chesapeake Bay	–	75	–	80	–	–	–	–
Bressy et al. (2012)	Paris storm drains	–	85		90	–	–	–	–
ZWW (2017)	Seattle catch basins	–	–	–	–	–	–	2,000	–
Zgheib et al. (2011)	Paris storm drains	–	–	–	–	–	–	5,000	81
King County (2013)	Storm and stream discharging to Lake Washington	–	73.7	–	–	–	85.5	–	–
Average		**21.8**	**78**	**108**	**85**	**2.2**	**86**	**2,743**	**81**

[a] ug/kg columns indicate the concentration of the organic chemical in collected sediment (typically from sediment traps or catch basin sumps).

[b] % in Sed = the portion of the organic chemical associated with suspended solids in collected water samples.

Percent removal of the organic pollutants via treatment with the Actions was estimated based on research by Schueler and Youngk (2015) that established simple, relative relationships between TSS removal using stormwater treatment best management practices and the removal of various pollutants. This research established these specific relationships for TSS and the organic pollutants:

- Total PCB removal = TSS removal
- Total PAH removal > TSS removal
- PBDE removal < TSS removal
- BEHP removal < TSS removal

Based on these relationships, total PCB and total PAH percent removal was assumed to be equivalent to the TSS percent removal identified for each Action through the literature review. Percent removal for PBDE and BEHP was reduced relative to the TSS percent removal based on the partitioning values from Table 3 as follows:

- PBDE removal = TSS removal * 0.86
- BEHP removal = TSS removal * 0.81

These equations assume that PBDE and BEHP in the aqueous phase act conservatively as the Action treats the stormwater. While this is an oversimplification, the resultant values from these equations are considered acceptable given the lack of data directly related to these pollutants.

Total Nitrogen and Fecal Coliform

TSS is not strongly related to total nitrogen and fecal coliform bacteria in stormwater; therefore, TSS was not considered a suitable surrogate for estimating effluent concentrations and percent removal of these pollutants via treatment with the Actions. Other pollutants were also not considered suitable for this purpose. Therefore, data gap still exists in the performance parameter data for the following combinations of Actions and pollutants:

- Total nitrogen treatment with the media filter drain.
- Fecal coliform bacteria treatment with the media filter drain, underground filter system, and stormwater park (water quality treatment).

Summary of Compiled Performance Parameter Data

Tables 3 through 12 in this section document the performance parameter data compiled for each Action and pollutant combination through the methods described above. These data will be used as SUSTAIN model input to estimate percent reductions and effluent concentrations for Actions that will be evaluated in specific Programs with the WQBE toolkit. During future phases, the performance parameter data for this set of Actions may be updated and refined and data for new Actions may be added.

Table 3. Bioretention/Bioretention Planter Performance Parameter Data.

Target Pollutants	Median Percent Removal[a,b]	25th Percentile Effluent Concentration[a,b]
Total Copper	62.3%	7.1 µg/L
Dissolved Copper	57.6%	4.6 µg/L
Total Zinc	91.0%	5.0 µg/L
Dissolved Zinc	86.2%	<4.0 µg/L[c]
Total Phosphorus	54.9%	0.024 mg/L
Total Nitrogen	51.3%	1.2 mg/L
Total Suspended Solids	78.0%	13.5 mg/L
Total PCBs	78.0%	358 pg/L
Total PBDEs	67.1%	0.034 ng/L
Total PAHs	95.1%	<0.01 µg/L[c]
BEHP	63.2%	0.044 µg/L
Fecal Coliform	61.5%	31.5 CFU/100 mL

[a] Bioretention and bioretention planters are assumed to have equivalent performance (see assumptions in Attachment A).

[b] Performance based on the low phosphorus alternative bioretention soil media with 70% sand/20% coconut coir/10% high carbon wood ash.

[c] Method detection limit.

Note: Grey shaded values were derived from TSS translator equations discussed in the Methods section.

Table 4. Bioswale Performance Parameter Data.

Target Pollutants	Median Percent Removal	25th Percentile Effluent Concentration
Total Copper	33.9%	4.8 µg/L
Dissolved Copper	8.99%	3.6 µg/L
Total Zinc	33.3%	20.0 µg/L
Dissolved Zinc	29.0%	15.0 µg/L
Total Phosphorus	-37.2%	0.100 mg/L
Total Nitrogen	-7.63%	0.562 mg/L
Total Suspended Solids	27.9%	10.0 mg/L
Total PCBs	27.9%	265 pg/L
Total PBDEs	24.0%	0.025 ng/L
Total PAHs	27.9%	0.0012 µg/L
BEHP	23.0%	0.033 µg/L
Fecal Coliform	6.25%	1,775 CFU/100 mL

Note: Grey shaded values were derived from TSS translator equations discussed in the Methods section.

Table 5. Media Filter Drain Performance Parameter Data.

Target Pollutants	Median Percent Removal	25th Percentile Effluent Concentration
Total Copper	86.2%	9.45 µg/L
Dissolved Copper	40.8%	6.25 µg/L
Total Zinc	85.1%	22.0 µg/L
Dissolved Zinc	80.8%	16.0 µg/L
Total Phosphorus	85.7%	0.033 mg/L
Total Nitrogen	NF	NF
Total Suspended Solids	94.1%	2.8 mg/L
Total PCBs	94.1%	74.3 pg/L
Total PBDEs	80.9%	0.007 ng/L
Total PAHs	94.1%	0.00035 µg/L
BEHP	76.2%	0.0091 µg/L
Fecal Coliform	NF	NF

NF = No data found

Note: Grey shaded values were derived from TSS translator equations discussed in the Methods section.

Table 6. Stormwater Treatment Wetland Performance Parameter Data.

Target Pollutants	Median Percent Removal	25th Percentile Effluent Concentration
Total Copper	25.0%	3.0 µg/L
Dissolved Copper	0.0%	2.0 µg/L
Total Zinc	45.9%	12.0 µg/L
Dissolved Zinc	0.0%	10.0 µg/L
Total Phosphorus	24.2%	0.071 mg/L
Total Nitrogen	5.81%	0.932 mg/L
Total Suspended Solids	52.4%	6.81 mg/L
Total PCBs	78.1%	165 pg/L
Total PBDEs	45.1%	0.017 ng/L
Total PAHs	85.6%	0.024 µg/L
BEHP	42.4%	0.022 µg/L
Fecal Coliform	19.1%	425 CFU/100 mL

Note: Grey shaded values were derived from TSS translator equations discussed in the Methods section.

Table 7. Detention Pond Performance Parameter Data.

Target Pollutants	Median Percent Removal	25th Percentile Effluent Concentration
Total Copper	26.2%	4.17 µg/L
Dissolved Copper	3.23%	3.0 µg/L
Total Zinc	44.0%	18.0 µg/L
Dissolved Zinc	13.6%	16.1 µg/L
Total Phosphorus	17.7%	0.113 mg/L
Total Nitrogen	7.80%	0.674 mg/L
Total Suspended Solids	57.6%	12.9 mg/L
Total PCBs	57.6%	342 pg/L
Total PBDEs	*56.9%*	*93.5 ng/L*
Total PAHs	*52.1%*	*0.228 µg/L*
BEHP	46.7%	0.042 µg/L
Fecal Coliform	31.5%	500 CFU/100 mL

Note: Grey shaded values were derived from TSS translator equations discussed in the Methods section.
Italicized values derived from surrogate BMP (Detention vault).

Table 8. Detention Vault Performance Parameter Data.

Target Pollutants	Median Percent Removal	25th Percentile Effluent Concentration
Total Copper	*26.2%*	*4.17 µg/L*
Dissolved Copper	*3.23%*	*3.0 µg/L*
Total Zinc	*44.0%*	*18.0 µg/L*
Dissolved Zinc	*13.6%*	*16.1 µg/L*
Total Phosphorus	*17.7%*	*0.113 mg/L*
Total Nitrogen	*7.80%*	*0.674 mg/L*
Total Suspended Solids	*57.6%*	*12.9 mg/L*
Total PCBs	*57.6%*	*342 pg/L*
Total PBDEs	56.9%	93.5 ng/L
Total PAHs	52.1%	0.228 µg/L
BEHP	*46.7%*	*0.042 µg/L*
Fecal Coliform	*31.5%*	*500 CFU/100 mL*

Italicized values derived from surrogate BMP (Detention pond).

Table 9. Wetpond Performance Parameter Data.

Target Pollutants	Median Percent Removal	25th Percentile Effluent Concentration
Total Copper	45.0%	3.0 µg/L
Dissolved Copper	22.7%	3.0 µg/L
Total Zinc	62.5%	13.0 µg/L
Dissolved Zinc	36.8%	10.0 µg/L
Total Phosphorus	49.5%	0.071 mg/L
Total Nitrogen	27.6%	0.904 mg/L
Total Suspended Solids	76.2%	7.5 mg/L
Total PCBs	76.2%	199 pg/L
Total PBDEs	65.5%	0.019 ng/L
Total PAHs	76.2%	0.00093 µg/L
BEHP	61.7%	0.025 µg/L
Fecal Coliform	60.0%	85.5 CFU/100 mL

Note: Grey shaded values were derived from TSS translator equations discussed in the Methods section.

Table 10. Wetvault Performance Parameter Data.

Target Pollutants	Median Percent Removal	25th Percentile Effluent Concentration
Total Copper	*45.0%*	*3.0 µg/L*
Dissolved Copper	*22.7%*	*3.0 µg/L*
Total Zinc	*62.5%*	*13.0 µg/L*
Dissolved Zinc	*36.8%*	*10.0 µg/L*
Total Phosphorus	*49.5%*	*0.071 mg/L*
Total Nitrogen	*27.6%*	*0.904 mg/L*
Total Suspended Solids	*76.2%*	*7.5 mg/L*
Total PCBs	*76.2%*	*199 pg/L*
Total PBDEs	*65.5%*	*0.019 ng/L*
Total PAHs	*76.2%*	*0.00093 µg/L*
BEHP	*61.7%*	*0.025 µg/L*
Fecal Coliform	*60.0%*	*85.5 CFU/100 mL*

Italicized values derived from surrogate BMP (Wetpond).

Table 11. Underground Filter System Performance/Stormwater Park (Water Quality Treatment) Performance Parameter Data.

Target Pollutants	Median Percent Removal[a,b]	25th Percentile Effluent Concentration[a,b]
Total Copper	51.6%	3.1 µg/L
Dissolved Copper	34.2%	2.0 µg/L
Total Zinc	56.4%	20.1 µg/L
Dissolved Zinc	53.4%	26.0 µg/L
Total Phosphorus	42.4%	0.034 mg/L
Total Nitrogen	45.8%	0.422 mg/L
Total Suspended Solids	86.4%	2.45 mg/L
Total PCBs	84.1%	414.1 pg/L
Total PBDEs	74.3%	0.0061 ng/L
Total PAHs	86.4%	0.00031 µg/L
BEHP	70.0%	0.008 µg/L
Fecal Coliform	NF	NF

[a] Underground filter systems and stormwater park (water quality treatment) are assumed to have equivalent performance (see assumptions in Attachment A).

[b] Performance based on proprietary Filterra® engineered media.

NF = No data found; Assigned a value of 0 in SUSTAIN since no data was found.

Note: Grey shaded values were derived from TSS translator equations discussed in the Methods section.

Table 12. Sports Field and Parks Detention

Target Pollutants	Median Percent Removal	25th Percentile Effluent Concentration
Total Copper	*26.2%*	*4.17 µg/L*
Dissolved Copper	*3.23%*	*3.0 µg/L*
Total Zinc	*44.0%*	*18.0 µg/L*
Dissolved Zinc	*13.6%*	*16.1 µg/L*
Total Phosphorus	*17.7%*	*0.113 mg/L*
Total Nitrogen	*7.80%*	*0.674 mg/L*
Total Suspended Solids	*57.6%*	*12.9 mg/L*
Total PCBs	*57.6%*	*342 pg/L*
Total PBDEs	*56.9%*	*93.5 ng/L*
Total PAHs	*52.1%*	*0.228 µg/L*
BEHP	*46.7%*	*0.042 µg/L*
Fecal Coliform	*31.5%*	*500 CFU/100 mL*

Italicized values derived from surrogate BMP (Detention pond).

Limitations and Future Considerations

This document summarizes the pollutant removal performance data and approach used to represent the typical performance of the Actions included in the WQBE toolkit. The following text provides a summary of the limitations in the data available:

- When performance parameter data were not identified through the literature review, data gaps were filled based on data from surrogate Actions and pollutants as appropriate. Periodic reviews should be conducted to identify new data that could be used to quantify the pollutant removal performance of an Action.
- To simplify modeling assumptions, the 25th percentile effluent concentration was used as a surrogate for the irreducible concentration for each pollutant based on best professional judgement.
- The influent and effluent concentration data from individual sampling events were analyzed to compute the median percent removal for each Action and pollutant combination. These data were then used to represent the typical pollutant removal performance of each Action. However, these data do not capture complex dynamics that occur in association with specific unit processes for pollutant removal. For example, these data do not reflect variations in pollutant removal performance stemming from biological processes that may be influenced by seasonal factors (e.g., nutrient capture in plants during the growing season and subsequent release with plant senescence). Due to model limitations, it is generally not possible to capture the influence of these complex dynamics in the model output.
- Correction factors were derived using the data from Table 2 to quantify the partitioning of organic pollutants between the solid and aqueous phase in stormwater. These correction factors were then used to derive a final estimate of the effluent organic pollutant concentration for each Action. These estimates could be refined in future phases of the project using partition coefficient (Kow) that are derived from literature.

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Attachment A

Phase 2 and Phase 3 Action Screening Process, Data Sources, and Key Assumptions

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Table A-1. Phase 2 and Phase 3 Action Screening Process, Data Sources, and Key Assumptions.

Action	WQBE Phase	Primary Unit Processes	Screening Process Category	Data Source	Modeling and Performance Assumptions
Bioretention	2	Sedimentation, sorption, filtration, biological uptake, Infiltration	4	Herrera (2015), Herrera (2020)	Concentration percent reductions from this review are assigned to underdrain outflow. All water that infiltrates is lost from the model to groundwater, so the associated pollutants are 100 percent removed from the surface water model. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment. Performance results were gathered from lab studies, which used the Puget Sound region's new High Performance Bioretention Media (HPBSM) specification, a mixture of sand, coconut coir, and biochar (Herrera 2020).
Rain garden	2	Sedimentation, sorption, filtration, biological uptake, Infiltration	3		All water that infiltrates is lost from the model to groundwater, so the associated pollutants are 100 percent removed from the surface water model. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment.
Bioretention Planter	2	Sedimentation, sorption, filtration, biological uptake, Infiltration	4	Herrera (2015), Herrera (2020)	Concentration percent reductions from this review are assigned to underdrain outflow. All water that infiltrates is lost from the model to groundwater, so the associated pollutants are 100 percent removed from the surface water model. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment. These systems function equivalent to bioretention.
Bioswale	2	Sedimentation, filtration, biological uptake, infiltration	4	ISBMPD (2019)	Bioswales are modelled as a flow through system. Concentration percent reductions from this review are assigned to water that exits the bioswale. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment.
Media filter drain	2	Sedimentation, sorption, filtration, infiltration	4	Herrera (2006), WSDOT (2013)	Concentration percent reductions from this review are assigned to underdrain outflow. All water that infiltrates is lost from the model to groundwater, so the associated pollutants are 100 percent removed from the surface water model. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment.
Dry well	2	Infiltration	3		All water that infiltrates is lost from the model to groundwater, so the associated pollutants are 100 percent removed from the surface water model. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment. Action will be paired with a pretreatment Action when included in a Program.

Table A-1 (continued). Phase 2 and Phase 3 Action Screening Process, Data Sources, and Key Assumptions.

Action	WQBE Phase	Primary Unit Processes	Screening Process Category	Data Source	Modeling Assumptions
Deep underground injection control (UIC) well	2	Infiltration	3		All water that infiltrates is lost from the model to groundwater, so the associated pollutants are 100 percent removed from the surface water model. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment. Action will be paired with a pretreatment Action when included in a Program.
Permeable pavement	2	Infiltration	3		All water that infiltrates is lost from the model to groundwater, so the associated pollutants are 100 percent removed from the surface water model. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment.
Depaving	2	–	2		Action will be modeled in SUSTAIN by converting the depaved area from an impervious to pervious surface. Load reduction would be the result of the differences in pollution generating in surface runoff from the different land surfaces.
Detention vault	2	Sedimentation	4	Sebastian et al. (2014), ISBMPD (2019)	Water that flows through the orifice is assigned a percent removal and irreducible concentration for each pollutant based on the Action effectiveness (while not designed for treatment, there will be some pollutant removal via sedimentation). Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment. Performance assumed equivalent to a detention pond except for the specific data found for detention vaults for PBDEs and Total PAHs.
Detention pond	2	Sedimentation	4	Sebastian et al. (2014), ISBMPD (2019)	Water that flows through the orifice is assigned a percent removal and irreducible concentration for each pollutant based on the Action effectiveness (while not designed for treatment, there will be some pollutant removal via sedimentation). Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment. Performance for PBDEs and Total PAHs assumed equivalent to detention vaults.

Table A-1 (continued). Phase 2 and Phase 3 Action Screening Process, Data Sources, and Key Assumptions.					
Action	**WQBE Phase**	**Primary Unit Processes**	**Screening Process Category**	**Data Source**	**Modeling Assumptions**
Infiltration vault	2	Sedimentation, infiltration	3	Sebastian et al. (2014), ISBMPD (2019)	All water that infiltrates is lost from the model to groundwater, so the associated pollutants are 100 percent removed from the surface water model. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment. Action will be paired with a pretreatment Action when included in a Program. Assumed same performance as detention pond/vault, but will be part of a treatment train.
Infiltration pond	2	Sedimentation, infiltration	3	Sebastian et al. (2014), ISBMPD (2019)	All water that infiltrates is lost from the model to groundwater, so the associated pollutants are 100 percent removed from the surface water model. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment. Action will be paired with a pretreatment Action when included in a Program. Assumed same performance as detention pond/vault, but will be part of a treatment train.
Cistern	2	–	1		Model will assume no treatment provided unless Program includes manual operation of orifice valve by property owner. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment.
Stormwater treatment wetland	2	Sedimentation, sorption, filtration, biological uptake	4	ISBMPD (2019), King County (2019)	Water that flows through the Action (to the max flow rate) is assigned a percent removal and irreducible concentration for each pollutant based on the Action effectiveness. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment.
Wetponds	2	Sedimentation, biological uptake (depends on pond quality)	4	ISBMPD (2019)	Water that flows through the Action (to the max flow rate) is assigned a percent removal and irreducible concentration for each pollutant based on the Action effectiveness. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment.
Wetvaults	2	Sedimentation	4	ISBMPD (2019)	Water that flows through the Action (to the max flow rate) is assigned a percent removal and irreducible concentration for each pollutant based on the Action effectiveness. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment. Performance assumed equivalent to Wetpond.

Table A-1 (continued). Phase 2 and Phase 3 Action Screening Process, Data Sources, and Key Assumptions.					
Action	**WQBE Phase**	**Primary Unit Processes**	**Screening Process Category**	**Data Source**	**Modeling Assumptions**
High Rate Underground Filtration System	2	Sedimentation, sorption, filtration	4	Gilbreath et al. (2018), ISBMPD (2019)	Underdrain flow is assigned a percent removal and irreducible concentration for each pollutant based on media effectiveness. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment. Performance assumed equivalent to Filterra®.
Stormwater park (water quality treatment)	2	Sedimentation, sorption, filtration	4	Gilbreath et al. (2018), ISBMPD (2019)	Underdrain flow is assigned a percent removal and irreducible concentration for each pollutant based on media effectiveness. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment. Performance assumed equivalent to Filterra®.
Sports field and park detention	3	Sedimentation	4	Sebastian et al. (2014), ISBMPD (2019)	Water that flows through the orifice is assigned a percent removal and irreducible concentration for each pollutant based on the Action effectiveness (while not designed for treatment, there will be some pollutant removal via sedimentation). Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment.
Compost Amendment	3	Sedimentation, sorption, filtration, infiltration	3		All water that infiltrates is lost from the model to groundwater, so the associated pollutants are 100 percent removed from the surface water model. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment.
Blue roof	3	–	1		Model will assume no treatment. Water that exceeds the capacity of the Action is modeled as bypass and receives no treatment.
Reforest High Density Development	3	–	2		Action will be modeled in SUSTAIN by converting the reforested area from an impervious to forested surface. Load reduction would be the result of the differences in pollution generating in surface runoff from the different land surfaces.
Reforest Pervious Area	3	–	2		Action will be modeled in SUSTAIN by converting the reforested area from a pervious to forested surface. Load reduction would be the result of the differences in pollution generating in surface runoff from the different land surfaces.