Contaminants of Emerging Concern, Crop Production, and Soil Fertility After Irrigation with Sammamish Valley Recycled Water and Surface Water

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Executive Summary

Background and Purpose

Rivers, streams, and their interconnected groundwater supplies throughout Washington face increasing demands. Climate change makes water supplies less secure for both in-stream needs like fish and habitat as well as out-of-stream needs like human consumption and irrigation—especially during dry summer months. Salmon need both sufficient flows and cool water to live, grow, and reproduce. Irrigating with recycled water is a reliable and established way to restore surface water flows, maintain groundwater inputs to rivers and streams, and find advantageous uses for residual nutrients in wastewater.

Currently, farmers in the Sammamish Valley irrigate many edible food crops using surface or groundwater from the Sammamish River basin, which reduces critical stream flow and elevates temperatures during dry summer months. Recycled water contains agronomically valuable nutrients, which makes it effective at reducing the need for carbon and energy-intensive commercial fertilizers. In addition, using recycled water for irrigation rather than discharging it to Puget Sound can help reduce phytoplankton blooms or other degradation of water quality.

This report presents the results of a 2-year study of crop productivity, soil fertility, and the occurrence and fate of unregulated contaminants of emerging concern (CECs) in garden beds in the Sammamish Valley. Researchers irrigated edible crops (specifically, kale and carrot) in the garden beds with either recycled water from King County Wastewater Treatment Division's (WTD) Brightwater Treatment Plant (Brightwater) or surface water from the Sammamish River, comparing soil and plant characteristics, including CEC exposure, to demonstrate the efficacy of recycled water as an irrigation choice in the Sammamish Valley. The study was conducted by University of Washington and Washington State University researchers in partnership with the Washington Water Trust, WTD, and the King County Water and Land Resources Division.

Study Objectives and Design

The primary objective of this study was to investigate crop productivity, soil health, and the potential occurrence of CECs in representative Sammamish Valley food crops. In the spring of 2020, study partners built a demonstration garden on the grounds of King County's Hollywood Pump Station in the Sammamish Valley. Researchers used carrots as a representative root crop and kale as a representative leafy green. The demonstration plots were irrigated with recycled water from Brightwater, located in Woodinville, Washington, or Sammamish River water. Researchers evaluated the effects of irrigation water type on soil fertility status and crop growth. Data were collected in July (mid-season) and September (harvest) during both 2020 and 2021 to identify consistent trends across the two growing seasons and allow results to be replicated year to year.

The study also addressed producer and consumer concerns about possible exposures to unregulated CECs or changes to soil health. CECs commonly occur in soil, water, and air, including many environments where consumer, commercial, and industrial products are used. CEC sources include not only municipal wastewater effluent and associated recycled water, but also stormwater and roadway runoff, septic systems, airborne deposition, and generalized human use of the environment. Various CECs have been detected, often at low concentration, in nearly all environmental waters, including irrigation waters.

Using the demonstration garden system as experimental plots, researchers analyzed the two types of water, soil, and two edible crops for the presence of a comprehensive suite of CECs and soil health parameters, consisting of 206 to 222 individual analytes (2020 and 2021 analyte numbers, respectively). Based on published research and regional data, the selected CECs included pharmaceuticals and personal care products, polybrominated diphenyl ethers, the herbicide glysophate and its metabolite AMPA, and PFAS analytes. PFAS are a notable example because PFAS are widespread and persistent CECs with ubiquitous exposures in modern society. PFAS are currently receiving heightened scrutiny, and their toxicological science and impacts are rapidly evolving. As a result, PFAS exposure pathways and related risk assessment will remain somewhat uncertain and likely subject to regulatory change for the near future.

Key Results

Study researchers detected CECs across all demonstration garden sample types, including many commonly used CECs as well as several hard-to-degrade compounds. Most CECs occurred at low concentrations—single digits to tens of nanograms per liter—both in recycled and Sammamish River water. Many CECs were either close to analytical method limits of detection, not replicated in identical samples, not consistently detected, or were not detected in both sampling years. For these sporadically detected CECs, researchers have lower confidence in the implications of their potential presence and concentration. In terms of CECs, Brightwater recycled water was relatively high quality. The aforementioned data reflect about 2 months of annual irrigation effort; longer-term irrigation and sampling efforts would be necessary to determine trends in irrigation-derived CEC concentrations and fate in soils over longer irrigation periods.

Additional key results from the study include the following:

- Sammamish River water and recycled water both contained CECs (25–27 CECs and 59–63 CECs, respectively). The Sammamish River contains many CECs arising from stormwater, septic tank, groundwater, agricultural, or veterinary use discharges and other human contact events.

- Detections of CECs in Brightwater recycled water were typically low (between 1 and 50 ng/L). No obviously unexpected or atypical CEC compositions were observed in the Brightwater recycled water across monitored CECs. All recycled waters contain CECs because many thousands of chemicals are originally present in municipal wastewaters from human activities and no treatment process removes them all.

- Little evidence of CEC accumulation in irrigated soils was observed from 2020 to 2021. Irrigated soils had far fewer CEC detections than either water source, indicating that these compounds were either

not partitioning into soils, were degrading in soils, or that any loading was slight and below limits of detection.

- CECs were detected in both crops grown with both irrigation waters, again at low concentrations.

- More CECs and higher CEC concentrations were observed in kale (16–25 CECs) than carrots (9–19 CECs).

- Among detected CECs, concentrations of per- and polyfluorinated substances (PFAS) and the chemotherapy drug, etoposide merited further evaluation and a focused human health risk assessment. Intertox, a scientific consulting firm specializing in toxicology, conducted a screening level human health risk assessment using conservative assumptions. Overall, the Intertox report concluded that the health risks from consumption of carrots and kale treated with recycled water are minimal and not expected to exceed allowable risk ranges. Exposures to PFOA, a type of PFAS, in particular, are likely to be a fraction of what a person could get from other common, daily sources. (See Appendix A for the full Intertox report.)

- For pharmaceutical CECs, concentrations in food crops were many fold below pharmacological doses, and likely not at biologically active levels. For context, when comparing the CEC concentrations detected in carrots and kale to pharmacological doses, an adult would have to eat at least 1,600 lb of produce to reach a single adult dose of any detected pharmaceutical CEC. For other pharmaceutical CECs, such as antibiotics, up to 41,000 lb of kale would need to be consumed to reach one human pharmacological dose.

- Recycled water was rich in nitrogen, phosphorus, and organic carbon relative to Sammamish River water. These nutrients led to 26% to 147% higher edible crop yields depending on the recycled water irrigated crop and year.

- Recycled water was also higher in sodium and total conductivity than Sammamish River water, but neither affected crop health in this 2-year study.

Introduction

This report presents the results of a 2-year study of crop production, soil fertility, and the occurrence and fate of unregulated contaminants of emerging concern (CECs) in Sammamish Valley recycled water and Sammamish River water used for edible crop irrigation. During the study, researchers irrigated edible crops (specifically, kale and carrots) grown in demonstration garden beds in the valley with either recycled water from the King County Wastewater Treatment Division's (WTD) Brightwater Treatment Plant (Brightwater) or surface water from the Sammamish River, comparing soil and plant characteristics and assessing CEC exposure. A previous review of recycled water conducted by King County (2019) identified some data gaps in our understanding of CECs in crops despite the prevalence of recycled water use in other regions. The purpose of this study was to demonstrate the safety and efficacy of recycled water as an irrigation choice in the Sammamish Valley.

During summer months, large volumes of Class A recycled water are produced from the advanced treatment processes used at Brightwater, which is located in Woodinville, Washington. Class A recycled water is the highest quality, most intensely treated and disinfected recycled water product produced for non-potable purposes. It has no known health or safety concerns and both the Washington State Department of Ecology (Ecology) and the Washington State Department of Health consider it suitable for spray irrigation and other agronomic applications. Recycled water is also an accepted irrigation water source for certified organic crops (Sheikh, 2015). The Brightwater facility delivers recycled water via a service line from Brightwater south through the Sammamish Valley, with potential use as irrigation water for edible food crops.

Currently, agricultural crops in the Sammamish Valley are primarily irrigated with groundwater or Sammamish River surface water. As rivers and streams throughout Washington face increasing demands and climate change stressors, particularly during dry summers, substituting Class A recycled water for existing surface or groundwater irrigation provides an important tool to restore streamflow, cool surface waters, and protect aquatic habitats. This is particularly true for salmonids sensitive to flow and temperature conditions.

This study was initiated by Washington Water Trust in partnership with the King County WTD, the Water and Land Resources Division, Science and Technical Support Section. Funding support was provided by King Conservation District, King County WaterWorks, The Bullitt Foundation, and The Goode Foundation. This technical study was led by University of Washington and Washington State University researchers. Intertox, Inc., provided additional scientific consultation.

Study Objectives

The primary objective of this study was to investigate crop productivity, soil health, and the potential occurrence of CECs in representative Sammamish Valley food crops—specifically, a root crop (carrots) and a leafy green vegetable (kale)—after irrigation with recycled water from Brightwater and Sammamish River water. Because recycled water is a potential substitute for other water sources used for irrigation, the

study directly compared river water and recycled water irrigation sources to understand CEC exposure from existing and potential water sources. Researchers also conducted a human health screening risk assessment for those CECs that merited closer evaluation of potential effects upon human exposure. The study also evaluated the effect of irrigation water type on soil fertility status and crop growth.

This study evaluated the occurrence of CECs in agroecosystems irrigated with recycled water and potential impacts on crop productivity and soil health. Researchers did this to better define the outcomes of recycled water substitution and address consumer concerns over potential exposures to unregulated CECs via food crops. The study was designed to address several data gaps surrounding the occurrence of unregulated CECs in recycled water from Brightwater and, subsequently, CEC occurrence in agricultural soils and edible produce (carrots and kale) irrigated with recycled water.

The specific study objectives were as follows:

- **Objective 1**: Evaluate the occurrence of CECs in recycled water obtained from the King County Brightwater Wastewater Treatment Plant (Woodinville WA) and in Sammamish River water.

- **Objective 2**: Evaluate the occurrence of CECs in agricultural soils irrigated with recycled water or Sammamish River water.

- **Objective 3**: Evaluate the occurrence and risk of CECs in edible tissues of food crops (carrots and kale) irrigated with recycled water and Sammamish River water.

- **Objective 4**: Evaluate soil and water agronomic parameters and crop growth of food crops (carrots and kale) irrigated with recycled water and Sammamish River water.

- **Objective 5**: Survey and share research data with farmers and consumers to inform regional conversations and perspectives about the use of recycled water for food crops.

Study Background and Design

Information about the occurrence (i.e., presence and concentration) of unregulated contaminants such as CECs in recycled water is regionally rare for advanced wastewater treatment processes like Brightwater's membrane bioreactor process. Membrane bioreactors are considered a form of "advanced" or "tertiary" wastewater treatment because they produce a highly treated, high-quality, and disinfected effluent. Currently, most published data describing the occurrence of CECs in recycled water used for agricultural irrigation (including edible food crops) is from arid areas like California, Arizona, Israel, and Spain. These arid regions tend to have different sources of CECs, more concentrated saline wastewater influents and effluents, and different treatment standards compared to Washington State.

Globally, information about CECs in agroecosystems irrigated with recycled water remains fragmented and scarce, particularly with respect to CEC uptake into edible food crops under real-world agricultural irrigation scenarios. Additionally, the potential accumulation of CECs in agricultural soils and the potential impacts (either beneficial or adverse) on crop growth from recycled water are not fully understood, especially for Pacific Northwest conditions.

To address such data gaps, study researchers assessed CEC occurrence in Sammamish Valley recycled water and other local waters used for agricultural irrigation. WTD prioritized information gathering for new and unregulated CECs potentially present in the various water sources used for irrigation in the Sammamish Valley. Using a demonstration garden system as a pilot-scale facility, samples of Brightwater recycled water, soil, and edible crop tissues were analyzed in during 2020 and 2021 for the presence of a comprehensive suite of CECs and soil health parameters, consisting of 206 to 222 individual analytes.

Researchers noted that nearly all irrigation water sources contain CECs of some type because CECs can also come from stormwater and roadway runoff, septic systems, airborne deposition, and human use of the environment in general. Therefore, CECs occur in many soil, water, and air environments, including many environments where consumer, commercial, and industrial products exist. Even the irrigation system itself (e.g., plastic pipes/fittings) might be expected to contribute CECs to soils and plants. Therefore, we can reasonably expect CEC detections in all samples tested, with only uncertainties about which specific CECs exist in these sample types and their concentrations.

CEC concentrations in recycled water and environmental systems are typically very low relative to prescribed doses in humans (Sheikh, 2015). For example, detected CEC concentrations are often many thousands of times lower than pharmaceutical CEC doses; such exposures are not known to be hazardous to humans because they cannot attain levels where pharmacological effects on humans would occur. Thus, it is difficult to identify exposure scenarios that are significant to human health despite the common detection of low concentrations of CECs in aquatic environments. Uptake into food crops from irrigation waters is the exposure scenario that was evaluated in this study. Researchers expected detectable CEC concentrations in the low nanograms per gram range or low nanograms per liter range, representing part per billion (1:1,000,000,000) to part per trillion (1:1,000,000,000,000) level detections, in many environmental media near people.

Demonstration Garden Location and Design

In the spring of 2020, study researchers built a demonstration garden at King County's Hollywood Pump Station in the Sammamish Valley. To determine a site for the demonstration garden, study partners assessed numerous potential public and private garden locations within the Sammamish Valley. Ultimately, they decided that King County ownership, direct access to existing recycled water and surface water from the Sammamish River, and a public location along the Sammamish River trail were important siting criteria. Of the available locations, the Hollywood Pump Station site was deemed the most suitable. Figure 1 shows the location of the demonstration garden in relation to the region.

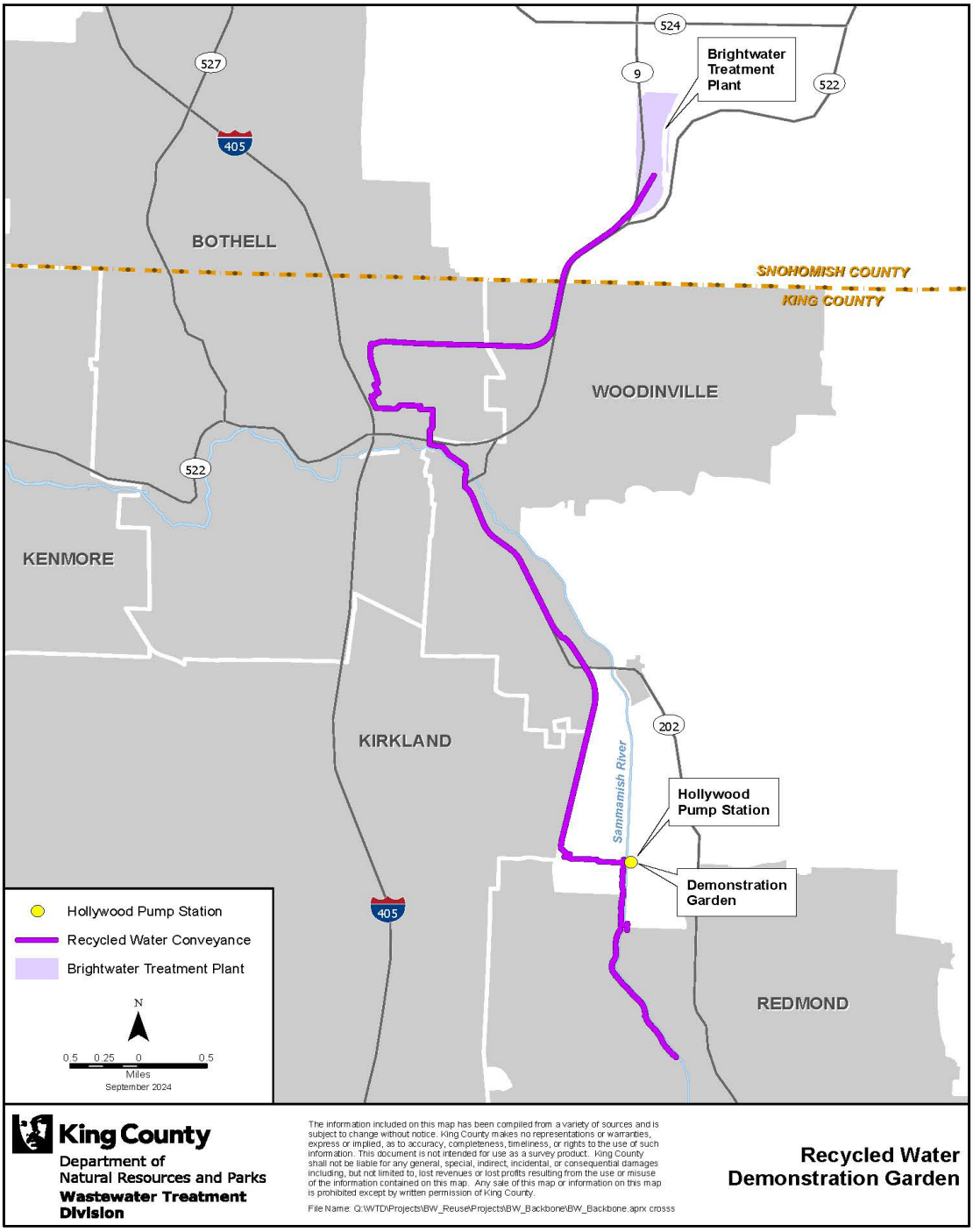

Figure 1. The location of the demonstration garden at the Hollywood Pump Station, in relation to the region.

The garden consisted of 16 raised beds (3-ft. wide x 5-ft. long x 2-ft. deep) constructed from pine lumber. The beds were filled with 20 in. of locally sourced topsoil (72.25% sand, 21.5% silt, 6.25% clay) without additional compost. Researchers used an experimental design consisting of a randomized block, 2 x 2 factorial (crop and water combinations) with four identical replications of each specific crop–water combination. The two factors were crop type (kale or carrots) and irrigation source (Sammamish River or Brightwater recycled). Eight garden beds (four kale, four carrot) were irrigated with recycled water and the remaining eight garden beds (four kale, four carrot) were irrigated with Sammamish River water. Figure 2 presents a schematic of the demonstration garden study design and Figure 3 presents a broader picture of the garden.

Prior to planting, researchers amended the soil with an organic fertilizer reflecting typical agricultural practices. Carrots received 0.52 lb of a 5-5-5 (N-P_2O_5-K_2O) per bed, equivalent to 75 lb N, P_2O_5, K_2O per acre. Kale received 0.41 lb of 5-5-5 and an additional 0.22 lb of 14-0-0, equivalent to 150, 60, and 60 lb N, P_2O_5, K_2O per acre. Metrics of soil health and crop productivity were assessed at harvest.

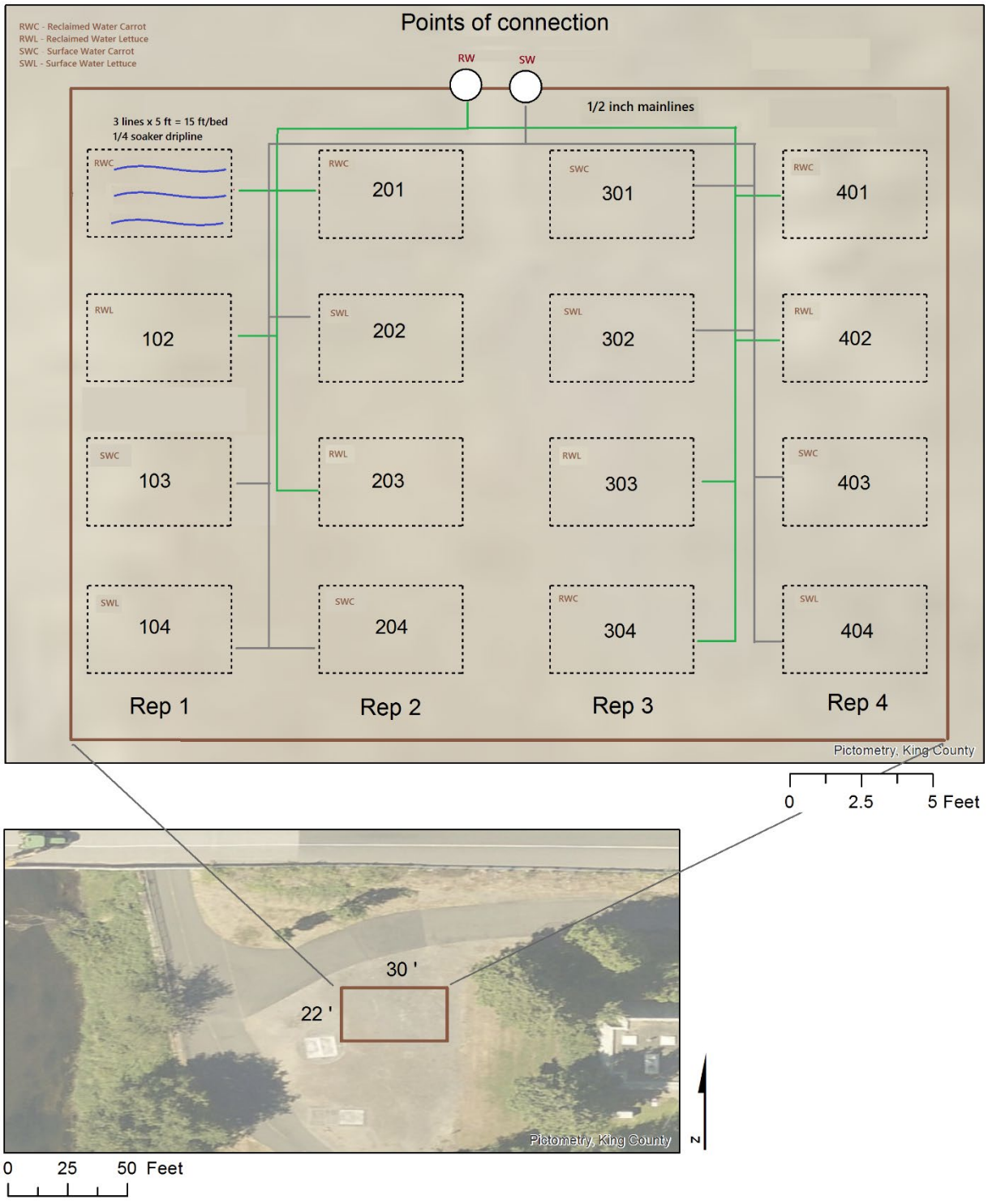

Figure 2. Schematic of the demonstration garden experimental study design.

Figure 3. Members of the research team at the demonstration garden in 2020.

CEC Analysis

Researchers selected CEC parameters for analysis based on the availability of commercial analytical methods (analyses by SGS-AXYS Analytical Services, Sidney, British Columbia, Canada), expert knowledge, and literature review. Researchers prioritized the CECs after reviewing other reclaimed/recycled water research and also considered the public interest in some specific CECs, like per- and polyfluorinated substances (PFAS) and glyphosate, which Livingston et al. (2015) described as the most commonly applied herbicide in the United States for over 20 years.

CECs were analyzed in irrigation water, soil, and crop tissues. Not every matrix had analytical methods available for every CEC; crop tissues, in particular, had fewer available methods. Sammamish River water, recycled water, edible plant tissue, and garden soil samples were analyzed for CECs at the beginning, middle and end of the growing season in the summer of 2020, and at the beginning and end of the growing season in 2021.

The study's sampled CEC parameters, with some slight differences between 2020 and 2021, included the following:

- 95 to 116 pharmaceutical and personal care products
- 40 polybrominated diphenyl ethers (PBDEs)

- 6 bisphenol compounds
- Glyphosate (herbicide) and its main metabolite AMPA
- 40 PFAS

Crop Productivity and Soil Health-Related Goals

Crops need both water and nutrients for growth; recycled water can potentially provide both and reduce fertilizer costs. Concentrations of nitrogen, phosphorus, sulfur, calcium, potassium, and magnesium are typically much higher in recycled water relative to surface water (Campi et al., 2014; Chaganti et al., 2020). Sodium is also typically higher. The higher ionic strength of recycled water may concern some irrigators that are anticipating long-term use in some soils. The goals for this portion of the study were to characterize the nutrient concentrations of recycled water and surface water and analyze the effect on soil fertility and plant growth. In addition to CEC analysis, the study analyzed 18 to 23 agronomic parameters to evaluate the quality of the recycled water for agricultural irrigation and the resultant crop growth.

The following agronomic parameters were evaluated:

- Soil nutrients (nitrate-N, ammonium-N, P, S, K, Ca, Mg, Na, B, Zn, Mn, Cu, and Fe)
- Soil Na, soluble salts, pH
- Soil organic carbon
- Water nutrients (nitrate-N, ammonia-N, P)
- Water conductivity, Na, and organic carbon
- Bulk density
- Crop yield

Sampling Design

Researchers collected grab samples of water; soil and tissue samples were composites of multiple subsamples to help ensure representative sampling. In 2020, 12 irrigation water samples (equally split between Sammamish River and recycled water), 10 composite soil samples (including before irrigation and after irrigation with both water types) and 32 composite crop samples (equally split between carrots and kale) were analyzed. Additional irrigation water samples were collected on September 8, 2020. These samples were delayed during shipping to SGS-Axys Analytical and were not analyzed because they exceeded sample hold times. For soil health and crop productivity, 16 samples were collected at harvest in both 2020 and 2021.

Data were collected in July (mid-season) and September (harvest) of both 2020 and 2021 to identify consistent trends/data across the 2 years and allow results to be replicated (Table 1). CEC detections in 2020 (and 2021) were often close to method limits of detection and detections were frequently inconsistent across replicates. This reduced study partners' confidence in the data outcomes and necessitated additional sampling effort. The effort to resolve data uncertainty observed in 2020 in 2021 was partly an outcome of the variable and sporadic detection data observed for some CECs.

Table 1. Sampling design and data collection efforts in 2020 and 2021.

Sample Type (#)	Irrigation Source	Sample Date		Replicates	Comment
Water (12/18)	Sammamish River	7/21/2020	7/19/2021	3	**Samples collected on 9/8/2020 exceeded allowable hold times in shipping.*
		9/08/2020*	9/14/2021	3	
		9/22/2020	9/27/2021	3	
	Recycled water	7/21/2020	7/19/2021	3	
		9/08/2020*	9/14/2021	3	
		9/22/2020	9/27/2021	3	
Soil (10/12)	Pre-Irrigation	7/14/2020	7/19/2021	2 (6)	(2021 data)
	Sammamish River	9/22/2020	9/27/2021	2 (3)	Carrot (both)
		9/22/2020		2	Kale
	Recycled water	9/22/2020	9/27/2021	2 (3)	Carrot (both)
		9/22/2020		2	Kale
Crop tissue (32/32)	Sammamish River	9/8/2020	9/14/2021	4	Carrot
		9/8/2020	9/14/2021	4	Kale
	Recycled water	9/8/2020	9/14/2021	4	Carrot
		9/8/2020	9/14/2021	4	Kale
	Sammamish River	9/22/2020	9/27/2021	4	Carrot
		9/22/2020	9/27/2021	4	Kale
	Recycled water	9/22/2020	9/27/2021	4	Carrot
		9/22/2020	9/27/2021	4	Kale
Crop Yield (16/16)	Sammamish River	9/22/2020	9/27/2021	4	Carrot
		9/22/2020	9/27/2021	4	Kale
	Recycled Water	9/22/2020	9/27/2021	4	Carrot
		9/22/2020	9/27/2021	4	Kale

Results and Analysis

Overview

Individually, 54 separate samples (12 water, 10 soil, and 32 crop tissue) were analyzed for CECs in year 1 (2020) and 62 separate samples (18 water, 12 soil, and 32 crop tissue) were analyzed in year 2 (2021) of the study. In total, 185 to 201 CEC parameters were analyzed. Each year varied slightly as analytical capabilities evolved. To facilitate communication of these results, research partners developed outreach materials that can be seen in Appendix D.

Quality Assurance and Quality Control

The study design included triplicate or quadruple analysis of most matrices. In addition to this, laboratory triplicates, blanks, and spikes were analyzed as part of the SGS-Axys' methods. Consistent with standard practice, SGS-AXYS reported, but did not correct or adjust CEC concentrations for detections in blanks. In general, their laboratory spikes met their internal performance criteria for all sample batches, although some samples had low recoveries and, consequently, are less reliable. Their detections of low concentrations in blanks also is typical because many of these CECs are ingredients in widely used consumer products, plastics, and even air, reflecting the challenge of completely avoiding trace contamination during sample collection, processing, and analysis.

This report focuses its discussion and detailed analysis on CECs with concentrations that were

- at least 3 times above their respective batch blank detection (see Table 2),
- clearly above the reported method limits of detection, and
- consistently detected in multiple replicates (>1) and sample events.

Across both years and all sample types, many CECs were not detected across all replicate or triplicate samples. Therefore, this report prioritizes its discussion of those CECs that were both consistently detected across replicate samples and with observed concentrations clearly above blank concentrations. Researchers defined "clearly above" as those CECs whose concentrations exceeded 3-fold higher concentrations than their blank detections (if any). This was based on numerous observations of widely different reported concentrations of CECs within the data, either due to lack of detection confirmation in replicates or blank detections with concentrations near limits of detection.

For example, in some cases there were blank or background detections and some associated samples reported concentrations that were very close to that concentration (i.e., quite similar to potential background levels). Alternatively, other CEC concentrations were an order of magnitude higher than blank concentrations or limits of detection and more clearly represented a confident detection of that CEC in the system—that is, one highly unlikely to arise from lab/air/dust etc. contamination, matrix effects, or variation in analytical method performance. Such criteria were applied for parameters that reflect the exclusion of a small subset of CEC data from the data discussion (see Table 2).

Table 2. CECs and sample numbers in 2020 and 2021 that were impacted by trace detections at "background" concentrations that did not meet the 3-fold higher than blanks screening criteria.

Year	Parameter	Matrix	Number of Affected Samples
2020	6:2 FTS	Plant Tissue	1
2020	Bisphenol A	River Water	3
2020	DEET	River Water	1
2020	DEET	Soil	10
2020	DEET	Plant Tissue	32
2020	Enrofloxacin	Plant Tissue	16
2020	Iopamidol	Soil	8
2020	Metformin	River Water	3
2021	Bisphenol A	Plant Tissue	5
2021	Bisphenol A	Soil	2
2021	Clinafloxin	Plant Tissue	7
2021	DEET	River Water	7
2021	DEET	Soil	7
2021	Flumequine	Soil	2
2021	Metformin	River Water	3
2021	Metformin	Reuse water	3
2021	Penicillin V	Plant tissue	11

CECs in Recycled Water and Sammamish River Water Irrigation Sources

Of the 185 CEC analytes of 2020, 25 were detected in Sammamish River water across the summer (July 21) and harvest (September 22) sample dates (see Figure 4). These 25 detections were mostly PFAS (10 compounds detected of the 40 total possible PFAS parameters analyzed), with the remainder including antibiotics (4), herbicides (glyphosate and AMPA), illicit drugs (amphetamine and cocaine), plasticizers (BPA and BPF) and various other pharmaceuticals and personal care products. Most of these CEC detections were at low concentrations (less than 10 ng/L). Only bisphenol A exceeded 100 ng/L and only glyphosate and its metabolite AMPA exceeded 10 ng/L.

For 2021, 16 additional CECs were added to the analytical method. Sammamish River detected compounds and concentrations were broadly similar to 2020 results (see Figures 4 and 5, Figures A1 and A2 in Appendix B). Both glyphosate and AMPA were again sporadically detected at concentrations up to 60 ng/L. The PFAS compound 6:2 FTS had one relatively high detection at 38 ng/L in a single sample, but this detection was not confirmed across the two replicates. Bisphenol A (and BPS and BPF) were again commonly detected up to 30 ng/L. Researchers detected very low levels of 11 different PFAS compounds (6:2 FTS and 10 others) in nearly all samples, though often near method limits of detection. Lastly, in 2021, the pharmaceuticals topiramate (an anti-convulsant medication) and theophyilline (an asthma

medication) were often present at <5 ng/L. Unlike 2020, etoposide was not detected in any 2021 Sammamish River or recycled water samples. Other CEC concentrations and compositions were generally similar to 2020 results (see Appendix C for complete CEC detection data).

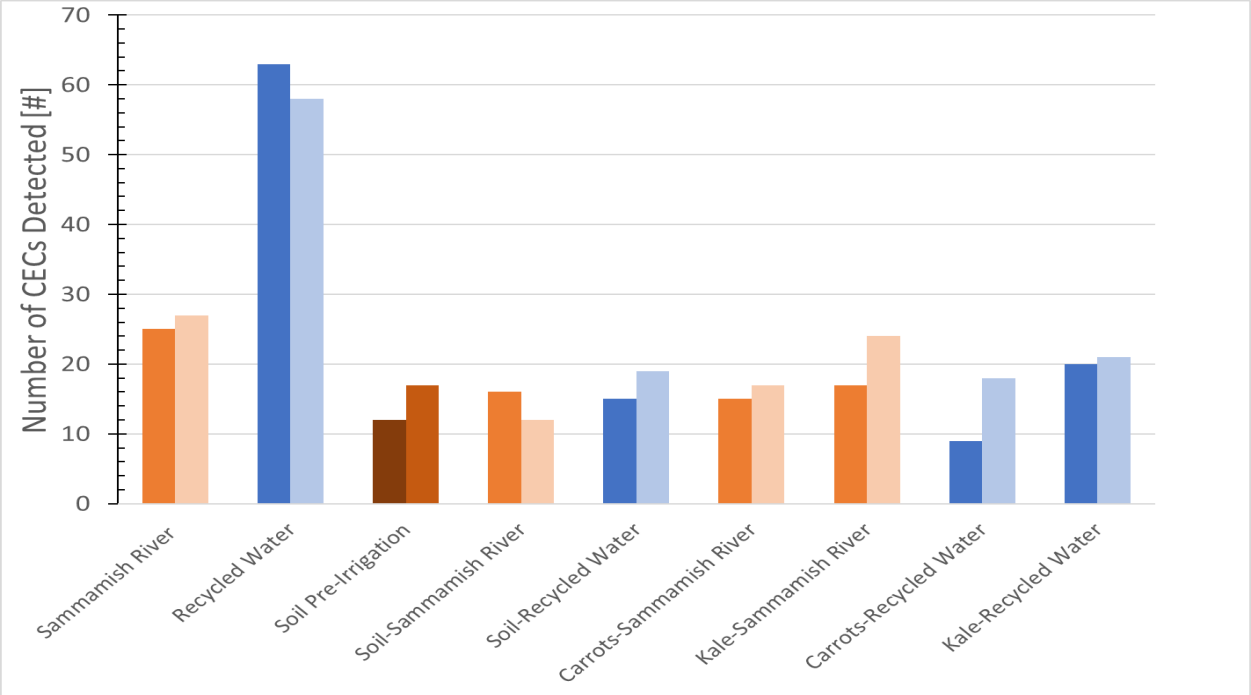

Figure 4. Number of individual CEC detections in collected samples. Bars on the left reflect 2020 samples and the lighter right bars reflect 2021 samples; brown/orange colors reflect the Sammamish River and blue colors reflect recycled water.

These samples indicated the presence of a number of CECs, including industrial and agricultural chemicals, in Sammamish River water used for summer irrigation of edible crops. Given the substantial human population within the Sammamish River watershed, the detection of multiple CECs typical of human activities and chemical discharges was expected and is consistent with decades of similar reports across the United States. The composition of the detected CECs also is consistent with multiple chemical sources, which, together, contribute various types and concentrations of CECs to the Sammamish River and is typical of human CEC impacts to surface waters where many people live, work, or recreate. None of the observed CEC detections or their concentrations would be considered unexpected or atypical.

In recycled water, 63 CECs were detected (122 not detected) across the same sample events in 2020 (Figure 4). PFAS (12 compounds detected) and antibiotics (12 detected) were the most abundant CECs. The remaining detections included herbicides (glyphosate and AMPA), illicit drugs (amphetamine and cocaine), plasticizers (BPA and BPF), and various other pharmaceuticals and personal care products. Among the detected pharmaceutical CECs, antibiotics, blood pressure medications, anti-diabetics, and anti-depressant compounds were the most commonly detected classes. Most of these CECs were less than 10 ng/L, and often near analytical method detection limits. A few CECs like caffeine, metformin, valsartan,

meprobomate, hydrochlorothiazide, carbamazepine, metoprolol, and theophylline were sometimes at concentrations exceeding 100 ng/L in some recycled water samples. Iopamidol, an X-ray contrast agent that does not degrade, was by far the most abundant CEC observed (concentrations of 1,000 to 12,000 ng/L) in recycled water (see Appendix C for complete CEC detection data).

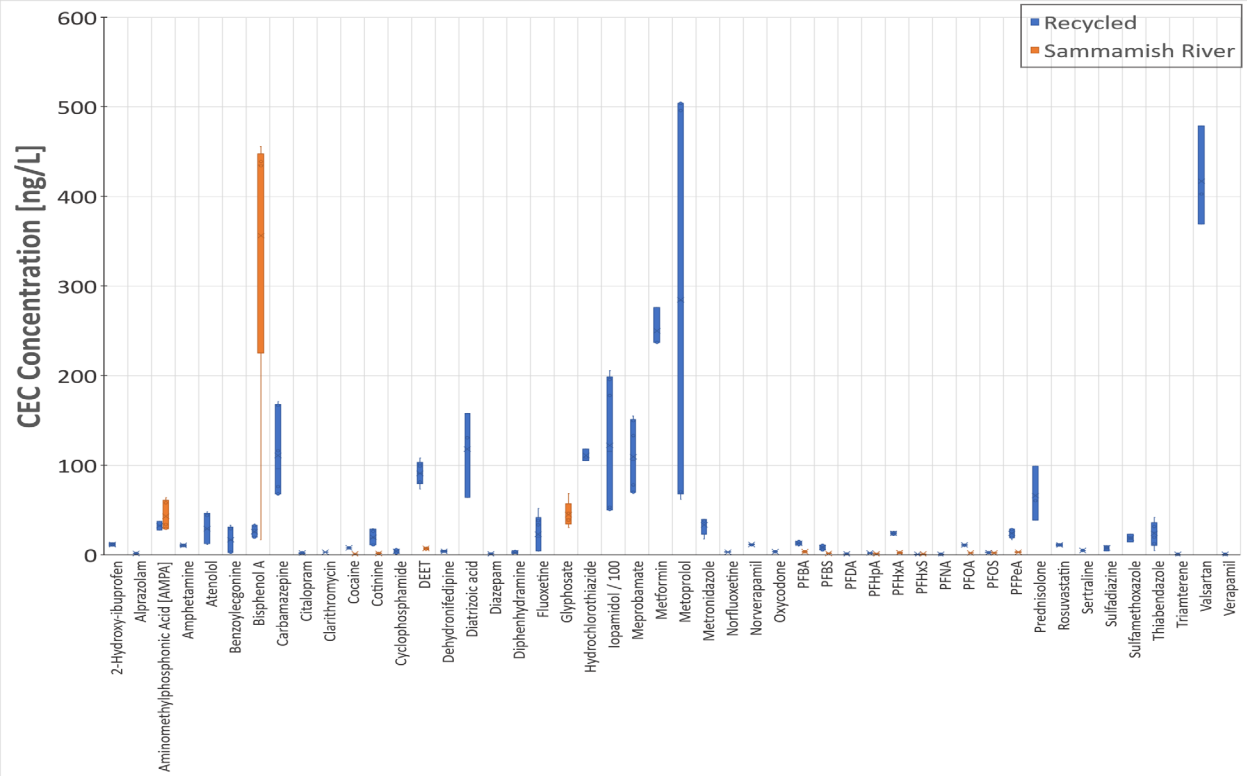

Figure 5. Example concentrations of CECs present in either recycled water or Sammamish River water used for irrigation in 2020. CECs reported here represent detections that were more than 2-fold above method limits of detection and were detected in at least 2 replicate samples.

In recycled water, 63 CECs were detected (143 not detected) across the 2021 samples (see Figure A3 in Appendix B). Many of the same CECs were detected in 2021 as for 2020, but a few differences are noted. Iopamidol was somewhat lower (up to 8,700 ng/L), but diatrizoic acid, another iodinated X-ray contrast chemical that is hard to degrade, was up to 1,800 ng/L, which was substantially higher than 2020 concentrations. Topiramate and lamotrigine, both new anticonvulsant analytes in 2021, were present at concentrations up to 750 and 150 ng/L, respectively. Metformin, metaprolol, theophylline, and valsartan, all at >100 ng/L in 2020 recycled water, were all detected at much lower (7 to 44 ng/L) concentrations in 2021. Etoposide was not detected. PFAS concentrations were similar across the 2 years, with only minor differences near limits of detection. The observed variability in recycled water may arise from several factors and would require additional sampling and studies to fully evaluate. We do not know the significance any of these possible trends in concentration or over time.

The Brightwater CEC detections were similar to those within effluents from other advanced/tertiary wastewater treatment processes (Grandclement et al., 2017; Oulton et al., 2010). All recycled waters

contain CECs because many thousands of chemicals are present in municipal wastewaters, and no existing wastewater treatment process removes them all (Oulton et al., 2017). Although concentrations of many CECs are greatly reduced or completely eliminated during wastewater treatment, some CECs are recalcitrant and survive treatment processes. With limited or no removal during treatment, these CECs then persist in recycled water. These hard-to-degrade characteristics (for iopamidol, diatrizoic acid, carbamazepine, and others) also imply that they survive many environmental degradation processes.

Wastewater treatment plants use many of the same oxidation, reduction, and mineralization pathways that occur in the natural environment. Chemicals and pharmaceuticals recalcitrant to these processes have increased potential for occurrence and transport through various environmental systems. Most of these compounds are relatively water soluble and can be passively taken up into plants as the roots absorb water from the soil and move the water throughout the plant. Additionally, modern analytical instruments are very sensitive and easily capable of detecting and reporting the trace concentrations present in recycled water and related systems.

In relative terms, Brightwater recycled water is among the higher quality of similar recycled waters. It contains fewer numbers of CECs and many of these detected CECs were in the lower range of values compared to similar recycled waters.[2, 3] Our results indicate that while Brightwater recycled water contains many CECs (as expected), the recycled water from Brightwater is of quite high quality, with no obvious unexpected or atypical CEC compositions.

CECs in Agricultural Soils

In 2020 soil samples, 12 CECs were detected in the agricultural soil prior to any irrigation (see Figures 4 and 6). Concentrations were highest for bisphenol A (up to ~8 ng/g) and caffeine (up to ~43 ng/g) in the soils prior to any irrigation. Single detections (e.g., not repeated in replicates) of prednisolone, metformin, and erythromycin were also reported, with the remaining CEC detections often at low (<1 ng/g, and often near method limits of detection or quantification) concentrations. Across the CEC chemical classes, six of the 12 detections in the pre-irrigation soil were for various PFAS, with all their concentrations below 1 ng/g (see Appendix C). The pre-irrigation detections are a reflection of the ubiquity of CECs in human impacted environments, including in urban air and rainfall.

Sixteen CECs were subsequently detected in soil irrigated with Sammamish River water across the summer of 2020 (see Figure A5 in Appendix B). Researchers collected two replicates during crop harvest on September 22 that reflect ~2 months of irrigation. Researchers collected eight composite sample aliquots using a prewashed, 20-mm-diameter stainless steel soil coring tube. These were mixed in a stainless steel bowl compositing within individual planter boxes from two different carrot and kale planter boxes, yielding four soil replicates total.

CEC detections included six different PFAS, with the remainder including various other antibiotics (2), plasticizers (bisphenol A), X-ray contrast media (iopamidol), pharmaceuticals (e.g. metformin), and personal care products. Most of these CEC detections were less than 5 ng/g (dry weight [dw]), and often

below 1 ng/g for PFAS. Of note, one of the Sammamish River irrigated soil samples contained several pharmaceutical CECs at relatively high reported concentrations, especially for daunorubicin (32 ng/g) and doxorubicin (49 ng/g). Both are chemotherapy drugs. These compounds were not detected in the identical replicate sample and in any 2021 samples, and the method detection limits were relatively high for these compounds. Therefore, this particular sample is probably an analytical or laboratory artifact and researchers had low confidence in its relevance. Other sporadic "single detection" CECs, especially when the reported concentration is unexpectedly high and no replicate detections are reported, also are likely false positives or method artifacts.

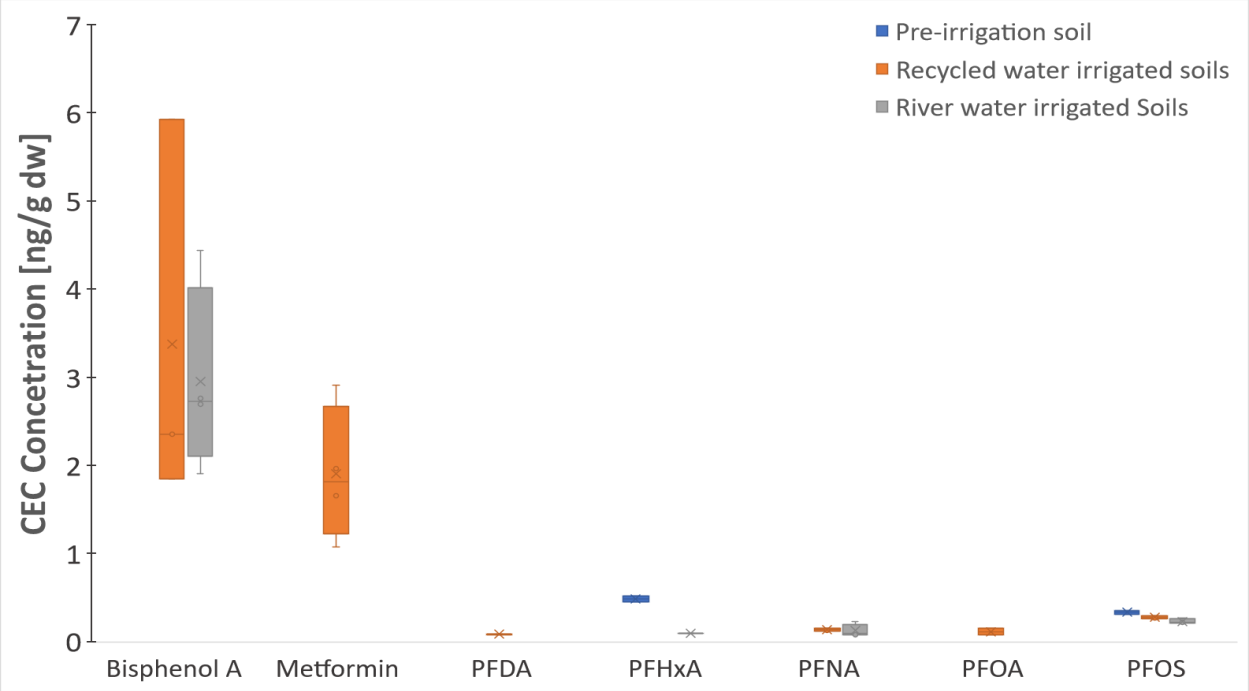

Figure 6. Concentrations of CECs present in agricultural soil both pre- and post-irrigation in 2020. CECs reported here represent detections that were more than 2-fold above method limits of detection, and were detected in at least 2 replicate samples.

In 2020, researchers detected 15 CECs in soils irrigated with recycled water, including seven PFAS, four antibiotics, and iopamidol, bisphenol A, metformin, amphetamine, and cotinine (see Figure A5 in Appendix B). Excluding the PFAS, bisphenol A and metformin were the most consistently detected CECs in the irrigated soils. Other CECs were only sporadically detected. Most soil CEC detections were at trace concentrations (<5 ng/g, and often below 1 ng/g as for the PFAS). Only metformin was consistently higher (2.9 ng/g) in recycled water irrigated soil relative to the Sammamish River irrigated soils (0.63 ng/g) and only in 2020. As for the Sammamish River water irrigated soil, iopamidol was present in both irrigated soils (see Figure A5 in Appendix B).

Researchers repeated the soil sampling in 2021, including triplicate samples of each soil prior to irrigation (July 19, 2021), and triplicates collected at harvest (September 27, 2021; see Figure A6 in Appendix B). The

pre-irrigation samples showed the presence of 13 CECs, with the highest concentration CEC as AMPA (a glyphosate metabolite), followed by BPA and DEET (~2 to 3 ng/g; note that DEET was not detected in 2020 soils). Eight PFAS compounds were detected in the pre-irrigation soil samples at concentrations similar to those observed in 2020. No obvious difference in CEC composition or concentration was evident between river and recycled water irrigated soils, or between 2020 and 2021 soils.

In Sammamish River irrigated soil (2021 data) after 2 months of summer irrigation, researchers detected 12 CECs, with almost the same CECs and concentrations as seen before irrigation. BPA and DEET were not present, low concentrations of PFAS compounds were present, and a few detections of other CECs occurred. Very similar data were evident for recycled water irrigated soil, with 20 CECs detected in 2021. However, these samples again had a number of detections that were not reported in replicate samples and had nearly the same CEC composition and concentrations as the pre-irrigation and Sammamish River irrigated soils. Among recycled water irrigated soil, the only consistently detected CEC that may have accumulated during 2021 irrigation was the anti-depressant drug citalopram (see Appendix C).

Both Sammamish River water and recycled water had negligible impacts on CEC concentrations in soils in both years. Despite >60 CECs in recycled water, far fewer CECs were detected in irrigated soils. Most soil CECs were neither abundant nor detected in either recycled water or Sammamish River water. The initial agricultural soil obtained from a commercial supplier contained six PFAS, bisphenol, metformin, and triclocarban prior to irrigation. Some of the highest concentrations for specific CECs were detected before any irrigation at all. This likely indicates the use of a municipal compost, air deposition, manure, or other human affected soil source or handling process.

In either year, researchers observed little increase in CEC soil concentrations even after the 2 months of irrigation with either water source, although both water sources contained many more CECs than were subsequently detected in the irrigated soils. Of all the CECs analyzed, only metformin, iopamidol, and citalopram showed any possible evidence of soil accumulation after irrigation in either 2020 or 2021 samples. Despite its high concentrations and frequent 2020 detections in irrigated soils, iopamidol was not detected in any 2021 soil samples. Therefore, for almost all CECs, the study data indicate limited potential for accumulation over these timescales. For many CECs, researchers observed substantial degradation over even these relatively short summer irrigation periods.

CECs in Edible Plant Tissues

Study partners chose carrots as the representative root crop to evaluate. Researchers sampled both crops just prior to harvest (September 8) and during harvest approximately 2 weeks later (September 22). Therefore, CEC concentrations in these plant tissues reflect just over 2 months of irrigation (July to September). Of the 183 CEC analytes, only 15 were detected in carrots irrigated with Sammamish River water in 2020 (see Figure 7 for high confidence results and Figure A7 in Appendix B for complete results). In the Sammamish River carrots, the 15 detected CECs included PFBA; the remaining CECs included seven antibiotics and pharmaceuticals (e.g., metformin, paroxetine). Notably, nine of these 15 detections were unique to a single sample of pre-harvest carrot, including most of the antibiotic detections. No other carrot

replicate showed any similar detections or these particular CECs (e.g., amscrine, clotrimazole, daunorubicin, moxifloxacin, norverapamil, paroxetine, verapamil). That specific sample composition is a distinct outlier or artifact relative to all of the other samples analyzed in this study (see Figure A7 in Appendix B). Both the specific compounds detected and their reported concentrations were atypical for all other 2020 and 2021 CEC data and this detection is a likely artifact.

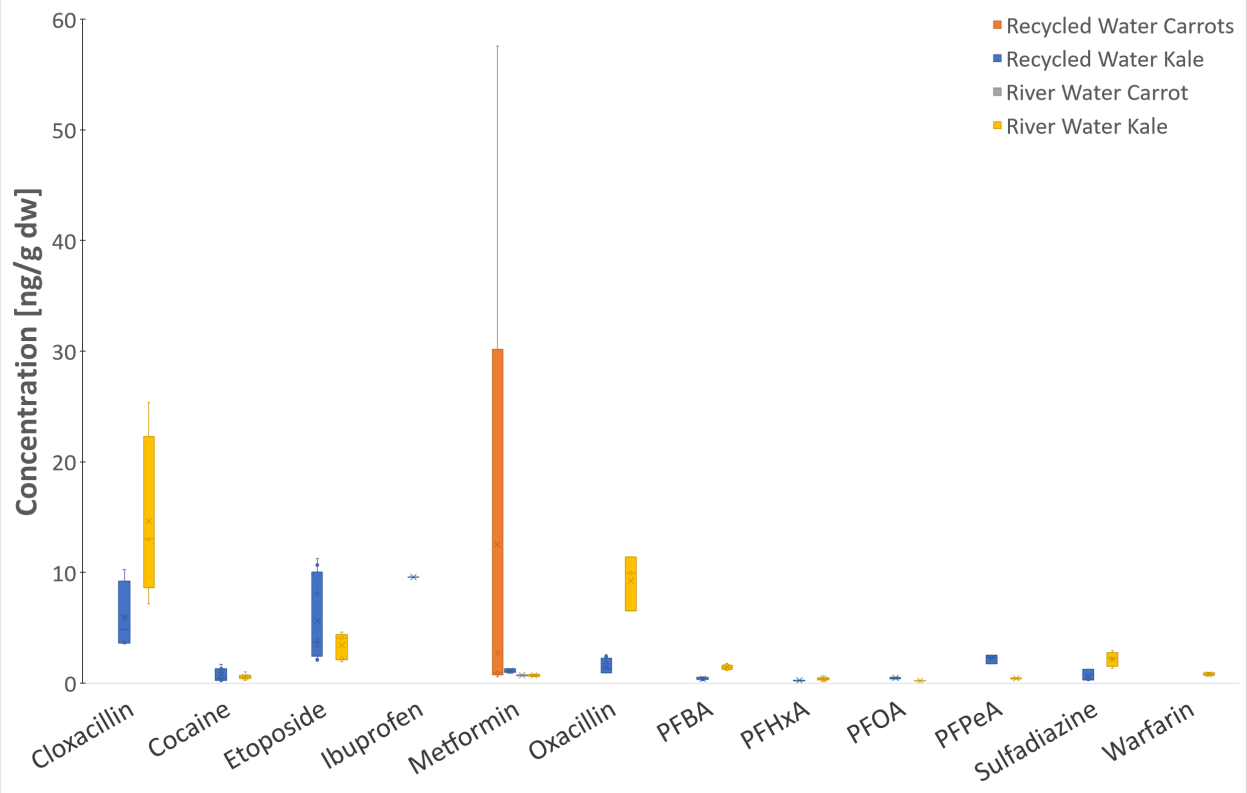

Figure 7. Concentrations of CECs in edible crop tissues irrigated with either recycled water or Sammamish River water in 2020. CECs reported here represent detections that were more than 2-fold above method limits of detection and were detected in at least 2 replicate samples.

Three tetracycline antibiotics, anhydrotetracycline, anhydrochlortetracycline, and tetracycline, were detected in two carrot samples across the two sampling dates, but replicates did not confirm these detections and researchers observed no similar tetracycline detections in kale. If accurate, this indicates some potential for tetracycline antibiotics to occur or accumulate in carrot. Excluding those potential outlier samples, only six other CECs were detected in the carrot tissue. Most of these CEC detections were at trace concentrations (less than 5 ng/g dw, and often below 1 ng/g as for the PFAS). The higher detections (>5 ng/g dw) were anhydrochlortetracycline (~9 ng/g), anhydrotetracycline (~6 ng/g), clinafloxacin (~7 ng/g), and the anti-depressant paroxetine (5 ng/g).

In 2020, nine CECs were detected in edible tissues from carrots (root crop) irrigated with recycled water. These nine detections included PFBA and PFOA, both PFAS compounds, with the remainder including three antibiotics, pharmaceuticals (e.g. metformin, paroxetine, diphenhydramine), and the herbicide glyphosate (see Figure A7 in Appendix B). As typical for these data, most of these CEC detections were at trace concentrations (<5 ng/g dw, and often <1 ng/g for the PFAS), often at levels near the method detection limits. The notable exception was a single detection of metformin present at ~58 ng/g in one carrot tissue sample. While metformin was consistently present, this especially high concentration also is likely an analytical overestimate. Almost all other metformin detections in carrot tissues were 1 ng/g or less, including the consistent detections of metformin in carrot tissues irrigated with Sammamish River water. Its concentration is also inconsistent with 2021 detections of metformin in both carrots and kale.

The study's 16 CEC detections in 2021 in Sammamish River irrigated carrots were broadly similar to 2020. However, no tetracycline antibiotics, chemotherapy agents (etoposide, duanorubicin, etc.), or warfarin were detected in any 2021 carrot or kale (see Figure A8 in Appendix B). Sammamish River irrigated carrot CECs included hydroxy-ibuprofen, BPA, DEET, metformin, the antidepressant amitriptyline/hydroxy-amitriptyline; the antibiotics clinafloxacin and triclocarban; and six PFAS compounds. Researchers detected 18 CECs in 2021 recycled water irrigated carrots, also mostly similar in composition and concentration to those observed in river water irrigated carrots. Amitriptyline seemed to be slightly higher in recycled water carrots (2 to 3 ng/g versus 1 to 2 ng/g in Sammamish River irrigated) and gemfibrozil, ibuprofen, and cloxacillin were only present in the recycled water carrots. Interestingly, only 6:2 FTS and PFBA (PFAS compounds) were detected in recycled water carrots, compared to the six PFAS detected in the Sammamish River irrigated carrot.

Study partners selected kale as a representative leafy green to evaluate, in part because it is commonly grown in the Sammamish River valley. Kale grows rapidly and requires a significant amount of water. CECs can readily move with this water into kale's leaves. Kale and other leafy greens are thus considered to represent the highest real world agricultural crop exposure scenario (Christou et al., 2019). Few other food crops so easily move (i.e., "translocate") irrigation water CECs through roots and stems and into edible crop tissues. Therefore, kale is considered to represent a "worst case" scenario for CEC accumulation in edible crops (Christou et al., 2019).

In 2020, researchers detected 17 CECs in edible kale leaves irrigated with Sammamish River water (see Figure A9 in Appendix B). These 17 detections included four PFAS, with the remainder including six antibiotics, the illegal drug cocaine, the personal care product DEET, and pharmaceuticals such as metformin, verapamil, and warfarin. All of these CEC detections in Sammamish River irrigated kale were less than 5 ng/g dw, and often below 1 ng/g. The highest PFAS concentration was PFBA at 1.8 ng/g.

In Sammamish River irrigated kale, the chemotherapy drug etoposide was the highest reported concentration, up to ~4.6 ng/g. This detection was surprising because etoposide was not detected in the Sammamish River irrigation water itself during either sampling event. However, two other chemotherapy drugs, daunorubicin (32 ng/g) and doxorubicin (49 ng/g), were detected in a Sammamish River irrigated soil sample. This could suggest a source of chemotherapy drugs somewhere in the Sammamish River

watershed. Chemotherapy drugs were detected in only a few samples, not always in replicate samples, and at low concentrations. Notably, researchers did not detect any of these chemotherapy drugs in any 2021 samples. Given these characteristics, their occurrence in river water and potential accumulation into kale should be interpreted with caution. Researchers suspect they are false positives, or potentially do not represent typical river water quality in this system.

In 2021, researchers detected 24 CECs in Sammamish River irrigated kale. They were broadly similar to 2020 samples, including BPA, DEET, metformin, and four PFAS compounds. Cocaine, etoposide, and warfarin were not detected in any 2021 kale samples (see Figure A10 in Appendix B). New CECs reported in Sammamish River irrigated kale included the antidepressant amitriptyline, the heartburn medication cimetidine, the high blood pressure drug furosemide, the asthma drug theophylline, and six antibiotics. The PFAS compound 6:2 FTS was more commonly detected in 2021 versus 2020 (only one detection). Concentrations of PFAS were consistently present, but low in both years across almost all sample types. Cimetidine was consistently present at the highest concentration (17 ng/g); 3 to 7 ng/g furosemide was also consistently detected. Other CECs tended to be 5 ng/g or less.

In 2020, researchers detected 20 CECs in recycled water irrigated kale. These 20 detections included five PFAS, six antibiotics, cocaine, the personal care product DEET, BPA, and pharmaceuticals such as metformin, ibuprofen, and warfarin. Most of these CEC detections were less than 5 ng/g, and the PFAS were often below 1 ng/g. The higher concentration detections in recycled water irrigated kale included bisphenol A (up to ~13 ng/g), ibuprofen (up to ~9.6 ng/g), clinafloxacin (up to ~5.5 ng/g), and oxacillin at up to ~5.2 ng/g. The highest PFAS concentration was PFBA at ~1.8 ng/g. Matching the detections in kale irrigated with Sammamish River water, researchers detected the anticancer drug etoposide at concentrations up to ~11 ng/g in the recycled water irrigated kale (see CEC detections data in Appendix C).

Researchers detected 21 CECs in recycled water irrigated kale in 2021, mostly similar in composition (BPA, DEET, ibuprofen, seven antibiotics, four PFAS compounds) and concentration (<1-5 ng/g) to other carrot or kale samples (see Figure A10 in Appendix B). Like 2021 carrot, amitriptyline was present, but slightly lower in recycled water kale (~1 ng/g) versus carrot (1-3 ng/g). Topiramate was only present (0.7 to 1.5 ng/g) in recycled water irrigated kale, but theophylline was present (2 to 5 ng/g) in kale irrigated with both water types. Like the Sammamish River irrigated kale, cimetidine was again the highest concentration (20.1 ng/g) CEC that was consistently present; no other CEC consistently detected exceeded 6 ng/g. For PFAS compounds, 6:2 FTS and PFPeA were present in recycled water kale at slightly higher concentrations relative to Sammamish River kale, but the PFBA and PFHxA detections were similar for both water sources and all <0.9 ng/g.

Many of the CEC detections in both carrot and kale (and also many detections in the soils and waters) were quite low and near method detection limits. Analytical uncertainties and estimated concentration variability are inherently higher near limits of detection. Many CEC detections were sporadic, present in only a single sample and with identical replicate samples non-detect. As discussed earlier, such detections and those within a factor of 2 to 3 of method detection limits indicate a relatively low precision and accuracy for the CEC occurrence data. For example, across all samples and replicates, there were 187

individual CEC detections in either carrots or kale during 2020. However, only 77 of these detections occurred at concentrations more than 3-fold above method limits of detection.

When we compared CEC occurrence in samples across replicates, only 22 detections would subsequently be considered "high confidence" (i.e., likely to be real detections and accurate concentrations) in edible tissues that represent a confident human exposure pathway. As mentioned previously, the study defined "high confidence" as those CECs present at levels more than 3-fold above method detection limits and detected in at least two replicate samples. The study analysis and discussion primarily focused on these more consistent and higher confidence detections because of their lower analytical uncertainty.

Implications for CEC Detections in Water and Food Crops

These data, collected across 2 years of sampling and irrigation, reveal both human- and veterinary-derived CECs in water, soil, and edible crop tissue samples. Many individual CECs were detected, but many were also low, sporadic, or very close to method detection limits. Researchers' confidence in them is inherently lower relative to BPA, DEET, iopamidol, ibuprofen, metformin, antibiotics, some PFAS, and others that showed consistent detections across time and sample type. For compounds demonstrating sporadic or especially low detections, we recommend a cautious interpretation because many are potentially false positives or reflect quantitative errors arising from inherent analytical uncertainty near limits of detection.

A few to several dozens of CECs (10% to 30% of the total numbers of CECs the study analyzed for) were present in either the Sammamish River or recycled water. Most CEC detections in these irrigation waters were compounds generally expected to be present and at expected concentrations (Luo et al., 2014). Brightwater recycled water quality, as defined both by composition and concentrations, was among the higher quality examples of Class A recycled waters. For example, metformin (a diabetes medication) and carbamazepine (an anti-convulsant) are widely used pharmaceutical CECs that often occur in recycled waters, including Brightwater recycled water (Zhang et al., 2008). Metformin was present at concentrations of up to 280 ng/L and carbamazepine at concentrations up to 170 ng/L, although most detections were lower. In recycled waters elsewhere, these compounds are frequently reported at 500 to 1,000 ng/L, even in highly treated recycled waters (Trinh et al., 2012; Zhang et al., 2008).

Researchers consistently detected iopamidol in recycled water at high concentrations (1,430 to 8,670 ng/L). Similar to diatrizoic acid (also detected at up to 1,800 ng/L in this recycled water), iopamidol is an iodinated X-ray contrast media that does not degrade in people or during wastewater treatment. Its concentrations in recycled water are very high because iopamidol doses can be 2,000 to 20,000 mg/day for the relatively few people receiving medical imaging on any given day. Iopamidol and diatrizoic acid are both nearly inert and rapidly excreted in patients receiving large therapeutic doses that are millions of times higher than recycled water concentrations. Other CECs that sometimes exceeded 100 ng/L in recycled water tended to be antibiotics, caffeine, DEET, topiramate, lamotrigine, theophylline, and valsartan, a common blood pressure medication. None of these have any special exposure concerns and were thousands to millions of times lower than therapeutic doses.

Few of these CECs, even at the higher concentration ones in recycled water, were observed to consistently accumulate in soils to any significant degree after these summer irrigation applications. While the study period was relatively short, no evidence of substantial CEC accumulation in soils was observed in these data. Longer term studies would be needed to fully evaluate these possibilities.

Carrot and kale sampling detected ~15 to 25 CECs in edible crops irrigated with either Sammamish River or recycled water. This subset of CECs detected in the plants have a set of specific chemical characteristics that enables them to move through the soil without degrading, pass into plant roots, and then transport to different parts of these plants. In carrot and kale, detection numbers and concentrations were similar across both water types for most co-detected CECs (see Appendix C). Although present, most CECs were detected at low concentrations in food crops (and soil) without evidence of bioaccumulation over this time period. The low crop CEC concentrations likely reflect the relatively high quality of these irrigation water sources that were not contributing very many, or very high concentrations of, CECs to these types of rapidly growing crops over the short irrigation seasons.

Researchers detected 15 high-confidence CECs in either carrot or kale across 2020 to 2021 sampling. These were DEET, 4 PFAS (6:2 FTS, PFBA, PFPeA, and PFHxA), three antibiotics (cloxacillin, oxacillin, and sulfadiazine); the pharmaceuticals amitriptyline, cimetidine, etoposide, metformin, topiramate, and warfarin; and the illegal drug cocaine. Year 2020 versus year 2021 results, and sometimes across specific sample dates as well, were often distinctly different in terms of observed CEC compositions or concentrations within the plants.

For example, metformin was detected in both carrots and kale irrigated with recycled water in 2020, but not in 2021 when metformin concentrations were considerably lower and less consistent in both the Sammamish River and recycled water (see Figures A7 to A10 in Appendix B; Appendix C). Researchers detected etoposide in multiple sample types in 2020, but not at all in 2021. Amitriptyline, 6:2 FTS, bisphenol A, and DEET were all more commonly detected, or present at higher concentrations, in both river and recycled water irrigated carrots and kale in 2021 than in 2020. These data indicate that we should expect somewhat variable CEC compositions in these waters over time as human activities and hydrologic/environmental conditions change.

In addition to the common CEC detections in carrot and kale, there were detected CECs unique to one crop. This indicates that both the crop and tissue type influence CEC uptake. For example, more high-confidence CEC detections occurred in kale. In 2020 kale, metformin was only present for recycled water irrigation, oxacillin and warfarin only present for Sammamish River irrigation, and the remaining six high-confidence CECs of 2020 were present in kale irrigated with both waters. Several detected antibiotics (cloxacillin, oxacillin, sulfadiazine) had consistent detections in late September kale samples from both Sammamish River and recycled water irrigation (see Figures A9 and A10 in Appendix B). However, these antibiotics were not present in early September sampling, but when detected, concentrations were above limits of detection and replicate samples agreed.

In 2021, cloxacillin was not detected in any kale samples, but was present in one set of carrot samples irrigated with recycled water. In 2021 kale, cimetidine was only detected in kale, but for both irrigation sources; similarly, furosemide was only detected on one date in kale irrigated with Sammamish River water and topiramate was detected only in 2021 kale irrigated with recycled water (see Appendix C). Beyond the typical analytical uncertainties, these observations indicate that multiple seasonal, system, or environmental factors govern edible crop CEC occurrence.

Many of our monitored CECs are regulated by the U.S. Food and Drug Administration as pharmaceuticals when prescribed, but are unregulated in the environment. Their ongoing unregulated status reflects the current absence of any clear data indicating a definitive risk to humans through food crop exposures (or drinking water) that requires management. This is, in part, because potential human exposures are far below pharmacological doses. Human exposures to antibiotics like cloxacillin, oxacillin, and sulfadiazine in drinking water or food pathways occurs at doses far below pharmacologically relevant exposures (see Table 3).

For example, typical doses for these antibiotics range from 250 to 2,000 mg/day (visit www.drugs.com for more information on dosages). Concentrations of antibiotics in recycled water are generally 1 to 100 ng/L and up to 13.1 ng/g in edible crops, which is over a million times lower. To receive a single pharmaceutical dose of these detected antibiotics, a person would need to eat more than 41,000 lb of produce in a day or drink more than 1,600,000 gallons of this water (noting that neither Sammamish River nor recycled water is directly used for drinking water). Such consumption rates emphasize why human exposures to low concentrations of bioactive CECs in the environment have not merited regulatory attention. These comparisons also provide context for environmental detections of CECs and highlight exactly how small nanograms per liter or nanograms per gram concentrations are in comparison with CEC doses that are known to be biologically relevant to human health. Table 3 illustrates several such comparisons for detected “high confidence” CECs.

Several CECs repeatedly detected in carrot and kale tissue were not detected in either corresponding irrigation water (Table 3). These CECs included amitriptyline, cimetidine, etoposide, fureosemide, and warfarin. The most likely explanation for these detections is some level of CEC accumulation in edible crop tissues occurring over time. Presumably, the concentrations of these specific CECs in the irrigation waters were below analytical detection thresholds, yet over time, the small masses of these CECs transported into the plants, with the irrigation water accumulated enough to be analytically detectable. These types of observations are reasonable if the crops are accumulating low levels of these compounds in their tissues without breaking them down over the 2- to 3-month growing season, although more data would be needed to confirm whether this is what is happening.

Table 3. Comparison of high-confidence pharmaceutical CEC detections with pharmacologically relevant doses in humans.

Compound	Common Use	Maximum Concentration in Water (ng/L)	Maximum Concentration in Edible Crops (ng/g)	Typical Pharmaceutical Dose (mg/d)	Quantity of Produce Representing One Pharmaceutical Dose (lb)
Various antibiotics	Antibiotic	40 *(RW)*	13.1 *(K, SR)*	250-2000	>41,000
Amitriptyline	Anti-depressant	Not detected	3.5 *(C, RW)*	40-300	>25,000
Cimetidine	Heartburn/ulcers	Not detected	20.1 *(K, RW)*	300-1600	>32,000
Cocaine	Recreational	8.1 *(RW)*	1.7 *(K, RW)*	10-100	>12,000
Etoposide	Chemotherapy	Not detected	11.3 *(K, RW)*	50-300	>9,700
Furosemide	Diuretic/blood pressure	Not detected	7.3 *(K, SR)*	20-600	>6,000
Ibuprofen	Anti-inflammatory	4 *(RW)*	9.6 *(K,RW)*	100-1000	>22,000
Metformin	Diabetes	276 *(RW)*	58 *(once, C, RW)* 2.8 *(all others (C, RW)*	850-2000+	>32,000
Theophylline	Asthma	132 *(RW)*	4.8 *(K, RW)*	300-1600	>130,000
Topiramate	Anti-convulsant	745 *(RW)*	1.4 *(K, RW)*	25-400	>39,000
Warfarin	Anti-coagulant	Not detected	1.3 *(K, RW)*	1-10	>1,600

Notes: C = carrots, K = kale, RW = recycled water, SR = Sammamish River.
Parentheses exhibit sample type where detection occurred.
Dosage data obtained from www.drugs.com.

The etoposide detections in 2020 kale tissues were probably the most unexpected CEC detection in these samples (see Figure A10 in Appendix B). Etoposide, a chemotherapy drug used since 1983 for testicular and lung cancers, was detected in kale irrigated with both Sammamish River water and recycled water at relatively similar concentrations, which is a surprising observation that is difficult to explain well. Etoposide was confirmed in replicates across 2020 sampling, although concentrations were relatively low and based upon a small number of total samples. Although its concentrations are low in recycled water (<100 ng/L), etoposide has been detected elsewhere in hospital and wastewater effluents at concentrations up to 700 ng/L (Kosjek et al., 2016; Santana-Viera et al., 2019).

Etoposide was not detected in any 2021 samples of any type (water, soil, crop). It is possible that all the 2020 etoposide detections reflect a laboratory contamination event (like the single daunorubicin detection in 2020 carrot), especially because of the surprising detection of etoposide in the Sammamish River irrigated crops. Etoposide would be expected to pose higher than typical exposure hazards for a wastewater-derived CEC because chemotherapy drugs are very potent drugs that often have genotoxic,

mutagenic, or carcinogenic properties, although potential exposure concentrations via edible crops are far below pharmacological doses (Kosjek et al., 2016; Santana-Viera et al., 2019) (see Table 3). These etoposide detections, along with the PFAS data, were considered to require a more focused evaluation of human exposure and health risks given their potential toxicity characteristics.

Human Health Risk Assessment

A screening level human health risk assessment (HHRA; see Appendix A for the full Intertox report) was conducted to characterize potential exposures and hazards or risks to people exposed to "chemicals of interest" (COIs) through consumption of carrots or kale. Both children and adult exposures were evaluated. Twenty-eight CECs detected in carrots and kale were identified as COIs in the screening level HHRA. A chemical was identified as a COI if it was detected at a frequency of at least 25% in any of the four water–crop combinations (i.e., carrots irrigated with recycled water, carrots irrigated with Sammamish River water, kale irrigated with recycled water, or kale irrigated with Sammamish River water). Additionally, all PFAS detected at least once in either carrots or kale were considered COIs due to the high level of public interest in this chemical class.

Potential child and adult exposures were calculated using the maximum-detected concentration of each COI detected in the water–crop combination. Assumed consumption rates of carrots and kale were based on the upper bound (90th percentile) per capita average daily consumption rates of carrots and leafy vegetables consumed by U.S. populations for the corresponding age groups. Researchers assumed that people consume root crops, like carrots, and leafy greens, like kale, 350 days of the year, but only half of these days reflected locally grown crops.

To evaluate potential adverse health effects at these upper bound exposure level estimates, researchers used toxicity criteria from the following three sources: (1) published, peer-reviewed values; (2) derived using data from the toxicological literature; or (3) therapeutic doses (for pharmaceuticals). Using these values, upper bound estimates of noncancer hazard indices and cancer risks were calculated. As a general rule, hazard indices exceeding 1 and/or cancer risk factors exceeding 1 in 1,000,000 (or 1×10^{-6}) people are cause for concern that may merit more detailed exposure assessments and potentially risk mitigation measures or advisories. Cancer risks below 1 in 1,000,000 are typically characterized as de minimus by the U.S. Environmental Protection Agency (U.S. EPA) and we have maintained that threshold for this report.

Overall, the study's screening level HHRA showed that upper bound noncancer hazard indices exceeded 1.0 for only one chemical, PFOA, when hazard indices were calculated using the *draft* U.S. EPA reference dose (RfD) for PFOA of 0.0015 ng/kg-d. For the PFOA, the hazard indices ranged from 13 to 120 for both Sammamish River and recycled water irrigated crops. The Washington State Department of Health used an older, less conservative RfD when they derived the Washington State Action Level for PFOA in drinking water. Using this value of 3 ng/kg-d for PFOA, all of the hazard indices were well below 1.0.

Only one chemical and scenario exceeded a cancer risk of 1×10^{-6}: consumption of etoposide in kale irrigated with recycled water. For etoposide in recycled water irrigated kale, the lifetime excess cancer risk is 1.7 in a million (1.7×10^{-6}), which slightly exceeds the *de minimis* risk level. While this upper bound risk

estimate slightly exceeds the *de minimis* lifetime excess risk estimate, it is within the range of risks of 1×10^{-4} to 1×10^{-6} (1 in 10,000 to 1 in 1,000,000) considered to be allowable by U.S. EPA depending on specific situation and exposure characteristics. Further, considering that the average male has an approximately 1 in 2 chance (0.5000) of developing cancer at some point in his lifetime and a female has a slightly lower chance (1 in 3, or 0.3333) of the same, the upper bound LECR of a 1.7 in a million (0.0000017) for etoposide for this scenario is equal to a total lifetime cancer risk to an exposed man or woman of 0.5000017 or 0.3330017, respectively (see Appendix A for the full Intertox report).

Several PFAS compounds were nearly ubiquitous in these data. PFAS were detected in both irrigation water sources, in soil (including soil prior to irrigation), and, subsequently, in edible crop tissue irrigated with both water sources. Somewhat surprisingly, the water, soil, and edible crop tissues all contained relatively similar PFAS compositions at similar concentrations regardless of irrigation source. Although recycled water had higher concentrations of PFAS than Sammamish River water, PFAS levels in edible crop tissues irrigated with recycled water were not at distinctly higher levels than crops irrigated with Sammamish River water.

While some level of these compounds does seem to be present and accumulating in plants after irrigation, it is likely that the 2-month irrigation period was not long enough to increase concentrations in the plant to the point where Sammamish River and recycled water irrigation could be distinguished. It is also possible that aerial transport (e.g., wet and dry deposition of atmospheric particles and dusts) or other secondary sources contributed to some of the detected PFAS. This type of source/transport may be responsible for such similar compositions and concentrations across the different sample types and irrigation waters (Brown et al., 2020).

Among the detected CECs, these highly persistent and now-widespread PFAS (e.g. PFOA, PFOS) are the CECs whose reported concentrations were closest to levels of concern (Brown et al., 2020). The scientific and regulatory context around PFAS is rapidly evolving in light of the increasing recognition of their pervasive occurrence and observations of health risks to exposed human populations. However, in the United States, no regulatory standard for PFAS exposure in food crops yet to the best of study partners' knowledge, although diet is the major PFAS exposure pathway for most humans (Brown et al., 2020).

For example, human exposure to PFAS comes from food packaging, nonstick cookware, treated textiles, and household dust sources in addition to food and water. For most people, these types of exposures would tend to be much more significant exposure pathways relative to eating crops that contain trace levels of PFAS. Examples of these exposures were evaluated quantitatively in the HHRA (see Appendix B).

In carrot or kale, several PFAS were present, with concentrations up to 2.6 ng/g for PFBA (2020) and 6.1 ng/g for 6:2 FTS (2021). These were the highest PFAS concentrations detected in any carrot or kale samples. In 2020, PFOA was occasionally present (eight detections out of 32 total crop tissue samples) at concentrations up to 0.3 ng/g in both carrot and kale irrigated with either water. PFOA was present in both Sammamish River and recycled water irrigated crops and was present in the soil samples prior to irrigation. Thus, irrigation waters were not the only source of this compound (and other PFAS compounds) to these

samples. As environmentally widespread compounds, it is difficult to avoid exposure to similar concentrations of PFAS, either through food crops or other exposure pathways. The screening level HHRA evaluated risks to human health associated with these detections (see the full report in Appendix A for details).

Nutrient, Salts, and Carbon Additions in Water

To estimate total nutrient loading, water samples were collected at three distinct sampling periods throughout the irrigation season in both 2020 and 2021. Concentrations of nitrate-N, ammonium-N, P, and Na were much higher in recycled water than surface water (Table 4). Nitrate-N concentrations in recycled water ranged from 22.4 to 36.6 mg/L and averaged 29 mg/L in 2020. These nutrients ranged from 33.6 to 38.2 mg/L and averaged 36 mg/L in 2021 (see Figure A6 in Appendix B). Surface water nitrate-N concentrations ranged from 0.035 to 0.18 mg/L and averaged 0.11 mg/L in 2020. River nitrate-N ranged from 0.046 to 0.33 mg/L in 2021 (see Figure A11 in Appendix B). There was less N in the ammonia form than in the nitrate form in both recycled and surface water, although recycled water averages were an order of magnitude greater.

Orthophosphate averaged 4.1 mg/L in recycled water and 0.014 mg/L in surface water in 2020 and 5.5 and 0.017 mg/L in 2021, respectively (Table 4). Sodium concentrations averaged 87 mg/L in recycled water and 7.2 mg/L in surface water in 2020 and 69 mg/L in recycled water and 7.7 mg/L in surface water in 2021. Conductivity was 780 and 880 μmhos/cm in 2020 and 190 μmhos/cm in both 2020 and 2021 in recycled water and surface water, respectively. Organic carbon averaged 6.9 mg/L in recycled water and 4.0 mg/L in surface water in 2020 and 5.1 mg/L in recycled water and 3.5 mg/L in surface water in 2021.

Table 4. Average concentrations of nitrate-N, ammonia-N, orthophosphate-P, sodium, organic carbon, and conductivity in recycled water and surface water across 2020 and 2021 sampling dates.

	Concentration [mg/L]					
Year	Nitrate-N	Ammonia-N	Orthophosphate- P	Sodium	Organic Carbon	Conductivity [mmhos/cm]
Recycled Water						
2020	29.00	0.0470	4.100	87.0	6.9	780
2021	36.00	0.0310	5.500	69.0	5.1	870
Surface Water						
2020	0.11	0.0039	0.014	7.2	4.0	190
2021	0.22	0.0052	0.017	7.7	3.5	190

Researchers made an effort to match surface water and recycled water irrigation rates to the agronomic needs of each crop (Table 5). For example, kale was in the ground for a shorter period of time and received less of each water source than carrots. Total nutrient loading for each treatment and crop combination was estimated based on the total water application and the average nutrient concentration (Table 5). Campi et al. (2014) used recycled water with different levels of treatment to irrigate sorghum. The largest nitrate-N concentrations reported in their study were 2.42 mg/L following secondary treatment of municipal wastewater. This amount corresponded to 7.6 kg/ha of seasonal N application, which was more

than an order of magnitude less than the total N applied via recycled water in this study (156 kg/ha and 165 kg/ha to carrots in 2020 and 2021, respectively, and 121 kg/ha to kale in both 2020 and 2021).

Seasonal P from the same treatment was 24 kg/ha, which is close to what was observed in this study with recycled water (22.1 kg/ha and 25.3 kg/ha to carrots in 2020 and 2021, respectively and 17.1 kg/ha and 18.5 kg/ha to kale in 2020 and 2021, respectively). The Brightwater recycled water is a much more concentrated source of nutrients than many other sources, including other recycled waters—a valuable characteristic for use for crop irrigation.

Application of excessive sodium and salts is a potential concern with recycled water. In this study, cumulative sodium applications were more than 10 times greater with recycled water than surface water in 2020 and about 9 times greater in 2021. Conductivity of recycled water was approximately 4 times greater than surface water (Table 5). Chaganti et al. (2020) compared wastewater and freshwater applications in an arid agroecosystem in west Texas (United States). Interestingly, sodium levels in the freshwater source used in their study (107 mg/L) were similar to those in the recycled water used in the Sammamish Valley study (average of 87 mg/L). While crop dependent, the authors found that yield of sorghum, a relatively salt-tolerant plant, was not negatively affected by the larger sodium concentration in recycled water (286 mg/L), but soil electrical conductivity increased.

Recycled water organic carbon additions also have the potential to increase soil organic matter, a key component of soil quality. Xu et al. (2010) studied long-term applications of wastewater to soil and found that continual application for both 8 and 20 years increased total C. Annual rates of application were 2.57 million gallons/ha. Given the inherently high organic carbon content of Brightwater recycled water, organic carbon applications were 35% to 40% larger with recycled water than with surface water across 2020 to 2021 irrigation seasons.

Table 5. Total water applied and estimated nutrient loading for 2020 and 2021 irrigation seasons.

			[kg/ha]				
Treatment	Year	Water Applied [gal/acre]	Nitrate-N	Ammonia-N	Orthophosphate-P	Sodium	Organic Carbon
Carrot							
Recycled	2020	575291	156.000	0.2530	22.1000	0.4680	37.1
Surface Water	2020	566879	0.583	0.0207	0.0742	0.0382	21.2
Recycled	2021	490848	165.000	0.1420	25.3000	0.3170	23.4
Surface Water	2021	500281	1.030	0.0243	0.0796	0.0360	16.4
Kale							
Recycled	2020	446434	121.000	0.1960	17.1000	0.3630	28.8
Surface Water	2020	462535	0.476	0.0169	0.0606	0.0312	17.3
Recycled	2021	359796	121.000	0.1040	18.5000	0.2320	17.2
Surface Water	2021	342631	0.705	0.0167	0.0545	0.0247	11.2

Crop Yield

Recycled water significantly increased both carrot and kale growth (yield) in both years. Relative to surface water, yields were increased in 2020 by 26% in carrots and 147% in kale. In 2021, carrot yields were

increased by 134% and kale yields were increased by 71% (see Figure 7). Kale is a heavy nitrogen feeding plant and the increased nitrogen loading with recycled water was likely the primary reason for the increase (Table 5). Phosphorus loading was also significantly greater with recycled water, and this likely also influenced carrot and kale yields. Zhang and Shen (2019) reported that irrigating with wastewater could reduce fertilizer input by 45% for wheat and 94% for alfalfa. Campi et al. (2014) found that irrigation with wastewater increased sorghum yields by 12%. Not all literature reports show yield increases, however. Chaganti et al. (2020) found no difference between wastewater and freshwater irrigation yields.

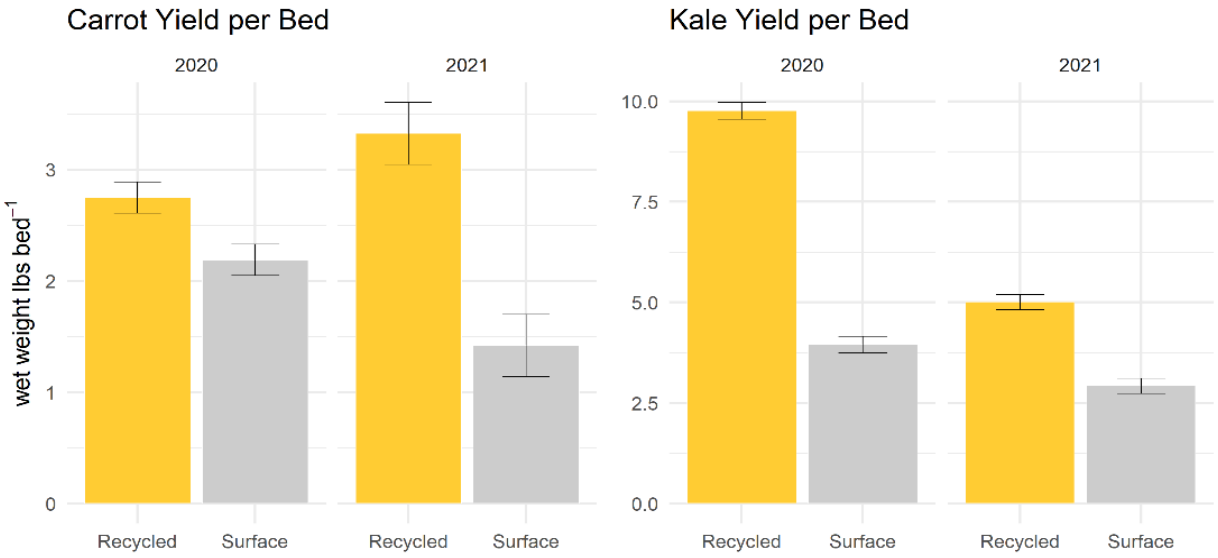

Figure 7. Observed carrot and kale yields after irrigation with recycled water or surface water in 2020 and 2021.

Soil Nutrients, Salts, and pH

Soil concentrations of several nutrients were affected by water source (recycled or surface water) and crop type (carrots or kale). Nutrient concentration in the soil was significantly impacted by year. Thus, years were analyzed separately for *Treatment, Crop,* and *Treatment X Crop* interactions, where both treatment and crop could have a combined effect. While much more nitrogen was applied to soil with recycled water than surface water, post-harvest soil nitrogen was not affected by water source in either 2020 or 2021 (Table 6). Both mineral forms of nitrate and ammonia were unaffected. Soils planted with kale did have higher residual nitrogen than those growing carrots in both years. Soil sulfur levels were not consistent across years.

In 2020, there was a *Treatment X Crop* interaction for soil sulfur. After kale harvest, there was significantly more sulfur in the soil that used Sammamish River irrigation. In 2021, the *Treatment* effect and *Treatment X Crop* interaction were not significant, though the average sulfur concentration was larger following surface water applications to carrots. Sulfur was not tested in the two irrigation waters, so it is unclear

whether more sulfur was applied via surface water. Recycled water led to a more than 100% increase in kale in 2020 and in carrot in 2021. It is possible that this dramatic increase in yield caused more soil sulfur to be removed from the soil in those plots (i.e., kale in 2020 and carrot in 2021). This would result in more residual sulfur in the soils with surface water application.

Sodium (Na), magnesium (Mg), calcium (Ca), and potassium (K) act as bases buffering soil acidity. Sodium and magnesium were increased with recycled water application in both carrots and kale in both 2020 and 2021 (Table 6). Potassium increased following recycled water application in carrots, but not kale in 2020; this effect was not observed in 2021. Calcium followed a different pattern than the other bases and was increased with surface water application with both carrots and kale in 2020 and 2021. Total bases (the sum of K, Ca, Mg, and Na) were greater following recycled water in 2021, but not in 2020. In 2020, there was a *Crop* effect on these parameters due to the larger calcium and manganese concentrations following carrot than kale.

Table 6. Soil concentrations of nitrate-N, ammonia-N, Bray P, sulfate-S, K, Ca, Mg, Na, and total bases before and after irrigation with recycled and surface water in kale and carrot production.

Year	Carrot		Kale		P values		
	Recycled	Surface	Recycled	Surface	Treatment (T)	Crop (C)	T X C
Nitrate-N, [ppm]							
2020	7.00	5.90	10.00	14.0	0.428	0.004	0.148
2021	11.00	11.00	17.00	24.0	0.230	0.006	0.221
Ammonia-N, [ppm]							
2020	5.30	5.70	7.30	5.90	0.295	0.047	0.079
2021	4.90	4.80	5.60	6.80	0.403	0.065	0.365
Bray P, [ppm]							
2020	86.0	54.0	70.0	50.0	<0.001	0.007	0.067
2021	96.0	66.0	87.0	73.0	<0.001	0.720	0.051
K, [ppm]							
2020	180	110	150	140	0.005	0.980	0.015
2021	140	160	160	160	0.577	0.557	0.628
Ca, [meq]							
2020	3.60	4.30	3.20	3.80	<0.001	<0.001	0.660
2021	3.20	3.60	3.10	3.60	0.024	0.876	0.970
Mg, [meq]							
2020	2.30	1.80	2.10	1.30	<0.001	0.004	0.138
2021	2.30	0.90	1.90	0.86	<0.001	0.166	0.251
Na, [meq]							
2020	0.26	0.13	0.29	0.093	<0.001	0.842	0.185
2021	0.33	0.16	0.30	0.130	<0.001	0.008	0.877
Sulfate-S, [ppm]							
2020	5.80	5.50	6.50	9.50	0.032	0.002	0.015
2021	22.0	38.00	20.00	18.00	0.163	0.051	0.108
Bases, [meq]							
2020	6.60	6.50	6.00	5.60	0.112	0.001	0.434
2021	6.10	5.10	5.70	5.00	0.010	0.400	0.605

Notes: "T X C" represents "treatment X crop" parameter.

Micronutrients boron (B), manganese (Mn), and iron (Fe) were increased with recycled water application in both 2020 and 2021 (Table 7). Copper (Cu) was increased with surface water in 2020, but not in 2021. Zinc (Zn) levels were not consistently affected by water source across the 2 years of the study. In 2020, there was a trend toward greater Zn levels with surface water (P value = 0.067), but in 2021, there was no significant effect. Micronutrients were not tested in the water sources, so it is difficult to say definitively if more B, Mn, and Fe were applied with recycled water than surface water, although researchers assumed the recycled water contained more of these micronutrients.

The increase in Cu following surface water application is noteworthy and could be due to differential uptake by plant roots in the different systems. This was especially pronounced in kale, which had more than double the yield with recycled water application. Kale's heightened productivity may have led to increased uptake of Cu and resulted in some nutrient depletion in the soil.

Table 7. Soil concentrations of B, Zn, Mn, Cu, and Fe before and after irrigation with recycled and surface water in kale and carrot production.

Year	Carrot		Kale		P values		
	Recycled	Surface	Recycled	Surface	Treatment (T)	Crop (C)	T X C
B, ppm							
2020	0.30	0.16	0.30	0.17	<0.001	0.790	0.539
2021	0.52	0.23	0.52	0.19	<0.001	0.529	0.529
Zn, ppm							
2020	5.80	6.20	4.60	6.00	0.067	0.140	0.259
2021	4.00	3.80	5.00	4.00	0.210	0.210	0.445
Mn, ppm							
2020	4.50	3.70	5.00	4.60	0.025	0.021	0.467
2021	5.70	8.30	7.90	10.00	0.003	0.008	0.699
Cu, ppm							
2020	1.50	1.80	1.30	1.60	0.027	0.057	0.911
2021	1.50	1.50	1.80	1.40	0.295	0.617	0.295
Fe, ppm							
2020	52.00	46.00	57.00	51.00	0.031	0.063	0.958
2021	64.00	80.00	79.00	78.00	0.002	0.005	0.001

Notes: "T X C" represents "treatment X crop" parameter.

In 2020, residual soluble salts in the soil were affected by crops, but not by water source. In 2021, there was no effect due to water source. In 2020, soils planted to kale had significantly greater residual salts than those planted to carrots (Table 8). Organic matter was not significantly affected by water source or crops in either year, despite the increased application of total carbon with recycled water (Table 5). In both years, pH was significantly affected by *Crop* and *Treatment*. Soil where kale was grown had lower pH than soils where carrots were grown. Irrigation with surface water produced lower pH than recycled water. The increase in total bases within kale with recycled water explains the increase in pH in these soils.

Table 8. Soil pH and concentrations of soluble salts and organic matter before and after irrigation with recycled and surface water.

Year	Carrot		Kale		P values		
	Recycled	Surface	Recycled	Surface	Treatment (T)	Crop (C)	T X C
pH							
2020	7.10	7.00	6.90	6.70	0.002	<0.001	0.017
2021	6.90	6.10	6.50	6.00	<0.001	0.012	0.148
Soluble salts, [mmhos]							
2020	0.22	0.18	0.26	0.27	0.320	0.002	0.064
2021	0.58	0.66	0.72	0.66	0.912	0.430	0.380
Organic Matter, [%]							
2020	2.90	2.80	2.90	2.50	0.080	0.163	0.212
2021	3.20	2.80	3.00	3.10	0.181	0.255	0.053

Summary and Observations

Between 2020 and 2021, study researchers collected 148 discrete samples from a demonstration garden system where either Sammamish River or recycled water was used for crop irrigation. These were analyzed for 206 to 222 analytical parameters, respectively, generating over 31,000 data points characterizing CECs and soil health. These data indicate that while CECs were present in both irrigation waters, soil, and carrot/kale samples, concentrations were generally low and consistent with expectations for the occurrence of CECs in the environment. No unexpected CECs or concentrations were consistently observed in any media across the 2 years of data.

Relative to surface water, Brightwater recycled water had significant nutrients present that substantially increased crop yield in both carrots (26% in 2020 and 134% in 2021) and kale (147% in 2020 and 71% in 2021) that were irrigated with this recycled water. Levels of N, P, Na, conductivity, and organic C were all higher in the recycled water relative to the surface water. Soil nutrient accumulation was affected by both water source and plant type. Nitrogen was effectively removed and incorporated by both kale and carrots, but phosphorus has some potential to accumulate following recycled water application. While excessive salts are a concern for recycled water in some agroecosystems, wet winters in Western Washington make this much less of a concern.

To the best of study researchers' knowledge, documented adverse impacts in humans consuming recycled water-derived CECs does not exist in the scientific literature. Recycled water irrigation of food crops with Class A recycled water is generally considered safe. However, some degree of incremental exposure would be expected for consumption of food crops that contain CECs. Both Sammamish River water and recycled water irrigation resulted in detections of CECs within carrots and kale, especially for kale. Concentrations within kale were often slightly to somewhat higher when recycled water was used for irrigation, although some CECs were higher in carrots.

PFAS compounds were consistently detected across both irrigation waters and in soil samples prior to irrigation; PFAS likely represent the highest-risk CECs in these systems. Using the study's maximum detected concentrations, researchers evaluated the processes and outcome of these CEC exposures through a HHRA (see Appendix B).

These results indicated that some exposure risks to CECs can be expected for beneficial uses of both Sammamish River water and recycled water. The Brightwater recycled water clearly represented a more chemically complex and diverse mixture of CECs with additional, and often higher, CEC concentrations relative to Sammamish River water. CECs detected in the highest risk food crop (leafy greens [kale]) were relatively similar to the CECs detected in kale irrigated with Sammamish River water.

In summary, the current scientific literature and the study's food crops both support the position that humans are exposed to minimal risks from pharmaceutical CEC exposures via food crops irrigated with recycled water. Very small masses of pharmaceutical and other CECs are within edible food crops. These low nanogram per gram levels translate to humans consuming a few tens of nanograms of CECs when they

eat a "serving" (e.g., 10 to 100 g of vegetables or leafy greens) of these crops. Notably, the CEC mass within the foods is very small relative to the milligram scale (1 mg = 1,000,000 ng) or higher typical pharmacological doses for humans taking these compounds (Table 3). Therefore, these exposures via food are typically far below active pharmacological doses for humans.

Key Observations

The following are key observations from study partners and researchers following completion of the study:

- Many to most CEC detections occurred at very low concentrations. However, for some compounds, reported detections were either close to analytical method limits of detection or represent detections that were not replicated in identical samples. Researchers had low confidence about these detections and focused their assessments on compounds with more consistent and confident detection patterns. For any sporadic or inconsistent CEC detections, additional sampling would be needed to further evaluate the potential significance of these detections and confirm existing CEC occurrence and concentration.
- The data indicate that the Brightwater recycled water was relatively high quality, with generally low CEC levels (<100 ng/L, and often <10 ng/L for detected CECs). No CEC detections were unexpectedly high or inconsistent with literature reports. When applied for irrigation, very few of the CECs exhibited clear potential for accumulation in agricultural soils, with the possible exceptions of AMPA, metformin, and some PFAS. These data reflected approximately 2 months of irrigation effort over each summer. Long-term, multi-year data would be needed to determine whether any irrigation-derived CECs remain in these soils or whether CEC concentrations increase with additional irrigation.
- Consistent with the published literature, leafy greens like kale represent the highest potential to accumulate CECs in edible tissues and subsequently expose humans to these CECs through dietary pathways. Despite this understanding, detected CEC concentrations were generally quite low (<5 ng/g). Of the detected CECs, the etoposide detections in 2020 and near ubiquitous PFAS detections across all water sources and sample types motivated a HHRA. Researchers pursued this additional investigation to better understand potential implications for human health.
- Overall, the results of the screening level HHRA showed that estimated upper bound noncancer hazard indices exceeded 1.0 for only one chemical, PFOA, when hazard indices were calculated using the *draft* U.S. EPA reference dose (RfD) for PFOA of 0.0015 ng/kg-d. For PFOA, hazard indices estimated based on the *draft* U.S. EPA RfD ranged from 13 to 120. Similar hazard indices were estimated for produce that was irrigated with recycled water or Sammamish River water. However, when hazard indices were estimated for PFOA using the Washington State Department of Health's PFOA Action Level of 3 ng/kg-d, all hazard indices were well below 1.0 (i.e., 0.0065 to 0.059 for the evaluated scenarios). Upper bound estimates of lifetime excess cancer risks exceeded a *de minimis* lifetime excess cancer risk level of 1 in 1,000,000 for only one chemical and scenario: etoposide in kale irrigated with recycled water. For this chemical and scenario, the lifetime excess cancer risk was 1.7 in a million (1.7×10^{-6}), which slightly exceeded the *de minimis* risk level.

- Recycled water used in this study was rich in nitrogen, phosphorus, and carbon. This represents a valuable fertilizer opportunity for vegetable production and potentially increases soil organic matter. Added nitrogen is likely taken up and incorporated into vegetable tissues, but phosphorus may be applied in excess of plant requirements, so there is a possibility soils may accumulate phosphorus over time. Soil phosphorus monitoring should be included in long-term recycled water applications to soil. Salts are not likely to accumulate in soils in a typical Western Washington field setting. However, soils under cover year-round in hoop houses or greenhouses and irrigated with recycled water would be more prone to salt accumulation and may need to monitor these parameters during use.

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Appendix A: Intertox Report

SCREENING LEVEL ASSESSMENT OF HUMAN HEALTH RISKS ASSOCIATED WITH CONSUMPTION OF CARROTS AND KALE IRRIGATED WITH RECYCLED WATER IN A SAMMAMISH VALLEY DEMONSTRATION GARDEN

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EXECUTIVE SUMMARY

A screening level human health risk assessment (HHRA) was conducted to characterize potential exposures and noncancer hazards or cancer risks to hypothetical populations that could be exposed to contaminants of emerging concern (CECs) through consumption of carrots or kale that have been irrigated with recycled or Sammamish River water, including children and adults. As part of a study conducted by King County/Washington Water Trust (KC/WWT), in 2020 and 2021 carrots and kale were grown in a demonstration garden in the Sammamish River Valley and irrigated with either recycled water (from the King County Brightwater Recycled Water Treatment Plant in Woodinville, WA) or Sammamish River water. Carrots and kale, which were considered representative of root and leafy vegetables, respectively, were sampled and analyzed for as many as 198 CECs to characterize uptake of the chemicals from irrigation water or soil into edible vegetables. The CECs included pharmaceuticals and personal care product ingredients, pesticides, and other chemicals associated with plastics, clothing, or industrial processes, that have been characterized as potentially present in recycled water.

Twenty-eight CECs detected in carrots and kale were identified as chemicals of interest (COIs) for closer quantitative evaluation of potential human health risks in the screening level HHRA. A chemical was identified as a COI if it was detected at a frequency of at least 25% in any of the four data subsets considered in the HHRA (i.e., carrots irrigated with recycled water, carrots irrigated with Sammamish River water, kale irrigated with recycled water, or kale irrigated with Sammamish River water), or if it was a member of the per- and polyfluoroalkyl substances (PFAS) chemical group and was detected at least once in samples of carrots or kale.

Quantitative estimates of exposure to hypothetically exposed populations (children and adults who consume produce grown in gardens irrigated with recycled water or Sammamish River water) were then calculated based on the maximum-detected concentration of each COI in the corresponding data subset. Assumed consumption rates of carrots and kale were based on the upper bound (90^{th} percentile) per capita average daily consumption rate of carrots and leafy vegetables for U.S. populations for the corresponding age group, combined with the assumption that exposure occurs for 350 days per year and that people consume locally grown carrots and kale from the irrigated plots for half (50%) of the year.

To evaluate the potential for adverse health effects at estimated exposures levels, toxicity criteria for the COIs were identified based on published, peer-reviewed estimates, or were derived using data from the toxicological literature or from therapeutic dosing (for pharmaceuticals). Using these values, upper bound estimates of noncancer hazard indices (HIs) and lifetime excess cancer risks (LECRs) were calculated.

Overall, the results of the screening level HHRA showed that estimated upper bound noncancer HIs exceed 1 for only one chemical, perfluorooctanoic acid (PFOA), when HIs were calculated using the draft U.S. EPA reference dose (RfD) for PFOA of 0.0015 nanograms per kilogram body weight per day (ng/kg-d). A HI of 1 or lower means the COI is unlikely to cause adverse noncancer health effects over a lifetime of exposure. However, an HI greater than 1 does not necessarily mean adverse

effects are likely. For PFOA, HIs estimated based on the draft U.S. EPA RfD range from 13 to 120 for the evaluated scenarios, with comparable values estimated for produce that was irrigated with recycled water or with Sammamish River water. However, when HIs were estimated for PFOA using the Washington State Action Level (SAL) for PFOA of 3 ng/kg-d, all HIs were well below 1, ranging from 0.0065 to 0.059 for the evaluated scenarios.

Upper bound estimates of lifetime excess cancer risks exceed a *de minimis* LECR level of 1 in 1,000,000 (1 in a million or 1×10^{-6}) for only one chemical and scenario: consumption of etoposide in kale irrigated with recycled water. For this chemical and scenario, the lifetime excess cancer risk is 1.8 in a million (1.8×10^{-6} or 0.0000018), which slightly exceeds the *de minimis* risk level. One can interpret this risk estimate for etoposide as a probability that, using the conservative upper bound cancer risk estimate for etoposide derived in this screening level HHRA, 1.8 persons in one million people could develop cancer if they are exposed to this chemical at this rate over their lifetime. However, while this upper bound risk estimate slightly exceeds the *de minimis* lifetime excess risk estimate, it is within the range of risks of 1×10^{-4} to 1×10^{-6} (1 in 10,000 to 1 in 1,000,000) considered to be allowable by U.S. EPA depending on specific site and exposure characteristics. Further, considering that the average male has an approximately 1 in 2 chance (0.5000) of developing cancer at some point in his lifetime and a female has a slightly lower chance (1 in 3, or 0.3333) of the same, the upper bound LECR of a 1.8 in a million (0.0000018) for etoposide for this scenario is equal to a total lifetime cancer risk to an exposed man or woman of 0.5000018 or 0.3330018, respectively.

People can be exposed to PFAS from multiple sources, including food and water ingestion, ingestion of house dust, inhalation from impregnated clothes, and hand-to-mouth transfer from carpets. Based on detected concentrations, estimated average daily doses (ADDs) of PFOA in the current study from consumption of carrots and kale grown in the test plots irrigated with recycled water are 0.18 ng/kg-d for a child and 0.20 ng/kg-d for an adult. However, these dose are only a fraction of the average daily PFOA dose from all sources as reported in the literature. Specifically, the total child dose of PFOA estimated in the screening level HHRA (from carrots and kale: 0.18 ng/kg-d) is about 1/360 of the total child dose from all sources estimated by Trudel et al. (2008) (66 ng/kg-d), while the total adult dose of PFOA estimated in the screening HHRA (carrots and kale: 0.20 ng/kg-d) is approximately 1/220 of the total adult dose from all sources estimated by Trudel et al. (2008) (approximately 44.5 ng/kg-d) and approximately 1/14 to 1/63 of the total adult dose from all sources estimated by Fromme et al. (2009) (2.86 to 12.61 ng/kg-d). Diet is characterized as a primary source of exposure to PFOA, but other sources of exposure, including carpet (hand-to-mouth exposure), dust ingestion, and inhalation of PFOA from impregnated clothing, are also important.

This screening level evaluation was conducted using conservative assumptions about exposure to COIs in carrots or kale irrigated with recycled water (specifically, with regard to carrots and kale grown locally and irrigated with recycled water, the assessment assumes that every day for one-half of the year, a child eats about 1/5 cup of carrots and about 1/2 cup of kale and an adult eats about 1/5 of a cup of carrots and about 1.5 cups of kale, and that concentrations of the chemicals in these

vegetables are equal to the maximum concentrations that were ever detected in the KC/WWT study). Because of the conservative methods applied in this screening level HHRA, it is likely that exposures and risks are overestimated and actual exposures and risks that would occur are much lower.

Overall, this screening level HHRA concludes that, based on the data and methods applied here, health risks from consumption of carrots and kale treated with recycled water are minimal and not expected to exceed allowable risk ranges, for example as established by U.S. EPA or other agencies, and that exposures to PFOA, in particular, are likely to be a fraction of what a person could get from other common daily sources.

1.0 INTRODUCTION

In 2020 and 2021, samples of fresh carrots and kale grown in demonstration gardens irrigated with either recycled water (from the King County Brightwater Recycled Water Treatment Plant in Woodinville, WA) or water from the Sammamish River were collected and analyzed by King County (KC) and the Washington Water Trust (WWT) for contaminants of emerging concern (CEC) (Jack et al., 2022). These CECs included pharmaceuticals and personal care product ingredients, pesticides, and other chemicals associated with plastics, clothing, or industrial processes. In order to assist in characterizing the significance of detected concentrations with regard to potential human health risks, KC/WWT contracted Intertox to conduct a screening level human health risk assessment (HHRA) to assess potential exposure and health risks through consumption of these CECs in food crops irrigated with recycled water.

A screening level HHRA estimates potential human health risks associated with particular chemicals or conditions by applying conservative (i.e., health protective) assumptions that are intended to overestimate potential human health risks. Per U.S. EPA and other agencies, the goal of using screening level approaches is to identify areas, contaminants, or conditions that require further attention and to "screen out" those that are highly unlikely to be of concern. Specifically, if estimated health risks for a particular chemical or exposure scenario fall below health effects thresholds, then adverse health effects from these exposures are not expected. However, if chemical concentrations or exposures are above health effects thresholds, it does not mean that adverse health effects are likely or expected, but that further evaluation of the potential risks posed by the chemical is appropriate.

1.1 Objectives of the Screening Level HHRA

The goals of the screening level HHRA conducted for KC/WWT are to:

- Identify chemicals of interest (COIs) based on relative frequencies of detection of the chemicals in carrots and kale that were irrigated by either recycled water or Sammamish River water.
- For each COI, derive upper-bound estimates of potential exposure (estimated average daily doses) for representative populations (child and adult residents) who may consume carrots or kale irrigated with each water type.
- For each COI, identify toxicity criteria that can be used to estimate risks for oral exposure, specifically acceptable daily intakes (ADIs) for noncancer effects and quantitative dose-response estimates for cancer incidence.
- Based on the estimated average daily doses and toxicity criteria for each COI, derive quantitative estimates of the potential for adverse health effects to exposed populations, including noncancer hazards indices (HIs) and lifetime excess cancer risks (LECRs).
- Identify COIs that exceed accepted risk-based thresholds for noncancer HIs or for LECRs based on the assumptions applied in the screening level HHRA.

- For those COIs that exceed risk-based thresholds, present information on how estimated risks compare to other types of risks, and as well as other information to support risk communication.

This screening level HHRA applies methodologies from current U.S. EPA and other risk assessment guidance and policy as appropriate**,** including the following:

- U.S. EPA. 1989. *Risk Assessment Guidance for Superfund (RAGS), Volume I — Human Health Evaluation Manual, Part A. Interim Final*. Office of Solid Waste and Emergency Response, United States Environmental Protection Agency. Washington, D.C. EPA/540/1-89/002. December.
- U.S. EPA. 1991. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Parameters*. Office of Solid Waste and Emergency Response, United States Environmental Protection Agency. Washington, D.C. June.
- U.S. EPA. 2002. *A Review of the Reference Dose and Reference Concentration Processes*. EPA/630/P-02/002F. U.S. Environmental Protection Agency. Washington, D.C.
- U.S. EPA. 2005. *Guidelines for Carcinogen Risk Assessment*. Risk Assessment Forum, United States Environmental Protection Agency. Washington, D.C. EPA/630/P-03/001F. March.
- U.S. EPA. 2008. *Child-Specific Exposure Factors Handbook*. United States Environmental Protection Agency. Washington, D.C. EPA/600/R-06/096F. September.
- U.S. EPA. 2011. *Exposure Factors Handbook*. Office of Research and Development, United States Environmental Protection Agency. Washington, D.C. EPA/600/R-090/052F. September.
- U.S. EPA. 2012. *Guidance for Considering and Using Open Literature Toxicity Studies to Support Human Health Risk Assessment*. Office of Pesticide Programs. United States Environmental Protection Agency. Washington, D.C.
- U.S. EPA. 2019. *Guidelines for Human Exposure Assessment*. Risk Assessment Forum. United States Environmental Protection Agency. Washington D.C. EPA/100/B-19/001. October.
- U.S. EPA. 2022. *Regional Screening Levels (RSLs).* U.S. Environmental Protection Agency. Washington, D.C.
- Washington State Department of Ecology. 2007. Model Toxics Control Act Statute and Regulation. Publication No. 94-06. November.

1.2 Document Overview

The methodologies applied in the screening level HHRA and the results of the assessment are described in this document. The subsequent sections of this document are organized as follows:

- **Data Evaluation and Hazard Characterization (Section 2.0).** This section describes the data used to conduct the screening level HHRA, outlines the process used to select COIs for purposes of the screening level HHRA, and identifies the COIs.

- **Exposure Assessment (Section 3.0).** This section identifies exposure point concentrations (EPCs) applied in the screening level HHRA, as well as the exposure parameters used to

estimate average daily doses (ADDs) for assessment of noncancer hazard or lifetime average daily doses (LADDs) for assessment of cancer risk. For purposes of this step, the EPC for each COI is assumed to be the maximum concentration measured in either carrots or kale that were irrigated with either recycled water or Sammamish River water, as determined in the sampling and analysis conducted by King County and WWT.

- **Toxicity Assessment (Section 4.0).** This section identifies toxicity criteria (e.g., acceptable daily intakes, or ADIs, for noncancer effects and cancer risk-based values) for each COI used to estimate noncancer hazard or cancer risk.
- **Risk Characterization (Section 5.0).** This section calculates noncancer hazard and/or cancer risk for COIs for each exposure scenario/ population, based on dose estimates determined in Section 3.0 and toxicity criteria identified in Section 4.0. If a COI exceed a risk threshold based on the results of the risk assessment, this section also presents relative risk estimates for that compound.
- **Comparison of Estimated PFOA Doses to Doses from Other Sources of Exposure (Section 6.0).** This section compares estimated doses from consumption of carrots and kale for the COI that exceeded a risk threshold (perfluorooctanoic acid (PFOA)) to typical daily doses from other sources of exposure.
- **Summary and Conclusions (Section 7.0).** This section summarizes the results and conclusions of the screening level HHRA.
- **References (Section 8.0).** This section provides the references used to develop the evaluation.
- **Appendix A.** This appendix summarizes the estimated noncancer ADDs and cancer LADDs calculated in this assessment.
- **Appendix B.** This appendix tabulates existing and derived toxicity criteria for the COIs evaluated in this assessment.

2.0 DATA EVALUATION AND HAZARD CHARACTERIZATION

The objective of the data evaluation and hazard characterization step is to review available data for conducting the screening level HHRA and identify COIs to be evaluated in the screening level HHRA. This section of the screening level HHRA addresses the following:

- Site description and identification of media of interest;
- Evaluation of relevant datasets; and
- Identification of COIs for the screening level HHRA.

Results of this step are described below.

2.1 Study Description and Identification of Media of Interest

In 2020 and 2021, KC/WWT collected samples of carrots and kale from a demonstration garden built on King County's Hollywood Pump Station grounds, comprised of 16 raised garden beds filled with a commercial gardening soil mix and irrigated with either recycled water (from the King County Brightwater Recycled Water Treatment Plant in Woodinville, WA) or Sammamish River water (Jack et al., 2022). Carrots and kale were selected as example edible crops commonly grown in the basin,

with carrots representative of a root crop and kale representative of a leafy green; these vegetables were sampled to characterize potential uptake of contaminants of emerging concern (CECs) from irrigation water and soil into edible produce. Samples were analyzed for CECs that were selected by KC/WWT based on a literature review, professional judgement, and analytical laboratory capabilities. Selected CECs included pharmaceutical and personal care product ingredients, per- and polyfluorinated substances (PFAS), bisphenol compounds, polybrominated diphenyl ethers (PBDEs), and glyphosate and its AMPA metabolite.

Samples of edible tissues of carrots (including whole carrots and peeled carrots) or kale were collected in September 2020 or September 2021 by KC/WWT and analyzed by AXYS-SGS laboratories for the CECs. As described by Jack et al. (2022), analysis of edible tissues was directed toward those tissues most likely to be consumed by people and considered to be representative of "marketable product" for agricultural producers. Thus, edible tissue was assumed to comprise carrot roots and kale leaves minus the largest stems.

2.2 Evaluation of Relevant Datasets and Identification of Chemicals of Interest

Samples of carrots (including peeled and unpeeled) and kale from the relevant media were analyzed for up to 198 CECs. Data were reviewed for quality and tabulated by KC/WWT prior to delivery to Intertox, and were assumed by Intertox to be of acceptable quality for use in risk assessment. These data were queried for use in the screening level HHRA. For purposes of the screening level HHRA, a distinction was not made for year of sample collection (i.e., data from 2020 and 2021 were combined for use the HHRA).

Overall, a total of 57 CECs including seven PFASs were detected in at least one plant tissue sample. CECs that were never detected in any sample (141 chemicals) are summarized in Table 2-1. Detected CECs are summarized in Table 2-2.

For consideration in the screening level HHRA, all CECs detected at a frequency of at least 25% in any of the data subsets (i.e., carrots irrigated with recycled water, carrots irrigated with Sammamish River water, kale irrigated with recycled water, or kale irrigated with Sammamish River water) as well as all CECs in the PFAS chemical group that were detected at least once in either carrots or kale were identified as chemicals of interest (COIs) for further evaluation. Chemicals identified as COIs (28 chemicals) are indicted in Table 2-2 with green shading and bolded text.

2.3 Chemicals of Interest Selection Uncertainties

If a chemical was never detected in carrots or kale, it was not included as a COI in the screening level HHRA and an assessment of risk was not conducted. In some cases, it is possible that detection limits for some never-detected chemicals could exceed health risk-based acceptable concentrations for a medium. However, detection limits for CECs in carrots or kale are low (e.g., for nondetected compounds, the maximum detection limit is 161 ng/g wet weight (parts per billion)), and for those chemicals that were evaluated in the HHRA, detection limits were below levels that would be

considered to be allowable based on health risk-based toxicity criteria. Further, as discussed in Sections 3.0 and 4.0, the estimated daily doses and derived toxicity criteria applied in this assessment incorporate multiple conservative assumptions and safety factors, such that actual risks would be much lower than estimated in this assessment. Consequently, it is assumed that for compounds that are never detected, even if a compound was present at a very low trace level below its detection limit, the potential for an adverse health effect from exposure to this compound is extremely low.

Also, with the exception of PFAS compounds, compounds that were detected but at a maximum overall frequency of detection of less than 25% in any medium were not included as COIs in the screening level HHRA. However, given that the estimated noncancer hazards and cancer risks for compounds that were evaluated as COIs in the screening level HHRA are overall very low (as described in this assessment), it is unlikely that risks for compounds that were detected infrequently are significant.

Overall, it is unlikely that compounds that were either not detected or were detected very infrequently were present at levels associated with significant health risk.

Table 2-1. CECs that were Never Detected in Any Sample and Are Not Further Evaluated in the Screening level HHRA

Compound	Count of Samples: Carrots, Irrigated w/ Recycled Water	Carrot-peeled, Irrigated w/ Recycled Water	Kale, Irrigated w/ Recycled Water	Carrots, Irrigated w/ Sammamish River Water	Carrot-peeled, Irrigated w/ Sammamish River Water	Kale, Irrigated w/ Sammamish River Water	Total Count	Max Detection Limit (ng/g, wet)
11Cl-PF3OUdS	16	2	16	16	2	16	68	0.401
3:3 FTCA	8	2	8	8	2	8	36	0.4
4:2 FTS	16	2	16	16	2	16	68	0.4
4-Epianhydrochlortetracycline [EACTC]	16	2	16	16	2	16	68	24
4-Epianhydrotetracycline [EATC]	16	2	16	16	2	16	68	6
4-Epichlortetracycline [ECTC]	16	2	16	16	2	16	68	6
4-Epioxytetracycline [EOTC]	16	2	16	16	2	16	68	2.5
4-Epitetracycline [ETC]	16	2	16	16	2	16	68	2.4
5:3 FTCA	8	2	8	8	2	8	36	2.5
7:3 FTCA	8	2	8	8	2	8	36	2.5
8:2 FTS	16	2	16	16	2	16	68	0.4
9Cl-PF3ONS	16	2	16	16	2	16	68	0.401
Acetaminophen	16	2	16	16	2	16	68	8.85
ADONA	16	2	16	16	2	16	68	0.4
Albuterol	16	2	16	16	2	16	68	0.3
Alprazolam	16	2	16	16	2	16	68	0.4
Amlodipine	16	2	16	16	2	16	68	0.6
AMPA	8	NA	8	8	NA	8	32	0.752
Atenolol	16	2	16	16	2	16	68	0.3
Atorvastatin	16	2	16	16	2	16	68	6.11
Azathioprine	12	NA	12	12	NA	12	48	0.8
Benzoylecgonine	16	2	16	16	2	16	68	0.4
Benztropine	16	2	16	16	2	16	68	0.28
Betamethasone	16	2	16	16	2	16	68	6

Compound	Count of Samples: Carrots, Irrigated w/ Recycled Water	Carrot-peeled, Irrigated w/ Recycled Water	Kale, Irrigated w/ Recycled Water	Carrots, Irrigated w/ Sammamish River Water	Carrot-peeled, Irrigated w/ Sammamish River Water	Kale, Irrigated w/ Sammamish River Water	Total Count	Max Detection Limit (ng/g, wet)
Busulfan	12	NA	12	12	NA	12	48	3.08
Caffeine	16	2	16	16	2	16	68	57.7
Carbadox	16	2	16	16	2	16	68	1.49
Carbamazepine	16	2	16	16	2	16	68	0.6
Chlortetracycline [CTC]	16	2	16	16	2	16	68	2.52
Clarithromycin	16	2	16	16	2	16	68	0.978
Clonidine	16	2	16	16	2	16	68	1.2
Clopidogrel	8	2	8	8	2	8	36	0.192
Codeine	16	2	16	16	2	16	68	1.2
Colchicine	12	NA	12	12	NA	12	48	0.574
Cotinine	16	2	16	16	2	16	68	0.3
Cyclophosphamide	12	NA	12	12	NA	12	48	0.32
Dehydronifedipine	16	2	16	16	2	16	68	0.284
Demeclocycline	16	2	16	16	2	16	68	6
Diatrizoic acid	12	NA	12	12	NA	12	48	17
Diazepam	16	2	16	16	2	16	68	0.291
Diclofenac	8	2	8	8	2	8	36	1.28
Digoxigenin	16	2	16	16	2	16	68	33.9
Digoxin	16	2	16	16	2	16	68	2.4
Doxorubicin	12	NA	12	12	NA	12	48	14.6
Doxycycline	16	2	16	16	2	16	68	2.43
Drospirenone	12	NA	12	12	NA	12	48	6.25
Enalapril	16	2	16	16	2	16	68	0.324
Eprosartan	8	2	8	8	2	8	36	0.481
EtFOSAA	16	2	16	16	2	16	68	0.1

Compound	Count of Samples: Carrots, Irrigated w/ Recycled Water	Carrot-peeled, Irrigated w/ Recycled Water	Kale, Irrigated w/ Recycled Water	Carrots, Irrigated w/ Sammamish River Water	Carrot-peeled, Irrigated w/ Sammamish River Water	Kale, Irrigated w/ Sammamish River Water	Total Count	Max Detection Limit (ng/g, wet)
Fenofibrate	8	2	8	8	2	8	36	0.192
Flumequine	16	2	16	16	2	16	68	0.6
Fluocinonide	16	2	16	16	2	16	68	7.99
Fluoxetine	16	2	16	16	2	16	68	1.97
Fluticasone propionate	16	2	16	16	2	16	68	4.93
Glipizide	16	2	16	16	2	16	68	0.96
Glyburide	16	2	16	16	2	16	68	0.32
HFPO-DA	16	2	16	16	2	16	68	0.38
Hydrochlorothiazide	16	2	16	16	2	16	68	10.6
Hydrocodone	16	2	16	16	2	16	68	1.2
Hydrocortisone	16	2	16	16	2	16	68	161
Iopamidol	12	NA	12	12	NA	12	48	32
Irbesartan	8	2	8	8	2	8	36	0.193
Isochlortetracycline [ICTC]	16	2	16	16	2	16	68	2.72
Lamotrigine	8	2	8	8	2	8	36	1.28
Lincomycin	16	2	16	16	2	16	68	1.2
Lomefloxacin	16	2	16	16	2	16	68	6.97
m-Chlorophenylpiperazine	8	2	8	8	2	8	36	0.768
Medroxyprogesterone acetate	12	NA	12	12	NA	12	48	1.6
MeFOSAA	16	2	16	16	2	16	68	0.1
Melengestrol acetate	8	2	8	8	2	8	36	0.192
Melphalan	12	NA	12	12	NA	12	48	103
Meprobamate	16	2	16	16	2	16	68	1.61
Methylprednisolone	16	2	16	16	2	16	68	80
Metoprolol	16	2	16	16	2	16	68	2.54

Compound	Count of Samples							
	Carrots, Irrigated w/ Recycled Water	Carrot-peeled, Irrigated w/ Recycled Water	Kale, Irrigated w/ Recycled Water	Carrots, Irrigated w/ Sammamish River Water	Carrot-peeled, Irrigated w/ Sammamish River Water	Kale, Irrigated w/ Sammamish River Water	Total Count	Max Detection Limit (ng/g, wet)
Metronidazole	12	NA	12	12	NA	12	48	1.6
Miconazole	16	2	16	16	2	16	68	1.1
Minocycline	16	2	16	16	2	16	68	24
Mycophenolate mofetil	8	2	8	8	2	8	36	0.192
Naproxen	16	2	16	16	2	16	68	5.28
N-EtFOSA	16	2	16	16	2	16	68	0.25
N-EtFOSE	16	2	16	16	2	16	68	0.748
NFDHA	8	2	8	8	2	8	36	0.263
N-MeFOSA	16	2	16	16	2	16	68	0.115
N-MeFOSE	16	2	16	16	2	16	68	1
Norfluoxetine	16	2	16	16	2	16	68	1
Norquetiapine	8	2	8	8	2	8	36	0.384
Ormetoprim	16	2	16	16	2	16	68	0.517
Oxazepam	12	NA	12	12	NA	12	48	1.6
Oxolinic acid	16	2	16	16	2	16	68	0.415
Oxycodone	16	2	16	16	2	16	68	0.6
Oxytetracycline [OTC]	16	2	16	16	2	16	68	2.4
PFDA	16	2	16	16	2	16	68	0.1
PFDoS	16	2	16	16	2	16	68	0.1
PFDS	16	2	16	16	2	16	68	0.1
PFEESA	8	2	8	8	2	8	36	0.1
PFHpA	16	2	16	16	2	16	68	0.1
PFHpS	16	2	16	16	2	16	68	0.1
PFHxS	16	2	16	16	2	16	68	0.1
PFMBA	8	2	8	8	2	8	36	0.1

Compound	Count of Samples							
	Carrots, Irrigated w/ Recycled Water	Carrot-peeled, Irrigated w/ Recycled Water	Kale, Irrigated w/ Recycled Water	Carrots, Irrigated w/ Sammamish River Water	Carrot-peeled, Irrigated w/ Sammamish River Water	Kale, Irrigated w/ Sammamish River Water	Total Count	Max Detection Limit (ng/g, wet)
PFMPA	8	2	8	8	2	8	36	0.2
PFNA	16	2	16	16	2	16	68	0.1
PFNS	16	2	16	16	2	16	68	0.1
PFOS	16	2	16	16	2	16	68	0.1
PFOSA	16	2	16	16	2	16	68	0.1
PFPeS	16	2	16	16	2	16	68	0.101
PFTeDA	16	2	16	16	2	16	68	0.1
PFTrDA	16	2	16	16	2	16	68	0.1
PFUnA	16	2	16	16	2	16	68	0.1
Prednisolone	16	2	16	16	2	16	68	24
Prednisone	16	2	16	16	2	16	68	26.7
Propoxyphene	16	2	16	16	2	16	68	0.161
Propranolol	16	2	16	16	2	16	68	0.8
Quetiapine	8	2	8	8	2	8	36	0.192
Ramipril	8	2	8	8	2	8	36	0.192
Ranitidine	16	2	16	16	2	16	68	0.708
Rosuvastatin	12	NA	12	12	NA	12	48	2.78
Sarafloxacin	16	2	16	16	2	16	68	6
Sertraline	16	2	16	16	2	16	68	1.02
Simvastatin	16	2	16	16	2	16	68	8
Sulfachloropyridazine	16	2	16	16	2	16	68	0.6
Sulfamerazine	16	2	16	16	2	16	68	0.882
Sulfamethazine	16	2	16	16	2	16	68	1.25
Sulfamethizole	16	2	16	16	2	16	68	0.346
Sulfamethoxazole	16	2	16	16	2	16	68	0.24

Compound	Count of Samples						Total Count	Max Detection Limit (ng/g, wet)
	Carrots, Irrigated w/ Recycled Water	Carrot-peeled, Irrigated w/ Recycled Water	Kale, Irrigated w/ Recycled Water	Carrots, Irrigated w/ Sammamish River Water	Carrot-peeled, Irrigated w/ Sammamish River Water	Kale, Irrigated w/ Sammamish River Water		
Sulfanilamide	16	2	16	16	2	16	68	19.2
Sulfathiazole	16	2	16	16	2	16	68	0.6
Tamoxifen	12	NA	12	12	NA	12	48	0.16
Teniposide	12	NA	12	12	NA	12	48	20.6
Thiabendazole	16	2	16	16	2	16	68	0.6
Tilmicosin	8	2	8	8	2	8	36	0.768
Trazodone	8	2	8	8	2	8	36	0.192
Trenbolone	16	2	16	16	2	16	68	1.61
Trenbolone acetate	16	2	16	16	2	16	68	0.347
Triamterene	16	2	16	16	2	16	68	0.3
Triclosan	16	2	16	16	2	16	68	2.4
Trimethoprim	16	2	16	16	2	16	68	0.6
Tylosin	16	2	16	16	2	16	68	2.4
Valsartan	16	2	16	16	2	16	68	2.63
Venlafaxine	12	NA	12	12	NA	12	48	0.762
Virginiamycin M1	16	2	16	16	2	16	68	2.21
Zidovudine	12	NA	12	12	NA	12	48	31.2

NA – Samples were not analyzed for this CEC

Table 2-2. CECs that were Detected in at Least One Sample and Identification of COIs for the Screening Level HHRA*

Compound	Frequency of Detection						
	Carrots, Irrigated w/ Recycled Water	Carrot-peeled, Irrigated w/ Recycled Water	Kale, Irrigated w/ Recycled Water	Carrots, Irrigated w/ Sammamish River Water	Carrot-peeled, Irrigated w/ Sammamish River Water	Kale, Irrigated w/ Sammamish River Water	Max FOD, any subset
1,7-Dimethylxanthine	0/16 (NA)	0/2 (NA)	0/16 (NA)	0/16 (NA)	0/2 (NA)	1/16 (6.25%)	6.25%
10-Hydroxy-amitriptyline	4/16 (25%)	2/2 (100%)	0/16 (NA)	4/16 (25%)	2/2 (100%)	0/16 (NA)	**100%**
2-Hydroxy-ibuprofen	2/16 (12.5%)	0/2 (NA)	2/16 (12.5%)	4/16 (25%)	0/2 (NA)	1/16 (6.25%)	**25%**
6:2 FTS	2/16 (12.5%)	0/2 (NA)	3/16 (18.75%)	3/16 (18.75%)	0/2 (NA)	5/16 (31.25%)	**31.25%**
Amitriptyline	4/16 (25%)	0/2 (NA)	4/16 (25%)	4/16 (25%)	0/2 (NA)	4/16 (25%)	**25%**
Amphetamine	0/16 (NA)	0/2 (NA)	0/16 (NA)	0/16 (NA)	0/2 (NA)	1/16 (6.25%)	6.25%
Amsacrine	0/16 (NA)	NA	0/12 (NA)	1/12 (8.3%)	NA	0/12 (NA)	8.3%
Anhydrochlortetracycline [ACTC]	0/16 (NA)	0/2 (NA)	0/16 (NA)	1/16 (6.25%)	0/2 (NA)	0/16 (NA)	6.25%
Anhydrotetracycline [ATC]	0/16 (NA)	0/2 (NA)	0/16 (NA)	1/16 (6.25%)	0/2 (NA)	0/16 (NA)	6.25%
Azithromycin	0/16 (NA)	0/2 (NA)	2/16 (12.5%)	0/16 (NA)	0/2 (NA)	1/16 (6.25%)	12.5%
Bisphenol A	4/28 (14.3%)	0/2 (NA)	8/28 (28.6%)	5/28 (17.9%)	2/2 (100%)	7/28 (25%)	**100%**
Cefotaxime	0/16 (NA)	0/2 (NA)	0/16 (NA)	0/16 (NA)	0/2 (NA)	1/16 (6.25%)	6.25%
Cimetidine	0/16 (NA)	0/2 (NA)	4/16 (25%)	0/16 (NA)	0/2 (NA)	4/16 (25%)	**25%**
Ciprofloxacin	5/16 (31.25%)	1/2 (50%)	1/16 (6.25%)	3/16 (18.75%)	2/2 (100%)	2/16 (12.5%)	**100%**
Citalopram	0/12 (NA)	NA	0/12 (NA)	1/12 (8.3%)	NA	0/12 (NA)	8.33%
Clinafloxacin	3/16 (18.75%)	0/2 (NA)	2/16 (12.5%)	3/16 (18.75%)	0/2 (NA)	1/16 (6.25%)	18.75%
Clotrimazole	0/12 (NA)	NA	0/12 (NA)	1/12 (8.3%)	NA	0/12 (NA)	8.33%
Cloxacillin	4/16 (25%)	0/2 (NA)	4/16 (25%)	0/16 (NA)	0/2 (NA)	5/16 (31.25%)	**31.25%**
Cocaine	0/16 (NA)	0/2 (NA)	8/16 (50%)	0/16 (NA)	0/2 (NA)	7/16 (43.75%)	**50%**
Daunorubicin	0/12 (NA)	NA	0/12 (NA)	1/12 (8.3%)	NA	0/12 (NA)	8.33%
DEET	14/16 (87.5%)	1/2 (50%)	16/16 (100%)	14/16 (87.5%)	2/2 (100%)	15/16 (93.75%)	**100%**
Desmethyldiltiazem	0/16 (NA)	0/2 (NA)	0/16 (NA)	0/16 (NA)	0/2 (NA)	1/16 (6.25%)	6.25%

Compound	Frequency of Detection						
	Carrots, Irrigated w/ Recycled Water	Carrot-peeled, Irrigated w/ Recycled Water	Kale, Irrigated w/ Recycled Water	Carrots, Irrigated w/ Sammamish River Water	Carrot-peeled, Irrigated w/ Sammamish River Water	Kale, Irrigated w/ Sammamish River Water	Max FOD, any subset
Diltiazem	0/16 (NA)	0/2 (NA)	0/16 (NA)	0/16 (NA)	0/2 (NA)	1/16 (6.25%)	6.25%
Diphenhydramine	1/16 (6.25%)	0/2 (NA)	1/16 (6.25%)	0/16 (NA)	0/2 (NA)	3/16 (18.75%)	18.75%
Enrofloxacin	4/16 (25%)	0/2 (NA)	0/16 (NA)	0/16 (NA)	0/2 (NA)	0/16 (NA)	**25.%**
Erythromycin-H2O	1/16 (6.25%)	0/2 (ND)	2/16 (12.5%)	3/16 (18.75%)	0/2 (ND)	1/16 (6.25%)	18.75%
Etoposide	0/12 (ND)	NA	8/12 (66.7%)	0/12 (ND)	NA	6/12 (50%)	**66.7%**
Furosemide	0/16 (ND)	0/2 (ND)	0/16 (ND)	0/16 (ND)	0/2 (ND)	4/16 (25%)	**25%**
Gemfibrozil	2/16 (12.5%)	0/2 (ND)	1/16 (6.25%)	0/16 (ND)	0/2 (ND)	0/16 (ND)	12.5%
Glyphosate	1/8 (12.5%)	NA	0/8 (ND)	0/8 (ND)	NA	0/8 (ND)	12.5%
Ibuprofen	2/16 (12.5%)	0/2 (ND)	5/16 (31.25%)	0/16 (ND)	0/2 (ND)	2/16 (12.5%)	**31.25%**
Metformin	8/16 (50%)	0/2 (ND)	9/16 (56.25%)	6/16 (37.5%)	0/2 (ND)	6/16 (37.5%)	**56.25%**
Moxifloxacin	0/12 (ND)	NA	0/12 (ND)	1/12 (8.3%)	NA	0/12 (ND)	8.3%
Norfloxacin	1/16 (6.25%)	0/2 (ND)	0/16 (ND)	0/16 (ND)	0/2 (ND)	0/16 (ND)	6.25%
Norgestimate	1/16 (6.25%)	0/2 (ND)	0/16 (ND)	0/16 (ND)	0/2 (ND)	0/16 (ND)	6.25%
Norverapamil	0/16 (ND)	0/2 (ND)	0/16 (ND)	1/16 (6.25%)	0/2 (ND)	0/16 (ND)	6.25%
Ofloxacin	1/16 (6.25%)	0/2 (ND)	0/16 (ND)	1/16 (6.25%)	1/2 (50%)	1/16 (6.25%)	**50%**
Oxacillin	1/16 (6.25%)	0/2 (ND)	3/16 (18.75%)	0/16 (ND)	0/2 (ND)	4/16 (25%)	**25%**
Paroxetine	0/16 (ND)	0/2 (ND)	0/16 (ND)	1/16 (6.25%)	0/2 (ND)	0/16 (ND)	6.25%
Penicillin G	0/16 (ND)	0/2 (ND)	1/16 (6.25%)	0/16 (ND)	0/2 (ND)	2/16 (12.5%)	12.5%
Penicillin V	2/16 (12.5%)	0/2 (ND)	3/16 (18.75%)	4/16 (25%)	0/2 (ND)	2/16 (12.5%)	**25%**
PFBA	11/16 (68.75%)	2/2 (100%)	15/16 (93.75%)	13/16 (81.25%)	2/2 (100%)	16/16 (100%)	**100%**
PFBS	0/16 (ND)	0/2 (ND)	1/16 (6.25%)	0/16 (ND)	0/2 (ND)	0/16 (ND)	6.25%
PFDoA	0/16 (ND)	0/2 (ND)	0/16 (ND)	3/16 (18.75%)	0/2 (ND)	0/16 (ND)	18.75%
PFHxA	0/16 (ND)	0/2 (ND)	14/16 (87.5%)	3/16 (18.75%)	0/2 (ND)	16/16 (100%)	**100%**
PFOA	1/16 (6.25%)	0/2 (ND)	4/16 (25%)	2/16 (12.5%)	0/2 (ND)	3/16 (18.75%)	**25%**

Compound	Frequency of Detection						
	Carrots, Irrigated w/ Recycled Water	Carrot-peeled, Irrigated w/ Recycled Water	Kale, Irrigated w/ Recycled Water	Carrots, Irrigated w/ Sammamish River Water	Carrot-peeled, Irrigated w/ Sammamish River Water	Kale, Irrigated w/ Sammamish River Water	Max FOD, any subset
PFPeA	0/16 (ND)	0/2 (ND)	14/16 (87.5%)	2/16 (12.5%)	0/2 (ND)	15/16 (93.75%)	**93.75%**
Promethazine	0/16 (ND)	0/2 (ND)	1/16 (6.25%)	0/16 (ND)	0/2 (ND)	0/16 (ND)	6.25%
Roxithromycin	0/16 (ND)	0/2 (ND)	2/16 (12.5%)	0/16 (ND)	0/2 (ND)	0/16 (ND)	12.5%
Sulfadiazine	0/16 (ND)	0/2 (ND)	4/16 (25%)	0/16 (ND)	0/2 (ND)	4/16 (25%)	**25%**
Sulfadimethoxine	0/16 (ND)	0/2 (ND)	0/16 (ND)	0/16 (ND)	0/2 (ND)	2/16 (12.5%)	12.5%
Tetracycline [TC]	0/16 (ND)	0/2 (ND)	0/16 (ND)	1/16 (6.25%)	0/2 (ND)	0/16 (ND)	6.25%
Theophylline	2/16 (12.5%)	0/2 (ND)	4/16 (25%)	0/16 (ND)	1/2 (50%)	4/16 (25%)	**50%**
Topiramate	0/8 (ND)	0/2 (ND)	8/8 (100%)	0/8 (ND)	0/2 (ND)	0/8 (ND)	**100%**
Triclocarban	1/16 (6.25%)	0/2 (ND)	0/16 (ND)	2/16 (12.5%)	0/2 (ND)	0/16 (ND)	12.5%
Verapamil	0/16 (ND)	0/2 (ND)	0/16 (ND)	1/16 (6.25%)	0/2 (ND)	1/16 (6.25%)	6.25%
Warfarin	0/16 (ND)	0/2 (ND)	4/16 (25%)	0/16 (ND)	0/2 (ND)	4/16 (25%)	**25%**

*Chemicals selected for further evaluation as COIs based on the inclusion criteria (detection in at least one data subset at a frequency of 25% or higher, or a PFAS) are shaded in green and bolded.
COI –chemical of interest; FOD – frequency of detection; NA – not analyzed; ND – not detected

Table 2-3. Summary of COIs Evaluated in the Screening level HHRA

Compound	CAS #	Class or Use
10-hydroxy-amitriptyline	1159-82-6	Metabolite of amitriptyline (tricyclic antidepressant)
2-Hydroxy-ibuprofen	51146-55-5	Metabolite of ibuprofen
6:2 FTS	27619-97-2	PFAS
Amitriptyline	50-48-6	Tricyclic antidepressant
Bisphenol A	80-05-7	Plastics ingredient
Cimetidine	51481-61-9	Anti-acid reflux
Ciprofloxacin	85721-33-1	Quinoline antibiotic
Clinafloxacin	105956-97-6	Quinoline antibiotic
Cloxacillin	61-72-3	β-lactam antibiotic
Cocaine	50-36-2	Opiate
DEET	134-62-3	Insect repellent
Enrofloxacin	93106-60-6	Quinolone antibiotic
Etoposide	33419-42-0	Chemotherapeutic
Furosemide	54-31-9	Diuretic
Ibuprofen	15687-27-1	Analgesic
Metformin	657-24-9	Anti-diabetic drug
Ofloxacin	82419-36-1	Antibiotic
Oxacillin	66-79-5	β-lactam antibiotic
Penicillin V	87-08-1	β-lactam antibiotic
PFBA	375-22-4	PFAS
PFBS	45187-15-3	PFAS
PFDoA	307-55-1	PFAS
PFHxA	307-24-4	PFAS
PFOA	335-67-1	PFAS
PFPeA	2706-90-3	PFAS
Sulfadiazine	68-35-9	Sulfonamide antibiotic
Theophylline	58-55-9	Bronchodilator
Topiramate	97240-79-4	Anti-epileptic
Warfarin	81-81-2	Anticoagulant

3.0 EXPOSURE ASSESSMENT

The goal of the Exposure Assessment is to identify and characterize the scenarios and populations for which exposures to CECs measured in carrots or kale irrigated with recycled or Sammamish River water are evaluated, and to develop chemical-specific upper-bound estimates of average daily exposure levels (i.e., doses) for each based on estimated exposure point concentrations (EPCs). For each COI and scenario/population, a dose was estimated using a pathway-specific equation and conservative (health protective) population-specific exposure parameters, according to methodologies consistent with guidance from U.S. EPA and others.

For the COIs, upper-bound estimates of dose are combined with toxicity criteria (described in Section 4.0) to estimate noncancer hazards and cancer risks, as described in Section 5.0.

The exposure scenarios/populations and exposure pathway evaluated in the screening level HHRA as well as the EPCs and exposure parameters applied to derive quantitative estimates of average daily doses for each of the COIs are described below.

3.1 Exposure Scenarios and Populations

The screening level HHRA focuses on characterizing potential exposures to hypothetical populations that could be exposed to COIs through consumption of carrots or kale that have been irrigated with recycled or Sammamish River water. The scenarios and populations evaluated in the HHRA are:

- **Child and adult consumers of fresh carrots** that have been irrigated with either recycled water or Sammamish River Water, and that contain COIs at concentrations measured and reported by King County and WWT.
- **Child and adult consumers of fresh kale** that have been irrigated with either recycled water or Sammamish River Water, and that contain COIs at concentrations measured and reported by King County and WWT.

For these populations, a reasonable maximum exposure (RME) scenario was evaluated. Per U.S. EPA (1989), an RME is defined as an upper bound estimate of exposure that could reasonably be expected to occur at a site, and in practice is estimated by combining upper bound (90–95th percentile) values for some but not all exposure parameters.

3.2 Exposure Pathways

An exposure pathway describes the course a chemical takes from a source to an exposed individual. In order for an exposure pathway to be complete, it must have four elements (U.S. EPA, 1989):

- A source and mechanism of chemical release,
- A retention or transport medium,
- A point of potential human contact with the contaminated medium, and
- An exposure route (e.g., ingestion) at the contact point.

Based on these elements, the following potential exposure pathways to COIs were evaluated in the

HHRA:

- Consumption of fresh carrots, including both peeled and unpeeled carrots
- Consumption of fresh kale

3.3 Quantification of Exposure

The general exposure equation and the EPCs and exposure parameters used to quantify doses for each COI, scenario, and population are described below.

3.3.1 Exposure Equations

In the HHRA, exposure is quantified as an estimated intake (dose) averaged over time (annually for noncarcinogenic compounds and over a lifetime for carcinogens). The general equation used to quantify dose for each COI, scenario, and population via consumption of carrots or kale is as follows. The EPCs used to quantify dose are described in Section 3.3.2 and the values applied for each exposure parameter are described in Section 3.3.3.

$$Dose\ (ng/kg-d) = \frac{C_{COI} \times IR_{carr\ or\ kale,c\ or\ a} \times Bioav \times FI \times EF \times ED}{BW_{c\ or\ a} \times AT_{nc\ or\ can}}$$

Where:

Dose	=	Average daily dose (ADD) for noncarcinogenic COIs or lifetime average daily dose (LADD) for carcinogenic COIs, from ingestion of fresh carrots or kale that have been irrigated with either recycled water or Sammamish River Water, by a child or adult, ng/kg-d
C_{COI}	=	EPC of each COI in fresh carrots or kale, which have been irrigated with either recycled water or Sammamish River Water, ng/g, wet weight
$IR_{carr\ or\ kale,\ c\ or\ a}$	=	Intake rate of fresh carrots or kale by a child or adult, g/d, wet weight
Bioav	=	Relative bioavailability of COI in carrots or kale, unitless
FI	=	Fractional intake of vegetables from local irrigated plots, unitless
EF	=	Exposure frequency, d/yr
ED	=	Exposure duration, yr
$BW_{c\ or\ a}$	=	Body weight, kg
$AT_{nc\ or\ c}$	=	Averaging time, d (equal to ED × 365 d/yr for noncarcinogens or 70 years × 365 d/yr for carcinogens)

Note that in characterizing an RME, U.S. EPA (1989; 1993a) recommends targeting 90th to 95th percentile (i.e., upper bound) values when identifying default factors for intake/contact rate (e.g., intake of fresh carrots or kale), exposure frequency, and exposure duration, and average or conservative estimates of media average concentrations contacted over an exposure period for body weight and exposure concentration. In this screening level assessment, as discussed below, this

convention was followed. It is assumed that the combination of these assumptions will yield an upper bound, though still plausible, estimate of potential exposures to persons who consume carrots or kale grown on these plots.

3.3.2 Exposure Point Concentrations (EPCs)

For purposes of this screening level HHRA, potential exposures to COIs by each scenario/population were quantified using the maximum-measured concentration of each COI detected in carrots or kale irrigated with recycled water or Sammamish River Water.

For each COI, EPCs were identified for the following media:

- Carrots (either peeled or unpeeled), irrigated with recycled water
- Carrots (either peeled or unpeeled), irrigated with Sammamish River water
- Kale, irrigated with recycled water
- Kale, irrigated with Sammamish River water

If a COI was not detected in a given medium, hazards or risks were not assessed for that medium. EPCs applied in the HHRA are summarized in Table 3-1.

3.3.3 Exposure Parameters

Quantification of exposure requires information on the behavioral characteristics of the populations of interest (e.g., how frequently the population engages in an activity, how much is taken in, and how many years the population is exposed) as well as information on physiological characteristics such as body weight.

In the absence of robust site-specific information describing population characteristics, for most exposure parameters considered in this assessment, characteristics considered descriptive of U.S. populations (e.g., as presented in U.S. EPA's *Exposure Factors Handbook* or *Child-Specific Exposure Factors Handbook*; U.S. EPA, 2008a; U.S. EPA, 2011) or U.S. EPA standardized default exposure parameters for characterizing reasonable maximum exposures (U.S. EPA, 2022a) were used. As appropriate, locally relevant information and/or professional judgment was applied for some parameters, such as assumptions about frequency of exposure on an annualized basis. Consistent with U.S. EPA guidance, for the RME resident scenario, exposure parameters were selected to represent reasonable upper bound estimates of exposure (U.S. EPA, 1989).

In order to ensure that risk estimates account for potential hazards to sensitive subgroups (e.g., pregnant women, immunodeficient persons, the elderly), the HHRA uses toxicity criteria that incorporate safety (or modifying) factors intended to provide an additional level of conservatism to protect these individuals, per U.S. EPA guidelines (see Section 4.0).

Exposure parameters for the populations of interest for each scenario are summarized in Table 3-2. Considerations for selection of specific exposure parameters are discussed below.

3.3.3.1 Vegetable Intake Rate (IR)

Vegetable intake rates (IR) of carrots and kale were obtained from the U.S. EPA's (2023a) *What We Eat in America – Food Commodity Intake Database, 2005–2010* (WWEIA-FCID 2005–10). This database presents food consumption rates from the National Health and Nutrition Examination Survey (NHANES), a survey conducted by U.S. Department of Health and Human Services to assess the health and nutritional status of a nationally representative sample of children and adults in the United States. WWEIA is the dietary intake interview component of the NHANES. This component collects 24-hour dietary recall data from two non-consecutive days from NHANES participants. WWEIA-FCID 2005–10 translates food consumption as reported in WWEIA into consumption of U.S. EPA-defined food commodities and as individual foods and food groups, expressed as grams of edible portions of uncooked food or food commodity consumed per day or per kg bodyweight per day. The data are used by U.S. EPA as the basis of food consumption rates presented in U.S. EPA's *Exposure Factor's Handbook*.

Intake rates applied in the screening level HHRA were 23 g/d (child) and 29 g/d (adult) wet weight (ww) for carrots (IR_{carr}) and 43 g/d (child) and 109 g/d (adult) ww for kale (IR_{kale}). For each category and population (a child is assumed to be age 2 to <16 years and an adult is assumed to be age 16 to <70 years), these rates are equal to the 90th percentile per capita consumption rate based on a 2-day sample for "carrots" and "leafy vegetables" [1] (edible portion, uncooked weight) per the WWEIA-FCID 2005-10. Per U.S. EPA (2018a), per capita intake rates (as opposed to "consumer only") are appropriate for use in exposure assessments for which average daily dose estimates are of interest, because they represent both individuals who consume during the survey period and individuals who consume at some time but not during the survey period (i.e., those who report "zero" consumption on these days). The 90th percentile values are assumed to represent reasonable upper bound per day consumption rates of carrots and kale for average persons in the population.

The frequency at which a person consumes the vegetable (i.e., days per year) is assumed to be reflected by the exposure frequency (EF) parameter. Of note, estimates based on short-term survey data may not necessarily reflect the long-term distribution of average daily intake rates, particularly for those food types with substantial seasonality (e.g., vegetables grown in home or local garden plots), but use of the 90th percentile consumption rate is assumed to be conservative.

For perspective, one cup of chopped, raw carrot weighs approximately 128 grams; therefore, the applied intake rates of 23 and 29 g/d ww for carrots for a child and adult, respectively, are approximately equivalent to consuming 0.18 and 0.23 cups (i.e., about 1/5 cup) of chopped, raw

[1] Leafy Vegetables (Brassica and Non-Brassica): Amaranth, leafy | Arugula | Beet, garden, tops | Belgium endive | Broccoli | Broccoli raab | Broccoli, Chinese | Broccoli-babyfood | Brussels sprouts | Cabbage | Cabbage, Chinese, bok choy | Cabbage, Chinese, mustard | Cabbage, Chinese, napa | Cardoon | Cauliflower | Celery | Celery-babyfood | Celtuce | Chicory, tops | Chrysanthemum, garland | Collards | Cress, garden | Cress, upland | Dandelion, leaves | Dasheen, leaves | Endive | Fennel, Florence | Kale | Kohlrabi | Lettuce, head | Lettuce, leaf | Mustard greens | Parsley, leaves | Radicchio | Radish, Oriental, tops | Radish, tops | Rape greens | Rhubarb | Salsify, tops | Seaweed | Seaweed-babyfood | Spinach | Spinach-babyfood | Swiss chard | Turnip, greens | Watercress

carrots per day. One cup of chopped, raw kale (with the stem) is approximately 67 grams; therefore, the applied intake rates of 43 and 109 g/d ww for kale for a child and adult, respectively, are approximately equivalent to 0.6 and 1.6 cups of chopped, raw kale per day for a child and adult, respectively.

3.3.3.2 Relative Bioavailability (Bioav)

A relative bioavailability factor (Bioav) is used to estimate the relative rate at which an orally administered chemical in a study used as the basis for a toxicity criterion (e.g., administered in food or water, or via gavage) is absorbed through the gastrointestinal tract, relative to the exposure scenario being evaluated in the risk assessment.

In the current screening level HHRA, relative bioavailability factors of 1.0 (i.e., 100%) were assumed for all COIs (i.e., it is assumed that the bioavailability of the chemical in consumed vegetable is this same as in the study upon which the toxicity criterion is based). This is expected to be a conservative (i.e., health-protective) assumption for most chemicals since most oral toxicity studies administer the chemical in water or another medium (e.g., corn oil) where it is expected to be more highly available for absorption relative to vegetable tissue. However, in some toxicity studies, the chemical is administered in diet—the relative bioavailability of the chemical when delivered via this medium is not known, though it is likely to be comparable to delivery via consumed vegetables. Use of a relative bioavailability value of 1.0 for all COIs is judged to be appropriate and health protective.

3.3.3.3 Fractional Intake of Vegetables from Local Sources (FI)

The fractional intake (FI) parameter is assumed to reflect, on an annualized basis, the average percentage of consumed vegetables that is from a source of interest (e.g., from garden plots irrigated with either recycled water or Sammamish River water). Note that the vegetable intake rates used in this assessment (i.e., published values that are based on two-day survey data for representative U.S. populations; Section 3.3.3.1) do not differentiate between local/homegrown vegetables and vegetables that are grown at other locations and then purchased (e.g., from grocery stores or markets and restaurants) for consumption, and thus are expected to overestimate vegetable intake from local or homegrown sources.

Use of a FI of 50% for carrots and kale in the dose calculations is assumed to be conservative given that peak harvest seasons for carrots and kale in Washington State is approximately three to five months per year. Specifically, in Washington State, although carrots are grown year-round, peak harvest season is from May through October (five months), and kale is grown for ten months a year (approximately July through April), with peak harvest season from September through November (three months; WSDA, 2010). It is possible that local produce may be stored (e.g., canned or frozen) and be available outside of peak harvest seasons.

3.3.3.4 Exposure Frequency (EF)

For the RME resident exposure scenarios (both adult and child), an exposure frequency (EF) to vegetables of 350 days per year is assumed. This EF is consistent with the recommended upper

bound value applied in U.S. EPA's Regional Screening Level (RSL) calculations for exposure frequency of a resident to media within the home (U.S. EPA, 2022a). RSLs are screening level calculations used to estimate "acceptable" exposure levels of chemicals in different media, and were developed by U.S. EPA to assist risk assessors, remedial project managers, and others involved with risk assessment and decision-making at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (i.e., Superfund) sites. In general, the RSLs incorporate exposure factors that, when combined, result in estimates of exposure assumed to represent RME conditions.

An EF of 350 days/year assumes a person is away from their home for 15 days per year (e.g., on vacation, traveling for work, etc.) and does not consume produce from a local source during this time. It is assumed that an annual EF to carrots and kale from the source of interest (garden beds irrigated with recycled water) of 350 days per year is conservative (health-protective).

3.3.3.5 Exposure Duration (ED)

Applied exposure durations (ED) are consistent with U.S. EPA recommendations for current residence time, that is, the length of time a household (as opposed to individual persons in a household) has been in their current residence. Per U.S. EPA (2011), based on data from the U.S. Census Bureau (2008, *American Housing Survey* for the United States: 2007, as cited in U.S. EPA, 2011), the 50th and 90th percentiles for current residence time of households in the U.S. are 8 years and 32 years, respectively, with mean and 95th percentile current residence times in the U.S. of 13 years and 46 years, respectively.

U.S. EPA (2022a) RSLs apply an upper bound estimate for residential exposure duration of 6 years for a child and 26 years for an adult. The summed total of these values (32 years total) is consistent with the 90th percentile current residence time value in the U.S.—these values are applied in the calculations for the child and adult in this assessment.

3.3.3.6 Body Weight (BW)

Per U.S. EPA (2011), the mean body weight for all adults (males and females, all age groups) is 80 kg. The average body weight for a child (males and females) age 2<16 years of age (the age range that is the basis of the child vegetable intake rates; Section 3.3.3.1) is 37 kg (U.S. EPA, 2011). These values are applied in this assessment.

3.4 Derivation of Dose Estimates

For each population and scenario, doses for each COI are estimated using the assumed exposure parameters and EPCs and are presented in units of milligrams per kilogram body weight per day (mg/kg-d). For evaluation of noncarcinogenic effects, doses are averaged over one year and presented as annual average daily doses (ADDs). For evaluation of cancer risk, doses are averaged over a lifetime (assumed to be 70 years) and presented as lifetime average daily doses (LADDs). These estimates are then combined with chemical-specific toxicity criteria to derive estimates of noncancer hazard and cancer risk associated with the exposures (Section 5.0).

The estimated ADDs and LADDs calculated for the COIs are summarized in Appendix A.

3.5 Exposure Assessment Uncertainties

Actual rates of exposure to individuals who consume carrots or kale grown in the Sammamish River Valley have not been measured. Instead, in this assessment, doses to hypothetical populations are estimated using exposure parameters representing a combination of average and upper bound exposure rates (e.g., values representing the mean and 90th or greater percentiles of distributions of the exposure rates), or default values compiled by U.S. EPA and used in RSL calculations (which are considered by U.S. EPA to yield screening levels protective for humans, including sensitive subgroups, over a lifetime, and are designed to assess if levels of contamination warrant further investigation; U.S. EPA, 2022a). Multiplicatively combining average and upper-bound exposure values is expected to yield estimates of exposure at the upper end of the exposure distribution, and will likely overestimate actual exposures to most individuals who are exposed to COIs in an HHRA.

For each COI, exposures from consumption of carrots or kale were estimated using the maximum concentration measured in each medium. Combined with the intake rate assumptions, this assumption is likely to overestimate intake rates of the COIs on an annualized basis.

Per capita intake rates for "carrots" and "leafy vegetables" were used for this analysis. U.S. EPA's *Update for Chapter 9 of the Exposure Factors Handbook* (2018a) describes per capita intake as follows:

> Per capita intake: These data are generated by averaging the consumer-only intakes over the entire population (including those individuals that reported no intake). In general, per capita intake rates are appropriate for use in exposure assessments for which average dose estimates are of interest because they represent both individuals who ate the foods during the survey period and individuals who may eat the food items at some time, but did not consume them during the survey period. Per capita intake, therefore, represents an average across the entire population of interest, but does so at the expense of underestimating consumption for the subset of the population that consumed the food in question.

Thus, use of per capita intake rates may underestimate consumption for very high end consumers of local vegetables. However, use of the 90th percentile per capita consumption rates combined with a FI value of 50% and the maximum detected concentration of each COI in each medium is assumed to yield an estimate of exposure that is not likely to be underestimated for nearly all possible consumers.

A consumption rate based on data for "leafy vegetables," which includes kale, was chosen as a surrogate for kale consumption because per capita data for intake rates specific to kale were indicated to be less statistically reliable (due to limited reporting for this vegetable) per guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII* (CDC, 1996). Use of a consumption rate for all leafy vegetables is assumed to overestimate exposure to kale.

Table 3-1. Exposure Point Concentrations (EPCs) Applied in the Screening Level HHRA*

Compound	Exposure Point Concentration (ng/g, wet weight)			
	Carrots, Irrigated w/ Recycled Water	Kale, Irrigated w/ Recycled Water	Carrots, Irrigated w/ Sammamish River Water	Kale, Irrigated w/ Sammamish River Water
10-hydroxy-amitriptyline	0.369	ND	0.279	ND
2-Hydroxy-ibuprofen	3.46	2.02	7.79	1.82
6:2 FTS	3.13	6.06	3.92	1.04
Amitriptyline	3.53	1.02	2.13	1.07
Bisphenol A	11.4	13	2.95	5.34
Cimetidine	ND	20.1	ND	17.2
Ciprofloxacin	4.06	3.43	5.85	6.25
Cloxacillin	2.02	10.3	ND	25.4
Cocaine	ND	1.73	ND	1.06
DEET	1.06	0.914	0.775	0.881
Enrofloxacin	1.57	ND	ND	ND
Etoposide	ND	11.3	ND	4.64
Furosemide	ND	ND	ND	7.26
Ibuprofen	2.86	9.59	ND	1.92
Metformin	57.6	5.73	0.9	0.799
Ofloxacin	1.27	ND	0.667	0.623
Oxacillin	1.16	5.2	ND	11.4
Penicillin V	1.15	2.35	1.37	2.65
PFBA	0.794	2.6	0.681	1.83
PFHxA	ND	0.59	1.11	0.665
PFOA	0.113	0.271	0.123	0.221
PFPeA	ND	0.805	0.331	0.538
Sulfadiazine	ND	2.56	ND	2.95
Theophylline	2.89	4.84	**2.16**	3.88
Topiramate	ND	1.47	ND	ND
Warfarin	ND	1.26	ND	1

*The EPC is equal to the maximum-detected concentration in each medium. Where both whole carrots and peeled carrots were analyzed, the applied EPC for whole carrots was the maximum value in either medium.

ND – not detected (chemical was not detected in this medium and so was not evaluated for this medium in the HHRA).

Table 3-2. Summary of Exposure Parameters Applied in the Screening level HHRA

Symbol	Units	Description	Child	Adult	Basis	Source
IR_{carr}	g/d ww	Carrot ingestion rate	23	29	90th %ile intake rate of "carrots" based on 2005–2010 NHANES and CSFII Per Capita 2-Day Average Intake data	U.S. EPA, 2023a
IR_{kale}	g/d ww	Kale ingestion rate	43	109	90th %ile intake rate of "leafy vegetables" based on 2005–2010 NHANES and CSFII Per Capita 2-Day Average Intake data	U.S. EPA, 2023a
Bioav	unitless	Relative bioavailability of COI in vegetable	1	1	Assume 100%	Professional judgment
FI	unitless	Fraction of vegetables consumed that are homegrown	0.5	0.5	Assume 50%	Professional judgment
EF	d/yr	Exposure frequency (days per year vegetables are consumed)	350	350	Upper bound, default for RME scenario, from U.S. EPA RSLs	U.S. EPA, 2022a; professional judgment
ED	yr	Exposure duration	6	26	U.S. 90th %ile residence time, from U.S. EPA RSLs	U.S. EPA, 2022a
AT_{car}	d	Averaging time, carcinogens	25,550	25,550	Equal to 70 years (lifetime) for carcinogens (default)	U.S. EPA, 1989
AT_{nc}	d	Averaging time, noncancer	2,190	2,190	Equal to 365 days per year × ED for non-carcinogens	U.S. EPA, 1989
BW	kg	Body weight	37	80	U.S. average, from U.S. EPA RSLs for a child and an adult (default)	U.S. EPA, 2022a

COI – chemical of interest; CSFII – Continuing Survey of Food Intakes by Individuals; NHANES – National Health and Nutrition Examination Survey; RME – reasonable maximum exposure; RSL – Regional Screening Level

4.0 TOXICITY ASSESSMENT

The goal of the Toxicity Assessment step is to identify toxicity criteria for each of the COIs to be used in the assessment of noncancer hazards and cancer risks. In the Risk Characterization section of the HHRA (Section 5.0), these toxicity criteria are combined with estimates of dose (Section 3.0) to derive a conservative estimate of the likelihood of an adverse noncancer or cancer effect.

The following sections describe the toxicity criteria identified for the COIs for assessment of noncancer hazard and cancer risk.

4.1 The Dose-Response Concept

Detection of a chemical in an exposure medium does not mean that adverse health effects will occur or are likely. While all chemicals are potentially toxic at some dose, many factors play a role in whether a chemical is toxic or harmful to humans or animals. In particular, the dose, or amount, of a chemical a person receives is important in determining the likelihood that it will cause an adverse effect. The duration that a person is exposed is also important: exposure to low levels of some substances over a short period of time (acute exposure) may not be harmful while exposure over many years (chronic exposure) can cause adverse health effects.

The nature of toxicological effects from exposure to different substances varies depending on how the chemicals act in the body. Effects that have been associated with repeated exposure to certain substances include effects on organ systems (e.g., liver, kidney, skin, lungs, nervous system), reproductive capacity, growth and development, and immune parameters. Exposures to some chemicals have been associated with an increase in certain types of cancers. To predict the potential for a given substance at particular levels of exposure to cause toxicological effects, scientists conduct tests in animals that are exposed to a controlled series of doses or evaluate humans that have been unintentionally (e.g., in the workplace) or intentionally (e.g., to medications) exposed. Newer methods that use laboratory desktop systems (*in vitro*) or computer models (*in silico*) can also predict toxicity. With this information, scientists can determine the types of adverse effects that can occur and the exposure level (including the amount and frequency of exposure) at which these effects can develop (the "dose-response"). Data that show a gradient of effects with increasing dose can be used to establish the threshold level of exposure at which effects first appear and to develop toxicity criteria that characterize the likelihood of a particular effect at a given exposure level.

For each COI considered in the HHRA, toxicity criteria were identified or derived to characterize the potential for noncancer or cancer effects associated with estimated doses. The sources of toxicity criteria applied in the HHRA are described below. The values selected for use in this assessment are presented in Table 4-1 (Noncancer Toxicity Values) and Table 4-2 (Cancer Toxicity Values). A more complete tabulation of published toxicity criteria for COIs and calculations and assumptions applied to derive values considered in this assessment is provided in Appendix B.

4.2 Sources of Toxicity Criteria

For purposes of this assessment, toxicity criteria for noncancer and cancer effects of the COIs were identified according to a hierarchical approach, wherein existing published criteria are selected or, in the absence of such values, values are derived from toxicity data or other information.

The hierarchy applied and sources of data are described below.

4.2.1 Hierarchy of Data Applied in the Selection of Toxicity Criteria for the Characterization of Noncancer or Cancer Effects

For characterization of noncancer effects, the hierarchy for selection or identification of toxicity criteria is as follows:

- If a published and verified (i.e., peer-reviewed) acceptable daily intake (ADI) for noncancer effects from an authoritative body is available (e.g., a U.S. EPA reference dose (RfD) or an Agency for Toxic Substances and Disease Registry (ATSDR) minimal risk level (MRL); see Section 4.2.2), apply this value. Consistent with U.S. EPA risk assessment guidance (U.S. EPA, 1989), toxicity criteria provided in U.S. EPA's Integrated Risk Information System (IRIS; https://www.epa.gov/iris) supersede other sources. Values in IRIS undergo external peer review and are used by U.S. EPA, state and local health agencies, other federal agencies, and international health organizations to assess chemical risk. Otherwise, if more than one value of sufficient quality from another non-U.S. EPA IRIS source is available, the lowest of these values is selected (i.e., corresponding to the most stringent estimate of noncancer hazard) for use in the HHRA.
- If a published and verified noncancer ADI is not available, search the toxicological literature or other safety information for relevant data on health effects from studies in animals or humans and derive an ADI for noncancer effects using data for the most sensitive toxicological endpoint combined with standard and accepted methodologies for deriving toxicity criteria of this type. If the chemical is a pharmaceutical, identify the lowest therapeutic dose and derive an ADI based on this value using an analogous approach to that used to derive values from toxicity data (see Section 4.2.3).

For evaluation of carcinogenic effects, the hierarchy for selection or identification of toxicity criteria is as follows:

- If a published and verified (i.e., peer-reviewed) cancer slope factor (SF; a quantitative measure of cancer risk associated with a given daily dose) from an authoritative body is available (see Section 4.2.2), apply this value. Consistent with U.S. EPA risk assessment guidance (U.S. EPA, 1989), information in the IRIS database supersedes other sources. Otherwise, if more than one value from another non-U.S. EPA IRIS source is available, select the highest of these values (which corresponds to the most stringent estimate of cancer risk) for use in the HHRA.
- If a published and verified cancer SF is not available, search the toxicological literature or other safety information for information on carcinogenicity and mutagenicity/genotoxicity from *in vitro* or *in vivo* studies. If a chronic animal study is available that shows evidence of dose-related carcinogenicity and evidence suggests that the chemical is mutagenic (i.e., that the carcinogenic response does not proceed through non-genotoxic, threshold mechanisms such as development

of hyperplasia followed by tumor development), and if tumor incidence data are available, use the tumor incidence data to derive a cancer SF using U.S. EPA methodologies (see Section 4.2.3).

The assumptions and methods used to identify or derive toxicity criteria for noncancer and cancer effects are described in more detail below. All identified toxicity criteria applied in the HHRA for noncancer and cancer effects are listed in Tables 4-1 and 4-2, respectively.

4.2.2 Identification of Existing Criteria from Authoritative Bodies for Noncancer and Cancer Effects

Availability of the following types of published and verified toxicity criteria from authoritative bodies was determined for each of the COIs:

- U.S. EPA reference doses (RfDs) for evaluation of noncarcinogenic effects
- U.S. EPA cancer slope factors (SFs) for evaluation of cancer risks
- Agency for Toxic Substances and Disease Registry (ATSDR) minimal risk levels (MRLs) for evaluation of noncarcinogenic effects
- California EPA Public Health Goals (PHGs) for drinking water or other noncancer criteria
- California EPA No Significant Risk Levels (NSRLs) for cancer or reproductive/ developmental toxicity developed as part of the Proposition 65 program
- California EPA oral SFs for cancer
- Minnesota Department of Health (MDH) Human Health-Based Values (HBVs)
- Washington State Draft State Action Levels (SALs) for per-and polyfluoroalkyl substances (PFAS)
- Texas Risk Reduction Program (TRRP) Protective Concentration Levels for PFAS
- European Food Safety Authority (EFSA) ADIs
- Joint FAO/WHO Expert Committee on Food Additives (JEFCA) ADIs
- Joint FAO/WHO Meeting on Pesticide Residues (JMPR) ADIs
- Other sources of values as appropriate

Note that where final peer-reviewed values are available, preference was given to these as opposed to "draft" values that have not undergone full peer-review.

The approach used by the U.S. EPA and other regulatory agencies to assess risks associated with noncarcinogenic effects is to identify an exposure threshold below which adverse effects are not observed. The first adverse effect that occurs as the dose or concentration increases beyond the threshold is called the "critical effect" (U.S. EPA, 1993b; 2002). Selection of regulatory levels for noncarcinogenic effects assumes that if the critical effect is prevented, then all toxic effects are prevented. For evaluation of noncarcinogenic effects, U.S. EPA has established RfDs, which are estimates of a daily oral exposure of a chemical to the human population (including sensitive subgroups) that are likely to be without an appreciable risk of deleterious effects during a lifetime (U.S. EPA, 1993b). U.S. EPA derives RfDs from such threshold doses as No Observed Adverse Effect Levels (NOAELs), Lowest Observed Adverse Effect Levels (LOAELs), or benchmark doses,

for noncarcinogenic endpoints including effects on reproduction, developmental effects, behavioral effects, or immunological effects. A NOAEL is the highest dose in a given study at which no statistically or biologically significant indication of a toxic effect of concern is identified, while a LOAEL is the lowest dose at which a toxic effect is identified. NOAELs and LOAELs are typically established from studies in animals or on occupational exposure in humans. The selected threshold dose is then divided by multiple uncertainty factors to account for limitations in extrapolating the doses to general human exposure, to develop an RfD. RfDs and other noncancer ADIs are typically expressed in units of milligram per kilogram of body weight per day (mg/kg-d) of exposure.

U.S. EPA evaluates cancer risks based on extrapolation of estimates of the increase in cancer incidence associated with exposure to known or estimated doses of a substance in animal or worker exposure studies. To evaluate cancer, U.S. EPA develops cancer SFs, which are upper bound estimates, approximating 95% confidence limits, of the increased cancer risk from a lifetime exposure to a unit dose or exposure level of an agent. SFs are typically expressed in units of proportion of a population affected per one milligram per kilogram of body weight per day of exposure to a chemical ($(mg/kg\text{-}d)^{-1}$), and are applied to exposures corresponding to risks less than 1 in 100 (U.S. EPA, 2005).

Available published noncancer ADIs and cancer SFs for the COIs are summarized in Appendix B, Table B-1.

4.2.3 Characterization of Toxicity of COIs without Existing Criteria

For COIs without established noncancer toxicity criteria, toxicity criteria for noncancer effects were derived from published toxicity data, lowest therapeutic doses (if the compound is pharmaceutical), and/or minimum inhibitory concentrations (MICs, if the compound is an antibiotic). For COIs without established toxicity criteria for cancer effects, a literature search was conducted to determine whether the chemical is a potential mutagen or genotoxicant, and whether toxicological data indicate it is potentially carcinogenic. If a chemical showed positive evidence of mutagenicity/genotoxicity and carcinogenicity, toxicity criteria that can be applied to quantify potential cancer risks were derived.

Methodologies used to derive toxicity criteria for COIs without existing values are described below.

4.2.3.1 Derivation of ADIs for Noncancer Effects Based on Published Toxicity Data

For noncancer effects, an ADI (including U.S. EPA reference doses (RfDs) and ATSDR minimal risk levels (MRLs)) is commonly defined as the amount of a chemical to which a person, including members of sensitive subpopulations, can be exposed on a daily basis over an extended period of time (usually a lifetime) without suffering a deleterious effect (U.S. EPA, 1993b). ADIs are often presented in terms of dose per day (e.g., mg/d) or dose per unit of body weight per day (e.g., mg/kg-d). Generally, several uncertainty factors (UFs) are applied, individually ranging in value from 3 to 10 with each factor representing a specific area of uncertainty in the available data including extrapolation from an animal study to humans, variations in sensitivity among humans, extrapolation

from a LOAEL to a NOAEL, extrapolation from less-than-lifetime exposures to lifetime exposures, and database limitations (U.S. EPA, 2002). When high-quality toxicity data are available, combined UFs typically range from 100 to 3,000.

In this assessment, for chemicals without identified existing toxicity criteria established by authoritative bodies, ADIs for noncancer effects were defined by reviewing animal toxicology and human clinical study data and identifying a point of departure upon which to base the ADI. This was typically the highest dose at which an effect was not seen (the NOAEL) or the lowest dose at which an effect was seen (the LOAEL). Below this dose, there is no evidence of a statistically or biologically significant increase in adverse effects, although some changes may occur that are not considered adverse (e.g., changes in certain enzyme levels). The point of departure was then divided by UFs to derive an ADI considered protective to broader population groups, including sensitive populations, such as children or people with immune compromised systems, as follows:

$$ADI(ng/kg\text{-}day) = \frac{NOAEL\ or\ LOAEL\ (mg/kg\text{-}d)}{UFs} \times 1{,}000{,}000\ ng/mg$$

Based on comments from an expert risk assessment panel convened as part Water Research Foundation (WRF) project 05-005 (WRF-05-005), to derive an ADI for noncancer effects, a default composite UF of 1,000 was applied if the selected point of departure is a NOAEL and a default composite UF of 3,000 was applied if the selected point of departure is a LOAEL (Snyder et al., 2010). Application of default UFs of 1,000 and 3,000 is supported by a statistical analysis of a set of 216 "learning compounds" with RfDs, NOAELs, and LOAELs conducted by U.S. EPA as part of the Drinking Water Contaminant Candidate List (CCL) Classification Process (U.S. EPA, 2008b). Based on this evaluation, U.S. EPA determined that an RfD could be approximated by dividing the NOAEL by 1,000 or the LOAEL by 3,000. U.S. EPA used this process to classify potential drinking water contaminants for inclusion in its draft third Drinking Water Contaminant Candidate List (CCL3).

Prior to marketing a pharmaceutical in the United States, the manufacturer is required to collect data to establish its safety; studies are conducted to assess the drug's behavior, toxicological effects in animals, and safety and efficacy in humans. For COIs that are pharmaceuticals, data from studies of this type were considered in developing ADIs. A typical suite of animal toxicology studies includes acute studies (exposure of one day or less to evaluate effects that happen very rapidly after an exposure), subchronic studies (up to three months in duration), chronic studies (repeated longer-term exposure, usually up to two years, to assess the potential for cancer, organ problems, nervous system impairment, reproductive effects, etc.), studies specific to effects on reproduction and offspring development (with administration just prior to, during, and immediately after pregnancy), and genotoxicity studies (to assess whether the agent causes genetic mutations). These studies generally use therapeutic or higher doses that are delivered for a relatively short period of time. In most cases, reproductive and developmental toxicity studies, or cancer studies, produced effects at the lowest doses.

For compounds that are not pharmaceuticals, other sources of toxicity information were considered, including monographs prepared by the U.S. EPA, the National Toxicology Program (NTP), the World Health Organization (WHO), the International Agency for Research on Cancer (IARC), and other agencies as appropriate. For all compounds, a search of the general scientific literature was also conducted using the National Library of Medicine's PubMed bibliographic database, focusing on toxicological studies conducted for sensitive endpoints, such as developmental and reproductive toxicity and carcinogenicity.

Noncancer toxicity data used as the basis of ADIs for each COIs without an established noncancer toxicity criterion are summarized in Appendix B, Table B-2. For each COI, an ADI was calculated by applying an appropriate composite UF to the selected point of departure (i.e., a UF of 1,000 or 3,000 applied to the NOAEL or LOAEL, respectively, that was identified for the most sensitive toxicological endpoint).

4.2.3.2 Derivation of ADIs Based on Lowest Therapeutic Doses of Pharmaceuticals

ADIs can also be derived based on the lowest therapeutic dose for pharmaceuticals. This approach assumes that the lower end of a drug's therapeutic range represents a threshold for appreciable biological activity in target populations, and therefore may be considered a threshold for potential adverse effects (i.e., a LOAEL). This point of departure is divided by UFs to account for variations in susceptibility between different members of the population or gaps in the dataset, to derive the ADI:

$$ADI\ (ng/kg-d)\ =\ \frac{Therapeutic\ dose\ (mg/kg-d)}{UFs}\ \times\ 1{,}000{,}000\ ng/mg$$

Other authors have used the lowest therapeutic dose as a starting point to characterize acceptable levels of pharmaceuticals in drinking water. Webb (2001) identified lowest therapeutic doses for 67 pharmaceuticals and compared assumed lifetime consumption rates (assuming consumption of 2 L water/day) to predicted environmental concentrations (PECs) in surface water in the European Union, estimated based on usage rates. Schwab et al. (2005) and Webb et al. (2003) used this approach to develop tolerable daily intakes (TDIs) for pharmaceuticals assuming exposure to them in drinking water.

For example, in developing screening levels from therapeutic doses, Schwab et al. (2005) assumed:

- Pharmacological effects from exposure to a drug product active ingredient present as a contaminant are assumed to be undesirable in the general population.
- The therapeutic effect usually occurs at a dose considerably below those expected to result in toxicity.
- Uncertainty factors are applied to reduce the point of departure dose to a dose where there is reasonable certainty that no effect will occur (Schwab et al. applied total UFs ranging in value from 9 to 1,000, comprised of UFs corresponding to five general categories consistent with those applied by U.S. EPA (2000a, 2002)).

Derivation of ADIs using this approach requires lowest therapeutic doses, in units of mg/kg-d, obtained from such sources as drug labels and monographs (e.g., from Drugs@FDA.com, Drugs.com, RxList.com). Lowest therapeutic doses identified for COIs that are pharmaceuticals are summarized in Appendix B, Table B-3. To derive ADIs from these values, a UF of 3,000 was applied (corresponding to individual UFs of 10 for sensitive subpopulations, 10 for extrapolation from a LOAEL to a NOAEL, 10 for extrapolation from subchronic to chronic exposure, and 3 for database uncertainties). Use of a composite uncertainty factor of 3,000 for application to therapeutic doses is supported by the consensus reached by the expert panel convened as part of WRF- 05-005 (Snyder et al., 2010).

4.2.3.3 Derivation of ADIs for Antibiotics Based on MICs

ADIs for antibiotics have been developed based on the minimum inhibitory concentration (MIC) to human gastrointestinal flora, that is, the lowest concentration of the antibiotic that will inhibit the visible growth of the microorganism (EMEA, 1998; Schwab et al., 2005; WHO, 2020).

ADIs can be developed from MICs using the following equation (WHO, 2020):

$$ADI\ (ng/kg-d) = \frac{MIC_{50}(\mu g/mL) \times MCC(mL/d)}{FA \times SF \times BW(kg)} \times 1{,}000\ ng/\mu g$$

Where:

MIC_{50} = Lowest (minimum) concentration at which 50% of the most sensitive relevant organism is inhibited (µg/mL)

MCC = Mass of colonic contents (mL/day)

FA = Available fraction of the dose to the gastrointestinal microflora (unitless)

SF = Safety factor; the magnitude depends on the quality and quantity of the microbiological data available (unitless)

BW = Body weight (kg)

For this assessment, values of MIC_{50} for each COI were obtained from the KnowledgeBase (2023) Antimicrobial Index, where the applied value was the mean MIC_{50} of the log transformed MIC_{50} values for the most sensitive relevant organism representing human intestinal flora (*Escherichia coli*, and species of *Bacteroides, Bifidobacterium, Clostridium, Enterococcus, Eubacterium (Collinsella), Fusobacterium, Lactobacillus, Peptostreptococcus/Peptococcus* (Silley, 2007)). The mass of colonic contents was assumed to be 500 mL/d, which corresponds to an adult human with a body weight of 60 kg (WHO, 2020). A safety factor (SF) of 1.0 was applied for all of the compounds, as sufficient MIC_{50} information was available for each in KnowledgeBase (2023).

ADIs identified for each COI that is an antibiotic based on MICs (if available) are summarized in Appendix B, Table B-4.

The possibility of microbial resistance induced by antibiotics in the environment is a subject of some controversy. Microbial resistance to antibiotics has been noted in surface water and sewage effluent;

however, it is likely that the most significant contributor to antibiotic resistance in aquatic environments is excretion of resistant organisms from humans and animals who receive antibiotic treatment (WHO, 2021). Further, high-quality dose-response data (i.e., data that reliably associate a dose level with a given response) are generally not available for induction of antibiotic resistance in aquatic environments as a result of exposure to a given contaminant. As such, this endpoint was not considered in the development of ADIs.

4.2.3.4 Derivation of ADIs Based on Cancer Effects

Some pharmaceuticals have been shown to be carcinogenic in high dose animal studies conducted as part of the drug development process. In addition, other chemicals found in the environment have been shown to have carcinogenic potential in animal toxicity testing. Carcinogenicity to humans could be a concern for these chemicals if there is chronic exposure.

For chemicals that show positive evidence of carcinogenicity in high dose animal studies, linear extrapolation models can be used to predict the tumorigenic response at low doses—these types of models are recommended as a default for tumor sites where the mode of action is unknown or the mode of action shows a linear response, and assume a linear relationship between risk and dose at low doses (U. S. EPA, 2005). The slope of the risk/dose line, known as the slope factor (SF), is an upper-bound estimate of risk per increment of dose (e.g., per 1 mg/kg-d of exposure) that can be used to estimate risk probabilities for different exposure levels.

In this assessment, if sufficient data on tumor incidence per dose level were available for a given compound with evidence of carcinogenicity in animal bioassays and data indicate that the compound is genotoxic and thus assumed to have a linear relationship between carcinogenicity and dose, a standard one-hit model was used to estimate a SF, using U.S. EPA's Benchmark Dose Software (BMDS) (U.S. EPA, 2023c). The one hit model is based on the mechanistic argument that a carcinogenic response can occur after a target site has been impacted by a single biologically effective unit of dose within a given time period (U.S. EPA, 2023b). The general form of the model is given by:

$$P(d) = 1 - e^{(-\lambda d)}$$

where P(d) is the probability of cancer from lifetime exposure at dose rate d, and λ is a fitted dose coefficient (U.S. EPA, 2023b).

For chemicals with available SFs or for which SFs were calculated, cancer risk-based ADIs were also calculated assuming an acceptable lifetime excess cancer risk of one in one million, as follows:

$$Cancer\ risk - based\ ADI\ (ng/kg - d) = \frac{10^{-6}}{SF\ (mg/kg - d)^{-1}} \times 1{,}000{,}000\ ng/mg$$

For compounds with evidence of carcinogenicity in animals but that lack tumor incidence data, or available data suggest that the carcinogenicity develops through nongenotoxic mechanisms (i.e., via a nonlinear response), a method was used that was proposed by Gaylor and Gold (1995) for calculating

a virtually safe dose (VSD) without the need to conduct multi-year laboratory studies for carcinogenicity. Gaylor and Gold created the Carcinogenic Potency Database as part of the Cancer Potency Project at the Lawrence Berkeley Laboratory (Gold et al., 2005, 2011). The Carcinogenic Potency Database summarizes results from 6,153 chronic, long-term animal cancer tests on 1,485 chemicals, as published in the general literature through 1997 and by the National Cancer Institute/National Toxicology Program through 1998 (Gold et al., 2011). Gaylor and Gold (1995) reviewed the results of two-year cancer bioassays for 139 chemicals tested by the National Toxicology Program (NTP) and determined that a "virtually safe dose" (VSD) corresponding to a cancer risk of one in one million can be estimated by dividing a chemical's maximum tolerated dose (MTD; from 90-day studies in rodents) by 740,000. The MTD is the highest dose predicted to produce minimal systemic toxicity over the course of a carcinogenicity study and is typically predicted from 90-day dose range finding studies (NRC, 1993). Effects of concern include alterations in physiological function which could alter the animal's normal life span or interfere with interpretation of the carcinogenicity study, such as more than a 10% decrease in body weight gain relative to controls, target organ toxicity, or significant alterations in clinical pathological parameters. The MTD is usually the high dose selected for a carcinogenicity study in the event such a study is conducted (NRC, 1993).

Evidence of mutagenicity/ genotoxicity as well as carcinogenicity for each of the COIs is summarized in Appendix B, Table B-5. If a COI is identified as potentially mutagenic and has evidence of being carcinogenic (based on animal or human data) and for which sufficient tumor incidence data are available to derive a cancer SF, but for which no existing published cancer SF is available, a SF was calculated based on the tumor incidence data, as summarized in Table B-5. For chemicals identified as mutagenic and potentially carcinogenic (based on animal or human data), but for which tumor incidence data were identified, a cancer-based ADI was derived using the VSD approach, as summarized in Table B-6.

4.3 Summary of Identified ADIs

Table 4-1 summarizes the noncancer toxicity values and Table 4-2 summarizes the cancer toxicity values identified based on the decision tree approach for the COIs. Existing toxicity criteria and calculated toxicity values derived using alternative methodologies are presented in Appendix B, Tables B-1 through B-6. Table B-7 summarizes all of the values identified for noncancer effects for each COI based on the alternative methodologies—for each COI, the lowest of these values was selected as the noncancer ADI.

Existing peer-reviewed and published toxicity values from regulatory agencies or other authoritative bodies were identified for nine of the COIs: bisphenol A, DEET, PFBA, PFBS, PFDoA, PFHxA, PFOA, PFPeA, and warfarin. These published values (listed in Table 4-1 for noncancer effects and Table 4-2 for cancer) were used in this assessment to calculate risk.

Of note, for PFOA, published values from authoritative bodies for noncancer effects were identified from several sources. In particular:

- The Washington State Department of Health has established a State Action Level (SAL) for PFOA of 3 ng/kg-d (WDOH, 2021). This value is equivalent to the ATSDR Minimal Risk Level (MRL) for PFOA, and is based on observation of developmental effects in mice exposed during gestation at a dose of 0.3 mg/kg-d (ATSDR, 2021). The resulting human equivalent dose was 0.00082 mg/kg-d was divided by a combined UF of 300 (3 to account for extrapolating from animals to humans, 10 to account for variability in sensitivity among humans, and 10 to account for use of a LOAEL rather than a NOAEL) to derive the MRL.
- U.S. EPA has more recently derived a *draft* noncancer RfD for PFOA of 0.0015 ng/kg-d (U.S. EPA, 2022b). This value is based on human epidemiological studies in which a developmental immune health outcome (decreased serum anti-tetanus antibody concentration following tetanus vaccination in 7-year-old children) was observed (U.S. EPA, 2021). A benchmark dose level ($BMDL_5$) human equivalent dose (HED) of 1.49×10^{-8} mg/kg-d was identified for this effect, and was divided a UF of 10 to account for variability in sensitivity among humans to derive the RfD.

Because the U.S. EPA RfD for PFOA is a draft value, and because the State of Washington has published its own SAL for PFOA, noncancer hazards from exposure to PFOA were calculated in this assessment using both of these toxicity criteria.

For the remaining COIs without published noncancer toxicity criteria, noncancer ADIs were derived from published toxicity data, lowest therapeutic doses (if the compound is pharmaceutical), and/or MICs (if the compound is an antibiotic), and the lowest of these values for each COI was selected as the noncancer ADI (Table 4-1).

In addition, three of the COIs were identified as potentially carcinogenic based on data from animals and/or humans. For these chemicals, potential lifetime excess cancer risk was evaluated (Table 4-2). These chemicals are:

- Etoposide: This chemical is a cancer chemotherapeutic agent and has been characterized as mutagenic based on *in vitro* tests and as potentially carcinogenic based on the occurrence of acute leukemia with or without a preleukemic phase in rare instances in patients treated with etoposide alone or in association with other neoplastic agents (Drugs.com). However, no long-term animal studies have been conducted to assess etoposide's potential carcinogenicity. Thus, no tumor incidence data are available and a cancer SF cannot be derived. As such, a cancer-based ADI for this chemical was derived based on the chemical's assumed maximum tolerated dose (MTD) per the VSD approach described in Section 4.2.3.4.

  Note, as described in Section 4.2.3.4, derivation of a cancer-based ADI using the VSD approach generally requires identification of an MTD from a 90-day study in rodents (which is then typically used as the high dose in an animal carcinogenicity study). To derive a VSD assumed to correspond to a *de minimis* lifetime excess cancer risk of 1 in a million, this MTD is then divided by a factor of 740,000. However, for etoposide, neither a 90-day study in animals or a chronic carcinogenicity study in animals was identified and as such, an MTD from animal studies was

not identified. However, a maximum tolerated clinical dose of 50 mg/m^2-d for oral exposure to etoposide in human clinical trials was identified (Hainsworth et al., 1989; Greco et al., 1990; Furuse, 1992). This dose was assumed to be an appropriate and conservative point of departure to derive a VSD for humans (particularly since other studies identified higher maximum tolerated clinical doses, e.g., up to 4,200 mg/m^2 in Herzig, 1991, >700 mg/m^2 in O'Dwyer et al., 1991, and
>400 mg/m^2 in Minami et al., 1993). To derive the VSD, the dose (in milligrams per square meter of body surface area per day (mg/m^2-d)) was converted to a dose in mg/kg-d by dividing by a factor of 37 kg/m^2, corresponding to a 60 kg human (from Nair and Jacob, 2016), and then divided by a factor of 740,000. The resulting cancer risk-based ADI is 1.8E-6 mg/kg-d, or 1.8 ng/kg-d.

- Furosemide: This chemical showed mixed evidence of mutagenicity in *in vitro* tests (some tests were positive and others were negative), and an increased incidence of mammary tumors was reported in a 2-year study in mice (CPDB, 2007). A published cancer SF was not identified for this chemical, but one was derived based on the tumor incidence data using BMDS. The resulting SF was 0.011 (mg/kg-d)$^{-1}$. A cancer risk-based ADI corresponding to a *de minimis* lifetime excess cancer risk of 1 in a million based on this SF of 0.091 ng/kg-d was also estimated.
- PFOA: This chemical showed mixed evidence of genotoxicity in *in vitro* and *in vivo* tests (some tests were positive and others were negative), and limited evidence of carcinogenicity in animals based on an increased incidence of one tumor type (Leydig cell tumors in the testes) of male rats (U.S. EPA, 2016). U.S. EPA (2016) considered the evidence of carcinogenicity to be only suggestive because only one species has been evaluated for lifetime exposures and the tumor responses occurred primarily in males. However, they proposed a draft cancer SF of 0.07 (mg/kg-d)$^{-1}$ based on these data. This value was used in this assessment to characterize the potential carcinogenicity of PFOA. In addition, a cancer risk-based ADI corresponding to a *de minimis* lifetime excess cancer risk of 1 in a million based on this SF of 14 ng/kg-d was estimated.

4.4 Toxicity Assessment Uncertainties

For both noncancer and cancer endpoints, toxicity criteria are generally based on observations of adverse health effects in animals that are exposed to very high doses of chemicals in the diet, in water, or via gastric gavage. Because of differences between the nature and magnitude of exposures that are the basis for these criteria and exposures evaluated in this screening level HHRA, these criteria may under- or overestimate, but most likely overestimate, actual risks to people from exposure to lower concentrations in environmental media.

Overall, all of the toxicity criteria applied in the screening level HHRA incorporate multiple uncertainty factors and are intended to be health protective. Thus, it is assumed that they are unlikely to underestimate, and more likely overestimate, potential risks from exposure to COIs. For example, noncancer ADIs are set using a number of conservative (health protective) assumptions, including selecting a point of departure that corresponds to the lowest effective dose level for any adverse effect from the database of studies, and use of multiple individual UFs (with a total UF ranging from 1,000 to 3,000 for most compounds) to further lower the ADI below the assumed threshold dose level.

Overall, because of the multiple conservative assumptions incorporated into all of the applied toxicity criteria, if the average daily dose estimated for a chemical in the screening level HHRA is below toxicity benchmarks that are associated with these criteria, one can be reasonably confident that adverse health effects due to exposure to these chemicals by potentially exposed populations are not likely. However, if a dose is at or above a toxicity benchmark, it does not mean that adverse health effects from exposure to the chemical are likely or will occur. Rather, more detailed evaluation of the chemical's toxicity and of the occurrence and exposure to the chemical (including examining how realistic the exposure estimates are for a particular population) may be warranted.

Table 4-1. Noncancer Toxicity Values for COIs Evaluated in the Screening level HHRA

Chemical	Noncancer Toxicity Value (ng/kg-d)	Toxicity Value Basis
10-Hydroxy-amitriptyline	360	Therapeutic dose (Table B-3)
2-Hydroxy-ibuprofen	950	Therapeutic dose (Table B-3)
6:2 FTS	15,000	NOAEL/LOAEL (Table B-2)
Amitriptyline	360	Therapeutic dose (Table B-3)
Bisphenol A	6,500	Existing published value (Table B-1; MDH Subchronic RfD (MDH, 2015))
Cimetidine	1,900	Therapeutic dose (Table B-3)
Ciprofloxacin	140	MIC (Table B-4)
Cloxacillin	4,800	Therapeutic dose (Table B-3)
Cocaine	67	NOAEL/LOAEL (Table B-2)
DEET	120,000	Existing published value (Table B-1; MDH Subchronic RfD (MDH, 2013))
Enrofloxacin	260	MIC (Table B-4)
Etoposide	44	NOAEL/LOAEL (Table B-2)
Furosemide	90	Therapeutic dose (Table B-3)
Ibuprofen	950	Therapeutic dose (Table B-3)
Metformin	2,400	Therapeutic dose (Table B-3)
Ofloxacin	520	MIC (Table B-4)
Oxacillin	1,200	Therapeutic dose (Table B-3)
Penicillin V	600	Therapeutic dose (Table B-3)
PFBA	1,000	Existing published value (Table B-1; Texas Chronic RfD (TCEQ, 2023))
PFBS	300	Existing published value (Table B-1; U.S. EPA RfD (U.S EPA, 2022b); Washington SAL (WDOH, 2021))
PFDoA	12	Existing published value (Table B-1; Texas Chronic RfD (TCEQ, 2023))
PFHxA	500	Existing published value (Table B-1; Texas Chronic RfD (TCEQ, 2023))
PFOA	3; 0.0015	Existing published values (Table B-1; WADOH SAL (WDOH, 2021); U.S. EPA RfD (U.S. EPA, 2022b))
PFPeA	500	Existing published value (Table B-1; Texas Chronic RfD (TCEQ, 2023))
Sulfadiazine	4,800	Therapeutic dose (Table B-3)
Theophylline	1,400	Therapeutic dose (Table B-3)
Topiramate	200	NOAEL/LOAEL (Table B-2)
Warfarin	300	Existing published value (Table B-1; U.S. EPA RfD (U.S. EPA, 1987))

LOAEL – lowest observed adverse effect level; MIC – minimum inhibitory concentration; NOAEL – no observed adverse effect level; RfD – Reference Dose; SAL – State Action Level

Table 4-2. Cancer Toxicity Values and Assumptions for COIs Evaluated in the Screening level HHRA

Chemical	Mutagenicity Assumption*	Carcinogenicity Assumption*	Slope Factor ((mg/kg-d)$^{-1}$) and Basis	Cancer-Based ADI (ng/kg-d)†
Etoposide	Mutagenic based on *in vitro* tests	Potentially carcinogenic. Carcinogenicity tests have not been conducted in animals, but the occurrence of acute leukemia with or without a preleukemic phase has been reported in rare instances in patients treated with etoposide alone or in association with other neoplastic agents. The risk of development of a preleukemic or leukemic syndrome is unclear (Drugs.com).	Not determined (no tumor incidence data available)	1.8 (based on VSD; see Table B-6)
Furosemide	Equivocal: mixed evidence in *in vitro* tests	Increased incidence of mammary tumors in 2-year study in mice (CPDB, 2007).	0.011 (derived from mouse mammary tumor incidence data)	91‡
PFOA	Equivocal: mixed evidence in *in vitro* and *in vivo* tests	IARC (2018) classified PFOA as possibly carcinogenic to humans (Group 2B) based on limited evidence for carcinogenicity in animals and in humans. In 2-year diet studies, male but not female rats showed a dose-response relationship with exposure for one tumor type (Leydig cell in testes) (U.S. EPA, 2016). Per U.S. EPA (2016), evidence for the carcinogenicity of PFOA is considered suggestive because only one species has been evaluated for lifetime exposures and the tumor responses occurred primarily in males.	0.07 (increase in Leydig cell tumors in male rats exposed in diet for 2 years (U.S. EPA, 2016))	14‡

*Data are summarized in Table B-5.

†Based on a *de minimis* lifetime excess cancer rate of 1 in 1,000,000 (i.e., 1×10^{-6})

‡Cancer-based ADI = (1/1,000,000)/SF (mg/kg-d)$^{-1}$ × 1,000,000 ng/mg

ADI – acceptable daily intake; IARC – International Agency for Research on Cancer; SF – Slope Factor; VSD – Virtually Safe Dose

5.0 RISK CHARACTERIZATION

In the Risk Characterization section, the results of the Exposure Assessment (Section 3.0) and Toxicity Assessment (Section 4.0) are integrated to develop quantitative measures of the potential for adverse health effects. Specifically, dose estimates are compared to toxicity criteria to provide a quantitative measure of the likelihood of noncarcinogenic effects or lifetime excess cancer risks. This section also provides perspective on the relative significance of the estimated hazards and risks compared to risk benchmarks and other sources of exposure, to support risk communication efforts.

5.1 Methodology for Estimating Noncancer Hazards and Cancer Risks

Different methods were used to estimate the potential for noncarcinogenic effects and the increase in lifetime excess cancer risks based on the estimates of dose for each of the COIs, as described below.

5.1.1 Noncarcinogenic Effects

The potential for noncarcinogenic effects was evaluated using the hazard index (HI) approach. This approach assumes that for a particular exposure scenario, the relative magnitude of the adverse effect associated with the total exposure to that chemical is proportional to the ratio of the exposure to the allowable exposure (U.S. EPA, 1989).

Per this approach, for a given COI and exposure scenario, hazard indices (HIs) are calculated by dividing the estimated ADD by the appropriate noncancer ADI for the chemical and exposure route (e.g., oral exposure), per the following equation:

$$HI = \frac{ADD\ (ng/kg-d)}{Noncancer-based\ ADI\ (ng/kg-d)}$$

According to U.S. EPA (1989) guidance, if the resulting HI does not exceed unity (1), then adverse health effects from exposure to that chemical are not expected. If an HI is exceeds 1, it does not mean that adverse health effects from exposure to that chemical are expected or will occur, but that further evaluation of the assumptions applied in the assessment and the significance of the findings is warranted.

5.1.2 Cancer Risks

Where cancer SFs were identified for a given COI, lifetime excess cancer risks (LECRs) were calculated for each exposure scenario. Per this approach, for a given COI and exposure scenario, LECRs are calculated by multiplying the estimated LADD by the appropriate cancer SF for the chemical and exposure route (e.g., oral), per the following equation:

$$LECR = LADD\ (mg/kg-d) \times SF\ (mg/kg-d)^{-1}$$

LECR represents the probability of cancer occurring as the result of exposure at some point during an individual's lifetime (U.S. EPA, 1989). That is, it is the additional or extra cancer risk incurred over the lifetime of an individual as a result of exposure to a toxic substance. For perspective, the average male has an approximately 1 in 2 chance (0.5000) of developing cancer at some point in his lifetime,

and a female has a slightly lower chance (1 in 3, or 0.3333) of the same (ACA, 2023). If the result of this cancer risk analysis estimated a 1 in a million LECR (0.000001, also written as 1×10^{-6} or 1E-06), the total lifetime cancer risk to an exposed man or woman would be 0.500001 or 0.333001, respectively.

Although there is no universally accepted allowable risk standard, the U.S. EPA Superfund program established under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) generally considers LECRs below 1×10^{-6} (1 in 1,000,000, also known as the *de minimis* risk level) to be allowable in nearly all circumstances and risks within the range of 1×10^{-4} to 1×10^{-6} (1 in 10,000 to 1 in 1,000,000) to be allowable depending on specific site and exposure characteristics (U.S. EPA, 1989; U.S. EPA, 1991). The National Contingency Plan (U.S. EPA, 1994), which provides the guidelines and procedures needed to respond to releases and threatened releases of hazardous substances, pollutants, or contaminants under CERCLA, defines the 1×10^{-6} (1 in a million) risk level as the "point of departure" for establishing remediation goals at contaminated sites. Risks above 1×10^{-4} are nearly always considered unacceptable. More specific allowable risk levels have been identified for certain circumstances. For example, under U.S. EPA's Great Lakes Initiative (U.S. EPA, 1995), a 1×10^{-5} (1 in 100,000) risk level is identified for use in deriving criteria and values for individual carcinogens in Great Lakes surface water and fish. Under the Health Advisory (HA) program for drinking water, U.S. EPA's Office of Water publishes Drinking Water Specific Risk Level Concentrations of drinking water contaminants corresponding to a lifetime excess cancer risk of 1×10^{-4} (1 in 10,000) (U.S. EPA, 2018).

In addition, for the COIs identified as potential carcinogens, a cancer risk index was calculated based the LADD and the cancer risk-based ADI (derived either from the cancer SF, assuming an allowable *de minimis* lifetime excess cancer risk of 1×10^{-6}, or based on a VSD) as described in Section 4.2.3.4, as follows:

$$Cancer\ Risk\ Index = \frac{LADD\ (ng/kg-d)}{Cancer-based\ ADI\ (ng/kg-d)}$$

If the resulting chemical-specific cancer risk index does not exceed unity (1), then the lifetime excess cancer risk is assumed to not exceed a *de minimis* risk level of 1×10^{-6}. If a cancer risk index exceeds 1, it does not mean that adverse health effects from exposure to that chemical are expected or will occur, but that further evaluation of the assumptions applied in the assessment and the significance of the findings is warranted.

5.2 Screening Level HHRA Results

Noncancer hazards and cancer risks were calculated for each of the exposure scenarios and populations for the 28 COIs.[2] These are described below.

5.2.1 Estimated Screening Level Noncancer Hazards

Screening level (upper bound) estimates of noncancer hazards (HIs) for each of the COIs for the child and adult for exposure to carrots or kale irrigated with recycled water or Sammamish River water are presented in Table 5-1. Upper bound estimates of noncancer HIs that exceed 1.0 are highlighted.

Estimated screening level noncancer HIs exceed 1 for only one chemical, PFOA, when HIs are calculated using the draft U.S. EPA RfD for PFOA of 0.0015 ng/kg-d. For PFOA, when the U.S. EPA draft RfD is used, estimated HIs range from 13 to 120 for the evaluated scenarios, with comparable values for produce irrigated with either recycled water or Sammamish River water.

However, when HIs are calculated using the Washington State SAL for PFOA of 3 ng/kg-d, all HIs are well below 1, ranging from 0.0065 to 0.059 for the evaluated scenarios.

One can interpret the upper bound HI estimates for PFOA for the vegetable consumption scenarios as follows:

- If an adult consumes kale with the assumed EPC of PFOA in kale irrigated with recycled water (EPC = 0.271 ng/g, wet weight, which is equal to the maximum concentration of PFOA detected in kale) nearly every day for six months and eats an average of 109 g (approximately 1.6 cups) of kale per day, the upper bound estimate of their average daily dose of PFOA is estimated to exceed U.S. EPA's allowable daily dose for this chemical based on U.S. EPA's draft RfD (that is, the estimated HI exceeds unity, or 1).
- However, if an adult eats fewer than four servings of kale with this concentration from this source per year, their estimated average daily doses would not exceed U.S. EPA's allowable daily dose for this chemical based on U.S. EPA's draft RfD (that is, the estimated HI is less than 1).
- U.S. EPA's draft RfD for PFOA of 0.0015 ng/kg-d is based on an extremely sensitive point of departure (it is based on a dose from human epidemiological studies in which a developmental immune health outcome—decreased serum anti-tetanus antibody concentration following tetanus vaccination in 7-year-old children—was observed; U.S. EPA, 2021). However, the State of

[2] Note that in this HHRA, estimated noncancer hazards and cancer risks are presented to two significant figures because most inputs to the dose and risk calculations are estimated to two or more significant figures (including the EPCs, most exposure parameters, and some toxicity criteria) and to distinguish between calculated hazard and risk estimates for different chemicals and scenarios that have slightly different values for input parameters. However, some risk assessment guidance, including U.S. EPA's *Risk Assessment Guidance for Superfund: Volume I — Human Health Evaluation Manual (Part A)* (U.S. EPA, 1989), recommends that risk estimates be expressed using one significant figure only because of limitations in the number of significant figures in some input parameters.

Washington has also promulgated a SAL for PFOA that is set equal to the Centers for Disease Control (CDC) ATSDR MRL for PFOA of 3 ng/kg-d, which is developed based on the lowest dose that was associated with reproductive and developmental effects in a study in mice, an effect endpoint that both the State of Washington Department of Health and the ATSDR consider to be the most sensitive for exposure to PFOA (WDOH, 2021; ATSDR, 2021)—that is, they assume that any other adverse effects that might occur would occur at a higher dose. When the SAL is used in the hazard calculation for PFOA, all estimated HIs for this chemical are well below 1 (i.e., estimated doses are below the toxicity criterion, and no significant noncancer hazard is estimated).

- An HI >1 does not mean that adverse health effects are expected or will occur. If the HI is close to 1, adverse health effects are unlikely even if a person's exposure is at the estimated upper bound level. This is because multiple uncertainty factors are incorporated into the derived the toxicity criterion for noncancer effects (i.e., the allowable daily dose) to ensure it is a level at or below which adverse health effects are not expected.

Estimated HIs for all other COIs and scenarios evaluated in this HHRA are below 1 (i.e., estimated upper bound screening level average daily doses are below the respective toxicity criteria for each COI).

5.2.2 *Estimated Screening Level Cancer Risks*

Upper bound estimates of LECRs for the COIs determined to be potential carcinogens are summarized in Table 5-2. LECRs were only calculated for furosemide and PFOA since these are the only two COIs for which cancer slope factors (SFs) were identified. None of the upper bound estimates of LECRs for these chemicals exceeds a *de minimis* lifetime excess cancer risk level of 1 in 1,000,000 (1×10^{-6}). This can be interpreted as a probability that, even at the upper bound exposure estimates, fewer than 1 person in one million (10^6) people would develop cancer over their lifetime as a result of this exposure.

In addition, cancer risk index values were calculated for all three COIs assumed to be potential carcinogens (etoposide, furosemide, and PFOA). Estimated cancer risk index values are less than 1 for furosemide and PFOA for all scenarios, and for consumption of etoposide in kale irrigated with Sammamish River water, meaning that lifetime excess cancer risks for these chemicals and scenarios are assumed to not exceed a *de minimis* risk level of 1 in 1,000,000 (1×10^{-6}). However, the estimated cancer risk index for consumption of etoposide in kale that is irrigated with recycled water is 1.8, meaning that the risk for this scenario slightly exceeds a *de minimis* risk level of 1 in 1,000,000 (1×10^{-6}) (this risk would be equivalent to an LECR of 1.8 in a million (1.8×10^{-6})).

One can interpret this risk estimate for etoposide as a probability that, using the conservative upper bound cancer risk estimate, 1.8 persons in one million (10^6) people could develop cancer if they are exposed to this chemical at this rate over their lifetime. As described in Section 5.1.2, while this upper bound risk estimate exceeds the *de minimis* lifetime excess risk estimate of 1 in 1,000,000 (1×10^{-6}), it is within the range of risks of 1×10^{-4} to 1×10^{-6} (1 in 10,000 to 1 in 1,000,000) considered to be allowable depending on specific site and exposure characteristics (U.S. EPA, 1989; U.S. EPA, 1991). Further, considering that the average male has an approximately 1 in 2 chance (0.5000) of

developing cancer at some point in his lifetime and a female has a slightly lower chance (1 in 3, or 0.3333) of the same (ACA, 2023), the estimated upper bound LECR of a 1.8 in a million (0.0000018) for etoposide for this scenario is equal to a total lifetime cancer risk to an exposed man or woman of 0.5000018 or 0.3330018, respectively.

Table 5-1. Estimated Chemical- Specific Noncancer Hazard Indices (HIs) for COIs in Carrots and Kale

	Irrigated with Recycled Water				Irrigated with Sammamish River Water			
	Carrots		Kale		Carrots		Kale	
Chemical of Interest	**Child**	**Adult**	**Child**	**Adult**	**Child**	**Adult**	**Child**	**Adult**
10-hydroxy-amitriptyline	0.00031	0.00018	ND	ND	0.00023	0.00013	ND	ND
2-Hydroxy-ibuprofen	0.0011	0.00063	0.0012	0.0014	0.0024	0.0014	0.0011	0.0013
6:2 FTS	0.000062	0.000036	0.00023	0.00026	0.000078	0.000045	0.000039	0.000045
Amitriptyline	0.0029	0.0017	0.0016	0.0019	0.0018	0.001	0.0017	0.0019
Bisphenol A	0.00052	0.0003	0.0011	0.0013	0.00014	0.000079	0.00046	0.00054
Cimetidine	ND	ND	0.0059	0.0069	ND	ND	0.005	0.0059
Ciprofloxacin	0.0086	0.005	0.014	0.016	0.012	0.0073	0.025	0.029
Clinafloxacin	0.032	0.019	0.046	0.054	0.025	0.014	0.033	0.039
Cloxacillin	0.00013	0.000073	0.0012	0.0014	ND	ND	0.0029	0.0035
Cocaine	ND	ND	0.014	0.017	ND	ND	0.0088	0.01
DEET	0.0000026	0.0000015	0.0000042	0.000005	0.0000019	0.0000011	0.0000041	0.0000048
Enrofloxacin	0.0018	0.001	ND	ND	ND	ND	ND	ND
Etoposide	ND	ND	0.14	0.17	ND	ND	0.059	0.069
Furosemide	ND	ND	ND	ND	ND	ND	0.045	0.053
Ibuprofen	0.0009	0.00052	0.0056	0.0066	ND	ND	0.0011	0.0013
Metformin	0.0072	0.0042	0.0013	0.0016	0.00011	0.000065	0.00019	0.00022
Ofloxacin	0.00073	0.00042	ND	ND	0.00038	0.00022	0.00067	0.00078
Oxacillin	0.00029	0.00017	0.0024	0.0028	ND	ND	0.0053	0.0062
Penicillin V	0.00057	0.00033	0.0022	0.0026	0.00068	0.0004	0.0025	0.0029
PFBA	0.00024	0.00014	0.0014	0.0017	0.00026	0.00015	0.001	0.0012
PFBS	ND	ND	0.0002	0.00023	ND	ND	ND	ND
PFDoA	ND	ND	ND	ND	0.003	0.0018	ND	ND
PFHxA	ND	ND	0.00066	0.00077	0.00066	0.00039	0.00074	0.00087
PFOA (based on U.S. EPA draft RfD)	22	13	100	120	24	14	82	96
PFOA (based on Washington DOH SAL)	0.011	0.0065	0.050	0.059	0.012	0.0071	0.041	0.048

	Irrigated with Recycled Water				Irrigated with Sammamish River Water			
	Carrots		Kale		Carrots		Kale	
Chemical of Interest	**Child**	**Adult**	**Child**	**Adult**	**Child**	**Adult**	**Child**	**Adult**
PFPeA	ND	ND	0.0009	0.0011	0.0002	0.00012	0.0006	0.0007
Sulfadiazine	ND	ND	0.0003	0.00035	ND	ND	0.00034	0.0004
Theophylline	0.00062	0.00036	0.0019	0.0023	0.00046	0.00027	0.0015	0.0018
Topiramate	ND	ND	0.0041	0.0048	ND	ND	ND	ND
Warfarin	ND	ND	0.0023	0.0027	ND	ND	0.0019	0.0022

ND – Not detected; RfD – Reference Dose; SAL – State Action Level

Table 5-2. Estimated Chemical- Specific Lifetime Excess Cancer Risks (LECRs) and Cancer Indices for COIs in Carrots and Kale

Chemical of Interest	LECR				Cancer Risk Index			
	Carrot-Recycled Water	Kale-Recycled Water	Carrot-Sammamish River Water	Kale-Sammamish River Water	Carrot-Recycled Water	Kale-Recycled Water	Carrot-Sammamish River Water	Kale-Sammamish River Water
Etoposide	ND	Not calculated*	ND	Not calculated*	ND	1.8*	ND	0.75*
Furosemide	ND	ND	ND	2.3×10^{-8}	ND	ND	ND	0.023
PFOA	7.1×10^{-10}	5.5×10^{-9}	7.8×10^{-10}	4.5×10^{-9}	0.00071	0.0055	0.00078	0.0045

*LECR not calculated because a cancer slope factor (SF) is not available due to the lack of tumor incidence data. However, an ADI was estimated based on the maximum tolerated clinical dose using the VSD method—this ADI was used to calculate a Cancer Risk Index.

ADI – acceptable daily intake; LECR – lifetime excess cancer risk; ND – Not detected; SF – slope factor; VSD – virtually safe dose

6.0 COMPARISON OF ESTIMATED PFOA DOSES TO DOSES FROM OTHER SOURCES OF EXPOSURE

As described in Section 5.2, estimated exposures for one COI exceeded the allowable risk threshold based on the results of this screening level HHRA: for PFOA, when HIs were calculated using the draft U.S. EPA RfD for PFOA of 0.0015 ng/kg-d, estimated noncancer HIs range from 13 to 120 for the evaluated scenarios, with comparable values for produce irrigated with either recycled water or Sammamish River water. However, when noncancer HIs were calculated using the Washington State SAL for PFOA of 3 ng/kg-d, all HIs are well below 1, ranging from 0.0065 to 0.059 for the evaluated scenarios.

However, people can be exposed to PFAS from multiple sources, including food and water ingestion, ingestion of house dust, inhalation from impregnated clothes, and hand-to-mouth transfer from carpets. To provide perspective on the doses of PFOA estimated in the screening level HHRA, potential exposures from other sources are described below, based on data described in the scientific literature.

6.1 Summary of Findings Reported in Other Studies

Studies describing concentrations of PFOA detected in consumer media or that characterize estimated doses of PFOA based on detected (not modeled) concentrations in environmental and food sources are summarized below. Described studies focus on exposures characterized for the United States or other western countries (e.g., North America or Europe), and are reported in chronological order.

6.1.1 PFOA in Food Packaging and Migration into Food (Begley et al., 2005 and Schaider et al., 2017))

Several studies have investigated the concentrations of PFOA and other PFAS in food-contact materials, and assessed the potential for transfer of the PFAS to food. The studies showed the presence of PFAS in many of the tested food contact materials, but that transfer to food depended on several factors, including initial concentration, presence of oils, and temperature.

Begley et al. (2005) investigated the amounts of PFOA and other PFAS in food-contact materials and in several other types of materials including dental floss, dental tubing, PTFE (polytetrafluoro-ethylene) tape, and FEP (fluoro-ethylene-propene copolymer) tubing. The authors also investigated the mass transfer of PFOA and other fluorotelomers from the materials into a food oil simulant (Miglyol®) and water.

Table 6-1 summarizes the concentrations of PFOA detected in the products. Detectable concentrations were reported in several products, with the highest concentration of 1,800 ng/g measured in PTFE film/ sealant and somewhat lower concentrations or non-detect concentrations reported in products with direct food application, although the detection limit is not reported.

Concentrations of PFOA in perfluoro paper coatings prior to application to products ranged from 88,000 to 160,000 ng/g—however, these coatings are diluted prior to application.

Begley et al. (2005) also evaluated migration of PFOA from PTFE-coated cookware and popcorn bags. To evaluate migration of PFOA from PTFE-coated cookware to food, Begley et al. (2005) used a surrogate material—a 75-µm thick PTFE film (sealant film) that contained enough residual PFOA (1.8 mg/kg) to make reliable mass transfer measurements. PFOA was shown to migrate from PTFE to both water and oil at 100°C, at a fractional migration rate of about 4% when migration cells were heated for 2 hours. Migration increased with increasing temperatures. Evaluation of migration of PFOA from microwave popcorn bags that initially contained about 300 µg/kg PFOA to Miglyol® showed that the concentration of PFOA in Miglyol® after microwaving was less than 1 µg/kg. Subsequent analysis of the popcorn bags suggested the particular test bags that were used primarily contained PFOA on the outside of the bags.

In a later study, Schaider et al. (2017) investigated the presence of PFAS in fast food wrappers and containers from various regions across the United States. The wrappers were categorized into six types including food contact paper (such as a sandwich wrapper), non-contact paper (e.g., the outer bag of a fast food order), food contact paperboard (such as the boxes for fries), paper cups, other beverage containers, and miscellaneous items such as lids. A total of 407 samples were analyzed for total fluorine using particle-induced γ-ray emission (PIGE) spectroscopy, with a smaller subset of 20 compounds analyzed for specific PFAS compounds by liquid chromatography/high-resolution mass spectrometry to gain insight into the types of PFAS present. Table 6-2 presents the estimated frequencies of detection of selected PFAS compounds in the dataset, based on analysis of a subset (n = 20) of the samples. As shown, PFBS and PFHxA were detected most frequently (35% of the samples), followed by PFOA (30% of the samples). Detected levels or detection limits in ng/g or similar measurement are not reported, but the authors report that fluorine concentrations in analyzed samples ranged from 16 to 800 nmol F/cm^2.

Approximately 33% of all food wrappers and containers tested had fluorine concentrations above the limit of detection (LOD) (characterized as equivalent to 30 µg/dm^2 of fluorine, which for PFOA is reported to 44 µg PFOA/dm^2). The authors reported that the LOD exceeded the Danish Ministry of Environment and Food's regulatory limit of 0.35 µg/dm^2 of fluorine permitted—values were compared to the Danish limit because no other U.S. or international limit for PFAS compounds in food wrappers and containers was identified. According to the authors, this limit corresponds to 0.5 µg PFOA equivalents/dm^2, which they assumed would correspond to a tolerable daily intake from food of 5 µg PFOA equivalents/kg food (they assumed a person eats 1 kg of food/day, that 1 kg of food comes into contact with 10 dm^2 of paper, and that 100% of PFASs in packaging migrate into food).

6.1.2 PFOA Exposure to Consumers in Canadian Dietary Exposure Study (Tittlemier et al., 2007)

Tittlemier et al. (2007) conducted a dietary exposure study of Canadians exposed to PFAS compounds via consumption of packaged fast foods, meat, poultry, and eggs, fish and seafood, and pre-prepared food items. Different types of composite samples were prepared in 1998 or 2004 from each of these main subtypes (e.g., the "fast food" category included multiple composites of "chicken burger", "egg breakfast sandwich", "French fries", "hamburger", and "pizza"; the "meat, poultry, and eggs" category included composites such as "beef steak", "ground beef", "luncheon meat", and eggs; the "fish and seafood category" included composites of "fish, freshwater", "fish, marine", "fish, canned", and "shellfish"; and the "prepared foods" category included composites of "frozen entrée" and "microwave popcorn"). A total of 54 different composite types were analyzed. The authors detected PFAS in 9 of 54 composites (specifically, beef steak, roast beef, ground beef, luncheon meats/cold cuts, marine fish, freshwater fish (two composites, from 1998 and 2004), pizza, and microwave popcorn). PFOA was detected in only three of these composites, at concentrations of 0.74 ng/g wet weight (ww) in pizza, 2.6 ng/g ww in roast beef, and 3.6 ng/g ww in microwave popcorn.

6.1.3 PFOA Exposure from Food, Environmental, and Consumer Product-Related Sources (Trudel et al., 2008 and Fromme et al., 2009)

Two studies (Trudel et al., 2008 and Fromme et al., 2009) were identified that conducted comprehensive evaluations of PFOA exposure from multiple nonoccupational sources in North America.

Trudel et al. (2008) conducted a comprehensive assessment of consumer exposure to PFOA and PFOS from a variety of food, environmental, and consumer product-related sources in North America, as well as in Europe, including oral sources (e.g., food consumption, ingestion of house dust, hand-to-mouth transfer from treated carpets, migration from paper and cardboard into food), and inhalation (e.g., inhalation of indoor and ambient air and spray aerosols). Doses were estimated based on media concentrations reported in other publications (which are not explicitly reported by the authors, but the timeframe for data collection ranged from 1999 to 2007), combined with intake rate assumptions for each exposure route. A "high-exposure" estimate was calculated using upper-bound (95th percentile) exposure parameter values and assuming that non-detected concentrations were present at their detection limit.

The analysis estimated that younger consumers tend to receive higher PFAS doses on a per kilogram body weight basis than older consumers, due largely to greater contributions from hand-to-mouth exposures from contact with carpet as well as ingestion of dust. Estimated doses of PFOA for the different exposure populations and exposure routes based on data for North America are summarized in Table 6-3. As shown, the population group with the highest calculated long-term average total daily dose of PFOA was toddlers (128 ng/kg-d) and the lowest was adults (approximately 47 and 42 ng/kg-d, for females and males, respectively). For teens and adults, food consumption was estimated to contribute most to daily exposure, while for infants, toddlers, and children, contact with treated

carpets (through hand-to-mouth exposure followed by ingestion) and indoor dust ingestion (of dust contaminated by PFAS-containing materials such as carpets, upholstery, and clothes in the household) also contributed significantly to exposure.

In a different study, Fromme et al. (2009) estimated average daily exposure of the general population in western countries (e.g., North America, Europe, Japan) to PFAS from indoor and ambient air, house dust, drinking water, and food, based on concentrations measured in these media between 2001 and 2006 and reported in different publications. For adults, the estimated average and upper levels of daily exposure including all potential routes were 2.9 ng/kg-d and 12.6 ng/kg-d, respectively (Table 6-4). The majority of exposure was attributed to the oral route, mainly to diet (approximately 98% and 91%, for the average and upper level exposure estimates, respectively).

6.1.4 PFOA Concentrations in Food Samples from Dallas, Texas (Schecter et al., 2010)

Schecter et al. (2010) conducted a study to measure concentrations of persistent organic pollutants (POPs), including PFAS compounds and in particular PFOA, in composite food samples consisting of 10 samples of 31 different food types. The authors also estimated daily exposure to the compounds based on detected concentrations.

Food samples were collected from five grocery stores in Dallas, TX in 2009. A total of 310 individual food samples were collected. Concentrations of PFOA detected are summarized in Table 6-5. The estimated per capita exposure to PFOA for an average consumer in the U.S., based on the detected concentrations, was 60 ng/d, of which 65.6% was estimated to be contributed by meat (39.4 ng/d), 13.1% by vegetable products (7.9 ng/d), 11.2% by dairy and eggs (6.7 ng/d), and 10% by fish (6.0 ng/d).

6.1.5 PFOA Exposure from Diet in European Countries (EFSA, 2020)

The European Food Safety Authority (EFSA, 2020) conducted an evaluation to estimate dietary exposures (including from food as well as drinking water and other beverages) to PFOA and other PFAS. Daily exposures were estimated for infants (<12 months), toddlers (≥ 12 months to <36 months), "other children" (≥ 36 months to <10 years), adolescents (≥ 10 to <18 years), adults (≥18 to <65 years), elderly persons (≥ 65 to <75 years), and "very elderly" persons (≥ 75 years), based on dietary surveys conducted between 2010 and 2018 in up to 25 European countries. The majority of data were provided by France, Germany, and Norway. Lower- and upper-bound estimates of average daily exposure were derived by assigning a value of zero to non-detected measurements in the derivation of lower bound estimates and a value equal to the detection limit to non-detected measurements in the derivation of upper bound estimates.

Table 6-6 summarizes estimated daily dietary exposures to PFOA reported in EFSA (2020). Given that the "lower bound" mean estimate assumes a concentration of "zero" for all nondetects (a likely underestimate) and the "upper bound" mean estimate assumes that all nondetect values are at the detection limit (a likely overestimate), the true mean exposure level is expected to be between the two values. For example, for a child age 3 to 10 years, the lower bound estimate of mean dietary

exposure to PFOA is 0.30 ng/kg-d and the upper bound estimate is 13.82 ng/kg-d; a more likely exposure level can be approximated as around 7.1 ng/kg-d. For an adult, the lower bound estimate of mean daily dietary exposure to PFOA is 0.18 ng/kg-d, and the upper bound estimate is 4.18 ng/kg-d; a more likely exposure level can be approximated as around 2.2 ng/kg-d.

Per EFSA (2020), fish and other seafood as well as eggs and egg products, meat and meat products, fruit and fruit products, vegetables and vegetable products, and drinking water were the major dietary contributors to PFOA exposure for all age groups.

6.1.6 PFOA and other PFAS in Grocery Store-Purchased Kale (Ames-Sikora et al., 2023)

A recent study conducted by the Alliance for Natural Health (Ames-Sikora et al., 2023) measured concentrations of various PFAS, including PFOA, in samples of kale collected from grocery stores in the United States.

In this study, two kale samples were purchased from each of four grocery stores located in Arizona, Pennsylvania, Georgia, and New York, and the samples were analyzed for 16 PFAS compounds including PFOA[3]. The kale samples included three that were "conventionally grown" and five that were "organically certified." Of the three conventionally grown samples, two were purchased "loose" (i.e., not pre-packaged in plastic packaging) and one was purchased in plastic packaging, and of the five organic samples, two were purchased loose and three were in plastic packaging.

Table 6-7 shows frequencies of detection and maximum-detected concentrations of each PFAS compound in organic and conventional kale. For comparison, PFAS concentrations detected in kale in the KC/WWT study are also shown.

As shown, at least one PFAS compound was detected in seven of the eight grocery store samples. The only sample with no detected PFAS was a conventionally grown kale sample purchased loose from a store in New York. However, PFOA was not detected in any of the eight samples (with a detection limit of 20 ng/kg), and only four of the 16 PFAS were ever detected—these were PFBA, PFPA, PFHxA, and PFOS. PFBA was the most frequently detected PFAS (it was detected in two of three conventional samples and all five organic samples).

Total PFAS concentrations (the sum of all detected concentrations) in conventional and organic kale samples ranged from 120–223 ng/kg and non-detect to 183 ng/kg, respectively. No clear difference in concentrations in samples related to packaging type was apparent—the total PFAS concentrations in "loose" kale ranged from 100–180 ng/kg, while in packaged kale, the total PFAS concentration

[3] The analyzed compounds are identified in thte report as PFBA (perfluorobutanoic acid), PFBS (perfluorobutane sulfonic acid), PFDA (perfluorodecanoic acid), PFHpA (perfluoroheptanoic acid), PFHxA (perfluorohexanaoic acid), PFHxS (perfluorohexanesulfonic acid), PFHS (perfluoroheptane sulfonic acid), PFNA (perfluorononanoic acid), PFPA (perfluoropentaoic acid), PFPS (perfluoropentane sulfonic acid), PFOA (perfluorooctanoic acid),), HFPODA (hexafluoropropylene oxide-dimer acid), PFOS (perfluorooctyl sulfonate), 4,8-dioxa-3H-perfluorononanoic acid, 9Cl-PF3ONS (9-chlorohexadecafluoro-3-oxanonane-1-sulfonateand 11Cl-PF3OUdS (11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid).

ranged from 120–223 ng/kg. In every sample where PFAS was detected, PFBA was the largest contributor to the total PFAS concentration, contributing from 46–100% of total PFAS.

Some similarities and differences in PFAS compounds detected in kale in the grocery store study and the current study are apparent. Like the grocery store study, PFBA was also one of the most frequently detected PFAS in kale in the KC/WWT study, being detected in 15 of 16 samples of kale collected from plots that were irrigated with recycled water and 16 of 16 samples of kale collected from plots irrigated with Sammamish River water. PFPA was also detected in the KC/WWT in 15/16 samples irrigated with recycled water and 16/16 samples irrigated with Sammamish River water. While not detected in the grocery store study, PFOA was detected in kale samples in the KC/WWT study (in 4/16 samples irrigated with recycled water and 3/16 samples irrigated with Sammamish River water), and PFBS was detected in one kale sample in the KC/WWT study but in no samples in the grocery store study. PFAS that were detected in the grocery store study but not in the KC/WWT study were PFHxA (which was detected in three of eight grocery story samples) and PFOS (which was detected in one of eight grocery store samples).

6.1.7 PFOA Exposure Through Consumption of Fish in the United States (Bedi et al., 2023)

Seafood has been recognized as a significant contributor of exposure to PFAS through the diet (Bedi et al., 2023). Bedi et al. (2023) performed a pilot study on seafood purchased grocery stores in Pittsburgh from January to April, 2022. The study aimed to quantify PFAS in seafood and thus the diet, and to produce exposure-based estimates highlighting potentially susceptible populations. PFOA was detected in 6 of 46 seafood samples analyzed (13%), at concentrations of 0.12–2.40 ng/g, with the highest concentration detected in China-sourced clams. Concentrations of PFOA detected in clams in three of the 46 samples were above the European Union's maximum limit (ML) in crustaceans (0.7 ng/g) set by the European Commission.

Estimated intakes of PFAS (the sum of doses of PFOA, PFNA, PFHxS, and PFOS) for low and high exposure scenarios (where low exposure was based on average seafood consumption of 18 g/meal assumed to correspond to consumption of a single meal/week or the average consumption rate for consumers and nonconsumers, and high exposure was based on consumption rates for "adult seafood consumers", defined as those reporting recent seafood consumption in a survey of U.S. consumers) ranged between 0.10–0.30 and 0.45–2.25 ng/kg bw/week, respectively.

6.2 Comparison of PFOA Exposures Reported in the Literature to the Current Study

Table 6-8 compares estimated daily doses of PFOA from various sources, as reported in the reviewed studies, to ADDs of PFOA from consumption of carrots and kale irrigated with recycled water, as estimated in the current screening level HHRA.

Estimated ADDs in the current study are assumed to be upper bound estimates, as they are calculated using maximum-detected concentrations of PFOA in each medium combined with upper bound exposure rate assumptions for ingestion of carrots and leafy vegetables. By comparison, the exposure

estimates from the literature are derived using varying methodologies for calculating dose, but are considered to be conservative estimates.

As shown, estimated ADDs of PFOA in the current screening level HHRA are 0.034 ng/kg-d and 0.15 ng/kg-d for consumption of carrots and kale irrigated with recycled water by a child and 0.020 ng/kg-d and 0.18 ng/kg-d for consumption of carrots and kale irrigated with recycled water by an adult. If these doses are summed (total child dose = 0.18 ng/kg-d and total adult dose = 0.20 ng/kg-d), these dose estimates from consumption of carrots and kale irrigated with recycled water are only a fraction of the daily PFOA dose from all sources, based on estimates reported by Trudel et al. (2008) and Fromme et al. (2009). For example:

- The total child dose of PFOA for consumption of carrots and kale irrigated with recycled water estimated in the screening level HHRA (carrots + kale = 0.18 ng/kg-d) is 1/360 of the total child dose from all sources estimated by Trudel et al. (2008) (66 ng/kg-d).
- The total adult dose of PFOA for consumption of carrots and kale irrigated with recycled water estimated in the screening HHRA (carrots + kale = 0.20 ng/kg-d) is approximately 1/220 of the total adult dose from all sources estimated by Trudel et al. (2008) (approximately 44.5 ng/kg-d) and approximately 1/14 to 1/63 of the total adult dose from all sources estimated by Fromme et al. (2009) (2.86 to 12.61 ng/kg-d).
- The total adult dose of PFOA for consumption of carrots and kale irrigated with recycled water estimated in the screening HHRA (carrots + kale = 0.20 ng/kg-d) is less than the estimated upper bound dose from consumption of fish by an adult presented by Bedl et al. (2003) (0.32 ng/kg-d) and less than the upper bound dose from consumption of total diet by an adult estimated by EFSA (2020) (4.18 ng/kg-d).

For the estimates of PFOA exposure reported in the literature, diet is characterized as a primary source of exposure to PFOA. However, other sources of exposure, including carpet (hand-to-mouth exposure), dust ingestion, and inhalation of PFOA from impregnated clothing are also important.

Table 6-1. PFOA Concentrations Detected in Various Commercial Products and Food-Contact Materials (Begley et al., 2005)

Material/Product	Concentration of PFOA (ng/g)
PTFE cookware	4–75
Dental floss (PTFE based)	3
Dental tape (PTFE based)	4
PTFE film/sealant tape	1,800
FED (fluoro-ethylene-propene copolymer) tubing	ND
Popcorn bags*	6–290
Hamburger wrapper	ND
Sandwich wrapper*	ND
French fry box[1]	ND
Paper plates (soak-proof shield)*	ND

*Paper products were not necessarily treated with perfluoro paper coatings

ND – not detected (detection limit not reported); PTFE – polytetrafluoroethylene

Table 6-2. Estimated Frequencies of Detection of PFAS Compounds in Food Wrappers and Containers in the U.S. (Schaider et al., 2017)

PFAS Compound	Frequency of Detection*
PFOA	30% (6/20)
PFBA	10% (2/20)
PFBS	35% (7/20)
PFDoA	5% (1/20)
PFHxA	35% (7/20)
PFPeA	25% (5/20)

*Estimated frequency of detection was based on chemical-specific analyses of a subset of 20 samples

Table 6-3. Estimated Contribution of Different Exposure Pathways to PFOA Exposure in North America, based on Data Collected in 1999–2007 (Trudel et al., 2008)

	Average Daily Dose (ng/kg-d)						
Pathway	**Infants**	**Toddlers**	**Children**	**Female teens**	**Male teens**	**Female adults**	**Male adults**
Food (not migrated from paper) and water, oral	29	18	12	7.8	8.0	6.7	7.0
Food (migrated from paper/ packaging), oral	10	5.3	3.1	30	28	28	23
Carpet-mill treated (as purchased), hand-to-mouth, oral	29	40	19	0.82	1.0	0.34	0.4
Carpet-home treated (after market), hand-to-mouth, oral	25	35	16	1.1	0.92	0.68	0.35
Dust ingestion	25	13	5.9	4.1	5.3	3.9	4.7
Clothes, impregnated, inhalation	1.5	15	8.2	7.9	7.4	7.3	6.2
Other pathways	1.6	1.1	1.0	0	0	0	0
Total	120	130	66	52	51	47	42

Table 6-4. Estimated Contribution of Different Exposure Pathways to PFOA Exposure (adult, general population) in Western Countries, based on Data Collected in 2001–2006 (Fromme et al., 2009)

	Concentration			Intake (ng/d)		Daily dose (ng/kg-d)	
Pathway	**Mean**	**High**	**Intake rate**	**Mean**	**High**	**Mean**	**High**
Indoor air	4.4 pg/m^3	---	12 m^3/d	0.053	0.053	0.0009	0.0009
Outdoor air	58.4 pg/m^3	552 pg/m^3	1.3 m^3/d	0.076	0.718	0.0013	0.012
House dust	19.72 ng/g	1,234 ng/g	50 mg/d	0.986	61.7	0.0164	1.0283
Diet	---	---	---	169	689	2.8167	11.4833
Drinking water	1.0 ng/L	4.0 ng/L	1.3 L/d	1.3	5.2	0.0217	0.0867
Total	---	---	---	---	---	**2.857**	**12.6112**

Table 6-5. Concentrations of PFOA in 31 Different Food Types Collected in Grocery Stores in Dallas, TX in 2009 (Schecter et al., 2010)

Food Type	Category	PFOA (ng/g)
Hamburger	Meat	0.15
Bacon	Meat	0.24
Sliced turkey	Meat	ND (0.02)
Sausage	Meat	0.09
Ham	Meat	0.02
Sliced chicken breast	Meat	0.02
Roast beef	Meat	ND (0.02)
Canned chili	Fish	0.02
Salmon	Fish	0.23
Canned tuna	Fish	ND (0.05)
Fresh catfish fillet	Fish	0.3
Tilapia	Fish	0.1
Cod	Fish	0.1
Canned sardines	Fish	0.19
Frozen fish sticks	Fish	0.21
Butter	Dairy and egg	1.07
American cheese	Dairy and egg	ND (0.04)
Other cheese	Dairy and egg	ND (0.04)
Whole milk	Dairy and egg	ND (0.02)
Ice cream	Dairy and egg	ND (0.03)
Frozen yogurt	Dairy and egg	ND (0.02)
Whole milk yogurt	Dairy and egg	ND (0.02)
Cream cheese	Dairy and egg	ND (0.03)
Eggs	Dairy and egg	ND (0.04)
Olive oil	Vegetable-based products	1.8
Canola oil	Vegetable-based products	ND (0.05)
Margarine	Vegetable-based products	0.19
Cereals	Vegetable-based products	ND (0.04)
Apples	Vegetable-based products	ND (0.02)
Potatoes	Vegetable-based products	0.07
Peanut butter	Vegetable-based products	0.1

ND – not detected

Table 6-6. Estimates of Mean Dietary Exposure to PFOA in European Countries (data collected in 2010–2018)

	Mean Daily Dietary Exposure to PFOA (ng/kg-d)	
Age Group	**Lower bound**	**Upper bound**
Infant (<12 mo)	0.19	17.33
Toddler (≥ 12 mo to <36 mo)	0.41	18.87
Other children (≥ 36 mo to <10 yr)	0.30	13.82
Adolescent (≥ 10 to <18 yr)	0.17	7.00
Adult (≥18 to <65 yr)	0.18	4.18
Elderly (≥ 65 to <75 yr),	0.17	4.01
Very elderly (≥ 75 yr)	0.15	4.08

Source: EFSA (2020)

Table 6-7. Comparison of Concentrations of Sixteen PFAS Compounds Detected in Kale in the Grocery Store Study (Ames-Sikora et al., 2023) to Concentrations Detected in Kale in the Current Study

	Grocery Store Kale Study (Ames-Sikora et al., 2023)			Current Study		
	Frequency of Detection (Range of concentrations)			Frequency of Detection (Range of concentrations)		
PFAS Compound	Organic Kale	Conventional Kale	Detection Limit (ng/kg)	Kale irrigated w/ Recycled Water	Kale irrigated w/ Sammamish River Water	Detection Limit (ng/kg)
PFOA	0/5 (ND)	0/3 (ND)	20	4/16 (ND–271 ng/kg)	3/16 (ND–221 ng/kg)	94–100
PFBA	5/5 (80–190 ng/kg)	2/3 (ND–150 ng/kg)	80	15/16 (ND–2,600 ng/kg)	16/16 (456–1,830 ng/kg)	400
PFHxA	3/5 (ND–33 ng/kg)	0/3	20	0/16	0/16	100
PFOS	0/5	1/3 (ND–33 ng/kg)	20	0/16	0/16	94–100
PFPA	1/5 (ND–68 ng/kg)	0/3 (ND)	20	15/16 (ND–805 ng/kg)	15/16 (ND–538 ng/kg)	190–192
PFBS	0/5	0/3	40	1/16 (ND–107 ng/kg)	0/16	94–100
PFDA	0/5	0/3	20	0/16	0/16	94–100
PFHpA	0/5	0/3	20	0/16	0/16	94–100
PFHS	0/5	0/3	20	0/16	0/16	94–100
PFHxS	0/5	0/3	20	0/16	0/16	94–100
PFNA	0/5	0/3	20	0/16	0/16	94–100
PFPS	0/5	0/3	20	0/16	0/16	95–101
HFPODA	0/5	0/3	100	0/16	0/16	358–380
11Cl-PF3OUdS	0/5	0/3	20	0/16	0/16	378–401
4,8-Dioxa-3H-perfluoro-nonanoic acid	0/5	0/3	20	Not analyzed	Not analyzed	Not analyzed
9Cl-PF3ONS	0/5	0/3	20	0/16	0/16	378–401

ND – not detected

Table 6-8. Comparison of Estimated PFOA Doses from Carrot or Kale Consumption in the Current Study to Exposure Estimates from Different Sources in the Literature

		PFOA Dose (ng/kg-d)				
Source Category	**Current Study**	**Trudel et al. (2008), North America (collected 1999-2007) Child**	**Trudel et al. (2008), North America (collected 1999-2007) Adult[a]**	**Fromme et al. (2009), Western Countries (collected 2001-2006) Adult[b]**	**EFSA (2020), Europe (collected 2010-2018) Adult**	**Bedl et al (2023), United States (collected 2022) Adult**
Literature						
Diet	--	12[c]; 3.1[d]	6.7–7.0[c]; 23–28[d]	2.8–11.5	0.18–4.18[e]	0.06–0.32[f]
Drinking water	--	---	---	0.022–0.087	---	---
Carpet-mill treated (as purchased), hand-to-mouth, oral	--	19	0.34–0.40	---	---	---
Carpet-home treated (after market), hand-to-mouth, oral	--	16	0.35–0.68	---	---	---
Dust ingestion	--	5.9	3.9–4.7	0.016–1.03	---	---
Clothes, impregnated, inhalation	--	8.2	6.2–7.3	---	---	---
Indoor air	--	---	---	0.0009	---	---
Outdoor air	--	---	---	0.0013–0.012	---	---
Other pathways	--	1.0	0	---	---	---
Total	--	**66**	**42–47**	**2.86–12.61**	---	---
Current Study						
Child, consumption of carrots irrigated with recycled water	0.034	--	--	--	--	--
Child, consumption of kale irrigated with recycled water	0.15	--	--	--	--	--
Adult, consumption of carrots irrigated with recycled water	0.020	--	--	--	--	--
Adult, consumption of kale irrigated with recycled water	0.18	--	--	--	--	--

A Range of estimates for adult females and males

B Range for mean and upper level estimates

c Range for "food (not migrated from paper) and water, oral"

d Range for "food (migrated from paper/ packaging), oral"

e Range based on lower bound and upper bound exposure

f Fish consumption only, "high" exposure scenario (i.e., "seafood consumers")

7.0 SUMMARY AND CONCLUSIONS

A screening level HHRA was conducted to characterize potential exposures and noncancer hazards or cancer risks to hypothetical populations that could be exposed to COIs through consumption of carrots or kale that have been irrigated with recycled or Sammamish River water, including children and adults. As part of a study conducted by KC/WWT, in 2020 and 2021, carrots and kale were grown in a demonstration garden in the Sammamish River Valley and irrigated with either recycled water (from the King County Brightwater Recycled Water Treatment Plant in Woodinville, WA) or Sammamish River water. Carrots and kale, which were considered representative of root and leafy vegetables, respectively, were sampled and analyzed for as many as 198 CECs to characterize uptake of the chemicals from irrigation water or soil into edible vegetables. The CECs included pharmaceuticals and personal care product ingredients, pesticides, and other chemicals associated with plastics, clothing, or industrial processes, which have been characterized as potentially present in recycled water.

Twenty-eight CECs detected in carrots and kale were identified as COIs in the screening level HHRA. A chemical was identified as a COI if it was detected at a frequency of at least 25% in any of the four data subsets considered in the HHRA (i.e., carrots irrigated with recycled water, carrots irrigated with Sammamish River water, kale irrigated with recycled water, or kale irrigated with Sammamish River water), or if it was a member of the PFAS chemical group and was detected at least once in samples of carrots or kale.

Exposures to hypothetically exposed populations (children and adults who consume produce grown in gardens irrigated with recycled water or Sammamish River water) were then calculated based on the maximum-detected concentration of each COI detected in the corresponding data subset. Assumed consumption rates of carrots and kale were based on the upper bound (90^{th} percentile) per capita average daily consumption rates of carrots and leafy vegetables consumed by U.S. populations for the corresponding age groups, combined with the assumption that exposure occurs for 350 days per year and that people consume locally grown carrots and kale from the irrigated plots for half (50%) of the year.

To evaluate the potential for adverse health effects at estimated exposures levels, toxicity criteria for the COIs were identified based on published, peer-reviewed values, or derived using data from the toxicological literature or from therapeutic doses (for pharmaceuticals). Using these values, upper bound estimates of noncancer HIs and cancer risks were calculated.

Overall, the results of the screening level HHRA showed that estimated upper bound noncancer HIs exceed 1 for only one chemical, PFOA, when HIs were calculated using the draft U.S. EPA RfD for PFOA of 0.0015 ng/kg-d. For PFOA, HIs estimated based on the draft U.S. EPA RfD range from 13 to 120 for the evaluated scenarios, with comparable values estimated for produce that was irrigated with recycled water or Sammamish River water. However, when HIs were estimated for PFOA using

the Washington State SAL for PFOA of 3 ng/kg-d, all HIs were well below 1, ranging from 0.0065 to 0.059 for the evaluated scenarios.

Upper bound estimates of lifetime excess cancer risks exceed a *de minimis* lifetime excess cancer risk level of 1 in 1,000,000 (1×10^{-6}) for only one chemical and scenario: consumption of etoposide in kale irrigated with recycled water. For this chemical and scenario, the lifetime excess cancer risk is 1.8 in a million (1.8×10^{-6}), which slightly exceeds the *de minimis* risk level. One can interpret this risk estimate for etoposide as a probability that, using the conservative upper bound cancer risk estimate for etoposide derived in this screening level HHRA, 1.8 persons in one million (10^6) people could develop cancer if they are exposed to this chemical at this rate over their lifetime. However, while this upper bound risk estimate slightly exceeds the *de minimis* lifetime excess risk estimate, it is within the range of risks of 1×10^{-4} to 1×10^{-6} (1 in 10,000 to 1 in 1,000,000) considered to be allowable by U.S. EPA depending on specific site and exposure characteristics. Further, considering that the average male has an approximately 1 in 2 chance (0.5000) of developing cancer at some point in his lifetime and a female has a slightly lower chance (1 in 3, or 0.3333) of the same, the upper bound LECR of a 1.8 in a million (0.0000018) for etoposide for this scenario is equal to a total lifetime cancer risk to an exposed man or woman of 0.5000018 or 0.3330018, respectively.

People can be exposed to PFAS from multiple sources, including food and water ingestion, ingestion of house dust, inhalation from impregnated clothes, and hand-to-mouth transfer from carpets. Estimated ADDs of PFOA in the current study from consumption of carrots and kale grown in the test plots irrigated with recycled water are 0.18 ng/kg-d for a child and 0.20 ng/kg-d for an adult. However, these dose estimates from consumption of carrots and kale are only a fraction of the daily PFOA doses from all sources as reported in the literature. Specifically, the total child dose of PFOA estimated in the screening level HHRA (carrots + kale, or 0.18 ng/kg-d) is about 1/360 of the total child dose from all sources estimated by Trudel et al. (2008) (66 ng/kg-d), while the total adult dose of PFOA estimated in the screening HHRA (carrots + kale, or 0.20 ng/kg-d) is approximately 1/220 of the total adult dose from all sources estimated by Trudel et al. (2008) (approximately 44.5 ng/kg-d) and approximately 1/14 to 1/63 of the total adult dose from all sources estimated by Fromme et al. (2009) (2.86 to 12.61 ng/kg-d). Diet is characterized as a primary source of exposure to PFOA, but other sources of exposure, including carpet (hand-to-mouth exposure), dust ingestion, and inhalation of PFOA from impregnated clothing are also important.

This screening level evaluation was conducted using conservative assumptions about exposure to chemicals of potential concern in carrots or kale irrigated with recycled water (specifically, the assessment assumes that for approximately one-half of the year, a person eats daily about 1/5 of a cup of carrots, and about one-half cup (for a child) or one-and-a-half cups (for an adult) of kale, grown locally and irrigated with recycled water, and that concentrations of the chemicals in these vegetables are equal to the maximum concentrations that were detected in the KC/WWT study). Because of the conservative methods applied in this screening level HHRA, it is likely that exposures and risks are overestimated, and actual exposures and risks that could occur are much lower. Overall,

this screening level HHRA concludes that, based on the data and methods applied here, health risks from consumption of carrots and kale treated with recycled water are minimal and not expected to exceed allowable risk ranges, and that exposures to PFOA, in particular, are likely to be a fraction of what a person could get from other common, daily sources.

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APPENDIX A

SUMMARY OF ESTIMATED NONCANCER AVERAGE DAILY DOSES (ADDS) AND CANCER LIFETIME AVERAGE DAILY DOSES (LADDS) FOR CHEMICALS OF INTEREST (COIS) FOR EACH POPULATION AND SCENARIO

Table A-1: Noncancer Average Daily Doses (ADDs) for Chemicals of Interest (COIs) in Carrots and Kale

Compound	ADD (ng/kg-d)– Recycled Water, carrot, child	ADD (ng/kg-d)– Recycled Water, carrot, adult	ADD (ng/kg-d)– Recycled Water, kale, child	ADD (ng/kg-d)– Recycled Water, kale, adult	ADD (ng/kg-d)– Sammamish River Water, carrot, child	ADD (ng/kg-d)– Sammamish River Water, carrot, adult	ADD (ng/kg-d)– Sammamish River Water, kale, child	ADD (ng/kg-d)– Sammamish River Water, kale, adult
10-hydroxy-amitriptyline	1.1E-01	6.4E-02	ND	ND	8.3E-02	4.8E-02	ND	ND
2-Hydroxy-ibuprofen	1.0E+00	6.0E-01	1.1E+00	1.3E+00	2.3E+00	1.4E+00	1.0E+00	1.2E+00
6:2 FTS	9.3E-01	5.4E-01	3.4E+00	4.0E+00	1.2E+00	6.8E-01	5.8E-01	6.8E-01
Amitriptyline	1.1E+00	6.1E-01	5.7E-01	6.7E-01	6.3E-01	3.7E-01	6.0E-01	7.0E-01
Bisphenol A	3.4E+00	2.0E+00	7.2E+00	8.5E+00	8.8E-01	5.1E-01	3.0E+00	3.5E+00
Cimetidine	ND	ND	1.1E+01	1.3E+01	ND	ND	9.6E+00	1.1E+01
Ciprofloxacin	1.2E+00	7.1E-01	1.9E+00	2.2E+00	1.7E+00	1.0E+00	3.5E+00	4.1E+00
Clinafloxacin	2.1E+00	1.2E+00	3.1E+00	3.6E+00	1.6E+00	9.6E-01	2.2E+00	2.6E+00
Cloxacillin	6.0E-01	3.5E-01	5.7E+00	6.7E+00	ND	ND	1.4E+01	1.7E+01
Cocaine	ND	ND	9.6E-01	1.1E+00	ND	ND	5.9E-01	6.9E-01
DEET	3.2E-01	1.8E-01	5.1E-01	6.0E-01	2.3E-01	1.3E-01	4.9E-01	5.8E-01
Enrofloxacin	4.7E-01	2.7E-01	ND	ND	ND	ND	ND	ND
Etoposide	ND	ND	6.3E+00	7.4E+00	ND	ND	2.6E+00	3.0E+00
Ibuprofen	8.5E-01	5.0E-01	5.3E+00	6.3E+00	ND	ND	1.1E+00	1.3E+00
Metformin	1.7E+01	1.0E+01	3.2E+00	3.7E+00	2.7E-01	1.6E-01	4.5E-01	5.2E-01
Oxacillin	3.5E-01	2.0E-01	2.9E+00	3.4E+00	ND	ND	6.4E+00	7.4E+00
Penicillin V	3.4E-01	2.0E-01	1.3E+00	1.5E+00	4.1E-01	2.4E-01	1.5E+00	1.7E+00
PFBA	2.4E-01	1.4E-01	1.4E+00	1.7E+00	2.6E-01	1.5E-01	1.0E+00	1.2E+00
PFBS	ND	ND	6.0E-02	7.0E-02	ND	ND	ND	ND
PFDoA	ND	ND	ND	ND	3.6E-02	2.1E-02	ND	ND
PFHxA	ND	ND	3.3E-01	3.9E-01	3.3E-01	1.9E-01	3.7E-01	4.3E-01
PFOA	3.4E-02	2.0E-02	1.5E-01	1.8E-01	3.7E-02	2.1E-02	1.2E-01	1.4E-01
PFPeA	ND	ND	4.5E-01	5.3E-01	9.9E-02	5.8E-02	3.0E-01	3.5E-01

Compound	ADD (ng/kg-d)– Recycled Water, carrot, child	ADD (ng/kg-d)– Recycled Water, carrot, adult	ADD (ng/kg-d)– Recycled Water, kale, child	ADD (ng/kg-d)– Recycled Water, kale, adult	ADD (ng/kg-d)– Sammamish River Water, carrot, child	ADD (ng/kg-d)– Sammamish River Water, carrot, adult	ADD (ng/kg-d)– Sammamish River Water, kale, child	ADD (ng/kg-d)– Sammamish River Water, kale, adult
Sulfadiazine	ND	ND	1.4E+00	1.7E+00	ND	ND	1.6E+00	1.9E+00
Theophylline	8.6E-01	5.0E-01	2.7E+00	3.2E+00	6.4E-01	3.8E-01	2.2E+00	2.5E+00
Topiramate	ND	ND	8.2E-01	9.6E-01	ND	ND	ND	ND
Warfarin	ND	ND	7.0E-01	8.2E-01	ND	ND	5.6E-01	6.5E-01

ADD – average daily dose; COI – chemical of interest; ND – not detected

Table A-2: Cancer Lifetime Average Daily Doses (LADDs) for Chemicals of Interest (COIs) in Carrots and Kale

Chemical of Interest	LADD (ng/kg-d) – Recycled Water, carrot	LADD (ng/kg-d) – Recycled Water, kale	LADD (ng/kg-d) – Sammamish River Water, carrot	LADD (ng/kg-d) – Sammamish River Water, kale
Etoposide	ND	3.281	ND	1.347
Furosemide	ND	ND	ND	2.108
PFOA	0.0102	0.0787	0.0111	0.0642

*LECR not calculated because a cancer slope factor (SF) is not available

COI – chemical of interest; LADD – lifetime average daily dose; LECR – lifetime excess cancer risk; ND – not detected

APPENDIX B

SUMMARY OF PUBLISHED AND ESTIMATED TOXICITY VALUES FOR CHEMICALS OF INTEREST (COIS)

Table B-1. Published Noncancer Acceptable Daily Intakes (ADIs) or Cancer Slope Factors (SFs) for COIs from Authoritative Sources

Chemical	CAS #	Type	ADIs for Noncancer Effects (ng/kg-d)	Oral Cancer SFs $(mg/kg\text{-}d)^{-1}$
10-hydroxy-amitriptyline	1159-82-6	Metabolite of amitryptyline (tricyclic antidepressant)	NA	NA
2-Hydroxy-ibuprofen	51146-55-5	Metabolite of ibuprofen	NA	NA
6:2 FTS	27619-97-2	PFAS	NA	NA
Amitriptyline	50-48-6	Tricyclic antidepressant	NA	NA
Bisphenol A	80-05-7	Plastics ingredient	50,000 (U.S. EPA RfD; U.S. EPA, 1988); 6,500 (MDH Subchronic RfD; MDH, 2015)*	NA
Cimetidine	51481-61-9	Antacid reflux	NA	NA
Ciprofloxacin	85721-33-1	Quinoline antibiotic	NA	NA
Cloxacillin	61-72-3	β-lactam antibiotic	NA	NA
Cocaine	50-36-2	Opiate	NA	NA
DEET	134-62-3	Insect repellent	120,000 (MDH Subchronic RfD (MDH, 2013)); 1,000,000 (ATSDR Intermediate MRL (ATSDR, 2017))	NA
Enrofloxacin	93106-60-6	Quinolone antibiotic	NA	NA
Etoposide	33419-42-0	Chemotherapeutic	NA	NA
Furosemide	54-31-9	Diuretic	NA	NA
Ibuprofen	15687-27-1	Analgesic	NA	NA
Metformin	657-24-9	Anti-diabetic drug	NA	NA
Ofloxacin	82419-36-1	Antibiotic	NA	NA
Oxacillin	66-79-5	β-lactam antibiotic	NA	NA
Penicillin V	87-08-1	β-lactam antibiotic	NA	NA
PFBA	375-22-4	PFAS	1,000 (Texas Chronic RfD (TCEQ, 2023))	NA

Chemical	CAS #	Type	ADIs for Noncancer Effects (ng/kg-d)	Oral Cancer SFs $(mg/kg-d)^{-1}$
PFBS	45187-15-3	PFAS	300 (U.S. EPA RfD (U.S EPA, 2022), Washington SAL (WDOH, 2019), Michigan RfD (MI SAW, 2019)); 1,400 (Texas Chronic RfD (TCEQ, 2023))	NA
PFDoA	307-55-1	PFAS	12 (Texas Chronic RfD (TCEQ, 2023))	NA
PFHxA	307-24-4	PFAS	500 (Texas Chronic RfD (TCEQ, 2023)); 83,000 (Michigan RfD (MI SAW, 2019))	NA
PFOA	335-67-1	PFAS	3 (Washington SAL (WDOH, 2021)); ATSDR MRL (ATSDR, 2021); 0.0015 (U.S. EPA RfD (U.S. EPA, 2022)); 12 (Texas Chronic RfD (TCEQ, 2023)); 3.9 (Michigan RfD (MI SAW, 2019)	0.07 (U.S. EPA, 2016)
PFPeA	2706-90-3	PFAS	500 (Texas Chronic RfD (TCEQ, 2023))	NA
Sulfadiazine	68-35-9	Sulfonamide antibiotic	NA	NA
Theophylline	58-55-9	Bronchodilator	NA	NA
Topiramate	97240-79-4	Anti-epileptic	NA	NA
Warfarin	81-81-2	Anticoagulant	300 (U.S. EPA RfD (U.S. EPA, 1987))	NA

* The MDH subchronic RfD (2015) for bisphenol A was selected as the ADI for noncancer effects rather than the U.S. EPA RfD (1988), as the MDH value is lower (more health protective) and is based on a more recently completed subchronic toxicity study in mice (Tyl et al., 2008).

ADI – acceptable daily intake; ATSDR – Agency for Toxic Substances and Disease Registry; MDH – Minnesota Department of Health; MRL – Minimum Risk Level; NA – not available; RfD – reference dose from U.S. EPA; SAL – State Action Level; SF – cancer slope factor

Table B-2. Lowest Effect Doses for Noncancer Toxicity Endpoints and Corresponding Comparison Levels for Compounds Without Existing ADIs

Compound	Species, Gender, Duration	Effect dose (mg/kg-d)	Effect	UF	Comparison value (µg/kg-d)	Reference
10-hydroxy-amitriptyline	Rat, F, gestation	25	LOAEL, developmental (delayed ossification)	3,000	8.3	Drugs.com
2-Hydroxy-ibuprofen	Rat, F, GD21	1	NOAEL, cardiovascular, developmental	1,000	1.0	Momma and Takeuchi, 1983
6:2 FTS	Rat, M/F, combined repeat dose/ reproductive/ developmental toxicity	15	NOAEL, reproductive/ developmental, systemic	1,000	15	ECHA, 2023
Amitriptyline	Rat, F, gestation	25	LOAEL, developmental (delayed ossification)	3,000	8.3	Drugs.com
Cimetidine	Rat, 2 yrs	150	LOAEL, reproductive (reduced prostate and seminal vesicle weights)	3,000	50	Drugs.com
Ciprofloxacin	Monkey	5	LOAEL, kidney (crystalluria without nephropathy)	3,000	1.7	Drugs.com
Cloxacillin	Mice, F, GD11 and 15	21	LOAEL, immunotoxicity (increased spleen anti-SRBC IgM)	3,000	7	Dostal et al., 1994
Cocaine	Monkey, M	0.2	LOAEL, reproductive (male copulatory behavior)	3,000	0.067	Pomerantz et al., 1994
Enrofloxacin	Dog, 14 d	5	LOAEL, systemic toxicity	3,000	1.7	Traş et al., 2001
Etoposide	Rat, F, organogenesis	0.4	LOAEL, maternal toxicity, embryotoxicity, and teratogenicity	9,000*	0.044	Drugs.com
Furosemide	Rabbit, F, gestation	25	LOAEL, reproductive/ developmental (unexplained maternal death and abortions)	3,000	8.3	Drugs.com
Ibuprofen	Rat, F, GD21	1	NOAEL, cardiovascular, developmental	1,000	1.0	Momma and Takeuchi, 1983
Metformin	Rat and rabbit, M/F	600	NOAEL, reproductive/developmental	1,000	600	Drugs.com
Ofloxacin	Dog (juvenile), M, Single dose	20	LOAEL, systemic (arthropathy)	3,000	6.7	Yabe et al., 2004
Oxacillin	No data	NA	NA	NA	NA	NA
Penicillin V	No data	NA	NA	NA	NA	NA
Sulfadiazine	Dog	25	NOAEL, systemic toxicity (hypothyroidism)	1,000	25	USPC, 2007
Theophylline	Mice, M/F, mating	120	LOAEL, developmental/reproductive (litter size, pup mortality)	3,000	40	Drugs.com
Topiramate	Rat, F, during gestation thru lactation	0.2	NOAEL, reductions in pre-and/or postweaning body weight gain	1,000	0.20	Drugs.com

*Additional UF of 3 was applied because compound shows evidence of genotoxicity (see Table B-5).

F – female; GD – gestation day; LOAEL – lowest observed adverse effect level; M – male; NA – not available; NOAEL – no observed adverse effect level; UF – uncertainty factor

Table B-3. Lowest Therapeutic Doses for Pharmaceutical Compounds and Corresponding Comparison Levels

Compound	Lowest therapeutic dose (mg/d)	Treatment endpoint	Age group and assumed body weight (kg)	Pregnancy category & adverse effects	Comparison level (µg/kg-d)*
10-hydroxy-amitriptyline	75	Depression	Adult, 70	C (delayed ossification, malformations)	0.36
2-Hydroxy-ibuprofen	200	Pain relief	Adult, 70	C	0.95
Amitriptyline	75	Depression	Adult, 70	C (delayed ossification, malformations)	0.36
Cimetidine	400	Duodenal ulcer prophylaxis	Adult, 70	B	1.9
Ciprofloxacin	250	Urethral and cervical gonoccoccal infection	Adult,70	C	1.2
Cloxacillin	1000	Upper respiratory tract infection	Adult, 70	B	4.8
Cloxacillin	50 mg/kg-d	Upper respiratory tract infection	Child, >1 to 18 yrs	B	17
Enrofloxacin	No data	Veterinary use	NA	NA	NA
Etoposide	87.5 (50 mg/m2/d for 5 d)	Small cell lung cancer	Adult, 70	D (teratogenic in mice and rats)	0.42
Furosemide	20	Diuresis	Adult, 70	C (fetal abortions)	0.090
Ibuprofen	200	Pain relief	Adult, 70	C	0.95
Metformin	500	Type 2 diabetes	Adult, 70	B	2.4
Ofloxacin	400	Urinary tract infection	Adult, 70	C	1.9
Oxacillin	250	Antibiotic	Adult, 70	B	1.2
Penicillin V	125	Antibiotic	Adult, 70	B	0.60
Sulfadiazine	1000	Rheumatic fever prophylaxis	Adult, 70	C (neonatal jaundice and kernicterus)	4.8
Theophylline	300	Bronchodilator	Adult, 70	C	1.4
Theophylline	12 mg/kg-d	Bronchodilator	Pediatric, 10	C	4.0
Topiramate	400	Epilepsy	Adult, 70	D (increased risk for oral cleft palate)	1.9
Topiramate	150	Epilepsy	Pediatric, 11	D (increased risk for oral cleft palate)	4.6
Topiramate	100	Preventative treatment of migraine	Adult, 70	D (increased risk for oral cleft palate)	0.48
Warfarin	2	Anticoagulant	Adult, 70	D (congenital malformations, fetal mortality)	0.010

Source: Drugs.com for all chemicals except NLM-NIH (2023) for etoposide.

*A combined uncertainty factor (UF) of 3,000 was applied to calculate comparison values
NA – not available

Table B-4. Minimum Inhibitory Concentrations (MICs) for Antibiotics and Corresponding Comparison Levels

Antibiotic	MIC_{50}* (µg/mL)	Comparison level (µg/kg-d) †
Cimetidine	NA	NA
Ciprofloxacin	0.017 *(E. coli)*	0.14
Cloxacillin	0.63 *(E. coli)*	5.2
Enrofloxacin	0.031 *(E. coli)*	0.26
Erythromycin-H2O	NA	NA
Ofloxacin	0.063 *(E. coli)*	0.52
Oxacillin	16 *(Enterococcus faecalis)*	130
Penicillin G	0.08 *(Clostridium bifermentans)*	0.67
Penicillin V	0.08 *(Clostridium bifermentans)*	0.67
Sulfadiazine	NA	NA

*Data obtained from KnowledgeBase (2023) Antimicrobial Index

†Comparison level = MIC_{50} (µg/mL) × MCC (500 mL/d) /(FA (1) × SF (1) × BW (60 kg)) (Silley, 2007; WHO, 2020)

BW – body weight; FA – fraction available; MCC – mass of colonic contents; MIC_{50} – mean of MIC_{50} (minimum inhibitory concentration of 50% of strains) for the most sensitive relevant organism representing human intestinal flora (*Escherichia coli*, and species of *Bacteroides, Bifidobacterium, Clostridium, Enterococcus, Eubacterium (Collinsella), Fusobacterium, Lactobacillus, Peptostreptococcus/Peptococcus*; Silley, 2007)); SF – safety factor (a value of 1 was applied for all chemicals due to judgment of sufficient data for all compounds).

Table B-5. Carcinogenicity and Genotoxicity Data and Corresponding Comparison Levels for Compounds Without Existing ADIs

Compound	Evidence	Genotoxicity assumption	Carcinogenicity assumption	Cancer SF $(mg/kg\text{-}d)^{-1}$	Comparison level based on Cancer SF (µg/kg-d)*
10-hydroxy-amitriptyline	Assume same as amitriptyline	Not genotoxic	No data	---	---
2-Hydroxy-ibuprofen	Assume same as ibuprofen	Not genotoxic	No data	---	---
6:2 FTS	Not mutagenic in *in vitro* bacterial reverse mutation assays in *S. typhimurium* (Ames assay) (ANSES, 2013; Unnamed study report, 2007 as cited in ECHA, 2023). In an *in vitro* chromosomal aberration assay in CHO cells, produced induction of chromosomal aberrations with and without metabolic activation with 4 hrs of treatment at 300 µg/mL, but not with 20 hrs of treatment at 250 µg/mL (ANSES, 2013). *In vivo* genotoxicity assays were negative, including a micronucleus assay/chromosomal aberration assay in mice, an unscheduled DNA synthesis (UDS) assay in rats, and a Comet assay in rats (ANSES, 2013). No data on the carcinogenicity of 6:2 FTS in humans or animals were located.	Not genotoxic	No data	---	---
Amitriptyline	Not mutagenic in somatic mutation and recombination test (SMART) in wing cells of Drosophila melanogaster (HSDB, 2016). Nortriptyline was negative in *in vitro* bacterial reverse mutation assays in *S. typhimurium* (Ames assay) (CCRIS, 2006a).	Not genotoxic	No data	---	---
Bisphenol A	Negative in multiple *in vitro* tests for bacterial reverse mutagenicity in *S. typhimurium* and *E. coli,* positive in *in vitro* micronucleus test in human lymphoblastoid AHH-1 cells, mixed results in *in vitro* chromosomal aberration assays in CHO cells. Positive in *in vivo* chromosomal aberration assays in mouse bone marrow, negative in *in vivo* mouse micronucleus assays. (CCRIS, 2010). Per NTP, there was no convincing evidence that bisphenol A was carcinogenic in F344 rats or B6C3F1 mice of either sex (oral administration in feed for 103 weeks at 1,000 or 2,000 ppm in rats or 5,000 or 10,000 ppm in mice) (NTP, 1982).	Mixed results/ Inconclusive	Negative	---	---

Compound	Evidence	Genotoxicity assumption	Carcinogenicity assumption	Cancer SF $(mg/kg\text{-}d)^{-1}$	Comparison level based on Cancer SF (µg/kg-d)*
Cimetidine	Not mutagenic to and did not cause DNA damage *in S. typhimurium* or *E. coli* (IARC, 1990) In a 24-month study in rats at 150, 378 and 950 mg/kg/day (approximately 8 to 48 times the recommended human dose), there was a small increase in the incidence of benign Leydig cell tumors in each dose group; when the combined drug-treated groups and control groups were compared, increase reached statistical significance. In a subsequent 24-month study, no differences between rats receiving 150 mg/kg/day and untreated controls, but a statistically significant increase in benign Leydig cell tumor incidence was seen in rats that received 378 and 950 mg/kg/day. These tumors were common in control groups as well as treated groups and the difference became apparent only in aged rats (Drugs.com).	Not genotoxic	Negative (not classifiable as to carcinogenicity per IARC, 1990)	---	---
Ciprofloxacin	Negative in six *in vitro* mutagenicity tests (*Salmonella*/microsome test, *E. coli* DNA repair assay, Chinese hamster V79 cell HGPRT test, Syrian hamster embryo cell transformation assay, *Saccharomyces cerevisiae* point, mitotic crossover, and gene conversion assays) and positive in two *in vitro* tests (mouse lymphoma cell forward mutation assay and rat hepatocyte DNA repair assay). Results were negative in three tests *in vivo* systems (rat hepatocyte DNA repair assay, mouse micronucleus test, and mouse dominant lethal test). Long-term carcinogenicity studies in rats and mice resulted in no carcinogenic or tumorigenic effects at doses up to 500 and 750 mg/kg-d to rats and mice, respectively (Drugs.com).	Not genotoxic	Negative	---	---
Cloxacillin	No data	No data	No data	---	---
Cocaine	No data	No data	No data	---	---
DEET	Not mutagenic in either *in vitro* or *in vivo* test systems (U.S. EPA, 1998). Cancer studies in mice, rats, rabbits, and dogs were negative. According to U.S. EPA (1998), "The RfD Peer Review Committee has recommended that DEET be classified as Group D (i.e., not classifiable as a human carcinogen) because the mouse and rat carcinogenicity studies did not demonstrate any carcinogenic potential and because the Committee believed that the male rats could have tolerated higher doses."	Not genotoxic	Negative	---	---
Enrofloxacin	No data on genotoxicity. No evidence of carcinogenicity in long-term studies in rats and mice (WHO, 1997)	No data	Negative	---	---

Compound	Evidence	Genotoxicity assumption	Carcinogenicity assumption	Cancer SF $(mg/kg\text{-}d)^{-1}$	Comparison level based on Cancer SF (µg/kg-d)*
Etoposide	Mutagenic *in vitro* in Ames test (*S. typhimurium*) (Drugs.com). Carcinogenicity tests have not been conducted in animals. The occurrence of acute leukemia with or without a preleukemic phase has been reported in rare instances in patients treated with Etoposide alone or in association with other neoplastic agents. The risk of development of a preleukemic or leukemic syndrome is unclear (Drugs.com).	Mutagenic	Insufficient data; no tumorigenicity data (see Table B-6 for derivation based on VSD)	---	---
Furosemide	Negative in *in vitro* tests of mutagenicity in Ames test (*S. typhimurium*), positive in *in vitro* mouse lymphoma L5178Y (TK+/TK-) cell assay with but not without activation, positive for chromosomal aberrations in vitro in CHO cells with and without activation (CCRIS, 2006b). Increased incidence of mammary tumors in 2-year study in mice (CPDB, 2007).	Possibly genotoxic	Potentially carcinogenic based on increased incidence in mammary tumors in female mice (CPDB, 2007): 0 mg/kg-d = 0/50 89.3 mg/kg-d = 2/50 180 mg/kg-d = 5/50	0.011	0.091
Ibuprofen	Negative in *in vitro* tests of mutagenicity in Ames test (*S. typhimurium*) (Oldham et al., 1986; Philipose et al., 1997). In two *in vivo* tests using human lymphocytes, did not affect the rates of sister chromatid exchange technique (Kullich and Klein, 1986; Ozcul et al., 1996). No data on carcinogenicity.	Not genotoxic	No data	---	---
Metformin	Negative *in vitro* in Ames test (*S. typhimurium*), gene mutation test (mouse lymphoma cells), and chromosomal aberrations test (human lymphocytes). Negative in *in vivo* micronucleus test in mice (CCRIS, 2009). No evidence of carcinogenic potential in a 104-week study in male and female rats receiving metformin hydrochloride at up to 900 mg/kg-d or in a 91-week study in male and female mice at up to 1500 mg/kg-d (Drugs.com).	Not genotoxic	Negative	---	---

Compound	Evidence	Genotoxicity assumption	Carcinogenicity assumption	Cancer SF $(mg/kg\text{-}d)^{-1}$	Comparison level based on Cancer SF (µg/kg-d)*
Ofloxacin	Ofloxacin produced mixed results *in vitro* in Ames test (*S. typhimurium*) (CCRIS, 2006c). Reportedly negative *in vitro* in gene mutation test in mouse lymphoma cells, sister chromatid exchange assays in Chinese hamster and human cell lines, and DNA repair (UDS) assay using human fibroblasts, and in *in vivo* dominant lethal assays and a mouse micronucleus assay. It was reportedly positive in vitro in a UDS test using rat hepatocytes and a mouse lymphoma cell assay. Long-term studies to determine carcinogenic potential have not been conducted (Drugs.com).	Mutagenic/ genotoxic	No data	---	---
Oxacillin	No mutagenicity data. No data on carcinogenicity (Drugs.com).	No data	No data	---	---
Penicillin V	Negative in one *in vitro* mouse lymphoma L5178Y (TK+/TK-) cell assay and positive in another, both with and without metabolic activation (CCRIS, 1995). No data on carcinogenicity.	Insufficient information	No data	---	---
PFBA	No DNA damage in liver or kidney following administration of a single intraperitoneal injection of 100 mg/kg to male Fischer-344 rats (Takagi et al. 1991, in ATSDR, 2021).	Insufficient information	No data	---	---
PFBS	Negative *in vitro* in Ames test (*S. typhimurium*), for DNA damage in human HepG2 cells, and for chromosomal aberrations in CHO cells; negative in *in vivo* micronucleus assay in rats (Ericksen et al., 2010; U.S. EPA, 2018).	Not genotoxic	No data	---	---
PFDoA	No mutagenicity data. No data on carcinogenicity.	No data	No data	---	---
PFHxA	Negative *in vitro* in Ames test (*S. typhimurium*), in chromosomal aberration assay in human peripheral blood lymphocytes, and in micronucleus assay in V79 cells. Negative *in vivo* for chromosomal aberrations in female rat with equivocal results in male rat (Luz et al., 2019).	Not genotoxic	No data	---	---

Compound	Evidence	Genotoxicity assumption	Carcinogenicity assumption	Cancer SF $(mg/kg\text{-}d)^{-1}$	Comparison level based on Cancer SF (µg/kg-d)*
PFOA	Predominantly negative. Per ATSDR (2021), in general, results show that PFOA can produce DNA damage, but is not mutagenic at noncytotoxic concentrations. Negative in *in vitro* Ames test (*S. typhimurium)* and in *E. coli* (U.S. EPA, 2016). Clastogenicity studies in CHO cells were positive for chromosomal abnormalities and polyploidy with activation and equivocal in the absence of activation. Micronucleus assays were negative (U.S. EPA, 2016). IARC (2018) classified PFOA as possibly carcinogenic to humans (Group 2B) based on limited evidence for carcinogenicity in animals and in humans. In 2-year diet studies, male but not female rats showed a dose-response relationship with exposure for one tumor type (Leydig cell in testes) (U.S. EPA, 2016). Per U.S. EPA (2016), evidence for the carcinogenicity of PFOA is considered suggestive because only one species has been evaluated for lifetime exposures and the tumor responses occurred primarily in males.	Not genotoxic	U.S. EPA modeled cancer risk from dose-response data for Leydig cell tumors in rats and derived a cancer SF of 0.07 $(mg/kg\text{-}d)^{-1}$ (U.S. EPA, 2016).	0.07	0.014
PFPeA	No data	No data	No data	---	---
Sulfadiazine	No data	No data	No data	---	---
Theophylline	Negative in *in vitro* Ames test (*S. typhimurium*), and in *in vivo* and *in vitro* cytogenetics, micronucleus and CHO system tests (CCRIS, 2003; Drugs.com). Long-term carcinogenicity studies in mice (oral doses 30-150 mg/kg-d) and rats (oral doses 5-75 mg/kg-d) were negative (CCRIS, 2003).	Not genotoxic	Negative	---	---
Topiramate	Not mutagenic in the Ames test (*S. typhimurium*), or the *in vitro* mouse lymphoma assay; it did not increase unscheduled DNA synthesis in rat hepatocytes *in vitro*; and it did not increase chromosomal aberrations in human lymphocytes *in vitro* or in rat bone marrow *in vivo*. (Drugs.com). An increase in urinary bladder tumors was observed in mice (at 20, 75, and 300 mg/kg-d in the diet for 21 months). The statistically increased incidence of bladder tumor in male and female mice receiving 300 mg/kg was due primarily to the increased occurrence of a smooth muscle tumor considered histomorphologically unique to mice. No evidence of carcinogenicity seen in rats following oral administration for 2 years at doses of up to 120 mg/kg-d (Drugs.com).	Not genotoxic	Insufficient evidence for carcinogenicity	---	---

Compound	Evidence	Genotoxicity assumption	Carcinogenicity assumption	Cancer SF $(mg/kg\text{-}d)^{-1}$	Comparison level based on Cancer SF (µg/kg-d)*
Warfarin	No mutagenicity data. No long-term animal studies have been conducted (Drugs.com).	No data	No data	---	---

*Calculated assuming an allowable lifetime excess cancer risk of 1 in one million and that a person is exposed to the chemical at this dose daily for a lifetime, or comparison level = $(10^{-6} / SF) \times 1000$ µg/mg.

ATSDR Agency for Toxic Substances and Disease Registry; CCRIS – Chemical Carcinogenesis Research Information System; CHO – Chinese hamster ovary; HGPRT – Hypoxanthine-guanine phosphoribosyltransferase; IARC – International Agency for Research on Cancer; NTP – National Toxicology Program; SF – slope factor; SMART somatic mutation and recombination test; UDS – unscheduled DNA synthesis; VSD – Virtually Safe Dose

Table B-6. Comparison Levels for Compounds with Evidence of Genotoxic Carcinogenicity but No Tumor Incidence Data, Based on the Virtually Safe Dose (VSD) Method

Compound	Genotoxicity assumption (see Table B-5)	Maximum tolerated dose (MTD)	VSD (ng/kg-d)
Etoposide	Genotoxic	50 mg/m^2-d for oral exposure in human trials (Hainsworth et al., 1989; Greco et al., 1990; Furuse, 1992). This is conservative compared to other studies that report higher MTDs (e.g., up to 4,200 mg/m^2 in Herzig, 1991, >700 mg/m^2 in O'Dwyer et al., 1991, and >400 mg/m^2 in Minami et al., 1993).	1.8*

*VSD (ng/kg-d) = (MTD (mg/m^2-d)/37 kg/m^2) /740,000) × 1,000,000 ng/mg, where the MTD in units of milligram per meter squared of body surface area per day (mg/m^2-d) is converted to a dose in mg/kg-d by dividing by a factor of 37 kg/m^2, corresponding to a 60 kg human (from Nair and Jacob, 2016).

MTD – maximum tolerated dose; VSD – Virtually Safe Dose

Table B-7. Summary of Comparison Levels for Noncancer Effects of COIs and Selected Value for Application to Screening level HHRA per Decision Tree Approach

Compound	CAS #	Class or Use	Existing value (ng/kg-d)	NOAEL/ LOAEL-based (ng/kg-d)	Therapeutic dose-based (ng/kg-d)	MIC-based (ng/kg-d)	Existing or Lowest Value (ng/kg-d)
10-hydroxy-amitriptyline	1159-82-6	Metabolite of amitriptyline	---	8,300	360	---	360
2-Hydroxy-ibuprofen	51146-55-5	Metabolite of ibuprofen	---	1,000	950	0	950
6:2 FTS	27619-97-2	PFAS	---	15,000	---	---	15,000
Amitriptyline	50-48-6	Tricyclic antidepressant	---	8,300	360	0	360
Bisphenol A	80-05-7	Plastics ingredient	6,500	---	---	---	6,500
Cimetidine	51481-61-9	Anti-acid reflux	---	50,000	1,900	---	1,900
Ciprofloxacin	85721-33-1	Quinoline antibiotic	---	1,700	1,200	140	140
Cloxacillin	61-72-3	β-lactam antibiotic	---	7,000	4,800	5,200	4,800
Cocaine	50-36-2	Opiate	---	67	17,000	---	67
DEET	134-62-3	Insect repellent	120,000	---	---	---	120,000
Enrofloxacin	93106-60-6	Quinolone antibiotic	---	1,700	---	260	260
Etoposide	33419-42-0	Chemotherapeutic	---	44	420	---	44
Furosemide	54-31-9	Diuretic	---	8,300	90	---	90
Ibuprofen	15687-27-1	Analgesic	---	1,000	950	---	950
Metformin	657-24-9	Anti-diabetic drug	---	600,000	2,400	---	2,400
Ofloxacin	82419-36-1	Antibiotic	---	6,700	1,900	520	520
Oxacillin	66-79-5	β-lactam antibiotic	---	---	1,200	130,000	1,200
Penicillin V	87-08-1	β-lactam antibiotic	---	---	600	670	600
PFBA	375-22-4	PFAS	1,000	---	---	---	1,000
PFBS	45187-15-3	PFAS	300	---	---	---	300
PFDoA	307-55-1	PFAS	12	---	---	---	12
PFHxA	307-24-4	PFAS	500	---	---	---	500
PFOA	335-67-1	PFAS	0.0015; 3	---	---	---	0.0015; 3
PFPeA	2706-90-3	PFAS	500	---	---	---	500
Sulfadiazine	68-35-9	Sulfonamide antibiotic	---	25,000	4,800	---	4,800
Theophylline	58-55-9	Bronchodilator	---	40,000	1,400	---	1,400
Topiramate	97240-79-4	Anti-epileptic	---	200	480	---	200
Warfarin	81-81-2	Anticoagulant	300	10	---	---	300

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Appendix B: CEC Data Figures

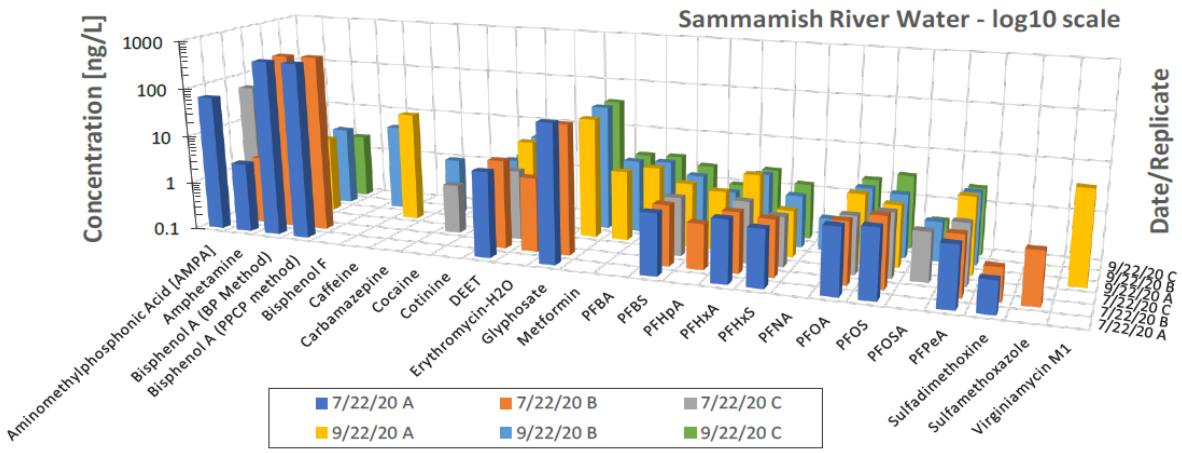

Figure A1. Concentrations of CECs present in Sammamish River water (logarithmic scale) used for irrigation in 2020. CECs reported here represent all reported CEC detections.

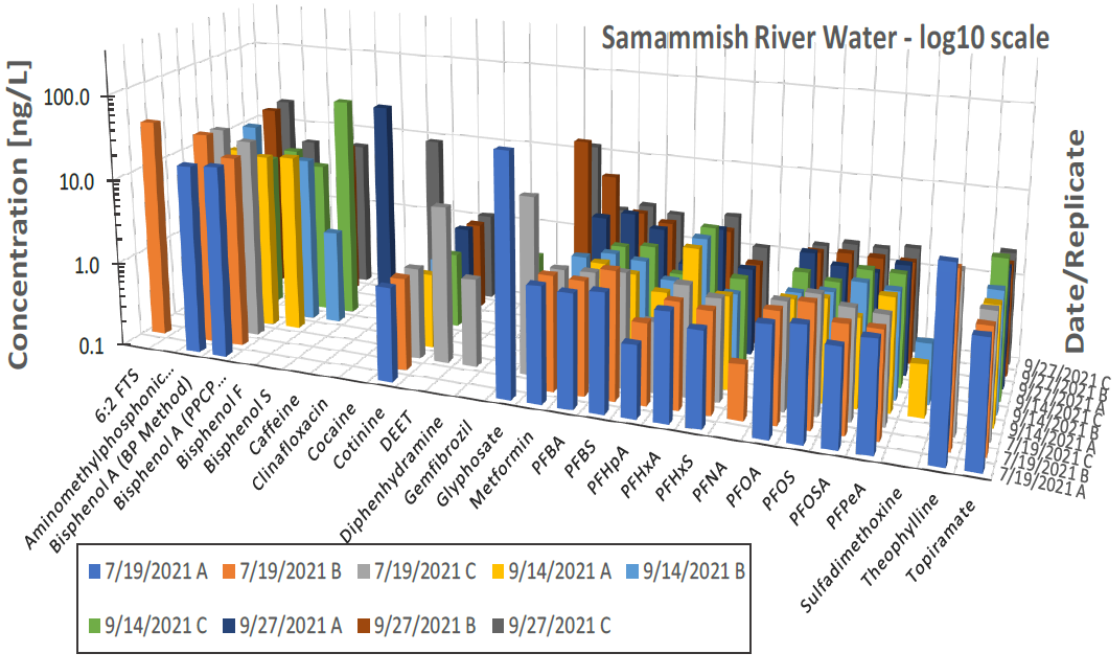

Figure A2. Concentrations of CECs present in Sammamish River water (logarithmic scale) used for irrigation in 2021. CECs reported here represent all reported CEC detections.

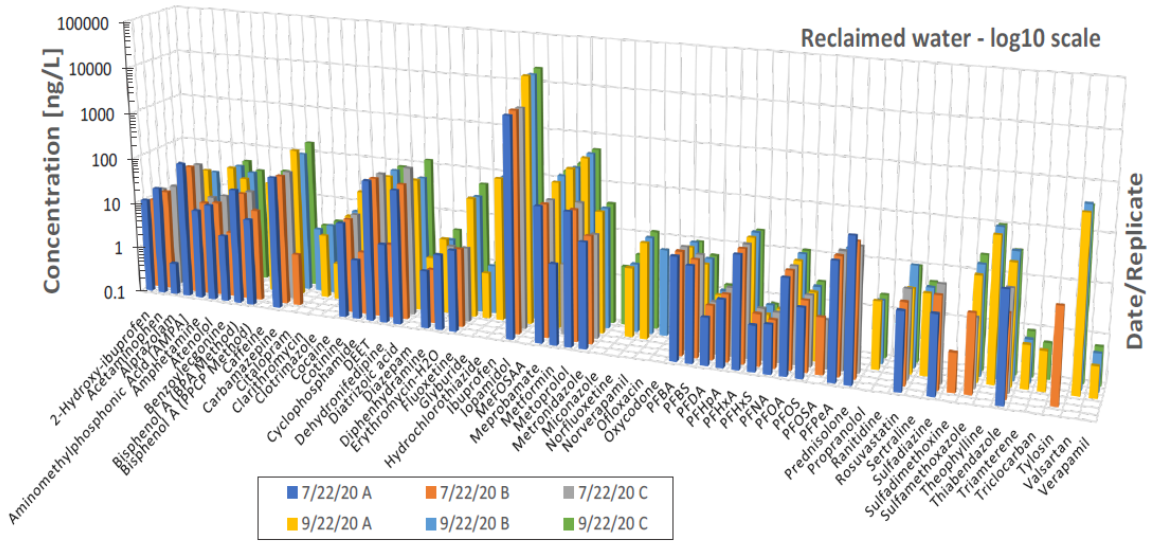

Figure A3. Concentrations of CECs present in Class A recycled water (logarithmic scale) from the Brightwater facility used for irrigation in 2020. CECs here represent all reported CEC detections.

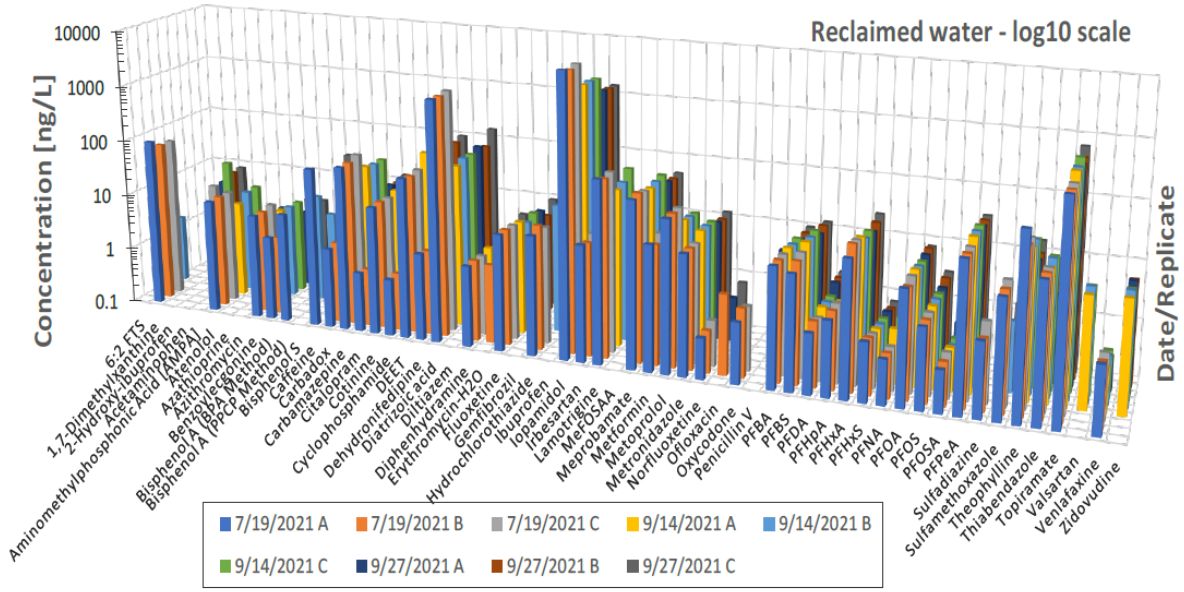

Figure A4. Concentrations of CECs present in Class A recycled water (logarithmic scale) from the Brightwater facility used for irrigation in 2021. CECs here represent all reported CEC detections.

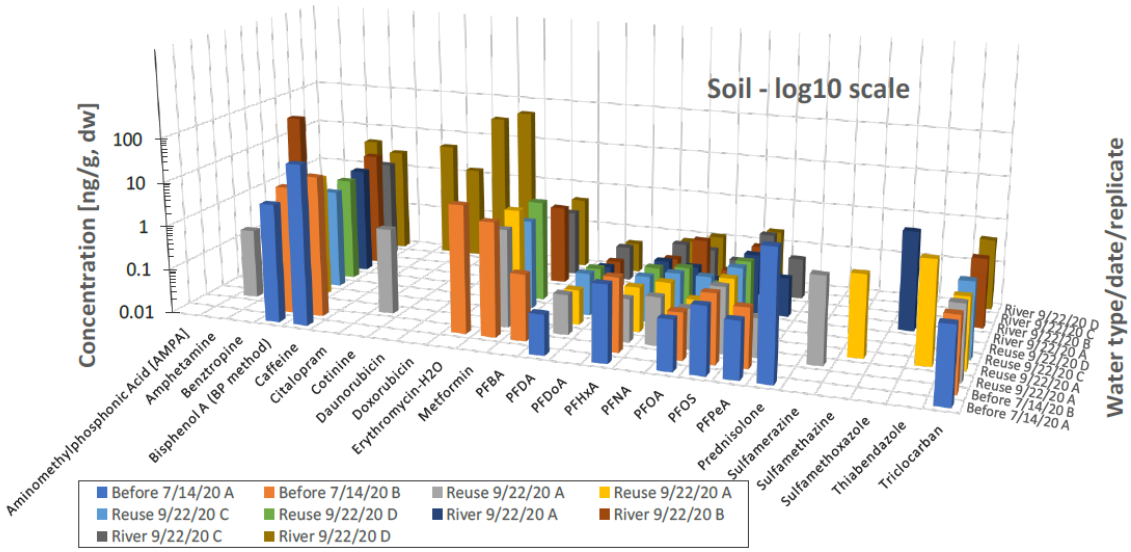

Figure A5. Concentrations of CECs present in agricultural soils pre- and post-irrigation in 2020. The first two data rows are prior to any irrigation. CECs reported here represent all reported CEC detections.

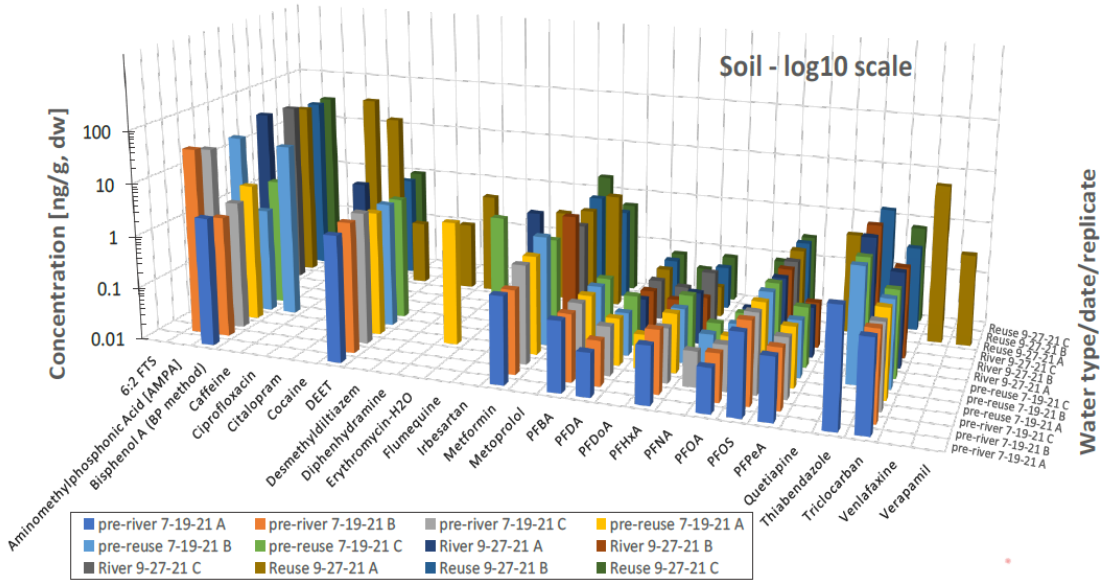

Figure A6. Concentrations of CECs present in agricultural soils pre- and post-irrigation in 2021. The first 6 rows are prior to any 2021 irrigation (but after prior year 2020 irrigation), later rows are post-irrigation. CECs reported here represent all reported CEC detections.

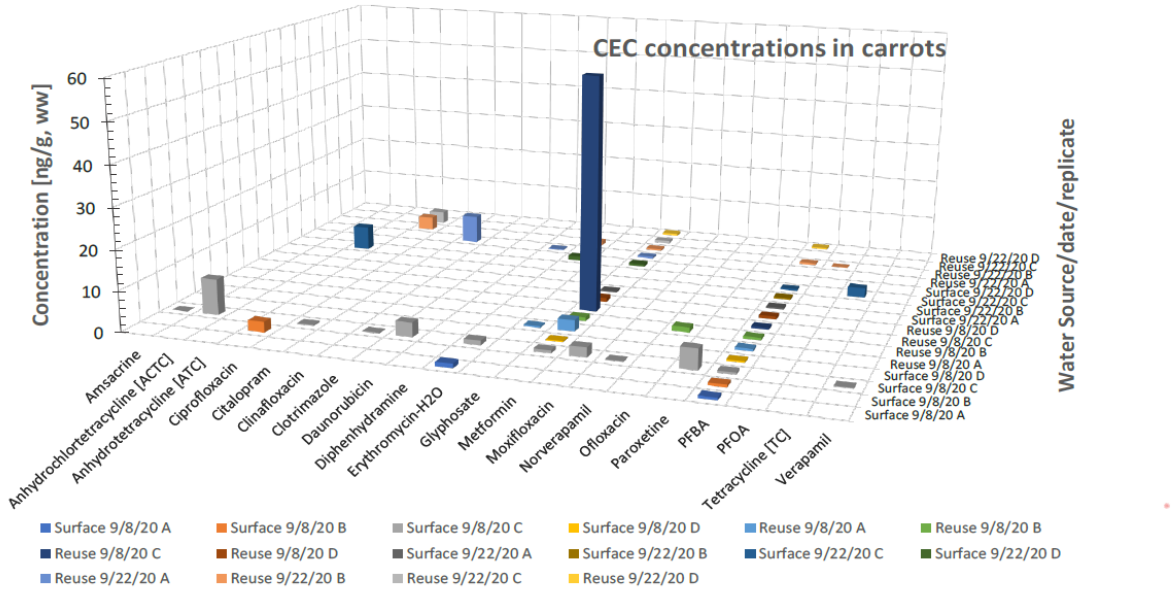

Figure A7. Concentrations of CECs present in edible tissues of carrots irrigated with either Sammamish River water or recycled water in 2020. All replicates are shown, CECs here represent all reported CEC detections.

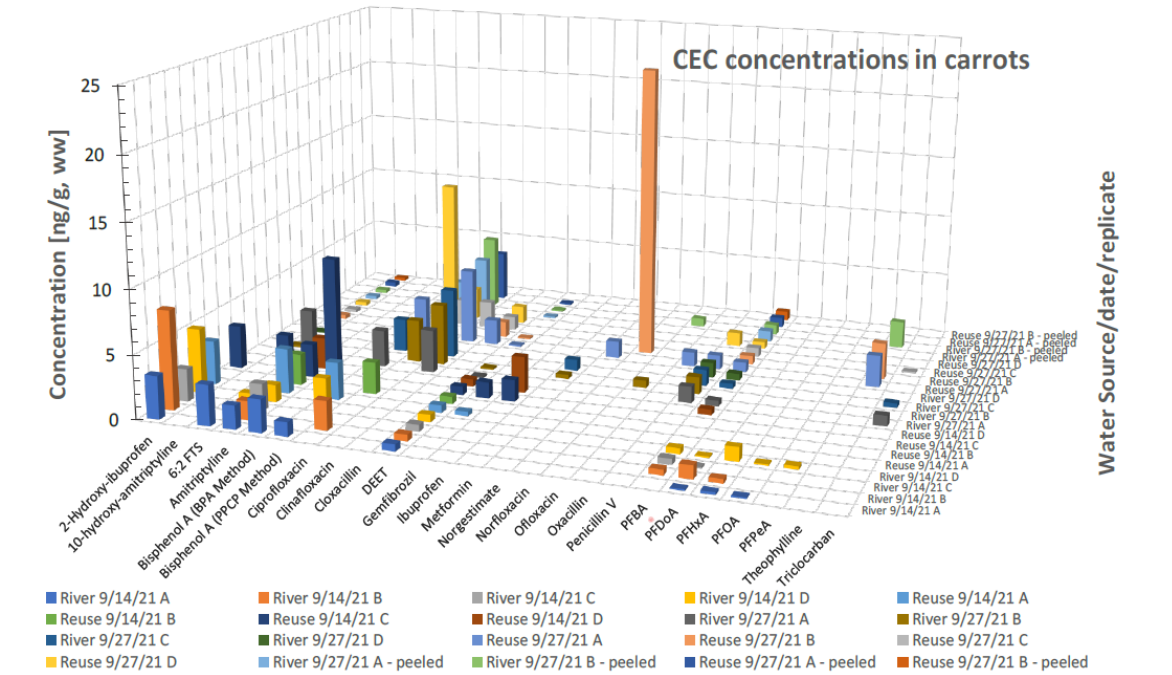

Figure A8. Concentrations of CECs present in edible tissues of carrots irrigated with either Sammamish River water or recycled water in 2021. All replicates are shown, CECs here represent all reported CEC detections.

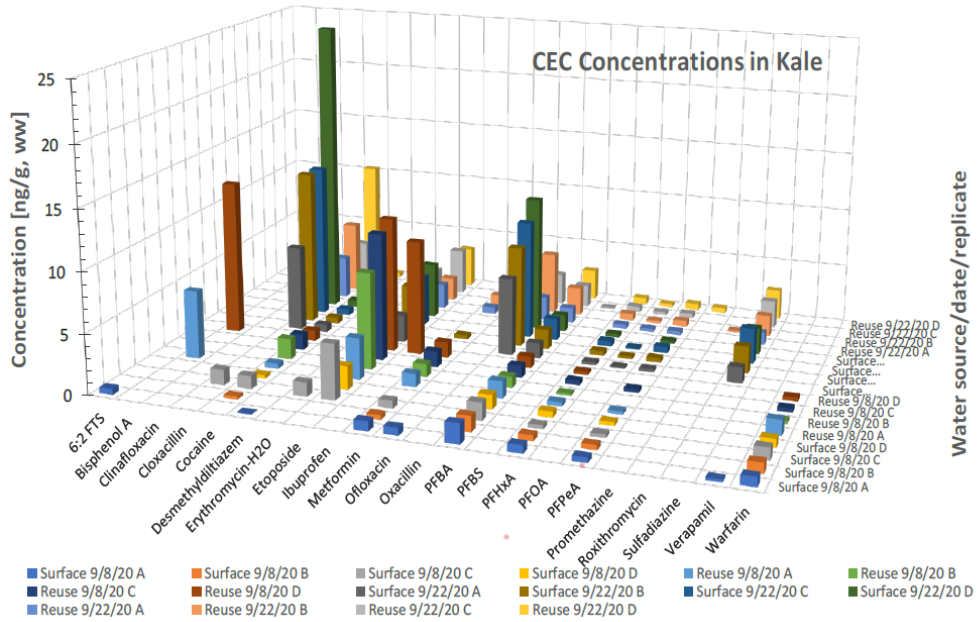

Figure A9. Concentrations of CECs present in edible tissues of kale irrigated with either Sammamish River water or recycled water in 2020. All replicates are shown, CECs here represent all reported CEC detections.

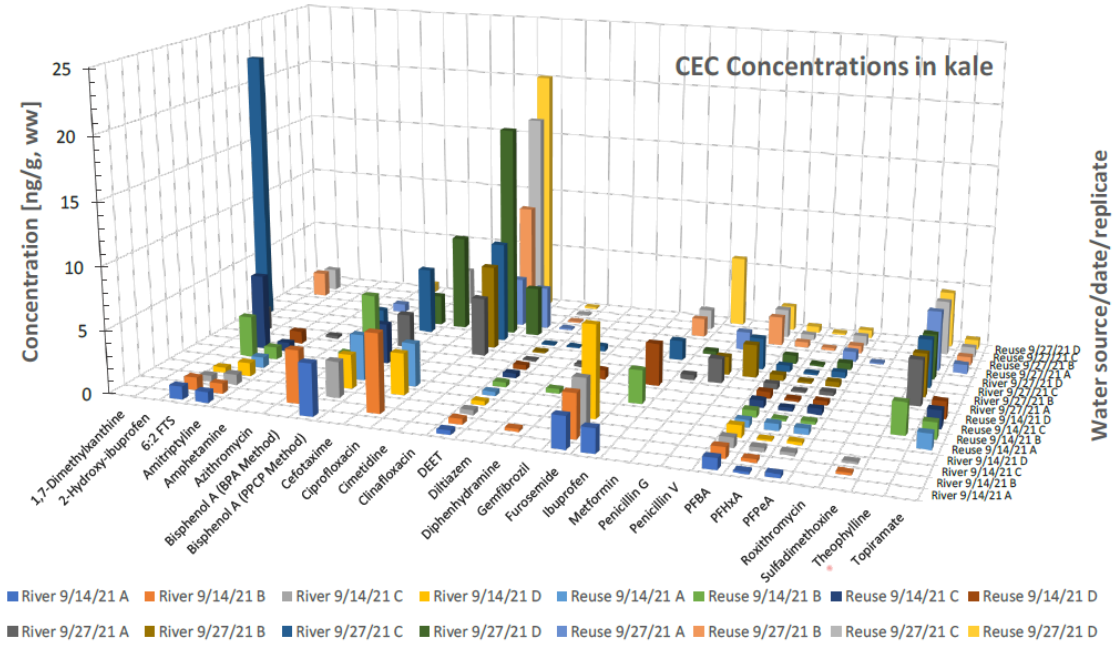

Figure A10. Concentrations of CECs present in edible tissues of kale irrigated with either Sammamish River water or recycled water in 2021. All replicates are shown, CECs here represent all reported CEC detections.

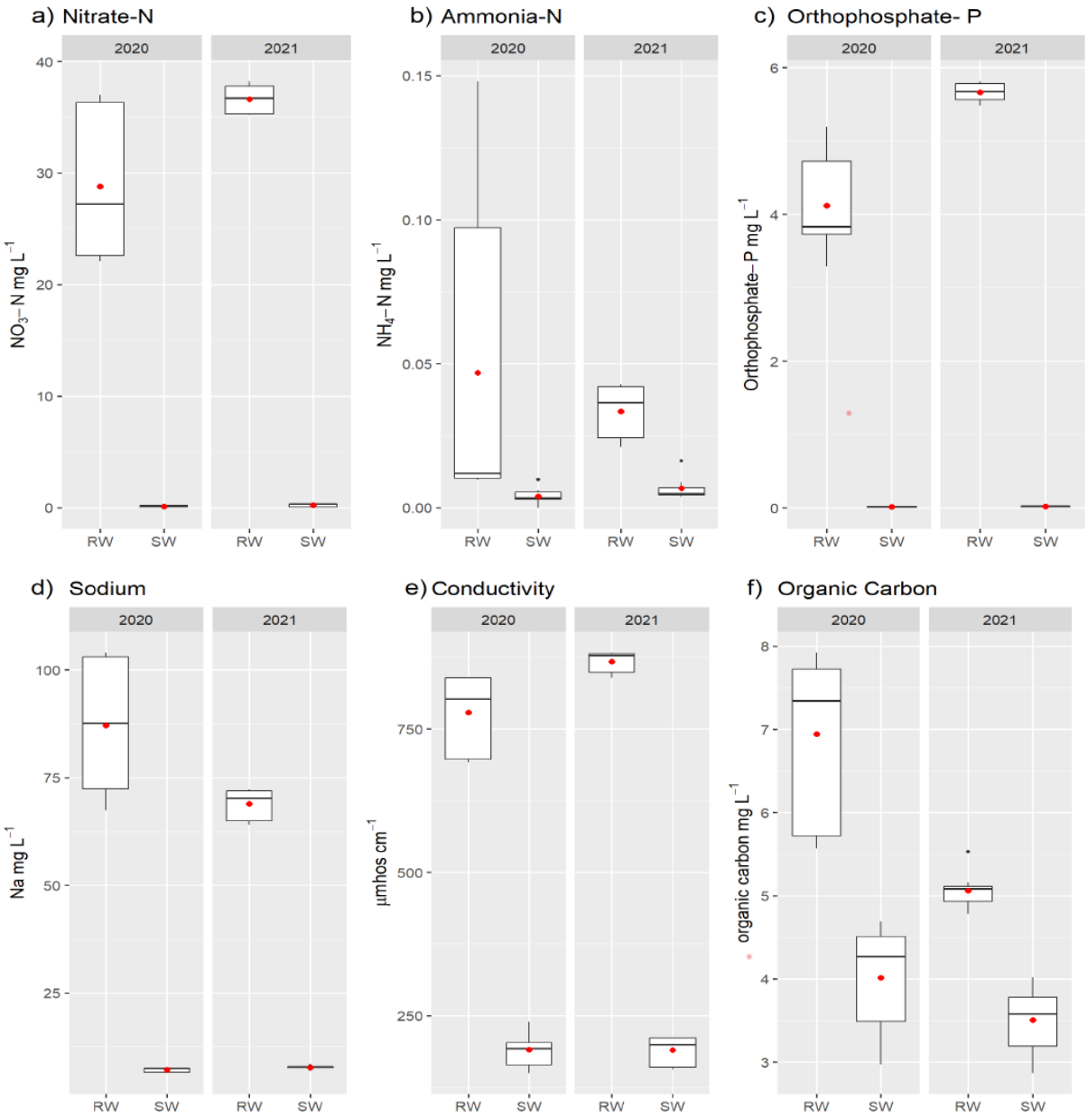

Figure A11. Concentrations of (a) nitrate-N, (b) ammonia-N, (c) orthophosphate-P, (d) sodium, (e) conductivity, and (f) organic carbon in recycled water and surface water used for irrigation in 2020 and 2021. Three replicate samples were collected during the irrigation season in both years.

Appendix C: Complete CEC Data Table

Complete CEC data, organized by name, collected during 2020 and 2021 in the demonstration garden system.

COMPOUND	Matrix type	Water type	Unit	2020 Results					2021 Results				
				Minim.	Averg.	Maxim.	# Detects	Detection Frequency	Minim.	Averg.	Maxim.	# Detects	Detection Frequency
1,7-Dimethylxanthine	Kale	Sammamish	ng/g					0%	22.2	22.2	22.2	1	13%
1,7-Dimethylxanthine	Recycled	Recycled	ng/L					0%	73	82	100	3	33%
10-hydroxy-amitriptyline	Carrot	Sammamish	ng/g					0%	0.1	0.15	0.23	4	50%
10-hydroxy-amitriptyline	Carrot	Recycled	ng/g					0%	0.19	0.26	0.33	4	50%
10-hydroxy-amitriptyline	Carrot peel	Sammamish	ng/g					n/a	0.27	0.28	0.28	2	100%
10-hydroxy-amitriptyline	Carrot peel	Recycled	ng/g					n/a	0.25	0.31	0.37	2	100%
2-Hydroxy-ibuprofen	Carrot	Sammamish	ng/g					0%	2.5	4.7	7.8	4	50%
2-Hydroxy-ibuprofen	Carrot	Recycled	ng/g					0%	3.4	3.4	3.5	2	25%
2-Hydroxy-ibuprofen	Kale	Sammamish	ng/g					0%	1.82	1.82	1.82	1	13%
2-Hydroxy-ibuprofen	Kale	Recycled	ng/g					0%	1.78	1.9	2.02	2	25%
2-Hydroxy-ibuprofen	Recycled	Recycled	ng/L	9.59	11.6	13.7	3	50%	6.19	7.4	8.15	3	33%
6:2 FTS	Carrot	Sammamish	ng/g					0%	0.442	2.5	3.92	3	38%
6:2 FTS	Carrot	Recycled	ng/g					0%	0.433	1.8	3.13	2	25%
6:2 FTS	Kale	Sammamish	ng/g	0.486	0.486	0.486	1	13%	0.449	0.75	1.04	4	50%
6:2 FTS	Kale	Recycled	ng/g					0%	3.28	4.67	6.06	2	25%
6:2 FTS	Recycled	Recycled	ng/L					0%	1.61	1.61	1.61	1	11%
6:2 FTS	Sammamish	Sammamish	ng/L					0%	38.3	38.3	38.3	1	11%
6:2 FTS	Soil	Recycled	ng/g					0%	1.13	1.13	1.13	1	17%
Acetaminophen	Recycled	Recycled	ng/L	15.6	18.3	22.6	3	50%	18.6	18.6	18.6	1	11%
Alprazolam	Recycled	Recycled	ng/L	0.49	1.27	1.74	5	83%					0%
AMPA	Recycled	Recycled	ng/L	27.6	56.8	93	5	83%	12.8	12.8	12.8	1	11%
AMPA	Sammamish	Sammamish	ng/L	28.3	42.9	63.9	5	83%	18.1	18.9	19.6	2	22%
AMPA	Soil	Sammamish	ng/g	28.2	28.2	28.2	1	25%	27.4	36.8	45.5	4	67%
AMPA	Soil	Recycled	ng/g					0%	26.3	28	28.9	4	67%
Amitriptyline	Carrot	Sammamish	ng/g					0%	1.36	1.7	2.13	4	50%
Amitriptyline	Carrot	Recycled	ng/g					0%	2.46	2.8	3.53	4	50%

Amitriptyline	Kale	Sammamish	ng/g					0%	0.81	0.89	1.07	4	50%
Amitriptyline	Kale	Recycled	ng/g					0%	0.71	0.89	1.02	4	50%
Amphetamine	Kale	Sammamish	ng/g	9.06	10.6	11.8	3	38%	0.22	0.22	0.22	1	13%
Amphetamine	Sammamish	Sammamish	ng/L	2.57	2.675	2.78	2	33%					0%
Amphetamine	Soil	Sammamish	ng/g	0.351	0.351	0.351	1	25%					0%
Amphetamine	Soil	Recycled	ng/g	0.375	0.375	0.375	1	25%					0%
Amsacrine	Carrot	Sammamish	ng/g	0.035	0.035	0.035	1	13%					0%
Anhydrochlortetracycline [ACTC]	Carrot	Sammamish	ng/g	8.89	8.89	8.89	1	13%					0%
Anhydrotetracycline [ATC]	Carrot	Sammamish	ng/g	6.01	6.01	6.01	1	13%					0%
Atenolol	Recycled	Recycled	ng/L	11.8	29.3	48	6	100%	1.34	6.12	10.5	9	100%
Azathioprine	Recycled	Recycled	ng/L					0%	1.52	1.74	2.1	3	33%
Azithromycin	Kale	Sammamish	ng/g					0%	1.39	1.39	1.39	1	13%
Azithromycin	Kale	Recycled	ng/g					0%	0.69	0.71	0.73	2	25%
Azithromycin	Recycled	Recycled	ng/L					0%	2.8	2.8	2.8	1	11%
Benzoylecgonine	Recycled	Recycled	ng/L	2.76	17	33	6	100%	2.5	4.8	7.6	9	100%
Benztropine	Soil	Sammamish	ng/g	4.57	4.57	4.57	1	25%					0%
Bisphenol A	Carrot	Sammamish	ng/g					0%	1.14	1.14	1.14	1	13%
Bisphenol A	Carrot	Sammamish	ng/g					0%	2.38	2.6	2.95	4	50%
Bisphenol A	Carrot	Recycled	ng/g					0%	9.73	9.73	9.73	1	13%
Bisphenol A	Carrot	Recycled	ng/g					0%	2.94	5.84	11.4	3	38%
Bisphenol A	Carrot peel	Sammamish	ng/g					n/a	2.36	2.4	2.47	2	100%
Bisphenol A	Kale	Sammamish	ng/g					0%	4.21	4.21	4.21	1	13%
Bisphenol A	Kale	Sammamish	ng/g					0%	2.48	3.37	5.34	6	75%
Bisphenol A	Kale	Recycled	ng/g	5.74	9.37	13	2	25%	3	4	6.2	4	50%
Bisphenol A	Kale	Recycled	ng/g					0%	1.3	1.7	2.1	2	25%
Bisphenol A	Recycled	Recycled	ng/L	19.6	26	34.2	6	100%	2.46	2.76	3.06	3	33%
Bisphenol A	Recycled	Recycled	ng/L	7.68	8.84	10	2	33%	7.71	12	24.3	4	44%
Bisphenol A	Sammamish	Sammamish	ng/L	435	446	456	2	33%	9.4	16	23	5	56%
Bisphenol A	Sammamish	Sammamish	ng/L	16.8	297	439	3	50%	6	18	32	7	78%
Bisphenol A	Soil	Before irrigation	ng/g	4.78	6.3	7.75	2	100%				n/a	0%
Bisphenol A	Soil	Sammamish	ng/g	1.91	2.95	4.44	4	100%	1.97	2.47	2.76	3	50%
Bisphenol A	Soil	Recycled	ng/g	1.44	2.9	5.93	4	100%	1.03	2.76	4.37	3	50%

Bisphenol F	Sammamish	Sammamish	ng/L	6.45	6.45	6.45	1	17%	6.21	8.5	12.8	5	56%
Bisphenol S	Recycled	Recycled	ng/L					0%	1.38	2.41	4.19	3	33%
Bisphenol S	Sammamish	Sammamish	ng/L					0%	1.3	23	45	2	22%
Caffeine	Recycled	Recycled	ng/L	14.9	17.9	20.9	2	33%	66.2	66.2	66.2	1	11%
Caffeine	Sammamish	Sammamish	ng/L	19	19	19	1	17%	33.8	33.8	33.8	1	11%
Caffeine	Soil	Before irrigation	ng/g	15.4	29.4	43.4	2	100%				n/a	0%
Caffeine	Soil	Recycled	ng/g					0%	21.5	21.5	21.5	1	17%
Carbadox	Recycled	Recycled	ng/L					0%	2.58	2.63	2.68	2	22%
Carbamazepine	Recycled	Recycled	ng/L	67.2	110	171	6	100%	12	48	94	9	100%
Carbamazepine	Sammamish	Sammamish	ng/L	1.5	1.5	1.5	1	17%					0%
Cefotaxime	Kale	Sammamish	ng/g					0%	7.68	7.68	7.68	1	13%
Cimetidine	Kale	Sammamish	ng/g					0%	4.75	9.2	17.2	4	50%
Cimetidine	Kale	Recycled	ng/g					0%	3.98	12.6	20.1	4	50%
Ciprofloxacin	Carrot	Sammamish	ng/g	2.6	2.6	2.6	1	13%	2.3	2.8	3.39	2	25%
Ciprofloxacin	Carrot	Recycled	ng/g	3.07	3.28	3.49	2	25%	2.09	2.4	2.54	3	38%
Ciprofloxacin	Carrot peel	Sammamish	ng/g					n/a	4.55	5.2	5.85	2	100%
Ciprofloxacin	Carrot peel	Recycled	ng/g					n/a	4.06	4.06	4.06	1	50%
Ciprofloxacin	Kale	Sammamish	ng/g					0%	3.33	4.79	6.25	2	25%
Ciprofloxacin	Kale	Recycled	ng/g					0%	3.43	3.43	3.43	1	13%
Ciprofloxacin	Soil	Recycled	ng/g					0%	56.3	56.3	56.3	1	17%
Citalopram	Carrot	Sammamish	ng/g	0.28	0.28	0.28	1	13%					0%
Citalopram	Recycled	Recycled	ng/L	1.32	2.1	2.52	3	50%	0.545	0.87	1.13	9	100%
Citalopram	Soil	Sammamish	ng/g	5.01	5.01	5.01	1	25%	2.62	2.62	2.62	1	17%
Citalopram	Soil	Recycled	ng/g					0%	0.941	8.8	24.6	3	50%
Clarithromycin	Recycled	Recycled	ng/L	2.45	3	3.3	3	50%					0%
Clinafloxacin	Carrot	Sammamish	ng/g					0%	3.42	4.6	5.53	3	38%
Clinafloxacin	Carrot	Recycled	ng/g	7.19	7.19	7.19	1	13%	2.15	4.1	6.02	2	25%
Clinafloxacin	Kale	Sammamish	ng/g					0%	3.98	3.98	3.98	1	13%
Clinafloxacin	Kale	Recycled	ng/g	5.5	5.5	5.5	1	13%	3.41	3.41	3.41	1	13%
Clinafloxacin	Sammamish	Sammamish	ng/L					0%	8.89	8.89	8.89	1	11%
Clotrimazole	Carrot	Sammamish	ng/g	0.221	0.221	0.221	1	13%					0%
Clotrimazole	Recycled	Recycled	ng/L	0.618	0.62	0.622	2	33%					0%
Cloxacillin	Carrot	Recycled	ng/g					0%	1.1	1.44	2.02	4	50%
Cloxacillin	Kale	Sammamish	ng/g	1.27	12	25.4	5	63%					0%

Cloxacillin	Kale	Recycled	ng/g	3.6	5.9	10.3	4	50%					0%
Cocaine	Kale	Sammamish	ng/g	0.26	0.55	1.06	7	88%					0%
Cocaine	Kale	Recycled	ng/g	0.28	0.7	1.73	8	100%					0%
Cocaine	Recycled	Recycled	ng/L	0.3	6.03	8.08	4	67%					0%
Cocaine	Sammamish	Sammamish	ng/L	1.03	1.03	1.03	1	17%					0%
Cocaine	Soil	Recycled	ng/g					0%	0.171	0.171	0.171	1	17%
Cotinine	Recycled	Recycled	ng/L	11	19.7	29.1	6	100%	18.1	19.7	20.8	9	100%
Cotinine	Sammamish	Sammamish	ng/L	1.64	1.78	1.95	3	50%	0.77	1.1	1.3	9	100%
Cotinine	Soil	Sammamish	ng/g	1.41	1.41	1.41	1	25%					0%
Cotinine	Soil	Recycled	ng/g	0.89	0.89	0.89	1	25%					0%
Cyclophosphamide	Recycled	Recycled	ng/L	1.92	3.9	6.31	6	100%	0.9	1.9	2.6	9	100%
Daunorubicin	Carrot	Sammamish	ng/g	3.6	3.6	3.6	1	13%					0%
Daunorubicin	Soil	Sammamish	ng/g	31.8	31.8	31.8	1	25%					0%
DEET	Carrot	Sammamish	ng/g					0%	0.125	0.41	0.56	6	75%
DEET	Carrot	Recycled	ng/g					0%	0.119	0.441	0.679	6	75%
DEET	Carrot peel	Sammamish	ng/g					n/a	0.117	0.134	0.151	2	100%
DEET	Carrot peel	Recycled	ng/g					n/a	0.131	0.131	0.131	1	50%
DEET	Kale	Sammamish	ng/g					0%	0.1	0.26	0.449	7	88%
DEET	Kale	Recycled	ng/g					0%	0.11	0.25	0.397	8	100%
DEET	Recycled	Recycled	ng/L	73.2	91	108	6	100%	62	89	112	9	100%
DEET	Sammamish	Sammamish	ng/L	5.69	7.1	8.6	5	83%	6.86	6.86	6.86	1	11%
DEET	Soil	Sammamish	ng/g					0%	2.41	2.85	3.2	3	50%
DEET	Soil	Recycled	ng/g					0%	2.23	2.3	2.44	3	50%
Dehydronifedipine	Recycled	Recycled	ng/L	2.59	3.7	5.01	6	100%	2.01	2.8	3.42	8	89%
Desmethyldiltiazem	Kale	Sammamish	ng/g	0.07	0.07	0.07	1	13%					0%
Desmethyldiltiazem	Soil	Recycled	ng/g					0%	0.203	0.203	0.203	1	17%
Diatrizoic acid	Recycled	Recycled	ng/L	64.3	98	158	6	100%	74	660	1840	9	100%
Diazepam	Recycled	Recycled	ng/L	1.23	1.4	1.53	3	50%					0%
Diltiazem	Kale	Sammamish	ng/g					0%	0.125	0.125	0.125	1	13%
Diltiazem	Recycled	Recycled	ng/L					0%	0.386	0.386	0.386	1	11%
Diphenhydramine	Carrot	Recycled	ng/g	0.24	0.24	0.24	1	13%					0%
Diphenhydramine	Kale	Sammamish	ng/g					0%	0.234	0.297	0.413	3	38%
Diphenhydramine	Kale	Recycled	ng/g					0%	0.367	0.367	0.367	1	13%
Diphenhydramine	Recycled	Recycled	ng/L	1.47	2.8	4.33	6	100%	1.29	2.44	4.22	9	100%
Diphenhydramine	Sammamish	Sammamish	ng/L					0%	1.08	1.08	1.08	1	11%

Diphenhydramine	Soil	Recycled	ng/g					0%	0.886	0.886	0.886	1	17%
Doxorubicin	Soil	Sammamish	ng/g	49.2	49.2	49.2	1	25%					0%
Erythromycin-H2O	Carrot	Sammamish	ng/g	1.06	1.1	1.14	3	38%					0%
Erythromycin-H2O	Carrot	Recycled	ng/g	1	1	1	1	13%					0%
Erythromycin-H2O	Kale	Sammamish	ng/g	1.16	1.16	1.16	1	13%					0%
Erythromycin-H2O	Kale	Recycled	ng/g	1.39	1.6	1.8	2	25%					0%
Erythromycin-H2O	Recycled	Recycled	ng/L	4.06	4.1	4.13	2	33%	2.44	2.44	2.44	1	11%
Erythromycin-H2O	Sammamish	Sammamish	ng/L	3.31	3.31	3.31	1	17%					0%
Erythromycin-H2O	Soil	Before irrigation	ng/g	7.59	7.59	7.59	1	50%				n/a	0%
Erythromycin-H2O	Soil	Recycled	ng/g					0%	2.16	2.16	2.16	1	17%
Etoposide	Kale	Sammamish	ng/g	1.97	3.6	4.64	6	75%					0%
Etoposide	Kale	Recycled	ng/g	2	5.6	11.3	8	100%					0%
Flumequine	Soil	Recycled	ng/g					0%	1.53	1.53	1.53	1	17%
Fluoxetine	Recycled	Recycled	ng/L	3.98	23	51.7	6	100%	5.75	9.3	11.1	9	100%
Furosemide	Kale	Sammamish	ng/g					0%	2.55	4.3	7.26	4	50%
Gemfibrozil	Carrot	Recycled	ng/g					0%	0.332	0.801	1.27	2	25%
Gemfibrozil	Kale	Recycled	ng/g					0%	0.737	0.737	0.737	1	13%
Gemfibrozil	Recycled	Recycled	ng/L					0%	1.76	2	2.25	2	22%
Gemfibrozil	Sammamish	Sammamish	ng/L					0%	0.995	0.995	0.995	1	11%
Glyburide	Recycled	Recycled	ng/L	0.974	1	1.11	3	50%					0%
Glyphosate	Sammamish	Sammamish	ng/L	30.6	45	68.4	5	83%	12	25	60	4	44%
Hydrochlorothiazide	Recycled	Recycled	ng/L	105	110	118	3	50%	11.4	17	23	8	89%
Ibuprofen	Carrot	Recycled	ng/g					0%	1.71	2.2	2.86	2	25%
Ibuprofen	Kale	Sammamish	ng/g					0%	1.59	1.8	1.92	2	25%
Ibuprofen	Kale	Recycled	ng/g	9.59	9.59	9.59	1	13%	1.49	2.28	3.36	4	50%
Ibuprofen	Recycled	Recycled	ng/L	3.99	3.99	3.99	1	17%	4.93	6.9	8.96	2	22%
Iopamidol	Recycled	Recycled	ng/L	4960	12200	20600	6	100%	1430	4230	8670	9	100%
Irbesartan	Recycled	Recycled	ng/L					0%	7.33	12	19.4	9	100%
Irbesartan	Soil	Sammamish	ng/g					0%	1.56	1.56	1.56	1	17%
Irbesartan	Soil	Recycled	ng/g					0%	0.589	0.589	0.589	1	17%
Lamotrigine	Recycled	Recycled	ng/L					0%	14.8	77	153	9	100%
MeFOSAA	Recycled	Recycled	ng/L	0.662	0.815	0.904	3	50%	0.435	0.52	0.58	4	44%
Meprobamate	Recycled	Recycled	ng/L	69.8	109	155	6	100%	46.9	68	84.2	9	100%
Metformin	Carrot	Sammamish	ng/g	0.311	0.5	0.748	4	50%	0.333	0.62	0.9	2	25%

Metformin	Carrot	Recycled	ng/g	0.424	8.1	57.6	8	100%					0%
Metformin	Kale	Sammamish	ng/g	0.331	0.53	0.799	4	50%	0.298	0.35	0.402	2	25%
Metformin	Kale	Recycled	ng/g	0.513	0.92	1.31	8	100%	5.73	5.73	5.73	1	13%
Metformin	Recycled	Recycled	ng/L	3.23	152	276	5	83%	0.883	7.9	15.4	7	78%
Metformin	Sammamish	Sammamish	ng/L					0%	1.56	2.8	6.93	7	78%
Metformin	Soil	Before irrigation	ng/g	3.72	3.72	3.72	1	50%				n/a	0%
Metformin	Soil	Sammamish	ng/g	0.322	0.46	0.633	3	75%	0.375	0.62	1.08	5	83%
Metformin	Soil	Recycled	ng/g	1.08	1.9	2.91	4	100%	0.731	1.1	1.95	6	100%
Metoprolol	Recycled	Recycled	ng/L	62	285	505	6	100%	5.5	24	45	9	100%
Metoprolol	Soil	Recycled	ng/g					0%	0.558	0.561	0.564	2	33%
Metronidazole	Recycled	Recycled	ng/L	16.6	28.3	39.8	6	100%	11	13	16	9	100%
Miconazole	Recycled	Recycled	ng/L	1.83	1.83	1.83	1	17%					0%
Moxifloxacin	Carrot	Sammamish	ng/g	2.41	2.41	2.41	1	13%					0%
Norfloxacin	Carrot	Recycled	ng/g					0%	23.3	23.3	23.3	1	13%
Norfluoxetine	Recycled	Recycled	ng/L	2.87	3.2	3.59	3	50%	0.521	0.59	0.692	5	56%
Norgestimate	Carrot	Recycled	ng/g					0%	1.36	1.36	1.36	1	13%
Norquetiapine	Soil	Recycled	ng/g					0%	1.61	1.61	1.61	1	17%
Norverapamil	Carrot	Sammamish	ng/g	0.174	0.174	0.174	1	13%					0%
Norverapamil	Recycled	Recycled	ng/L	11.1	11.5	12.1	3	50%					0%
Ofloxacin	Carrot	Sammamish	ng/g					0%	0.6	0.6	0.6	1	13%
Ofloxacin	Carrot	Recycled	ng/g	1.27	1.27	1.27	1	13%					0%
Ofloxacin	Carrot peel	Sammamish	ng/g					n/a	0.667	0.667	0.667	1	50%
Ofloxacin	Kale	Sammamish	ng/g	0.623	0.623	0.623	1	13%					0%
Ofloxacin	Recycled	Recycled	ng/L	6.77	6.77	6.77	1	17%	2.48	2.48	2.48	1	11%
Oxacillin	Carrot	Recycled	ng/g					0%	1.16	1.16	1.16	1	13%
Oxacillin	Kale	Sammamish	ng/g	6.53	9.095	11.4	4	50%					0%
Oxacillin	Kale	Recycled	ng/g	2.01	3.3	5.2	3	38%					0%
Oxycodone	Recycled	Recycled	ng/L	3.43	3.6	4.03	3	50%	1.16	1.4	1.57	3	33%
Paroxetine	Carrot	Sammamish	ng/g	5.06	5.06	5.06	1	13%					0%
Penicillin G	Kale	Sammamish	ng/g					0%	1.44	1.69	1.94	2	25%
Penicillin G	Kale	Recycled	ng/g					0%	1.49	1.49	1.49	1	13%
Penicillin V	Carrot	Sammamish	ng/g					0%	1.18	1.3	1.37	4	50%
Penicillin V	Carrot	Recycled	ng/g					0%	1.1	1.125	1.15	2	25%
Penicillin V	Kale	Sammamish	ng/g					0%	2.52	2.6	2.65	2	25%

Penicillin V	Kale	Recycled	ng/g					0%	2.02	2.2	2.35	3	38%
Penicillin V	Recycled	Recycled	ng/L					0%	4.08	4.58	5.3	3	33%
PFBA	Carrot	Sammamish	ng/g	0.4	0.508	0.632	7	88%	0.41	0.46	0.524	6	75%
PFBA	Carrot	Recycled	ng/g	0.412	0.538	0.681	6	75%	0.459	0.64	0.791	5	63%
PFBA	Carrot peel	Sammamish	ng/g					n/a	0.771	0.826	0.881	2	100%
PFBA	Carrot peel	Recycled	ng/g					n/a	0.744	0.769	0.794	2	100%
PFBA	Kale	Sammamish	ng/g	1.19	1.5	1.83	8	100%	0.456	0.7	0.923	8	100%
PFBA	Kale	Recycled	ng/g	0.932	1.6	2.6	8	100%	0.437	0.52	0.595	7	88%
PFBA	Recycled	Recycled	ng/L	9.63	13	15.1	6	100%	8.85	10.9	12.2	9	100%
PFBA	Sammamish	Sammamish	ng/L	3.18	3.49	3.81	3	50%	1.74	2.2	3.35	9	100%
PFBA	Soil	Before irrigation	ng/g	0.311	0.311	0.311	1	50%				n/a	0%
PFBA	Soil	Sammamish	ng/g					0%	0.183	0.19	0.207	3	50%
PFBA	Soil	Recycled	ng/g					0%	0.172	0.18	0.18	3	50%
PFBS	Kale	Recycled	ng/g	0.107	0.107	0.107	1	13%					0%
PFBS	Recycled	Recycled	ng/L	5.33	8.3	11.2	6	100%	9.69	13.7	16.7	9	100%
PFBS	Sammamish	Sammamish	ng/L	1.58	1.9	2.25	6	100%	1.56	2.2	3	9	100%
PFDA	Recycled	Recycled	ng/L	1.01	1.3	1.38	6	100%	1.1	1.5	1.85	9	100%
PFDA	Soil	Before irrigation	ng/g	0.081	0.081	0.081	1	50%				n/a	0%
PFDA	Soil	Sammamish	ng/g	0.043	0.051	0.061	4	100%	0.053	0.06	0.082	6	100%
PFDA	Soil	Recycled	ng/g	0.062	0.077	0.091	4	100%	0.065	0.07	0.092	6	100%
PFDoA	Carrot	Sammamish	ng/g					0%	0.109	0.11	0.122	3	38%
PFDoA	Soil	Sammamish	ng/g					0%	0.041	0.045	0.049	2	33%
PFDoA	Soil	Recycled	ng/g	0.046	0.046	0.046	1	25%	0.038	0.041	0.044	2	33%
PFHpA	Recycled	Recycled	ng/L	1.67	2.2	2.74	6	100%	1.47	1.8	2.31	9	100%
PFHpA	Sammamish	Sammamish	ng/L	0.843	1.1	1.64	4	67%	0.66	0.9	1.1	9	100%
PFHxA	Carrot	Sammamish	ng/g					0%	0.189	0.78	1.11	3	38%
PFHxA	Kale	Sammamish	ng/g	0.257	0.42	0.665	8	100%	0.119	0.18	0.307	8	100%
PFHxA	Kale	Recycled	ng/g	0.175	0.4	0.59	8	100%	0.138	0.25	0.556	6	75%
PFHxA	Recycled	Recycled	ng/L	23	24	26.2	6	100%	16.6	22.6	30.4	9	100%
PFHxA	Sammamish	Sammamish	ng/L	1.69	2.5	4.12	6	100%	1.67	2.6	3.84	9	100%
PFHxA	Soil	Before irrigation	ng/g	0.451	0.48	0.522	2	100%				n/a	0%
PFHxA	Soil	Sammamish	ng/g	0.07	0.09	0.101	4	100%	0.052	0.1	0.148	6	100%

PFHxA	Soil	Recycled	ng/g	0.093	0.1	0.109	4	100%	0.039	0.09	0.128	6	100%
PFHxS	Recycled	Recycled	ng/L	0.709	0.94	1.23	6	100%	0.672	0.81	1.05	9	100%
PFHxS	Sammamish	Sammamish	ng/L	0.9	1.2	1.45	6	100%	0.928	1.17	1.5	9	100%
PFNA	Recycled	Recycled	ng/L	0.846	0.98	1.1	6	100%	0.569	0.7	0.882	9	100%
PFNA	Sammamish	Sammamish	ng/L	0.458	0.458	0.458	1	17%	0.423	0.423	0.423	1	11%
PFNA	Soil	Sammamish	ng/g	0.084	0.13	0.23	4	100%	0.046	0.046	0.046	1	17%
PFNA	Soil	Recycled	ng/g	0.121	0.14	0.156	4	100%	0.04	0.04	0.043	2	33%
PFOA	Carrot	Sammamish	ng/g	0.113	0.113	0.113	1	13%	0.119	0.121	0.123	2	25%
PFOA	Kale	Sammamish	ng/g	0.152	0.18	0.221	3	38%					0%
PFOA	Kale	Recycled	ng/g	0.23	0.25	0.271	4	50%					0%
PFOA	Recycled	Recycled	ng/L	10.2	11	12.1	6	100%	7.53	8.5	9.36	9	100%
PFOA	Sammamish	Sammamish	ng/L	1.49	2.13	2.64	6	100%	1.2	1.6	2.01	9	100%
PFOA	Soil	Before irrigation	ng/g	0.114	0.124	0.134	2	100%				n/a	0%
PFOA	Soil	Sammamish	ng/g	0.049	0.05	0.057	3	75%	0.063	0.07	0.077	4	67%
PFOA	Soil	Recycled	ng/g	0.066	0.09	0.153	4	100%	0.065	0.07	0.081	4	67%
PFOS	Recycled	Recycled	ng/L	2.72	2.9	3.06	6	100%	2.45	2.6	2.92	9	100%
PFOS	Sammamish	Sammamish	ng/L	1.82	2.4	3.23	6	100%	1.34	1.8	2.49	9	100%
PFOS	Soil	Before irrigation	ng/g	0.317	0.33	0.352	2	100%				n/a	0%
PFOS	Soil	Sammamish	ng/g	0.21	0.23	0.271	4	100%	0.273	0.3	0.346	6	100%
PFOS	Soil	Recycled	ng/g	0.257	0.28	0.297	4	100%	0.285	0.31	0.331	6	100%
PFOSA	Recycled	Recycled	ng/L	0.505	0.864	1.52	5	83%	0.469	0.62	1.17	9	100%
PFOSA	Sammamish	Sammamish	ng/L	0.439	0.693	1	3	50%	1.05	1.6	2.04	9	100%
PFPeA	Carrot	Sammamish	ng/g					0%	0.251	0.291	0.331	2	25%
PFPeA	Kale	Sammamish	ng/g	0.25	0.35	0.517	8	100%	0.218	0.36	0.538	7	88%
PFPeA	Kale	Recycled	ng/g	0.254	0.386	0.542	6	75%	0.245	0.545	0.805	8	100%
PFPeA	Recycled	Recycled	ng/L	16.8	24	28.8	6	100%	32.2	36	41.5	9	100%
PFPeA	Sammamish	Sammamish	ng/L	1.64	2.3	3.64	6	100%	1.61	1.8	2.01	9	100%
PFPeA	Soil	Before irrigation	ng/g	0.186	0.198	0.21	2	100%				n/a	0%
PFPeA	Soil	Sammamish	ng/g	0.078	0.08	0.085	2	50%	0.074	0.115	0.145	5	83%
PFPeA	Soil	Recycled	ng/g	0.075	0.08	0.082	2	50%	0.117	0.129	0.135	3	50%
Prednisolone	Recycled	Recycled	ng/L	38.8	66.1	98.8	3	50%					0%

Prednisolone	Soil	Before irrigation	ng/g	7.52	7.52	7.52	1	50%				n/a	0%
Promethazine	Kale	Recycled	ng/g	0.422	0.42	0.422	1	13%					0%
Propranolol	Recycled	Recycled	ng/L	2.07	2.2	2.57	3	50%					0%
Quetiapine	Soil	Recycled	ng/g					0%	0.817	0.817	0.817	1	17%
Rosuvastatin	Recycled	Recycled	ng/L	4.26	7.4	12.8	6	100%					0%
Roxithromycin	Kale	Recycled	ng/g	0.13	0.13	0.13	1	13%	0.111	0.111	0.111	1	13%
Sertraline	Recycled	Recycled	ng/L	4.92	4.99	5.06	3	50%					0%
Sulfadiazine	Kale	Sammamish	ng/g	1.35	2.19	2.95	4	50%					0%
Sulfadiazine	Kale	Recycled	ng/g	1.07	1.935	2.56	4	50%					0%
Sulfadiazine	Recycled	Recycled	ng/L	4.46	7.61	10.3	3	50%	1.64	1.99	2.4	3	33%
Sulfadimethoxine	Kale	Sammamish	ng/g					0%	0.143	0.154	0.165	2	25%
Sulfadimethoxine	Recycled	Recycled	ng/L	0.644	0.644	0.644	1	17%					0%
Sulfadimethoxine	Sammamish	Sammamish	ng/L	0.444	0.46	0.471	2	33%	0.4	0.45	0.501	2	22%
Sulfamerazine	Soil	Recycled	ng/g	0.883	0.883	0.883	1	25%					0%
Sulfamethazine	Soil	Recycled	ng/g	0.69	0.69	0.69	1	25%					0%
Sulfamethoxazole	Recycled	Recycled	ng/L	2.72	13	23.1	5	83%	1.13	7.3	12.3	5	56%
Sulfamethoxazole	Sammamish	Sammamish	ng/L	1.15	1.15	1.15	1	17%					0%
Sulfamethoxazole	Soil	Sammamish	ng/g	1.76	1.76	1.76	1	25%					0%
Tetracycline [TC]	Carrot	Sammamish	ng/g	2.4	2.4	2.4	1	13%					0%
Theophylline	Carrot	Recycled	ng/g					0%	2.56	2.7	2.89	2	25%
Theophylline	Carrot peel	Sammamish	ng/g					n/a	2.16	2.16	2.16	1	50%
Theophylline	Kale	Sammamish	ng/g					0%	3.44	3.6	3.88	4	50%
Theophylline	Kale	Recycled	ng/g					0%	2.54	4.1	4.84	4	50%
Theophylline	Recycled	Recycled	ng/L	99.9	105	114	3	50%	11.2	44.4	132	9	100%
Theophylline	Sammamish	Sammamish	ng/L					0%	6.16	9.3	13	3	33%
Thiabendazole	Recycled	Recycled	ng/L	5.2	24	41.4	6	100%	3.25	15.6	23.5	9	100%
Thiabendazole	Soil	Sammamish	ng/g					0%	1.49	2.22	2.8	3	50%
Thiabendazole	Soil	Recycled	ng/g	2.05	2.05	2.05	1	25%					0%
Thiabendazole	Soil	Recycled	ng/g					0%	1.48	1.67	2.03	3	50%
Topiramate	Kale	Recycled	ng/g					0%	0.686	1	1.47	8	100%
Topiramate	Recycled	Recycled	ng/L					0%	485	580	745	9	100%
Topiramate	Sammamish	Sammamish	ng/L					0%	2.03	2.5	4.13	9	100%
Triamterene	Recycled	Recycled	ng/L	0.778	0.82	0.877	3	50%					0%
Triclocarban	Carrot	Sammamish	ng/g					0%	0.363	0.6	0.827	2	25%

Triclocarban	Carrot	Recycled	ng/g					0%	0.139	0.139	0.139	1	13%
Triclocarban	Recycled	Recycled	ng/L	0.553	0.609	0.665	2	33%					0%
Triclocarban	Soil	Before irrigation	ng/g	0.462	0.48	0.493	2	100%				n/a	0%
Triclocarban	Soil	Sammamish	ng/g	0.387	0.4	0.415	2	50%	0.391	0.5	0.615	5	83%
Triclocarban	Soil	Recycled	ng/g	0.393	0.46	0.508	3	75%	0.409	0.5	0.713	5	83%
Tylosin	Recycled	Recycled	ng/L	9.61	9.61	9.61	1	17%					0%
Valsartan	Recycled	Recycled	ng/L	369	417	479	3	50%	6.73	7.6	8.43	3	33%
Venlafaxine	Recycled	Recycled	ng/L					0%	0.397	0.9	1.45	7	78%
Venlafaxine	Soil	Recycled	ng/g					0%	10.1	10.1	10.1	1	17%
Verapamil	Carrot	Sammamish	ng/g	0.195	0.195	0.195	1	13%					0%
Verapamil	Kale	Sammamish	ng/g	0.217	0.217	0.217	1	13%					0%
Verapamil	Recycled	Recycled	ng/L	0.443	0.56	0.628	3	50%					0%
Verapamil	Soil	Recycled	ng/g					0%	0.553	0.553	0.553	1	17%
Virginiamycin M1	Sammamish	Sammamish	ng/L	8.14	8.14	8.14	1	17%					0%
Warfarin	Kale	Sammamish	ng/g	0.714	0.83	1	4	50%					0%
Warfarin	Kale	Recycled	ng/g	0.263	0.55	1.26	4	50%					0%
Zidovudine	Recycled	Recycled	ng/L					0%	6.38	7.6	8.66	5	56%

Appendix D: Community Outreach Graphics

The figures in this appendix are examples of outreach and summary materials that may be used to communicate key findings of the study to interested audiences. The outreach figures were developed by a King County graphic designer, in consultation with the study research team. They are designed to be accessible, providing context for study results for non-expert audiences. They will be used for in-person tabling events and will ultimately be available on King County's website.

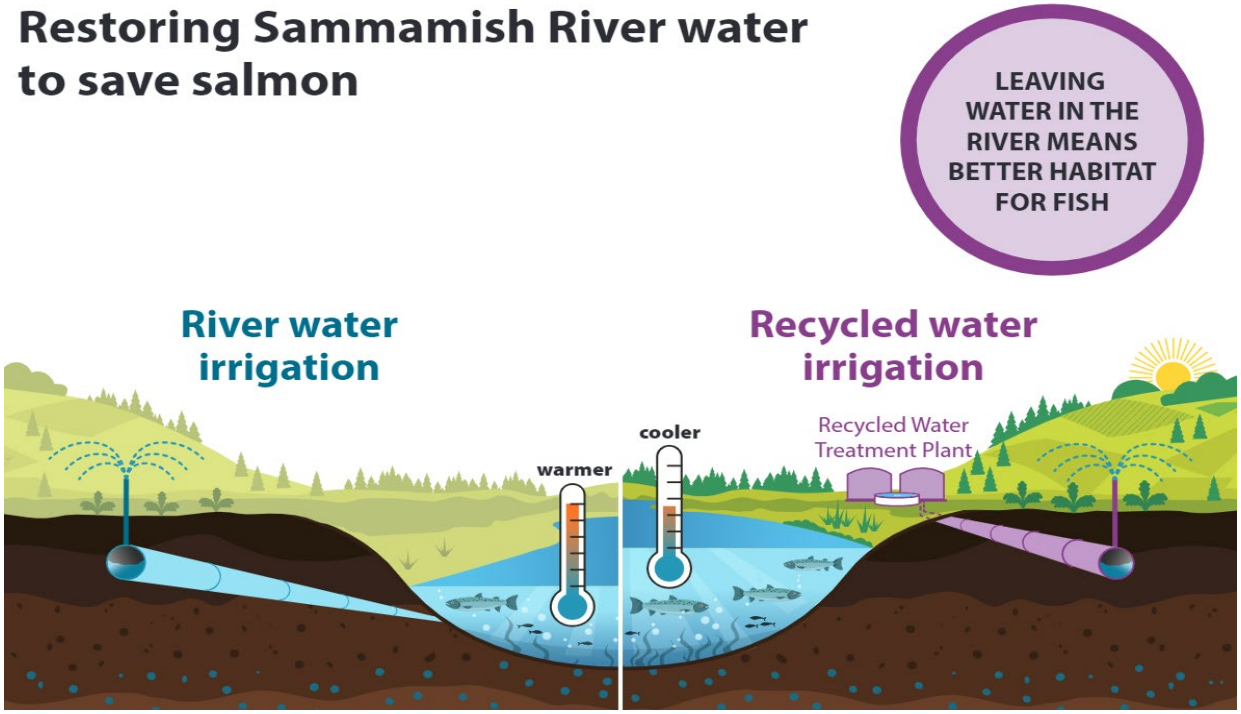

Figure A1. Schematic demonstrating potential ecological issues and associated implications for temperature and flow arising from irrigation source choice in the Sammamish River valley.

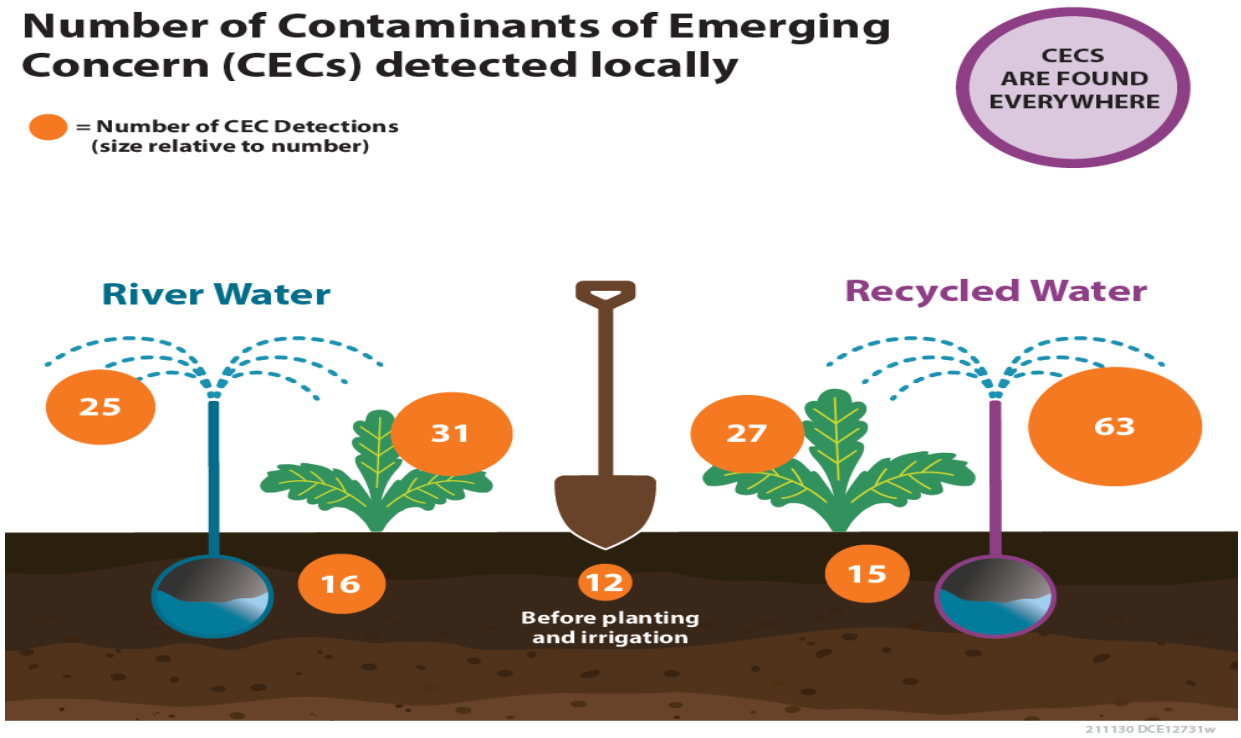

Figure A2. Schematic demonstrating total numbers of CECs detected in different sample types in 2020.

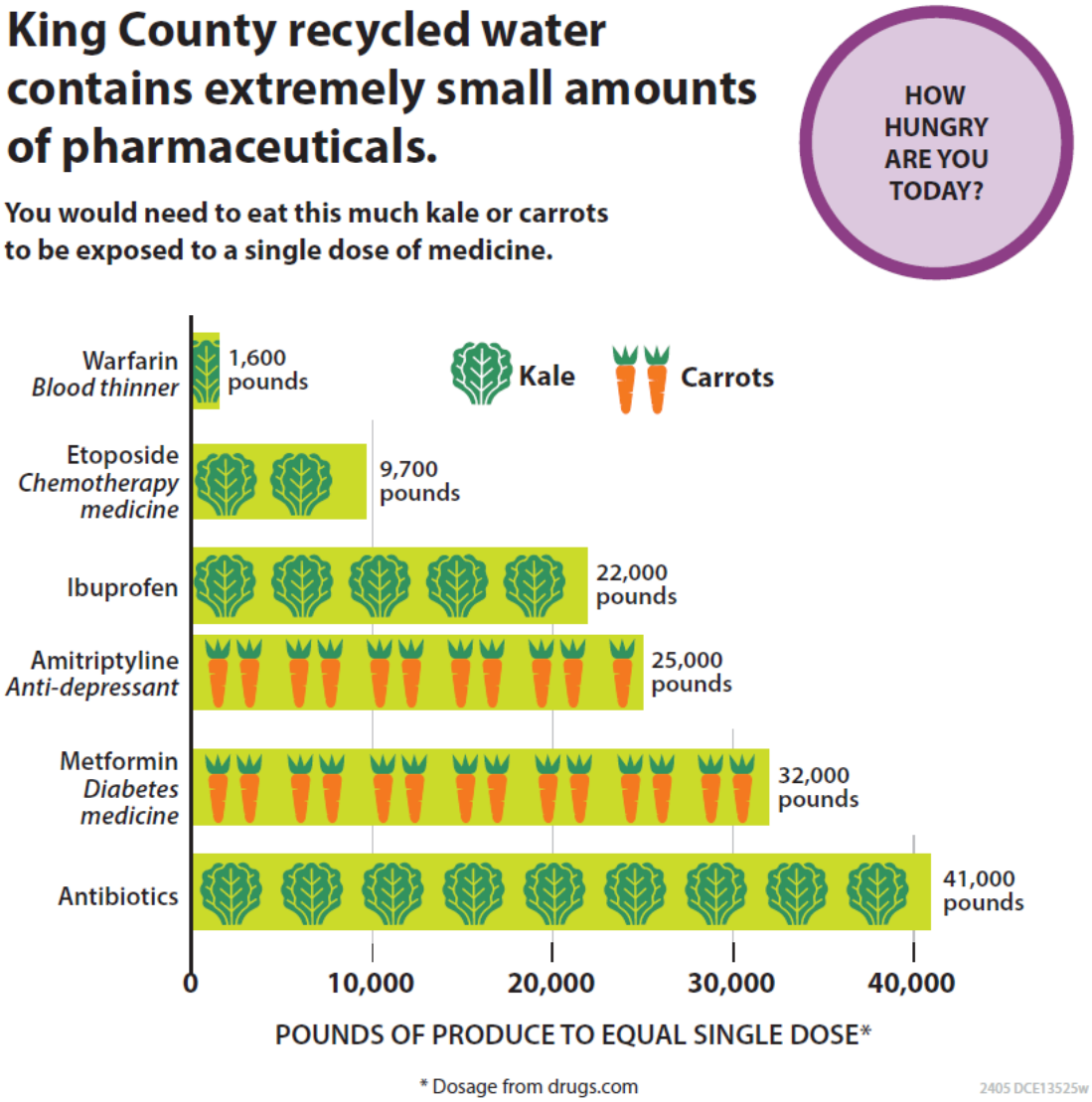

Figure A3. Graphic showing the amount of produce irrigated with recycled water one would have to eat to consume a dose of medication.

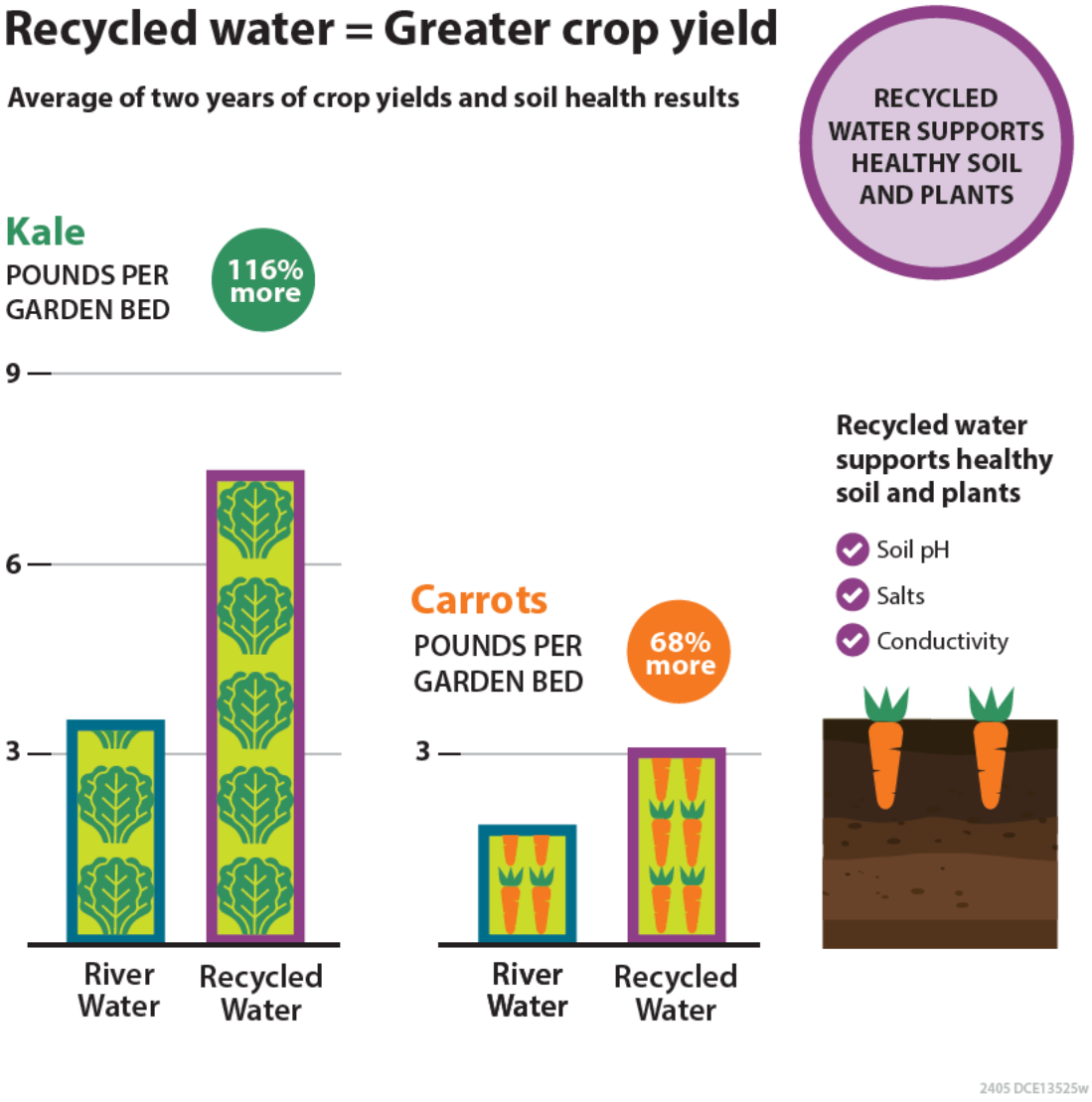

Figure A4. Graphic showing the yield increases from using recycled water instead of river water for crop irrigation.

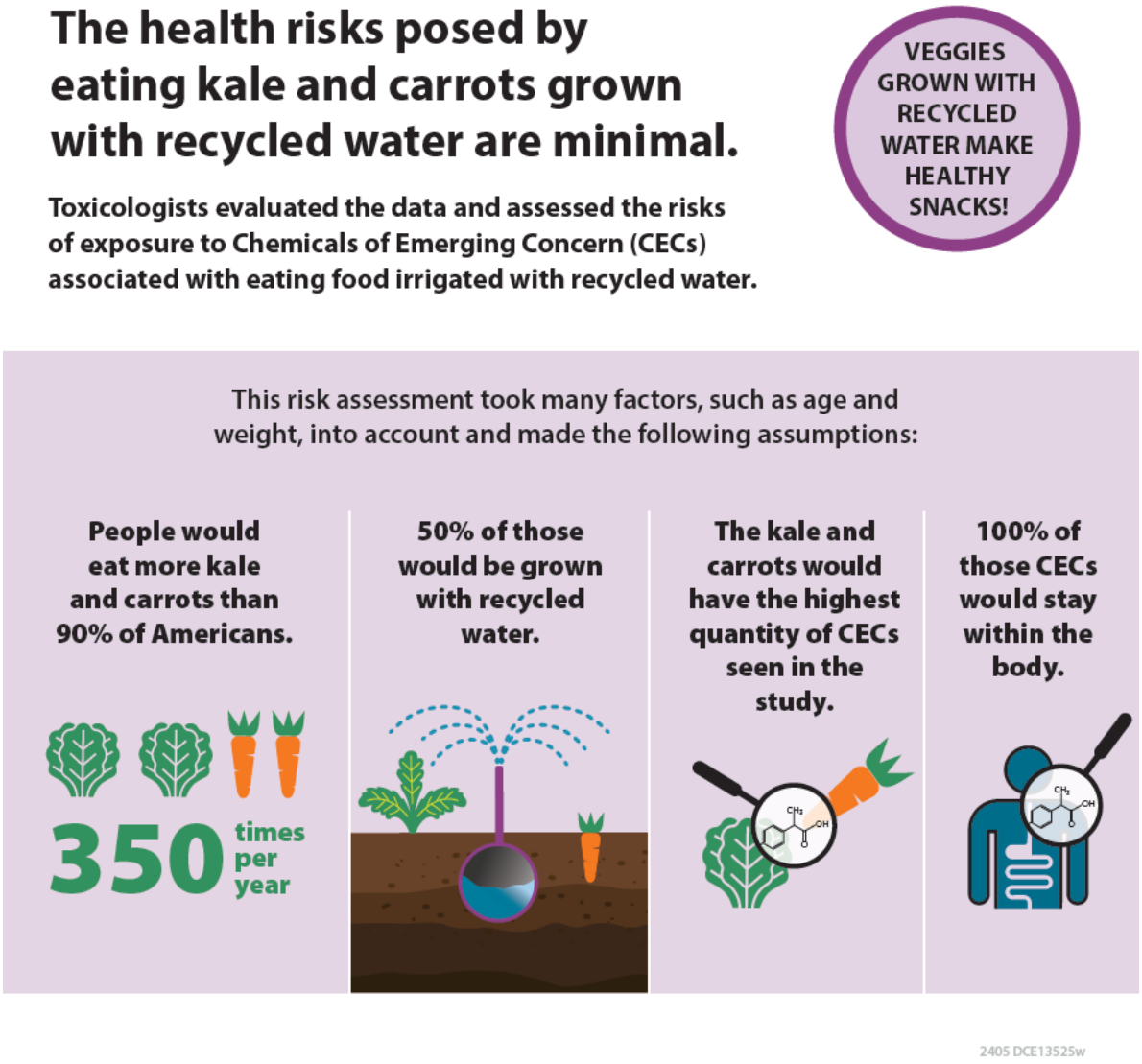

Figure A5. Graphic outlining the assumptions made to conduct the human health risk assessment.

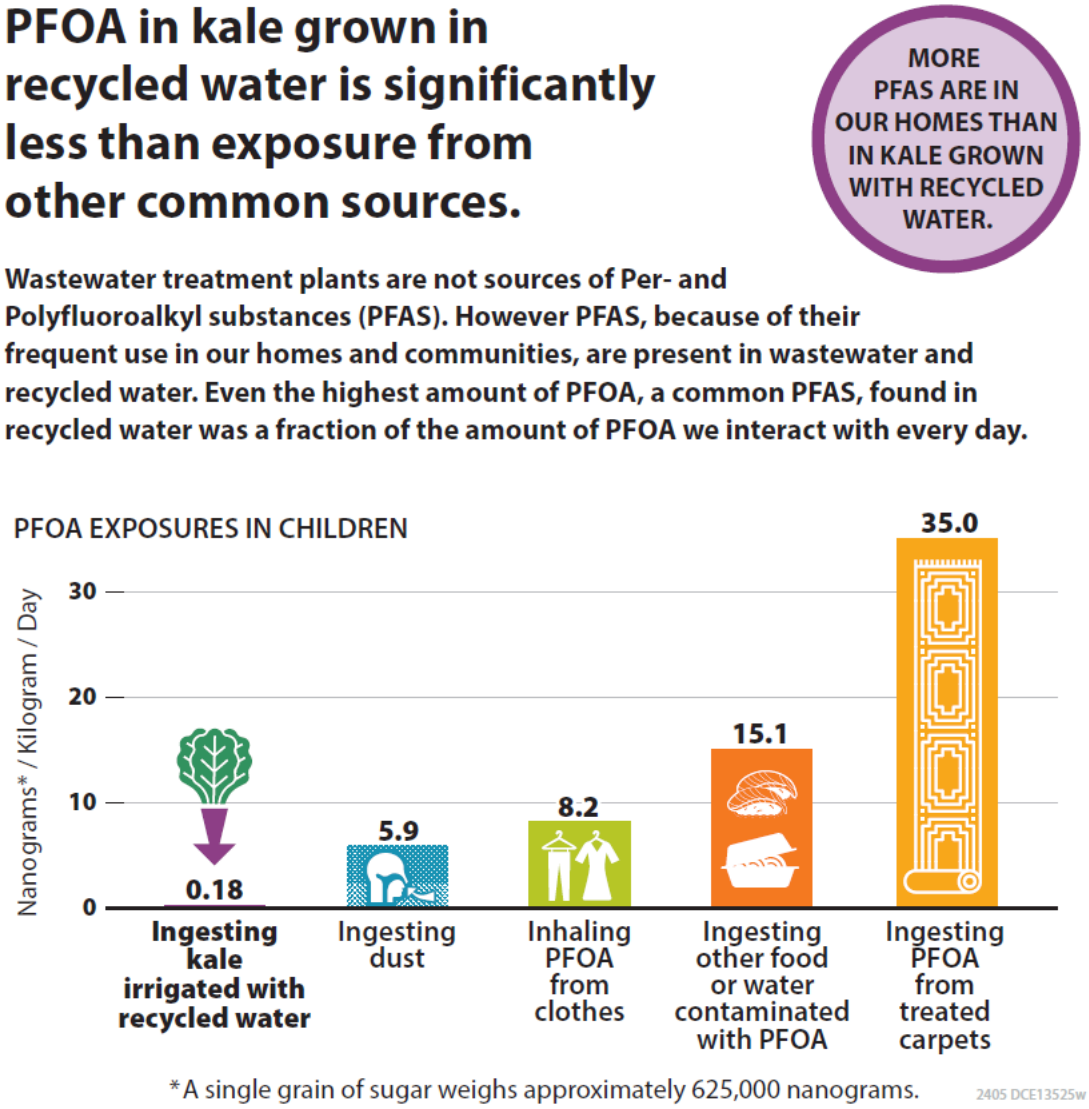

Figure A6. Graphic comparing exposures to PFOA from common household items versus kale irrigated with recycled water.