Control of Toxic Chemicals in Puget Sound

Phase 3 Data and Load Estimates

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Toxics in Surface Runoff to Puget Sound

Phase 3 Data and Load Estimates

by

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under contract to

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April 2011

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Abstract

The Washington State Department of Ecology identified surface runoff as the most significant contributor of toxic chemicals to Puget Sound during earlier phases of the Puget Sound Toxics Loading Analysis. The objectives of the current study were to refine previous estimates of contaminant load contributions to Puget Sound via surface runoff by monitoring contaminant concentrations and discharge from four land uses: commercial/industrial, residential, agricultural, and forest/field/other. The relative loading contribution from each of the uses was then calculated based on the data collected.

From August 2009 through July 2010, water samples were collected from 16 streams in the Puyallup and Snohomish watersheds during two baseflow events and six storm events. Each stream received surface runoff primarily originating from one of the four land uses. Samples were analyzed for an extensive list of organic compounds, heavy metals, and conventional water quality parameters.

The majority of the chemicals analyzed were detected more frequently and at higher concentrations during storm events than baseflow conditions among all land uses. Contaminant concentrations and area-normalized loading rates were generally higher in the commercial/ industrial basins and lower in the forested basins than the other land-use categories for both flow conditions. The fall storm had the highest incidence of oil and grease, TPH lube oil, triclopyr, and other parameters.

At the Puget Sound scale, the relative contaminant loading was strongly influenced by the relative amount of land area, rather than contaminant concentration; consequently, forested lands contributed the highest loads for most contaminants. Total loading rates were similar among the residential and agricultural areas even though residential land area was greater than agricultural in both study watersheds. However, Puget Sound may not be the most sensitive water body, and developed land uses likely influence conditions in smaller streams in the urban corridor.

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Executive Summary

Introduction

The primary objective of this 2009-10 study was to refine estimates of toxic chemical loadings from surface runoff in the Puget Sound basin. In this study, "surface runoff" is broadly defined to include stormwater, nonpoint source overland flow, and groundwater discharge to surface waters that flow to Puget Sound.

Beginning in 2006, the Washington Department of Ecology has been conducting studies to quantify the amount and to identify the primary sources of toxic chemicals in the Puget Sound ecosystem. Each successive study (Phase) improved upon the estimates of previous studies by including additional potential contaminant sources (i.e., land uses), or by increasing the number of parameters analyzed, or the sensitivity of analysis methods. Phase 1 and Phase 2 studies relied on existing data from literature sources. These two phases identified surface runoff as the primary source of toxic chemicals to Puget Sound relative to wastewater treatment plants, groundwater, spills, combined sewer overflows, and atmospheric deposition.

The current study is part of Phase 3. This study improves upon the Phase 1 and 2 loading estimates and advances understanding of the timing and sources of contaminant loading in the Puget Sound ecosystem by collecting and analyzing new local data on:

- Concentrations of toxic chemicals in 16 streams receiving surface runoff during storm events and periods between storms (baseflow).
- Concentrations of toxic chemicals associated with four specific land-use types: commercial/ industrial, residential, agricultural, and forest/field/other (forest).
- Relative contributions of toxic chemicals in surface runoff (based on loadings) from the four major land-uses identified above.

The project team consulted with external experts to develop and apply the calculation methodology.

Methods

Monitoring occurred in the Snohomish and Puyallup watersheds. These watersheds were selected because they contain all four land uses and span the geography of Puget Sound watersheds. The project team collected surface-runoff samples from eight streams in the Snohomish River watershed (Figure E-1), and eight streams in the Puyallup River watershed (Figure E-2). Two subbasins within each watershed were selected to represent each land use. Each site was sampled six times during storm events and twice during dry periods for a total of 126 samples[1] collected between October 2009 and July 2010. The study also recorded continuous flows from August 2009 through July 2010. Storm events were defined as a

[1] Two sites were dry during one baseflow event.

minimum of 0.25 inches of precipitation in 24 hours and an antecedent dry period of 12 hours to characterize fall, winter, and spring storm events. Baseflow events were captured based on precipitation and stream hydrograph patterns. The monitoring period was wetter than average, particularly the months of October, November, April, May, and June.

Samples were analyzed for the following classes of toxic chemicals, using methods that yielded significantly lower detection limits than have been typically reported in previous studies:

- Polycyclic aromatic hydrocarbons (PAHs)
- Phthalates
- Base/neutral/acid (BNA) extractable compounds (semi-volatile organic compounds)
- Pesticides
- Herbicides
- Polybrominated diphenyl ethers (PBDEs)
- Polychlorinated biphenyls (PCBs)
- Metals
- Petroleum hydrocarbons
- Oil and grease
- Conventional parameters (hardness, nutrients, solids, and field parameters)

The study applied several rules in calculating pollutant loading. Non-detected values were replaced with a value of one-half the reporting limit. When greater than 50 percent of the data were non-detects, we flagged the computed loading rates as estimates. Finally, when all the data were non-detect values, we computed loading rates based on the maximum reporting limit from the data. These loading rates were then qualified with a less than (<) sign.

Summary statistics focus on the 25th and 75th percentiles to communicate uncertainty. Analyses include land use-based concentrations and loads, as well as load estimates at the watershed (Snohomish or Puyallup) and Puget Sound scales. Loads were extrapolated from the 16 monitoring locations to the watershed and Puget Sound scales based on unit-area loads. An alternative extrapolation method was evaluated that uses concentrations from this study multiplied by precipitation-based runoff. However, unit-area loads were selected for extrapolation because concentration-based loads would overestimate forested land contributions. In addition to loading analyses, principal components analysis was performed on land use-based concentrations in order to distinguish patterns in the data.

Results

Rigorous quality assurance protocols were followed in the field and in laboratory analyses. Lab quality assurance data were evaluated closely. Data met the project data quality objectives or were flagged as estimates where appropriate. A limited number of results were rejected, ranging from <1 to 5 percent of samples by parameter class. Stream gauging data for several locations were flagged as estimates with overall errors ranging from 12 to 50 percent.

Detection frequency varied by parameter class, land use, and event type (storms and baseflow). Overall, metals and conventional pollutants were detected in nearly all samples. PCBs and

PBDEs were detected in a majority of samples; however, only a few individual congeners from each of these classes were routinely detected. PAHs, phthalates, BNA extractable compounds, pesticides, herbicides, and petroleum hydrocarbons in the gasoline or diesel fraction were rarely detected or not detected at all in the analyzed samples. Detection frequency was highest in commercial/industrial subbasins and lowest in forest/field/other subbasins for most parameters, although exceptions occurred. Storm events had higher detection frequencies than baseflow events.

The PCA analysis assessed the concentration data structure of the 21 priority parameters as a function of land use. The analysis indicated that during storm events, the forested land uses and commercial land uses were chemically distinct from each other and the other land use types. Forested land uses were characterized by lower concentrations of nitrate+nitrite nitrogen, total phosphorus, total mercury, total arsenic, total copper, and total suspended solids. The commercial basins were characterized by relatively high concentrations of total PCBs, total zinc, total lead, and total PBDEs. Residential and agricultural basins had similar chemical signatures and generally exhibited higher concentrations than forested basins and lower concentrations than commercial basins. During baseflow conditions, the differences among the land uses were less pronounced, but in general followed the same pattern as in the storm-event PCA analysis.

At the subbasin scale, loading rates of toxic chemicals were substantially higher for storm events than baseflow. Figures E-3 and E-4 provide examples of this phenomenon for total copper and oil and grease, respectively. Rain-induced surface runoff during storm events resulted in higher measured streamflow rates. Higher flow rates coupled with increased chemical concentrations resulted in substantially higher loading rates for storm events than baseflow. This suggests that the greatest opportunity for toxic chemicals to be transported to Puget Sound and its fresh waters occurs during storm events.

Organic pollutants and metals were generally detected more frequently and at higher concentrations in the commercial/industrial basins compared to the other land uses. Total copper and oil and grease data are presented in Figures E-5 and E-6, respectively, as examples of this pattern in the dataset as a whole. Metals were occasionally detected more frequently and at higher concentrations in the agricultural subbasins. Agricultural subbasins also had higher concentrations of some nutrients. Except for metals and nutrients, contaminant concentrations were generally similar between the residential and agricultural land-use types. Contaminants were detected least frequently in the forested areas, and when they were detected, they were generally at substantially lower concentrations than any of the other land uses. In general, unit-area loading rates[2] for the four land-use types matched the same pattern that was observed for concentration patterns.

Stormwater runoff, particularly from commercial/industrial subbasins, did not meet water quality criteria or human health criteria for several parameters. These include dissolved copper, lead, and zinc; total mercury; total PCBs; bis(2-ethylhexyl) phthalate; several carcinogenic PAHs; and one pesticide.

[2] i.e., the quantity of a toxic chemical generated from a defined area (e.g., kilogram per square kilometer per year).

Loads at the Puget Sound scale are dominated by contributions from forested lands, which cover 83 percent of the land area tributary to Puget Sound and the Straits of Georgia and Juan de Fuca within Washington State. However, forested lands had the lowest frequency of detection of the four land uses studied. Therefore, the load estimates expressed by the 25th to 75th percentiles are strongly influenced by how non-detects were treated. Conversely, the commercial/industrial land uses contributed a smaller amount of contaminants at the Puget Sound scale than the residential or agricultural land uses. The contaminant concentrations in the commercial/ industrial areas were much higher, but they comprise a relatively small portion of the total watershed area. The watershed-scale (Table E-1) and Puget Sound-wide (Table E-2) total loading estimates by land use for total copper and oil and grease provide examples of this pattern in the dataset.

The study confirmed several land use-based and event-based patterns in the concentration data and load estimates:

- The detection frequency for each of the chemical classes was generally higher for samples collected during storm events than those collected in baseflow conditions. Likewise, the magnitude of concentrations for each chemical class was higher during storm events.
- Contaminants were generally detected more frequently and at higher concentrations in the commercial/industrial basins compared to the other land uses.
- Agricultural and residential stormwater also contained higher concentrations of many toxic chemicals than stormwater from forested lands.
- The fall storm generally had the highest incidence of oil and grease, lube oil total petroleum hydrocarbons, triclopyr, and other contaminants.
- At the Puget Sound scale, relative loads for most parameters were proportional to the relative areas covered by each land use.

Discussion

In this Phase 3 study, the use of newly collected data with much lower detection limits and a refined calculation approach resulted in improved overall loading estimates for toxic chemicals relative to the Phase 1 and 2 studies. However, several estimates were strongly influenced by how non-detects are factored into the load estimates, particularly given the high absolute loads from forested lands. The total loading rates from the Phase 3 study were lower than rates from the Phase 2 study for PCBs, copper, zinc, and oil and grease. Of these four parameters, the most substantial difference between the two studies was observed for total PCBs. Total loading rate for total PCBs from the Phase 3 study was over an order of magnitude lower than the rate from the Phase 2 study. In contrast, total PBDEs was the only parameter to have higher total loading rates from the Phase 3 study relative to Phase 2. These loads mirror the patterns in the concentration data collected in Phase 3 compared with the literature-based concentration data used to generate the Phases 1 and 2 loads.

Loading estimates from the Phase 3 study were likely lower because the Phase 2 study used literature sources of data from both stormwater conveyance systems and instream samples.

Phase 3 loading estimates were based on data collected only from streams, where concentrations are expected to be lower due to attenuation, degradation, deposition, or dilution. This will underestimate loads in areas that discharge directly to Puget Sound through stormwater conveyance systems. For those regions, conveyance system data will be more appropriate for estimating loads, but this was beyond the scope of this study.

Beyond the earlier phases, no other study has quantified loads for so many constituents at the Puget Sound scale. However, a recent study that focused on four land uses in the Green-Duwamish River watershed found similar unit-area loads as the current study. The most recent phase of the Puget Sound Basin National Water Quality Assessment (NAWQA) study found pesticides, herbicides, and insecticides in urban streams.

While the Phase 3 study was designed to minimize bias, several factors may have produced overestimates or underestimates of loads at various scales. Factors possibly leading to overestimates include instream processes and selection of forested basins close to population centers. Factors possibly leading to underestimates include land cover heterogeneity, particularly for commercial/industrial; residential characterized low density only; use of stream data to characterize lands discharging through conveyance systems; and under sampling fall storms. Other factors could produce either overestimates or underestimates, including use of grab samples, legacy contaminants, and the much smaller proportion of forested lands in the Puget Sound watershed characterized by the four forested subbasins

Total contaminant load to Puget Sound is not the only scale of importance. Given that the highest concentrations and unit-area loads were found in stormwater from the most highly developed land uses, controls may be needed to address levels that could be found in small streams in the urban corridor. In addition, while instream data were used to estimate loads by different land uses and at different spatial scales, these data may not represent stormwater that discharges to marine (salt) waters or near marine waters. As previously mentioned, conveyance system data may be more appropriate; however, this study did not distinguish loads in these areas.

Conclusions and Recommendations

Because the majority of the total chemical loading to Puget Sound is derived from very low-level concentrations in forested subbasins and from somewhat higher concentrations in residential subbasins, management strategies for controlling toxic chemical loadings to Puget Sound must be broadly applied across the large areas represented by these land uses. If load reductions are needed at the Puget Sound scale, then the most effective control strategies for some parameters may be source prevention (e.g., emission controls, removing toxics from consumer products); especially given that it may be difficult to reduce the low concentrations in runoff from forested areas using conventional stormwater treatment practices (Schueler 1996).

Though commercial/industrial land use did not contribute as much total mass of contaminants as forested basins, streams draining this land use did exhibit the highest concentrations of contaminants. This study did not evaluate adverse impacts to sensitive organisms in streams and other water bodies that receive direct runoff from this land-use type, although some high

concentrations did not meet either water quality or human health criteria. Given the relatively large concentrations being exported from these areas and the relatively small geographic areas they occupy, effective management tools are generally available (e.g., structural and programmatic best management practices) to control the releases of contaminants.

Additional studies could further characterize and refine levels of toxic chemicals in surface runoff in the Puget Sound ecosystem. These include additional monitoring data as well as new analyses of data collected in this study. Efforts could target particular areas of uncertainty, including new monitoring:

- Characterize a seasonal first flush, especially in more developed watersheds.
- Install continuous monitoring equipment in a small number of basins to compare with grab samples.
- Evaluate whether pollutant loads scale up with precipitation in forested lands.
- Quantify how various instream processes affect pollutant loads.
- Characterize surface runoff from areas of higher-intensity residential development.
- Evaluate loads of toxics from specific types of agriculture.

Finally, several additional analyses could build from the information presented in this report. For example, a sample size power analysis is a statistical evaluation to quantify how many samples are required to reduce levels of uncertainty further. This would inform future monitoring studies in the region. The hydrologic monitoring data have not been evaluated in detail but suggest patterns that could inform stormwater design. Better estimates for those areas discharging stormwater to marine areas rather than small streams could be developed. Conveyance system data could be used to characterize these loads, and the estimates merged with those for lands discharging to small streams or larger rivers at the watershed scale or Puget Sound scale.

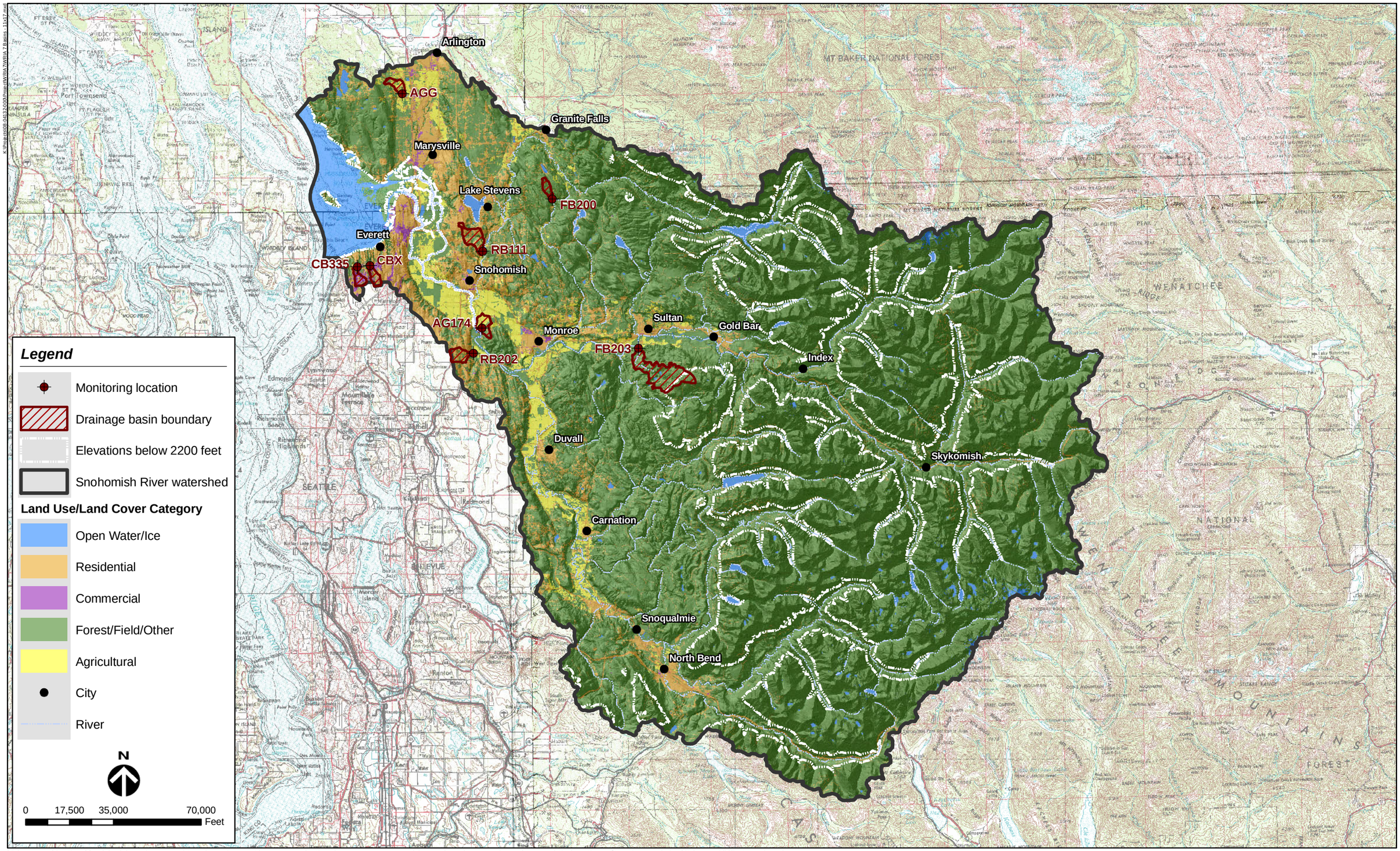

Figure E-1. Individual monitoring locations and their corresponding drainage basins within the Snohomish River Watershed.

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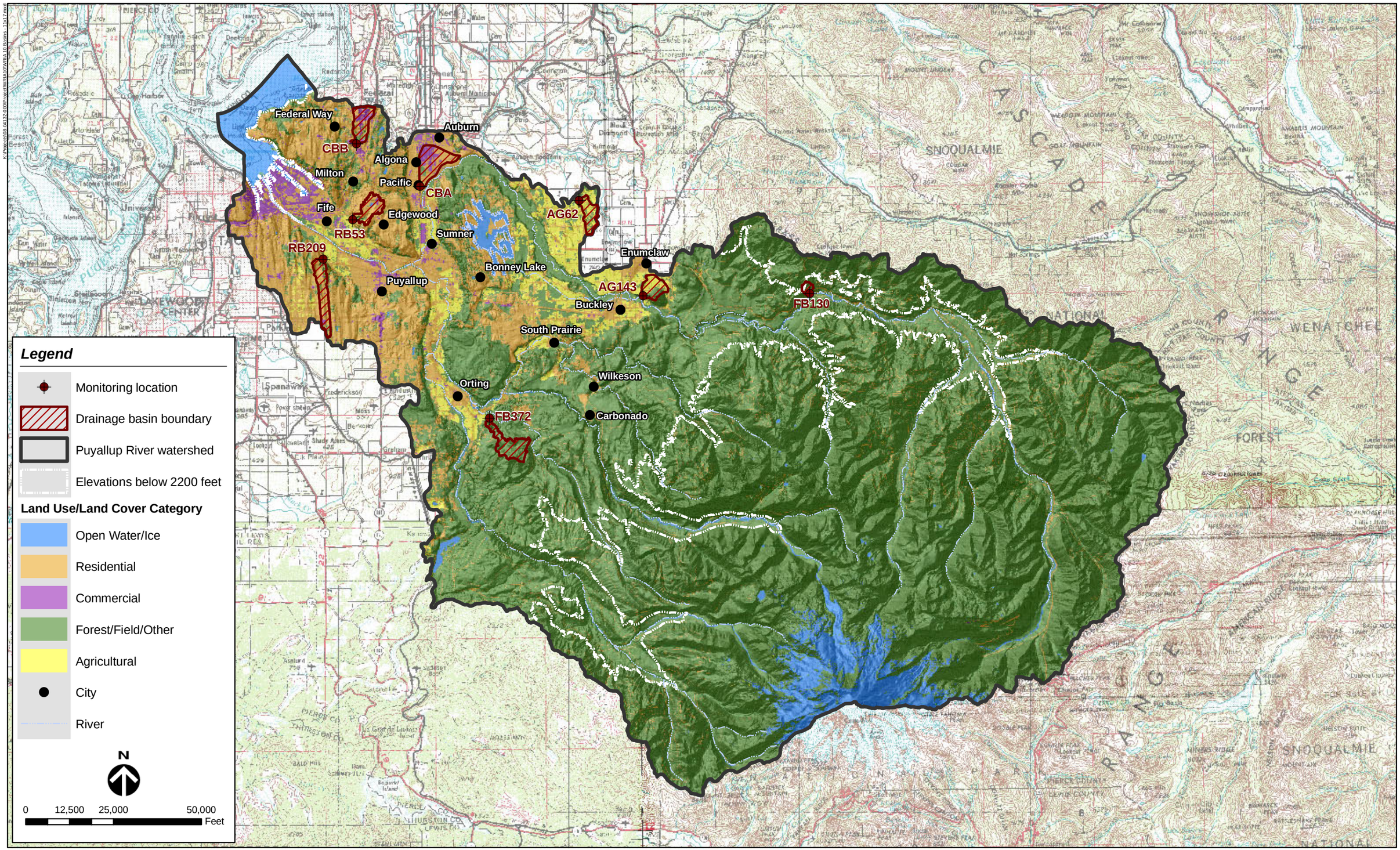

Figure E-2. Individual monitoring locations and their corresponding drainage basins within the Puyallup River Watershed.

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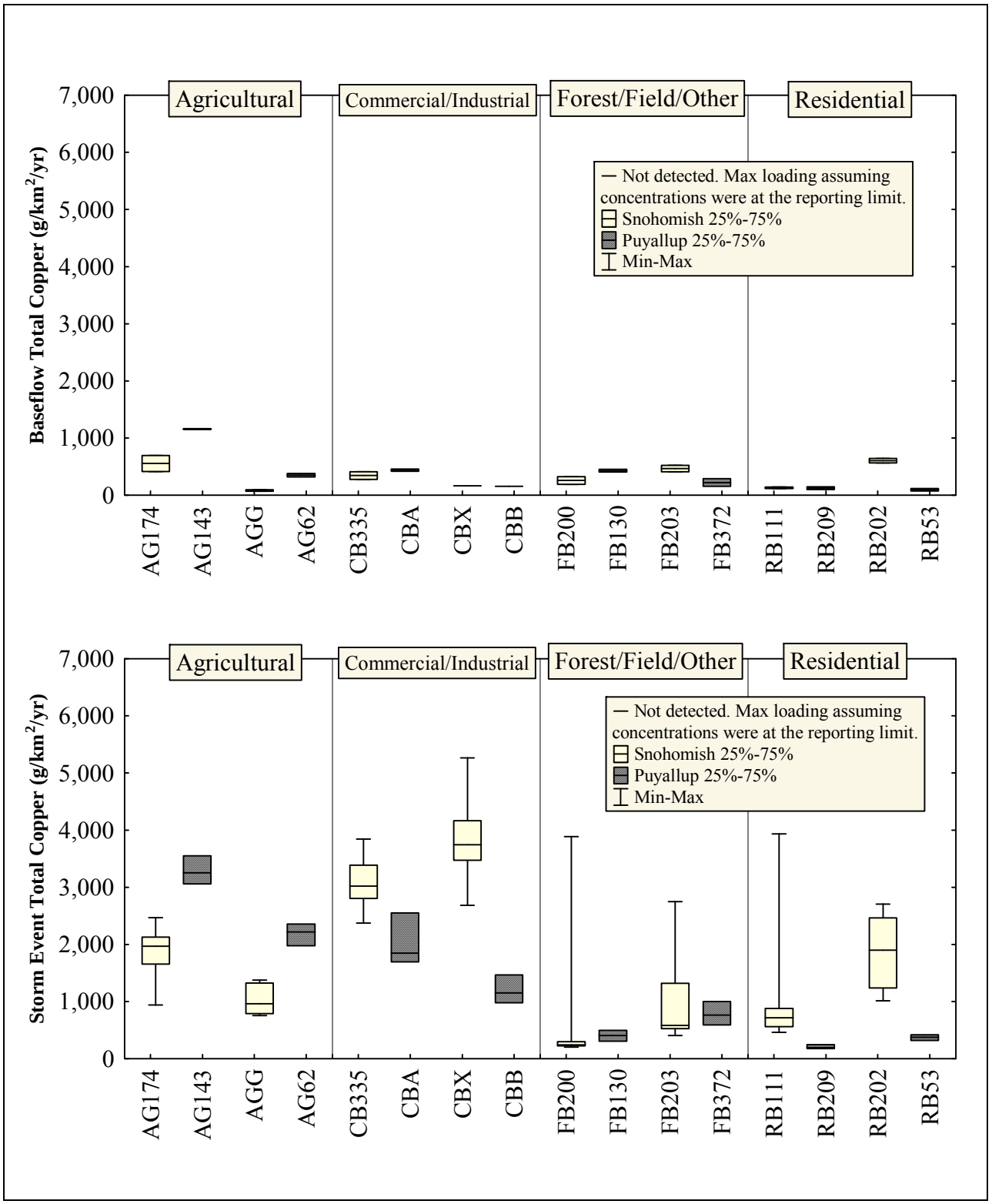

Figure E-3. Baseflow and storm-event unit-area chemical loading box plots for total copper for the Phase 3 study of toxics in surface runoff to Puget Sound.

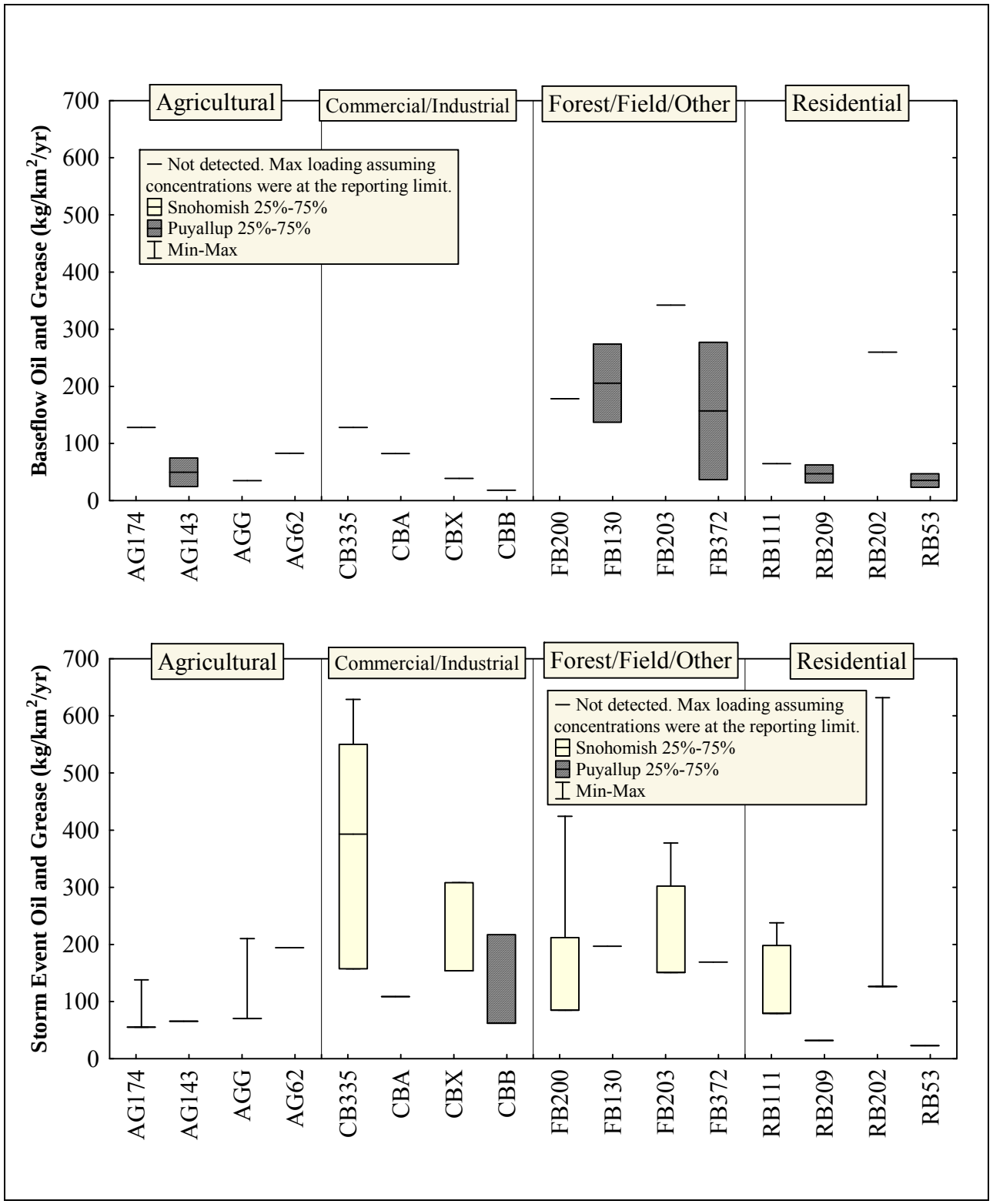

Figure E-4. Baseflow and storm-event unit-area chemical loading box plots for oil and grease for the Phase 3 study of toxics in surface runoff to Puget Sound.

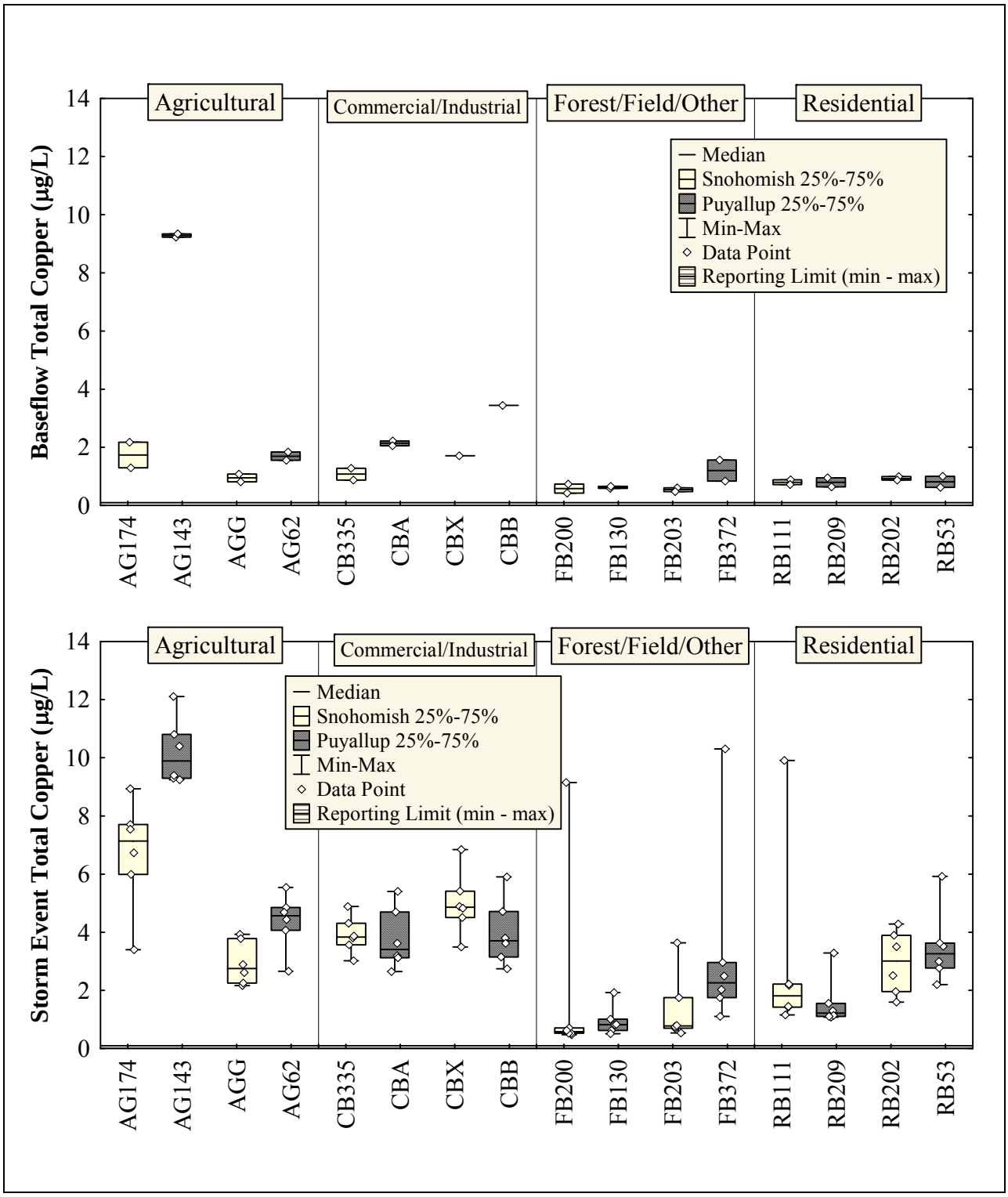

Figure E-5. Baseflow and storm-event total copper concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

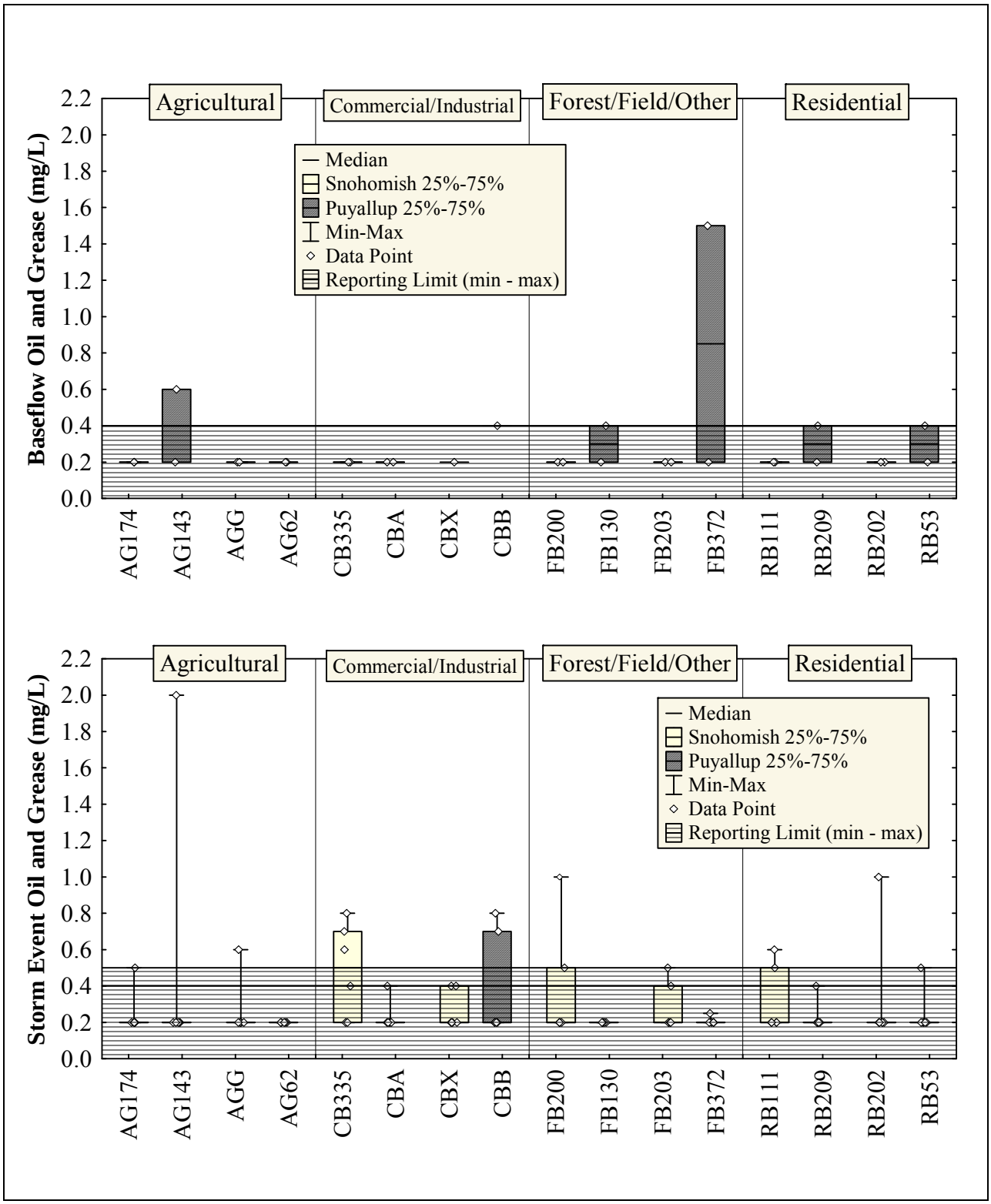

Figure E-6. Baseflow and storm-event oil and grease concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

Table E-1. Comparison of total loading rates by land use for the Snohomish and Puyallup watersheds.

Parameter	Units	Commercial/Industrial						Residential						Agricultural						Forest/Field/Other					
		Snohomish			Puyallup			Snohomish			Puyallup			Snohomish			Puyallup			Snohomish			Puyallup		
		25th	Median	75th	25th	Median	75th	25th	Median	75th	25th	Median	75th	25th	Median	75th	25th	Median	75th	25th	Median	75th	25th	Median	75th
Total Copper	kg/yr	31.2	37.6	42.1	24.0	27.3	36.1	429	579	894	78.6	140	187	145	200	355	182	334	474	3,040	3,870	5,940	929	1,450	2,290
Oil and Grease	MT/yr	1.59-2.43	2.37-3.21	3.96-4.80	1.67	1.67	2.60	40.9-99.0	40.9-99.0	71.6-130	17.0	21.3	25.6	8.53-20.2	8.53-20.2	8.53-20.2	9.75	9.75	12.6	588-1,910	588-1,910	1,320-2,640	104-474	156-526	492-862

Note: where a range of values is presented, the low value was calculated by assuming a zero for nondetect values, and the high value was calculated assuming the maximum method reporting limit for non-detect values.
25th = 25th percentile
75th = 75th percentile
kg/yr = kilograms per year
MT/yr = metric tons per year

Table E-2. Comparison of loading rates by land use for Puget Sound.

Parameter	Units	Commercial/Industrial			Residential			Agricultural			Forest/Field/Other		
		25th	Median	75th	25th	Median	75th	25th	Median	75th	25th	Median	75th
Total Copper	kg/yr	541	642	805	2,510	3,700	5,450	2,360	3,390	6,780	22,200	28,000	52,700
Oil and Grease	MT/yr	37.9	37.9	66.9	455	455	553	171	171	171	7,730	7,730	9,720

25th = 25th percentile
75th = 75th percentile
kg/yr = kilograms per year
MT/yr = metric tons per year

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Introduction

Project Background and History

Puget Sound is the largest fjord-like estuary in the continental United States. Located between the Cascade and Olympic mountain ranges in Washington State (Figure 1), the Puget Sound basin covers more than 43,400 square kilometers (16,800 square miles) of land and water (Hart Crowser et al. 2007). The basin is made up of a series of interconnected underwater basins, separated by shallow ridges or "sills." These basins include the deep Main basin and the shallower South Sound, Hood Canal, and Whidbey basins. Admiralty Inlet connects Puget Sound to the Pacific Ocean through the Strait of Juan de Fuca. For the purposes of this study, the term "Puget Sound" includes all of Puget Sound, Hood Canal, and the Straits of Georgia and Juan de Fuca within Washington State.

Over the past 150 years, human activity has introduced a wide range of toxic chemicals in the Puget Sound ecosystem at levels that are harmful to aquatic life (Puget Sound Partnership 2006). Despite a ban on some harmful chemicals in the 1970s and numerous cleanup efforts, toxic chemicals continue to persist and circulate throughout the Puget Sound ecosystem and are still being introduced via stormwater runoff, municipal sewage treatment plants, and atmospheric deposition. These toxic chemicals can have acute and chronic effects on nearshore organisms. Once in the food web, certain toxic chemicals can also be concentrated in larger predatory animals, ultimately affecting marine fish and mammals. These contaminants are also a significant concern for human health, especially for those who frequently consume fish with high contaminant levels.

Recognizing these concerns, the Washington State Department of Ecology (Ecology) has been collaborating with the Puget Sound Partnership and other state and federal agencies to conduct a multi-year, multi-phase effort to study toxic chemicals in the Puget Sound ecosystem from various sources. This report presents the results of the Phase 3 study of toxics in surface runoff to Puget Sound. The following summaries of the Phase 1 and 2 efforts are provided as context for understanding the objectives for Phase 3.

Phase 1: Initial Estimate of Toxic Chemical Loadings to Puget Sound

The Phase 1 study was completed in 2007 and provided estimates of the total amount (load) of 17 toxic chemicals, or classes of chemicals, entering Puget Sound from the following sources:

- Surface runoff
- Atmospheric deposition
- Wastewater
- Combined sewer overflows
- Unintentional spills

The Phase 1 study (Hart Crowser et al. 2007) provided loading estimates for the entire Puget Sound basin based on loading estimates derived for 14 hydrologically-based upland study areas (Figure 2) that comprise the Puget Sound basin. These 14 study areas are linked to Ecology's Puget Sound Box Model. This Box Model is a computerized tool for predicting contaminant movement within the Puget Sound ecosystem (Pelletier and Mohamedali 2009).

The Phase 1 report also provided toxic chemical loading estimates to Puget Sound from surface runoff originating from the following land uses within each study: commercial/industrial, residential, agricultural, and forest/field/other (forest). The Phase 1 results indicated that surface runoff was the highest contributor of toxic chemicals to Puget Sound. In this analysis, "surface runoff" included stormwater, nonpoint source overland flow, and groundwater discharge to surface waters that flow to Puget Sound.

Phase 2: Improved Loading Estimates

Phase 2 studies[3] were conducted in 2008 with the goal of improving the toxic chemical loading estimates developed during Phase 1. One of the Phase 2 studies provided revised toxic chemical loading estimates to Puget Sound (which were based on literature values) from surface runoff for the four land-use categories that were targeted in the Phase 1 analysis (EnviroVision et al. 2008; Herrera 2010). Estimates were improved by updating land-use data and including highways as a fifth land-use category. This generally resulted in reduced loadings estimates for some chemicals.

Results from this Phase 2 study confirmed that surface runoff remained the largest single contributor of toxic chemicals to Puget Sound. It also showed that residential and forested areas generally contributed more mass loading of toxic chemicals to Puget Sound than the other land-use types. This was not because runoff from residential and forested land use had higher concentrations of toxic chemicals than commercial/industrial areas; rather, it was because residential and forested land uses represented a much greater proportion of the land area. Runoff from commercial/industrial areas and highways were found to have higher concentrations of many toxic chemicals. These results were generally consistent with other regional studies of toxic chemical loading (Herrera 2007).

Despite these general conclusions, the estimates of the quantities of toxic chemicals released from different land uses and highway areas were still not certain enough to guide regulation and policy recommendations to reduce releases of toxic chemicals to Puget Sound. The datasets used for the Phase 1 and 2 estimates were developed from numerous regional and national studies. These studies had widely divergent objectives and varied sampling and analytical techniques. This meant that many assumptions had to be applied in order to incorporate the disparate sets of data into one analysis for the Puget Sound ecosystem. Another important limitation was that many of the data values were below quantifiable levels of detection that varied among the data sources and further weakened the analysis. Therefore, Ecology initiated the Phase 3 study of toxics in surface runoff to further improve loading estimates to Puget Sound and obtain new data from local watersheds for quantifying specific toxic chemicals by different land uses.

[3] More detailed information on the Phase 2 studies is available from www.ecy.wa.gov/programs/wq/pstoxics/index.html

Phase 3: Project Description

The Phase 3 studies (www.ecy.wa.gov/programs/wq/pstoxics/index.html) further quantify various sources and improve estimates of the quantities of toxic chemicals entering the Puget Sound ecosystem. Six of the 11 Phase 3 studies involved the collection and analysis of environmental samples from within the Puget Sound basin to improve the quality of the data sources; this included the Phase 3 study of toxics in surface runoff.

The project team for the Phase 3 study of toxics in surface runoff consisted of the following organizations:

- Washington State Department of Ecology (Ecology)
- Herrera Environmental Consultants (Herrera)
- Practical Stats, Inc.
- Ecology and Environment (E&E)
- Manchester Environmental Laboratory (MEL)
- Axys Analytical Services, Ltd. (Axys)
- Pacific Rim Laboratories (Pacific Rim)

Ecology provided technical oversight for the study, data quality assurance (QA) review, and report review. Under contract to Ecology, Herrera was the study lead and oversaw the development of the study's Quality Assurance Project Plan (QAPP) (Herrera et al. 2009). Herrera conducted the field monitoring, performed the data analysis, and led development of this report. Practical Stats, Inc. provided statistical analysis support during QAPP development and the data analysis for this report. E&E also provided support during QAPP development and oversaw the review and validation of laboratory data from the study. MEL coordinated all laboratory work and provided analytical support for selected parameters. Axys and Pacific Rim worked under contract to MEL and provided analytical support for the remaining parameters.

Ecology also convened two groups of experts to vet the approach for analyzing the data obtained through the Phase 3 study of toxics in surface runoff.

1. Three local professionals met to recommend a conceptual approach for analyzing the data in May 2010: USGS National Water Quality Assessment (NAWQA) scientist, City of Tacoma stormwater engineer, and King County toxicologist. This approach was developed further and presented through a facilitated discussion to a group of 13 experts in June 2010.

2. The calculation work group included biologists, toxicologists, biogeochemists, engineers, and other scientists and stormwater professionals from federal, state, county and city government; a university representative; a petroleum industry representative; a non-governmental organization representative; and a national laboratory representative. The group provided feedback on the conceptual approach and requested a subsequent briefing once initial study results were available. The project team briefed the group again in August 2010 and provided a draft memorandum explaining how the approach developed with input from the group was applied for several representative parameters.

Individuals also provided comments during the external review period.

At the outset of the Phase 3 study of toxics in surface runoff to Puget Sound, the project team defined the following study objectives:

- Perform an in-depth study within two pilot watersheds to determine the relative contributions of toxic chemicals in surface runoff from the four major land uses identified above (i.e., residential, commercial/industrial, agricultural, and forest/field/other).
- Reduce the uncertainty of the total loading estimates for toxic chemicals that are discharged to Puget Sound via surface runoff relative to the estimates determined in the Phase 1 and Phase 2 studies.

To meet these objectives, the project team conducted flow monitoring and water quality sampling during baseflow and storm-event conditions in representative streams within the Snohomish watershed and Puyallup watershed (Figure 1) that receive runoff from the four targeted land uses. The samples were collected using ultraclean techniques and analyzed for the following toxic chemicals, or classes of chemicals, and contaminants of concern in surface runoff:

- Heavy metals
- Polychlorinated biphenyls (PCBs) congeners
- Polybrominated diphenyl ethers (PBDEs) congeners
- Polycyclic aromatic hydrocarbons (PAHs)
- Base/neutral/acid (BNA) extractables (semi-volatile organic compounds)
- Pesticides
- Herbicides
- Petroleum hydrocarbons
- Oil and grease (n-hexane extractable material [HEM])
- Conventionals (hardness, nutrients, total suspended solids, and field parameters)

Because many of these parameters were not detected in other regional studies of toxic chemicals in surface runoff (Herrera 2004, 2007; USGS 2003) using generally available detection limits, the collection of new data for these parameters with lower detection limits was identified as a high priority by the project team in the early planning phases of the project.

The monitoring data were used to calculate the total load of toxic chemicals transported by surface runoff at each monitoring location (subbasin scale) over the period of a year. This value was then normalized based on the contributing land area to determine the quantity of toxic chemicals generated per area (e.g., square kilometer) of a subbasin which was chosen to represent one of the four land-use categories. These normalized or "unit-area" toxic chemical loading estimates at the subbasin scale were then used to estimate total toxic chemical loadings by land use for the 2 pilot watersheds (watershed scale) and extrapolated to the 14 study areas that are linked to the Puget Sound Box Model (Puget Sound scale).

Based on the results that were obtained from these analyses, the project team identified several broad management implications for controlling toxic chemicals in surface runoff. These management implications generally address toxic loading impacts at both the Puget Sound scale and the scale of smaller receiving waters that receive direct runoff from the land uses that were targeted in this study.

Document Organization and Content

This report summarizes and discusses results from the Phase 3 study of toxics in surface runoff to Puget Sound. The remainder of this report is organized to include the following sections:

- **Methods:** Summarizes the experimental design and describes the monitoring locations, sampling procedures, monitoring parameters, and data analysis methods.
- **Results:** Summarizes the results from the review and validation of analytical and hydrologic data, key trends in the data based on the detection frequency of individual parameters in each class of toxic chemicals, and contaminant loading estimates for priority toxic chemicals at the subbasin, watershed, and Puget Sound scale.
- **Discussion:** Presents an interpretation of the results that describes key trends in the data and their management implications for toxic chemicals, evaluates the representativeness of the collected data based on comparisons to data from other regional monitoring, and identifies key limitations of the data and results from this study.
- **Conclusions:** Compiles high-level findings from this study and summarizes their implications.
- **Recommendations:** Provides recommendations for further study and analysis.

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Methods

General Approach

The project team conducted monitoring at representative locations within the Snohomish watershed and Puyallup watershed (Figure 1). Within each watershed, eight monitoring locations were established, each to represent one of the following land uses: commercial/ industrial, residential, agricultural, or forest/field/other (Appendix A). Two monitoring locations in each watershed were selected to represent each land-use type. Therefore, a total of four monitoring locations represent each of the four land uses.

The project team sampled each monitoring location eight times over a one-year period extending from August 2009 through July 2010. Two of the eight sampling events occurred during baseflow conditions, with one event in the summer (July 2010) and one event in winter (May 2010). The remaining six events occurred during storm events. One of the storm events occurred in October 2009 to target a fall event; three occurred from November 2009 through January 2010 to target winter storm events; and two occurred from April through May 2010 to target spring storm events.

Samples collected from all events were analyzed for an extensive list of toxic chemicals and contaminants of concern in surface runoff. In addition to sample collection, the project team established gauging stations at all 16 monitoring locations to obtain a continuous record of discharge over the study period. The discharge data were used in conjunction with the chemical data to calculate total and unit-area loading rates for each monitoring location. Data obtained from these samples were then used to evaluate differences in toxic chemical concentrations and loads in relation to land use, watershed, and flow conditions at the subbasin scale. In addition, the project team used these data to estimate total toxic chemical loadings by land use for the two pilot watersheds (watershed scale) and the 14 study areas linked to the Puget Sound Box Model (Puget Sound scale).

The following subsections provide a summary of the rationale and methods behind monitoring location selection; sample collection, stream gauging, and laboratory procedures; and data analysis techniques. More detailed information is provided in the QAPP for the study (Herrera et al. 2009).

Monitoring Locations

The process of selecting monitoring locations began with the selection of two watersheds. The project team selected the Snohomish River and Puyallup River watersheds for monitoring based on the following reasons:

- Each had areas representing all four land uses.
- Each had a U.S. Geological Survey (USGS) gauging station at or near its mouth that could provide a continuous record of flow during the sampling period.

- Each had available land-use/land-cover data to support the required analyses for this study.
- Each represented some of the geographic diversity within the Puget Sound basin and yet both were centrally located, which was critical to optimizing travel time and other sampling logistics.

The project team used geographic information system (GIS) analyses to select representative monitoring locations within each watershed using a stratified random approach. Appendix B documents the specific steps that were performed during the GIS analyses to select the final monitoring locations for this study. As documented in this appendix, a number of issues arose that required modifications to the site-selection criteria, and not all sites were randomly selected. In general, the stratified random approach was intended to eliminate potential bias in the monitoring location selection process by randomly selecting monitoring locations in each watershed that met pre-defined physical, geographic, and land-use criteria. These criteria were specifically developed to balance the following requirements of the study design during the selection of monitoring location:

- Identify monitoring locations with drainage basins that are sufficiently representative of the four targeted land-use categories.
- Identify monitoring that will remain accessible to field personnel over the entire monitoring period.
- Identify monitoring locations that have a sufficient baseflow component to the hydrograph for sampling during the summer months.

In keeping with these requirements, the project team limited monitoring location selection to subbasins for second-order streams that were below 2,200 feet in elevation. This step was performed to ensure the monitoring locations selected would not be rendered inaccessible due to winter snow conditions. It is recognized that this introduced a bias in that the areas therefore were closer to population centers than higher elevation locations would have been.

In addition, the project team used the National Land Cover Database (MRLC 2001) to select subbasins for second-order streams by representative land use for each specific category. While first-order streams would likely have more homogeneous land use, second-order streams were specifically targeted for monitoring due to concerns that baseflows would be intermittent through the monitoring year in first-order streams. The land-cover datalayer was developed from Landsat satellite imagery using a nationally standardized approach; 2001 was the most recently available compilation.

Originally the intent was to select the most homogeneous subbasins. However, few second-order streams were available with >90 percent coverage by specific land uses other than forested. Therefore, the percent cover threshold was decreased to identify sufficient potential sites for further evaluations. In particular, the threshold for commercial/industrial subbasins decreased to <50 percent cover, and other land uses likely affected results from those areas. Final subbasins were selected using the following criteria:

- **Commercial/Industrial:** At least 30 percent of the drainage subbasin must be classified as commercial/industrial land use.

- **Residential:** At least 50 percent of the drainage basin must be classified as residential land use, and no more than 10 percent may be classified as commercial/industrial land use.
- **Agricultural:** At least 50 percent of the drainage basin must be classified as agricultural land use.
- **Forest/Field/Other:** At least 90 percent of the drainage basin must be classified as forest/field/other land use.

Each of the 16 monitoring locations selected for this study received runoff from a relatively small drainage area with land uses corresponding to one of the four primary land-use categories. It should be noted that roads and highways were not specifically called out as unique land-use categories in this study because the contaminant contribution from these areas could not be explicitly separated from the contaminant contribution from the other four land uses given the experimental design for this study. As was noted in the Phase 2 study, roads and highways are both a unique contaminant source and a conduit for transporting contaminants from surrounding lands uses; therefore, a more focused sampling effort than the one used for this study would be required to quantify the associated contaminant loadings. Instead, roads are included in the four land-use categories used in this study.

Detailed monitoring location information, including GIS coordinates and drainage basin characteristics, are provided in Table 1. Figures 3 and 4 also show the eight monitoring locations and their corresponding drainage basins within the Snohomish and Puyallup watersheds, respectively. More detailed maps are also provided in Appendix A for each monitoring location with the following information:

- Monitoring locations relative to delineated basin boundaries
- Land use breakdown within the delineated basin boundaries
- Stream channel network within the delineated basin boundaries

For the purpose of this study, the project team computed toxic chemical loading estimates for each monitoring location based on the assumption that the entire drainage basin was representative of the targeted land use, even though Table 1 indicates there is actually a mix of land uses present, particularly in commercial/industrial subbasins. However, as noted above, the land-use breakdown in each drainage basin was determined from relatively low-resolution data that were obtained from the National Land Cover Database (MRLC 2001). In general, the maps provided in Appendix A suggest that the actual land use in the drainage basins is more representative of the targeted land use for each monitoring location than Table 1 implies. Despite this consideration, the implications for interpreting results from this study given the lack of uniform land use in each subbasin are presented in the Discussion section.

The following subsections provide a general description of each monitoring location, including its watershed characteristics, channel configuration, predominant substrate, and any known pollutant sources in the immediate vicinity of the monitoring site. In general, there are no point (discrete) sources tributary to any of these monitoring locations. As documented below, sampling at some monitoring locations occurred downstream of galvanized steel culverts that could have been a source from some pollutants (e.g., metals); the potential implications of this artifact of the sampling design are evaluated in the *Discussion* section of this report.

Snohomish Watershed

AGG

This monitoring location was on an unnamed tributary to the West Fork of Quilceda Creek in the Snohomish Watershed. The predominant land use in the 249.4-hectare basin is agricultural (49.7 percent) with lesser amounts of residential and forested areas (Table 1). At the sampling location, the channel width was approximately 7 feet. Relatively steep riparian buffers, approximately 5 feet wide, lined each side of the stream. No erosional features or channel incision were observed at the sampling location or immediately upstream, likely due to the low gradient of the stream. The stream substrate was characterized by a mix of various-sized rocks and cobbles. During low-flow periods, large quantities of duck weed (*Lemna* spp.) were observed in the stream.

The sampling location was immediately downstream of a large galvanized steel culvert and dirt road used to access a nearby residential property. Moderately consolidated rock and dirt were stacked on top of the culvert. The stream was bordered on the west side by a residential street and pasture land to the east.

AG174

This monitoring location was on an unnamed tributary to French Creek/French Slough in the Snohomish watershed. The predominant land use in the 360.5-hectare basin is agricultural (49.6 percent) with lesser amounts of forested and residential areas (Table 1). At the sampling location, the channel width was approximately 2 to 3 feet. Relatively steep riparian buffers lined each side of the stream. No erosional features or channel incision were observed at the sampling location or immediately upstream, likely due to the low gradient of the stream. The stream substrate was characterized by a mix of 1- to 2-foot diameter rip rap and asphalt, cobble, tires, woody debris, and other miscellaneous metal debris. Discharge at this monitoring location typically exhibited a tannin color.

The sampling location was immediately below a concrete culvert, which was in poor condition and had collapsed in some places, dispersing the flow. Streamflow from the broken culvert cascaded into a small pool below, where the stream gradient was low. Several large warehouses, storage sheds, and dirt roads associated with a large farm were located above the culvert.

FB200

This monitoring location was on an unnamed tributary to Carpenter Creek in the Snohomish watershed. The 174.2-hectare basin is primarily forested (90.7 percent) with a minor amount of residential area land use (Table 1). At the sampling location, the channel width was approximately 10 feet. Signs of channel incision were observed upstream of the culvert, and evidence of recent cobble deposition at the sampling location was also apparent. The stream substrate was characterized by a mix of cobbles that were 2 to 18 inches in diameter.

The sampling location was immediately downstream of a large galvanized steel culvert. Moderately consolidated rock and dirt were stacked on the top of the culvert. The majority

of the forest area was immediately upstream, while at the sampling location, the stream was bordered on each side with small riparian buffers approximately 5 to 10 feet in width; land use outside the buffer was predominately agricultural (i.e., pasture) with a road paralleling the channel.

FB203

This monitoring location was on McCoy Creek in the Snohomish watershed. The 1,657.6-hectare basin is primarily forested (95.8 percent) with a minor amount of residential area land use (Table 1). At the sampling location, the channel width was approximately 25 feet. No erosional features or channel incision were observed at the sampling location or immediately upstream, likely due to the moderate gradient of the stream. The stream substrate was characterized by large, irregularly shaped rocks and cobbles ranging from 6 to 18 inches in diameter.

The sampling location was immediately downstream of a large galvanized steel culvert. Lush riparian growth surrounded the immediate area of the monitoring location, including areas on top of the culvert. Numerous pink and silver salmon (*Oncorhynchus gorbuscha* and *Oncorhynchus kisutch*, respectively) were observed spawning at this location during the fall.

CBX

This monitoring location was on Merrill and Ring Creek in the Snohomish watershed. The land use in the 224.2-hectare basin is predominantly residential (62.4 percent) and commercial/ industrial (29.6 percent) (Table 1). At the sampling location, the channel width was approximately 15 feet. No erosional features or channel incision were observed at the sampling location or immediately upstream. The stream substrate was characterized by large, irregularly shaped rocks ranging from 6 to 24 inches in diameter.

The sampling location was immediately downstream of a large concrete box culvert and paved road used to access a commercial property. The immediate area around the monitoring location was characterized by a riparian buffer 10 to 15 feet wide on each side of the stream surrounded by commercial land use.

CB335

This monitoring location was on Powder Mill Creek in the Snohomish watershed. The land use in the 213.4-hectare basin is predominantly commercial/industrial (62.7 percent) with minor amounts of residential and forested areas (Table 1). At the sampling location, the channel width was approximately 10 feet. Channel incision approximately 1 foot in depth was observed at the sampling location and immediately upstream, likely due to the high gradient of the stream. The stream substrate was characterized by irregularly shaped rocks and cobbles ranging from 2 to 18 inches in diameter.

The sampling location was approximately 150 feet downstream of a 48-inch diameter concrete culvert with galvanized steel wing-walls. The immediate area around the monitoring location exhibited lush riparian growth approximately 10 to 15 feet wide. Snohomish County dirt access roads parallel the riparian buffers on each side of the stream.

RB111

This monitoring location was on an unnamed stream (WRIA-7: 0137) in the Snohomish watershed. The land use in the 581.2-hectare basin is predominantly residential (58.2 percent) with minor amounts of forested, agricultural, and commercial/industrial areas (Table 1). At the sampling location, the channel width was approximately 10 feet. No erosional features or channel incision were observed at the sampling location or immediately upstream, likely due to the low gradient of the stream. The stream substrate was characterized by cobbles that were 2 to 6 inches in diameter with minor amounts of woody debris and a large volume of sediment deposited in the culvert.

The sampling location was immediately downstream of a large galvanized steel culvert. The immediate area around the monitoring location included a steep bank with rip rap and Himalayan blackberries (*Rubus* spp.) to the west and north and a flat area with some riparian vegetation to the east. Numerous pink and silver salmon (*Oncorhynchus gorbuscha* and *Oncorhynchus kisutch*, respectively) were observed spawning in the creek during the fall.

RB202

This monitoring location was on Evans Creek in the Snohomish watershed. The land use in the 334.3-hectare basin is predominantly residential (64.0 percent) with minor amounts of forested and commercial/industrial areas (Table 1). At the sampling location, the channel width was approximately 12 feet. No erosional features or channel incision were observed at the sampling location or immediately upstream, likely due to the moderate gradient of the stream. The stream substrate was characterized by small cobbles that were 1 to 4 inches in diameter.

The sampling location was immediately downstream of a galvanized steel culvert and small pool. Flow typically emerged into the pool from below the perched culvert, as the stream typically short-circuited the culvert. The immediate area around the monitoring location included a small pool surrounded by heavy Himalayan blackberry (*Rubus* spp.) growth and lush riparian vegetation below.

Puyallup Watershed

CBA

This monitoring location was on an unnamed stream in the Puyallup watershed. The land use in the 655.9-hectare basin is predominantly residential (62.1 percent) and commercial/industrial (31.8 percent) with minor amounts of forested areas (Table 1). At the sampling location, the channel width was approximately 15 feet. No erosional features or channel incision were observed at the sampling location or immediately upstream, likely due to the low gradient of the stream. The stream substrate was characterized by cobbles approximately 2 to 12 inches in diameter with silty sand deposits located sporadically within the channel.

The sampling location was immediately downstream of four 18-inch diameter galvanized steel culverts. The immediate area around the monitoring location included grass-dominated riparian buffers approximately 10 feet wide bordered by residential houses and yards on each side of the

stream. The culverts were stabilized with cobbles embedded in concrete with a metal railing and sidewalk above.

CBB

This monitoring location was on an unnamed tributary to West Hylebos Creek in the Puyallup watershed. The predominant land use in the 435.3-hectare basin is residential (48.4 percent) and commercial/industrial (38.1 percent) with minor amounts of forested areas (Table 1). At the sampling location, the channel width was approximately 5 feet. No erosional features or channel incision were observed at the sampling location or immediately upstream, likely due to the low gradient of the stream. The stream substrate was characterized by large irregularly shaped rocks and rip rap approximately 6 to 24 inches in diameter. Discharge at this monitoring location typically exhibited a tannin color.

No culverts were located within the immediate vicinity of the sampling location. The immediate area around the monitoring location included sporadic riparian vegetation intermixed with quarry spalls to the north and a grass-dominated border to the south that was approximately 15 feet wide. A large stormwater detention pond was located approximately 800 feet upstream of the sampling location.

RB53

This monitoring location was on a Surprise Lake Drain tributary to Hylebos Creek in the Puyallup watershed. The land use in the 435.3-hectare basin is predominantly residential (81.7 percent) with minor amounts of forested, commercial/industrial, and agricultural areas (Table 1). At the sampling location, the channel width was approximately 4 feet. No erosional features or channel incision were observed at the sampling location or immediately upstream, likely due to the low gradient of the stream. The stream substrate was characterized by silty sand mixed with fine organic debris.

The sampling location was immediately downstream of a galvanized steel culvert. The immediate area around the monitoring location contained extensive stands of reed canary grass (*Phalaris arundinacea*) intermixed with minor amounts of Himalayan blackberries (*Rubus* spp.).

RB209

This monitoring location was on an unnamed tributary to Clear Creek in the Puyallup watershed. The land use in the 548.7-hectare basin is predominantly residential (81.6 percent) with minor amounts of forested and commercial/industrial areas (Table 1). At the sampling location, the channel width was approximately 7 feet. No erosional features or channel incision were observed at the sampling location or immediately upstream, likely due to the moderate gradient of the stream. The stream substrate was characterized primarily by sand and minor amounts of woody debris.

The sampling location was immediately downstream of a concrete box culvert. The immediate area around the monitoring location included reed canary grass (*Phalaris arundinacea*) intermixed with minor amounts of Himalayan blackberries (*Rubus* spp.). A roadside ditch also discharged stormwater into the creek from the east. However, water samples were collected

above the confluence of the ditch and the creek. Numerous chum salmon (*Oncorhynchus keta*) were observed staging in the creek during November.

AG143

This monitoring location was on an unnamed tributary in the Puyallup watershed. The land use in the 337.5-hectare basin is predominantly agricultural (53.1 percent) with forested, residential, and minor amounts of commercial/industrial areas (Table 1). At the sampling location, the channel width was approximately 6 feet. The channel was purposely incised, likely to help drain the surrounding pasture land. The stream substrate was characterized by gravel and sand mixed with minor amounts of cobbles approximately 2 to 6 inches in diameter.

The sampling location was immediately downstream of a large galvanized steel culvert. The culvert was heavily degraded; the bottom of the culvert at the sampling location was covered in rust and had several large holes in it. The immediate area around the monitoring location was dominated by Himalayan blackberries (*Rubus* spp.) intermixed with minor amounts of reed canary grass (*Phalaris arundinacea*) and other grass species. Cattle pasture land bordered each side of the riparian areas.

AG62

This monitoring location was on an unnamed tributary to the White River (WRIA-10: 0048) in the Puyallup watershed. The land use in the 330.9-hectare basin is predominantly agricultural (50.0 percent) with forested, residential, and minor amounts of commercial/industrial areas (Table 1). At the sampling location, the channel width was approximately 6 feet. A small cut bank was located at the monitoring location on the north side of the creek, likely due to increased stream velocities at the mouth of the concrete culvert. The stream substrate was characterized by gravel and cobbles, approximately 2 to 6 inches in diameter.

The sampling location was immediately downstream of a concrete culvert. The immediate area around the sampling location was characterized by heavy riparian growth and red alder (*Alnus rubra*) stands intermixed with Himalayan blackberries (*Rubus* spp.), approximately 20 feet wide on each side. Pasture land bordered each side of the riparian buffers.

FB130

This monitoring location was on an unnamed stream in the Puyallup watershed. The land use in the 80.4-hectare basin is predominantly forested (96.5 percent) with minor amounts of residential areas (Table 1). At the sampling location, the channel width was approximately 3.5 feet. The stream gradient was moderately high; however, no erosional features or channel incision were observed at the sampling location or immediately upstream. The stream substrate was characterized by cobbles approximately 4 to 16 inches in diameter with minor amounts of woody debris.

The sampling location was immediately downstream of a concrete culvert. The immediate area around the sampling location had been clear-cut recently and was characterized by sparse amounts of riparian vegetation intermixed with Himalayan blackberries (*Rubus* spp.).

FB 372

This monitoring location was on Coplar Creek in the Puyallup watershed. The land use in the 528.0-hectare basin is predominantly forested (97.5 percent) with minor amounts of residential areas (Table 1). At the sampling location, the channel width was approximately 9 feet. No erosional features or channel incision were observed at the sampling location or immediately upstream. The stream gradient was moderately high, and typically exhibited high stream velocities during storm events. The stream substrate was characterized by cobbles approximately 4 to 36 inches in diameter intermixed with minor amounts of woody debris.

The sampling location was immediately downstream of an oversized galvanized steel culvert. The immediate area around the sampling location was characterized by heavy riparian vegetation on both sides of the stream.

Water Quality Sampling

As described above, the project team collected baseflow samples at the 16 monitoring locations on two occasions. Table 2 identifies the specific date for each baseflow sampling event and its associated type (i.e., winter or summer). Baseflow samples consisted of a single grab sample that was collected from the thalweg of the channel at each monitoring location. Each baseflow sampling event was to occur following a period of at least one week without rainfall. Although the actual antecedent dry period ranged from only 28 to 124 hours (1 to 5 days) for the baseflow sampling events due to frequent rainfall conditions (see Table 2), water level data were evaluated prior to sampling to ensure that baseflow conditions were present at each location.

The project team collected storm-event samples at the 16 monitoring locations on six occasions. Table 2 identifies the specific date that each sampling event took place and its associated type (i.e., fall storm, winter storm, spring storm). The project team began storm-event sampling as early as possible during each event to ensure the full complement of samples could be collected before the end of the storm or the end of the high-flow period. The following guidelines for storm-event characteristics were established in the QAPP to ensure that representative storm samples would be collected:

- **Target storm precipitation depth:** Minimum of 0.25 inches of precipitation in a 24-hour period.
- **Antecedent conditions:** A period of at least 12 hours preceding the event with less than 0.01 inches of precipitation.

These storm-event guidelines were met based on data from representative rain gauges in the Snohomish watershed and Puyallup watershed (see Table 2).

Due to staffing and equipment resource constraints, the project team sampled only one of the two watersheds during any particular storm event. During storm-event sampling, the intent was to collect two grab samples from each monitoring location, with each of the grab samples separated by a period of approximately 4 hours. However, occasionally the rain stopped or the stream water level began to drop before the second grab sample could be collected. Overall, a second

sample was not collected following 54 of the 96 first samples (i.e., 56 percent of the time). Information on the number of sampling rounds that were performed at each monitoring location during each sampling event is provided in Appendix C. Figures showing the sample collection times relative to the stream hydrograph at each monitoring location are presented in Appendix D.

In cases where two grab samples were collected during successive rounds within a storm event, the project team composited the two samples into a single sample. Compositing was done in proportion to the flow measured when the two individual samples were collected (see Appendix C). For parameters that could not be composited (see description below), only one grab sample was collected during the first round of sampling.

The project team also measured field parameters (dissolved oxygen, pH, specific conductance, and temperature) immediately following the collection of grab samples. When two field measurements were made during a storm event, they were averaged to obtain a single value for each event.

Monitoring Parameters

The project team submitted samples collected during baseflow and storm events to MEL where they were analyzed for the toxic chemicals and contaminants of concern identified in Appendix E. Since multiple laboratories provided analytical support, MEL staff coordinated preparation and delivery of the samples to the appropriate laboratory. Appendix E presents the target method reporting limits (MRLs) identified in the QAPP (Herrera et al. 2009) and the actual MRLs achieved by the laboratory for each parameter. Appendix E also identifies the field parameters measured *in situ* by the project team during both types of events. Appendix F contains detailed information on the analytical procedures used for this study.

The water quality sampling design described above should have resulted in a total of 128 samples for any given parameter if sampling occurred at all 16 monitoring locations across all the baseflow and storm events (16 locations × 8 events = 128 samples). However, some parameters were analyzed only for a subset of the locations while others were analyzed only for a subset of the events. In addition, two monitoring locations (CBX in the Snohomish watershed and CBB in the Puyallup watershed) were dry and not sampled during the summer baseflow sampling event, and the total number of samples was 126. Tables 3 and 4 identify the number of samples collected at each monitoring location for each parameter during baseflow and storm events, respectively. The actual number of samples available for each monitoring location may be less than the number collected if data were rejected during the data validation process.

Stream Gauging

The project team established stream gauging stations at each monitoring location identified in Table 1 to obtain a continuous record of discharge from August 2009 through July 2010. At each gauging station, a staff gauge was installed to manually measure stream level at a consistent reference point. A well point, pressure transducer, and data logger were also installed at each station. The data loggers were programmed to record water level at 15-minute intervals and were operated throughout the sampling period. Additional details about stream gauging

equipment specifications and installation configurations can be obtained from Appendix G and H of the QAPP (Herrera et al. 2009). The specific configuration of this equipment at each monitoring location was documented in an addendum to the QAPP (Herrera 2011).

The project team conducted routine site visits approximately once every three weeks to ensure the data loggers were operating properly. During these visits, the water level data were uploaded and the project team collected a staff gauge reading. The uploaded data were immediately transferred to a secure server located in Herrera's Seattle office; the server was backed up on a daily basis. The project team then used AQUARIUS Time-Series software to process and analyze the compiled water level data.

The project team also made manual measurements of discharge during the routine site visits and sampling events. The AQUARIUS Rating Curve software was then used to develop stream discharge rating curves from these data for each monitoring location using USGS protocols. These rating curves were used to convert the continuous record of water level data from each station to a continuous record of discharge. The total flow volume derived from the stream discharge rating curves for each monitoring location over the 12-month monitoring period is summarized in Table 5. Figures are also provided in Appendix D that show the continuous discharge record over this period for each monitoring location.

Data Analysis

The project team performed the following analyses of the data compiled through the monitoring activities described above:

- Computation of summary statistics.
- Correlation analyses.
- Computation of loading estimates at the subbasin scale.
- Computation of loading estimates at the watershed scale.
- Computation of loading estimates at the Puget Sound-basin scale.

The specific steps we performed in each of these analyses are described separately below. These steps were developed in consultation with a calculation work group, comprising local experts in stormwater and related fields.

Computation of Summary Statistics

We computed the following summary statistics for each toxic chemical or contaminant identified in Appendix E:

- Number of samples
- Minimum reporting limit (concentrations only, not loading)
- Maximum reporting limit (concentrations only, not loading)
- Percentage of detected values
- Median
- Mean

- Minimum
- 25th percentile
- 75th percentile
- Maximum
- Interquartile range

For these calculations, we successively pooled the data obtained from the baseflow and storm-event sampling, respectively, to generate these summary statistics for the following groupings of data:

- Individual monitoring locations.
- Land-use categories within the Snohomish watershed and Puyallup watershed, respectively.
- Land-use categories across both watersheds combined.
- All data combined.

A high number of non-detect values in a dataset can introduce bias in calculated summary statistics (Antweiler and Taylor 2008; Helsel 2005). Therefore, we computed and qualified the summary statistics based on the following rules:

- If all data were non-detect values, we only reported the following summary statistics: number of samples, minimum reporting limit, maximum reporting limit, percentage of non-detect values (100 percent in all cases), and maximum value. The maximum value was assigned the same value as the maximum reporting limit and qualified with a less than (<) sign. All summary statistics were also assigned a "U" qualifier to indicate there were no detected values in the data.
- If there were detected values in the data, but the percentage of non-detect values represented 50 percent or more of the data, we computed all summary statistics identified above by assigning a value of one-half the MRL to the non-detect values. All summary statistics were assigned an "E" qualifier to indicate they were estimates with relatively low accuracy due to the high number of non-detect values.
- If the percentage of non-detect values represented less than 50 percent of the data, we computed all summary statistics identified above by assigning a value of one-half the MRL limit to the non-detect values. All summary statistics were then reported without qualification.

Our decision to use a 50 percent threshold to qualify the accuracy of the computed summary statistics based on non-detect values stemmed from a separate analysis that was performed by Antweiler and Taylor (2008). In comparisons to other methods for computing summary statistics from censored data (e.g., regression on order statistics), this analysis showed that reasonable estimates can be obtained by assigning a value of one-half the MRL limit to the non-detect values when up to 70 percent of the data are non-detect values; the accuracy of the computed summary statistics is highly questionable when the percentage of non-detect values exceeds this threshold. However, the analysis by Antweiler and Taylor was performed using 43 datasets with sample sizes ranging from 34 to 841. Because samples sizes for the Phase 3 study were much lower, we used a more conservative approach by qualifying all summary statistics as estimates when 50 percent or more of the data were non-detect values.

We presented the computed summary statistics in separate tables for each parameter in this study. We also used range plots and box plots to present summary statistics for the data from each individual monitoring location. The range plots show the median, minimum, and maximum values from each monitoring location; the box plots show the median, 25th, and 75th percentiles and the minimum and maximum values. In computing the summary statistics for these plots, we assigned a value of one-half the MRL to the non-detect values.

In addition to computing summary statistics for each toxic chemical or contaminant identified in Appendix E, we also computed summary statistics for the following major classes of toxic chemicals:

- Total PCBs
- Total PBDEs
- Total PAHs
- Carcinogenic PAHs
- High molecular weight PAHs
- Low molecular weight PAHs
- Total DDT
- Total chlordane

To obtain representative concentrations for each chemical class, we summed the reported concentrations of the individual parameters within each class of toxic chemicals for each sample. Specifically, concentrations for total PCBs were obtained by summing the concentrations from the 162 individual PCB congeners identified in Appendix E. Likewise, concentrations for total PBDE were obtained by summing the concentrations from the 36 individual PBDE congeners identified in Appendix E. Total DDT concentrations were obtained by summing the concentrations of the 2,4' and 4,4' isomers of DDT, DDE, and DDD. Total chlordane concentrations were obtained by summing five compounds; cis- and trans-chlordane, cis- and trans-nonachlor, and oxychlordane. The specific parameters that were summed to obtain concentrations for PAH classes shown above are identified in Appendix E.

For these summations, we substituted a value of zero (0) for all non-detect values of individual parameters unless all the reported values for the individual parameters in a given chemical class/event/monitoring location combination were non-detects. In that case, we used the highest reporting limit of all the individual parameters within that chemical class/event/monitoring location combination to represent the non-detect concentration. Once these representative concentrations were obtained for each chemical class, we computed and qualified the summary statistics for each chemical class using the same rules that are described above for the individual toxic chemicals and contaminants of concern identified in Appendix E.

Principal Component Analysis

Principal component analysis (PCA) is a technique for simplifying a dataset so that broad patterns may be more readily detected. In PCA, the data are transformed to a new coordinate system such that the greatest variance by any projection of the data comes to lie on the first coordinate (referred to as the *first principal component*), the second greatest variance on the second coordinate, and so on (Ludwig and Reynolds 1988; StatSoft 1994). PCA can be used for

dimensionality reduction in a dataset while retaining those characteristics of the dataset that contribute most to its variance, by keeping lower order principal components and ignoring higher order ones. Such low-order components often contain the most important aspects of the data.

We performed PCA independently on data that were obtained from storm-event and baseflow samples, respectively. Inputs to the PCA were median storm-event or baseflow concentrations from each monitoring location for the following toxic chemicals: total arsenic, total copper, total lead, total mercury, total zinc, total PCBs, total PBDEs, total suspended solids, total phosphorus, and nitrate+nitrite nitrogen. The specific toxic chemicals used in the analysis were a subset of the 21 priority parameters having greater than 40 percent detection frequency. In cases where the dissolved and total fractions of specific heavy metals were frequently detected, we only used data for the total fraction in the PCA analysis. Data for all toxic chemicals were log transformed, centered, and standardized by their standard deviations prior to the PCA analysis. This step was necessary since the concentrations in the input matrix have different units, distributions, and magnitudes.

We ran the PCA in the Matlab Statistics Toolbox and extracted the first and second principal components with their associated eigenvalues. (An eigenvalue is a measure of the variance accounted for by each principal component.) We used this information to generate principal component ordinations for both the individual monitoring locations and the parameters included in the analysis. Separate scatter plots were then generated to show the principal components that were derived from the individual monitoring locations (across all the parameters) and the individual parameters (across all monitoring locations). The monitoring locations were labeled with the associated land-use category and watershed (i.e., Snohomish or Puyallup).

The monitoring location and the parameter plots are related in that the monitoring locations that form a group in the same region of the ordination as the water quality parameters are the monitoring locations that are responsible for the trend in the water quality data. For example, a heavily impacted agricultural site will project in the same area as the constituents usually associated with such sites (e.g., sediment, nutrients, temperature). By analyzing parameter groupings and the associated groupings of land-use categories, patterns in the dataset can be discerned.

Computation of Loading Estimates at the Subbasin Scale

To determine which of the four targeted land uses were significant sources for specific toxic chemicals and contaminants, we computed total and unit-area loading estimates for each subbasin (see Table 1) using the summary statistics described in the *Computation of Summary Statistics* section. Because toxic chemical concentrations in baseflow were expected to be different from storm-event flow due to physical, chemical, and/or biological processes that occur in the ground, these loading estimates were computed separately for the “baseflow” and “storm event” components of the hydrograph over the one-year monitoring period for this study.

In this analysis, the baseflow loading component is defined as the mass of toxic chemical that is exported to receiving waters via groundwater and shallow subsurface flow during periods *between* storm events. The storm-event loading component is defined as the mass of a toxic chemical that is exported to receiving waters via groundwater, shallow subsurface flow, and

overland flow *during* storm events. These components of the hydrograph are shown graphically in Figure 5.

To obtain these estimates, we performed the following computational steps for each combination of toxic chemicals or contaminants identified in Appendix E and the major classes of chemicals identified in the *Computation of Summary Statistics* section:

1. The continuous discharge data from each monitoring location were processed using a hydrograph separation algorithm developed for the *Green/Duwamish Watershed Water Quality and Contaminant Loading Analysis* that was implemented by the King County Department of Natural Resources and Parks (Herrera 2007). This algorithm identifies the baseflow and storm-event components of a hydrograph using a sliding interval to assign a preliminary baseflow discharge rate based on the minimum flow over a 3-day window. It then adjusts the baseflow and identifies storm periods using the following user input variables:

    - Starting baseflow discharge rate (cubic feet per second [cfs]) if the initial flow value is missing from the hydrologic record.
    - Maximum percent increase per day in baseflow discharge.
    - Maximum amount (cfs) of increase per day in baseflow discharge.
    - Minimum percent that the maximum daily discharge must exceed the daily average baseflow discharge rate to be categorized as a storm event.

    Additional documentation on this algorithm and the specific inputs that were used for each monitoring location are presented in Appendix H. Note that the QAPP had originally indicated that hydrograph separation for this study would be performed using the HYSEP algorithm (USGS 1996). The HYSEP algorithm uses an empirical relationship that is derived from the drainage area to estimate the maximum duration of surface runoff in days following a rain event. However, the minimum duration of three days that can be computed from this relationship was considered too high given that some of the drainage basins in this study were relatively small and contained a high percentage of impervious surfaces. Due to this consideration, the algorithm developed for the *Green/Duwamish Watershed Water Quality and Contaminant Loading Analysis* was used instead. The baseflow and storm-event volumes computed for each monitoring station using this algorithm are summarized in Table 5.

2. Total loads (i.e., the total mass of contaminants discharged from each subbasin) for the baseflow component of the hydrograph were estimated by multiplying the baseflow volume derived from Step 1 by representative concentrations obtained from samples collected during baseflow. The resultant total load estimates were then divided by the area of each subbasin to obtain unit-area loads (i.e., the mass of contaminants that is discharged from each subbasin from a defined area of land).

3. Total loads for the storm-event component of the hydrograph were estimated by multiplying the storm-event volume derived from Step 1 by representative concentrations obtained from samples collected during storm events. The resultant total load estimates were also divided by the area of each subbasin to obtain unit-area loads.

In these analyses, we successively summed the flow volumes identified in Table 5 for baseflow and storm events, respectively, and multiplied these volumes by appropriate representative concentrations (see *Computation of Summary Statistics* section) to generate total and unit-area load estimates for the following groupings of data:

- Individual monitoring locations
- Land-use categories within the Snohomish watershed and Puyallup watershed, respectively
- Land-use categories across both watersheds combined

For example, to obtain total load estimates for baseflow from all commercial/industrial land use in the Snohomish watershed, we summed the flow volumes for baseflow from the two monitoring locations for commercial/industrial land use in that watershed (CB335 and CBX). We then multiplied this volume by representative concentrations that were computed using the pooled data from the baseflow samples collected at both stations. To obtain the unit-area loading rate, we divided the calculated total loading rate by the combined area for the two commercial/industrial subbasins. This process was repeated, as appropriate, for each different grouping of data identified above.

In all these calculations, the following summary statistics were used as representative concentrations for each grouping of data: minimum, 25th percentile, median, 75th percentile, and maximum. To account for bias that might be introduced in the load estimates due to non-detect values in the concentration data, we computed and qualified the load estimates for each grouping of data based on the following rules:

- If all the concentration data were non-detect values, we computed the total and unit-area load estimates based on the maximum reporting limit from the data. These total and unit-area load estimates were qualified with a less than (<) sign. A "U" qualifier was also assigned to these load estimates to indicate there were no detected values in the concentration data.
- If there were detected values in the concentration data but the percentage of non-detect values represented 50 percent or more of the data, we computed the total and unit-area load estimates based on all summary statistics identified above. All computed loads were assigned an "E" qualifier to indicate they are estimates with relatively low accuracy due to the high number of non-detect values in the concentration data.
- If the percentage of non-detect values represented less than 50 percent of the data, we computed the total and unit-area load estimates based on all summary statistics identified above. All the computed load estimates were then reported without qualification.

The computed total and unit-area load estimates are presented in separate tables for each parameter in this study. We also used range plots and box plots to summarize the unit-area load estimates for each individual monitoring location. The range plots show the unit-area load estimates computed based on the median, minimum, and maximum concentration values from each monitoring location. The box plots show the unit-area load estimates computed based the median, 25th, and 75th percentiles and the minimum and maximum concentrations values.

Computation of Loading Estimates at the Watershed Scale

To determine the contribution of toxic chemicals from the aggregate area for each of the four land-use types within the Snohomish watershed and Puyallup watershed, we computed watershed-scale total load estimates for baseflow and storm events for a subset of 21 priority parameters that are identified in Table 6. Sixteen of the 21 parameters were previously identified as priority parameters during the Phase 1 and Phase 2 studies of toxic chemical loading to Puget Sound. Five additional parameters and dissolved metals were subsequently identified as priorities by the Phase 3 project team.

We computed the watershed-scale total load estimates by multiplying unit-area loading rates for each parameter, land use, and watershed combination by the area represented by the land use in each watershed. The unit-area loading rates in these calculations were derived from the subbasin-scale loading analysis described above. For example, to obtain total load estimates for baseflow from commercial/industrial land use in the Snohomish watershed, we multiplied the total area of commercial/industrial land use in the watershed by the unit-area loading rate that was derived from baseflow samples collected from the two monitoring locations for commercial/industrial land use in the watershed (CB335 and CBX). This process was repeated for each combination of parameter, land use, and watershed. The actual drainage areas used in these calculations for each watershed are shown in Table 7.

In all these calculations, the unit-area loading rates were derived from the following summary statistics for the underlying concentration data: minimum, 25th percentile, median, 75th percentile, and maximum. To account for bias that might be introduced in the load estimates due to non-detect values in the concentration data, we computed and qualified the load estimates for each combination of parameter, land use, and watershed based on the following rules:

- If all the concentration data were non-detect values, we computed the total load estimates based on the maximum reporting limit from the data. These total load estimates were qualified with a less than (<) sign. A "U" qualifier was also assigned to these load estimates to indicate there were no detected values in the concentration data.

- If there were detected values in the concentration data but the percentage of non-detect values represented 50 percent or more of the data, we computed the total load estimates based on all summary statistics identified above. All computed loads were assigned an "E" qualifier to indicate they were estimates with relatively low accuracy due to the high number of non-detect values in the concentration data.

- If the percentage of non-detect values represented less than 50 percent of the data, we computed the total load estimates based on all the summary statistics identified above. All computed load estimates were then reported without qualification.

The computed total load estimates are presented in separate tables for each of the 21 priority parameters in this study.

The project team also considered an alternative method for computing watershed load estimates in this study that was based on the method used for the Phase 2 study (Herrera 2010). This alternate method has different underlying assumptions relative to the method above. Specifically, the

method above generally assumes that contaminant export from any given land use is "source limited"; or, in other words, there is a finite amount of contaminant available for export via surface runoff. In contrast, the alternative method that is described in Appendix G assumes that pollutant export is "flow-limited." In this case, the amount of contaminant that is present in association with any given land use is not the limiting factor for export; rather, the amount of runoff that is available for mobilizing the contaminant is the limiting factor.

Both approaches, extrapolation based on unit-area loads (Herrera 2007) and extrapolation based on concentrations times spatially varying flows (Herrera 2010), have been used in the region and nationally, and the selected method was discussed and preferred by the calculation work group. Appendix G describes this alternative method and compares the associated results for a subset of parameters with the results from the method described above. In general, extrapolating using unit-area loads produces lower overall load estimates for a subset of parameters evaluated than estimated using concentration times flow. The results from this alternative method are not presented in detail within the main body of this report, but Appendix G contains representative calculations and comparisons. The specific rationale for not calculating all pollutant loads based on this alternative method is presented in the *Discussion* section. The *Discussio*n section also compares the unit-area loading rates developed in this study with other studies.

Computation of Loading Estimates at the Puget Sound Scale

The goal of this study was to refine the previous toxic loading estimates from Phase 1 and Phase 2 studies using new data from local watersheds with substantially lower detection limits relative to data from previous studies of toxic chemicals in the region. To do this, total load estimates from the 14 study areas linked to the Puget Sound Box Model (Figure 2) for the subset of 21 priority parameters that are identified in Table 6 were re-computed using the new results generated in this study. Separate estimates were provided for the baseflow and storm-event contribution of the load.

To compute these Puget Sound-scale total load estimates, we multiplied unit-area loading rates for each parameter, land use, and study area combination by the area represented by the land use in each study area. The unit-area loading rates in these calculations were derived from the subbasin scale loading analysis described above. For example, to obtain total load estimates for baseflow from commercial/industrial land use in the Main basin study area, we multiplied the total area of commercial/industrial land use in the study area by the unit-area loading rate that was derived from baseflow samples collected from the four monitoring locations representing commercial/industrial land use (CB335, CBX, CBA, CBB). This process was repeated for each combination of parameter, land use, and study area. The actual drainage areas used in these calculations for each study area are shown in Table 8.

In all these calculations, the unit-area loading rates were derived from the following summary statistics for the underlying concentration data: minimum, 25th percentile, median, 75th percentile, and maximum. To account for bias that might be introduced in the load estimates due to non-detect values in the concentration data, we computed and qualified the load estimates for each combination of parameter, land use, and watershed based on the following rules:

- If all the concentration data were non-detect values, we computed the total load estimates based on the maximum reporting limit from the data. These total load estimates were qualified with a less than (<) sign. A "U" qualifier was also assigned to these load estimates to indicate there were no detected values in the concentration data.
- If there were detected values in the concentration data but the percentage of non-detect values represented 50 percent or more of the data, we computed the total load estimates based on all summary statistics identified above. All computed loads were assigned an "E" qualifier to indicate they were estimates with relatively low accuracy due to the high number of non-detect values in the concentration data.
- If the percentage of non-detect values represented less than 50 percent of the data, we computed the total load estimates based on all summary statistics identified above. All the computed load estimates were then reported without qualification.

The computed total load estimates are presented in separate tables for each of the 21 priority parameters in this study.

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Results

This section presents results from monitoring conducted for the Phase 3 study of toxic chemicals in surface runoff in the Puget Sound ecosystem. We begin by summarizing the results from QA reviews that were performed on laboratory analytical and hydrologic data from the study. To provide some context for interpreting the results, precipitation patterns during the monitoring period are summarized next. Key trends in the data are then identified based on the detection frequency of individual parameters. Finally, toxic chemical loading estimates are presented from calculations performed at the subbasin, watershed, and Puget Sound scales.

Review of Data Quality

Laboratory Analytical Data

Appendix I contains copies of the Data Usability Summary Reports that document the results of the Level 1 data quality review. Brief descriptions of the data quality are provided below for each analytical method.

Appendix R identifies when field duplicate samples were collected and presents the calculated relative percent difference (RPD) between sample and the field duplicate concentrations. Based on these data, the potentially uncertainty in the data from these sources averaged 30 percent across all the monitoring parameters. PCB congeners had the highest mean RPD (40 percent), followed by PBDE congeners (29 percent); however, 52 percent of these results were very close to the reporting limit. The remaining parameters averaged 14 percent RPD.

For individual parameters, this error ranged from <1.0 to 131.0 percent on average; however, extremely high error values were typically associated with sample and duplicate concentrations that were near the reporting limit where the analysis error is generally greatest but of low concern. All parameters with mean RPDs >20 percent were associated with values less than five times the reporting limit except 4-Nitrophenol and Chlorpyrifos.

Metals

MEL analyzed all samples for total and dissolved metals[4] using U.S. Environmental Protection Agency (EPA) Method 200.8 (*Inductively Coupled Plasma – Mass Spectrometry*), and total and dissolved mercury using EPA Method 245.7, in accordance with the QAPP. MEL also analyzed one storm-event sample from 12 locations for a secondary set of total and dissolved metals[5] using EPA Method 200.8. The metals results generally met the project data quality objectives for reporting and quality control (QC) limits. The project team qualified a small number of results as tentatively identified when qualitative QC criteria were not met and qualified several results as estimated to indicate uncertainty in the quantitative measurements.

[4] Arsenic, cadmium, copper, lead, and zinc
[5] Aluminum, antimony, barium, beryllium, cobalt, manganese, nickel, selenium, and thallium

Polychlorinated Biphenyls (PCBs)

Test America Tacoma analyzed samples collected on the following dates from the Snohomish watershed for PCBs: October 17 and November 19, 2009, and April 2 and May 14, 2010. Samples collected on the following dates from the Puyallup watershed were also analyzed for PCBs: October 26 and December 15, 2009, and May 13 and 19, 2010. Samples were analyzed for PCB congeners using EPA Method 1668 (*Chlorinated Biphenyl Congeners by HRGC/HRMS*) in accordance with the QAPP. Test America Sacramento analyzed all the required congeners. The following sets of congeners were reported as combinations rather than single congeners.

- PCB-004/010
- PCB-007/009
- PCB-008/005
- PCB-012/013
- PCB-016/032
- PCB-020/021/033
- PCB-024/027
- PCB-041/064/068
- PCB-043/049
- PCB-047/048/075
- PCB-052/073
- PCB-056/060
- PCB-061/074
- PCB-066/080
- PCB-083/108
- PCB-085/120
- PCB-086/087/097/111/115/116/117/125
- PCB-088/121
- PCB-089/090/101
- PCB-093/095
- PCB-098/102
- PCB-105/127
- PCB-107/108
- PCB-118/106
- PCB-131/142/165
- PCB-132/168
- PCB-135/144
- PCB-138/163/164
- PCB-139/149
- PCB-158/160
- PCB-170/190
- PCB-172/192
- PCB-182/187
- PCB-196/203

The inability of the laboratory to separate these very similar congeners did not negatively impact the data usability. The PCB results generally met the project data quality objectives for reporting and QC limits. The project team qualified a small number of results as tentatively identified when qualitative QC criteria were not met, and qualified others as estimated to indicate uncertainty in the quantitative measurements. Between the initial data screening performed by MEL and the Level 1 QA review performed by E&E, 28 results were rejected for failing to meet QC criteria (representing less than 1 percent of the total possible PCB results). Results were rejected for the following 14 compounds:

1. PCB-001: 5 rejected
2. PCB-002: 6 rejected
3. PCB-003: 5 rejected
4. PCB-006: 1 rejected
5. PCB-007/009: 1 rejected
6. PCB-012/013: 1 rejected
7. PCB-014: 1 rejected
8. PCB-029: 1 rejected
9. PCB-030: 1 rejected
10. PCB-034: 1 rejected
11. PCB-035: 1 rejected
12. PCB-036: 1 rejected
13. PCB-038: 1 rejected
14. PCB-039: 1 rejected

Polybrominated Diphenyl Ethers (PBDEs)

Pacific Rim Laboratories analyzed samples collected on the following dates from the Snohomish watershed for PBDEs: October 17, November 5, and November 19, 2009, and April 2 and May 14, 2010. Samples collected on the following dates from the Puyallup watershed were also analyzed for PBDEs: October 26, November 16, and December 15, 2009, and May 13 and 19, 2010. Samples were analyzed for PBDE congeners using EPA SW-846 Method 1614 (*Brominated Diphenyl Ethers in Water, Soil, Sediment, and Tissue by HRGC/HRMS*) rather than EPA Method 1668 as specified in the QAPP. This variation was acceptable because it provided equivalent or better data than required to meet project data quality objectives.

Pacific Rim analyzed all the required congeners. Results for BDE-156 and BDE-169 were reported as a combination rather than separate congeners. Results for BDE-197 and BDE-204 were also reported as a combination rather than separate congeners. The inability of the laboratory to separate these very similar congeners did not negatively impact the data usability. In addition, Pacific Rim provided data for the following three congeners not specified in the QAPP, but incorporated into this report:

1. BDE-007
2. BDE-010
3. BDE-015

The PBDE results generally met the project data quality objectives for reporting and QC limits. The project team qualified a small number of results as tentatively identified when qualitative QC criteria were not met and qualified several results as estimated to indicate uncertainty in the quantitative measurements. Between the initial data screening performed by MEL and the Level 1 QA review performed by E&E, 67 results were rejected for failing to meet QC criteria (representing less than 3 percent of the total possible PBDE results). Results were rejected for the following four compounds:

1. BDE-007: 22 rejected
2. BDE-010: 22 rejected
3. BDE-015: 22 rejected
4. BDE-077: 1 rejected

Polycyclic Aromatic Hydrocarbons (PAHs)

MEL analyzed all samples for PAHs using EPA SW-846 Method 8270D SIM (Polycyclic Aromatic Hydrocarbons by gas chromatography/mass spectrometry [GC/MS]) in accordance with the QAPP. The PAH results generally met the project data quality objectives for reporting and QC limits. The project team qualified several results to indicate uncertainty in the quantitative measurements. Between the initial data screening performed by MEL and the Level 1 QA review performed by E&E, seven results for Acenaphthylene were rejected for failing to meet QC criteria (representing less than 1 percent of the total possible PAH results).

Base/Neutral/Acid (BNA) Extractable Compounds

MEL analyzed all samples for BNAs using EPA SW-846 Method 8270 (Semi-volatile Organic Compounds by GC/MS) in accordance with the QAPP. The laboratory provided data for the following additional five toxic chemicals that were not specified in the QAPP, but were incorporated into this report:

1. 2-Methylphenol
2. 4-Methylphenol
3. Cholesterol
4. 2-Chloroethanol phosphate (3:1)
5. Pentachlorophenol

The BNA results generally met the project data quality objectives for reporting and QC limits. The project team qualified several results to indicate uncertainty in the quantitative measurements. Between the initial data screening performed by MEL and the Level 1 QA review performed by E&E, 243 results were rejected for failing to meet QC criteria (representing approximately 5 percent of the total possible BNA results). Results were rejected for the following six compounds:

1. 3,3'-Dichlorobenzidine: 40 rejected
2. 3-Nitroaniline: 44 rejected
3. 4-Chloroaniline: 104 rejected
4. 4-Nitrophenol: 7 rejected

5. Cholesterol: 16 rejected
6. N-Nitrosodiphenylamine: 32 rejected

Pesticides

MEL analyzed all samples for pesticides using EPA SW-846 Method 8081 (Chlorinated Pesticide Compounds by gas chromatography/electron capture detector [GC/ECD]) in accordance with the QAPP (Herrera et al. 2009). In addition, MEL provided data for the following seven toxic chemicals not specified in the QAPP, but incorporated into this report:

1. 2,4'-DDD
2. 2,4'-DDE
3. 2,4'-DDT
4. Dacthal (DCPA)
5. DDMU
6. Mirex
7. Pentachloroanisole

The pesticide results generally met the project data quality objectives for reporting and QC limits. The project team qualified a small number of results to indicate uncertainty in the quantitative measurements.

Herbicides

MEL analyzed all samples for herbicides using EPA SW-846 Method 535/8270 (Chlorinated Herbicides by Solid-Phase Extraction and GC/MS) in accordance with the QAPP. Results for all herbicide chemicals specified in the QAPP were received with the exception of Chloramben.

The herbicide results generally met the project data quality objectives for reporting and QC limits. The project team qualified a small number of results as tentatively identified when qualitative QC criteria were not met, and qualified others as estimated to indicate uncertainty in the quantitative measurements. Between the initial data screening performed by MEL and the level one QA review performed by E&E, 29 results were rejected for failing to meet QC criteria (representing less than 2 percent of the total possible herbicide results). Results were rejected for the following two compounds:

1. Acifluorfen (Blazer): 7 rejected
2. Dinoseb: 22 rejected

Petroleum and Oil

MEL analyzed all samples for gasoline using Method NWTPH-GX, #2 diesel using Method NWTPH-DX, lube oil using Method NWTPH-DX, oil and grease (n-hexane extractable material) using EPA 1664/EPA 1664A, and lube oil using EPA 1664/EPA 1664A and Method NWTPH-DX on the dissolved oil and grease (DOG) extract in accordance with the QAPP. The petroleum and oil results generally met the project data quality objectives for reporting and QC limits. The project team qualified a small number of results as tentatively identified when

qualitative QC criteria were not met and qualified several results as estimated to indicate uncertainty in the quantitative measurements.

Conventional Parameters

MEL analyzed all samples for ammonia using SM 4500-NH3 H, dissolved and total organic carbon using SM 5310 B, hardness as calcium carbonate ($CaCO_3$) using SM 2340B, nitrate+nitrite nitrogen using SM 4500NO3 I, orthophosphate phosphorus using SM 4500 P G, total persulfate nitrogen using SM 4500NB/SM 4500-NH3 H, total phosphorus using SM 4500 P F, and total suspended solids using SM 2540D. The conventional parameter results generally met the project data quality objectives for reporting and QC limits. The project team qualified a small number of results as tentatively identified when qualitative QC criteria were not met and qualified several results as estimated to indicate uncertainty in the quantitative measurements.

Stream Gauging Data

This section presents a QA summary of the hydrologic data collected at each of the 16 monitoring locations in the Snohomish and Puyallup watersheds. A detailed presentation of the rating curves, data corrections, bias testing of the sensors, and overall assessment of the hydrograph is presented for each monitoring location in a separate memorandum in Appendix J.

After assessing the quality of the hydrologic data at each location, it was determined that all hydrologic data for five of the 16 locations should be flagged as estimates and used with caution (i.e., locations AG174 and FB200 in the Snohomish watershed and locations RB53, RB209, and FB130 in the Puyallup watershed; see Table 5). This is because these data failed to meet the minimum measurement quality objectives (MQOs) specified in the QAPP for completeness and bias. In addition, some data from these stations were flagged as estimates following quantitative evaluations of rating curve quality and qualitative evaluations of hydrograph form. Loading calculations based on the hydrologic data from those five locations should be considered estimates.

Snohomish Watershed

Monitoring Location CB335

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location CB335. There were no data gaps or shifts in the rating curve, and the rating curve error was relatively low. After assessing the quality of the hydrologic data at CB335, it was determined that the data could be used without qualification.

Monitoring Location CBX

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location CBX. There were no data gaps or shifts in the rating curve. Although there was a relatively high degree of rating curve error, most of the error was on the low end of the rating curve (i.e., only affecting low flows) and the data are otherwise of a high quality. After assessing the quality of the hydrologic data at CBX, it was determined that the data could be used without qualification.

Monitoring Location RB111

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location RB111. There was one shift in the rating curve and the rating curve errors were reasonably low, which is generally expected when rating small dynamic stream channels. After assessing the quality of the hydrologic data at RB111, it was determined that the data should be used without qualification.

Monitoring Location RB202

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location RB202. There were two shifts in the rating curve and the rating curve errors were relatively low. This amount of flow conversion error is generally expected when rating small dynamic stream channels. After assessing the quality of the hydrologic data at location RB202, it was determined that the data should be used without qualification.

Monitoring Location AG174

The water level and streamflow data from location AG174 had numerous QA issues. The data from January 18 to April 7, 2010 were missing and replaced with modeled data from RB202. In addition, rating curve had a high degree of error and the hydrograph form was unusual. These combined factors resulted in a hydrograph of poor quality. After assessing the quality of the hydrologic data at AG174, it was determined that the hydrologic data should be flagged as estimates and used with caution. In addition, all loading calculations based on the hydrologic data from AG174 should be considered estimates.

Monitoring Location AGG

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location AGG. Data from May 14 to July 8, 2010 were missing and replaced with modeled data from AG174. A moderate amount of error was observed in the modeled data (25 percent) and the rating curves. These combined factors resulted in a hydrograph of average quality. After assessing the quality of the hydrologic data and characteristics of the hydrograph at AGG, it was determined that the hydrologic data should be used without qualification. Although there were some QA issues, the overall form of the hydrograph was judged to be reasonably accurate.

Monitoring Location FB200

The water level and streamflow data from location FB200 have numerous QA issues. The data from August 1 to December 12, 2009 were noisy and had to be replaced with modeled data from FB203. In addition, the rating had a relatively high degree of error and one erroneous manual discharge measurement had to be excluded from the rating. These combined factors resulted in a hydrograph of average quality. After assessing the quality of the hydrologic data at FB200, it was determined that the hydrologic data should be flagged as estimates and used with caution. In addition, all loading calculations based on the hydrologic data from FB200 should be considered estimates.

Monitoring Location FB203

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location FB203. There were no major data gaps or shifts in the rating curve,

and the rating curve error was very low. After assessing the quality of the hydrologic data at FB203, it was determined that the data should be used without qualification.

Puyallup Watershed

Monitoring Location CBA

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location CBA. There was one shift in the rating curve and the rating curve errors were relatively low, which is generally expected when rating in small dynamic channels. After assessing the quality of the hydrologic data at CBA, it was determined that the data should be used without qualification.

Monitoring Location CBB

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location CBB. There were no significant gaps in the data record, and the rating curve error was relatively low. After assessing the quality of the hydrologic data at CBB, it was determined that the data should be used without qualification.

Monitoring Location RB53

The water level and streamflow data from location RB53 had numerous QA issues. Noisy data from August 1 to December 12, 2009 were replaced with modeled data from FB372, and a data gap from April 1, 2009 to April 29, 2009 was also filled with modeled data from FB372. The remaining data had intermittent issues with noise. The rating curve for RB53 was extrapolated by a factor of 3.3 and the total error in the rating was high. All of these combined factors resulted in a hydrograph of poor quality. After assessing the quality of the hydrologic data at RB53, it was determined that all of the hydrologic data should be flagged as estimates and used with caution. In addition, all loading calculations based on the hydrologic data from RB53 should be considered estimates.

Monitoring Location RB209

The water level and streamflow data from location RB209 had numerous QA issues. The data from August 1 to November 3, 2009 were noisy and replaced with modeled data from FB372. In addition, the channel bottom was sandy and unstable, which contributed to a relatively inaccurate rating curve. The combination of these factors resulted in a hydrograph of poor quality. After assessing the quality of the hydrologic data at RB209, it was determined that the hydrologic data should be flagged as estimates and used with caution. In addition, all loading calculations based on the hydrologic data from RB209 should be considered estimates.

Monitoring Location AG143

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location AG143. There was one shift in the rating curve and the rating curve errors were relatively high, but this amount of flow conversion error is generally expected when rating small dynamic stream channels. After assessing the quality of the hydrologic data at AG143, it was determined that the data should be used without qualification.

Monitoring Location AG62

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location AG62. There was one shift in the rating curve and the rating curve errors were relatively high, but this amount of flow conversion error is generally expected when rating small dynamic stream channels. After assessing the quality of the hydrologic data at AG62, it was determined that the data should be used without qualification.

Monitoring Location FB130

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location FB130. However, the level data were noisy, the rating curve error was high, and much of the high-flow records exceeded the maximum discharge measurement. For these reasons, all flow data for this location should be flagged as estimates and used with caution. In addition, all loading calculations based on the hydrologic data from FB130 should be considered estimates.

Monitoring Location FB372

All hydrologic MQOs identified in the QAPP were met for the water level and stream discharge data collected at location FB372. There were no major data gaps or shifts in the rating curve, and the rating curve error was reasonably low. After assessing the quality of the hydrologic data at FB372, it was determined that the data should be used without qualification.

Precipitation Patterns During the Monitoring Period

To provide some context for interpreting the results from this study, monthly and annual precipitation totals for August 2009 through July 2010 (the monitoring period) were compiled from a National Weather Service gauge (Station #457473) at the SeaTac Airport in SeaTac, Washington and compared to historical totals from the same gauge (Table 9). The historical totals were derived from data collected from 1948 to 2009. These data indicate the monitoring period was generally wetter than normal and close to the annual 75th percentile. For example, the precipitation total for the 12-month monitoring period was 42.73 inches. In comparison, the annual average from the historical data was 38.12 inches. The months of October, November, April, May, and June were particularly wet: each had monthly totals that exceeded the 75th percentile total for the respective month from the historical data. Only July was drier than normal based on comparisons of the measured total to the 25th percentile total from the historical data.

In general, these data suggest that higher than normal flows may have occurred at each monitoring location in response to the higher precipitation totals. It follows that toxic chemical loading estimates that were derived from this study may overestimate loads that might be expected during periods with more typical precipitation patterns if loads continue to increase as flows increase; however, if loads are source limited, then there is no expected bias in the estimates.

Detection Frequency Analysis

This section summarizes the detection frequency of the major chemical groups analyzed for this study. The detection frequency results for the priority parameters identified in Table 6 are summarized in Table 10, and results for all parameters are summarized in Appendix K.

Detection frequency is the percentage of samples for which the concentration of a parameter was high enough to be detected in the sample. Analyzing patterns in detection frequency (i.e., where, and under what conditions, specific chemicals were detected) provides a valuable understanding of the sources of the chemicals. Additionally, pinpointing which compounds were rarely or never detected can help improve the efficiency and cost effectiveness of future studies.

The following paragraphs compare the detection frequency for each of the major chemical groups for the four different land uses that were examined (commercial/industrial, agricultural, residential, and forest/field/other) under baseflow and storm-event conditions. Thanks to improved laboratory techniques, low detection limits were achieved for this study compared to previous studies.

Metals

Fifteen metals were analyzed for this study. The following five metals were rarely detected (less than 10 percent frequency):

1. Beryllium
2. Cadmium
3. Selenium
4. Thallium
5. Tin

With the exception of cadmium, these five metals were analyzed only in one storm-event sample from 12 locations. The following four metals were detected but were analyzed only in one storm-event sample from 12 locations:

1. Aluminum
2. Barium
3. Cobalt
4. Manganese

The following six metals were among “key contaminants” identified in Phase 2. All six metals will be discussed in more detail below:

1. Arsenic
2. Cadmium
3. Copper
4. Lead
5. Mercury
6. Zinc

Arsenic, cadmium, and copper were generally detected with equal frequency in storm-event and baseflow samples. In contrast, lead, mercury, and zinc were detected more frequently in storm-event samples (Appendix K, Table K-1). Most of these metals were also detected with equal frequency in samples from the four different land uses. However, the following exceptions were identified based on the data presented in Table K-2:

- Cadmium was generally detected only in samples from the commercial/industrial subbasins.
- Lead and mercury were detected less frequently in samples from forest/field/other subbasins relative to samples from the other three lands use types.

There were no substantial differences in the detection frequency for metals between the Snohomish watershed and Puyallup watershed (Appendix K, Table K-3). Finally, it should be noted that the detection frequency was substantially higher for the dissolved fraction of some metals relative to the total fraction of that metal. This discrepancy in detection frequency is an artifact of using a higher MRL for the total metal compared to the dissolved metal. For example, the detection frequency was 90.0 percent for dissolved zinc versus 46.7 percent for total zinc in baseflow samples because the MRL was 1.0 µg/L for dissolved zinc and 5.0 µg/L for total zinc.

Polychlorinated Biphenyl (PCB) Congeners

The majority of PCB congeners were detected in a small percentage of the samples collected or were not detected in any sample. The following PCB congeners were detected in 50 percent or more of the samples from any of the land-use types:

- PCB-043/049
- PCB-044
- PCB-052/073
- PCB-066/076/080
- PCB-070
- PCB-084
- PCB-086/087/097/ 111/115/116/117/125
- PCB-089/090/101
- PCB-092
- PCB-093/095
- PCB-099
- PCB-105/127
- PCB-110
- PCB-118/106
- PCB-128
- PCB-132/168
- PCB-138/163/164
- PCB-135/144
- PCB-136
- PCB-139/149
- PCB-141

- PCB-146
- PCB-151
- PCB-153
- PCB-170/190
- PCB-174
- PCB-180
- PCB-182/187
- PCB-183

Most of the PCB congeners were detected more frequently during storm events than during baseflow, while a few PCB congeners had similar detection frequencies during baseflow and storm events (Appendix K, Table K-1). The PCB congeners listed above were detected more frequently in commercial/industrial subbasin samples compared to the other land uses (Table K-2). However, PCB detection frequencies for samples from the other land-use types were often above 30 percent. Detection frequencies of PCBs were substantially higher in samples from the Puyallup watershed than the Snohomish watershed (Table K-3). Total PCBs will be discussed in more detail in this report, but the individual congeners will not be described in further detail although data results are available in Appendix L.

Polybrominated Diphenyl Ether (PBDE) Congeners

Of the 36 PBDE congeners analyzed for this study, only the following three congeners were detected at a frequency higher than 50 percent in at least one of the land-use types:

1. PBDE 100
2. PBDE 153
3. PBDE 209

PBDEs were generally detected more frequently in storm-event samples than baseflow samples when compared across all land uses with the exception of PBDE 100 (Appendix K, Table K-1). PBDEs were detected most frequently in commercial/industrial subbasin samples and least frequently in forested and residential subbasin samples (Table K-2). PBDEs were detected somewhat more frequently in the Puyallup watershed than the Snohomish watershed (Table K-3). Total PBDEs will be discussed in more detail in this report, but the individual parameters will not be described in further detail although data results are available in Appendix L.

Polycyclic Aromatic Hydrocarbons (PAHs)

Carcinogenic PAHs

Out of a total of seven carcinogenic PAHs (cPAHs), the following two cPAHs were only detected in a small percentage of the samples collected:

1. Benzo(k)fluoranthene
2. Dibenzo(a,h)anthracene

In contrast, the following five cPAHs were detected at a frequency higher than 50 percent for at least one of the land-use types:

1. Benzo(a)anthracene
2. Benzo(a)pyrene
3. Benzo(b)fluoranthene
4. Chrysene
5. Indeno(1,2,3-cd)pyrene

The latter five compounds were only detected in storm-event samples (Appendix K, Table K-1). These five compounds were primarily detected in commercial/industrial subbasin samples and were almost never detected in agricultural or forested subbasin samples (Table K-2). There was no substantial difference in detection frequency of cPAHs between the Snohomish and Puyallup watersheds (Table K-3). Total cPAHs will be discussed in more detail in this report, but the individual parameters will not be described in further detail although data results are available in Appendix L.

High Molecular Weight PAHs

Out of a total of 10 high molecular weight PAHs (HPAHs), the following two HPAHs were only detected in a small percentage of the samples collected:

1. Benzo(k)fluoranthene
2. Dibenzo(a,h)anthracene

In contrast, the following eight HPAHs were detected at a frequency higher than 50 percent for at least one of the land-use types:

1. Benzo(a)anthracene
2. Benzo(a)pyrene
3. Benzo(b)fluoranthene
4. Benzo(ghi)perylene
5. Chrysene
6. Fluoranthene
7. Indeno(1,2,3-cd)pyrene
8. Pyrene

All 10 HPAHs were detected more frequently in storm-event samples than baseflow samples (Appendix K, Table K-1). These 10 compounds were also primarily detected in commercial/industrial subbasin samples and were almost never detected in agricultural or forested subbasin samples (Table K-2). There was no substantial difference in detection frequency of HPAHs between the Snohomish and Puyallup watersheds (Table K-3). Total HPAHs will be discussed in more detail in this report, but the individual parameters will not be described in further detail although data results are available in Appendix L.

Low Molecular Weight PAHs

Out of a total of six low molecular weight PAHs (LPAHs), the following five LPAHs were detected in a very small percentage of the collected samples or not at all:

1. Acenaphthene
2. Acenaphthylene
3. Anthracene
4. Fluorene
5. Naphthalene

Only one of the LPAHs analyzed (phenanthrene) was detected at a frequency higher than 50 percent of the samples from any land use. Phenanthrene was detected substantially more frequently in storm-event samples than baseflow samples (Appendix K, Table K-1). Phenanthrene was detected almost exclusively in commercial/industrial subbasin samples, and was never detected in agricultural or forested subbasin samples (Table K-2). Phenanthrene was detected slightly more frequently in samples from the Puyallup watershed than the Snohomish watershed (Table K-3). Total LPAHs will be discussed in more detail in this report, but the individual parameters will not be described in further detail although data results are available in Appendix L.

Other Base/Neutral/Acid (BNA) Extractable Compounds

Samples were tested for 52 semi-volatile organic compounds that fall in the category of other BNA extractable compounds. Of this list of 52, only the following six compounds were detected at frequencies higher than 50 percent for any of the land-use types:

1. Bisphenol A
2. Caffeine
3. Cholesterol
4. Ethanol, 2-Chloro-,Phosphate (3:1)
5. Pentachlorophenol (PCP)
6. Retene

When compared across all land-use types, these six BNA compounds were detected more frequently in storm-event samples than baseflow samples (Appendix K, Table K-1). Most of these compounds were detected with the highest frequency in commercial/industrial subbasin samples, with the exception that cholesterol and PCP were detected most frequently in agricultural subbasin samples (Table K-2). The detection frequency for all six of these compounds was the lowest in the forested subbasin samples. There was no substantial difference in the detection frequency of BNA compounds between the Puyallup and Snohomish watersheds (Table K-3).

Nonylphenol was listed as a "key contaminant" in the Phase 2 report (EnviroVision et al. 2008; Herrera 2010), but was rarely detected in this study (Appendix K). Therefore, a comparison in detection frequency among land uses, watersheds, or storm and baseflow samples cannot be made. Nonylphenol is the only BNA compound discussed in more detail in this report. Data for the BNA compounds not discussed are available in Appendix L.

Phthalates

None of the six phthalates analyzed for this study had a detection frequency higher than 50 percent for any of the land-use types. The most frequently detected phthalate was bis(2-ethylhexyl) phthalate (Appendix K).

Bis(2-ethylhexyl) phthalate was listed as a "key contaminant" in the Phase 2 report (EnviroVision et al. 2008; Herrera 2010). This compound was detected more frequently in storm-event samples than baseflow samples when compared across all land uses (Appendix K, Table K-1). Bis(2-ethylhexyl) phthalate was also detected most frequently in commercial/industrial subbasin samples (Table K-2). There was no substantial difference in detection frequency among samples from the other three land-use types. There was also no notable difference in detection frequency of bis(2-ethylhexyl) phthalate or any of the other phthalates between the Snohomish and Puyallup watersheds (Table K-3). Bis(2-ethylhexyl) phthalate is the only phthalate discussed in more detail in this report. Data for the phthalates compounds not discussed are available in Appendix L.

Pesticides

None of the 34 pesticides analyzed had a detection frequency higher than 50 percent for any of the land-use types. The most frequently detected pesticide was pentachloroanisole (Appendix K). For this particular pesticide, the detection frequency was higher for baseflow samples than storm-event samples when compared across all land uses (Table K-1). Pentachloroanisole was detected most frequently in agricultural subbasin samples (Table K-2). There was no substantial difference in detection frequency of pentachloroanisole between the Puyallup and Snohomish watersheds (Table K-3).

DDT was highlighted as being a "key contaminant" in the report for the Phase 2 study of toxics in surface runoff (EnviroVision et al. 2008; Herrera 2010). However, DDT was infrequently detected during this study. Total DDT was detected in 8.3 percent of the storm-event samples and 6.7 percent of the baseflow samples (Appendix K, Table K-1) for all land-use types. Total DDT was detected almost solely in commercial/industrial subbasin samples (Table K-2). Lastly, DDT was detected more frequently in the Puyallup watershed than the Snohomish watershed (Table K-3). Total DDT is the only pesticide discussed in more detail in this report. Data for the pesticides not discussed are available in Appendix L.

Herbicides

Of the 18 herbicides analyzed (see Appendix E), only the following two herbicides were detected at frequencies close to 50 percent for any of the land-use types:

1. 2,4-D
2. Triclopyr

The detection frequency of these two herbicides was higher for storm-event samples than baseflow samples when compared across all land uses (Appendix K, Table K-1). Both 2,4-D and triclopyr were detected most frequently in commercial/industrial subbasin samples (50 percent and 47 percent, respectively) and were rarely detected in forested subbasin samples

(Table K-2). These two herbicides were detected slightly more frequently in the Puyallup watershed than the Snohomish watershed (Table K-3). 2,4-D will not be discussed further in this report because it was analyzed only in 25 percent of the storm-event samples and 13 percent of the baseflow samples. Triclopyr was detected more frequently during storm events (37.5 percent of samples) compared to baseflow conditions (20.0 percent of samples) and is the only herbicide discussed in more detail in this report. Data for the herbicides not discussed are available in Appendix L.

Petroleum and Oil

The following two classes of petroleum hydrocarbons were not detected at all during this study:

1. #2 Diesel
2. Gasoline

In contrast, the following three petroleum and related compound groups were detected more frequently:

1. Lube oil (TPH-Dx method)
2. Lube oil (TPH-DOG method)
3. Oil and grease

These three groups were detected more frequently in storm-event samples than baseflow samples (Appendix K, Table K-1). These three groups were detected at a much higher frequency in commercial/industrial subbasin samples than samples from the other land uses (Table K-2). These compounds were also detected somewhat more frequently in the Snohomish watershed than in the Puyallup watershed when compared across all land-use types (Table K-3). Oil and grease and lube oil (TPH-DOG method) are the only petroleum and related compounds discussed in more detail in this report. Data for the petroleum compounds not discussed are available in Appendix L.

Conventional Parameters

The following conventional parameters were detected in virtually 100 percent of the samples collected:

- Dissolved organic carbon
- Hardness as $CaCO_3$
- Nitrate+nitrite nitrogen
- Total organic carbon
- Total persulfate nitrogen
- Total phosphorus

Only three of the conventional parameters reported were detected in fewer than 100 percent of the samples from any given land use or flow condition:

1. Ammonia
2. Ortho-phosphate
3. Total suspended solids (TSS)

Ammonia and TSS were detected more frequently in storm-event samples than baseflow samples (Appendix K, Table K-1). There was not a substantial difference in ortho-phosphate detection frequency between storm and baseflow samples (Table K-1). Ortho-phosphate and ammonia were detected least frequently in forested subbasin samples and more frequently in the commercial/industrial and agricultural subbasin samples (Table K-2). There was little apparent difference in detection frequency of TSS among the land uses (Table K-2).

Ammonia, ortho-phosphate, and TSS were detected less frequently in samples from the Snohomish watershed than the Puyallup watershed (Table K-3). Otherwise, the detection frequency of conventional parameters was uniform between the two watersheds. Nitrate+nitrite nitrogen, total phosphorus, and TSS are the three conventional parameters discussed in more detail in this report. Data for the conventional parameters not discussed are available in Appendix L.

Principal Component Analysis

Results from the PCA are summarized using scatter plots that show the first principal component projected along the x-axis and the second principal component projected along the y-axis. As described in the *Methods* section, the first principal component explains the most variance in the data while each additional component that is extracted from the data represents successively lesser amounts of variance.

In the PCA that was performed on the data from storm-event sampling, the first and second principal components explain 48 and 25 percent of the variance, respectively. The scatter plot in Figure 6 shows the scores for the monitoring locations (based on median concentrations) in the principal component space while the scatter plot in Figure 7 shows the parameters that are associated with each of the principal components.

- The x-axis in Figure 6 (i.e., first principal component) generally shows that forested monitoring locations group to the right and the remainder of the monitoring locations are mixed in the center and to the left of the plot. At the same time, nitrate+nitrite nitrogen, total phosphorus, total mercury, total arsenic, total copper, and TSS group to the left on the x-axis in Figure 7. This indicates that forested monitoring locations are distinct from the remainder of the monitoring locations because they have particularly low concentrations of these parameters. Thus, the first principal component can generally be interpreted as explaining the chemical differences between developed and undeveloped land.

- If the y-axis in Figure 6 (i.e., second principal component) is then examined, it is evident that commercial/industrial monitoring locations are grouping far from the other monitoring locations in the lower region of the plot (Figure 6). This is apparently explained by commercial/industrial monitoring locations having particularly high concentrations of total PCBs, total zinc, total lead, and total PBDEs relative to the other monitoring locations, as indicated by the y-axis in Figure 7.

In the PCA that was performed on the data from baseflow sampling (Figures 8 and 9), the first and second principal components explained 29 and 25 percent of the variance, respectively.

This is less variance than was explained by the first two principal components of the storm-event data, an indication that the baseflow data are more randomly distributed.

- The x-axis in Figure 8 (i.e., first principal component) shows the forested monitoring locations are generally grouping on the right side of the plot and the rest of the monitoring locations are grouped together. The separation between the forested monitoring locations and the other monitoring locations is less pronounced relative to the pattern in Figure 6 for data that were collected during storm sampling; this is an indication that the chemistry among the land uses is more homogeneous during baseflow in comparison to storm events.

- The x-axis in Figure 9 indicates that the forested monitoring locations are grouping away from the other monitoring locations because they generally have lower concentrations of total phosphorus, total mercury, total arsenic, total lead, total copper, and total PCBs during baseflow conditions.

- Similar to the storm-event analysis, the second principal component for data that were collected during baseflow illustrates the difference between concentrations in the commercial/industrial monitoring locations versus the remainder of the monitoring locations (see y-axis in Figure 8). The difference is defined by relatively high concentrations of total zinc and total PBDEs and relatively low concentrations of nitrate+nitrite nitrogen and TSS in baseflow that was measured at the commercial/industrial monitoring locations (Figure 9).

Subbasin-Scale Contaminant Concentration and Loading Analysis

This section summarizes the contaminant concentrations and loadings for the 21 priority parameters for this study that are identified in Table 6. The goal of this section is to evaluate differences in concentrations and loads for these priority parameters in relation to land use and flow condition (baseflow versus storm-event) at the subbasin scale. Where applicable, exceedances of water quality criteria from the following sources are also compared across the different land uses:

- Acute and chronic freshwater criteria from WAC 173-201A.
- Human health freshwater criteria from National Toxics Rule (40 CFR 131.36)
- EPA National Recommended Water Quality Criteria (EPA 822-R-02-47)

To support this evaluation, summary statistics computed from the concentrations and load estimates for these parameters are provided in Table 10 and 11, respectively. In addition, Figures 10 through 36 present box plots for these parameters showing the following summary statistics for the concentrations: minimum and maximum (whiskers), median, and 25th and 75th percentiles. These same summary statistics are also presented in Figures 37 through 63 for the unit-area loading estimates that were computed for these parameters. Finally, to provide additional context for interpreting these results, the following appendices provide summary statistics for all parameters:

- **Appendix L:** summary statistics for toxic chemical concentrations by monitoring location, land use, and watershed
- **Appendix M:** box plots comparing toxic chemical concentrations between monitoring locations
- **Appendix N:** subbasin-scale total and unit-area toxic chemical loading estimates
- **Appendix O:** whisker plots comparing unit-area toxic chemical loading estimates between monitoring locations

Arsenic

Summary statistics for arsenic concentrations (total and dissolved) are presented in Table 10, Appendix L (Tables L-30 and L-31), and Figures 10 and 11. A comparison to water quality criteria is summarized in Table 12. Summary statistics for arsenic unit-area loading rates are presented in Table 11, Appendix N (Tables N-30 and N-31), and Figures 37 and 38.

Arsenic concentrations were generally similar in storm-event and baseflow samples, and well above the reporting limit of 0.10 micrograms per liter (µg/L). For example, the median dissolved arsenic concentration from all baseflow samples (0.75 µg/L) was only slightly higher than the median concentration from all storm-event samples (0.60 µg/L). Similarly, the median total arsenic concentration from all baseflow samples (0.77 µg/L) was only slightly lower than the median from all storm-event samples (0.81 µg/L).

The median dissolved and total arsenic concentrations were relatively similar for the commercial/industrial and agricultural subbasins, but were generally lower for residential and forested subbasins. For example, the median dissolved arsenic concentrations from all baseflow samples collected in the commercial/industrial and agricultural subbasins were both 1.31 µg/L. In comparison, the median dissolved arsenic concentrations from all baseflow samples collected in the residential and forested subbasins were 0.64 and 0.34 µg/L, respectively. A similar pattern was observed for total arsenic.

Dissolved arsenic concentrations were also compared to acute and chronic water quality criteria for Washington State (WAC 173-201A). No water quality criteria exceedances occurred for dissolved arsenic.

The median unit-area loading rate for dissolved arsenic was nearly the same for storm events (292 g/km^2/yr) and baseflow (279 g/km^2/yr) for all subbasin samples combined. The median unit-area loading rate for total arsenic was higher during storm events (394 g/km^2/yr) than baseflow (287 g/km^2/yr).

The median unit-area loading rates for dissolved and total arsenic were similar among the commercial/industrial and agricultural subbasins, but were generally lower for the residential and forested subbasins. For example, during storm events, the median unit-area loading rates for total arsenic from commercial/industrial and agricultural subbasins were 500 and 427 g/km^2/yr, respectively. In comparison, the median unit-area loading rates during storm events for total arsenic from residential and forested subbasins were 264 and 234 g/km^2/yr, respectively.

Cadmium

Summary statistics for cadmium concentrations (total and dissolved) are presented in Table 10, Appendix L (Tables L-36 and L-37), and Figures 12 and 13. A comparison to water quality criteria is summarized in Table 12. Summary statistics for cadmium unit-area loading rates are presented in Table 11, Appendix N (Tables N-36 and N-37), and Figures 39 and 40.

As noted in the *Detection Frequency Analysis* section, cadmium was generally only detected in samples from the commercial/industrial subbasins. For this land-use category, median dissolved cadmium concentrations were generally similar between storm-event and baseflow samples. For example, the median dissolved cadmium concentration for all samples collected during baseflow conditions from commercial/industrial subbasins was equivalent to the reporting limit of 0.02 µg/L, whereas the median dissolved cadmium concentration for samples collected during storm events was 0.03 µg/L. Total cadmium was not detected in samples collected from the commercial/industrial subbasins during baseflow conditions. The median total cadmium concentration for all storm-event samples was 0.05 µg/L, which is equivalent to one-half the reporting limit of 0.10 µg/L.

Cadmium concentrations showed a similar pattern across the four subbasin types to the pattern that was observed for detection frequency. Specifically, samples from commercial/industrial subbasins tended to have the highest concentrations of cadmium relative to the other subbasin types. For example, median storm-event concentrations of dissolved and total cadmium for the commercial/industrial subbasins were 0.03 and 0.05 µg/L, respectively. In comparison, the median storm-event dissolved cadmium concentration for the agricultural subbasins (the only other land use where cadmium was detected) was 0.01 µg/L (i.e., one-half the reporting limit).

Dissolved cadmium concentrations were also compared to acute and chronic water quality criteria for Washington State (WAC 173-201A). No water quality criteria exceedances occurred for dissolved cadmium.

The median storm-event unit-area loading rates for dissolved and total cadmium for commercial/industrial subbasins were 16.3 and 27.1 g/km^2/yr, respectively. In contrast, the median dissolved cadmium storm-event loading rate for the agricultural subbasins was 3.65 g/km^2/yr. The median loading rates for the remaining subbasin types (i.e., forested and residential) could not be calculated because cadmium was not detected in those subbasins.

Copper

Summary statistics for copper concentrations (total and dissolved) are presented in Table 10, Appendix L (Tables L-40 and L-41), and Figures 14 and 15. A comparison to water quality criteria is summarized in Table 12. Summary statistics for copper unit-area loading rates are presented in Table 11, Appendix N (Tables N-40 and N-41), and Figures 41 and 42.

Copper concentrations were generally higher in storm-event samples than baseflow samples, and well above the reporting limit of 0.10 µg/L. For example, the median dissolved copper concentration for storm-event samples from all subbasins (2.03 µg/L) was substantially higher than the median concentration for baseflow samples (0.74 µg/L). Similarly, the median total

copper concentration for storm-event samples (3.24 µg/L) was higher than the median for baseflow samples (0.97 µg/L).

For storm-event samples, median dissolved and total copper concentrations were highest for agricultural subbasins and lowest for forested subbasins. Commercial/industrial and residential subbasin samples fell into the middle of this range. For example, the median storm-event total copper concentration was 5.19 µg/L for agricultural subbasins, 3.84 µg/L for commercial/ industrial subbasins, 2.21 µg/L for residential subbasins, and 0.82 µg/L for forested subbasins.

For baseflow samples, median total copper concentrations were higher for agricultural and commercial/industrial subbasins relative to the medians for the residential and forested subbasins. For example, the median baseflow concentrations of total copper were 1.88 and 1.69 µg/L for the commercial/industrial and agricultural subbasins, respectively. In comparison, the median baseflow concentration of total copper was 0.88 and 0.63 µg/L for residential and forested subbasins, respectively.

Dissolved copper concentrations were also compared to acute and chronic water quality criteria for Washington State (WAC 173-201A). Two exceedances of the acute criterion for dissolved copper occurred during the monitoring period. Both exceedances occurred in commercial/industrial basins during storm-event monitoring. Ten exceedances of the chronic criterion for dissolved copper also occurred during the monitoring period. Nine of these exceedances occurred during storm-event monitoring. Five exceedances were measured in commercial/industrial subbasins, and four exceedances were measured in agricultural subbasins. One exceedance was found in a forested basin (FB372).

Unit-area loading rates for both dissolved and total copper were much higher during storm events than during baseflow. For example, the median unit-area loading rate for dissolved copper for all subbasin types was 988 g/km^2/yr for storm events and 276 g/km^2/yr for baseflow. The median unit-area loading rate for total copper for all subbasin types was 1,580 g/km^2/yr for storm events and 361 g/km^2/yr for baseflow.

Unit-area loading rates for copper were relatively similar among land uses during baseflow despite the apparent pattern in copper concentrations. For example, the median baseflow unit-area loading rates for dissolved copper only ranged from 152 to 317 g/km^2/yr among all the subbasin types. For storm events, the commercial/industrial and agricultural subbasins had substantially higher median loading rates than the residential and forested subbasins. For example, the median unit-area loading rates of total copper for commercial/industrial and agricultural subbasins during storm events were 2,090 and 1,890 g/km^2/yr respectively. In comparison, the median unit-area loading rates of total copper for residential and forested subbasins were 686 and 518 g/km^2/yr, respectively.

Lead

Summary statistics for lead concentrations (total and dissolved) are presented in Table 10, Appendix L (Tables L-42 and L-43), and Figures 16 and 17. A comparison to water quality criteria is summarized in Table 12. Summary statistics for lead unit-area loading rates are presented in Table 11, Appendix N (Tables N-42 and N-43), and Figures 43 and 44.

Lead concentrations were generally higher in storm-event samples than baseflow samples. For example, the median dissolved lead concentration for storm-event samples for all subbasins (0.12 µg/L) was substantially higher than median concentration for baseflow samples (0.04 µg/L). Similarly, the median total lead concentration for storm-event samples (0.50 µg/L) was higher than the median total lead concentration for baseflow samples (0.13 µg/L). These median concentrations are within six times the reporting limit of 0.02 µg/L for dissolved lead and 0.10 µg/L for total lead.

In general, higher concentrations of lead were observed in commercial/industrial subbasins relative to the other three subbasin types. For example, the median storm-event concentration of total lead for commercial/industrial subbasins was 1.68 µg/L. In contrast, the second highest median total lead concentration was only 0.52 µg/L for residential subbasins. In general, forested subbasin samples yielded the lowest median dissolved and total lead concentrations among the four subbasin types. The pattern of higher median lead concentrations for commercial/industrial subbasin samples and lower median lead concentrations for the forested subbasin samples was observed for both storm and baseflow samples.

Dissolved lead concentrations were also compared to acute and chronic water quality criteria for Washington State (WAC 173-201A). Dissolved lead concentrations did not exceed the acute criterion for dissolved lead during the monitoring period. Six exceedances of the chronic criterion for dissolved lead occurred during the monitoring period, all of which were measured in commercial/industrial subbasins during storm-event monitoring.

Unit-area loading rates for both dissolved and total lead were much higher for storm events than baseflow. The median unit-area loading rate for dissolved lead for all land uses was 58.4 g/km^2/yr for storm events and 14.9 g/km^2/yr for baseflow. The median unit-area loading rate for total lead across all land uses was 243 g/km^2/yr for storm events and 48.4 g/km^2/yr for baseflow.

Unit-area loading rates for lead were relatively similar among land uses during baseflow despite the apparent pattern in lead concentrations. For example, the median unit-area loading rates for total lead ranged from 17.7 to 43.3 g/km^2/yr across all the land-use categories during baseflow. For storm events, the commercial/industrial subbasins yielded substantially higher median unit-area loading rates than the other subbasins. For example, the median unit-area loading rates of total lead for commercial/industrial subbasins during storm events was 912 g/km^2/yr, whereas the median unit-area loading rates for the other three subbasin types ranged from 82.2 to 161 g/km^2/yr.

Mercury

Summary statistics for mercury concentrations (total and dissolved) are presented in Table 10, Appendix L (Tables L-46 and L-47), and Figures 18 and 19. A comparison to water quality criteria is summarized in Table 12. Summary statistics for mercury unit-area loading rates are presented in Table 11, Appendix N (Tables N-46 and N-47), and Figures 45 and 46.

Mercury concentrations were generally similar for storm-event and baseflow samples. For example, the median dissolved mercury concentration for storm-event samples across all subbasins was 0.004 µg/L while the median concentration for baseflow samples was 0.002 µg/L. The median total mercury concentration for storm-event samples (0.008 µg/L) was also higher than the median concentration from baseflow samples (0.003 µg/L). These median concentrations are within four times the reporting limit of 0.002 µg/L for dissolved and total mercury.

The median dissolved and total mercury concentrations were relatively similar among samples from the commercial/industrial, residential and agricultural subbasins. In contrast, median mercury concentrations were lower for forested subbasin samples. For example, the median storm-event concentrations of total mercury for the commercial/industrial subbasins, residential subbasins, and agricultural subbasins were 0.007, 0.008, and 0.011 µg/L, respectively. In contrast, the median total mercury storm-event concentration for all of the forested subbasins was 0.004 µg/L. The same pattern was observed for dissolved mercury.

Total mercury concentrations were also compared to acute and chronic water quality criteria for Washington State (WAC 173-201A) and human health criteria from the National Toxics Rule (40 CFR131.36). Total mercury concentrations did not exceed the acute criterion or the human health criterion during the monitoring period. Three exceedances of the chronic criterion for total mercury occurred during storm-event monitoring. Two exceedances occurred in forested subbasins (FB200 and FB372), and one exceedance occurred in an agricultural subbasin (AG 143).

Unit-area loading rates for both dissolved and total mercury were higher for storm events than baseflow. For example, the median unit-area loading rate for dissolved mercury across all land uses was 1.95 g/km^2/yr for storm events and 0.745 g/km^2/yr for baseflow. Similarly, the median unit-area loading rate for total mercury for all land uses was 3.89 g/km^2/yr for storm events and 1.12 g/km^2/yr for baseflow.

Unit-area loading rates for mercury were generally higher in the forested subbasins than the other subbasins during baseflow despite the reverse pattern in mercury concentrations. For example, the median baseflow unit-area loading rate for dissolved mercury for all of the forested subbasins was 0.675 g/km^2/yr. In contrast, the median dissolved mercury values for the other three subbasin types were below 0.590 g/km^2/yr. For storm events, the agricultural subbasins had substantially higher median unit-area loading rates than the other subbasin types. For example, the median storm-event unit-area loading rate for dissolved mercury for all the agricultural subbasins was 2.55 g/km^2/yr. In contrast, the other three subbasin types all had median loading rates less than or equal to 1.63 g/km^2/yr.

Zinc

Summary statistics for zinc concentrations (total and dissolved) are presented in Table 10, Appendix L (Tables L-56 and L-57), and Figures 20 and 21. A comparison to water quality criteria is summarized in Table 12. Summary statistics for zinc unit-area loading rates are presented in Table 11, Appendix N (Tables N-56 and N-57), and Figures 47 and 48.

Median zinc concentrations were substantially higher for storm-event samples than baseflow samples. For example, the median storm-event dissolved zinc concentration for all samples was 5.5 µg/L. In contrast, the median baseflow dissolved zinc concentration was 2.3 µg/L. Likewise, the median storm-event concentration of total zinc (8.4 µg/L) was higher than samples collected during baseflow (2.5 µg/L). This pattern was generally observed across all of the individual subbasin types. These median concentrations are within six times the reporting limit of 1.0 µg/L for dissolved zinc and 5.0 µg/L for total zinc.

Zinc concentrations showed a similar pattern across the four land uses to the pattern that was observed for detection frequency. Specifically, commercial/industrial subbasin samples tended to have the highest concentrations (and detection frequency) of zinc relative to the samples collected from the other subbasin types. For example, median storm-event concentrations of dissolved and total zinc for all of the commercial/industrial subbasin samples were 29.1 and 37.2 µg/L, respectively. In comparison, the median dissolved zinc concentrations for samples from the other three subbasin types were less than 6.7 µg/L and median total zinc concentrations were less than 9.0 µg/L. Baseflow samples also showed the same pattern of median zinc concentrations relative to subbasin type.

Dissolved zinc concentrations were also compared to acute and chronic water quality criteria for Washington State (WAC 173-201A). Eleven exceedances of the acute criterion and 13 exceedances of the chronic criterion for dissolved zinc occurred during the monitoring period. All of the exceedances occurred in storm-event samples collected from commercial/industrial subbasins.

The median unit-area loading rate was generally higher in the commercial/industrial subbasins relative to the other subbasin types. This was especially true for storm-event samples. For example, the median storm-event unit-area loading rate for total and dissolved zinc was 20,200 and 15,800 g/km^2/yr, respectively. In comparison, median total zinc unit-area loading rates for the other three land uses were not higher than 3,280 g/km^2/yr, and the median dissolved zinc unit-area loading rate was not higher than 15,800 g/km^2/yr. During baseflow, there were generally less absolute differences in median unit-area loading rates for zinc among the land-use types. However, the median unit-area loading rate for the commercial/industrial subbasins was higher compared to the medians for other three subbasin types. The median unit-area loading rate for the residential subbasins was also lower than the medians for other three land-use types.

Total Polychlorinated Biphenyls (PCBs)

Summary statistics for total PCBs are presented in Table 10, Appendix L (Table L-194), and Figure 22. A comparison to water quality criteria is summarized in Table 12. Summary statistics for total PCB unit-area loading rates are presented in Table 11, Appendix N (Table N-194), and Figure 49.

In general, the median concentration of total PCBs was higher in storm-event samples than baseflow samples. For example, across all of the subbasins, the median total PCB concentration was 348.00 picograms per liter (pg/L) for storm-event samples compared to 226.95 pg/L for baseflow samples. For comparison, the reporting limit for total PCBs ranged from 10 to 820 pg/L.

The concentration of PCBs was much higher for the commercial/industrial subbasins relative to the other three subbasin types. For example, the median storm-event PCB concentration from storm-event samples for the commercial/industrial subbasins was 2,019.75 pg/L. In comparison, the median PCB concentrations for the other three subbasin types were all less than 275.50 pg/L.

Total PCBs were also compared to acute and chronic water quality criteria for Washington State (WAC 173-201A) and human health criteria from the National Toxics Rule (40 CFR131.36). Total PCB concentrations did not exceed the acute criterion; however, one exceedance of the chronic criterion and 23 exceedances of the human health criterion occurred during the monitoring period. The single exceedance of the chronic criterion for total PCBs occurred in one of the commercial/industrial subbasins during storm-event monitoring. Thirteen of the 23 exceedances of the human health criterion for PCBs occurred in commercial/industrial subbasins; however, exceedances also occurred in forested, residential, and agricultural subbasins. A majority of the exceedances (i.e., 18 out of 23 samples) occurred during storm-event monitoring.

Unit-area loading rates for total PCBs were generally higher during storm events than baseflow. The median unit-area loading rate for storm events for all subbasins was 169 mg/km^2/yr, compared to 84.5 mg/km^2/yr for baseflow.

Based on unit-area loading rates, the primary sources for total PCBs varied depending on the flow conditions. For example, the forested subbasins had the highest median unit-area loading rate (81.6 mg/km^2/year) during baseflow whereas the commercial/industrial subbasins had the highest unit-area loading rate (1,100 mg/km^2/yr) during storm events.

Total Polybrominated Diphenyl Ethers (PBDEs)

Summary statistics for total PBDEs are presented in Table 10, Appendix L (Table L-157), and Figure 23. Summary statistics for total PBDE unit-area loading rates are presented in Table 11, Appendix N (Table N-157), and Figure 50. No water quality criteria currently exist for total PBDEs, thus no evaluation of water quality exceedances was performed for this parameter as part of this study.

The same median concentration of total PBDEs (125.0 pg/L) was reported for both storm and baseflow samples across all subbasin types. However, interpretation of these median values is confounded by the high number of non-detect values in the underlying data and the wide range of reporting limits for total PBDEs (121 to 12,900 pg/L).

Substantially higher concentrations of PBDEs were generally observed in commercial/industrial subbasin samples where they were much higher during storm events than baseflow. Across all the commercial/industrial subbasin samples combined, the median total PBDE concentration was 436.0 pg/L for baseflow compared to 3,273.1 pg/L for storm events. PBDEs were detected infrequently in samples from the other three subbasin types (i.e., the median concentration reported for the other three land-use types was one-half the reporting limit), thus meaningful median concentration values could not be provided.

The median unit-area loading rate for total PBDEs was higher for storm events (60.8 mg/km^2/year) than baseflow conditions (46.6 mg/km^2/year) for all subbasins. As with the total PBDE concentration data, the true difference between storm and baseflow is masked by the high number of non-detect samples. For the commercial/industrial subbasins, where most of the PBDEs and the highest concentrations of PBDEs were detected, the difference is more apparent. The median storm-event unit-area loading rate for total PBDEs for all of the commercial/industrial subbasins was 1,780 mg/km^2/yr, and only 69.9 mg/km^2/yr for baseflow.

The median unit-area loading rate for total PBDEs was much higher for the commercial/industrial subbasins than for the other three land-use types. For example, the median storm-event unit-area loading rate for total PBDEs was 1,780 mg/km^2/yr for the commercial/industrial subbasins. In comparison, the medians for all other subbasin types were less than 79.0 mg/km^2/yr (based on median concentrations equal to one-half the reporting limit).

Total Polycyclic Aromatic Hydrocarbons (PAHs)

Summary statistics for total PAHs are presented in Table 10, Appendix L (Table L-357), and Figure 24. Summary statistics for total PAH unit-area loading rates are presented in Table 11, Appendix N (Table N-357), and Figure 51. No water quality criteria currently exist for total PAHs, thus no evaluation of water quality exceedances were performed for this parameter as part of this study. (Carcinogenic PAHs do have criteria, and these are described in the next subsection.)

Total PAHs were rarely detected during baseflow. For this reason, it is not worthwhile to make generalizations about the concentration or unit-area loading rates of these compounds for baseflow conditions. Only data for storm-event samples are discussed below.

Much higher concentrations of total PAHs were observed in the commercial/industrial subbasin samples. Across all of the commercial/industrial subbasins, the median total PAH concentration for storm-event samples was 0.1756 µg/L. In contrast, the next highest median total PAH concentration in storm-event samples for the other three subbasin types was 0.0098 µg/L for the residential subbasins. For reference, the reporting limit for total PAHs ranged from 0.0097 to 0.0340 µg/L.

The unit-area loading rates for total PAHs were also much higher in the commercial/industrial subbasins. The median storm-event unit-area loading rate for total PAHs for all of the commercial/industrial subbasins was 95.3 g/km^2/yr. In contrast, the median storm-event unit-area loading rates for the other three subbasin types were less than 6.07 g/km^2/yr.

Carcinogenic Polycyclic Aromatic Hydrocarbons (cPAHs)

Summary statistics for total cPAHs are presented in Table 10, Appendix L (Table L-392), and Figure 25. Summary statistics for total cPAH unit-area loading rates are presented in Table 11, Appendix N (Table N-392), and Figure 52. No water quality criteria currently exist for cPAHs as a sum. However, the six constituents that comprise the sum do have human health criteria, and these exceedances are summarized in Table 12; no acute or chronic freshwater criteria have been developed.

Total cPAHs were not detected during baseflow. Therefore, only data for storm-event samples are discussed below. Likewise, total cPAHs were never detected in forested subbasin samples so these parameters have been omitted from this discussion as well.

In general, substantially higher median concentrations of total cPAHs were observed in the commercial/industrial subbasin samples. Across all the commercial/industrial subbasins, the median total cPAH concentration for storm-event samples was 0.0845 µg/L. In contrast, the median storm-event total cPAH concentration for the residential subbasins was 0.0075 µg/L.

Six cPAHs were compared to human health criteria from the National Toxics Rule (40 CFR131.36). Sixty-six exceedances of the human health criteria occurred during the monitoring period. All 66 exceedances occurred during storm events, and all occurred in streams draining commercial/industrial subbasins.

The unit-area loading rates for total cPAHs were also much higher in the commercial/industrial subbasins. The median storm-event unit-area loading rate for total cPAHs for all of the commercial/industrial subbasins was 45.9 g/km^2/yr. In contrast, the median storm-event unit-area loading rates for the residential and agricultural subbasins were less than 2.33 g/km^2/yr.

High Molecular Weight Polycyclic Aromatic Hydrocarbons (HPAHs)

Summary statistics for total HPAHs are presented in Table 10, Appendix L (Table L-374), and Figure 26. Summary statistics for total HPAH unit-area loading rates are presented in Table 11, Appendix N (Table N-374), and Figure 53. No water quality criteria currently exist for HPAHs, thus no evaluation of water quality exceedances for this parameter were performed as part of this study. However, the six cPAHs included in total HPAHs do have criteria, and these are described above.

Total HPAHs were rarely detected during baseflow. For this reason, it is not worthwhile to make generalizations about the concentration or unit-area loading rates of these compounds for baseflow conditions. Only data for storm-event samples are discussed below. Likewise, total HPAHs were never detected in forested subbasin samples so these parameters have been omitted from discussion as well.

In general, substantially higher median concentrations of total HPAHs were observed in the commercial/industrial subbasin samples. Across all the commercial/industrial subbasins, the median total HPAH concentration for storm-event samples was 0.1516 µg/L. In contrast, the highest median storm-event total HPAH concentration for the residential subbasins was 0.0082 µg/L.

The unit-area loading rates for total HPAHs were much higher in the commercial/industrial subbasins. The median storm-event unit-area loading rate for total HPAHs for all of the commercial/industrial subbasins was 82.3 g/km^2/yr. In contrast, the median storm-event unit-area loading rates for the residential and agricultural subbasins were less than 2.56 g/km^2/yr.

Low Molecular Weight Polycyclic Aromatic Hydrocarbons (LPAHs)

Summary statistics for total LPAHs are presented in Table 10, Appendix L (Table L-385), and Figure 27. Summary statistics for total LPAH unit-area loading rates are presented in Table 11, Appendix N (Table N-385), and Figure 54. No water quality criteria currently exist for total LPAHs or for the individual constituents, thus no evaluation of water quality exceedances was performed for this parameter as part of this study.

Total LPAHs were rarely detected during baseflow. For this reason, it is not worthwhile to make generalizations about the concentration or unit-area loading rates of these compounds for baseflow conditions. Only data for storm-event samples are discussed below.

In general, substantially higher median concentrations of total LPAHs were observed in the commercial/industrial subbasin samples. Across all the commercial/industrial subbasins, the median total LPAH concentration for storm-event samples was 0.0135 µg/L. In comparison, the median total LPAH concentration for storm-event samples for each of the other three subbasin types was approximately 0.0050 µg/L.

The unit-area loading rates for total LPAHs were highest in the commercial/industrial subbasins. The median storm-event unit-area loading rate for total LPAHs for all of the commercial/ industrial subbasins was 7.33 g/km^2/yr. In contrast, the median storm-event unit-area loading rates for the other three subbasin types were less than 3.14 g/km^2/yr.

Bis(2-ethylhexyl) phthalate

Summary statistics for bis(2-ethylhexyl) phthalate are presented in Table 10, Appendix L (Table L-151), and Figure 28. A comparison to water quality criteria is summarized in Table 12. Summary statistics for bis(2-ethylhexyl) phthalate unit-area loading rates are presented in Table 11, Appendix N (Table N-151), and Figure 55.

Bis(2-ethylhexyl) phthalate was rarely detected during baseflow. For this reason, it is not worthwhile to try to make generalizations about the concentration or unit-area loading rates of this compound for baseflow conditions. Only data for storm-event samples are discussed below.

Substantially higher concentrations of bis(2-ethylhexyl) phthalate were observed in commercial/industrial subbasin samples. Across all the commercial/industrial subbasins, the median bis(2-ethylhexyl) phthalate concentration during storm events was 0.340 µg/L. Bis(2-ethylhexyl) phthalate was detected too infrequently in the other three subbasins to provide meaningful median concentration values (i.e., the median concentration reported for each of the other three land-use types was one-half the reporting limit).

No Washington State water quality criteria currently exist for bis(2-ethylhexyl) phthalate; however, there is a human health criterion for this parameter from the National Toxics Rule (40 CFR131.36). Only one exceedance of the human health criterion occurred in a residential basin during baseflow monitoring.

The unit-area loading rate for storm events for bis(2-ethylhexyl) phthalate was much higher (185 g/km^2/yr) for all the commercial/industrial subbasins combined compared to the other land-use types. The median unit-area loading rates for bis(2-ethylhexyl) phthalate for the other subbasin types ranged from 24.8 to 50.6 g/km^2/yr for residential and forested subbasins, respectively (based on median concentrations equal to one-half the reporting limit).

Triclopyr

Summary statistics for triclopyr are presented in Table 10, Appendix L (Table L-27), and Figure 29. Summary statistics for triclopyr unit-area loading rates are presented in Table 11, Appendix N (Table N-27), and Figure 56. No water quality criteria currently exist for triclopyr, thus no evaluation of water quality exceedances was performed for this parameter as part of this study.

It is difficult to meaningfully compare the median triclopyr concentrations for baseflow conditions and storm events. Triclopyr was detected in less than 50 percent of the samples for any of the subbasin types for either storm-event or baseflow conditions. Therefore the median reported value (approximately 0.0310 µg/L for all land-use types) reflects an estimate based on one-half the reporting limit and not actual conditions.

Trying to compare triclopyr concentrations between land-use types is also difficult due to the low detection frequency. For each of the subbasin types, the median triclopyr concentration is reported as approximately 0.0310 µg/L, which is equal to one-half the reporting limit.

Unit-area loading rates of triclopyr were higher during storm events than baseflow. The median storm-event unit-area loading rate was 15.1 g/km^2/yr for all subbasins combined, compared to 11.4 g/km^2/yr for baseflow. Because the loading rates for all of the subbasin types were based on median concentrations equal to one-half the reporting limit, differences in loading estimates reflect differences in land area and median discharge.

Nonylphenol

Summary statistics for nonylphenol are presented in Table 10, Appendix L (Table L-58), and Figure 30. A comparison to water quality criteria is summarized in Table 12. Summary statistics for nonylphenol unit-area loading rates are presented in Table 11, Appendix N (Table N-58), and Figure 57.

Nonylphenol was detected in only 1 percent of the samples collected for this study. Therefore, any comparisons of concentrations or loading rates among land uses or flow conditions would simply reflect differences in reporting limit and flow. No exceedances of acute or chronic water quality criteria for Washington State (WAC 173-201A) occurred in the collected samples. Based on the low detection frequency and the low concentrations of nonylphenol measured, an evaluation of nonylphenol is not provided in this section.

Total Dichlorodiphenyltrichloroethane (DDT)

Summary statistics for total DDT are presented in Table 10, Appendix L (Table L-111), and Figure 31. Summary statistics for total DDT unit-area loading rates are presented in Table 11, Appendix N (Table N-111), and Figure 58. Several forms or byproducts of DDT have water quality criteria; however, total DDT does not. Table 12 includes comparisons of DDT-related compounds to acute and chronic freshwater criteria and human health criteria.

It is difficult to meaningfully compare the median total DDT concentrations for baseflow and storm events based on the median concentrations for all land uses combined, due to the low detection frequencies. In this case, it is more useful to compare storm-event and baseflow DDT concentrations for the commercial/industrial subbasin samples only, because that is where DDT was the most frequently detected. For example, the median storm-event DDT concentration for commercial/industrial subbasins was 1.250 nanograms per liter (ng/L). In comparison, the median baseflow concentration for commercial/industrial subbasins was 0.100 ng/L.

The median DDT concentration for storm-event samples for three land-use types (i.e., commercial/industrial, agricultural, and forest) is reported as 1.250 ng/L (i.e., one-half the reporting limit). DDT was not detected in the residential subbasins. For baseflow samples, total DDT was only detected in commercial/industrial subbasins.

DDT-related compounds were also compared to acute and chronic water quality criteria for Washington State (WAC 173-201A) and human health criteria from the National Toxics Rule (40 CFR131.36). Results did not exceed the acute water quality criteria for 4,4'-DDD, 4,4'-DDE, or 4,4'-DDT. However, 13 exceedances of the chronic water quality criteria occurred during the monitoring period. All occurred in commercial/industrial subbasins and all but one during storm-event monitoring. Thirteen results exceeded the human health criteria, also for commercial/industrial subbasins and all but one during storm-event monitoring.

Unit-area loading rates of total DDT were higher during storm events than during baseflow. The median storm-event unit-area loading rate was 0.608 $g/km^2/yr$ during storm events compared to 0.0372 $g/km^2/yr$. Because all unit-area loading rates for total DDT were based on median concentrations equal to one-half the reporting limit, differences in loading rates reflect differences in land area and median discharge.

Oil and Grease

Summary statistics for oil and grease concentrations are presented in Table 10, Appendix L (Table L-149), and Figure 32. Summary statistics for oil and grease unit-area loading rates are presented in Table 11, Appendix N (Table N-149), and Figure 59. No water quality criteria currently exist for oil and grease, thus no evaluation of water quality exceedances was performed for this parameter as part of this study.

It is difficult to meaningfully compare the median oil and grease concentrations for baseflow conditions and storm events or between land uses. The detection frequency was less than 50 percent for each of the land-use types. The reported median value for all land-use types for

both storm and baseflow was calculated as 0.20 mg/L, which is equivalent to one-half the detection limit of 0.40 mg/L.

The median oil and grease unit-area loading rate for all land uses combined was slightly higher for storm events (97.3 kg/km^2/year) compared to baseflow (74.5 kg/km^2/year). Median unit-area loading rates for oil and grease were higher in the forested subbasins than the other land-use types for both storm and baseflow. For example, the median baseflow unit-area loading rate for the forested subbasins was 135 kg/km^2/year. In contrast, the next highest oil and grease baseflow loading rate (48.2 kg/km^2/year) occurred in the residential subbasins. Because these values were based on median concentrations equal to one-half the reporting limit, differences in loading rates only reflect differences in land area and median discharge.

It should be noted that baseflow from the forested subbasins was proportionally greater than from the other land uses. For example, the area-normalized baseflow discharge averaged 1.6 cubic feet per second per square mile (cfs/mi^2) among the four forested subbasins. The same values for the commercial/industrial, residential, and agricultural subbasins were 0.5, 0.8, and 0.4 cfs/mi^2, respectively (Table 5). This discrepancy explains why equivalent concentrations of oil and grease from each land use (Table 10) resulted in much higher unit-area loading rates from forested subbasins (Table 11). The source of oil and grease in the forested subbasins is likely different than in the other subbasins because there are no readily available anthropogenic sources of petroleum hydrocarbons in the forested subbasins. Decaying plant and animal matter is one potential natural source for oil and grease in the forested subbasins.

Lube Oil (TPH-DOG)

Summary statistics for lube oil analyzed by the total petroleum hydrocarbons – oil and grease (TPH-DOG) method are presented in Table 10, Appendix L (Table L-150), and Figure 33. Summary statistics for lube oil (TPH-DOG) unit-area loading rates are presented in Table 11, Appendix N (Table N-150), and Figure 60. No water quality criteria currently exist for lube oil (TPH-DOG), thus no evaluation of water quality exceedances was performed for this parameter as part of this study.

It is difficult to meaningfully compare the median lube oil (TPH-DOG) concentrations for baseflow conditions and storm events or between land uses. The detection frequency was less than 50 percent for each of the land-use types. The reported median value for agricultural subbasins during baseflow and agricultural, residential, and forested subbasins during storm events was 0.016 mg/L. Therefore, the reported median concentration values for lube oil (TPH-DOG) reflect an estimate based on the MRL and not actual conditions. One exception was commercial/industrial subbasins during storm events where lube oil (TPH-DOG) was detected 75 percent of the time with a median concentration of 0.075 mg/L.

Lube oil (TPH-DOG) was not detected in enough baseflow samples to draw meaningful comparisons regarding loading among land uses. For storm events, the highest median lube oil (TPH-DOG) unit-area loading rate (40.7 kg/km^2/year) occurred in the commercial/industrial subbasins. Median unit-area loading rates were less than 10.1 kg/km^2/year for the other three land-use types. Because these values were based on median concentrations equal to one-half the reporting limit, differences in loading rates only reflect differences in median discharge.

Total Suspended Solids (TSS)

Summary statistics for TSS are presented in Table 10, Appendix L (Table L-9), and Figure 34. Summary statistics for TSS unit-area loading rates are presented in Table 11, Appendix N (Table N-9), and Figure 61. No water quality criteria currently exist for TSS, thus no evaluation of water quality exceedances was performed for this parameter as part of this study.

TSS concentrations were generally higher for storm-event samples than baseflow samples when compared across all of the subbasins. The median TSS concentration for storm-event samples for all subbasin types was 9.00 milligrams per liter (mg/L). The median TSS concentration for baseflow samples was 2.00 mg/L.

During storm-event samples, median TSS concentrations were generally higher in the commercial/industrial and residential subbasins than in the agricultural or forested subbasins. For example, the median storm-event sample concentrations for the commercial/industrial and residential subbasins were 10.00 and 14.0 mg/L, respectively. In comparison, the median storm-event concentrations for the agricultural and forested subbasins were 5.50 and 7.00 mg/L, respectively.

Unit-area loading rates of TSS were generally higher during storm events than during baseflow when compared across all land uses. For example, the median unit-area loading rate for TSS for all land uses combined was 4,380 kg/km^2/yr for storm events and 745 kg/km^2/yr for baseflow.

For storm events, median TSS unit-area loading rates were generally higher for the commercial/ industrial, residential, and forested subbasins, compared to the agricultural subbasins. For example, the storm-event TSS unit-area loading rates for the commercial/industrial, residential, and forested subbasins were 5,430, 4,340, and 4,420 kg/km^2/yr, respectively. In comparison, the median storm-event unit-area loading rate for the agricultural subbasins was 2,010 kg/km^2/yr. For baseflow, the median TSS unit-area loading rates were generally similar for the residential, agricultural, and forested subbasins, but were substantially lower for the commercial/industrial subbasins. For example, the median loading rate for the commercial/industrial subbasins was 80.2 kg/km^2/yr, whereas the median unit-area loading rate for the other three subbasin types was greater than or equal to 590 kg/km^2/yr.

Total Phosphorus (TP)

Summary statistics for TP are presented in Table 10, Appendix L (Table L-8), and Figure 35. Summary statistics for TP unit-area loading rates are presented in Table 11, Appendix N (Table N-8), and Figure 62. No statewide water quality criteria currently exist for total phosphorus, thus no evaluation of water quality exceedances was performed for this parameter as part of this study.

TP concentrations were generally similar between storm-event samples and baseflow samples when compared across all of the subbasins. The median TP concentration for storm-event samples for all subbasins was 0.054 mg/L. The median concentration for baseflow samples was 0.038 mg/L.

Median TP concentrations were generally higher for the agricultural subbasin samples than samples from the other three subbasin types. For example, the median storm-event TP concentration for all agricultural subbasins was 0.206 mg/L. In comparison, the median storm-event sample TP concentration for the other three subbasin types ranged from 0.024 to 0.067 mg/L.

Unit-area loading rates of TP were generally slightly higher for storm events than baseflow when compared across all land uses. For example, the median unit-area loading rate for TP for all land-use types was 26.3 kg/km^2/yr for storm events and 14.2 kg/km^2/yr for baseflow.

The median TP unit-area loading rate was generally higher for the agricultural subbasins than for the other subbasin types. For example, the median storm-event TP unit-area loading rate for the agricultural subbasins was 75.2 kg/km^2/yr. In comparison, the median storm-event TP unit-area loading rate for the other three subbasin types ranged from 15.3 to 23.8 kg/km^2/yr.

Nitrate+Nitrite Nitrogen

Summary statistics for nitrate+nitrite nitrogen are presented in Table 10, Appendix L (Table L-4), and Figure 36. A comparison to water quality criteria is summarized in Table 12. Summary statistics for nitrate+nitrite nitrogen unit-area loading rates are presented in Table 11, Appendix N (Table N-4), and Figure 63.

Nitrate+nitrite nitrogen concentrations were generally similar between storm-event samples and baseflow samples when compared across all of the subbasins. The nitrate+nitrite nitrogen concentration for storm-event samples for all subbasins was 0.345 mg/L. The nitrate+nitrite nitrogen concentration for baseflow samples was 0.308 mg/L. However, unique patterns in concentration relative to flow condition were observed among the among the four land uses. These patterns are described below.

For baseflow samples, nitrate+nitrite nitrogen concentration was generally higher for the residential subbasins relative to the other subbasin types. For example, the median baseflow nitrate+nitrite nitrogen concentration for the residential subbasins was 1.027 mg/L. In comparison, the median baseflow nitrate+nitrite nitrogen concentrations for the other three land-use types ranged from 0.089 to 0.230 mg/L.

For storm-event samples, the median nitrate+nitrite nitrogen concentrations were generally higher in both the residential and agricultural subbasins relative to the commercial/industrial and forested subbasins. For example, the median storm-event nitrate+nitrite nitrogen concentrations for the residential and agricultural subbasins were 0.994 and 1.025 mg/L, respectively. In comparison, median storm-event nitrate+nitrite nitrogen concentrations for the commercial/ industrial and forested subbasins were 0.174 and 0.228 mg/L, respectively.

No Washington State water quality criteria currently exist for nitrate+nitrite nitrogen in surface water; however, there is a human health criterion for this parameter in the EPA National Recommended Water Quality Criteria (EPA 822-R-02-47). Three exceedances of the human health criterion occurred during the monitoring period. All three exceedances occurred in agricultural subbasins during storm-event monitoring.

Unit-area loading rates of nitrate+nitrite nitrogen were generally higher during storm events than during baseflow. For example, the median unit-area loading rate for nitrate+nitrite nitrogen for all land-use types was 168 kg/km^2/yr for storm events and 115 kg/km^2/yr for baseflow. The higher loading rates observed during storm events as opposed to baseflow are primarily the result of higher flow volume during storm events, because similar concentrations were observed under both flow conditions.

Unit-area loading rates for nitrate+nitrite nitrogen were generally higher for the residential subbasins during baseflow and higher in both the residential and agricultural subbasins during storm events. The median baseflow unit-area loading rate for nitrate+nitrite nitrogen for the residential subbasins was 247 kg/km^2/yr, whereas the median baseflow unit-area loading rates for the other subbasin types ranged from 36.9 to 60.1 kg/km^2/yr. For storm events, the median unit-area loading rates for the residential and agricultural subbasins were 308 and 374 kg/km^2/yr, respectively. In comparison, the median storm-event unit-area loading rate for the commercial/ industrial subbasins was 94.5 kg/km^2/yr, and 144 kg/km^2/yr for the forested subbasins.

Toxic Chemical Loading Estimates at the Watershed Scale

Total loads by land use from the Snohomish watershed are presented in Table 13 for the 21 priority parameters identified in Table 6. Total loads by land use for the Puyallup watershed are presented in Table 14 for these same parameters. In addition, both Tables 13 and 14 present total loads for each watershed from baseflow and storm events, respectively (by summing the loads from the individual land uses), and total loads for each watershed across all hydrologic conditions (by summing the baseflow and storm-event loads). Finally, more detailed summaries of the total loads for both watersheds are presented in Appendix P.

For parameters where one or more land uses or events were entirely non-detects, the tables reflect a range. The low end of the range treats all combinations of land use and event type as zero if all results were non-detects. The high end treats all categories composed of only non-detects as equal to the reporting limit. For example, dissolved cadmium was detected in both baseflow and storm events from commercial lands and only in storm events from agricultural lands. The agricultural contributions range from only the storm-event contributions to a higher value that treats baseflow non-detects as equivalent to the reporting limit. This range is carried through to the totals across land uses and over baseflow and storm events. The low end of the range represents what was documented from the detected results, while the high end represents that maximum that may have occurred if actual values were just below the reporting limit.

In general, these results show forested areas in both watersheds produced much higher total loads for the 21 priority parameters relative to the other land uses, even though forested land use had lower concentrations and unit-area loading rates for these parameters compared to the other land uses (Tables 10 and 11). These results, similar to the Phase 1 and Phase 2 findings, reflect the much greater land area that forests represent within each watershed compared to the other land uses (Table 8). Forested lands represent 88 percent of the Puyallup watershed and 84 percent of the Snohomish watershed areas (Table 7). When these large areas are multiplied by the unit-area loading rates for forested land use, a large total load is computed; however, this is likely an overestimation of the true contaminant yield from these areas (see *Discussion* section).

Among the developed land uses (commercial/industrial, residential, and agricultural), total loading rates for the 21 priority parameters were generally highest for the residential areas of both watersheds and lowest for commercial/industrial areas because of the proportion of these land uses in each watershed. As shown in Table 7, the residential land use in both watersheds (9.1 and 12.2 percent) represented a substantially larger area than commercial/industrial land use (0.2 and 0.6 percent). Thus, despite the fact that the commercial/industrial land use generally had higher concentrations of the 21 priority parameters, total loads were higher for the residential areas. Total loads for agricultural areas generally fell between these two values, which is consistent with its relative land area and unit-area loads. However, the following exceptions were observed, even considering differences in areas:

- **Copper and Lead**: The storm-event loads for copper and lead were higher for the agricultural area of the Puyallup watershed than for the other two developed land uses within the watershed.
- **Total PCBs**: The total PCB storm-event loads were higher for the commercial/industrial areas than for the other developed land uses in both watersheds.
- **Total PBDEs**: The total PBDE storm-event loads were higher for the commercial/industrial areas than for the other developed land uses in both watersheds.

Aside from the exceptions listed above, the total loads computed at the watershed scale were more influenced by relative land area than contaminant concentration. For example, the commercial/industrial subbasins generally had higher concentrations (and unit-area loading rates) of the 21 priority parameters than the other land uses. In contrast, total loads were smaller for the commercial/industrial land use in both watersheds compared to the other three land uses in almost all cases.

Toxic Chemical Loading Estimates for the Puget Sound Scale

The goal of the Phase 3 study was to refine the results from the previous Phase 1 and Phase 2 surface runoff studies using site-specific data. Phase 3 included collecting new environmental data with low detection limits and a more refined calculation approach. Appendix Q presents total loads for the priority parameters identified in Table 6 by land use for the 14 study areas linked to the Puget Sound Box Model.

Table 15 presents total loads for these same parameters by land use for the Puget Sound basin based on the combined loads from the individual study areas. In addition, Table 15 presents total loads for the Puget Sound basin from baseflow and storm events, respectively (by summing the loads from the individual land uses), and the total loads for the Puget Sound basin across all hydrologic conditions (by summing the baseflow and storm-event loads).

Ranges are included for any parameters with at least one combination of land use and event type where results were entirely non-detects. The range reflects treating this contribution as zero or equal to the reporting limit. The range spans several orders of magnitude for several parameters, including cadmium, total DDTs, and nonylphenol.

Heavy metal loads to Puget Sound in both total and dissolved form were not affected by detection limits, with the exception of cadmium. Detection frequency strongly included estimates of both total and dissolved cadmium, and load estimates are not as well constrained as for other metals. For all other metals, forested contributions dominate total loads at the Puget Sound scale due to the larger land area. Among developed lands, residential was the biggest contributor for arsenic, total copper, lead, mercury, and zinc, while agriculture was the biggest contributor for dissolved copper. Relative land area strongly influences relative metals contribution at the Puget Sound scale.

Total PCBs and total PBDEs from various land uses and event types were not strongly influenced by detection limits. Of the developed land uses, commercial lands contribute the most to Puget Sound-scale loads, although residential loads are comparable. Agricultural lands produce the lowest contributions of the four land uses. Forested lands contribute the highest loads at the Puget Sound scale due to the relative land area.

PAH loads at the Puget Sound scale were strongly influenced by non-detects, particularly during baseflow events. Storm-event PAH contributions from commercial areas were well characterized, but few or no detects in the other three land uses, even during storm events, produce ranges in the overall loads depending on how non-detects are treated. Among developed land uses, commercial lands contributed the highest loads of carcinogenic PAHs (treating non-detected contributions as zero). Carcinogenic PAHs were not detected at all in baseflow or storm events in streams draining forested lands, and these loads are not well described.

Bis(2-ethylhexyl) phthalate, triclopyr, nonylphenol, and total DDT load estimates at the Puget Sound scale were strongly influenced by non-detects, particularly in baseflow. Bis(2-ethylhexyl) phthalate was only found at high frequencies in storm events in commercial areas, while triclopyr was only detected in storm events in residential areas. Nonylphenol was only found in storms in commercial basins. At the Puget Sound scale, forested lands produced the highest loads due to the large forested land area. Among the developed lands, residential lands produced highest loads of bis(2-ethylhexyl) phthalate and triclopyr. Nonylphenol was not well characterized in the estimate, which spans several orders of magnitude depending on how non-detects are treated. Total DDT loads at the Puget Sound scale were influenced by non-detects, although resulting load estimates were better constrained than parameters such as nonylphenol.

Oil and grease and total petroleum hydrocarbon (TPH-Dog, lube oil) loads were strongly influenced by detection limits. Among developed land uses, residential lands produce the highest loads of both at the Puget Sound scale. Forested lands produce more oil and grease load due to the relative area. TPH was frequently found in storm events in commercial lands but load contribution at the Puget sound scale was low compared with other land uses due to relative land area and the treatment of non-detects. TPH was not found in forested baseflow and was found infrequently in storm events from forested lands, yet forested lands contributed the highest TPH loads at the Puget Sound scale. Among developed land uses, residential lands produced the highest loads at the Puget Sound scale.

TSS, total phosphorus, and nitrate+nitrite nitrogen loads at the Puget Sound scale were not influenced by reporting limits, and the estimates are well characterized. Forested lands produced the highest loads and commercial lands produced the lowest loads of all land uses. Relative contributions primarily reflect relative land area.

The following discussion compares the contaminant loading estimates between the Phase 2 and Phase 3 studies for the following five representative parameters:

1. Total copper
2. Total zinc
3. Total PCBs
4. Total PBDEs
5. Oil and grease

These parameters were chosen for comparison because they were included in all phases, and they were detected in the Phase 3 study at relatively high frequencies. Table 16 compares total loading rates from the Puget Sound basin between the Phase 2 Addendum (Herrera 2010) and Phase 3 studies for the combined loads from all land-use types using data from the five parameters listed above. In this table, the combined load for the Phase 3 study was derived by summing the individual loads from baseflow and storm events across all four land-use types within each of the 14 study areas. Additionally, Table 17 compares total loads for the Puget Sound basin between the two studies across the individual land-use types.

The data presented in Table 16 indicate the total loads from the Phase 3 study were lower than loads from the Phase 2 study for four of the five parameters compared. Of these four parameters, the most substantial difference between the two studies was observed for total PCBs. For example, the total loading rate for total PCBs from the Phase 3 study was 96 percent less than the rate from the Phase 2 study, or over an order of magnitude, due to the lower concentrations measured in the Phase 3 study. Total loads for three parameters (total copper, total zinc, and oil and grease) were approximately one-half the values calculated in the Phase 2 study. As shown in Table 16, total PBDEs had much higher total loads in the Phase 3 study relative to the Phase 2.

Differences in total loads between the Phase 2 and Phase 3 studies across the four land-use types generally showed a similar pattern to that observed for all land uses combined. Specifically, total loads from the Phase 2 study were generally higher than those from the Phase 3 study across all land-use types (Table 17). However, the following exceptions were noted:

- **Total Zinc:** Total zinc total loads from the forested land areas were slightly higher for the Phase 3 study relative to the Phase 2 study.
- **Oil and Grease:** Oil and grease total loads from the forested land areas were substantially higher for the Phase 3 study relative to the Phase 2 study. This is due to how non-detects were treated and the fact that the previous phases used 50th percentile concentrations that were below the detection limit for this parameter.
- **Total PBDEs**: Total PBDE total loads from all four land-use types were higher for the Phase 3 study relative to the Phase 2 study.

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Discussion

The data presented in the *Results* section provide a detailed description of the toxic contaminant concentrations and loads that were measured in this 2009-10 study. This section presents a discussion of these results in relation to the overall objectives of the study and use of the data. It begins with a description of potential sources of error in the data and provides some guidelines for their interpretation. It then discusses key patterns that were identified in the data and their implications for managing toxic chemicals in surface runoff. Finally, it evaluates the representativeness of the compiled data for computing loads at the Puget Sound scale based on comparisons to data from other regional and national studies.

Data Limitations and Guidelines for Interpretation

Accurately estimating contaminant loadings in stormwater remains one of the more challenging aspects of water resource investigations. Sources of error associated with loading estimates include:

- Flow gauge error – e.g., 5 to 10 percent for most USGS gauges or more for other gauges (USGS 1984)
- Chemical analysis error – e.g., 5 to 20 percent for most analyses or more for trace compounds (APHA et al. 1992)
- Error associated with extrapolating sampling results, which varies widely depending on method
- Sampling bias

In all loading estimates, there is a propagation of error when extrapolated or interpolated chemistry values are multiplied by discharge to generate a mass per unit of time. Consequently, the final loading value is not likely to be more accurate than ±20 percent, and in most cases loading values may be in error by more than 50 percent (Webb et al. 1997). This error was accounted for in this study by reporting the 25th and 75th percentile range of the water quality data for each loading calculation as opposed to one median loading value.

A brief explanation of specific sources of error and implications of this error in the study data is provided below regarding site selection, flow measurement, sample collection and analysis, and data extrapolation or interpolation.

Site Representativeness

Site selection can introduce error in contaminant load estimates for specific land-use types if the monitoring locations do not accurately represent the targeted land use. For this study, initially a stratified random site selection design was used to reduce site selection bias; the design was modified to account for low commercial land uses. However, each land-use category was represented by only four sites in the final design, and some results varied considerably within each land-use category. When relatively few sites are monitored and the land use in each basin

is not entirely composed of one specific land use, a random study design does not ensure that each of the sites is typical of the land use it represents. For example, our study results indicate that metals concentrations and unit-areal loading rates were particularly low for the residential and commercial/industrial land-use categories based on comparison to other studies, as discussed below. Without additional sampling at other representative sites, we cannot know if these data are indeed representative or if the sites selected were disproportionally low in metals.

This is confounded by the fact that the subbasins did not consist of 100 percent of their representative land use (Table 1). Based on the National Land Cover Database (MRLC 2001) used in this study to delineate land use, commercial/industrial land use represented, on average, only 40 percent of the area in the representative subbasins. Similarly, residential and agricultural land uses represented, on average, only 72 and 50 percent of the area, respectively, in the representative subbasins. Forested subbasins were the most homogeneous with an average of 90 percent forested land use.

For the commercial/industrial subbasins, the majority of the remaining land use was composed of residential. The data indicated that residential land use was characterized by lower concentration of contaminants than commercial/industrial; consequently, the estimate of commercial/industrial land-use contaminant export was likely reduced by the residential land-use contributions in the subbasins and the actual commercial contribution is higher than presented in this report. Likewise, for the residential basins, the next greatest land use was forest; the estimates of residential contaminant export was likely conservative as well.

For the agricultural basins, both residential and forest comprised equal parts of the remaining land uses in the associated subbasins. This complicates the interpretation of the data from the agricultural basins because it is difficult to interpret if the residential or agricultural areas were the primary contributor of some of the contaminants. For instance, metals concentrations from the agricultural basins tended to be higher than expected. These metals may have originated from either the residential or agricultural areas within the subbasins; however, without further investigations, the specific source cannot be determined. The forested subbasins were likely less affected by other land uses due to the fact that the vast majority of the land area within the forested basins was, in fact, forest.

In addition to incomplete land-use coverage in the subbasins, the land-use categorization was relatively coarse and did not, for example, differentiate between high-density and low-density residential. Consequently, because the subbasins that were finally selected through a random process were generally low-density residential, caution should be used when extrapolating these results to high-density residential areas; commercial/industrial water quality may be more representative. Likewise, not all commercial/industrial, agricultural, and forested areas are homogenous within their land-use categories; consequently, this caveat must accompany loading extrapolations beyond the monitored subbasins.

Another potential source of bias is the influence of factors close to the actual sampling locations. For example, results could vary if the sampling station was near or far from major roadways or highways, or was near other potential sources of specific chemicals. As noted in the *Methods* section, roads and highways were not specifically called out as unique land-use categories in this study. This is because the contaminant contribution from these areas could not be explicitly

separated from the contaminant contribution from the other four land uses given the experimental design for this study. As described in the *Methods* section, sampling at some monitoring locations also took place downstream of galvanized steel culverts that could be a potential pollution source, most notably for zinc. However, if these culverts were a significant source of zinc, higher concentrations would generally be expected during baseflow when there was less water at the monitoring station from up gradient sources to dilute the zinc coming from the culverts. In general, the data from this study generally show an opposite pattern occurred at each monitoring location; storm-event concentrations of zinc were typically higher than baseflow concentrations (Figures 20 and 21). Finally, there may be geologic or topographic variations which would influence groundwater flow patterns that may or may not interact with surface flow collected at the sampling station.

When scaling results up to represent land uses within the entire Puyallup and Snohomish watersheds, as well as the entire Puget Sound basin, we are assuming that the sampled basins are representative of their respective land uses on a broad scale. As discussed below, this assumption may not be true in many cases, particularly for forested land use because a proportionally smaller percentage of the associated area was sampled in this study and because site selection was limited to locations below an elevation of 2,200 feet.

Flow Measurement

Proper installation and routine calibration of flow gauging equipment are vital for reducing flow measurement error. Sensor error, loss of data due to instrument failure, shifting channel morphology, and stage-discharge regression error can also contribute to flow measurement error. To consistently control all these potential sources of error can be extremely difficult with temporary gauging installations in small channels. Consequently, errors of at least ±10 percent should be expected (USGS 1984).

Indeed, the error associated with the flow gauging component of this project ranged from 12 to 50 percent (see Appendix J) and therefore should be taken into account when interpreting the pollutant loading values in this report. However, it should be noted that variability in the water quality data has been quantified by reporting the 25th and 75th percentile load estimates that were derived using the 25th and 75th percentile concentrations for each parameter; the error reflected in the range between these values is typically several orders of magnitude and greatly exceeds the error associated with the flow measurements.

Sample Collection and Analysis

Grab sampling was selected for use in this study for the following reasons:

1. The sample volume, preservation, and handling requirements for the target analytes precluded the use of automated samplers.
2. The expense associated with automated sampling would have required fewer sites be monitored and fewer samples collected.

The primary drawback of not using automated sampling is that event mean concentrations are more difficult to approximate with grab sample data. Whenever possible, field crews collected two grabs for each event and composited the samples to better approximate the event mean concentration; however, this type of sampling was difficult in the flashier basins where storm durations were short relative to the time needed to conduct a full round of monitoring. Consequently, only a little over 50 percent of the targeted events were sampled twice.

There has been a limited amount of research regarding bias from grab versus automated sampling. Haraldsen and Stalnacke (2006) found that grab sampling was the least accurate method of estimating annual TSS loading, while time-weighted and flow-weighted composites provided better accuracy. However, Haraldsen and Stalnacke's study involved sampling at fixed time intervals (weekly) and did not specifically target storms. Lee et al. (2007) found that concentrations from storm-event grab sampling approached event mean concentrations from automated sampling if the grab sample was collected between the first 10 percent and last 10 percent of the event flow. In a similar study, Khan et al. (2006) examined 22 oil and grease pollutographs from highway drainages to determine when a single grab sample most closely approximated a flow-weighted composite sample. They found that grab samples collected between one and six hours after the beginning of the event generally provided a good approximation of the event mean concentration.

In this Phase 3 study, we collected 25 percent of the storm-event grab samples within the first 10 percent of the event flow and none during the last 10 percent of the event flow (Table 18). This indicates that we collected a majority of samples during the period when the event mean concentration would be estimated with the greatest accuracy based on grab samples.

The frequency of grab sampling has been shown to affect the accuracy of loading estimates for synthetic datasets (Webb et al. 1997). Using the same interpolation methods for calculating loading as was used in this study, Webb et al. (1997) found that weekly sampling was associated with an uncertainty of 33 percent and monthly sampling was associated with an uncertainty of 62 percent (based on 50 iterations). These results are useful for contextualizing the impact on accuracy that is likely induced by calculating annual loads from only eight samples in each subbasin.

Higher variability in the sample population decreases the likelihood of capturing the variability based on a small set of discrete samples. Many of the toxic chemicals evaluated in this study were only detected during the fall storm event. Consequently, the potential of the Phase 3 sampling design to capture the variability of the true population is low.

In addition, the transport of toxic chemicals in fluvial environments occurs within the water column, on the surface of the water, and within the alluvium. The sampling design used in this study focused on the contaminants within the water column and consequently did not account for transport on the water surface or within the alluvium. The seasonal export pattern observed in the data indicates that contaminant transport is most concentrated during early-season storm events. In order to gain a more robust estimate of total contaminant loading in streams, future studies should consider focusing on sampling the water surface, the water column, and the alluvium during these large early-season events.

All loading studies must address and mitigate the sources of sample collection and analysis error. In this study, the following steps were taken to reduce sample collection and analysis error in the loading estimates:

- Samples were collected using ultraclean technique, and field procedures were consistently employed according to approved methodology.
- Storm events were targeted for sampling, and more storm events than baseflow events were sampled.
- Two rounds of storm-event sampling were planned to more accurately estimate average contaminant concentrations for each event.
- Laboratory analyses were performed with rigorous QA controls and low detection limits.
- Advanced data processing tools were employed to correct spurious water level data.
- A flow-stratified interpolation technique was used to calculate contaminant loading.

Potential uncertainty in the results that stems from sampling and analysis error was quantified based on an analysis of field duplicate samples that were routinely collected for QA purposes. As presented in the *Results* section, Appendix R identifies when these field duplicate samples were collected and presents the calculated relative percent difference between sample and the field duplicate concentrations. Based on these data, the potentially uncertainty in the data from these sources averaged 30 percent across all the monitoring parameters.

Overall variability in the water quality data has also been quantified by reporting the 25th and 75th percentile load estimates that were derived using the 25th and 75th percentile concentrations for each parameter; the error reflected in the range between these values is typically several orders of magnitude. Despite this large error, the resultant data from this study are, in the majority of cases, consistent with previous studies, as discussed below. Consequently, the patterns in the data described below are our best estimate of actual conditions in the Puyallup and Snohomish watersheds.

Extrapolation and Interpolation of Loadings

Error originating from extrapolation and interpolation has been closely studied by numerous researchers. Webb et al. (1997) found that extrapolation or interpolation of discrete chemistry/loading results to create an annual loading estimate resulted in error ranging from -45 to +322 percent of the actual annual TSS loading. In a separate study of nitrate export, Webb et al. (2000) found that different extrapolation and interpolation techniques could produce median errors of up to 1,603 percent of the actual nitrate load.

Webb et al. (1997) assessed five loading interpolation methods using a synthetic dataset and iterative calculations of loading relative to the "true" dataset. Of the five methods, the method used for the Phase 3 study performed better than three of the other methods with an average underestimation in loading of approximately 50 percent. However, Webb et al. (1997) did not flow stratify the sampling strategy, a technique used in this study to avoid underestimation of loads.

Extrapolation Across Spatial Scales

In addition to concentration extrapolation error, error may have been introduced in this study by extrapolating unit-area loads from the subbasin scale to predict loads at the watershed and Puget Sound scale. Monitoring conducted at the subbasin scale generally measured contaminants relatively close to their source, although not within stormwater conveyance systems that are even closer.

However, after pollution has entered local waterways, there is considerable processing which occurs en route to the receiving water body. The bed of stream channels acts to filter water that passes through the alluvium (Grimm et al. 2005), and contaminant processing and sequestration is accelerated by a wide variety of macroorganisms (Fritioff and Greger 2003) and microorganisms (Bencala 2000) that thrive in healthy stream networks. In addition, legacy contaminated sediments within downstream channels can be mobilized during storm events and contribute to pollutant export (Hyun et al. 2010). These important factors are not addressed in this loading study because the unit-area loading from the subbasins are applied directly to estimate the total loading from the watersheds without accounting for contaminant processing or export that occurs in the downstream fluvial environment itself. This should be considered when interpreting the final results.

Various methods exist for extrapolating water quality data from monitored locations to unmonitored areas in order to generate watershed-wide loading estimates. The two most common are extrapolating land use-based export coefficients (unit-area loads, the method used in this study), and extrapolating land use-based concentrations to modeled flow volumes (concentration-based loads, the alternative method described in Appendix G that was previously used in the Phase 2 addendum). Unit-area loads are appropriate where loads scale by tributary area, whereas concentration-based loads are appropriate where loads scale by flow volume, which can vary within a watershed.

The primary assumption of the unit-area load approach we used in this study is that export coefficients (or unit-area loading rates) will remain constant despite variable rainfall patterns across the Puget Sound drainage. We also assumed that the land uses in the monitored subbasins are biogeochemically representative of the unmonitored basins to which we extrapolated the unit-area loading rates. An assessment of previous studies indicates that these assumptions are common (Tetra Tech 1995; Johnes 1996; Lin 2004; Bin Masood et al. 2008) and are even built into widely used watershed loading models such as PLOAD, an extension for BASINS (U.S. EPA 2001).

Most commercial, residential, and agricultural lands occur in the lowlands close to Puget Sound where rainfall variability is low. Therefore, extrapolating from these three land-cover categories using either unit-area loads or concentration times flow produces similar results. In contrast, forested lands span the full range of average annual rainfall and occur nearly exclusively at higher elevations where higher rainfall occurs. The unit-area loading rate method would break down in the forested areas if one assumes that pollutant export is “flow-limited”; or in other words, pollutant export is proportional to the amount of precipitation that falls. However, the data indicate that concentrations of most pollutants in runoff from the forested basins remain consistently low. In addition, there was little difference between storm-event and baseflow

concentrations for many pollutants in the forested basins relative to the basins for the other land uses (see discussion in *Summary of Key Patterns* section below); this would suggest there is no strong relationship between flow and pollutant export.

Based on these considerations, it is likely that forested regions are actually "source limited", and therefore the application of unit-area loading rates is justified in this analysis. For the loads of three parameters estimated for the Snohomish and Puyallup watersheds in Appendix G, the concentration-based method would estimate loads that are 20 to 50 percent higher than those developed from the unit area-based loads. Load estimates from forested lands constitute the biggest difference in load estimates at the watershed scale. This pattern likely holds at the Puget Sound scale, although Appendix G does not develop these estimates.

Finally, because data were collected from small streams, the concentrations and unit-area loads may not represent stormwater in areas adjacent to Puget Sound where conveyance systems discharge to marine waters or near marine waters. In these areas, conveyance system data may be more appropriate to quantify local loads. This report does not distinguish loads from these areas, and estimates are based on the Phase 3 instream data alone.

Other Sources of Bias (Overestimates and Underestimates)

While the study design was optimized to eliminate bias, several factors do introduce potential bias into the results. These factors may contribute to overestimates and underestimates at the watershed or Puget Sound scales.

The loads presented in the *Results* section may overestimate actual loads at the watershed or Puget Sound scale due to several factors:

- Instream processes may reduce the concentrations and loads reaching large rivers or Puget Sound. While these contaminants may still exist in the freshwater system in sediments, biota, or groundwater, the water delivered to downstream water bodies may have lower levels than characterized for small streams in this study.
- Forested lands were limited to areas below 2,200 feet in elevation. The selected subbasins are near population centers and may be subject to atmospheric deposition from local sources. Extrapolating from the four forested subbasins to all forested lands, even using the unit-area load method, may not characterize more remote forested regions.

The loads presented in *Results* may underestimate actual loads at the watershed or Puget Sound scale due to several factors:

- Subbasins selected to characterize commercial/industrial land covers averaged 40 percent land cover, and only one subbasin had >50 percent commercial/industrial land cover. Because concentrations and unit areas from other land uses were lower than those from the mixed commercial/industrial subbasins, commercial/industrial lands could produce even higher concentrations and unit-area loads.
- Subbasins selected to characterize residential land uses were almost exclusively low-density residential. Loads generated by medium- to high-density residential areas may be even higher

than those characterized based on low-density residential basins that also had significant forested lands.

- Loads from lands immediately adjacent to Puget Sound discharge directly through stormwater conveyance systems and not through small streams. Loads generated from these areas may be higher than those in this study, and stormwater conveyance data may be more appropriate.
- Several parameters were detected only during the October fall storm event. While not a true first-flush event, the results may be more characteristic of early-season storm events. Only one of the six storm events targeted this period, even though it produces a significant amount of the storm volume for the year.

Several factors could lead to overestimates or underestimates in the loads:

- Sample collection targeted the proportion of the hydrograph where the primary loads are delivered. Grab sampling may have missed the peak levels, which would underestimate the loads. However, if grab sampling captured peak levels and not average levels, the use of grab samples could overestimate the loads.
- Legacy contaminants may be remobilized during storms from existing contamination that is stored on the landscape or in sediment or biota. Levels captured in monitoring may overestimate true sources to the ecosystem. Because legacy contaminants may be associated with particles that are mostly delivered during several large storm events, monitored storms may not have captured these events and may underestimate legacy contaminants.
- Forested lands cover 83 percent of the Puget Sound watershed, much more than any other land use type. However, surface runoff was characterized by four subbasins just as for other land uses. Therefore, proportionally less forested land was monitoring than other land use types. Monitoring data may not have captured the full variability within forested land uses, which could lead to overestimates or underestimates.

Summary of Key Patterns

Undetected Parameters

One of the primary objectives of this study was to determine which of an extensive list of toxic contaminants are associated with surface runoff from various land-use types in the Puget Sound basin. To address this question, the collected samples from this study were analyzed for a wide range of contaminants. At the conclusion of this study, data were reported for 368 parameters; however, not all of these parameters were detected. Before focusing on the characteristics of the contaminants that were detected and are known to impact aquatic systems, it is important to first highlight those contaminants that were not found in any of the 126 samples collected.

Table 19 presents a list of the parameters that were not detected in any sample during this study. These results correlate well with another recent, similar Puget Sound-based study. For example, a study of contaminant loading in the Green River-Duwamish watershed in Washington evaluated many of the same parameters during baseflow and storm-event conditions from 2001 through 2003 (Herrera 2004). Selenium is the only parameter that was detected in the

Green/Duwamish study that was not detected in this study, and selenium was only detected in 1 of 114 samples collected for the Green/Duwamish study.

Storm-Event versus Baseflow Chemistry

Depending on the contaminant source, percent impervious cover, and fate and transport dynamics, toxic contaminants can either be preferentially exported to local waterways during baseflow or storm-event conditions. Parameter concentrations that are elevated in groundwater will contribute to elevated concentrations in baseflow and become diluted during storm events. When surface flow and interflow dominate during storm events, contaminants washed from the landscape will control the chemistry of local waterways. Consequently, by analyzing baseflow versus storm-event chemistry, inferences about contaminant source areas can be made.

Table 20 presents ratios of median storm-event to baseflow concentrations for 21 priority parameters. These storm-to-base ratios were computed separately for each land-use type in the study. Table 20 is formatted with horizontal bars indicating the relative degree of storm-event export. A long bar and high storm-to-base ratio indicate that the associated parameter has much higher concentrations during storm events relative to baseflow. Ratios that are less than one indicate the associated parameter concentration is elevated in baseflow relative to storm events; these values are highlighted in red in the table. If a priority parameter was not detected in any baseflow or storm-event samples, no ratio is provided in Table 20 for that parameter. It should be noted that parameters not detected in storm-event samples were also not detected in baseflow samples.

As is apparent from the ratios presented in Table 20, the commercial/industrial subbasins are characterized by increased storm-event export relative to the other land-use types. This is especially noticeable for TSS, total PBDEs, total PCBs, and total lead, where median concentrations in storm events exceed median baseflow concentrations by a factor ranging from 5.9 to 20. This pattern is indicative of what is observed in basins with a high percentage of impervious cover and has been observed in several studies in the region (Cullinan et al. 2007; Herrera 2007). Contaminants originating from sources within these basins undergo minimal processing during transport due to high transport velocities and have minimal opportunity for biofiltration (National Research Council 2008).

In addition, commercial/industrial basins tend to have more impervious and contaminant-generating surfaces than other land-use types, and the contaminants on these surfaces are more readily mobilized during storm events, which contributes to the pattern observed in Table 20. These areas might also have more contaminant sources, including air emissions from the facilities.

All the land-use types generally exhibited elevated metals concentrations during storm events, with the exception of arsenic. Dissolved arsenic concentrations were elevated in baseflow for all the land-use types, while total arsenic concentrations was elevated in baseflow in only the commercial/industrial and agricultural basins. In addition, concentrations of PAHs and other organic chemicals were also elevated during storm events, particularly in commercial/industrial land-use areas.

Storm-to-base ratios of nutrients did not exhibit consistent patterns across the four land-use types. In residential and agricultural subbasins, total phosphorus concentrations were greater during storm events than during baseflow (in addition, baseflow total phosphorus concentrations were higher than from any of the other land-use types during baseflow conditions). An unexpected result was that total phosphorus was not elevated during storm events in the commercial/industrial basins. Typically, total phosphorus behaves in a similar manner to TSS, but the storm-to-base ratio for total phosphorus in this study was 0.75 for the commercial/ industrial subbasins (Table 20). An analysis of storm-event and baseflow chemistry in densely developed areas within the Green-Duwamish watershed found that total phosphorus was approximately 40 percent greater in storm-event flow than baseflow (Herrera 2007), which is not consistent with this study.

In the commercial/industrial and residential subbasins, nitrate+nitrite nitrogen concentrations were higher in baseflow relative to storm events. However, nitrate+nitrite nitrogen concentrations were on average 4.7 times greater in storm-event flow than baseflow in agricultural subbasins (Table 20), indicating that runoff from fertilized fields or dairies may be contributing to elevated nitrate+nitrite nitrogen concentrations during storm events.

In the forested subbasins, differences between storm and baseflow concentrations were generally less than those observed in commercial/industrial and residential subbasins where storm-event concentrations tend to be much higher than baseflow concentrations. This difference is likely due to the lower impervious cover in forested basins than commercial/industrial or residential basins. In the forested subbasins, storm-to-base ratios only ranged from 0.77 to 3.50 (Table 20) and most parameters were slightly elevated in storm-event flow with the exception of dissolved arsenic, dissolved copper, and total PCBs that were elevated in baseflow.

The storm-event versus baseflow concentration analysis revealed the following findings and associated implications:

Finding	Implication
Commercial/industrial basins export proportionally more contaminants during storm events compared to baseflow than other land-use types.	Mitigation strategies in commercial/industrial basins should focus on storm events.
Nearly all metals (except arsenic) and trace organic chemicals concentrations are higher during storm events compared to baseflow for all land-use types.	Toxic metals and organic chemical mitigation strategies should focus on storm events.
Arsenic concentrations are higher in baseflow than storm events for all land-use types.	Arsenic primarily originates from groundwater across all land-use types.
Total phosphorus and ortho-phosphorus concentrations are higher during baseflow than during storm events in commercial/industrial basins (though agriculture had the highest baseflow concentrations). Nitrate+nitrite nitrogen concentrations are higher during baseflow than during storm events in commercial/industrial and residential basins.	Nutrient reduction strategies should address all hydrologic conditions in commercial/industrial, residential, and agricultural subbasins.
Forested subbasins exhibited relatively small differences between baseflow and storm-event flow concentrations.	Treating stormwater alone could be proportionally less effective at reducing contaminant export from forested basins than other land-use types, although specific geographically-based sources should be addressed.

Seasonality of Contaminant Export

Contaminant flushing dynamics are controlled by many factors, from rainfall intensity and volume, to contaminant mobility, uptake and biodegradation, proximity, and mass. Numerous studies have indicated that contaminant build up during dry periods leads to elevated concentrations in the first flows following an extended period with no precipitation (Han et al. 2006; Kayhanian and Stenstrom 2005; Lee et al. 2004; Soller et al. 2005). This phenomenon, known as a seasonal first flush, has been shown to contribute to contaminant concentrations that are between 1.2 and 20 times higher than storm-event concentrations later in the season (Lee et al. 2004). Although the current study was not explicitly designed to examine seasonal first-flush dynamics, the existing dataset can be examined to determine if some contaminants were detected with a greater frequency and at greater concentrations during early-season storms.

Appendix S reports detection frequencies and median concentrations for the 21 priority parameters during each of the six storm events sampled for this study. The six storm events were classified by season with storm 1 in the fall category, storms 2 through 4 in the winter storm category, and storms 5 and 6 in the spring storm category. Elevated concentrations and/or higher detection frequencies for specific parameters during storm 1 may be evidence of a seasonal pattern. However, this was only one event in the autumn. A more thorough investigation of the first flush would include more frequent sampling of the autumn and winter storm events; specifically sampling of the earliest autumn event and the most intense autumn event may have revealed a more pronounced flushing pattern. The following is an assessment of the autumn event, for the 21 priority parameters by land-use type.

In commercial/industrial subbasins, detection frequencies and concentrations were much higher for several parameters compared with the winter and spring storm events:

- Total cadmium
- Total PCBs
- Triclopyr
- Oil and grease

The oil and grease pattern was the most dramatic with 100 percent detects and a median concentration of 0.6 mg/L during storm 1, compared to subsequent events where the detection frequency did not exceed 50 percent and the median concentration did not exceed 0.3 mg/L.

Several parameters also had higher detection frequencies and concentrations in the fall storm compared with others in the residential subbasins:

- Dissolved arsenic
- Dissolved copper
- Dissolved lead
- Total PCBs
- Total PBDEs
- Triclopyr
- Oil and grease
- Lube oil (TPH-DOG)

In the residential subbasins, the pattern was most evident for total PCBs, triclopyr, oil and grease, and lube oil (TPH-DOG). It is interesting to note that total PCBs were higher during baseflow than storm events in the residential subbasins (Table 20), but there was a seasonal pattern of total PCBs. This observation suggests that the initial wash off of PCBs may be followed by persistent contamination of the streams from groundwater or benthic sediments.

Agricultural subbasins also exhibited a seasonal pattern in the storm data for:

- Dissolved cadmium
- Total and dissolved zinc
- Total PBDEs
- bis(2-Ethylhexyl) phthalate
- Triclopyr
- Oil and grease
- Lube Oil (TPH-DOG)

In these subbasins, total and dissolved zinc, bis(2-ethylhexyl) phthalate, triclopyr, oil and grease, and lube oil (TPH-DOG) were detected at higher frequencies and higher concentrations in the fall compared to other storms. Zinc concentrations in particular were approximately three times higher in storm 1 than in any of the other events.

In forested subbasins, the fall storm had higher frequencies of detection for:

- Total and dissolved arsenic
- Total and dissolved copper
- Total lead
- Total mercury
- Total zinc
- Total PCBs
- Total PBDEs

Although fall storm concentrations were generally not as high from the forested subbasins as the developed basins, total metals and PBDEs were higher in the fall storm than other events. It should be noted that oil and grease was detected in each of the developed land uses but not from forested subbasins.

In general, the higher incidence detection in the fall storm for a number of parameters suggests that stormwater management strategies should focus on early season storms where mitigating concentrations is appropriate. However, additional monitoring should verify this pattern as indicative of a seasonal or first-flush phenomenon. If the pattern is confirmed, stormwater monitoring designs should include fall flushing events to capture a wider range of contaminant concentrations, and future studies of parameters that are rarely detected in streams should focus on collecting data during fall flushing events.

Land-Use Patterns

This study showed a number of distinct patterns in pollutant concentrations that are related to land use. For example, the results from the PCA analysis that was performed on data from the storm-event sampling showed that forested monitoring locations were distinct from the remainder of the monitoring locations because they have particularly low concentrations of the following parameters: nitrate+nitrite nitrogen, total phosphorus, total mercury, total arsenic, total copper, and TSS. This pattern in the PCA results generally indicates most of the variance in the storm-event data is related to chemical differences between developed and undeveloped land.

The PCA analysis also showed a secondary pattern in the data that related to differences between the developed land uses. Specifically, the commercial/industrial monitoring locations were distinct from the monitoring locations for residential and agricultural land uses because they had particularly high concentrations of total PCBs, total zinc, total lead, and total PBDEs.

During baseflow conditions, the differences among the land uses were less pronounced, but generally showed the same patterns as the PCA analysis that was performed on data from storm-event sampling.

These trends are generally consistent with other studies in the region that have examined differences in pollutant concentrations across different land use types (Herrera 2004).

Management Implications

This study indicated that the majority of the total potential contaminant loading to Puget Sound is derived from very low-level concentrations in forested subbasins and from somewhat higher concentrations in residential subbasins. Total loading to Puget Sound is a concern for those contaminants that bioaccumulate or cycle within receiving waters and lead to persistent degraded conditions. Effective management strategies for controlling toxic loading to Puget Sound will be difficult to implement without their broad application across the areas represented by these land uses.

Traditional best management practices (BMPs) are often designed to treat relatively high concentrations (Schueler 1996; Ahearn and Tveten 2008), and source-control measures require that the contaminants be located in a manageable area of land or water. Low-impact development can provide a high level of treatment to lower concentrations of contaminants that are dispersed over a wider geographic area (Pennington et al. 2003) but generally does not apply to a forested setting. These factors indicate that the most effective measure that can be taken to reduce this low-level, widespread loading may be source prevention (e.g., emission controls, removing copper from brake pads or zinc from tires).

It is assumed that the majority of the forested area pollutant export is derived from atmospheric deposition. Because the pollutant export is too widespread and at too low a concentration to treat, the simplest method of reducing pollutant mass export is to reduce the atmospheric inputs through source prevention measures. However, contaminant loading to Puget Sound is not the only issue of concern. Some toxic contaminants do not readily bioaccumulate (e.g., metals) and thus low-level loading of these contaminants to receiving waters may be of less concern.

However, low-level concentrations of these same contaminants may affect instream organisms, including the endangered salmonid populations of the Pacific Northwest, in route to receiving waters (Hansen et al. 2002a; Hansen et al. 2002b; West et al. 2001). From this toxicity perspective, instream concentrations also must be addressed, not only low-level loading.

This study indicated that commercial/industrial subbasins export, in many cases, an order of magnitude higher concentration of organic chemicals than other land-use types. Commercial/industrial, agricultural, and residential land uses (in that order) are also associated with the highest concentrations of metals. These high contaminant concentrations may be adversely impacting sensitive organisms in streams and other water bodies that receive direct runoff from each land-use type (see Table 12). While effects on biota were not evaluated in this study, several contaminants exceeded water quality or human health criteria. Most of the exceedances occurred in streams draining commercial/industrial land uses.

Given the relatively large concentrations being exported from these areas and the relatively small geographic areas they occupy, effective management tools are generally available to control releases of contaminants. This points to the need to incorporate retrofit treatment in existing development and low-impact development strategies in new development of previously undeveloped lands. These are widely seen as the most effective structural and non-structural BMPs (Ahearn and Tveten 2008; Bedan and Clausen 2009; Selbig et al. 2008).

Comparisons to Other Studies

Commercial/Industrial

As was previously discussed, the results from this 2009-10 study indicate that the commercial/industrial subbasins were, in general, characterized by the highest concentrations of contaminants. Contaminant concentrations were, in most cases, higher in storm events than in baseflow. Consequently, storm events from commercial/industrial subbasins were characterized by high concentrations of most of the detected contaminants (see Table 10). This finding is consistent with other studies that have shown highly developed subbasins export higher contaminant concentrations than other land-use types (Basnyat et al. 1999; Cullinan et al. 2007; Herrera 2007; Lin 2004).

Residential and Agricultural

Contrary to this general pattern, the agricultural and residential subbasins in this study tended to export higher concentrations of nutrients than commercial/industrial subbasins. The agricultural subbasins also exported higher concentrations of arsenic, copper, and mercury (Table 10). The export of metals from agricultural basins was a result that is inconsistent with some studies (Sliva and Williams 2001) but consistent with the contaminant loading study in the nearby Green Duwamish watershed (Herrera 2007).

Of the four land-use categories, residential land use exhibited the highest nitrate+nitrite nitrogen concentrations in baseflow and the highest TSS concentrations during storm events (Table 10). The former result is unexpected as agricultural, not residential, land uses are usually associated

with the highest levels of nitrogen in groundwater (Dubrovsky and Hamilton 2010), while the latter result is consistent with what has been observed across the nation (National Research Council 2008). It may be the high percentage of residences with septic tanks contributed to elevated nitrate+nitrite nitrogen concentrations in baseflow, but further study would be required to identify the source.

When compared with the other land-use categories, the agricultural subbasins exported the highest concentrations of total phosphorus in both baseflow and storm events (Table 10). Nationwide, the trend is for urban and agricultural areas to export roughly equivalent concentrations of total phosphorus (Dubrovsky and Hamilton 2010), which highlights an important pattern in the data from this study. In general, the agricultural monitoring locations in this study exported more and higher concentrations of contaminants than expected based on previous studies, while the residential monitoring locations exported fewer and lower concentrations of contaminants than expected.

For example, the agricultural subbasins in this study exported the highest concentrations of mercury and copper when compared with other land uses. This finding was not consistent with some previous studies (Sliva and Williams 2001); however, one of the two agricultural basins monitored in the *Green-Duwamish Watershed Study* (Herrera 2007) did export comparably high levels of mercury and copper. This indicates that select agricultural basins may act as important source areas for metals export.

The residential subbasins in this study exported very little petroleum products, organic chemicals, and metals relative to the commercial/industrial subbasins. This may be due to a relatively low housing density in the residential subbasins studied that do not capture potential sources in higher intensities of residential land use.

These finding have important implications for the comparisons between the Puget Sound scale load estimates from this study and the Phase 2 study (see Tables 15, 16, and 17). The Phase 2 study found that residential land-use types had the greatest influence on total contaminant loading to Puget Sound. For a number of parameters, however, the relative proportion of modeled runoff from residential land use on overall loading was reduced because concentrations for residential land use in Phase 3 were considerably lower than in Phase 2.

As an example, runoff from residential land was estimated to have a total copper median concentration of 4 µg/L in residential subbasins in the Phase 2 study based on literature compilations. However, the Phase 3 study found total copper levels averaged, 2.2 µg/L during storm events and 0.88 µg/L during baseflow (Table 10). This pattern was also found for lead, mercury, zinc, total PCBs, PAHs, bis(2-ethylhexyl) phthalate, total DDT, and oil and grease. Oil and grease was an extreme case where the concentration used in the Phase 2 loading estimates was 3,000 µg/L compared to 200 µg/L in this study, which is an order of magnitude difference. Two factors may have contributed to this decrease. First, the Phase 1 and Phase 2 concentration estimates were based on compilations of both stream and conveyance system data for residential land uses, and these concentrations varied widely across the cited studies. Second, the Phase 3 residential subbasins included relative low-intensity residential land covers. The result of these differences was that residential land use contributed proportionally much less contaminant loading in this study relative to the Phase 2 study.

Forested

Surface runoff from forested areas produced the largest load in both phases, but because the relative contribution of contaminant loading from residential subbasins decreased in this study relative to the Phase 2 study, the relative contribution from forested subbasins increased. As noted in the *Results* section, forested land use contributed the greatest total loading of the 21 priority parameters whenever they were detected in the forested subbasins. This calculation result likely has multiple explanations.

For those of the 21 priority parameters that were detected at frequencies less than 50 percent in forested subbasins (i.e., total zinc, total PBDEs, PAHs, bis(2-ethylhexyl) phthalate, triclopyr, nonylphenol, total DDT, oil and grease, and lube oil [TPH-DOG]), the associated median concentration values are considered estimates. This means there is the potential for a high degree of error associated with these values, and this error is magnified when the concentrations are converted to total loading (using flow and land-use area). Total forested land area in the Puyallup and Snohomish watersheds was calculated to be on average 141 times higher than commercial/industrial area, 7 times higher than residential land area, and 29 times higher than agricultural land area. This means, for example, that an equivalent concentration error in commercial/industrial and forested land uses became 141 times greater for forested land use after converting the concentrations to total loadings.

However, error from a low detection frequency does not explain why those frequently detected parameters were still found to be exported primarily from forested subbasins. Another possible explanation is that the forested subbasins sampled were not representative of forested land use as a whole. As noted above, the forested land-use area (83 percent of the total Puget Sound watershed) far exceeds the area of the other land-use types within the two study watersheds. Therefore, the population of candidate forested subbasins was proportionally under-sampled versus the other land-use types with fewer candidate subbasins, which increased the likelihood that the four forested subbasins were not representative of forested land use as a whole in the Snohomish and Puyallup watersheds.

Additionally, to avoid ice and snow conditions that would interfere with sampling for this study, only forested subbasins below 2,200 feet in elevation were selected. This effectively biased the monitoring location selection to low elevation subbasins. The lower elevation subbasins and associated sampling sites may have exhibited higher contaminant concentrations due to their proximity to more populated areas and a greater number of roadways. If it is the case that the high elevation subbasins export lower levels of toxic contaminants than the low elevation subbasins, then the result would be an overestimate of contaminant concentrations from forested land use as a whole. Although when calculating areal loading, lower concentrations at higher elevations would likely be offset by increased flow driven by higher precipitation rates.

Loading Comparisons to Green-Duwamish Water Study and National Studies

As an additional check on the representativeness of this dataset, the unit-area loading rate results were compared with results from the *Green-Duwamish Watershed Study* (Herrera 2007) and to literature values based on national data (Tables 21 and 22). The total unit-area loading rates for

this study were generated by summing the baseflow and storm-event loading rates for each parameter across all the land-use types. Data from other studies were not available for all of the 21 priority parameters; consequently, the parameter list was shortened for this comparison. In general, unit-area loading rates from this study were more likely to be lower than those from the *Green-Duwamish Watershed Study* or other published studies. Major differences include the following:

- Total Suspended Solids (TSS)
  - For all land-use types, TSS loading in this study was two to three times lower than TSS loading from the *Green-Duwamish Watershed Study*.
  - Compared with literature values, this study produced TSS unit-area loading that was considerably lower (8 to 17 times) for agricultural and commercial/industrial land uses, while at the same time being much higher (5 to 20 times) for forest and residential land use.
- Nitrate+Nitrite Nitrogen
  - Nitrate+nitrite nitrogen values were generally higher in this study than those from literature values and lower than those from the *Green-Duwamish Watershed Study.* The one exception was for commercial/industrial land uses where this study exhibited the lowest nitrate+nitrite nitrogen of all the datasets.
  - Compared to the *Green-Duwamish Watershed Study*, unit-area loading of nitrate+nitrite nitrogen from forested and agricultural land uses was lower in this study by factors of 4 and 3, respectively.
- Total Phosphorus
  - The unit-area loading of total phosphorus was higher than literature values but comparable to the *Green-Duwamish Watershed Study* for all land uses but commercial/industrial.
  - Total phosphorus loading for commercial/industrial was one-half the values from the *Green-Duwamish Watershed Study* and one-third the literature values.
- Metals
  - Unit-area loading of metals for commercial/industrial and residential land uses was lower in this study than in the *Green-Duwamish Watershed Study* or in the national literature by factors of 1.25 to 6.
  - Metals unit-area loading rates from this study were between 1.2 to 3.3 times higher for forested subbasins and agricultural subbasins versus the *Green-Duwamish Watershed Study* with the exception of dissolved mercury which for forested subbasins was approximately equivalent between the two studies.
  - When compared with the national literature, total copper unit-area loading from residential and agricultural land uses were lower in this study, while total zinc unit-area loading was lower for agricultural land uses and higher for forested land uses.

The comparison of metals unit-area loading between this study and the *Green-Duwamish Watershed Study* highlights the fact that toxic substances like metals were elevated for forested and agricultural land uses and low for residential and commercial/industrial land uses relative to other studies. This may partially explain why total loading from forested land uses were much higher than total loading from residential land uses. This is counter to the findings in the Phase 2 study, which relied in part on data from the *Green-Duwamish Watershed Study*.

Comparisons to Puget Sound Ocean Exchange Study and Other Regional Studies

Simultaneous with this Phase 3 study of toxic chemicals in surface runoff, Ecology conducted another Phase 3 study to characterize toxic chemicals in marine waters and from ocean exchange (Gries and Osterberg 2011). This study, hereafter referred to as the *Puget Sound Ocean Exchange Study* (PSOES), involved sample collection in five rivers at their point of discharge to Puget Sound. The Snohomish River and Puyallup River were sampled in connection with this effort in July, October, and December of 2009. During each event, depth and width integrated samples were collected during various flow conditions. These samples were analyzed for a similar suite of toxic chemicals to those analyzed for this Phase 3 study.

In addition to the PSOES study, another study of regional significance was conducted from 1996 to 1998 as part of the USGS National Water Quality Assessment. The NAWQA study (USGS 2003) consisted of targeted baseflow and storm-event sampling in the Skokomish, Nooksack, Green, and Thornton Creek watersheds. A wide variety of parameters were analyzed in this NAWQA study, and the experimental design was amenable to comparison to this Phase 3 study.

Table 22 presents the results from the two aforementioned studies along with results from the *Green-Duwamish Watershed Study* (Herrera 2004) and this study. Concentrations (as opposed to loads) are reported by land use for a subset of parameters that were analyzed in both the NAWQA study and this study. Total suspended solids were comparable among the studies with the exception that agricultural areas in this study tended to export lower concentrations relative to the other studies. A land use-based comparison cannot be made to the PSOES study, but it is of interest to note that total suspended solids at the mouth of the Puyallup River were higher than those from any of the specific land uses in the other studies. This may be unique to the glacial influence in the Puyallup River watershed (Gries and Osterberg 2011).

Land use-based nutrient concentrations were comparable between the NAWQA study and *Green-Duwamish Watershed Study*, while commercial land use had noticeably lower concentrations in this study compared to these other studies. Based on data from the PSOES study, nutrient concentrations were also lower at the mouths of the Snohomish River and Puyallup River relative to concentrations measured for the majority of the individual land uses in the other studies, an indication that nutrient uptake during riverine transport may be reducing concentrations at the river mouths. Chlorpyrifos was the only organic chemical that was analyzed in all the studies presented in Table 22. The NAWQA study indicated that Thornton Creek (a medium-density residential basin) exported the highest concentration of this parameter in comparison to the other studies. In the *Green-Duwamish Watershed Study*, Chlorpyrifos was not detected in any of the basins, but the reporting limits for organic chemicals were much higher for the *Green-Duwamish Watershed Study* relative to those for the PSOES study or this study.

There was little difference between Chlorpyrifos concentrations measured at the mouths of the Snohomish River and Puyallup River through the PSOES study and those measured in the upland tributaries through this study; however, it is difficult to draw any conclusive inferences from this comparison due to the high percentage of non-detect values (3 to 13 percent, Appendix K).

The remainder of the organic chemicals in Table 22 were not analyzed in the PSOES study so further comparisons can only be made across the other studies. These comparisons show 2,4-D concentrations were elevated in the commercial/industrial and agricultural basins for the *Green-Duwamish Watershed Study* relative to this study and the NAWQA study. Dicamba, MCPA, and triclopyr were either not detected or were not detected with adequate frequency to calculate a median value in the NAWQA study and the *Green-Duwamish Watershed Study*. Median values are reported for these chemicals in this study, but the percent detections were very low (ranging from 0 to 50 percent; Appendix K). Taken together, these results indicate that comparisons of organic chemicals across these studies are complicated by the fact that these parameters are not commonly analyzed or have highly variable detection limits depending upon the laboratory.

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Conclusions

This report summarizes results from the Phase 3 study of toxics in surface runoff in the Puget Sound basin. The objectives of this study were to (1) refine previous estimates of contaminant load contributions to Puget Sound from surface runoff by monitoring contaminant concentrations and discharge in small streams from four land-use categories (commercial/industrial, residential, agricultural, and forest) and (2) calculate the relative contributions of toxic chemicals from the four land-use types.

From August 2009 through July 2010, samples were collected during six storm conditions and two baseflow conditions from 16 streams in the Puyallup and Snohomish watersheds. Each stream received surface runoff primarily originating from one of the four land uses. Samples were analyzed for conventional water quality parameters, heavy metals, and an extensive list of organic compounds. The specific analyses performed on these data included:

- Computation of summary statistics.
- Principal component analysis.
- Computation of loading estimates at the subbasin scale.
- Computation of loading estimates at the watershed scale.
- Computation of loading estimates at the Puget Sound-basin scale.

Based on these analyses, major conclusions from this study are presented below.

- Despite some limitations on the accuracy of the compiled data, this study provided a high quality dataset for generating improved toxic chemical load estimates in surface runoff in the Puget Sound ecosystem. Unlike the previous Phase 1 and Phase 2 studies, the data from this study were obtained from actual field sampling in representative subbasins for each land use using analytical methods that provided very low detection limits. The data were also subject to a rigorous quality assurance review process to ensure they are of a known and acceptable quality.
- Whenever possible, potential sources of error in the loading estimates were quantified based on analyses of compiled quality assurance data from the study. These data generally show that uncertainty in the loading estimates that stems from flow measurement error ranges from approximately 12 to 50 percent. Potential uncertainty in the water quality data from sampling and analysis error averaged 14 percent for all parameters but PCBs and PBDEs. Errors in congeners averaged 40 and 29 percent, respectively, although 52 percent of results were very close to the reporting limit. Overall variability in the loading estimates that stems from uncertainty in the water quality data was also quantified by reporting the 25th and 75th percentile load estimates that were derived using the 25th and 75th percentile concentrations for each parameter. The error reflected in the range between these values is typically several orders of magnitude. Despite this large error, the resultant data from this study are, in the majority of cases, consistent with previous studies.
- Consistent with other regional studies (e.g., Herrera 2004, 2007), concentrations of many parameters (e.g., metals) were higher during storm events in comparison to baseflow for each of the land-use types. This pattern was especially evident in the data collected from the

commercial/industrial and residential subbasins. Dissolved arsenic was an exception and also tended to be elevated during baseflow across all the land-use types.

- Although this study was not explicitly designed to examine seasonal first-flush dynamics, results from the fall storm indicated higher detection frequencies and concentrations than in winter or spring storm events. In particular, oil and grease, TPH (lube oil), and triclopyr were detected more frequently and at higher concentrations in samples collected during the fall storm relative to subsequent storm events. This pattern was generally observed for each of these parameters in the data from all the land-use types except forests.
- This study did not specifically evaluate adverse impacts to sensitive organisms in streams and other water bodies that receive direct runoff from each land-use type. However, stormwater runoff, particularly from commercial/industrial subbasins, did not meet water quality criteria or human health criteria for several parameters. These include dissolved copper, lead, and zinc; total mercury; bis(2-ethylhexyl) phthalate; and carcinogenic PAHs. However, no numeric criteria have been developed for most parameters analyzed in this study, and the lack of exceedances does not necessarily mean that the levels are safe for aquatic life or human health.
- This study indicated that commercial/industrial subbasins export, in many cases, an order of magnitude higher concentration of organic chemicals than other land-use types. Commercial/industrial, agricultural, and residential (in that order) land uses have substantially elevated levels of metals concentrations and unit loadings as compared to forested lands.
- This study indicated that the majority of the total contaminant loading to Puget Sound is derived from very low-level concentrations in forested subbasins and from somewhat higher concentrations in residential subbasins. Total loading to Puget Sound is a concern for those contaminants that bioaccumulate or cycle within receiving waters and lead to persistent degraded conditions.
- Total contaminant load to Puget Sound is not the only scale of importance. Given that the highest contaminant concentrations and unit-area loads were found in stormwater from the most highly developed land uses, controls may be needed to address contaminant levels that could be found in small streams in the urban corridor.
- While the study was designed to minimize bias, several factors may have produced overestimates or underestimates of loads at various scales. Factors possibly leading to overestimates include instream processes and selection of forested basins close to population centers. Factors possibly leading to underestimates include land cover heterogeneity particularly for commercial/industrial, residential characterized low-density only, use of stream data to characterize lands discharging through conveyance systems, and undersampling fall storms. Other factors could produce either overestimates or underestimates, including use of grab samples, legacy contaminants, and the much smaller proportion of forested lands in the Puget Sound watershed characterized by the four forested subbasins.
- While instream data were used to estimate loads by different land uses and at different spatial scales, these data may not represent stormwater that discharges to marine waters or near marine waters. Conveyance system data may be more appropriate; however, this study did not distinguish loads in these areas.

- Approximately 139 parameters out of the 368 evaluated were not detected in any of the collected samples despite the very low detection limits that were achieved for this study. Many of these same parameters were also not detected in other regional studies (e.g., Herrera 2007) of toxics loading in surface runoff. These parameters are unlikely to be detected in any future instream monitoring given reporting limits that can be achieved with existing analytical methods.

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Recommendations

Based on these study conclusions, the following recommendations are offered:

Management Needs

- Using the data obtained from this study, management actions should be developed to target specific toxic chemicals at the appropriate scale. For example, this study indicated that the majority of the total chemical loading to Puget Sound is derived from very low-level concentrations in forested subbasins and from somewhat higher concentrations in residential subbasins. Low-level loading to Puget Sound is a concern for those toxic chemicals that bioaccumulate or cycle within receiving waters and lead to persistent degraded conditions or are known to impact marine organisms at low concentrations (Puget Sound Partnership 2006).

  To be effective, management strategies for controlling toxic chemical loadings to Puget Sound must be broadly applied across forest and other land uses. Given that it may be difficult to reduce the low concentrations in runoff from these areas using conventional stormwater treatment practices (Schueler 1996), source prevention (e.g., emission controls, removing toxics from consumer products) may be the most effective control measure for parameters where Puget Sound-scale loads are of concern.

- Targeted management actions should be identified for specific land-use types with high unit-area loading rates of toxic chemicals (e.g., commercial/industrial) to reduce their associated acute and chronic toxicity in adjacent streams and other water bodies. Given the relatively high concentrations in runoff from these areas and the relatively small geographic areas they occupy, effective treatment options are generally available for reducing the export of toxic chemicals from these areas (Barrett 2005; Davis et al. 2009; Dietz 2007; Geosyntec and Wright Water 2008). This would include retrofitting treatment systems in existing development (USGS 2010) and low-impact development techniques in new development of previously undeveloped lands (Pennington et al. 2003).

Data and Analytical Needs

- Additional monitoring of toxic chemicals in surface runoff should be performed to address data gaps that were identified through this study. This would include further characterizing any seasonal first-flush dynamics for toxic chemicals in surface runoff, toxic chemical transport on the water surface and/or within the alluvium where the well-mixed assumption may not hold, and toxic chemical transport in association with large events.
- The study relied on the use of multiple grab samples to optimize resources. However, future studies should consider in-situ equipment to quantify within-storm variations in contaminant concentration and the associated loads.
- A sample size power analysis should evaluate the extensive dataset compiled in this study and quantify sampling program needs to further reduce uncertainty for specific parameters of interest.

- Supplemental sampling could be conducted for parameters that exhibited large variability among different subbasins within a given land use. More forested basins may be necessary to adequately characterize those land-use contributions for contaminants that persist or bioaccumulate, for example.
- Given that the residential sites selected in the stratified random-study design were entirely low-density residential, future studies should consider quantifying the full spectrum of residential land-cover intensity.
- If the total load of a given parameter to Puget Sound needs more precise quantification due to potential impacts, then additional characterization of forested lands may be warranted. Sampling sites were limited to forested lands below 2,200 feet in elevation to optimize sampling logistics and to avoid complications of snowmelt. Future studies could further stratify the forested lands by elevation or other factors.
- In addition, because stream and river processes may affect the delivery of contaminant loads generated by forested or other land covers, an understanding of how these processes affect particular parameters of concern may be warranted. These processes may mitigate loads delivered to Puget Sound but could be responsible for retaining contaminants in sensitive freshwater bodies where biota and human impacts are still possible.
- The hydrologic monitoring data were not evaluated in detail, but several patterns suggest land cover influences. Understanding patterns between hydrologic responses and pollutant loads could inform future stormwater management.
- Decisions about parameters to include in future studies in the region should consider the fact that many of the parameters identified in Appendix E will likely not be found unless substantially lower analytical detection limits are employed or unless sampling occurs closer to the point of generation where dilution is minimal. Reducing the parameter list could lead to potential cost savings in future monitoring efforts without compromising scientific rigor.
- Stormwater conveyance system data currently being collected by permittees should be compiled and analyzed in a Puget Sound context. For some areas, conveyance system data may be more appropriate to characterize loads. Future load estimates should consider this dataset.

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Glossary, Acronyms, and Abbreviations

Glossary

Alluvium: A general term for all sediment deposits resulting from the operation of modern rivers. The sediments laid down in river beds and flood plains. Often specifically refers to recent stream deposits.

Anthropogenic: Human-caused.

Areal flow: Surface water discharge per unit of watershed area, in units of length per time, for example inches per day.

Baseflow: Groundwater discharge. The component of total streamflow that originates from direct groundwater discharges to a stream.

Basin: A drainage area or watershed in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Benthic: Bottom-dwelling organisms.

Bioaccumulate: Build up in the food chain.

Box model: A computer prediction tool to simulate the movement of water and pollutants within a water body.

Congener: In chemistry, congeners are related chemicals. For example, polychlorinated biphenyls (PCBs) are a group of 209 related chemicals that are called congeners.

Conventional pollutants: Non-toxic pollutants. In this study, conventionals are hardness, nutrients, total suspended solids, and field parameters.

First flush: The initial runoff during a rain event flows over the ground and often carries more pollutants with it than runoff that occurs later in the storm.

Fluvial: Relating to or happening in a river.

Grab sample: A discrete sample from a single point in the water column or sediment surface.

Groundwater: Water in the subsurface that saturates the rocks and sediment in which it occurs. The upper surface of groundwater saturation is commonly termed the water table.

Hydrologic: Water in the atmosphere, on the surface of the earth and underground. Includes processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration.

Loading: The input of pollutants into a water body.

Marine water (seawater): Salt water.

Metals: Elements, such as cadmium, chromium, cobalt, copper, lead mercury, nickel, and zinc, which are of environmental concern because they do not degrade over time. Although many are necessary nutrients, they are sometimes magnified in the food chain, and they can be toxic to life in high enough concentrations. They are also referred to as heavy metals.

Noisy data: Poor quality hydrologic data (i.e., data spikes).

Nonpoint source: Unconfined and diffuse sources of contamination. Pollution that enters water from dispersed land-based or water-based activities. This includes, but is not limited to, atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System program.

Organics: Natural or synthetic compounds that contain carbon and hydrogen bonds. A few examples of organics in this study include oil and grease, PCBs, and PBDEs.

Parameter: An analyte or grouping of analytes.

Puget Sound: In this study, Puget Sound includes all of Puget Sound, Hood Canal, and the Straits of Georgia and Juan de Fuca within Washington State.

Puget Sound Box Model: A computerized tool for predicting contaminant movement within the Puget Sound ecosystem.

Sill: A relatively shallow area of the seabed.

Storm event: A distinct period of rainfall defined by a minimum precipitation depth (0.25 inches in 24 hours in this study) and a minimum antecedent dry period (12 hours with less than 0.01 inches of precipitation in this study).

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, and playfields, and from gravel roads and parking lots.

Surface runoff: In this study, surface runoff is broadly defined to include stormwater, nonpoint source overland flow, and groundwater discharge to surface waters that flow to Puget Sound.

Thalweg: The primary flow path and the deepest part of the stream channel.

Total suspended solids (TSS): The suspended particulate matter in a water sample as retained by a filter.

Unit area: A defined area (e.g., square kilometers).

Water column: A conceptual tube of water extending vertically from the top of the sediment layer to the surface of the water.

Water quality: The chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

BMP	Best management practice
BNA	Base/neutral/acid extractable compound
$CaCO_3$	Calcium carbonate
DDT	Dichlorodiphenyltrichloroethane
DOG	Dissolved oil and grease
Ecology	Washington State Department of Ecology
E&E	Ecology and Environment, Inc.
e.g.	For example
EPA	U.S. Environmental Protection Agency
et al.	and others
GC/ECD	Gas chromatography/electron capture detector
GC/MS	Gas chromatography/mass spectrometry
GIS	Geographic Information System software
Herrera	Herrera Environmental Consultants, Inc.
HPAH	High molecular weight polycyclic aromatic hydrocarbons
HRGC/HRMS	High resolution gas chromatography/high resolution mass spectrometry
i.e.	In other words
LPAH	Low molecular weight polycyclic aromatic hydrocarbons
MCPA	2-methyl-4-chlorophenoxyacetic acid
MEL	Manchester Environmental Laboratory
MQO	Measurement Quality Objective
MRL	Method reporting limit
n	Number
NAWQA	National Water Quality Assessment
PAH	Polycyclic aromatic hydrocarbon
PBDE	Polybrominated diphenyl ethers
PCA	Principal component analysis
PCB	Polychlorinated biphenyl
PSOES	Puget Sound Ocean Exchange Study
QA	Quality assurance

QAPP	Quality Assurance Project Plan
QC	Quality control
RPD	Relative percent difference
SM	Standard method
TP	Total phosphorus
TPH	Total petroleum hydrocarbon
TPH-DOG	Total petroleum hydrocarbons, extract of oil and grease (lube oil)
TSS	Total suspended solids
USGS	U.S. Geological Survey
WRIA	Water Resource Inventory Area

Units of Measurement

cfs	cubic feet per second
$g/km^2/yr$	grams per square kilometer per year
$kg/ km^2/yr$	kilograms per square kilometer per year
$mg/km^2/yr$	milligrams per square kilometer per year
g/km	grams per kilometer
g/yr	grams per year
kg/yr	kilograms per year
MT/yr	metric tons per year
mg/L	milligrams per liter (parts per million)
ng/L	nanograms per liter (parts per trillion)
pg/L	picograms per liter (parts per quadrillion)
µg/L	micrograms per liter (parts per billion)

Figures

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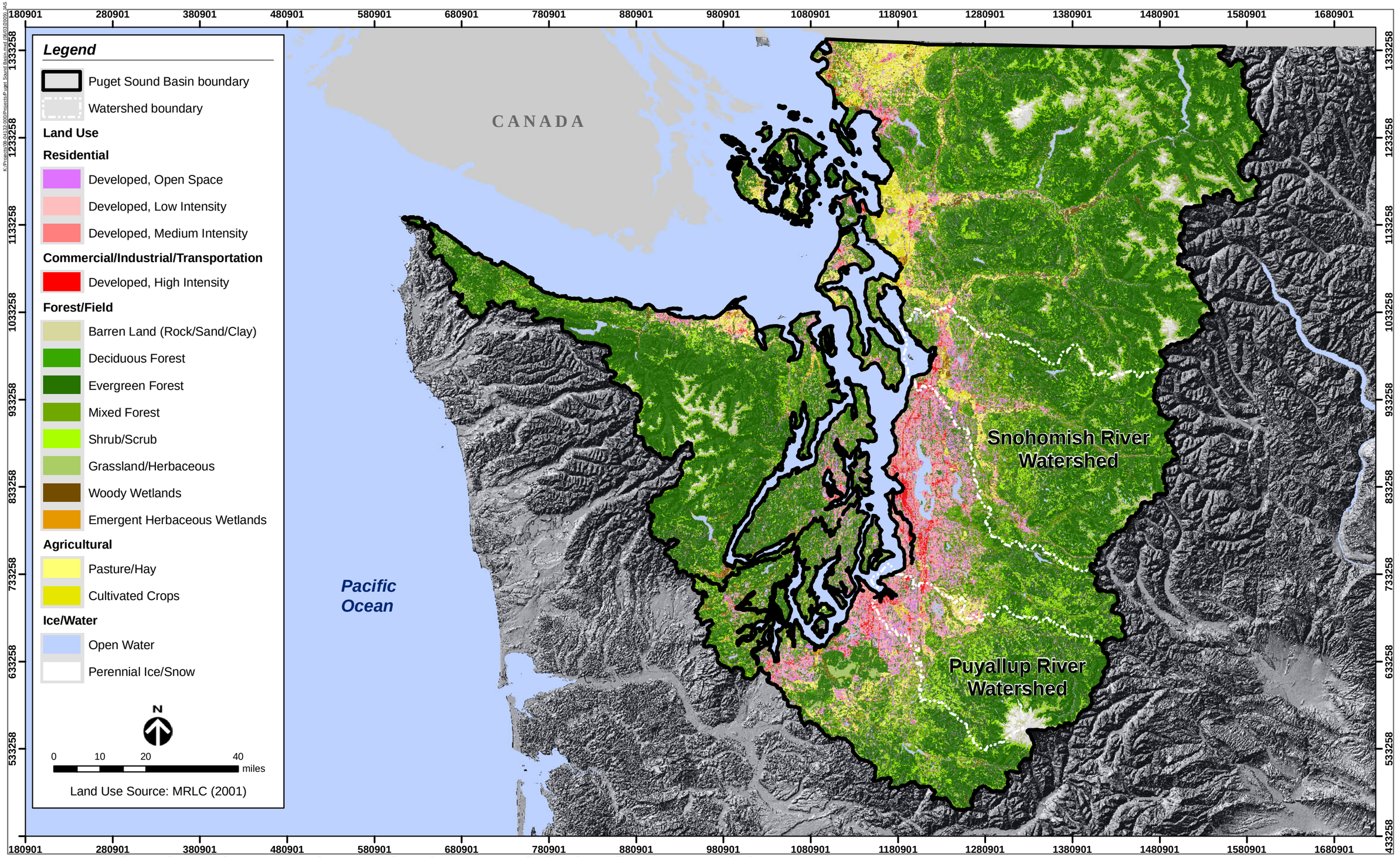

Figure 1. Regional map showing the Puget Sound Basin, Snohomish River Watershed, and Puyallup River Watershed.

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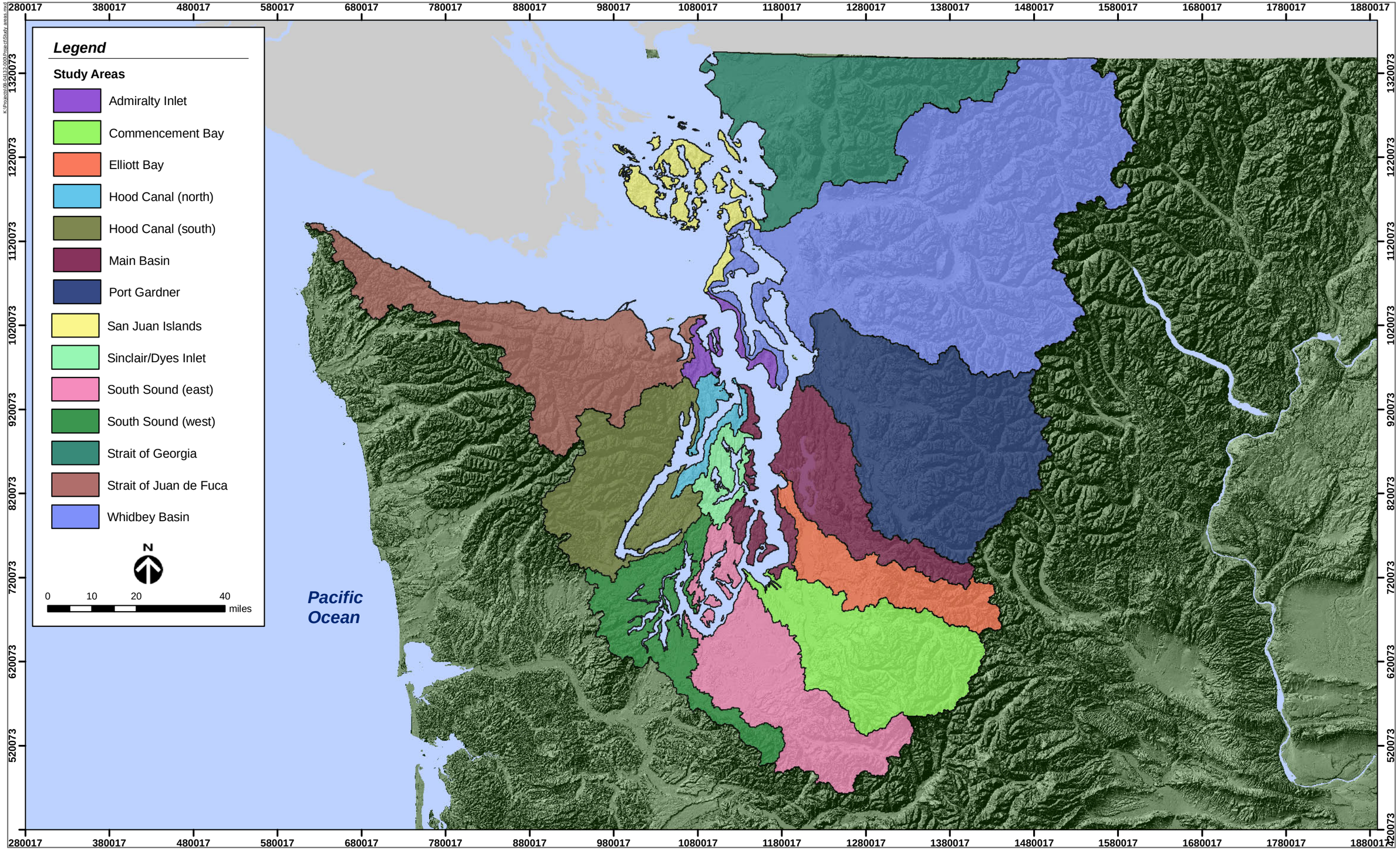

Figure 2. Fourteen study areas that provide input to the Puget Sound Box Model.

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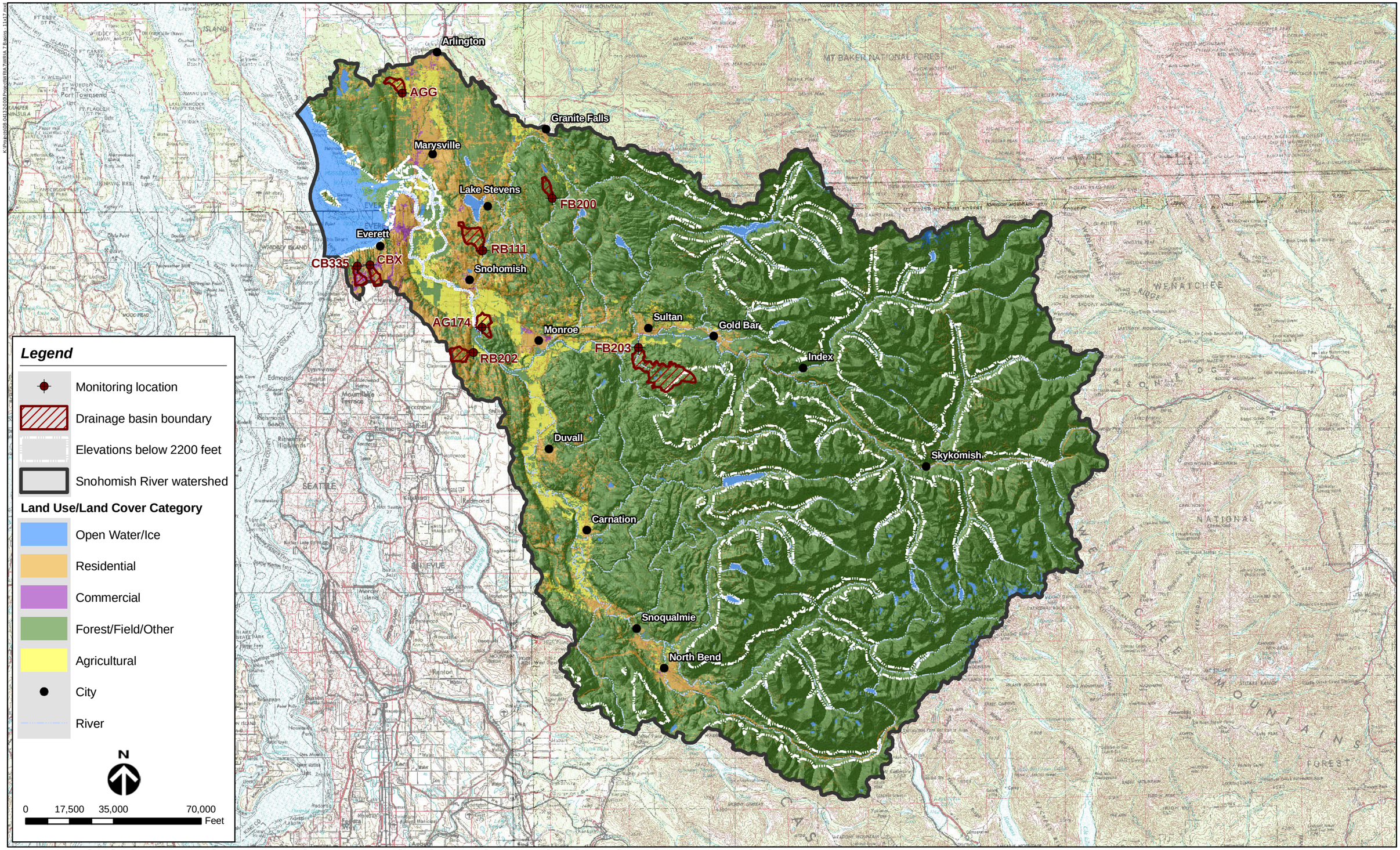

Figure 3. Individual monitoring locations and their corresponding drainage basins within the Snohomish River Watershed.

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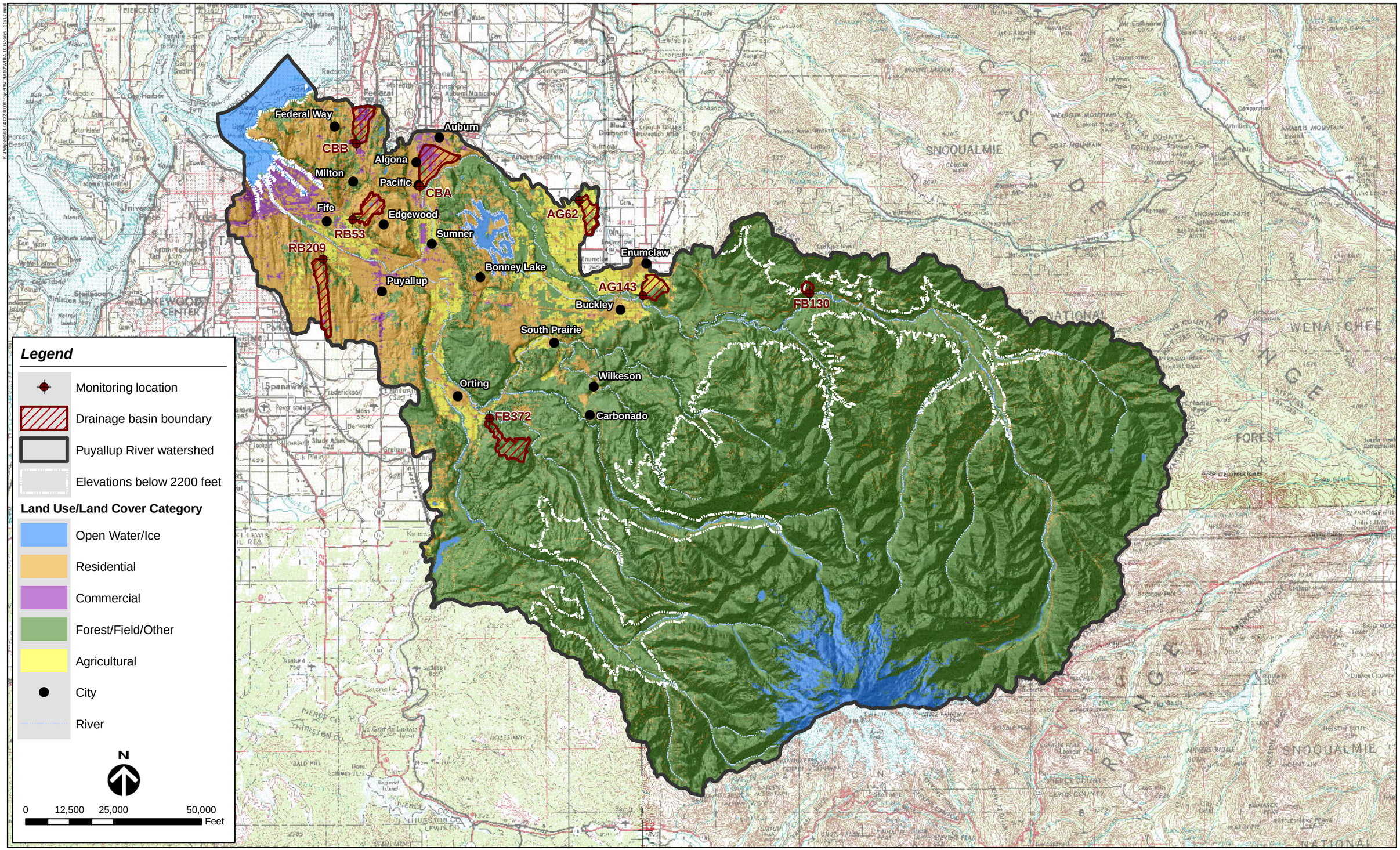

Figure 4. Individual monitoring locations and their corresponding drainage basins within the Puyallup River Watershed.

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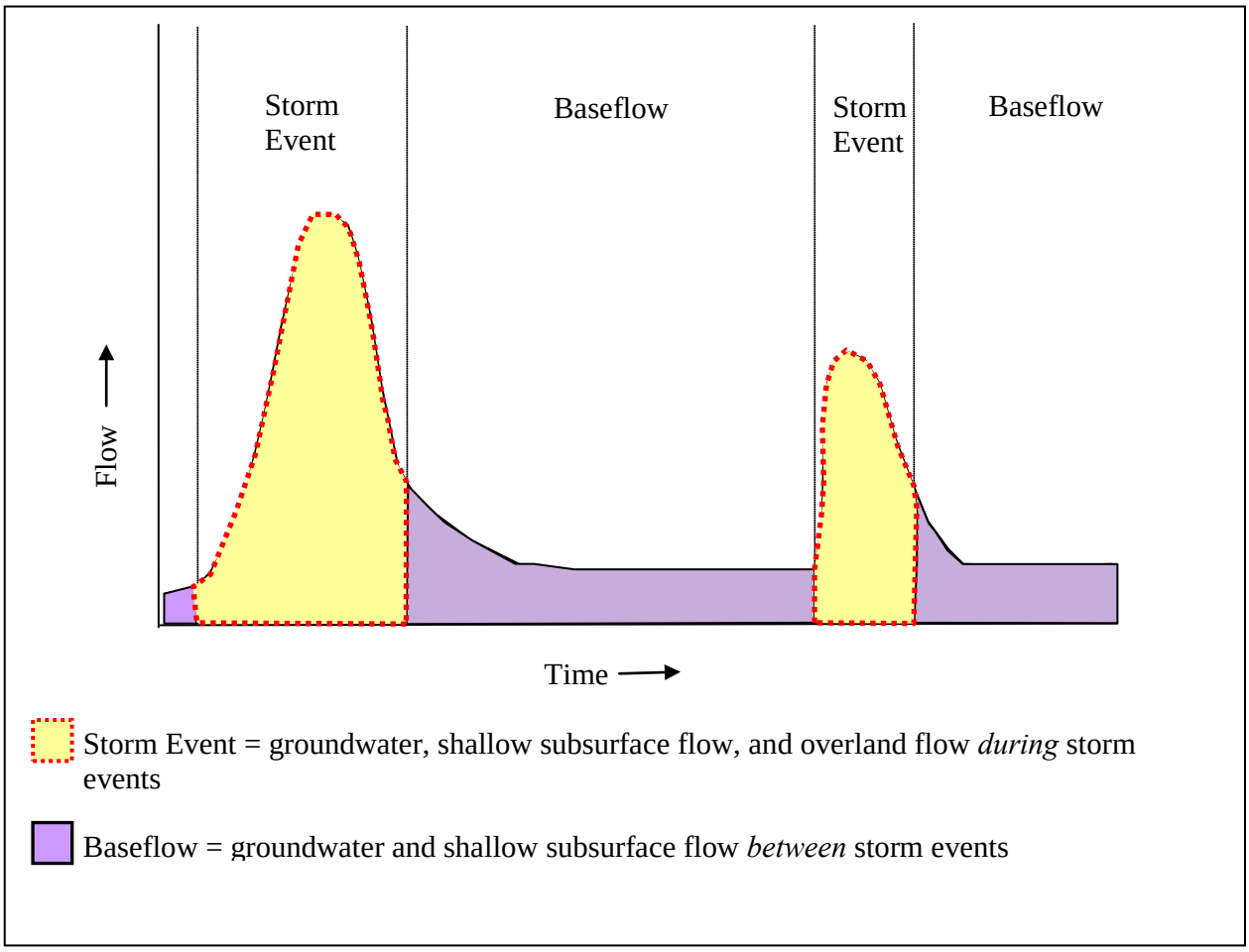

Figure 5. Hydrograph components delineated for computing loading estimates.

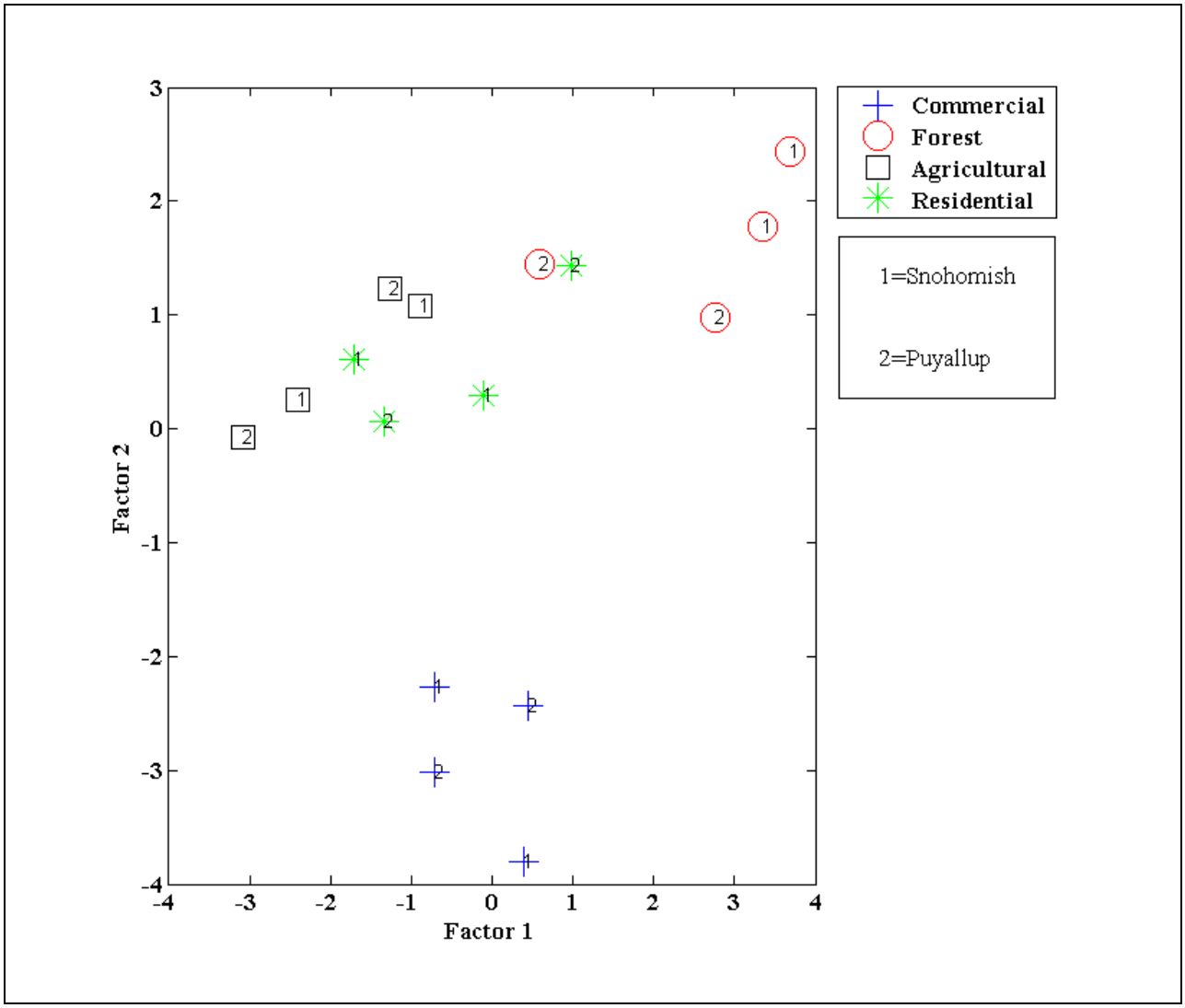

Figure 6. Results of the principal component analysis on data from storm-event sampling: mapping of monitoring locations (based on median concentrations) in the principal component space.

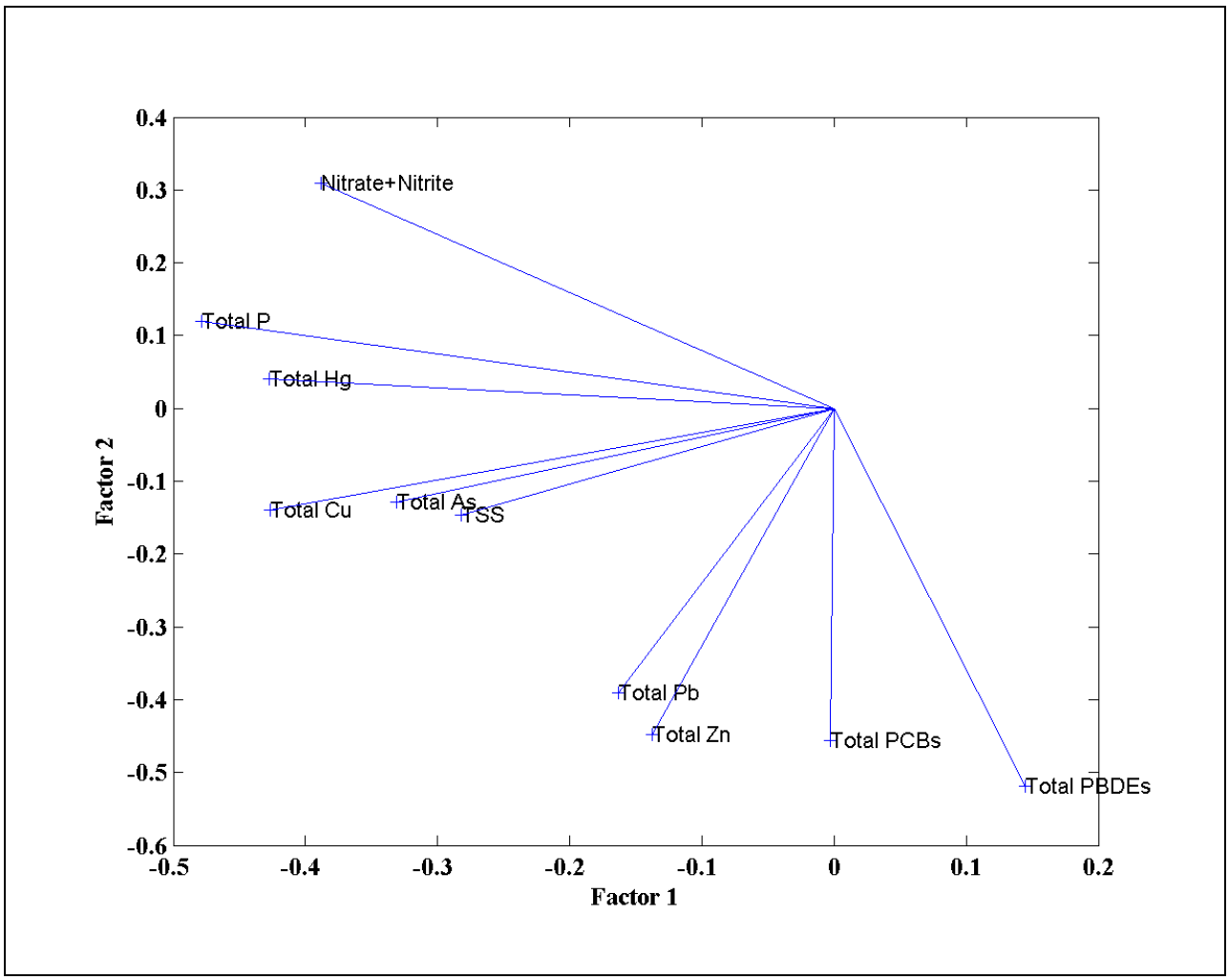

Figure 7. Results of the principal component analysis on data from storm-event sampling: mapping of monitoring parameters in the principal component space.

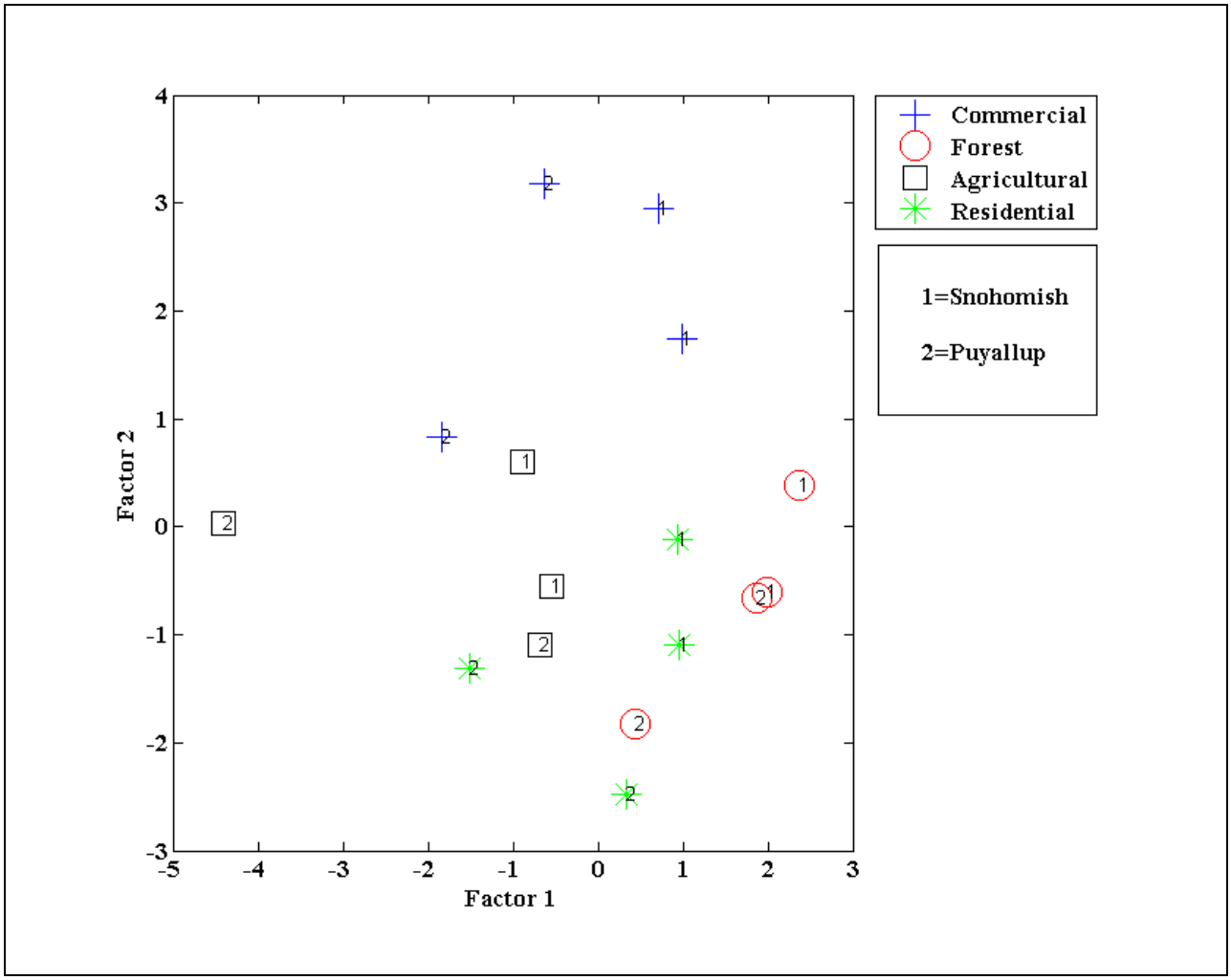

Figure 8. Results of the principal component analysis on data from baseflow sampling: mapping of monitoring locations (based on median concentrations) in the principal component space.

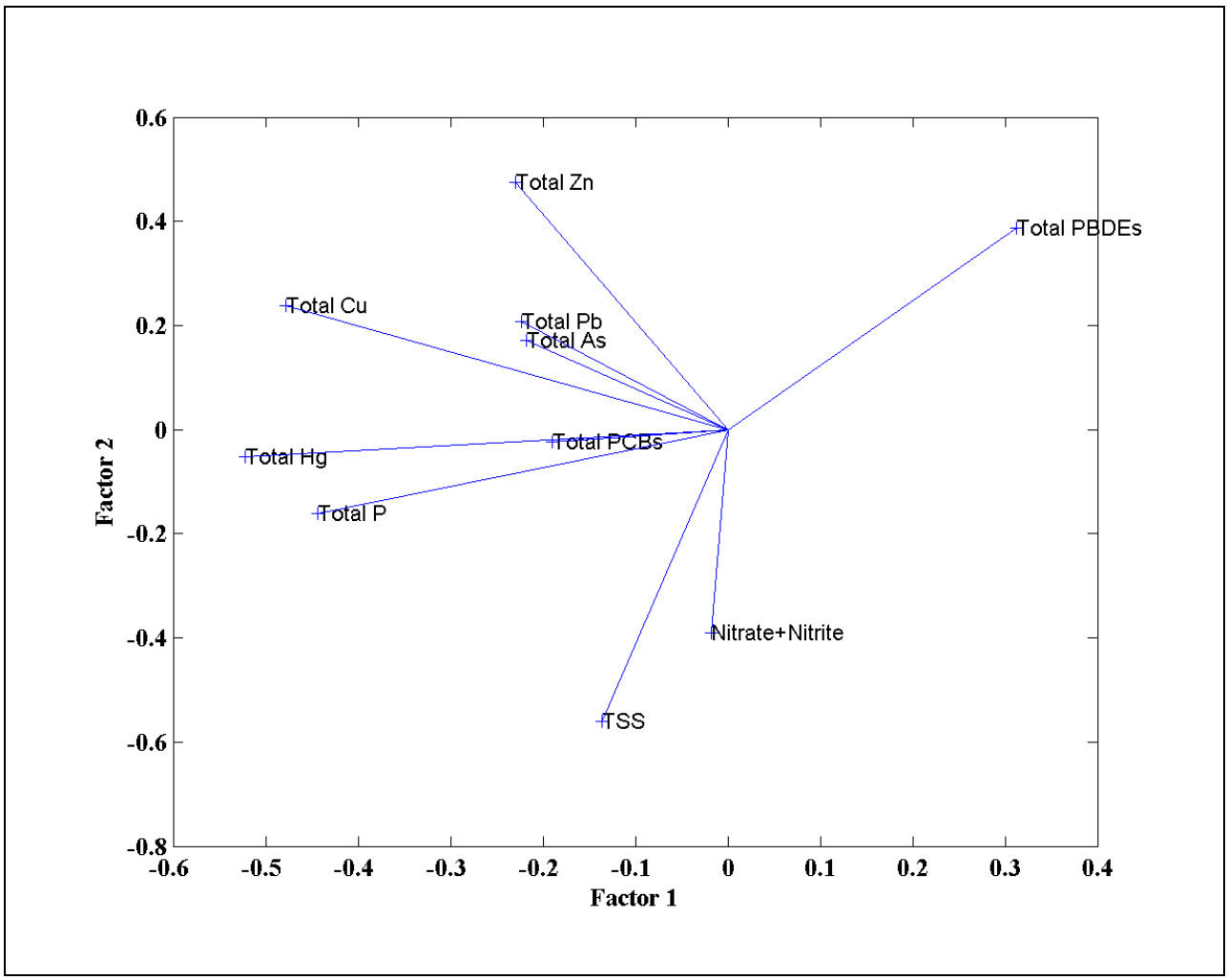

Figure 9. Results of the principal component analysis on data from baseflow sampling: mapping of monitoring parameters in the principal component space.

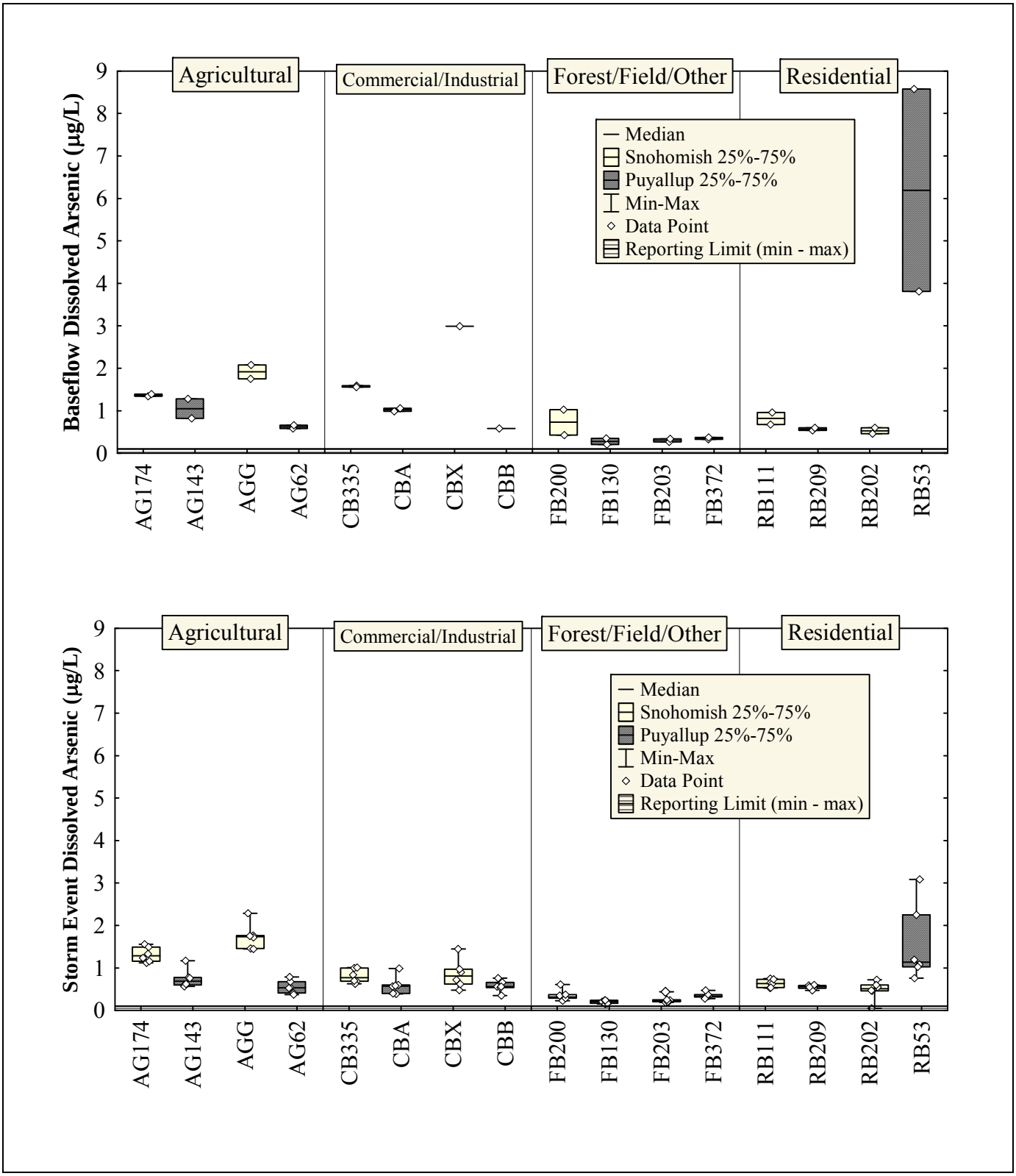

Figure 10. Baseflow and storm-event dissolved arsenic concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

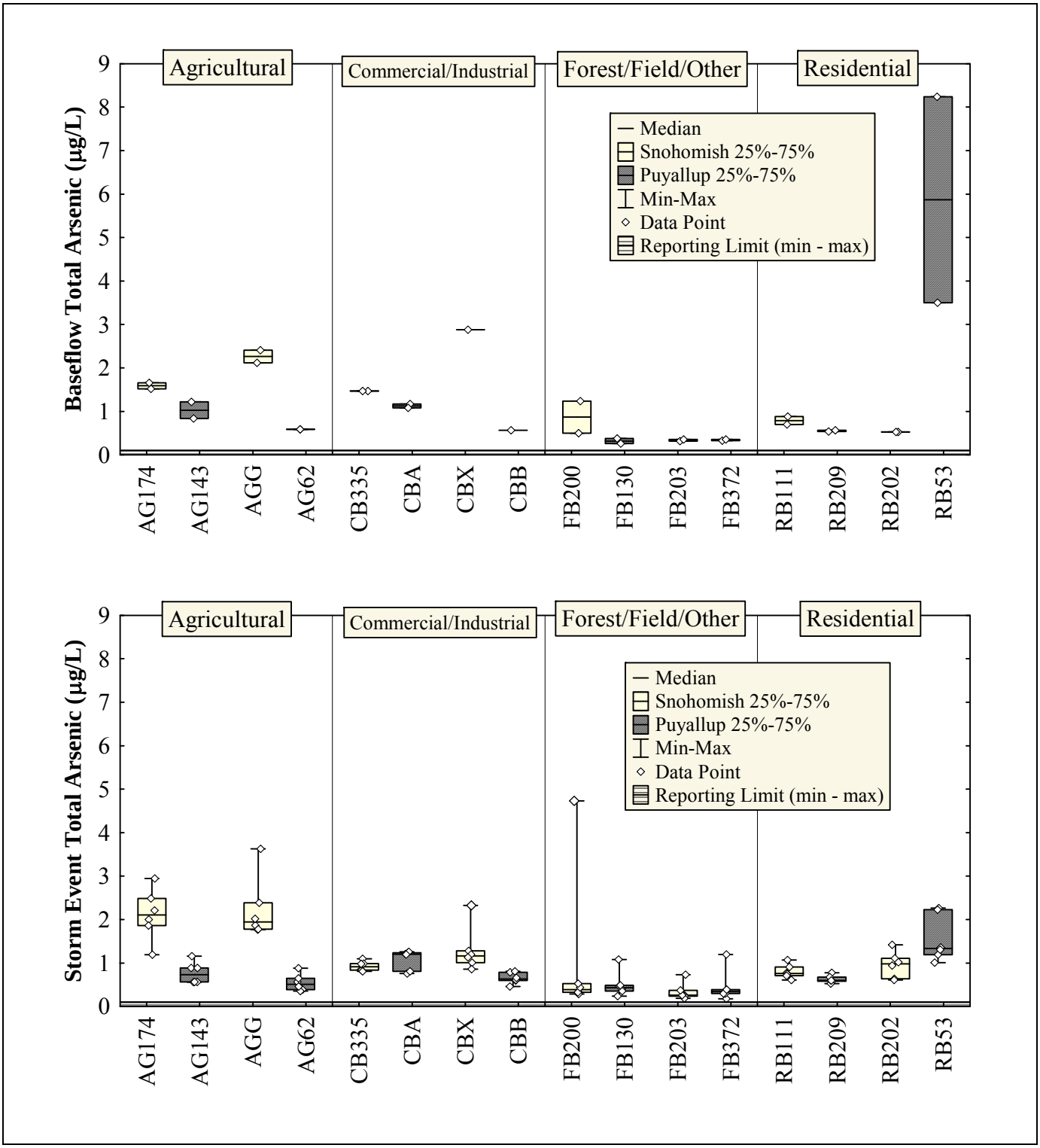

Figure 11. Baseflow and storm-event total arsenic concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

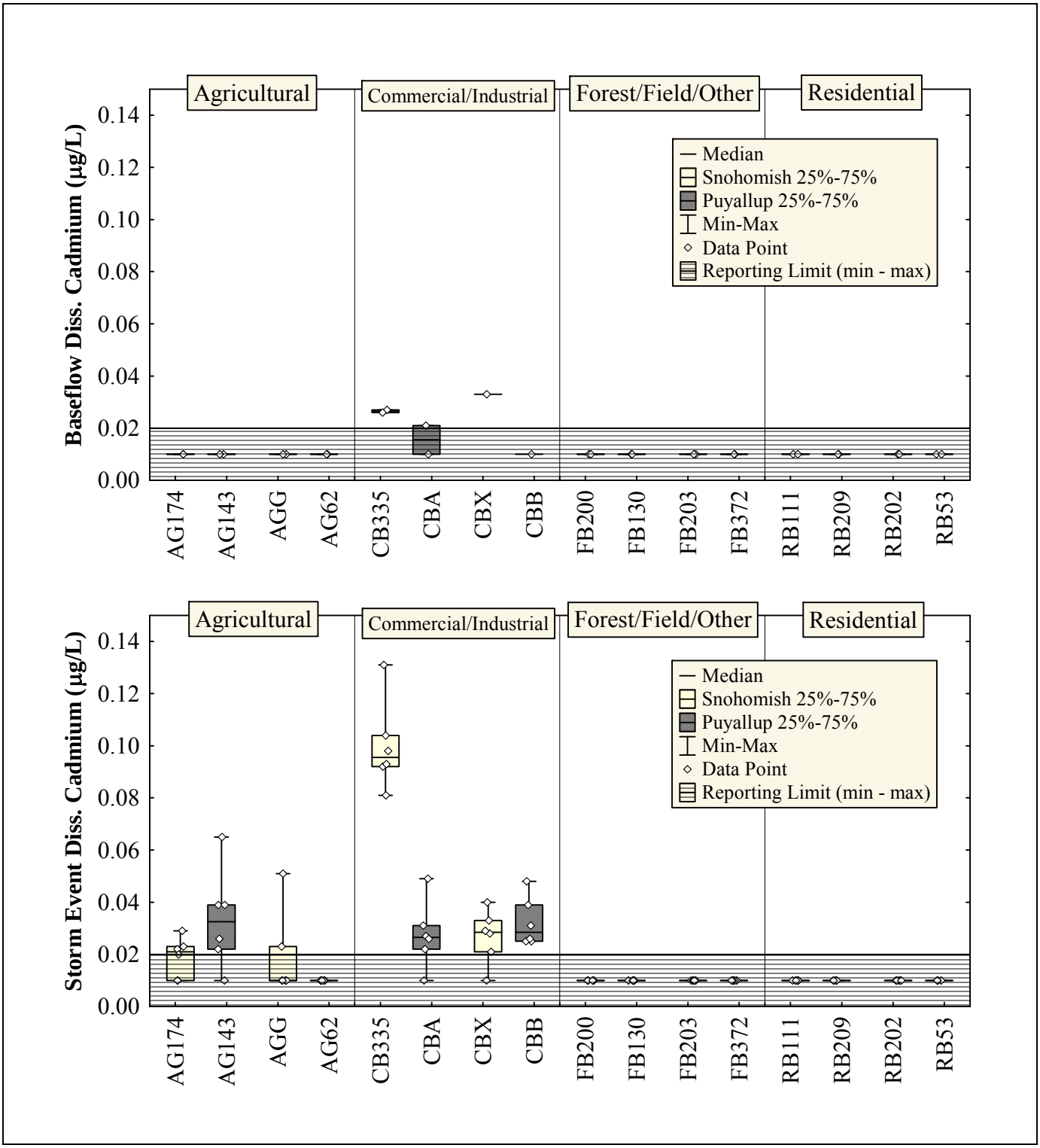

Figure 12. Baseflow and storm-event dissolved cadmium concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

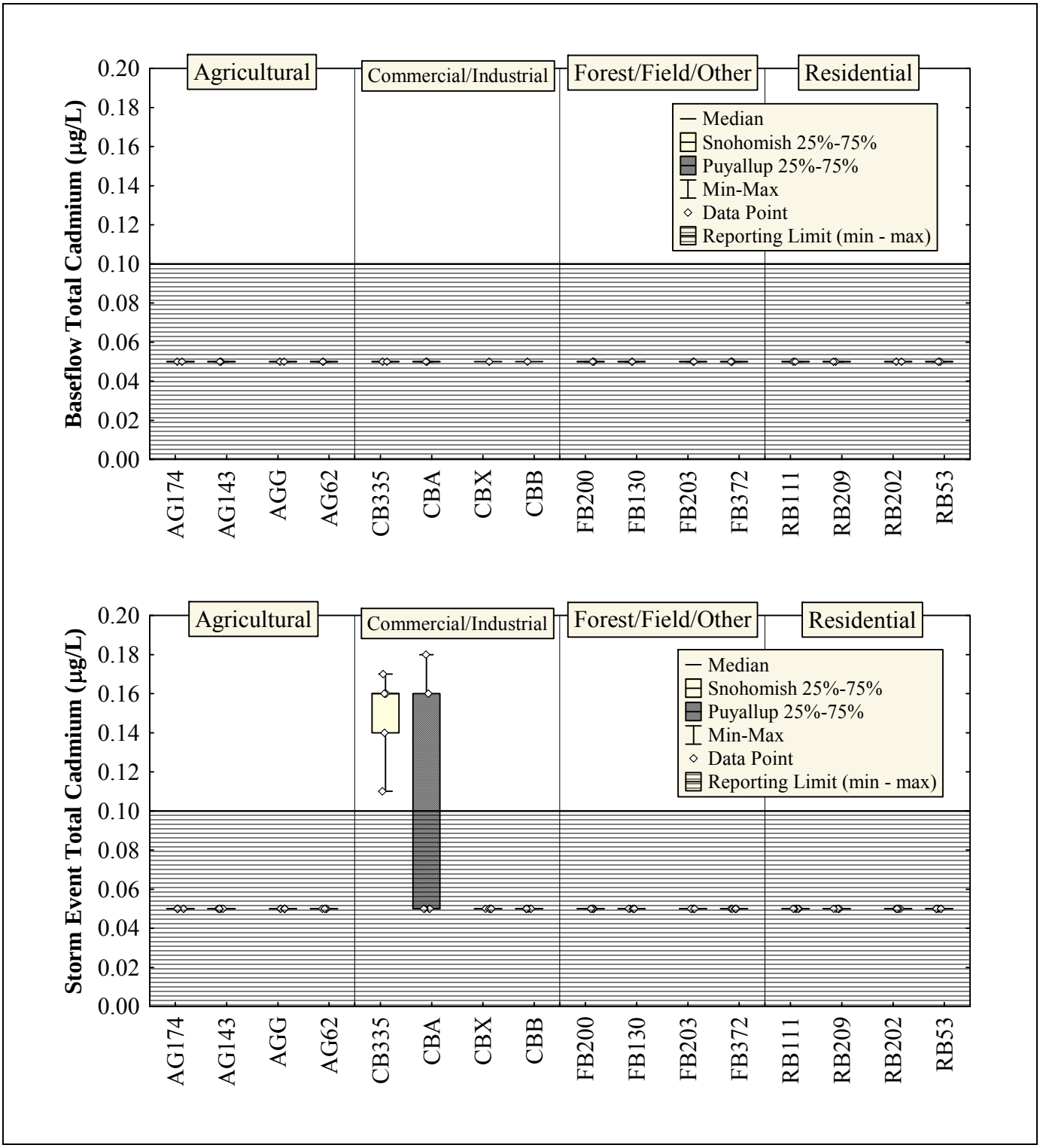

Figure 13. Baseflow and storm-event total cadmium concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

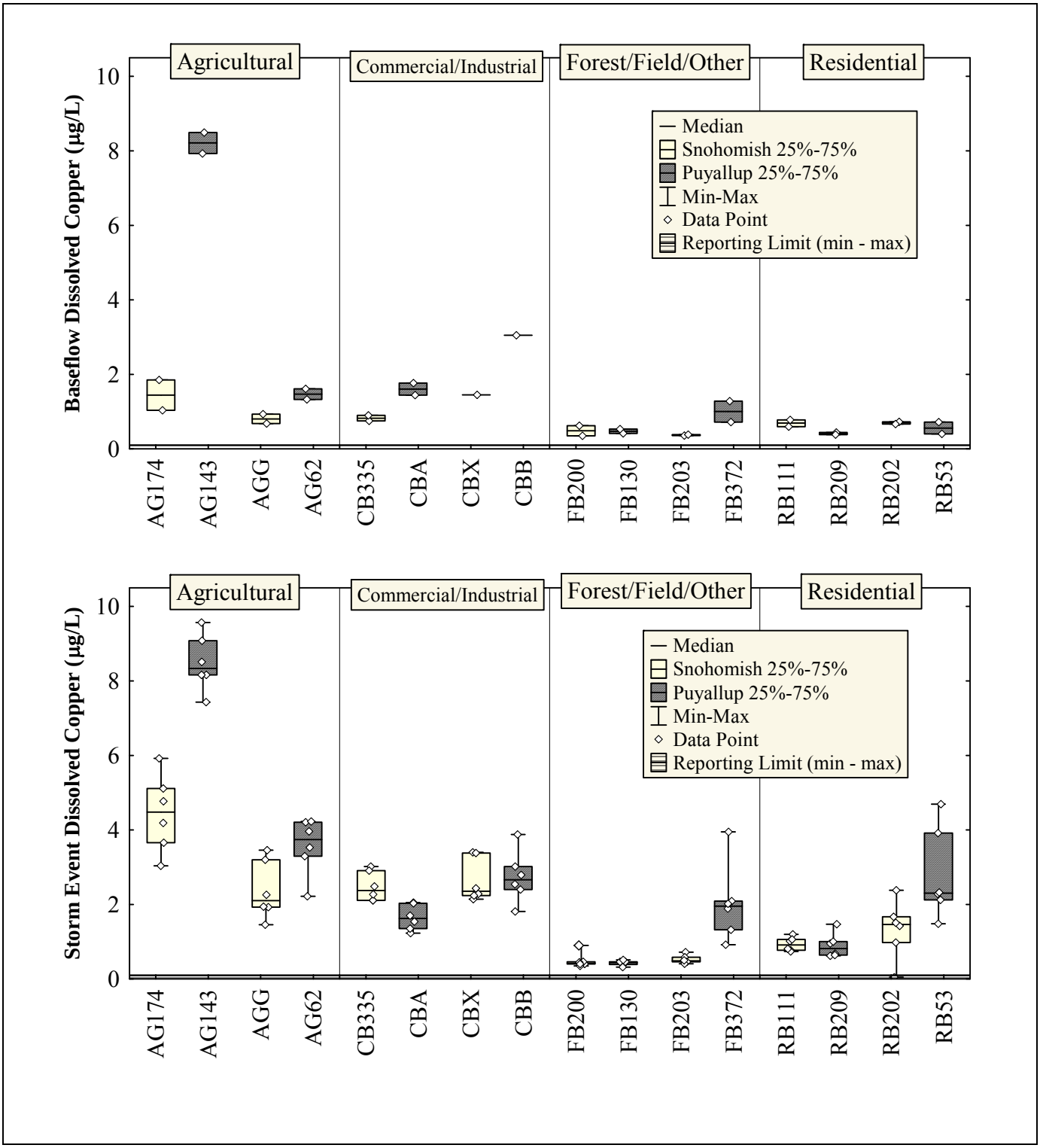

Figure 14. Baseflow and storm-event dissolved copper concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

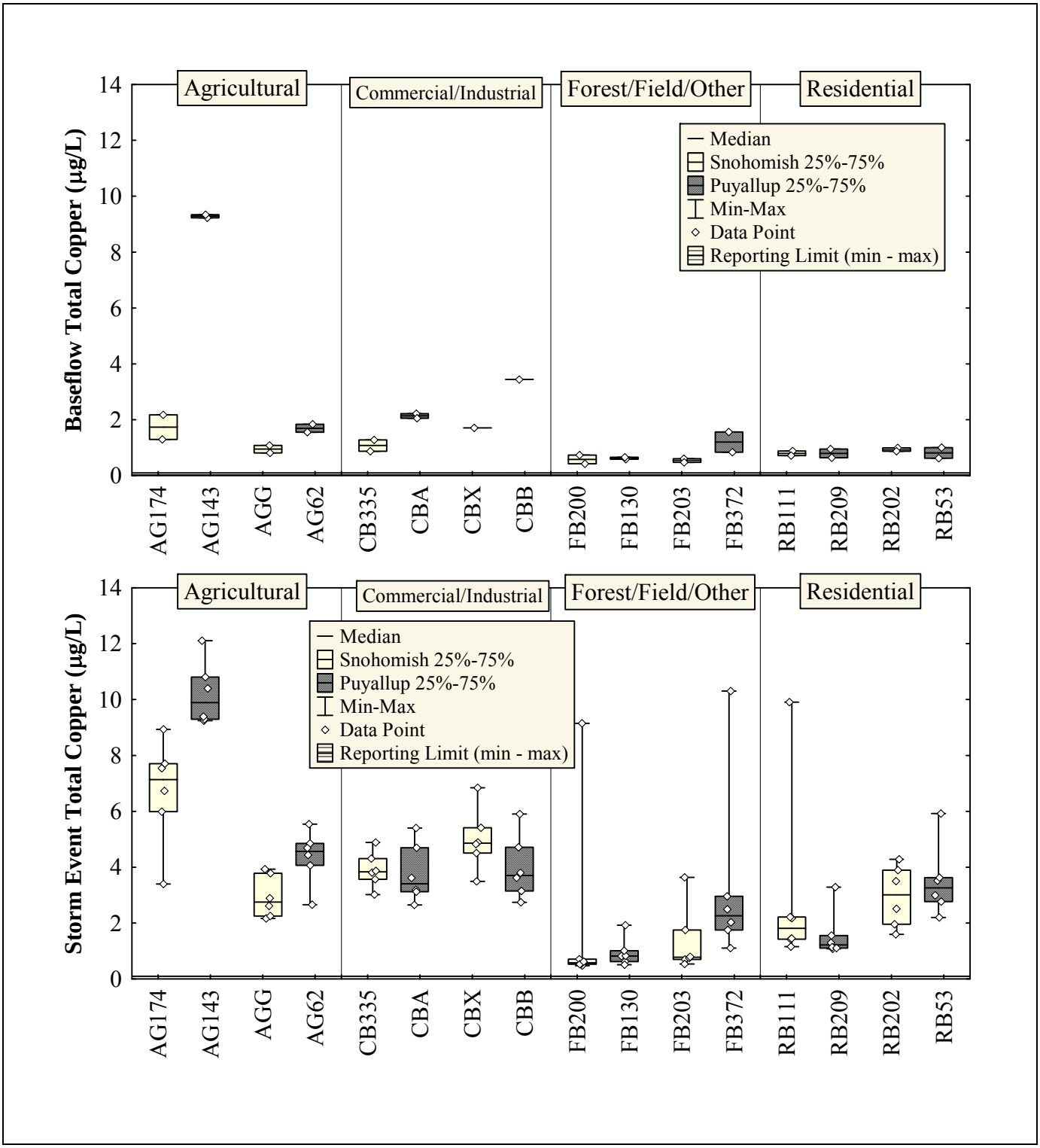

Figure 15. Baseflow and storm-event total copper concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

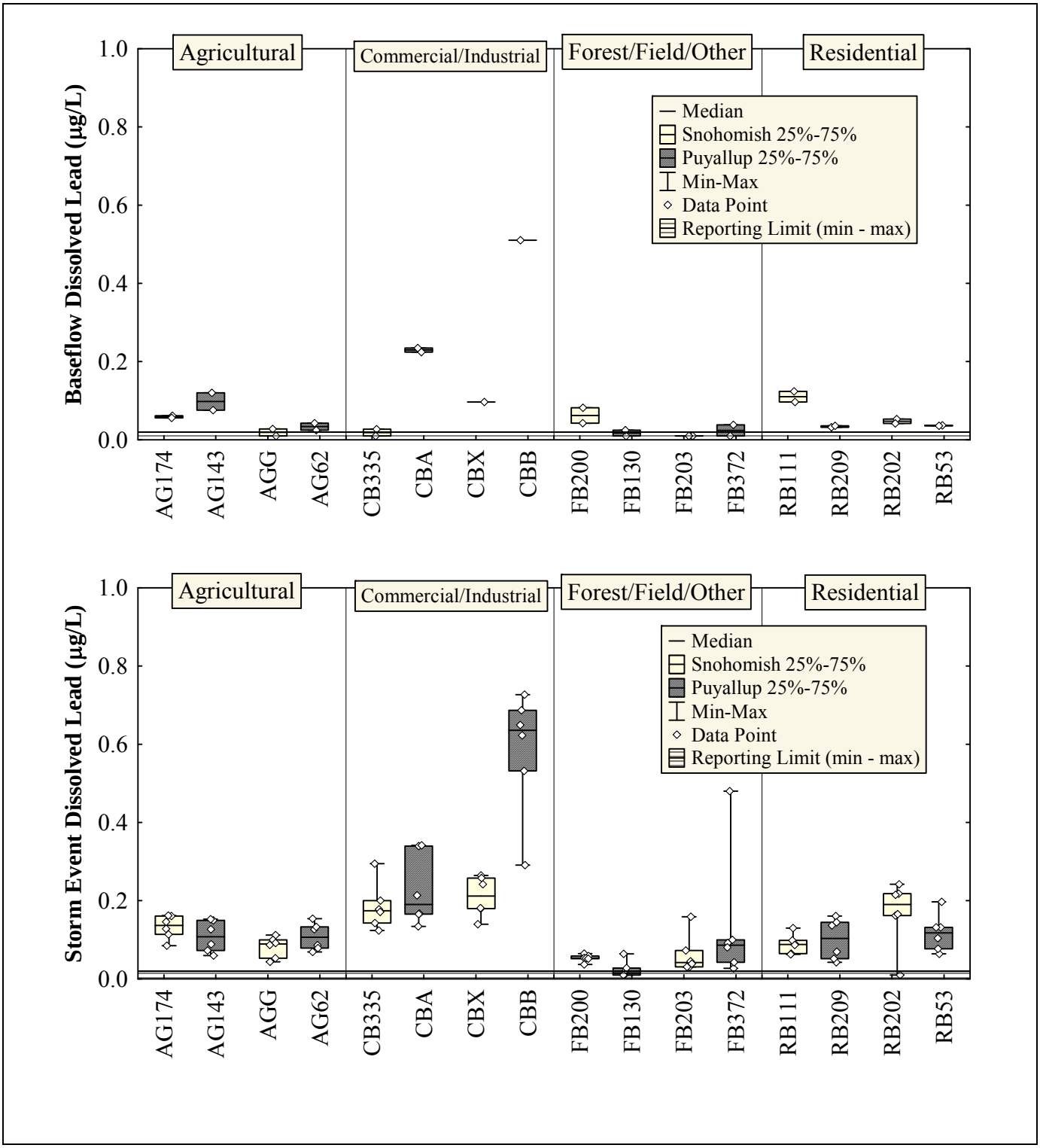

Figure 16. Baseflow and storm-event dissolved lead concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

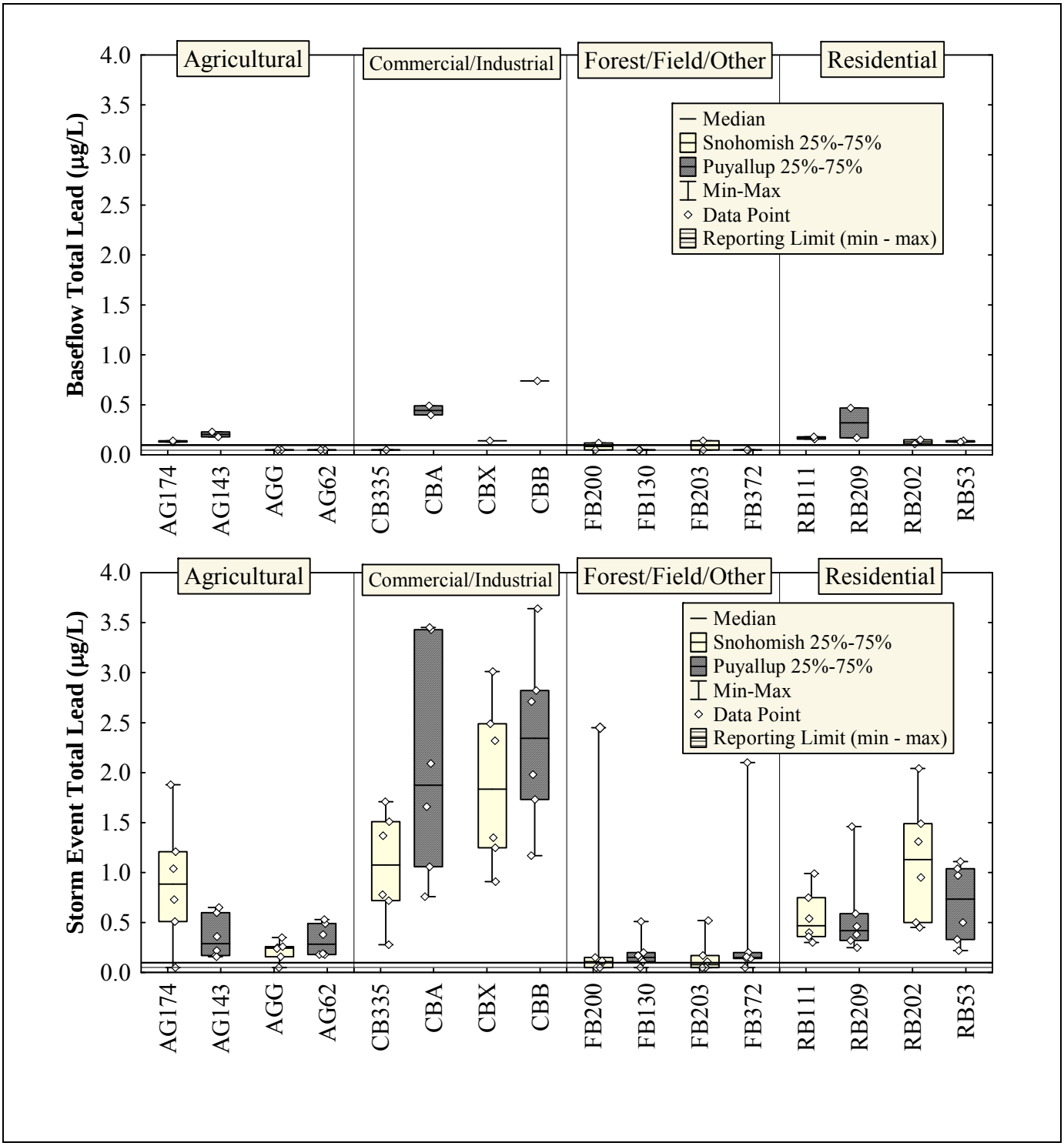

Figure 17. Baseflow and storm-event total lead concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

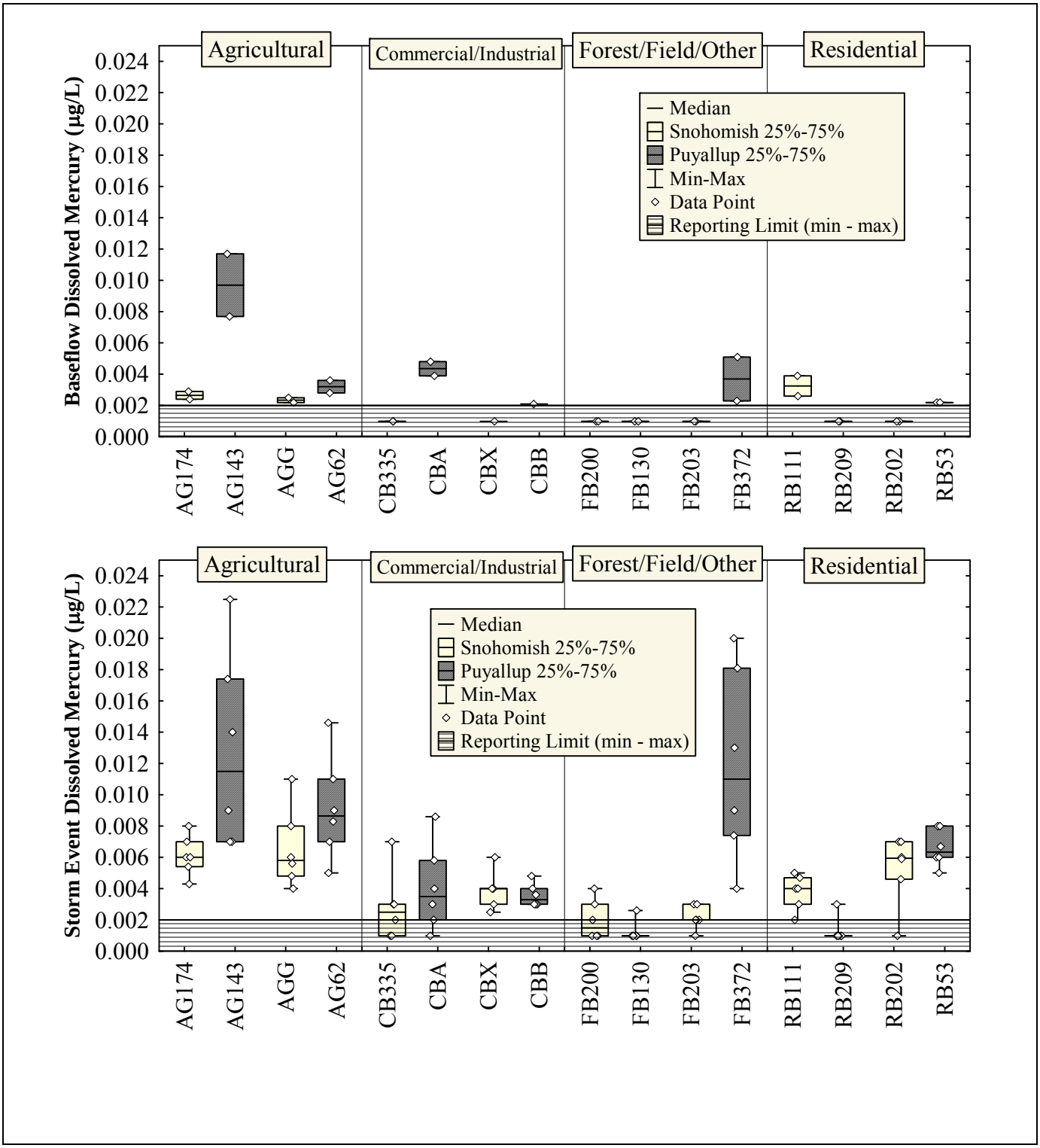

Figure 18. Baseflow and storm-event dissolved mercury concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

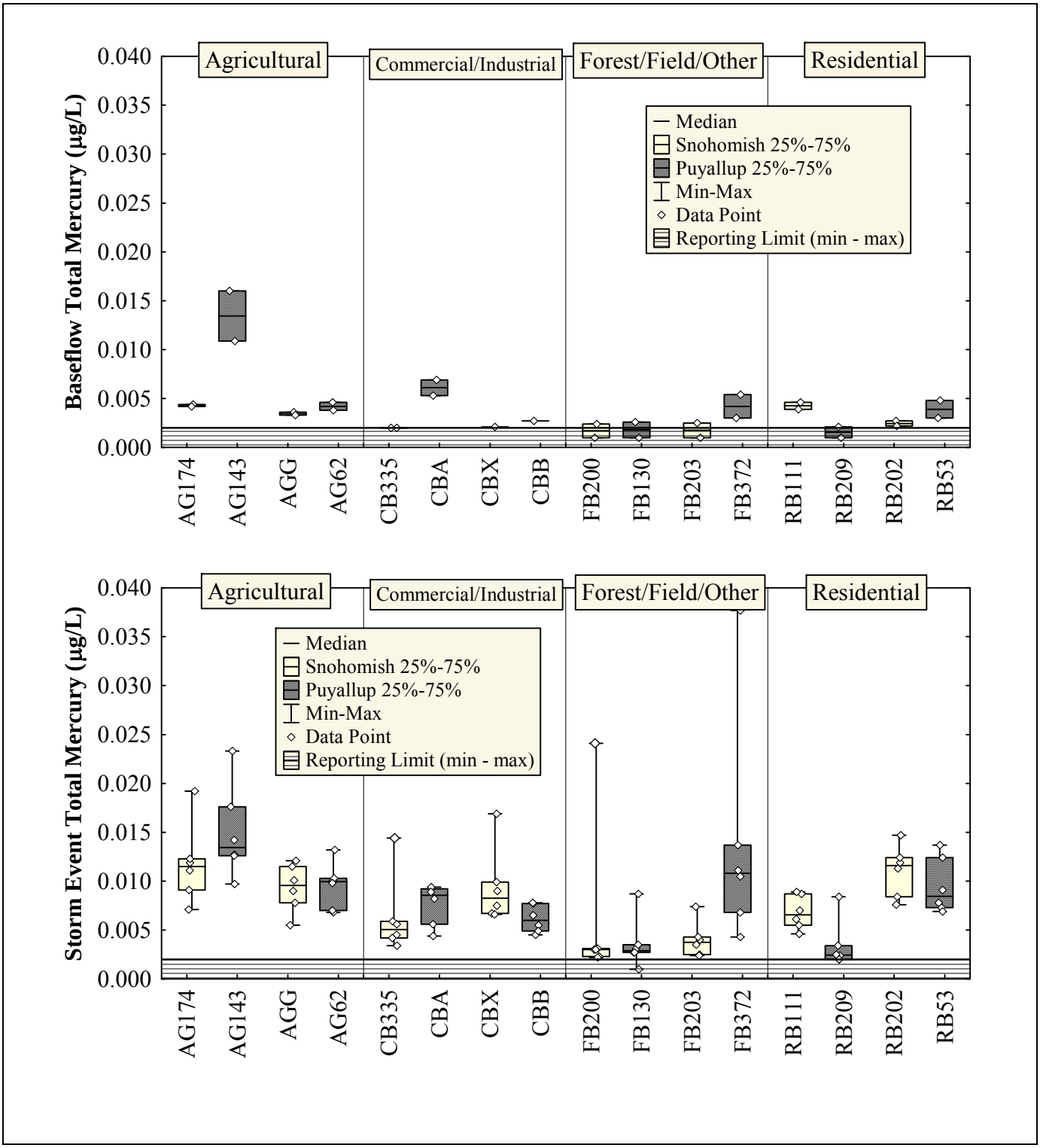

Figure 19. Baseflow and storm-event total mercury concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

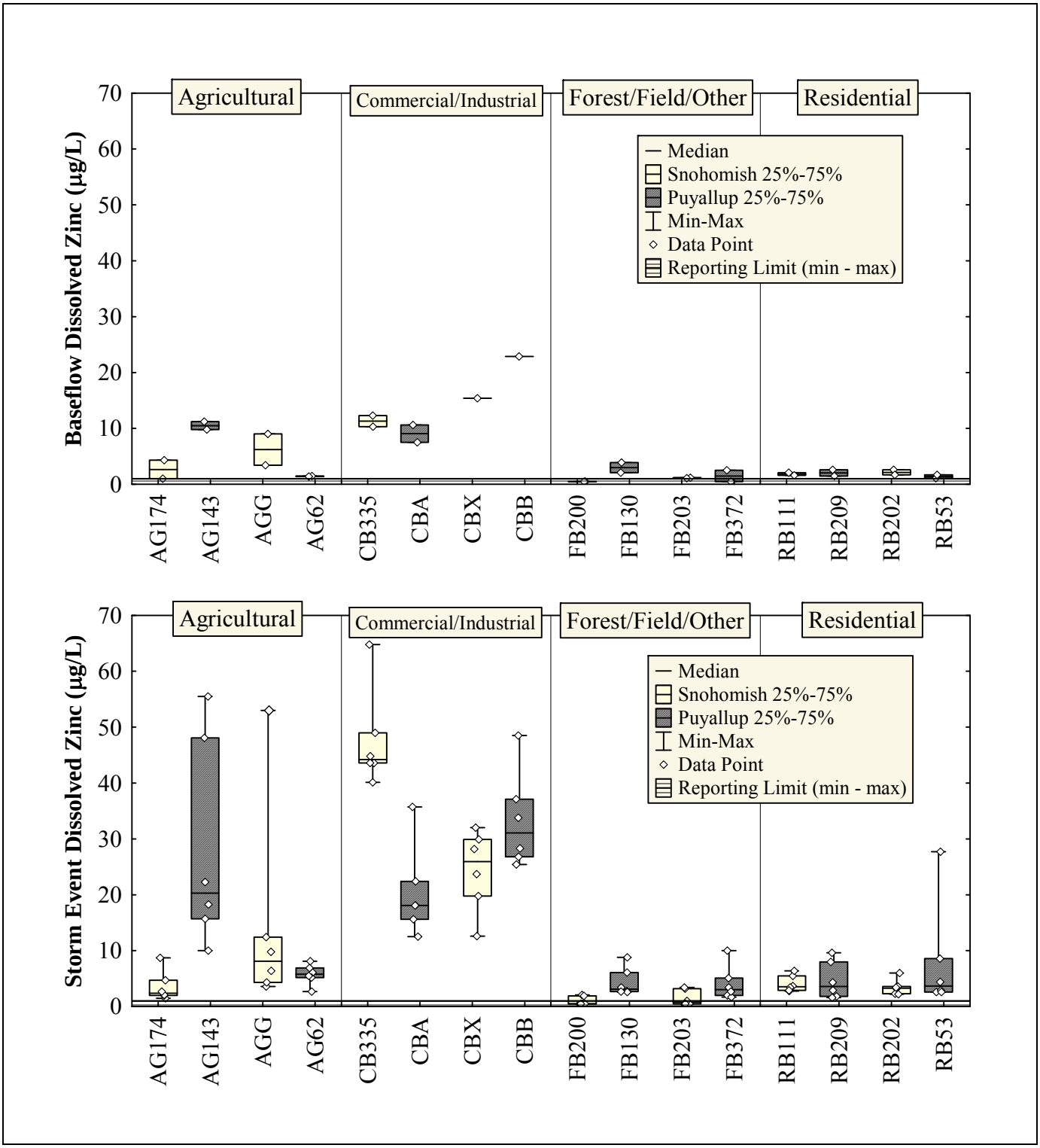

Figure 20. Baseflow and storm-event dissolved zinc concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

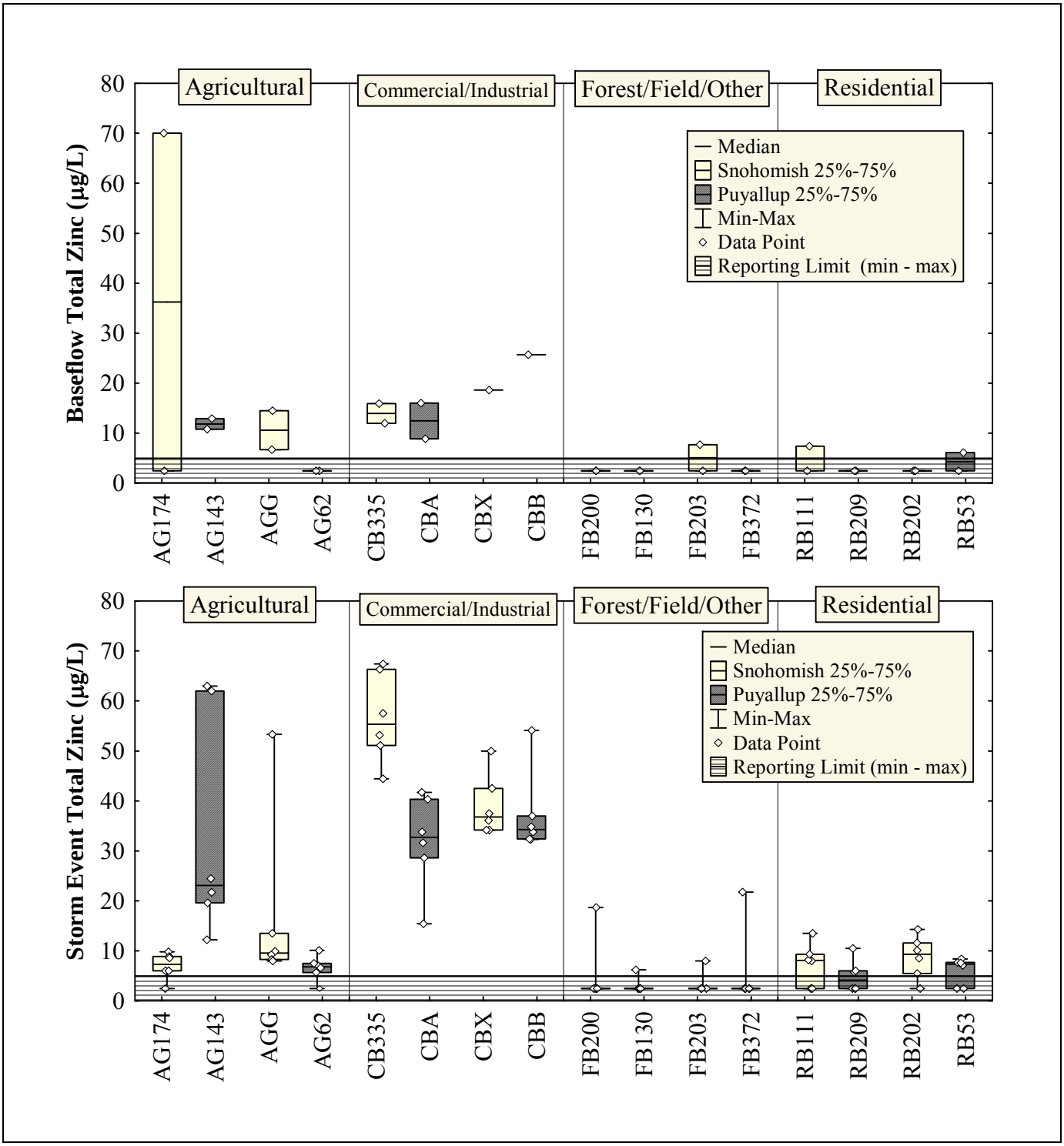

Figure 21. Baseflow and storm-event total zinc concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

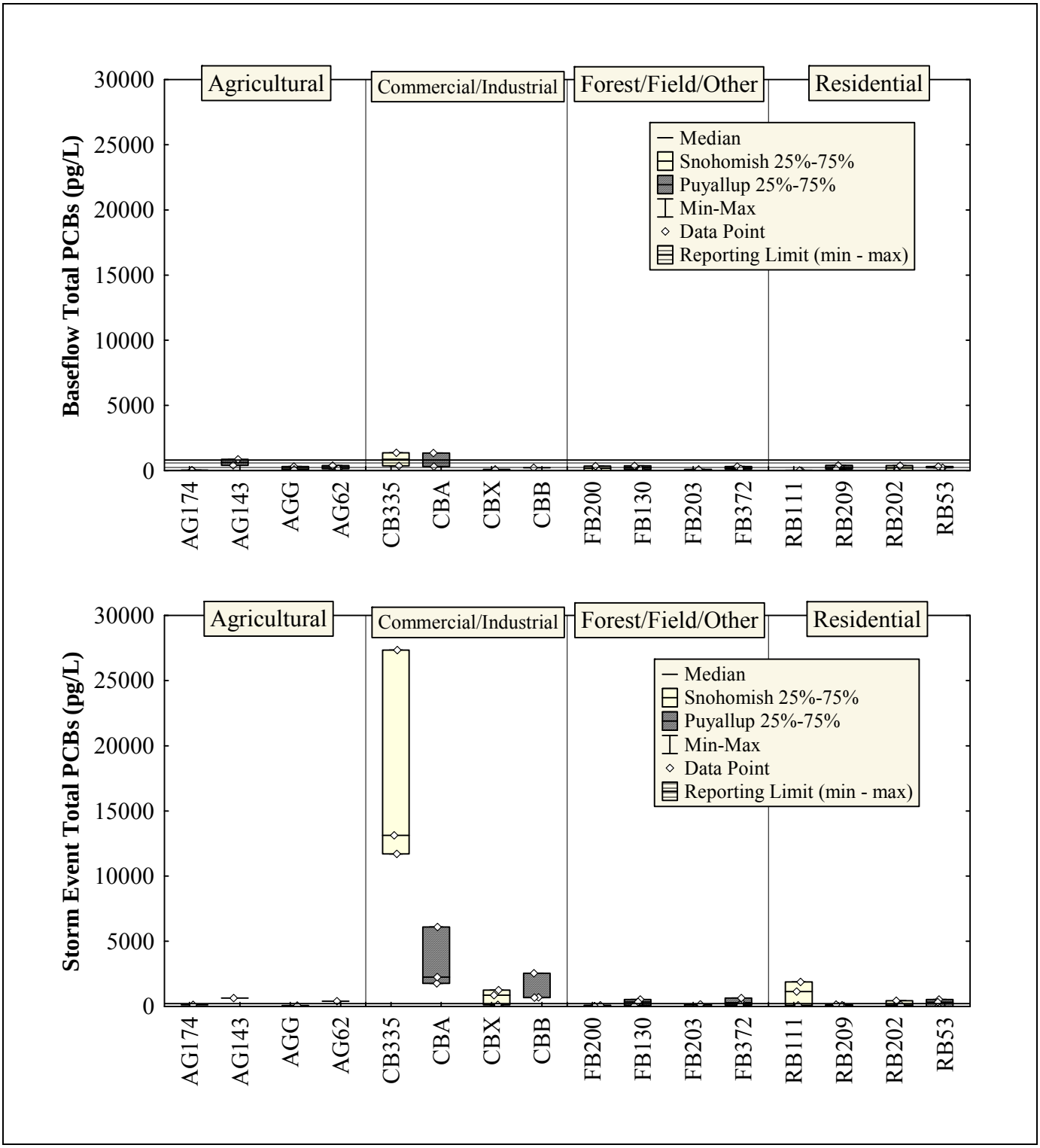

Figure 22. Baseflow and storm-event total polychlorinated biphenyls (PCBs) concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

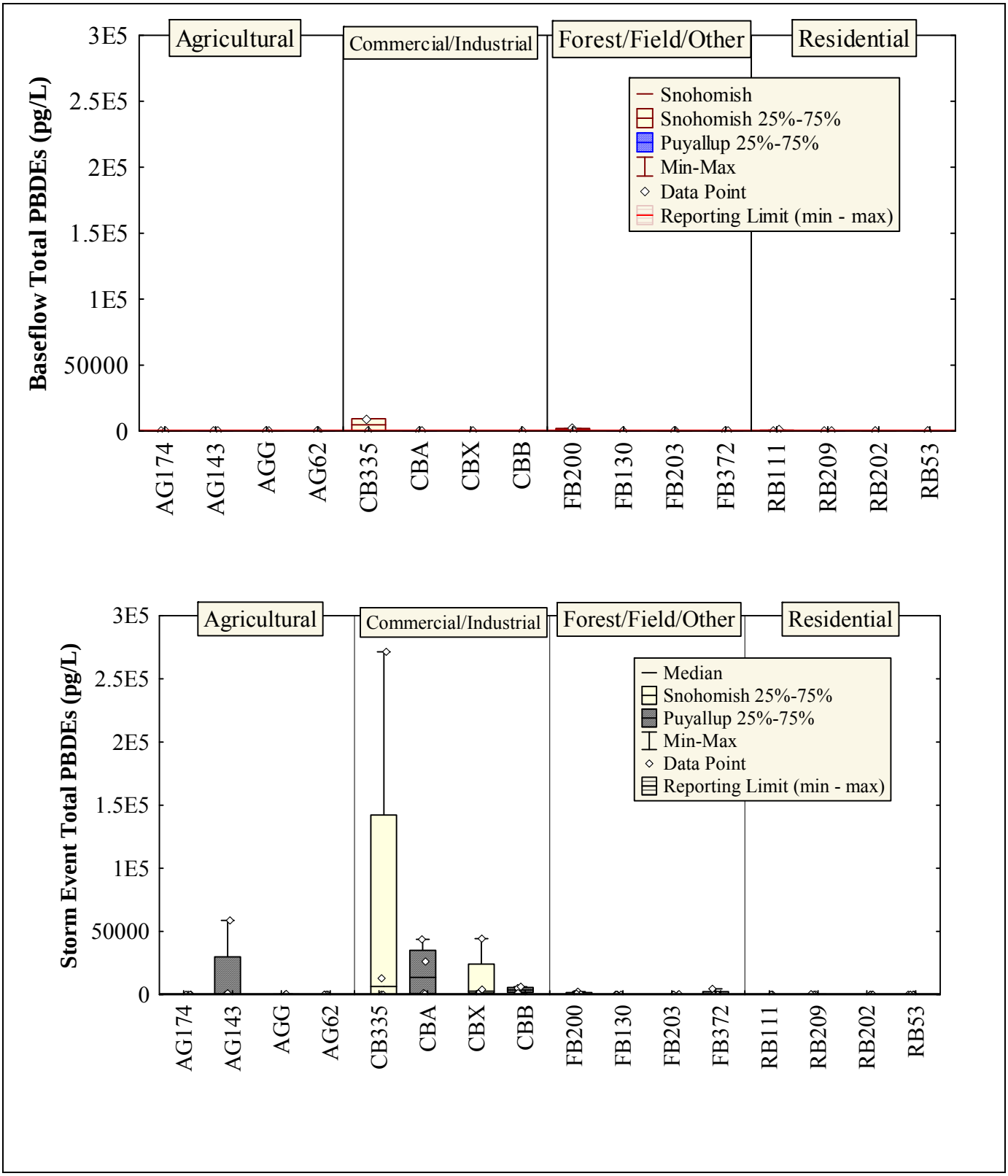

Figure 23. Baseflow and storm-event total polybrominated diphenyl ethers (PBDEs) concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

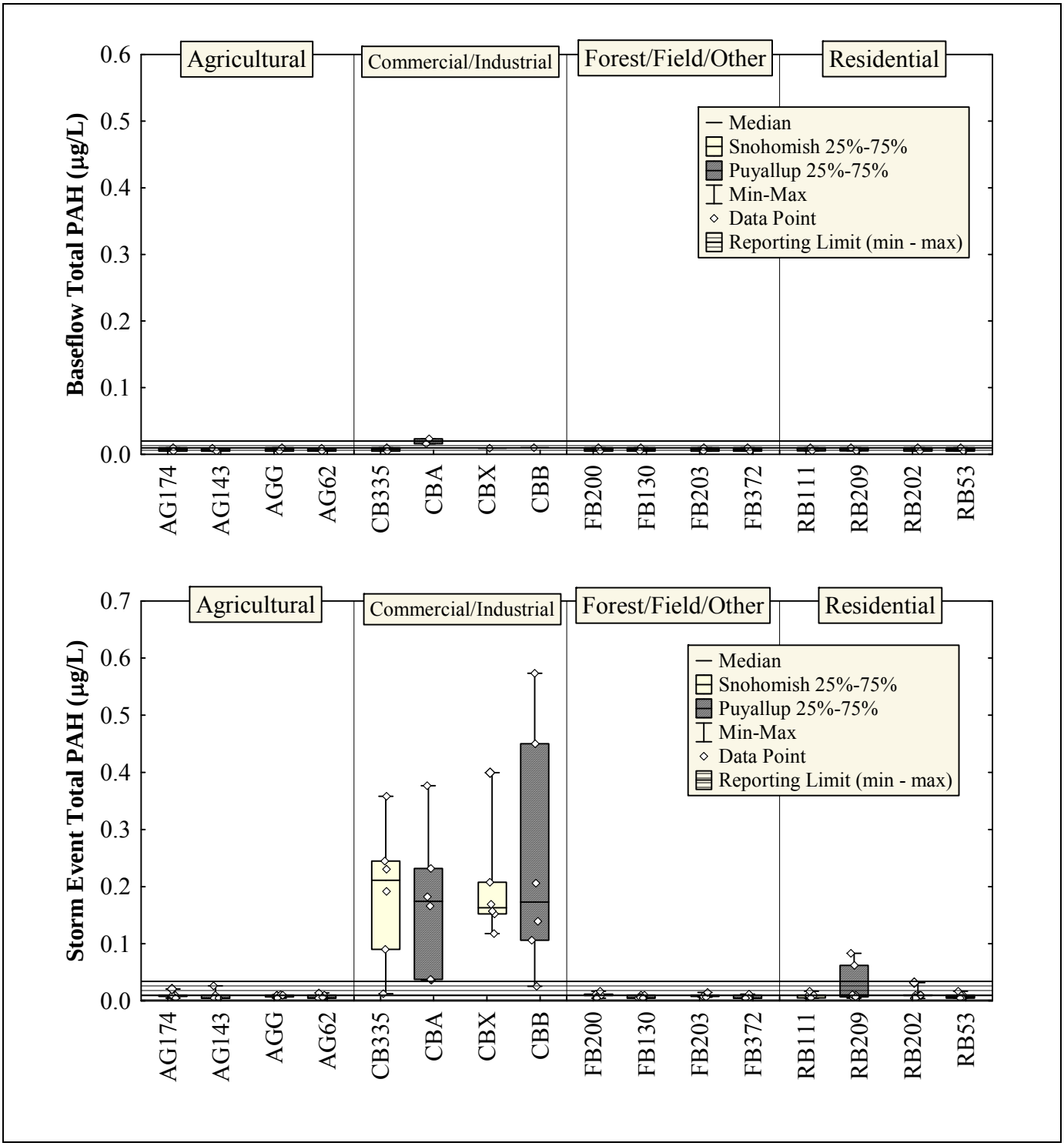

Figure 24. Baseflow and storm-event total polycyclic aromatic hydrocarbons (PAHs) concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

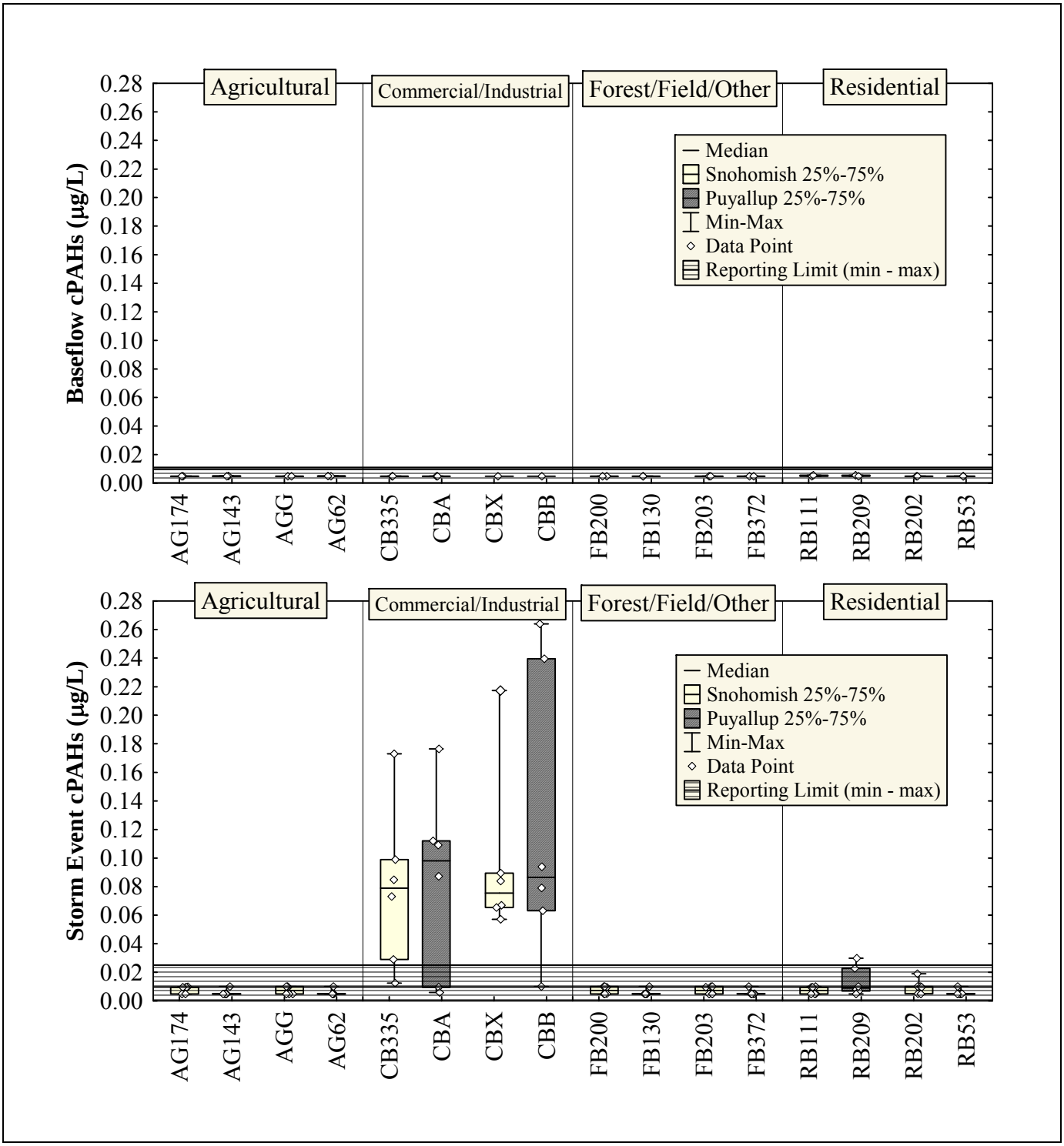

Figure 25. Baseflow and storm-event carcinogenic polycyclic aromatic hydrocarbons (cPAHs) concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

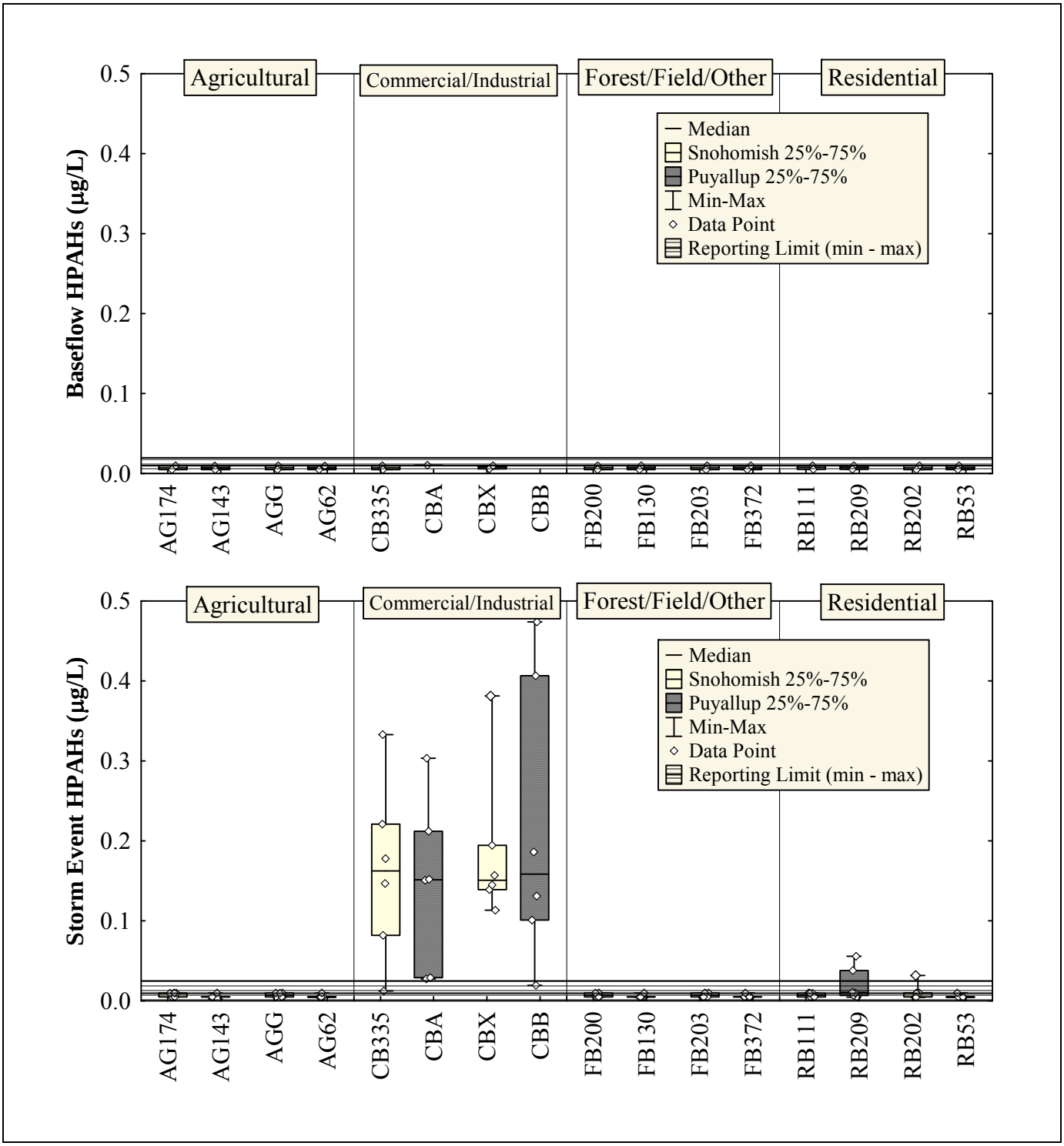

Figure 26. Baseflow and storm-event high molecular weight polycyclic aromatic hydrocarbons (HPAHs) concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

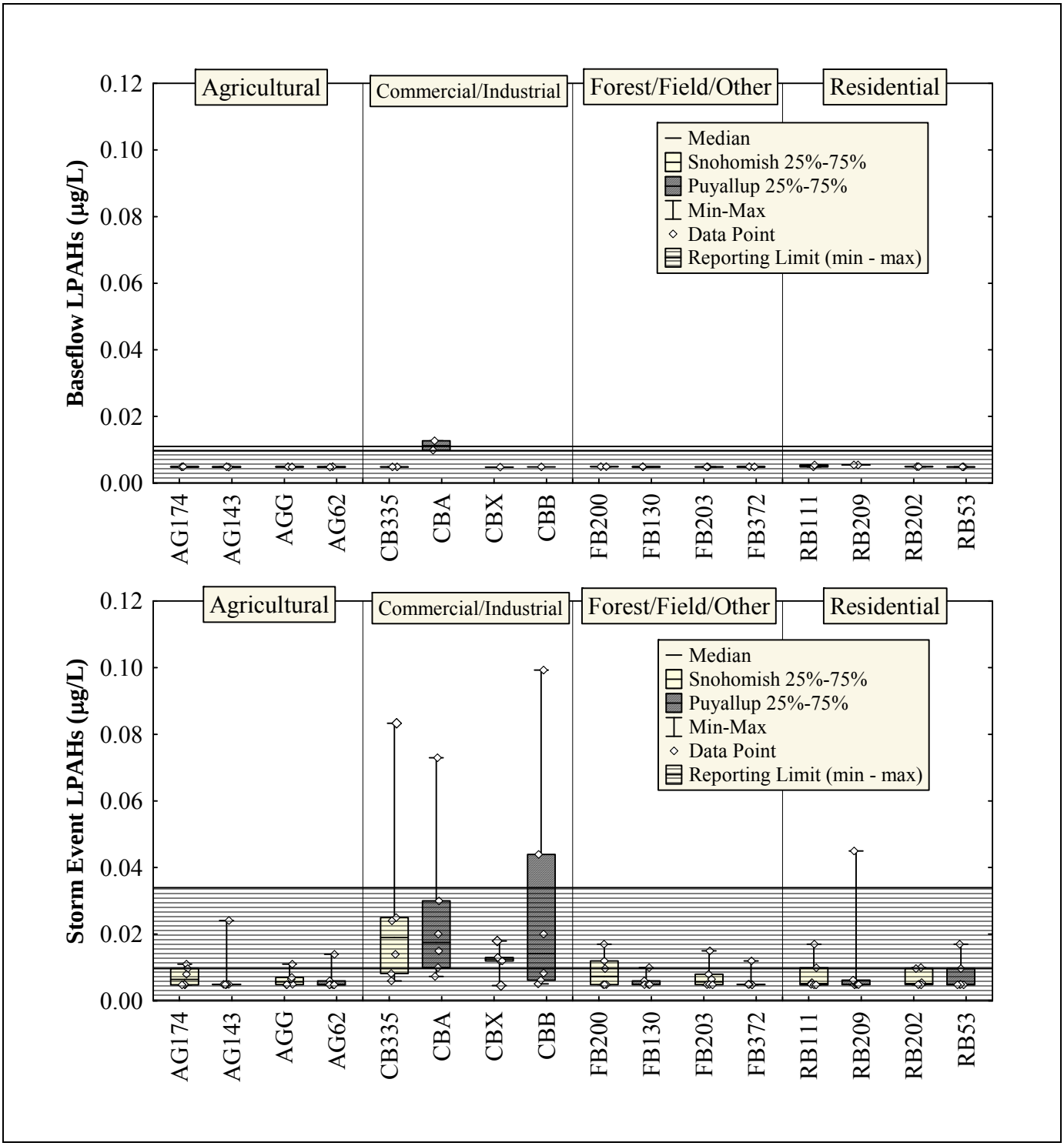

Figure 27. Baseflow and storm-event low molecular weight polycyclic aromatic hydrocarbons (LPAHs) concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

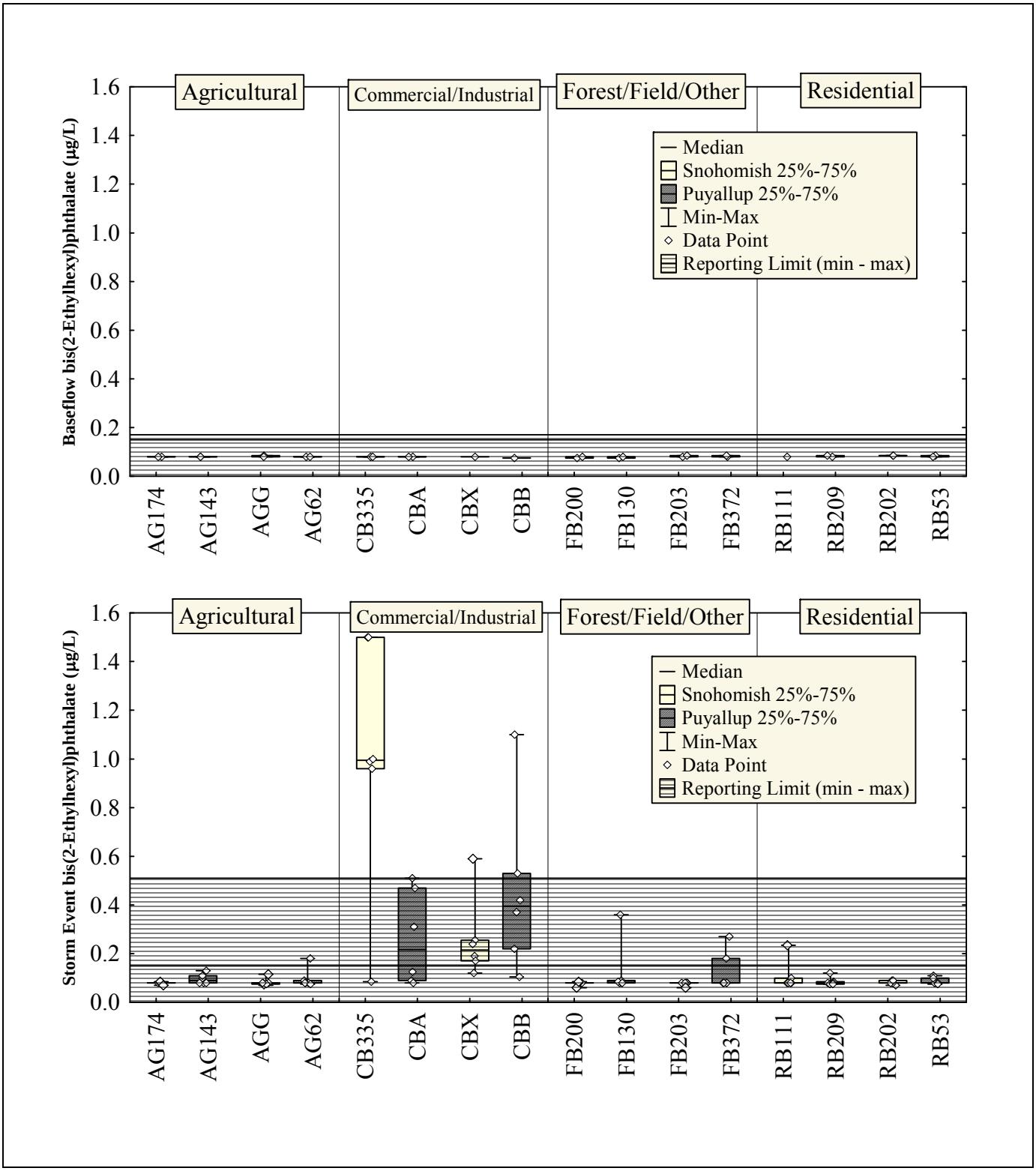

Figure 28. Baseflow and storm-event bis(2-ethylhexyl) phthalate concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

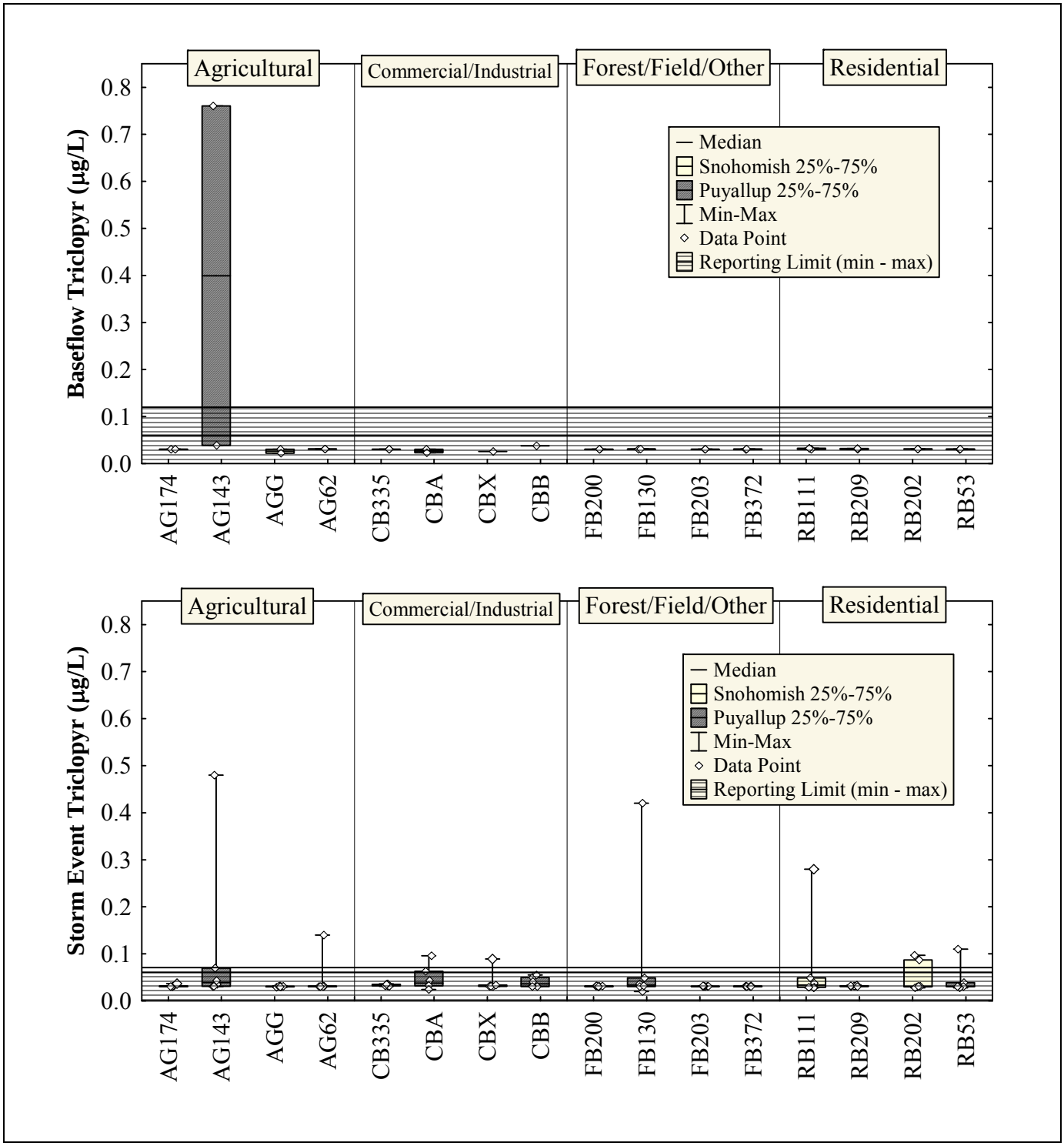

Figure 29. Baseflow and storm-event triclopyr concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

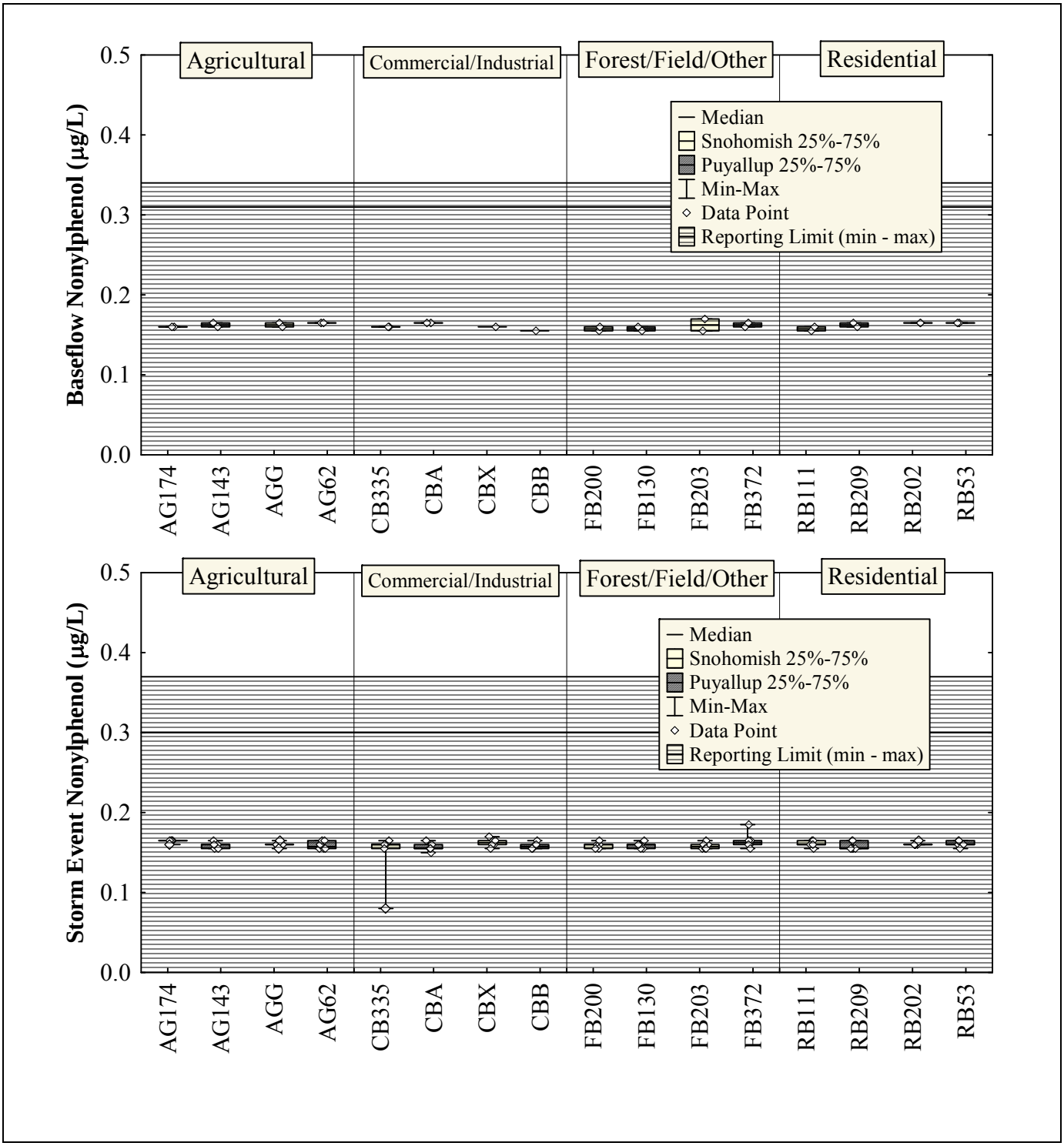

Figure 30. Baseflow and storm-event nonylphenol concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

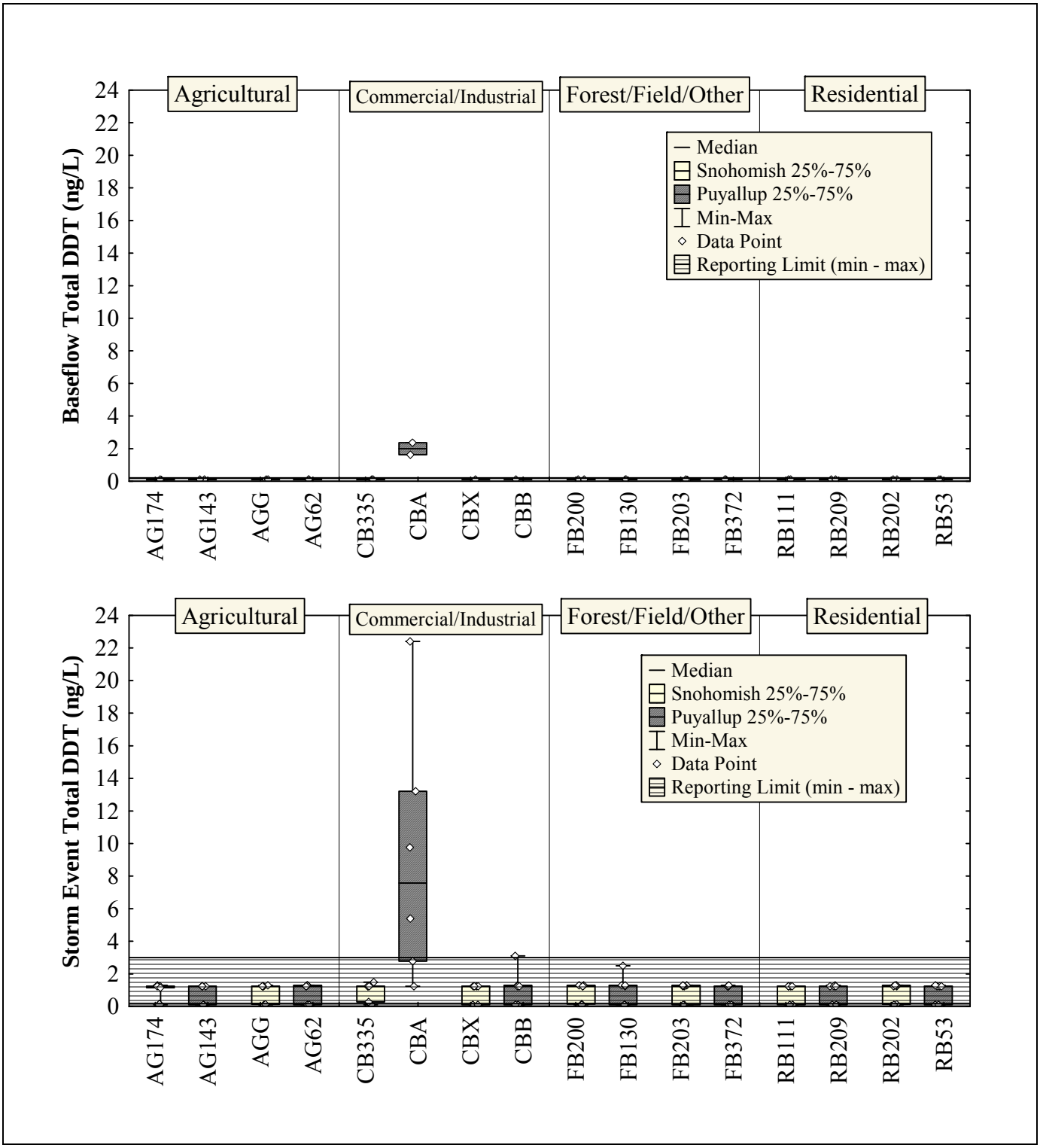

Figure 31. Baseflow and storm-event total dichlorodiphenyltrichloroethane (DDT) concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

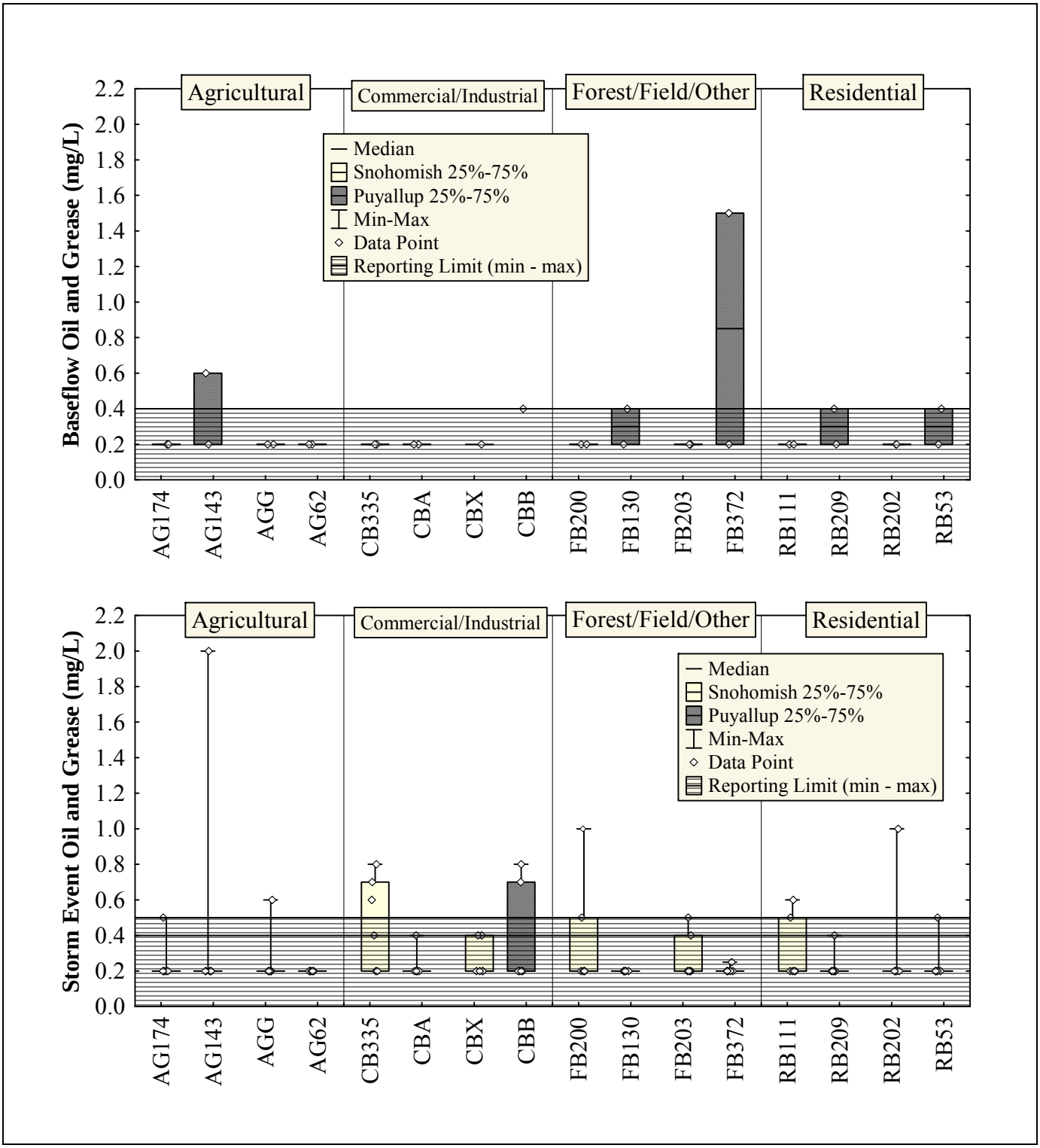

Figure 32. Baseflow and storm-event oil and grease concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

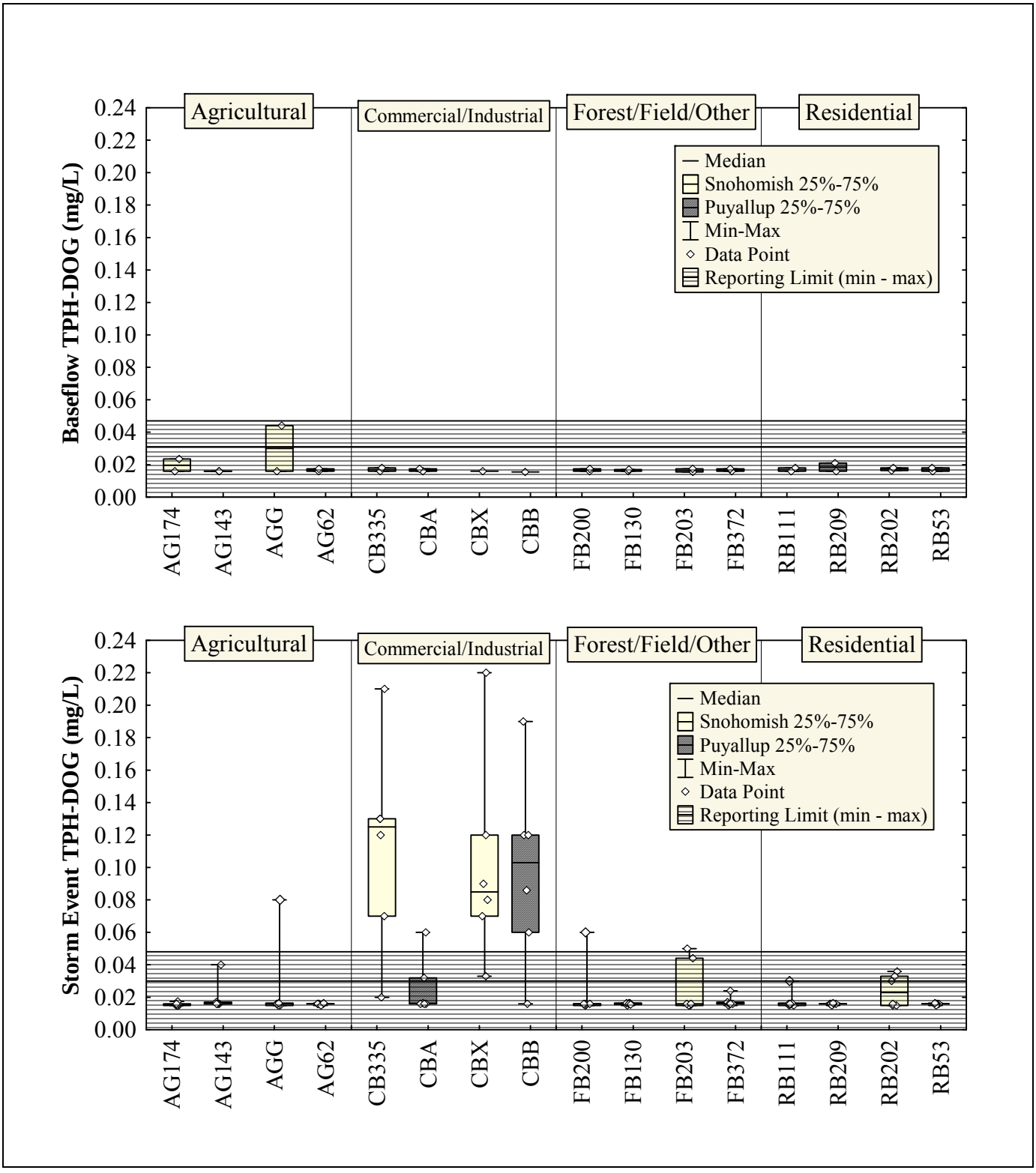

Figure 33. Baseflow and storm-event lube oil (TPH-DOG) concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

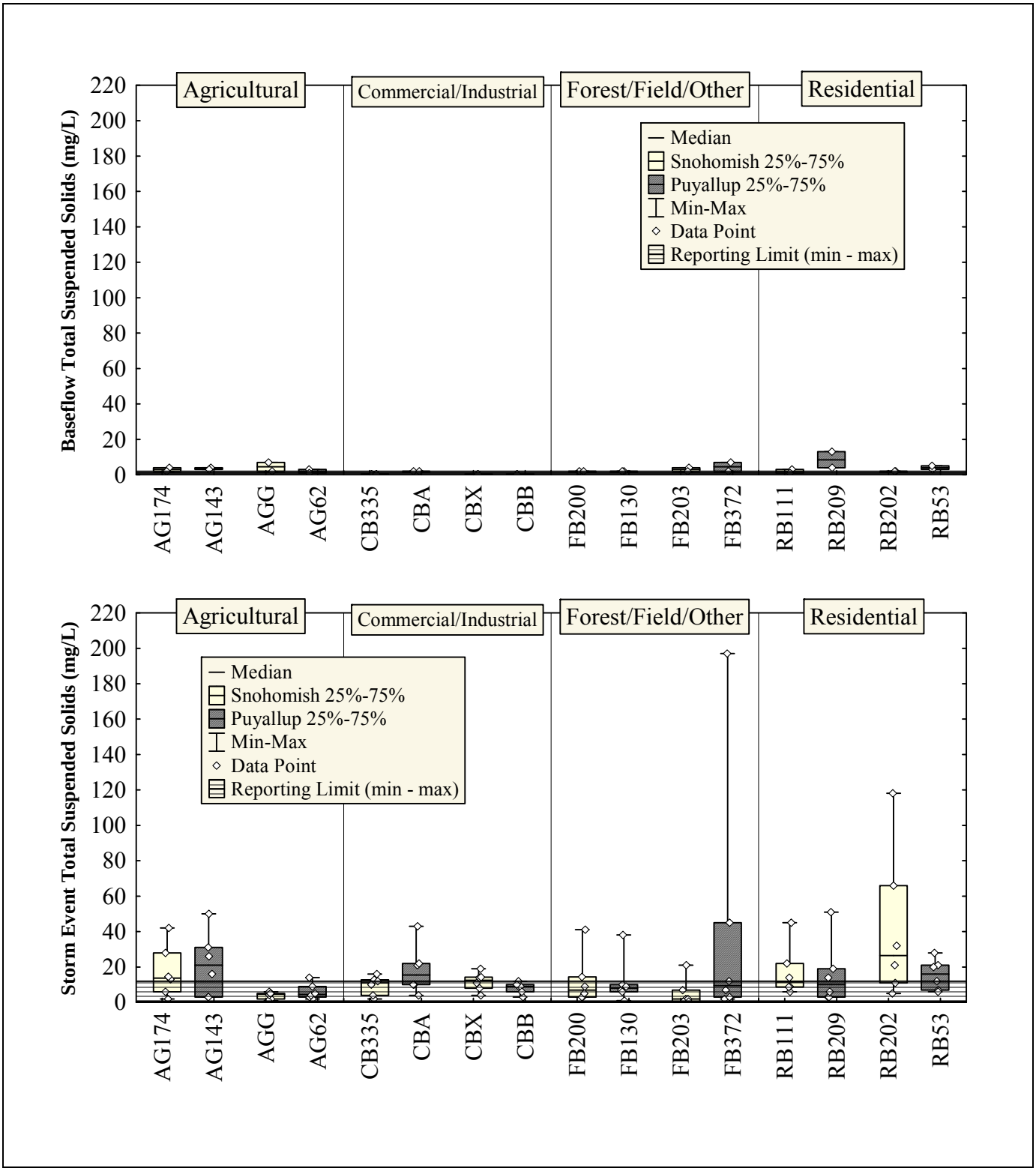

Figure 34. Baseflow and storm-event total suspended solids (TSS) concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

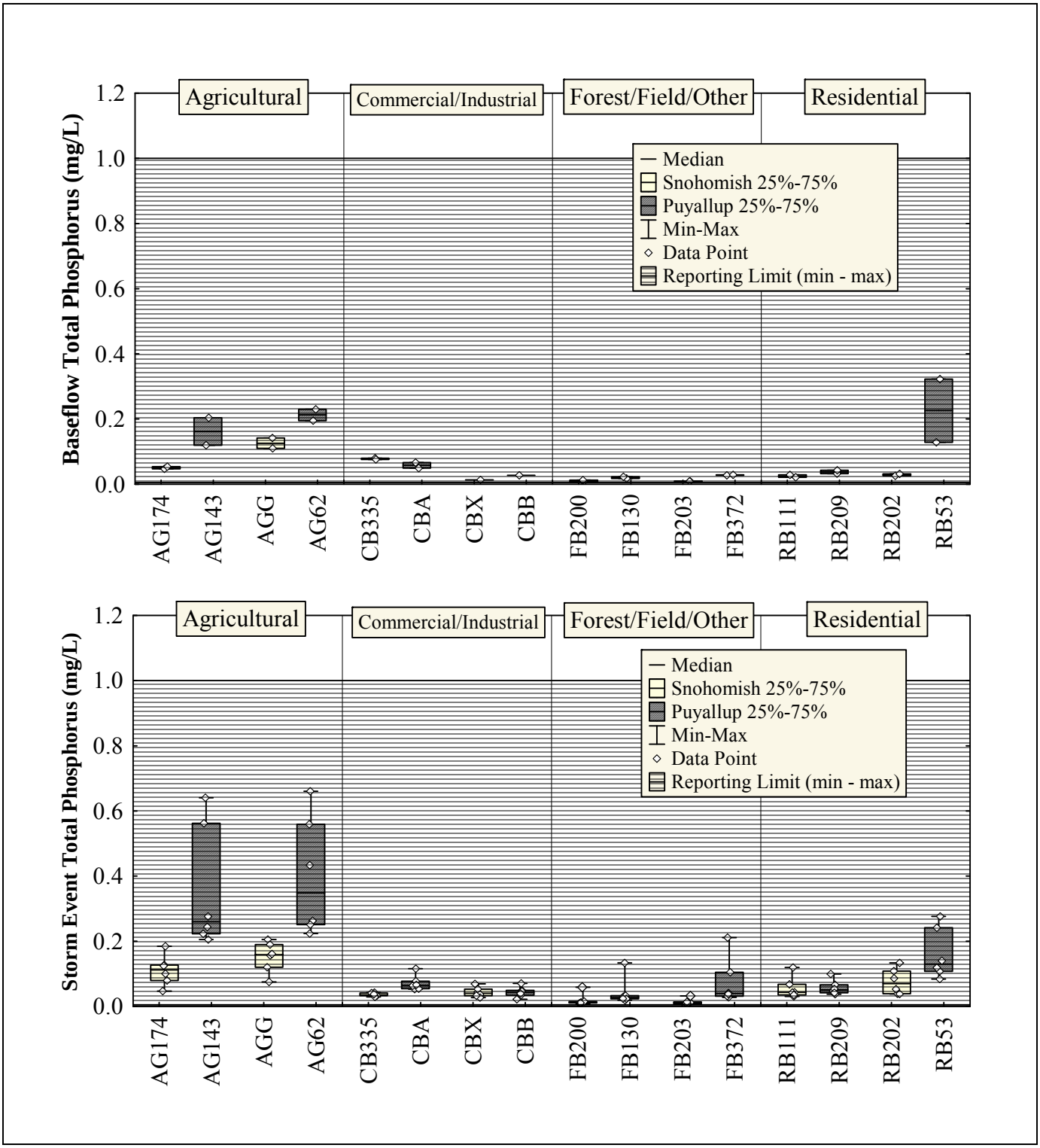

Figure 35. Baseflow and storm-event total phosphorus concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

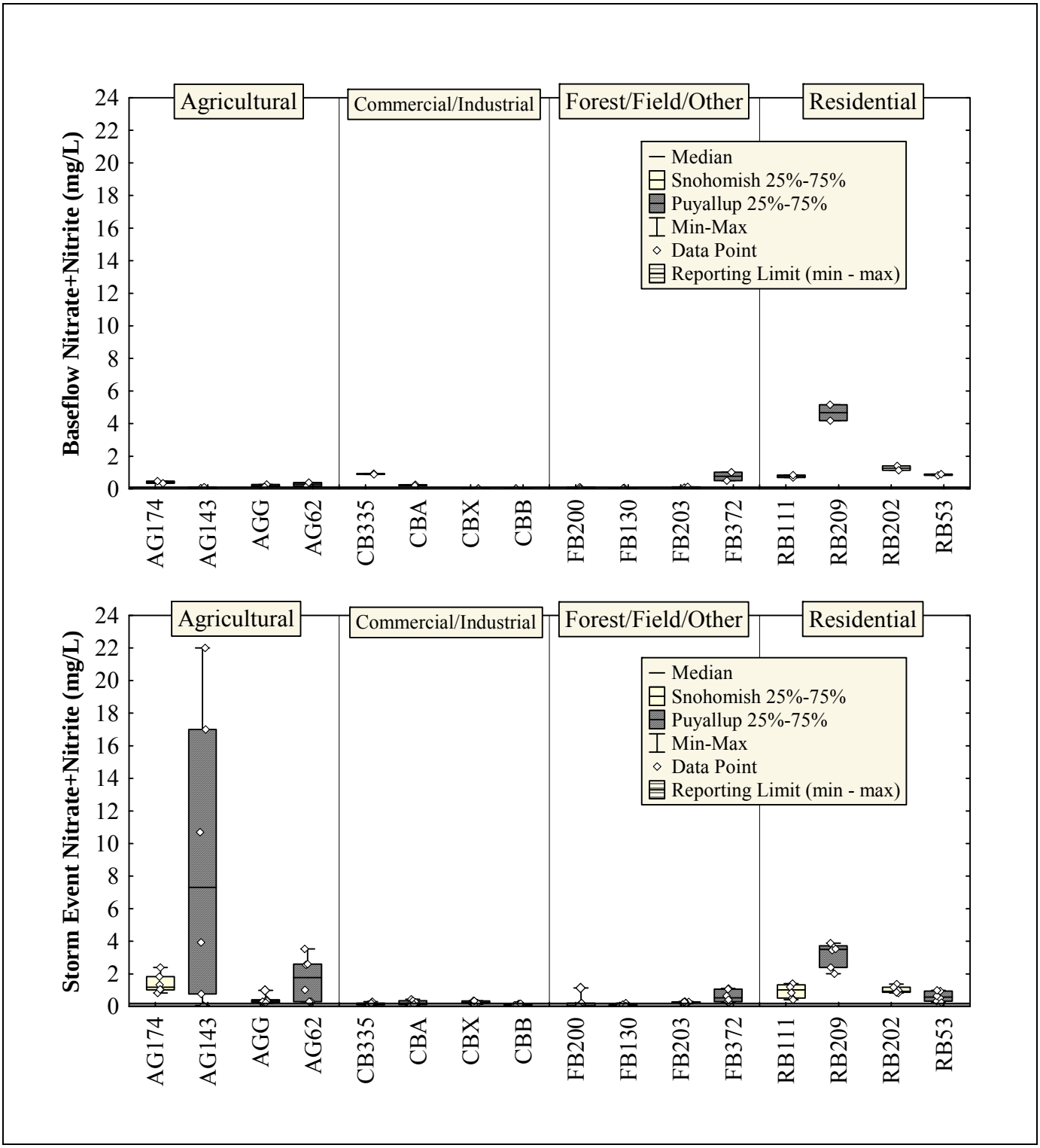

Figure 36. Baseflow and storm-event nitrate+nitrite nitrogen concentration box plots for the Phase 3 study of toxics in surface runoff to Puget Sound.

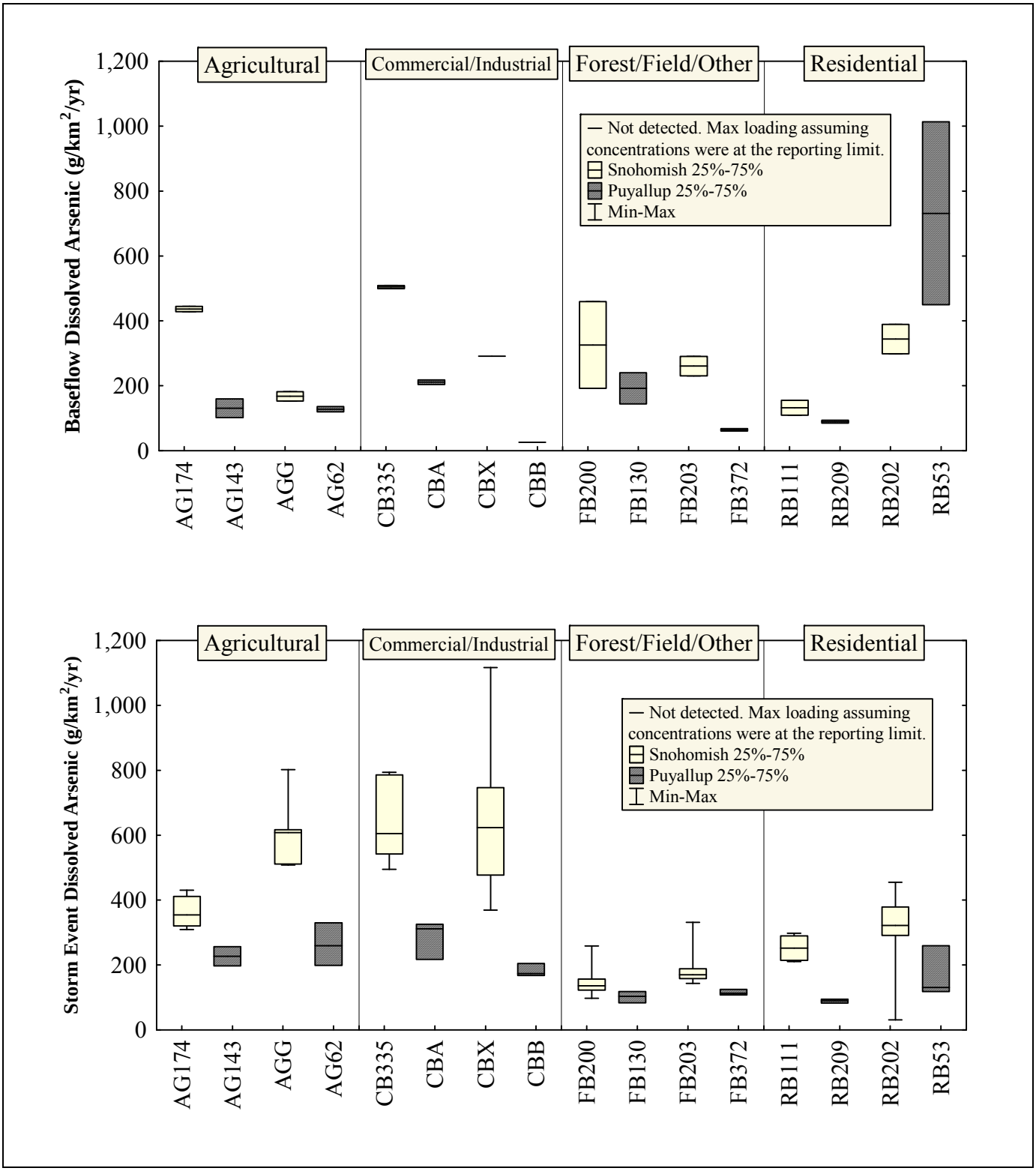

Figure 37. Baseflow and storm-event unit-area chemical loading box plots for dissolved arsenic for the Phase 3 study of toxics in surface runoff to Puget Sound.

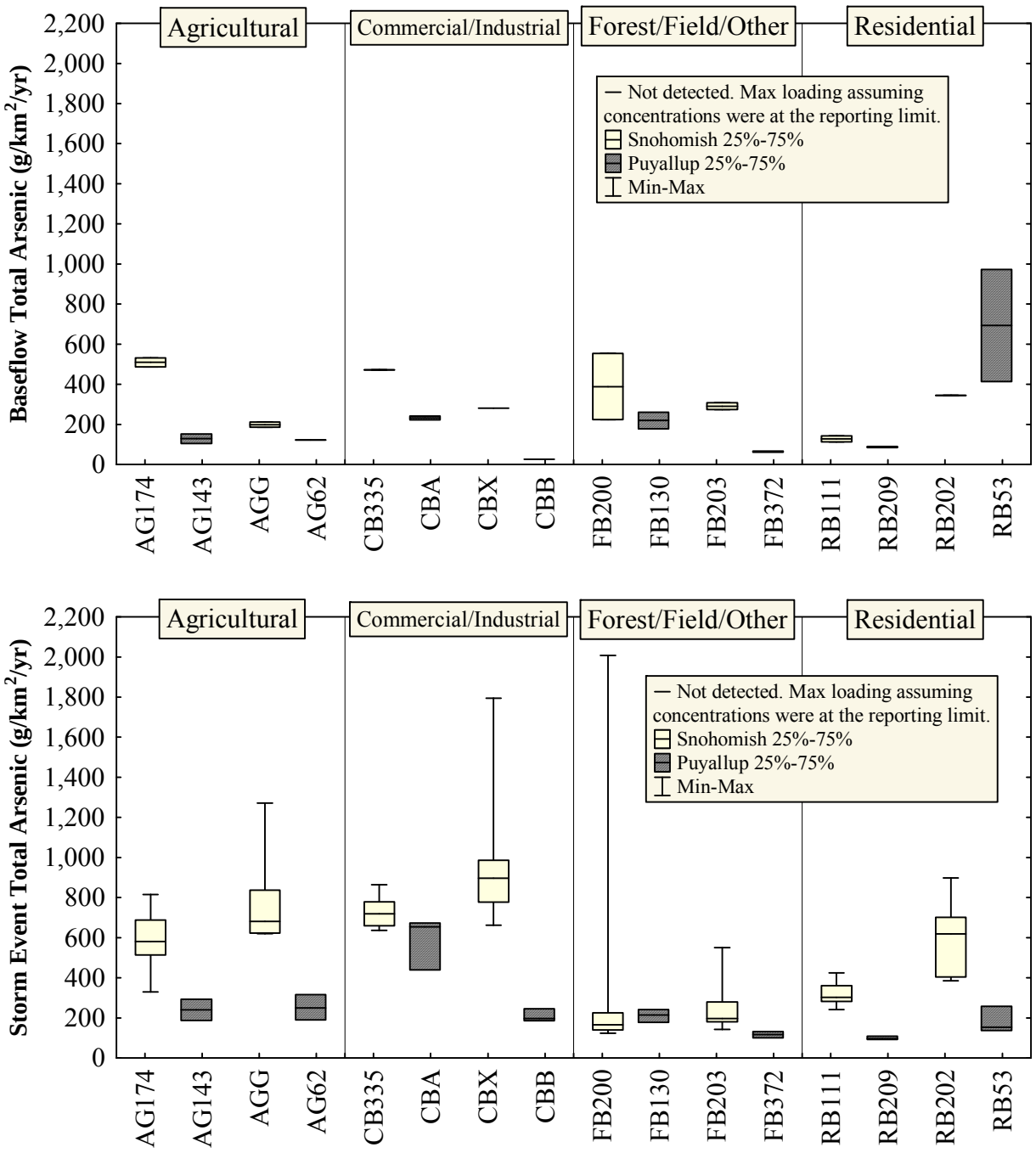

Figure 38. Baseflow and storm-event unit-area chemical loading box plots for total arsenic for the Phase 3 study of toxics in surface runoff to Puget Sound.

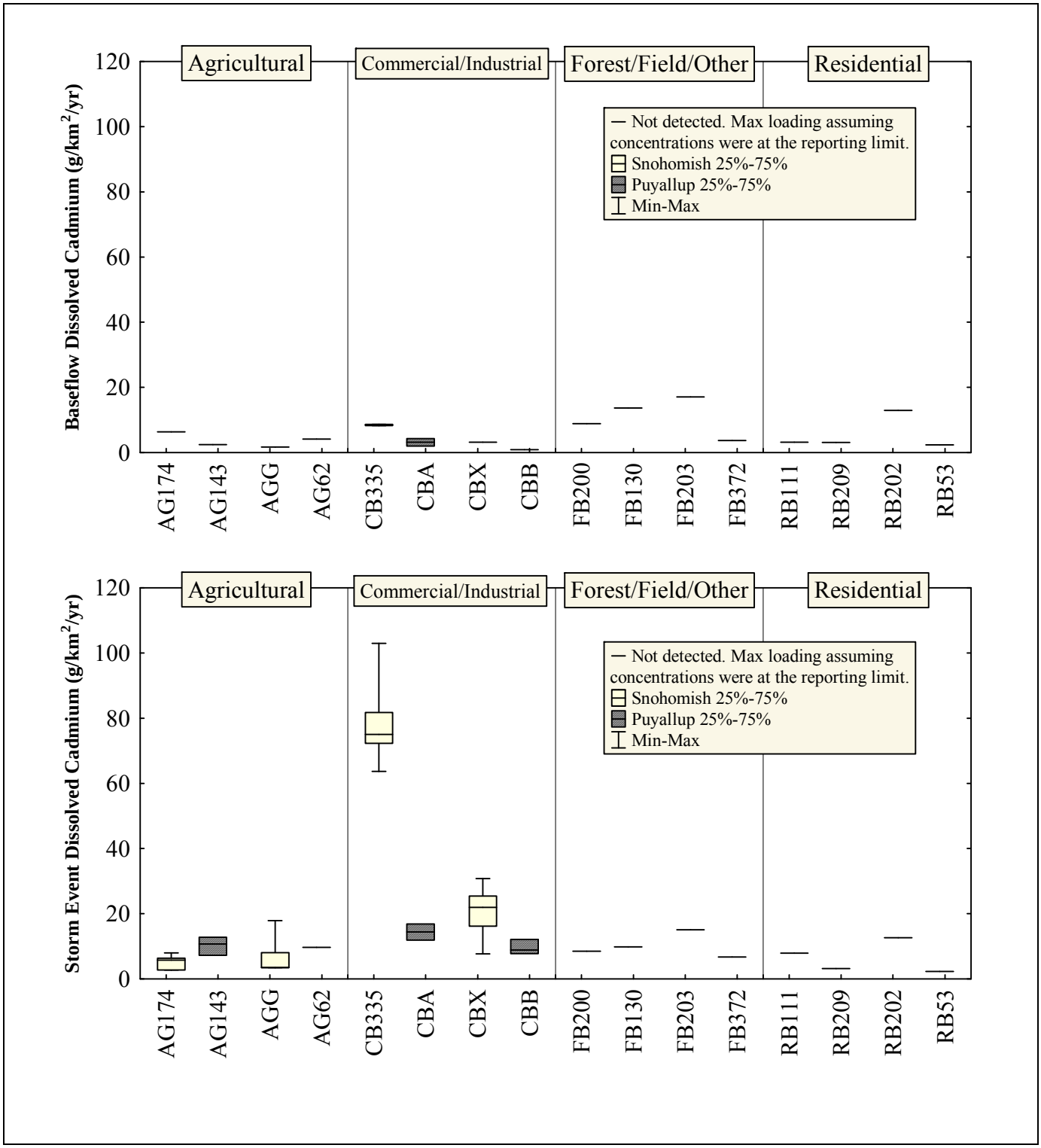

Figure 39. Baseflow and storm-event unit-area chemical loading box plots for dissolved cadmium for the Phase 3 study of toxics in surface runoff to Puget Sound.

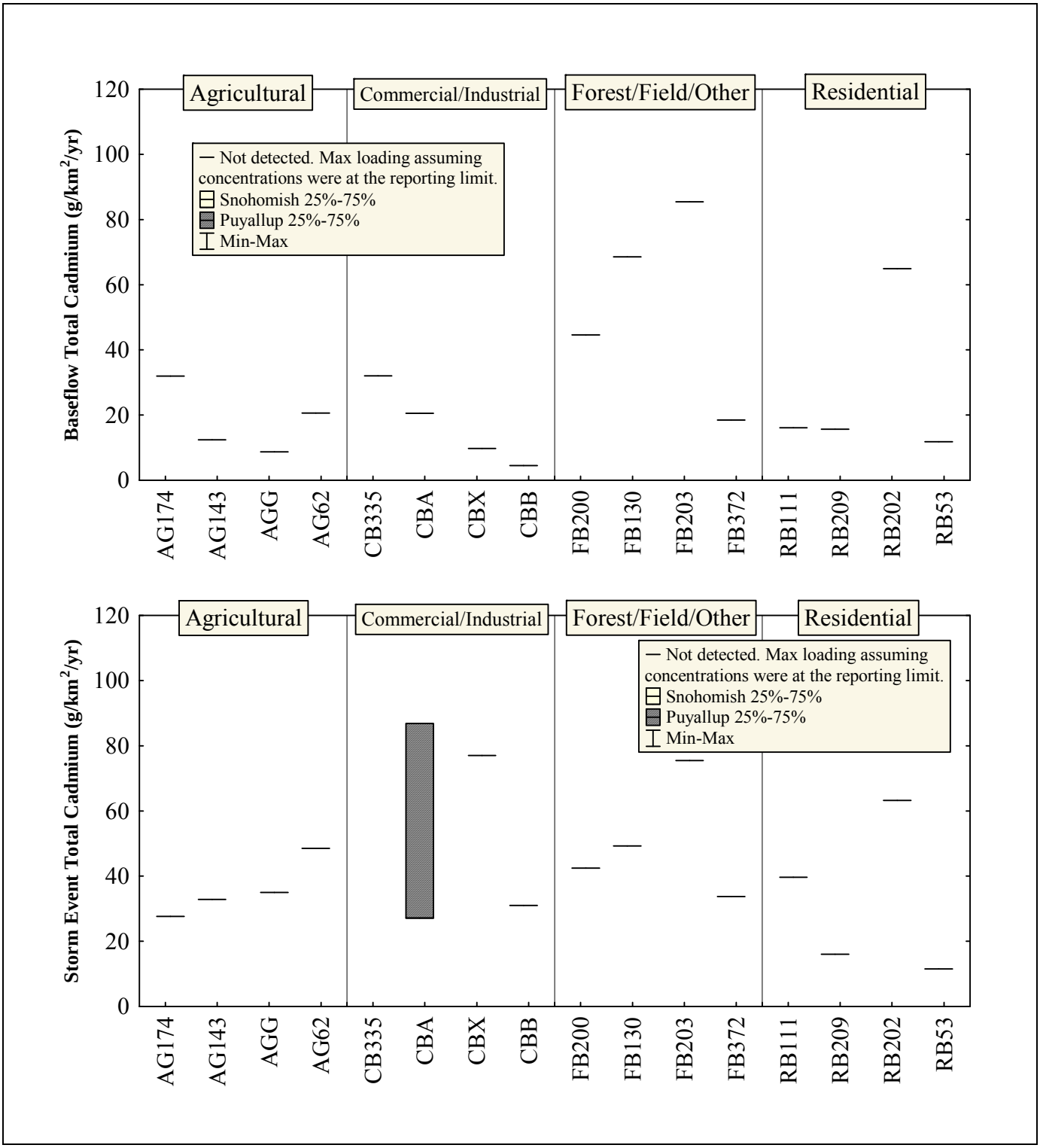

Figure 40. Baseflow and storm-event unit-area chemical loading box plots for total cadmium for the Phase 3 study of toxics in surface runoff to Puget Sound.

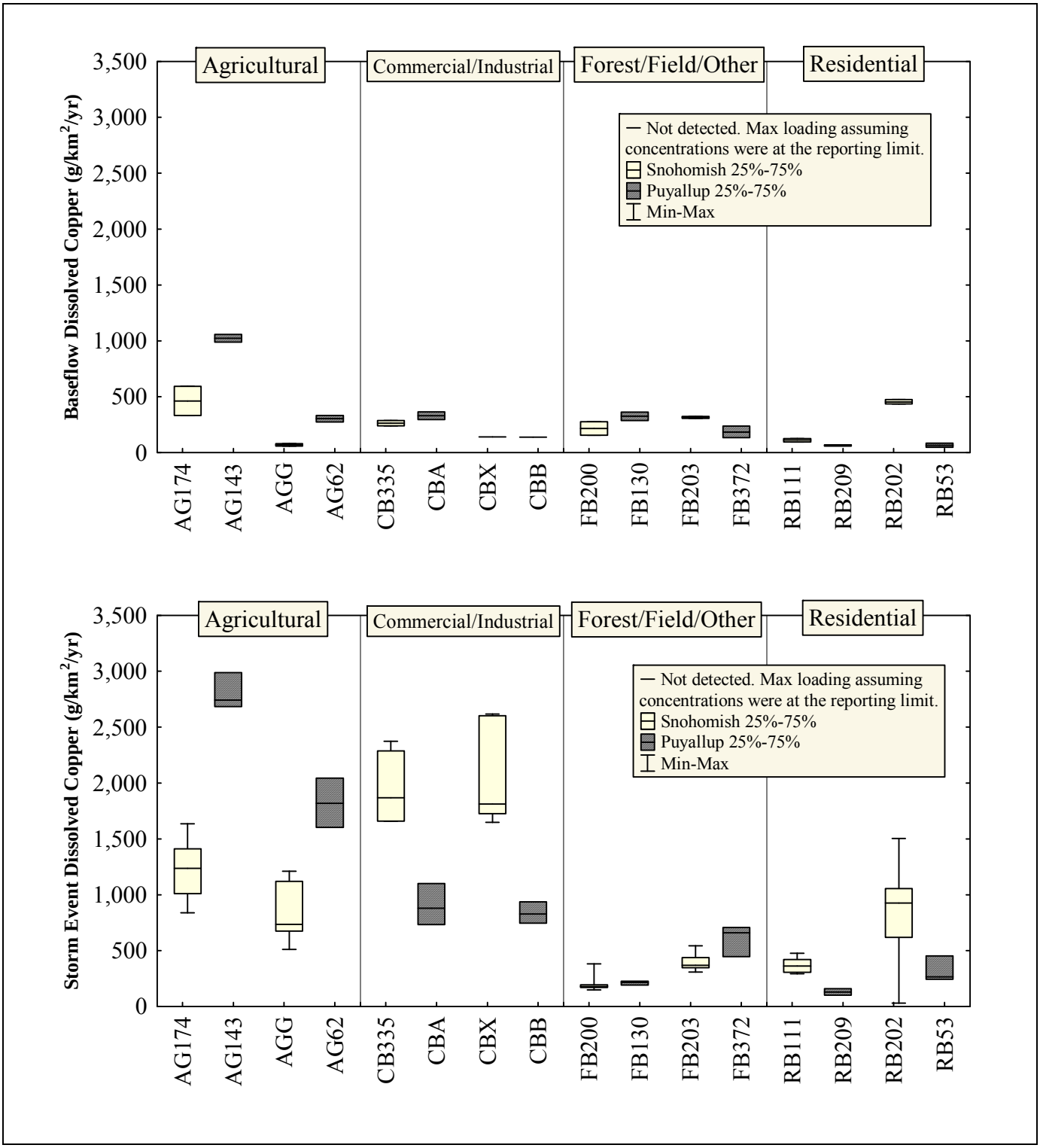

Figure 41. Baseflow and storm-event unit-area chemical loading box plots for dissolved copper for the Phase 3 study of toxics in surface runoff to Puget Sound.

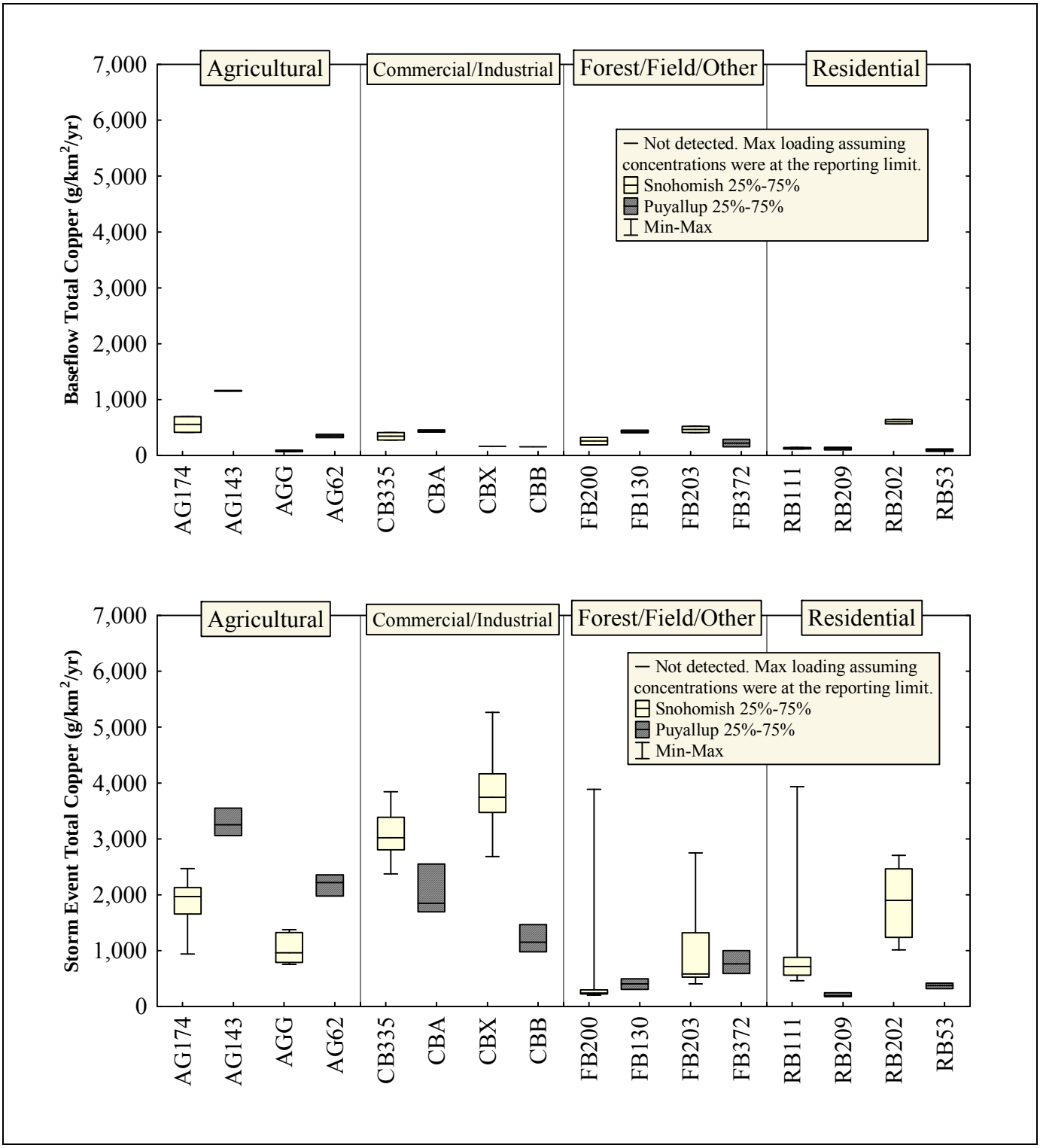

Figure 42. Baseflow and storm-event unit-area chemical loading box plots for total copper for the Phase 3 study of toxics in surface runoff to Puget Sound.

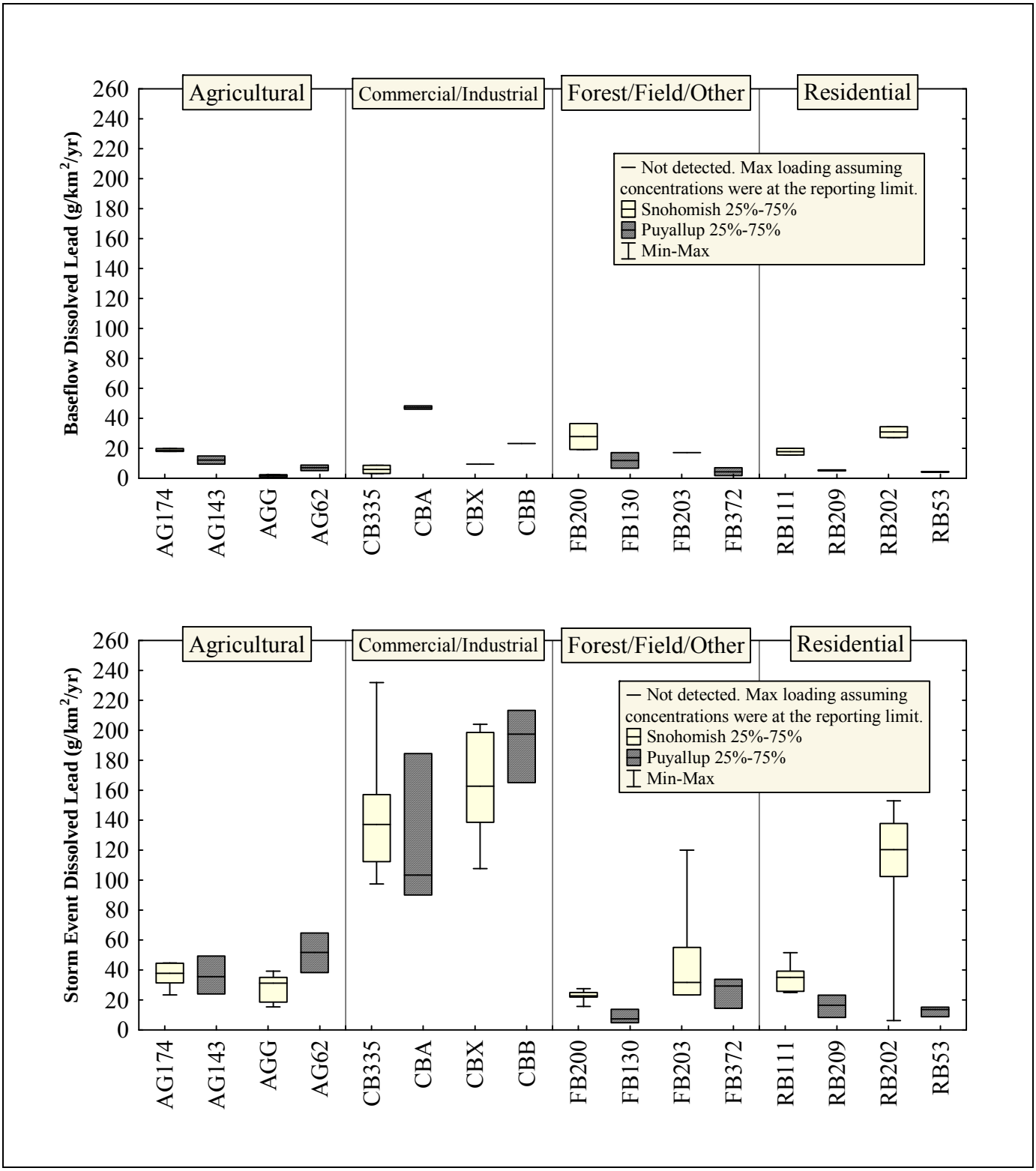

Figure 43. Baseflow and storm-event unit-area chemical loading box plots for dissolved lead for the Phase 3 study of toxics in surface runoff to Puget Sound.

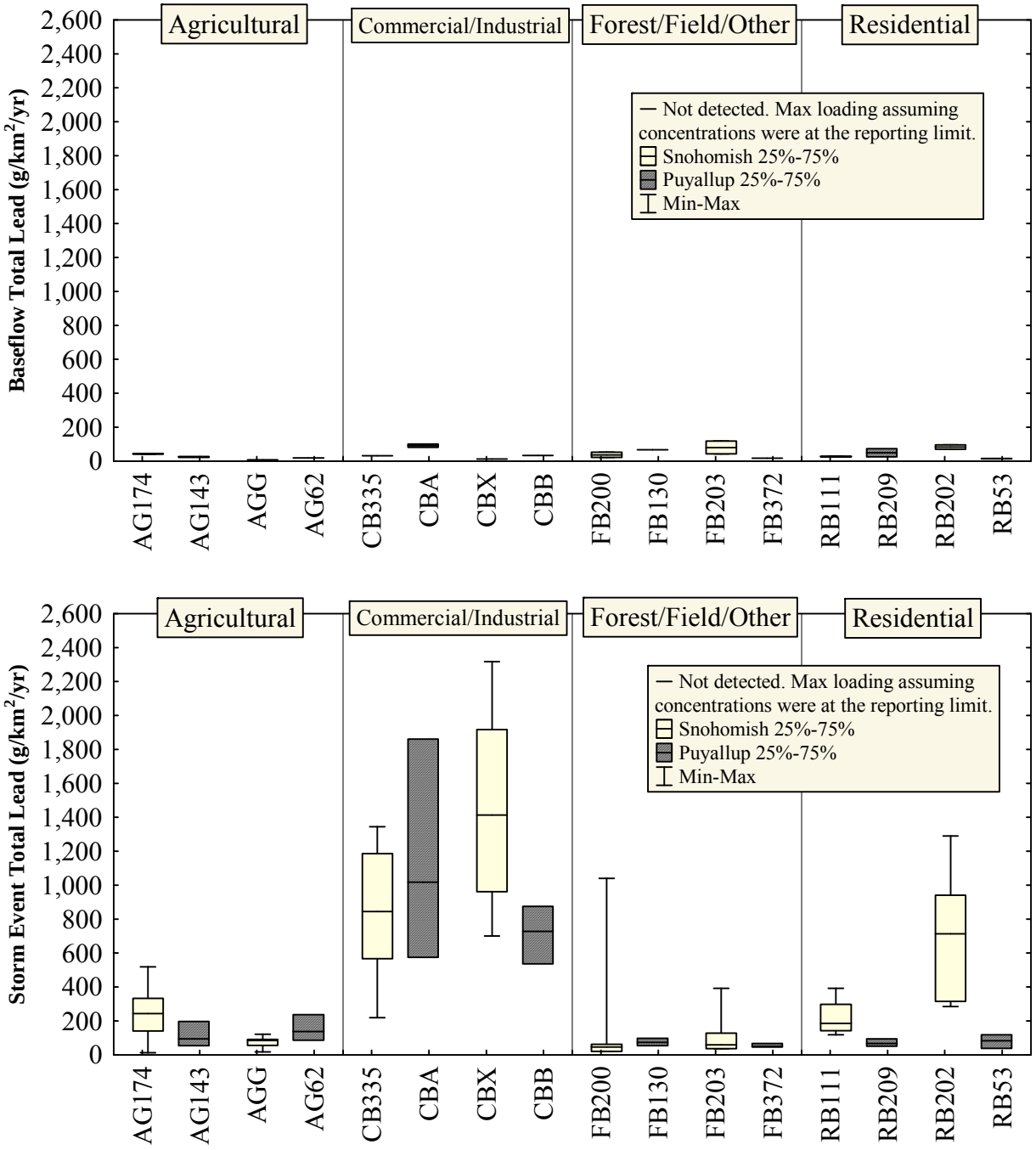

Figure 44. Baseflow and storm-event unit-area chemical loading box plots for total lead for the Phase 3 study of toxics in surface runoff to Puget Sound.

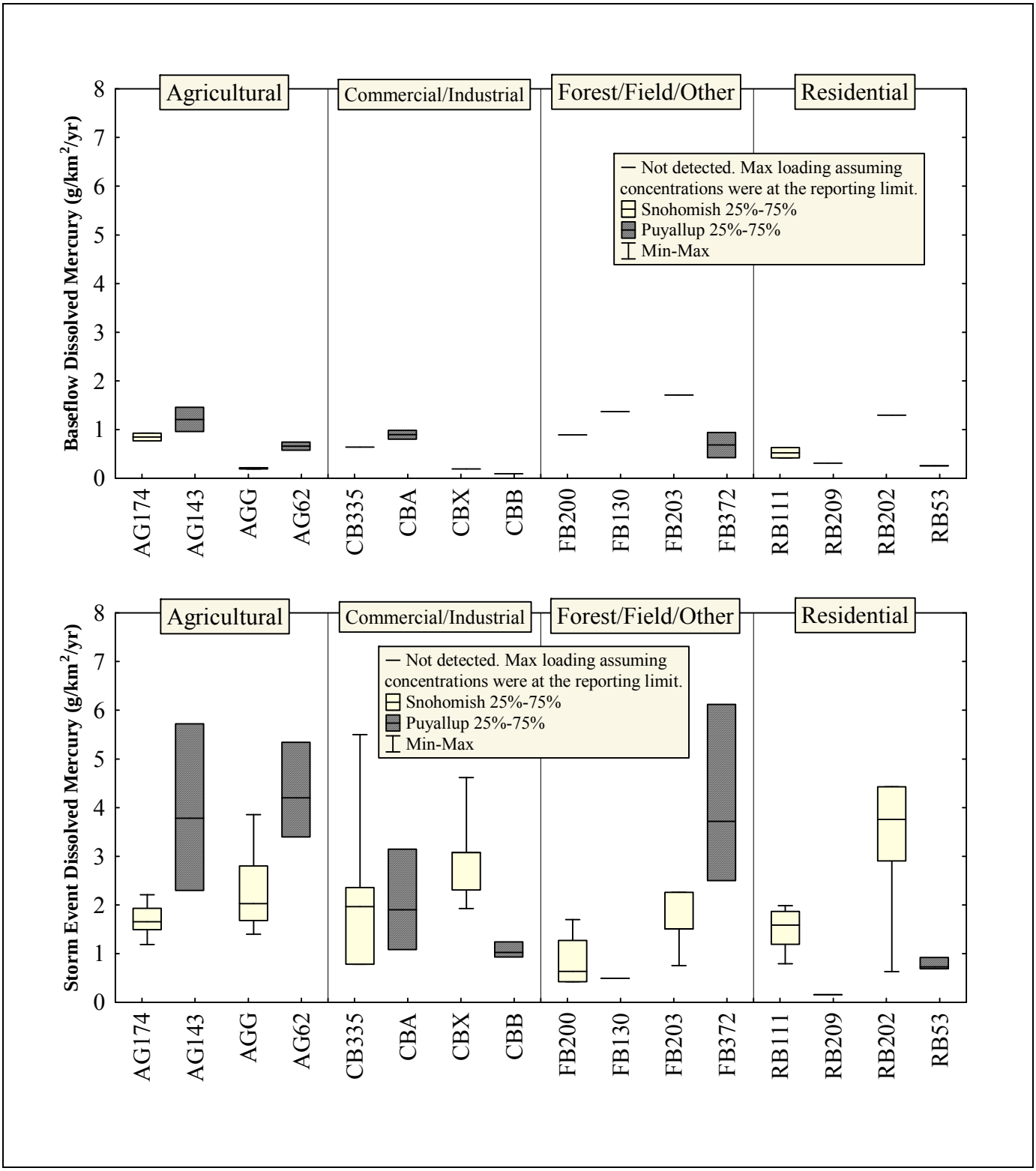

Figure 45. Baseflow and storm-event unit-area chemical loading box plots for dissolved mercury for the Phase 3 study of toxics in surface runoff to Puget Sound.

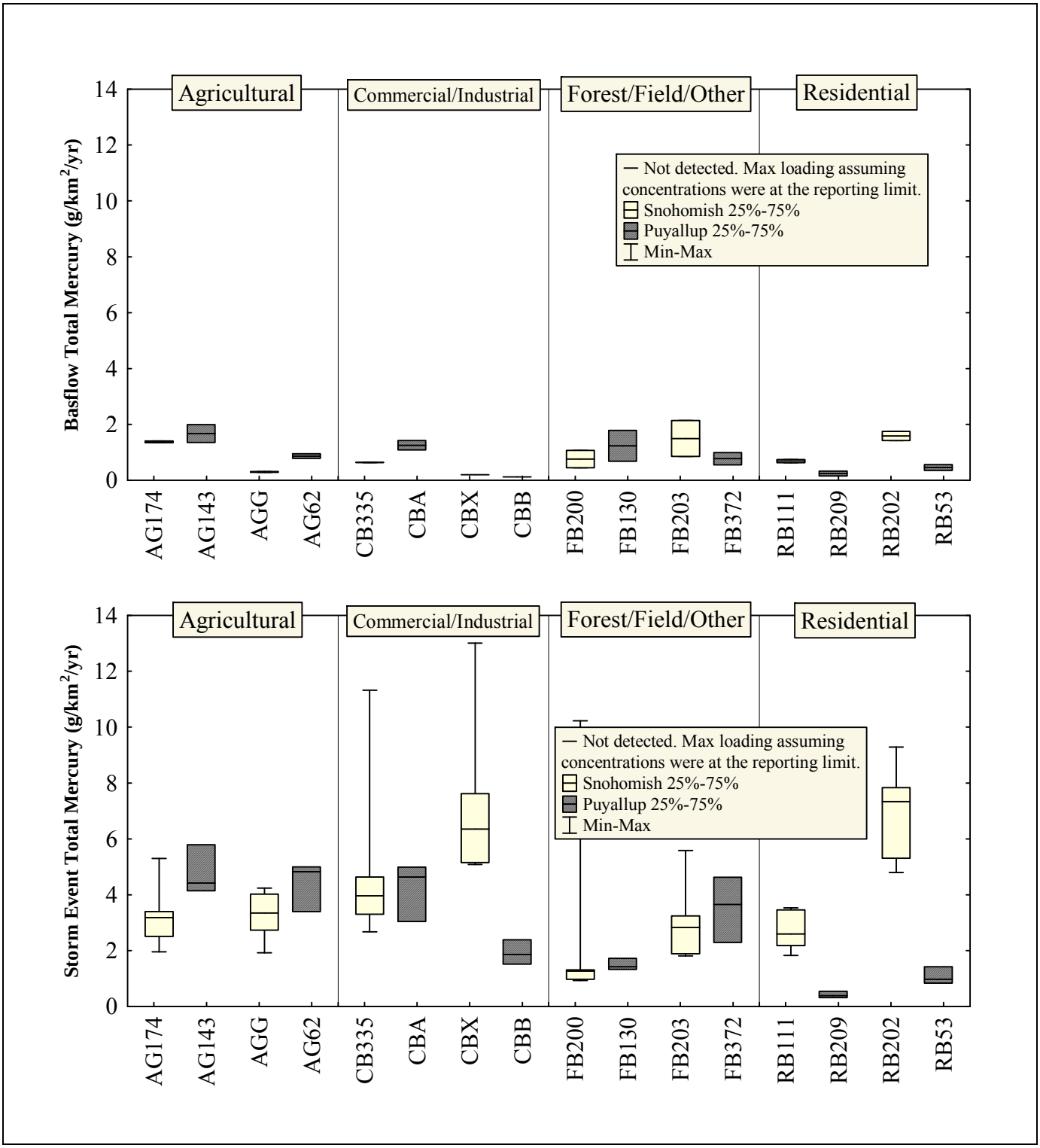

Figure 46. Baseflow and storm-event unit-area chemical loading box plots for total mercury for the Phase 3 study of toxics in surface runoff to Puget Sound.

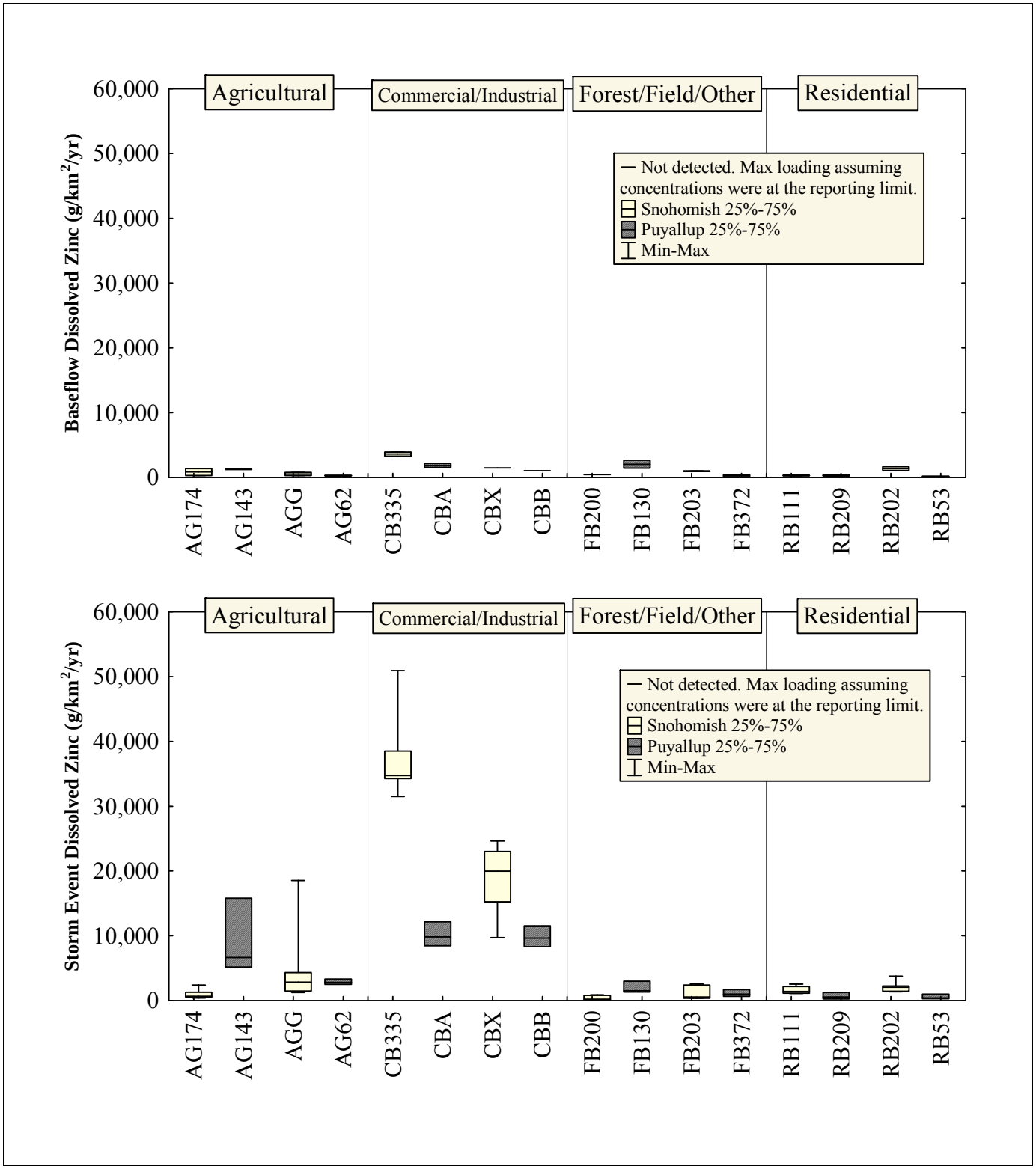

Figure 47. Baseflow and storm-event unit-area chemical loading box plots for dissolved zinc for the Phase 3 study of toxics in surface runoff to Puget Sound.

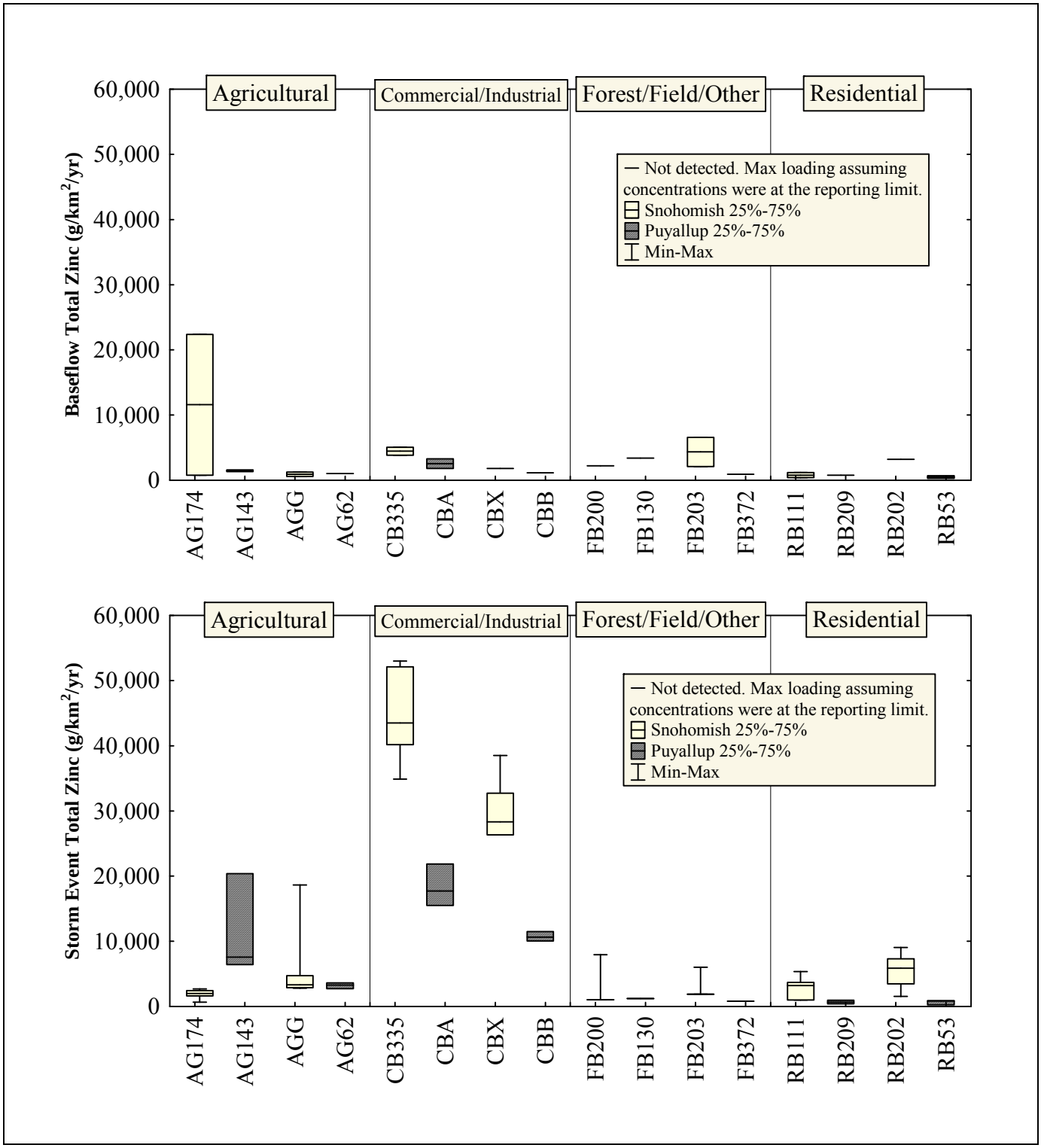

Figure 48. Baseflow and storm-event unit-area chemical loading box plots for total zinc for the Phase 3 study of toxics in surface runoff to Puget Sound.

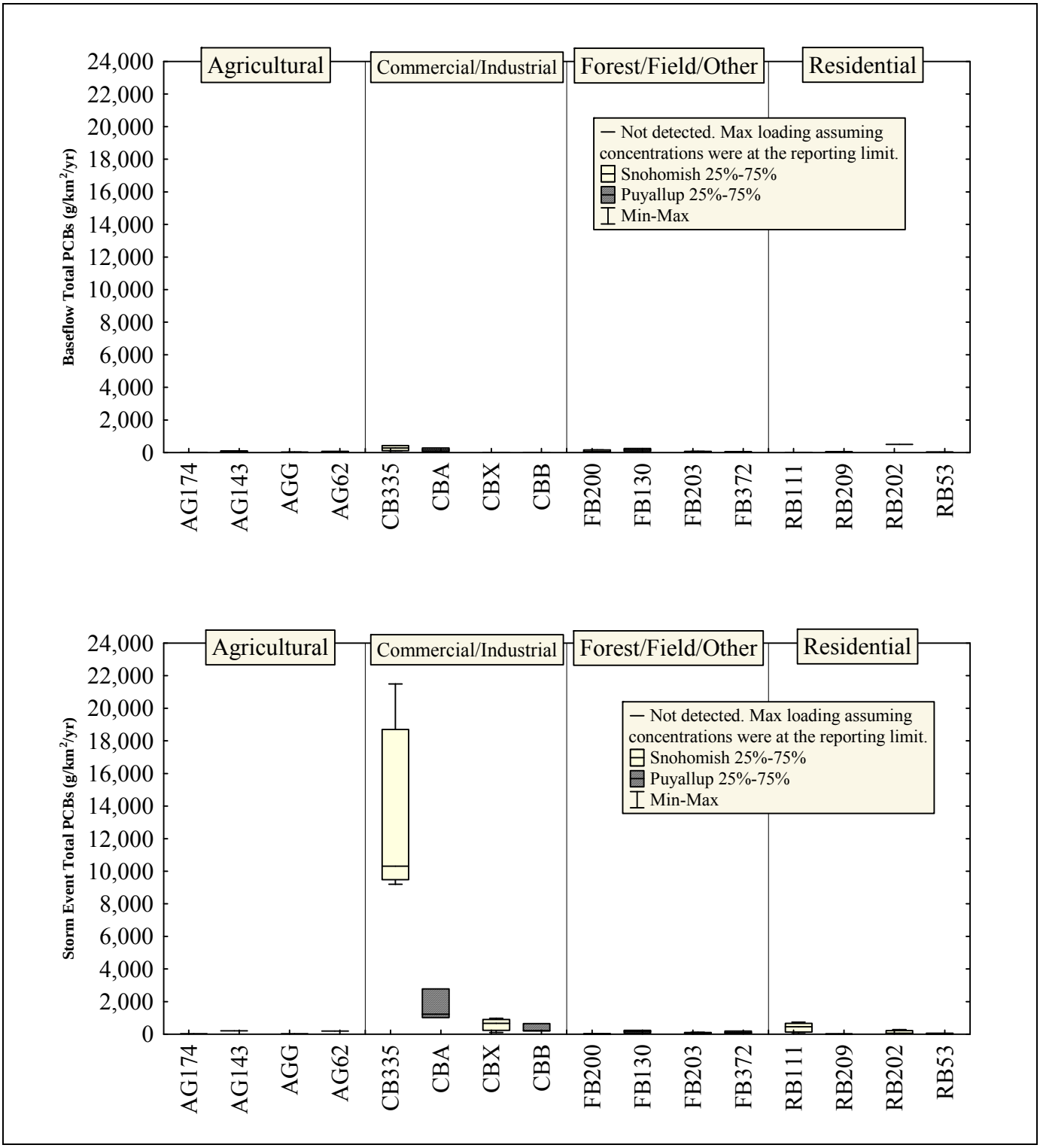

Figure 49. Baseflow and storm-event unit-area chemical loading box plots for total polychlorinated biphenyls (PCBs) for the Phase 3 study of toxics in surface runoff to Puget Sound.

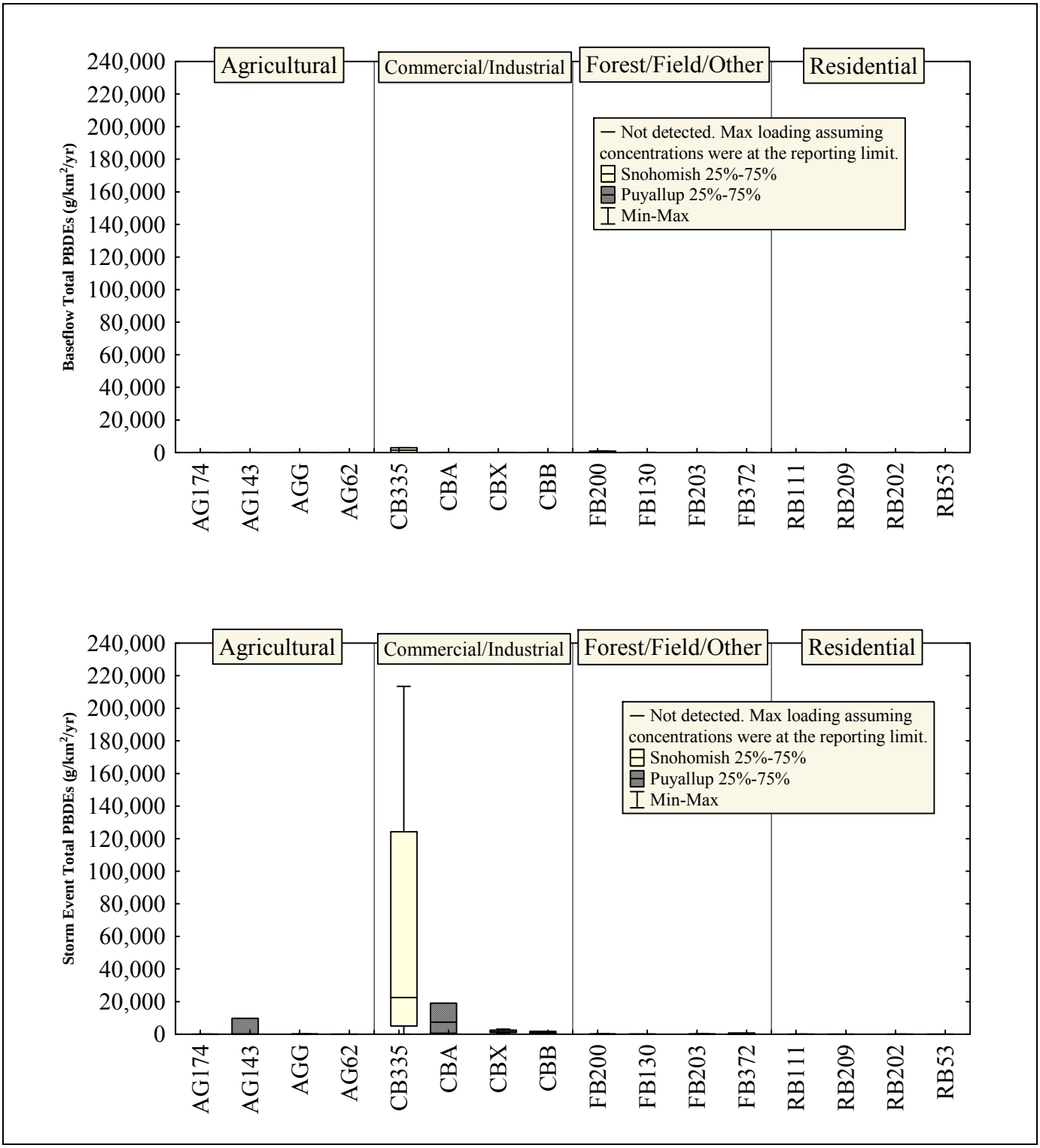

Figure 50. Baseflow and storm-event unit-area chemical loading box plots for total polybrominated diphenyl ethers (PBDEs) for the Phase 3 study of toxics in surface runoff to Puget Sound.

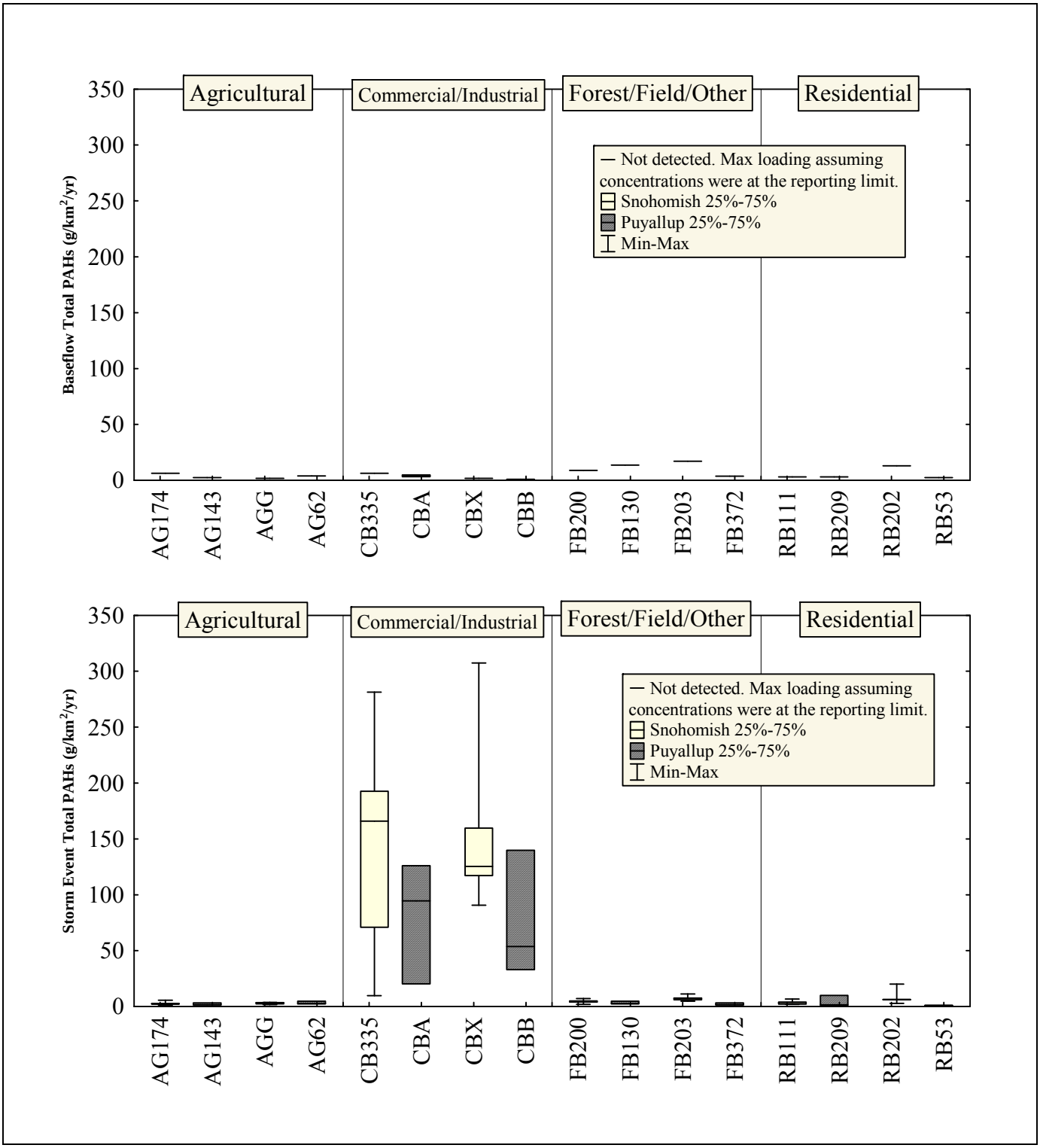

Figure 51. Baseflow and storm-event unit-area chemical loading box plots for total polycyclic aromatic hydrocarbons (PAHs) for the Phase 3 study of toxics in surface runoff to Puget Sound.

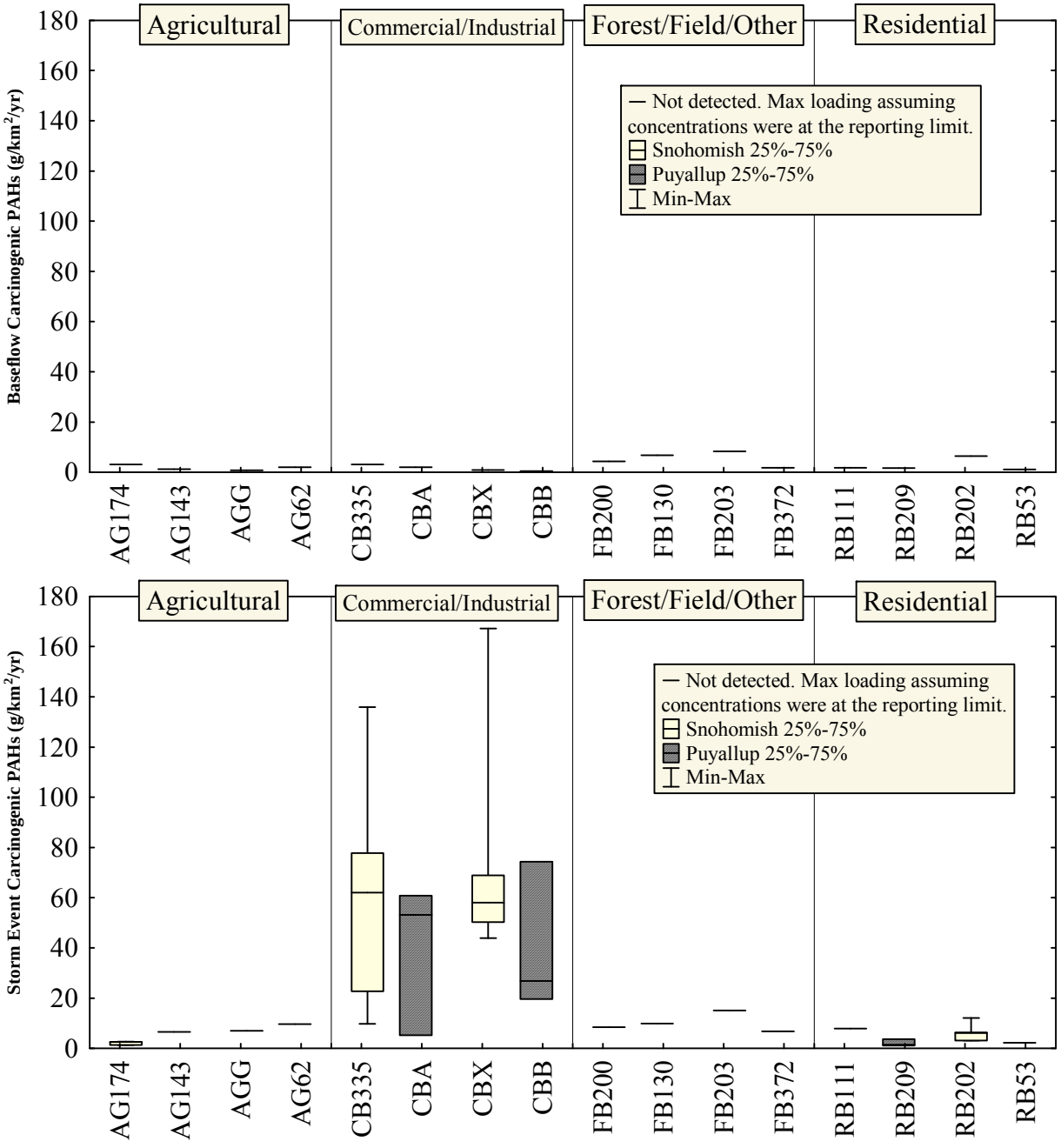

Figure 52. Baseflow and storm-event unit-area chemical loading box plots for carcinogenic polycyclic aromatic hydrocarbons (cPAHs) for the Phase 3 study of toxics in surface runoff to Puget Sound.

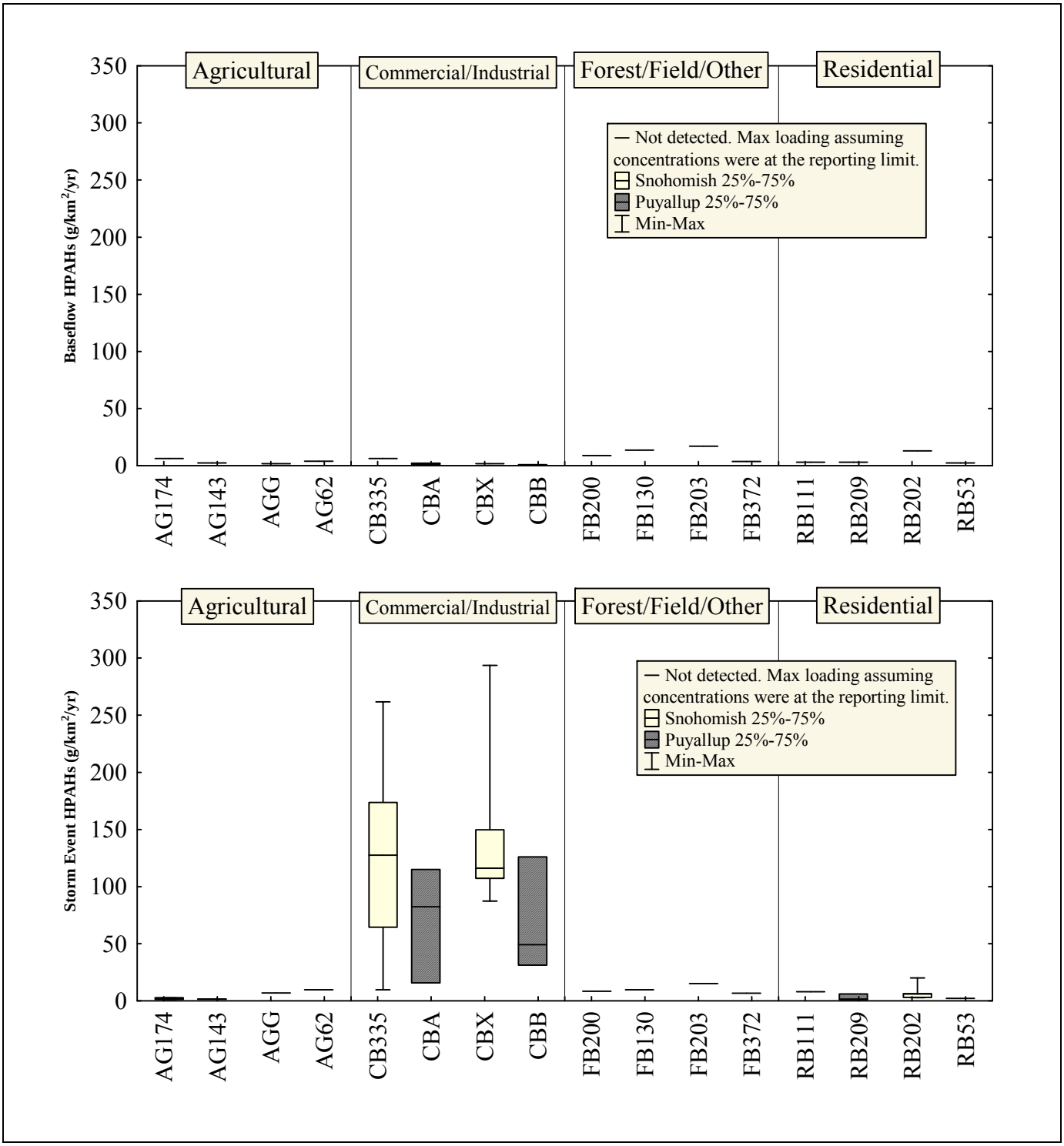

Figure 53. Baseflow and storm-event unit-area chemical loading box plots for high molecular weight polycyclic aromatic hydrocarbons (HPAHs) for the Phase 3 study of toxics in surface runoff to Puget Sound.

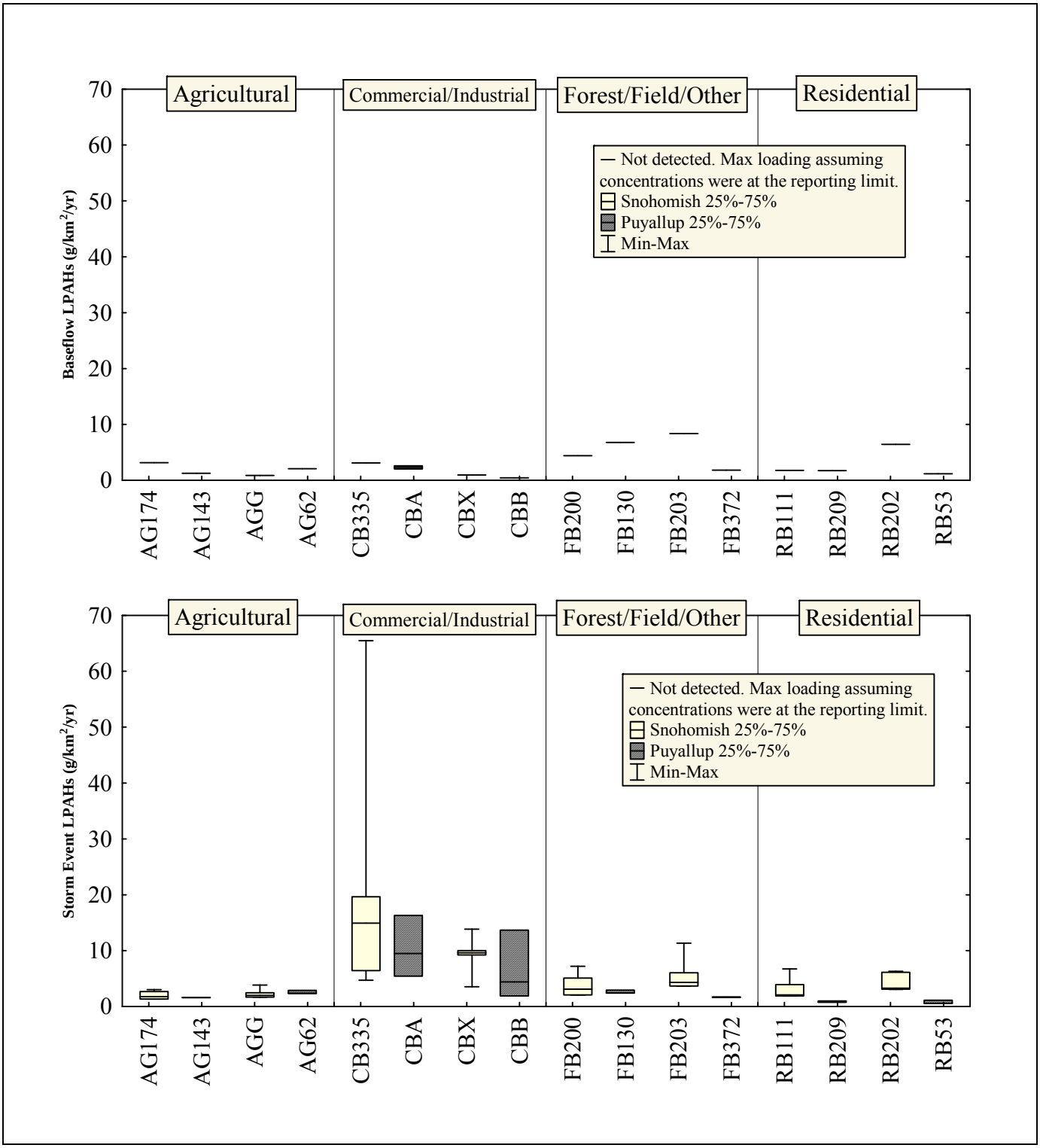

Figure 54. Baseflow and storm-event unit-area chemical loading box plots for low molecular weight polycyclic aromatic hydrocarbons (LPAHs) for the Phase 3 study of toxics in surface runoff to Puget Sound.

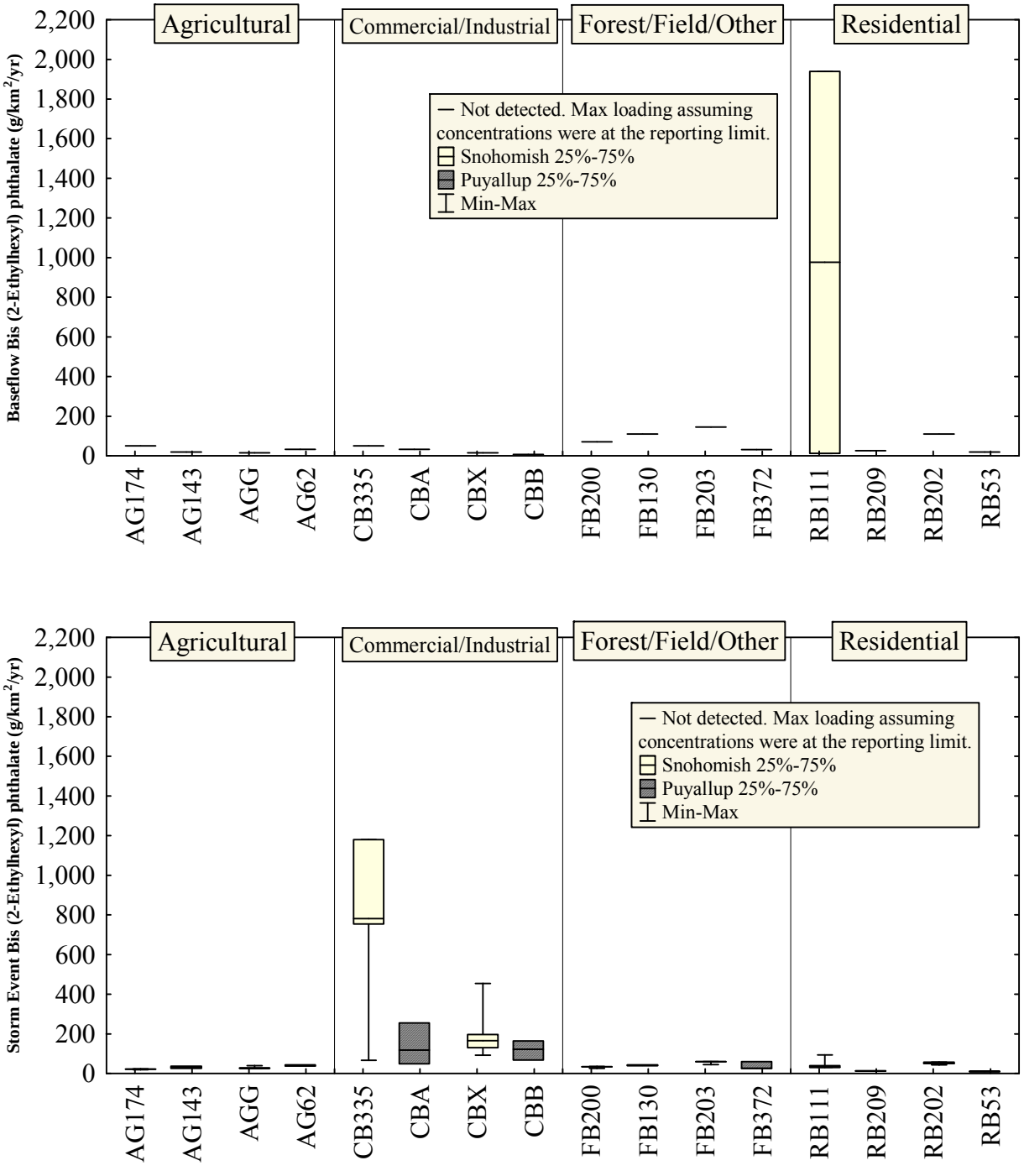

Figure 55. Baseflow and storm-event unit-area chemical loading box plots for bis(2-ethylhexyl) phthalate for the Phase 3 study of toxics in surface runoff to Puget Sound.

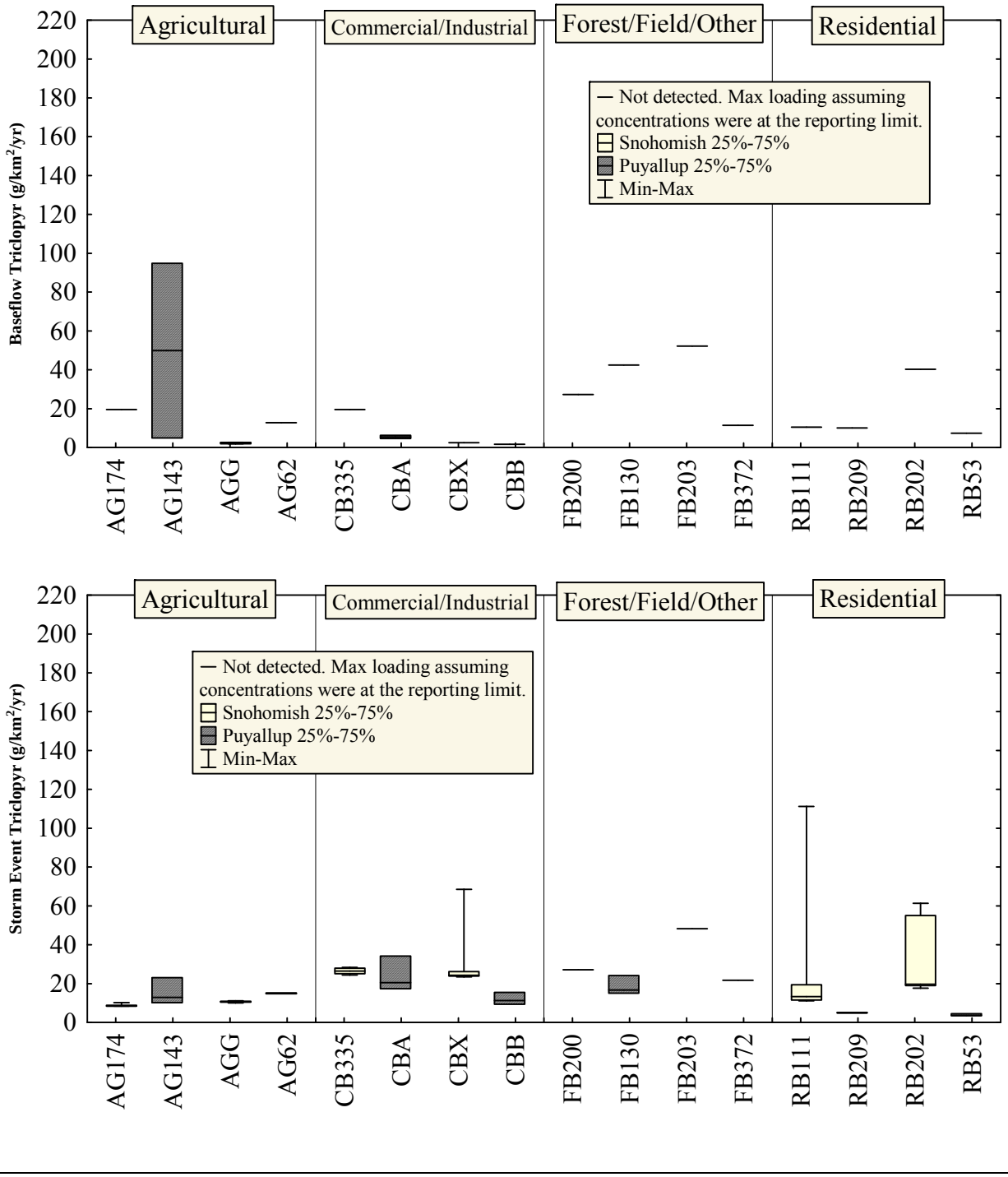

Figure 56. Baseflow and storm-event unit-area chemical loading box plots for triclopyr for the Phase 3 study of toxics in surface runoff to Puget Sound.

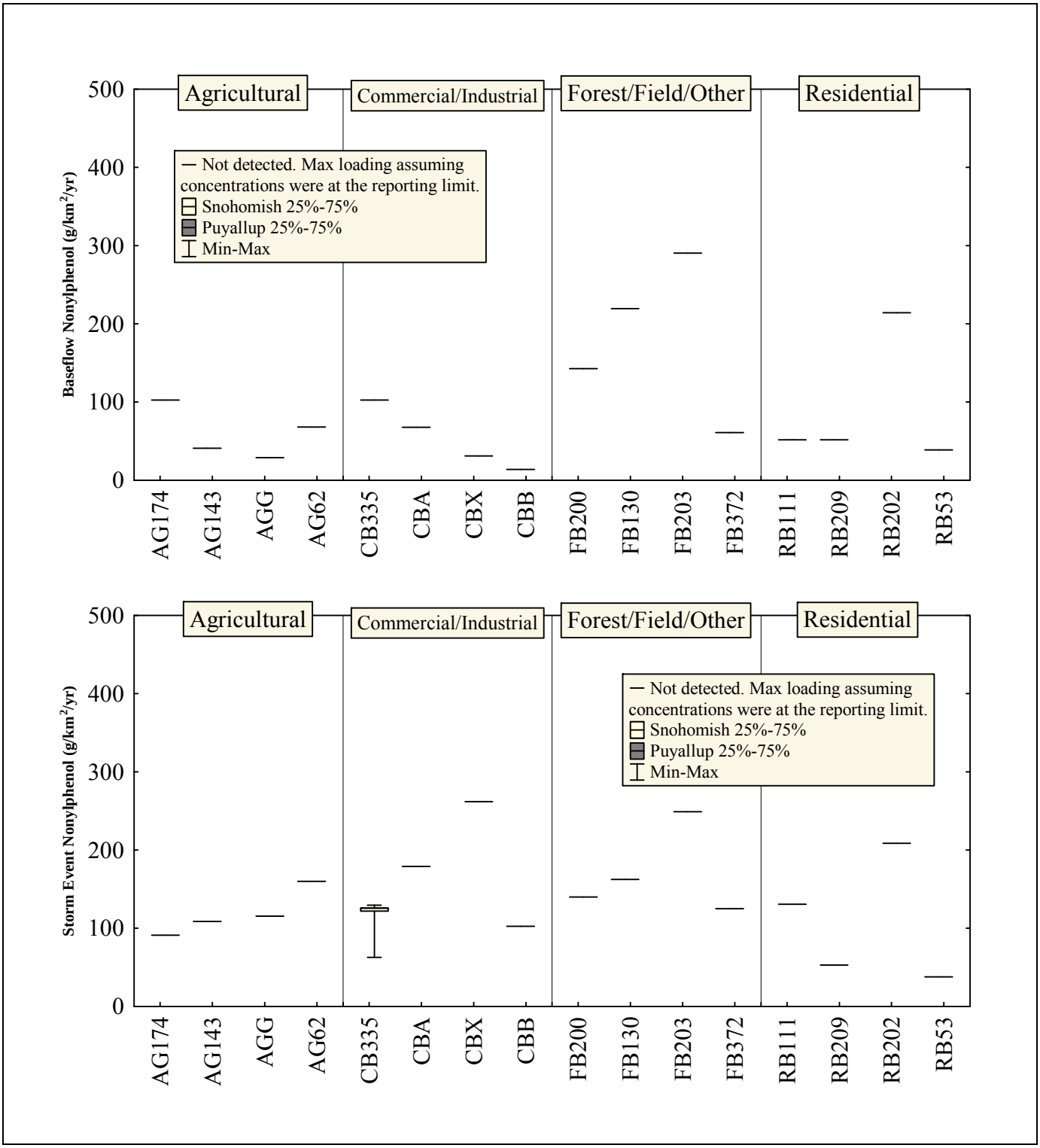

Figure 57. Baseflow and storm-event unit-area chemical loading box plots for nonylphenol for the Phase 3 study of toxics in surface runoff to Puget Sound.

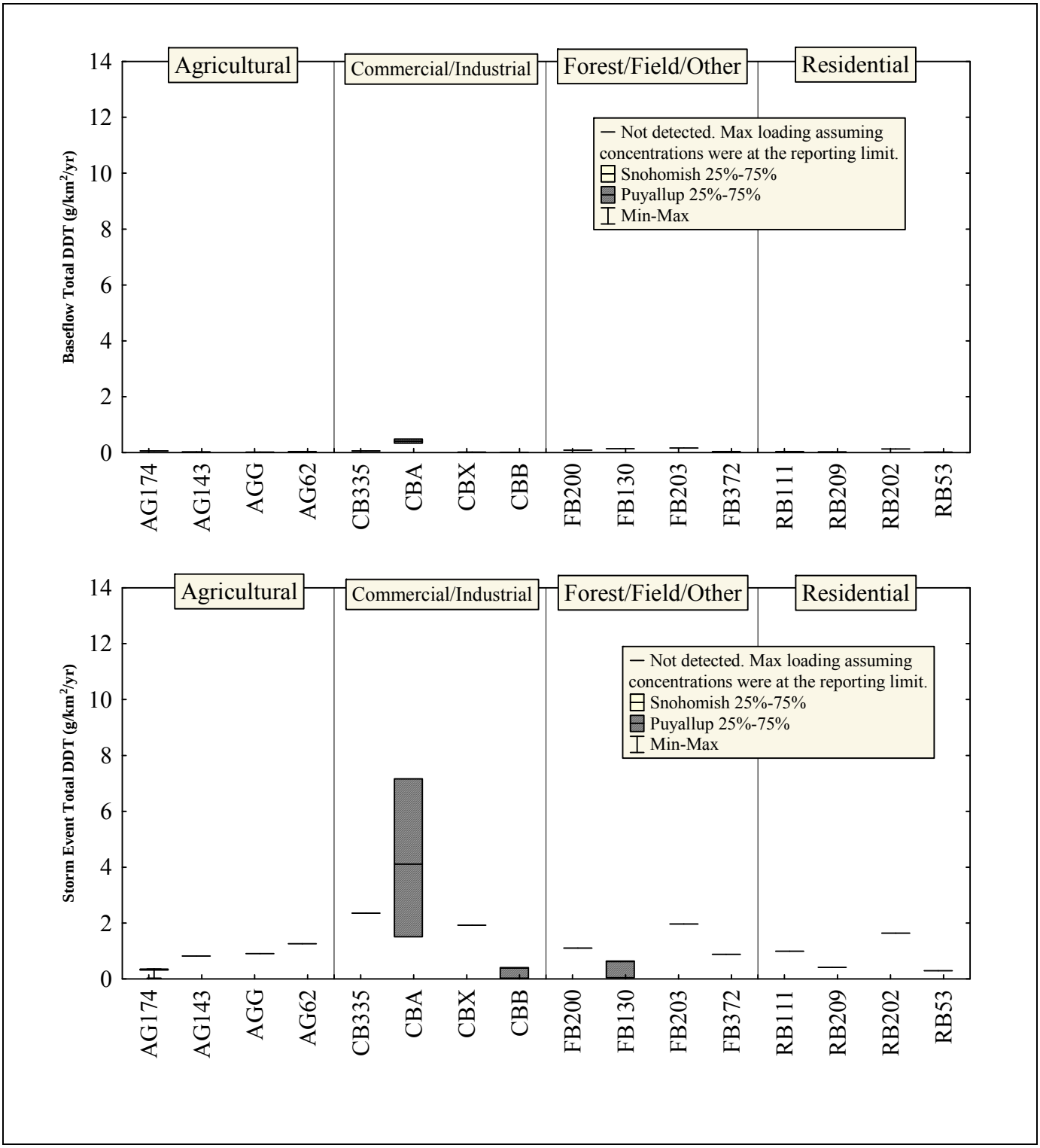

Figure 58. Baseflow and storm-event unit-area chemical loading box plots for total dichlorodiphenyltrichloroethane (DDT) for the Phase 3 study of toxics in surface runoff to Puget Sound.

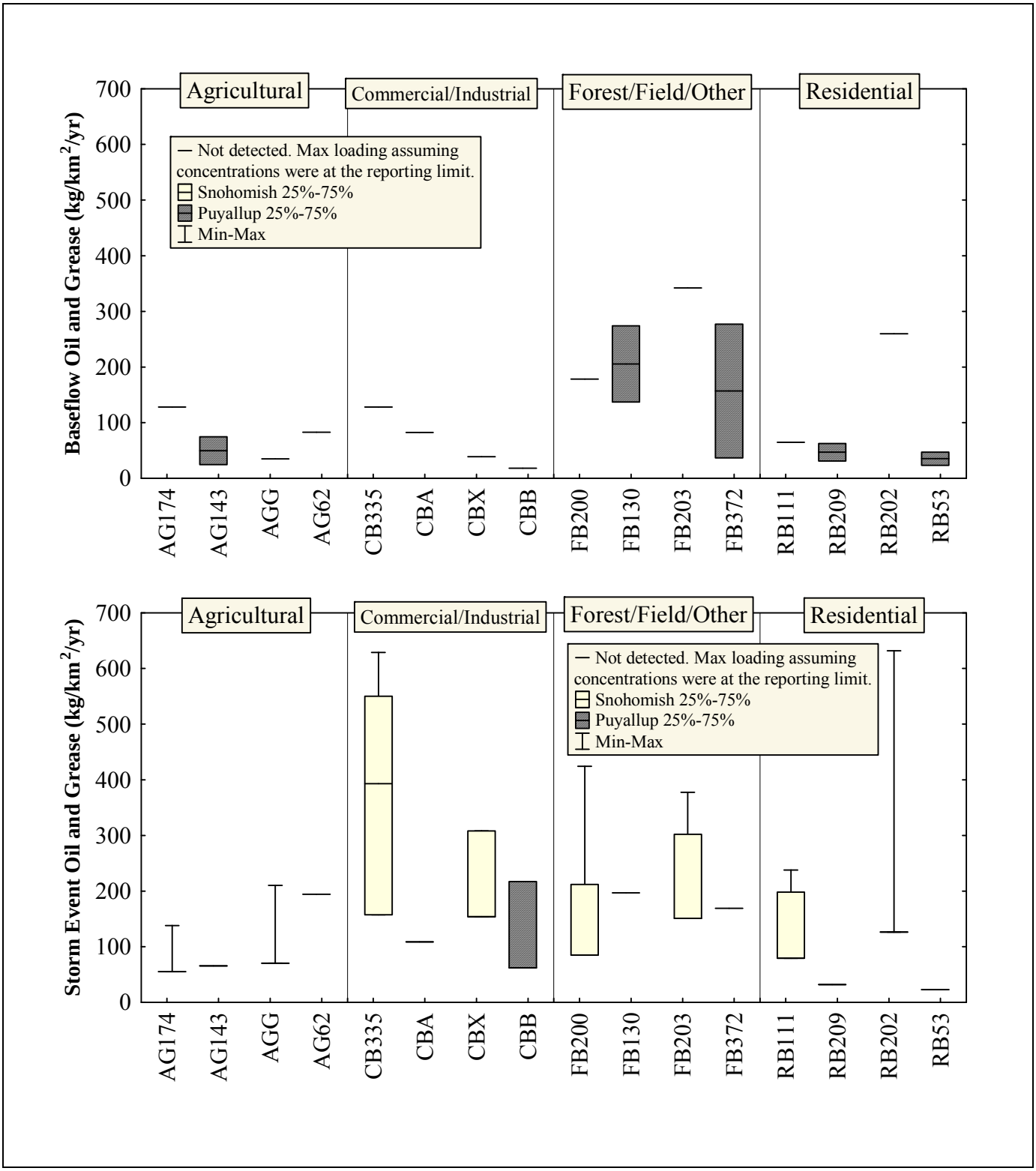

Figure 59. Baseflow and storm-event unit-area chemical loading box plots for oil and grease for the Phase 3 study of toxics in surface runoff to Puget Sound.

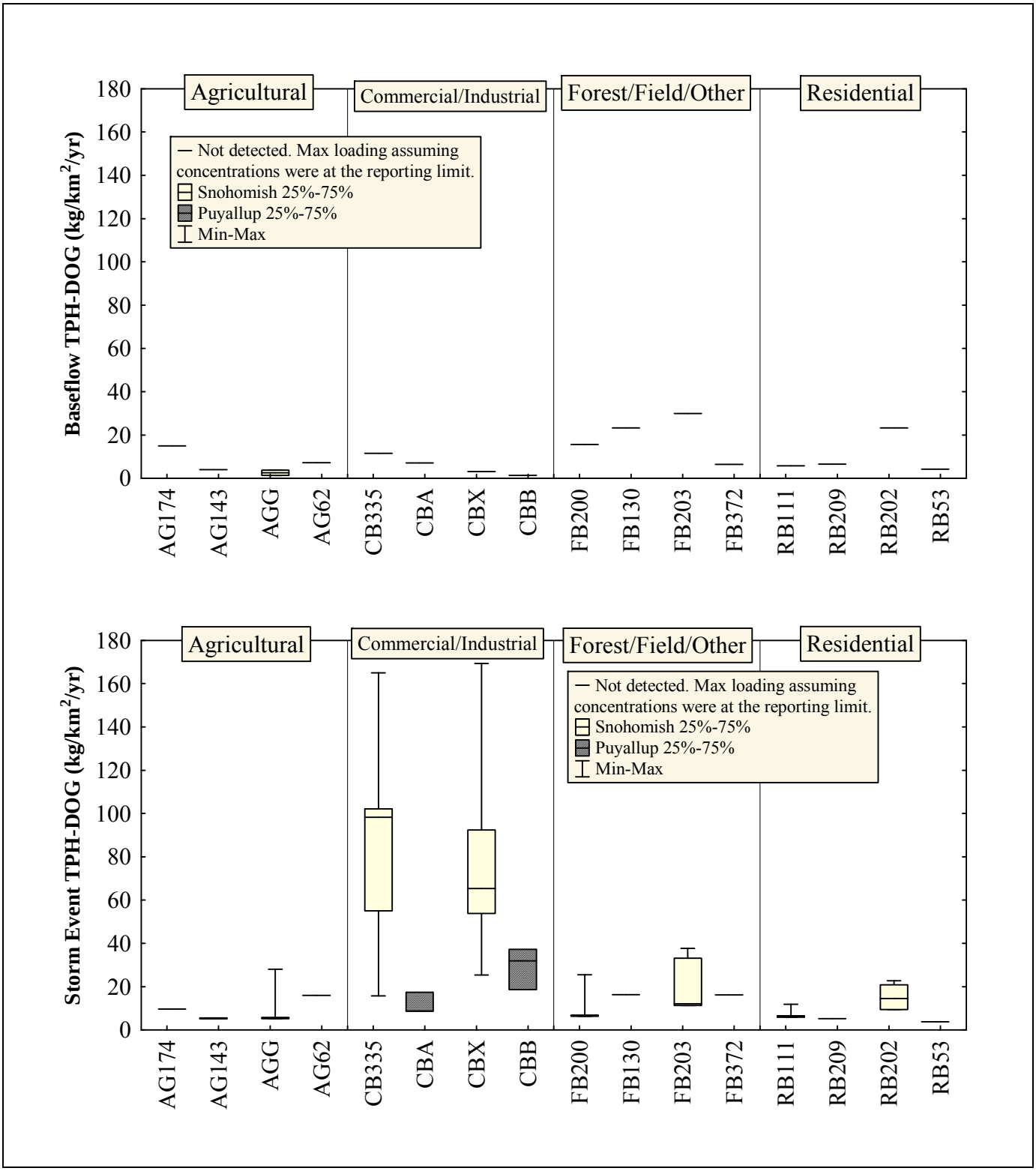

Figure 60. Baseflow and storm-event unit-area chemical loading box plots for lube oil (TPH-DOG) for the Phase 3 study of toxics in surface runoff to Puget Sound.

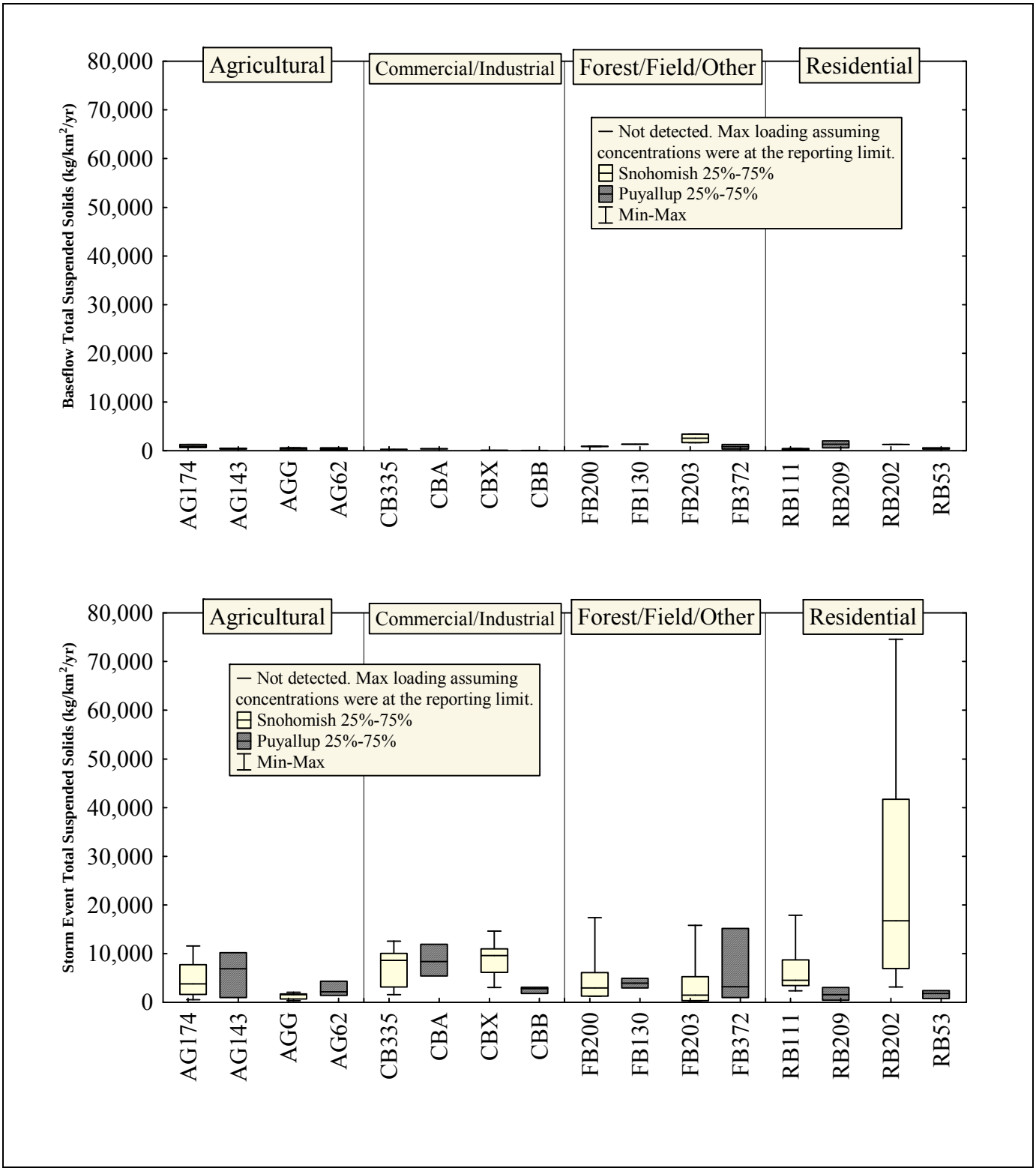

Figure 61. Baseflow and storm-event unit-area chemical loading box plots for total suspended solids (TSS) for the Phase 3 study of toxics in surface runoff to Puget Sound.

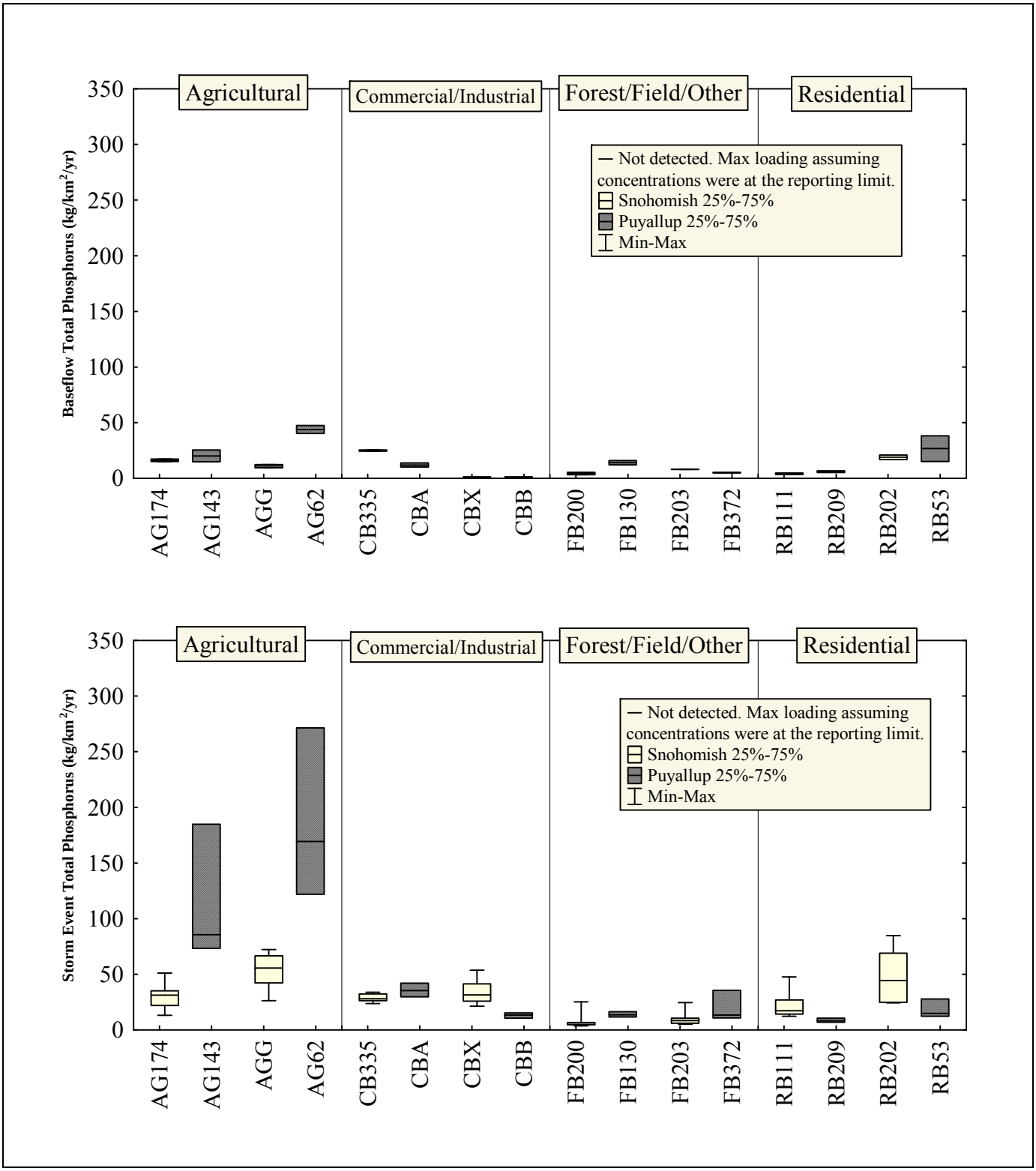

Figure 62. Baseflow and storm-event unit-area chemical loading box plots for total phosphorus for the Phase 3 study of toxics in surface runoff to Puget Sound.

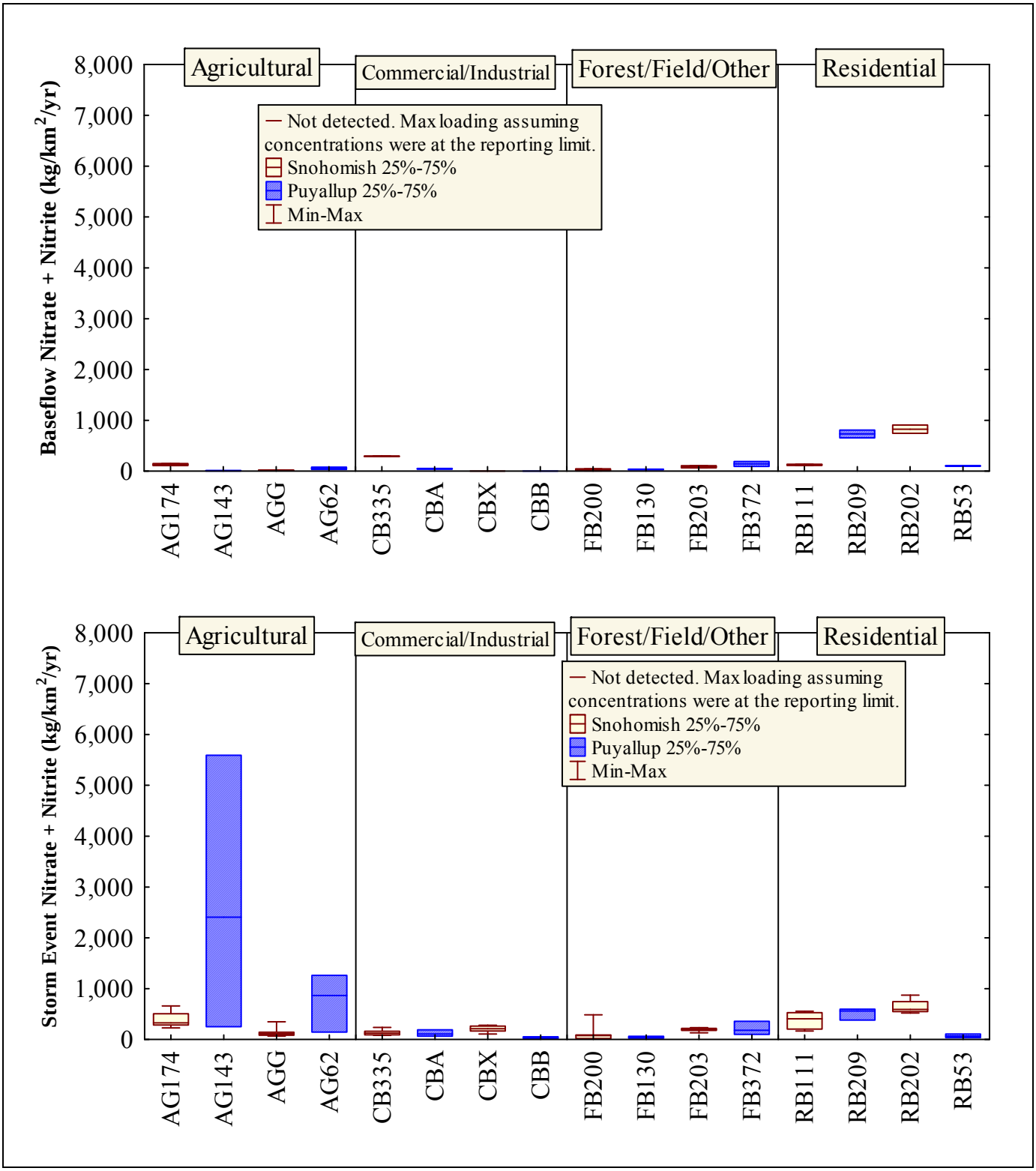

Figure 63. Baseflow and storm-event unit-area chemical loading box plots for nitrate+nitrite nitrogen for the Phase 3 study of toxics in surface runoff to Puget Sound.

Tables

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Table 1. Summary information for selected monitoring locations and their associated drainage basins in the Snohomish River watershed and Puyallup River watershed.

Monitoring Location ID	Monitoring Location Coordinates (UTM)	Drainage Basin Representative Land Use	Drainage Basin Area (hectares)	Land Use Breakdown (%)			
				Commercial/ Industrial	Residential	Agricultural	Forest/Field/ Other
Snohomish River Watershed							
CB335	554014.728964, 5309812.65922	Commercial/Industrial	213.6	62.7%	29.2%	0.0%	7.5%
CBX	555699.664563, 5309826.5359	Commercial/Industrial	219.4	26.4%	64.0%	0.0%	7.9%
RB111	569280.125094, 5311635.31379	Residential	556.3	0.2%	58.8%	3.4%	37.6%
RB202	568103.716954, 5299312.08525	Residential	334.1	0.4%	64.0%	0.0%	35.6%
AG174	569460.091694, 5302197.60046	Agricultural	290.4	0%	11.8%	57.1%	31.1%
AGG	559528.446036, 5330820.43366	Agricultural	246.4	0.0%	25.8%	49.0%	25.2%
FB200	577729.711516, 5318011.24222	Forest/Field/Other	174.4	0.0%	9.3%	0.0%	90.7%
FB203	588161.362388, 5299897.77717	Forest/Field/Other	1656.9	0.0%	2.9%	0.0%	95.8%
Puyallup River Watershed							
CBA	557134.530396, 5234155.0863	Commercial/Industrial	656.5	31.8%	62.1%	0.0%	6.2%
CBB	551484.812353, 5238023.54968	Commercial/Industrial	436.6	38.1%	48.4%	0.0%	13.4%
RB53	551168.088855, 5231526.86235	Residential	376.3	5.1%	81.7%	1.1%	9.8%
RB209	548616.293597, 5228040.37359	Residential	549.2	4.5%	81.6%	0%	13.9%
AG143	576488.827227, 5225382.62099	Agricultural	164.8	0.4%	10.6%	81.5%	7.5%
AG62	571169.400258, 5232968.32363	Agricultural	292.7	0.1%	23.3%	50.7%	25.9%
FB130	590848.135546, 5225066.88834	Forest/Field/Other	80.4	0.0%	3.5%	0.0%	96.5%
FB372	563043.022045, 5214260.42147	Forest/Field/Other	528.4	0.0%	2.5%	0.0%	97.5%

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Table 2. Storm-event and baseflow sampling dates in the Snohomish River watershed and Puyallup River watershed.

Event	Season	Sample Date	Antecedent Dry Period (hours)	Precipitation Duration (hours)	Precipitation Total (inches)	Precipitation Peak Hourly Intensity (inches/hour)
Snohomish Watershed [a]						
Storm - 1	Fall	10/17/2009	13	22	1.06	0.27
Storm - 2	Winter	11/5/2009	57	140	4.11	0.23
Storm - 3	Winter	11/19/2009	22	241	7.1	0.35
Storm - 4	Winter	1/4/2010	17	49	1.96	0.13
Storm - 5	Spring	4/2/2010	13	39	1.03	0.08
Storm - 6	Spring	4/21/2010	14	19	1.42	0.21
Base - 1	Winter	5/14/2010	88	NA	NA	NA
Base - 2	Summer	7/6/2010	28	NA	NA	NA
Puyallup Watershed [b]						
Storm - 1	Fall	10/26/2009	47	26	0.42	0.06
Storm - 2	Winter	11/16/2009	14	47	0.52	0.05
Storm - 3	Winter	12/14/2009	125	56	0.54	0.09
Storm - 4	Winter	1/11/2010	40	14	0.45	0.13
Storm - 5	Spring	5/19/2010	17	31	0.81	0.14
Storm - 6	Spring	5/28/2010	14	42	0.35	0.04
Base - 1	Winter	5/13/2010	124	NA	NA	NA
Base - 2	Summer	7/7/2010	66	NA	NA	NA

[a] Precipitation data for Snohomish watershed from USGS gauge 12143400 (gaps filled with data from 12147900)
[b] Precipitation data for Puyallup watershed from USGS gauge 12092000 (gaps filled with data from 12095000)
NA = not applicable

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Table 3. Monitoring parameters and number of samples collected during baseflow events for the Phase 3 study of toxics in surface runoff to Puget Sound.

Parameter	Snohomish Watershed								Puyallup Watershed								Total Number of Baseflow Event Samples [a]
	CB335	CBX	RB111	RB202	AG174	AGG	FB200	FB203	CBA	CBB	RB53	RB209	AG143	AG62	FB130	FB372	
Dissolved As, Cd, Cu, Pb, Zn	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Total As, Cd, Cu, Pb, Zn	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Dissolved Al, Ba, Be, Co, Mn, Ni, Se, Sn, Tl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Al, Ba, Be, Co, Mn, Ni, Se, Sn, Tl	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dissolved Mercury	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Total Mercury	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
PCBs (209 congeners)	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
PBDE (35 congeners)	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
PAHs	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
BNAs (plus Bisphenol A and Nonyphenol)	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Herbicides (plus Triclopyr)	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Pesticides	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
TPH – Gas (first grab only)	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
TPH – Diesel (first grab only)	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
TPH – Lube Oil (first grab only)	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Oil & Grease (first grab only)	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Oil &Grease – Lube Oil (first grab only)	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Total Hardness	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Ammonia Nitrogen	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Nitrate+Nitrite Nitrogen	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Total Nitrogen	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Dissolved Organic Carbon	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Total Organic Carbon	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Orthophosphate Phosphorus	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Total Phosphorus	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Total Suspended Solids	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
Dissolved Oxygen (*in situ*)	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	30
pH (*in situ*)	2	1	2	2	2	2	2	2	2	1	2	2	2	2	2	2	30
Specific Conductance (*in situ*)	2	1	2	2	2	2	2	2	2	1	2	2	2	2	2	2	30
Temperature (*in situ*)	2	1	2	2	2	2	2	2	2	1	2	2	2	2	2	2	30
Flow (*in situ*)	2	1	2	2	2	2	2	2	2	1	2	2	2	2	2	2	30

[a] Total number does not include samples collected for QA purposes. Actual number of samples available for each monitoring location may be less if data were rejected during the data validation process

BNAs: base/neutral/acid extractable compounds

PAH: polycyclic aromatic hydrocarbons

PBDEs: polybrominated diphenyl ethers

PCBs: polychlorinated biphenyls

TPH: total petroleum hydrocarbons

Al: aluminum

As: arsenic

Ba: barium

Be: beryllium

Cd: cadmium

Cu: copper

Mn: manganese

Ni: nickel

Pb: lead

Se: selenium

Sn: tin

Tl: thallium

Zn: zinc

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Table 4. Monitoring parameters and number of samples collected during storm events for the Phase 3 study of toxics in surface runoff to Puget Sound.

Parameter	Snohomish Watershed								Puyallup Watershed								Total Number of Storm-Event Samples [a]
	CB335	CBX	RB111	RB202	AG174	AGG	FB200	FB203	CBA	CBB	RB53	RB209	AG143	AG62	FB130	FB372	
Dissolved As, Cd, Cu, Pb, Zn	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Total As, Cd, Cu, Pb, Zn	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Dissolved Al, Ba, Be, Co, Mn, Ni, Se, Sn, Tl	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	12
Total Al, Ba, Be, Co, Mn, Ni, Se, Sn, Tl	1	1	1	1	0	0	1	1	1	1	1	1	0	0	1	1	12
Dissolved Mercury	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Total Mercury	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
PCBs (209 congeners)	3	3	3	3	1	1	3	3	3	3	3	3	1	1	3	3	40
PBDE (35 congeners)	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	64
PAHs	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
BNAs (plus Bisphenol A and Nonyphenol)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Herbicides (plus Triclopyr)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Pesticides	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
TPH – Gas (first grab only)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
TPH – Diesel(first grab only)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
TPH – Lube Oil (first grab only)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Oil & Grease (first grab only)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Oil & Grease – Lube Oil (first grab only)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Total Hardness	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Ammonia Nitrogen	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Nitrate+Nitrite Nitrogen	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Total Nitrogen	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Dissolved Organic Carbon	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Total Organic Carbon	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Orthophosphate Phosphorus	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Total Phosphorus	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Total Suspended Solids	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Dissolved Oxygen (*in situ)*	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
pH (*in situ)*	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Specific Conductance (*in situ)*	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Temperature (*in situ)*	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96
Flow (*in situ)*	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	96

[a] Total number does not include samples collected for QA purposes. Actual number of samples available for each monitoring location may be less if data were rejected during the data validation process

BNAs: base/neutral/acid extractable compounds

PAH: polycyclic aromatic hydrocarbons

PBDEs: polybrominated diphenyl ethers

PCBs: polychlorinated biphenyls

TPH: total petroleum hydrocarbons

Al: aluminum

As: arsenic

Ba: barium

Be: beryllium

Cd: cadmium

Cu: copper

Mn: manganese

Ni: nickel

Pb: lead

Se: selenium

Sn: tin

Tl: thallium

Zn: zinc

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Table 5. Average discharge measured at monitoring locations and associated hydrograph separation results from monitoring conducted over the period from August 1, 2009, through July 31, 2010.

Site	Discharge (cfs)			Area-Normalized Discharge (cfs/square mile)			Flow QA Flag [c]
	Average Baseflow [a]	Average Storm-Event [b]	Average Base and Storm	Average Baseflow	Average Storm-Event	Average Base and Storm	
Snohomish Watershed							
CB335	0.77	1.88	2.65	0.93	2.28	3.21	
CBX	0.24	1.89	2.13	0.28	2.19	2.46	
RB111	1.01	2.47	3.48	0.45	1.10	1.55	
RB202	2.43	2.36	4.79	1.88	1.83	3.71	
AG174	1.04	0.90	1.94	0.75	0.65	1.39	j
AGG	0.24	0.97	1.21	0.25	1.00	1.25	
FB200	0.87	0.83	1.70	1.30	1.23	2.53	j
FB203	15.9	14.0	29.9	2.48	2.19	4.67	
Puyallup Watershed							
CBA	1.51	3.99	5.50	0.60	1.58	2.17	
CBB	0.22	1.52	1.74	0.13	0.90	1.04	
RB53	0.50	0.49	0.98	0.34	0.34	0.68	j
RB209	0.96	0.99	1.95	0.46	0.47	0.92	j
AG143	0.23	0.61	0.84	0.18	0.47	0.64	
AG62	0.68	1.59	2.27	0.53	1.25	1.78	
FB130	0.62	0.44	1.06	1.99	1.43	3.42	j
FB372	1.09	2.00	3.09	0.54	0.98	1.52	

[a] Baseflow discharge is calculated as the flow which passed the gauging station between storm events

[b] Storm-event discharge is calculated as the sum of baseflow discharge and storm-event discharge through the duration of each delineated storm event

[c] Quality assurance (QA) flag from the hydrologic data QA memoranda

cfs = cubic feet per second

j = estimate

Table 6. Priority parameters for the Phase 3 study of toxics in surface runoff to Puget Sound.

Key Toxic Chemicals
Arsenic, total [a] and dissolved [b]
Cadmium, total [a] and dissolved [b]
Copper, total [a] and dissolved [b]
Lead, total [a] and dissolved [b]
Mercury. total [a] and dissolved [b]
Zinc, total [a] and dissolved [b]
Total PCBs [a]
Total PBDEs [a]
Total PAHs [b]
Carcinogenic PAHs (cPAHs) [a]
High molecular weight PAHs (HPAHs) [a]
Low molecular weight PAHs (LPAHs) [a]
bis(2-ethylhexyl) phthalate [a]
Triclopyr [a]
Nonylphenol [a]
Total DDT [a]
Oil and grease [a]
Lube oil (TPH-DOG) [b]
Total suspended solids [b]
Total phosphorus [b]
Nitrate+nitrite nitrogen [b]

[a] Priority parameter for the Phase 1 and 2 studies of toxics loading to Puget Sound

[b] Priority parameter added for the Phase 3 study

PCBs = polychlorinated biphenyls

PBDE = polybrominated diphenyl ethers

PAHs = polycyclic aromatic hydrocarbons

DDT = dichlorodiphenyltrichloroethane

TPH-DOG = total petroleum hydrocarbons lube oil from dissolved oil and grease

Table 7. Drainage basin area by land use in the Snohomish watershed and Puyallup watershed.

Land Use	Basin Area (square kilometers)
Snohomish Watershed	
Commercial/Industrial	10.2
Residential	421.2
Agricultural	137.5
Forest	4,057.6
Puyallup Watershed	
Commercial/Industrial	14.1
Residential	301.2
Agricultural	80.4
Forest	2,065.4

Table 8. Drainage basin area by land use for the 14 study areas in the Puget Sound basin.

	Drainage Basin Area (square kilometers)				
	Commercial / Industrial	**Residential**	**Agriculture**	**Forest**	**Total**
Main Basin	72.8	900.1	21.7	1,069.2	2,063.8
Port Gardner	19.7	452.8	142.9	4,141.1	4,756.5
Elliott Bay	57.3	317.6	55.6	879.1	1,309.6
Commencement Bay	32.5	401.9	75.6	2,181.2	2,691.3
South Sound (East)	27.8	518.3	131.7	2,054.9	2,732.7
South Sound (West)	10.0	257.8	35.5	1,270.1	1,573.4
Hood Canal (South)	0.6	93.3	5.5	2,320.3	2,419.7
Hood Canal (North)	0.5	48.5	0.9	295.6	345.4
Sinclair/Dyes Inlet	7.5	144.0	2.6	223.0	377.1
Admiralty Inlet	1.1	49.3	20.4	223.8	294.6
Strait of Juan de Fuca	7.0	135.1	87.0	2,914.3	3,143.4
Strait of Georgia	15.9	291.3	547.3	2,775.3	3,629.8
Whidbey Basin	9.8	410.9	328.2	8,798.1	9,547.0
San Juan Islands	6.0	98.0	71.0	494.7	669.7
Puget Sound Basin	268.5	4,118.9	1,525.8	29,640.7	35,553.9

Table 9. Monthly and annual precipitation totals (in inches) for 2009-2010 compared to historical totals at the SeaTac airport in SeaTac, Washington.

Month	SeaTac Airport Station #457473 Rainfall Data: 2009-2010	SeaTac Airport Station #457473 Historical Rainfall Data: 1948-2009		
		25th Percentile	Average	75th Percentile
August	1.16	0.32	1.10	1.62
September	1.75	0.79	1.73	2.26
October	**5.54**	2.15	3.48	4.30
November	**8.96**	4.12	6.15	8.02
December	*2.75*	4.40	5.81	7.13
January	6.17	4.09	5.76	7.71
February	3.52	2.31	3.93	4.97
March	3.76	2.67	3.73	4.38
April	**3.49**	1.56	2.52	3.31
May	**2.83**	1.11	1.72	2.10
June	**2.49**	0.72	1.44	1.85
July	*0.31*	0.32	0.75	1.15
Total	**42.73**	33.73	38.12	42.53

[a] Source: SeaTac Airport Station #457473 (WRCC 2011). Based on average monthly and annual precipitation totals measured over the period from 1948 to 2009.

Values in *italics* are below the 25th percentile value from the historical monthly or annual precipitation totals.

Values in **bold** are above the 75th percentile value from the historical monthly or annual precipitation totals.

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Table 10. Summary statistics for measured concentrations of priority parameters identified for the Phase 3 study of toxics in surface runoff to Puget Sound.

		Baseflow												Storm Event											
		Commercial/Industrial				Residential				Agricultural				Forest/Field/Other				Combined				Commercial/Industrial			
			Percent	Median			Percent	Median			Percent	Median			Percent	Median			Percent	Median			Percent	Median	
	Units	n	Detected	Concentration	Flag	n	Detected	Concentration	Flag	n	Detected	Concentration	Flag	n	Detected	Concentration	Flag	n	Detected	Concentration	Flag	n	Detected	Concentration	Flag
Metals																									
Dissolved Arsenic	µg/L	6	100%	1.31		8	100%	0.64		8	100%	1.31		8	100%	0.34		30	100%	0.75		24	100%	0.64	
Total Arsenic	µg/L	6	100%	1.32		8	100%	0.63		8	100%	1.37		8	100%	0.36		30	100%	0.77		24	100%	0.92	
Dissolved Cadmium	µg/L	6	67%	0.02		8	0%	< 0.02	U	8	0%	< 0.02	U	8	0%	< 0.02	U	30	13%	0.01	E	24	92%	0.03	
Total Cadmium	µg/L	6	0%	< 0.10	U	8	0%	< 0.10	U	8	0%	< 0.10	U	8	0%	< 0.10	U	30	0%	< 0.10	U	24	33%	0.05	E
Dissolved Copper	µg/L	6	100%	1.45		8	100%	0.63		8	100%	1.47		8	100%	0.47		30	100%	0.74		24	100%	2.28	
Total Copper	µg/L	6	100%	1.88		8	100%	0.88		8	100%	1.69		8	100%	0.63		30	100%	0.97		24	100%	3.84	
Dissolved Lead	µg/L	6	83%	0.16		8	100%	0.04		8	88%	0.05		8	50%	0.02	E	30	80%	0.04		24	100%	0.23	
Total Lead	µg/L	6	67%	0.27		8	100%	0.16		8	50%	0.09	E	8	25%	0.05	E	30	60%	0.13		24	100%	1.68	
Dissolved Mercury	µg/L	6	50%	0.002	E	8	50%	0.002	E	8	100%	0.003		8	25%	0.001	E	30	57%	0.002		24	88%	0.003	
Total Mercury	µg/L	6	100%	0.002		8	88%	0.003		8	100%	0.004		8	63%	0.002		30	87%	0.003		24	100%	0.007	
Dissolved Zinc	µg/L	6	100%	11.5		8	100%	1.7		8	100%	3.9		8	63%	1.2		30	90%	2.3		24	100%	29.1	
Total Zinc	µg/L	6	100%	15.9		8	25%	2.5	E	8	63%	8.8		8	13%	2.5	E	30	47%	2.5	E	24	100%	37.2	
Organics																									
Total PCBs	pg/L	6	100%	341.40		8	38%	178.95	E	8	63%	239.50		8	63%	121.00		30	63%	226.95		12	100%	2019.75	
Total PBDEs	pg/L	6	100%	436.0		8	38%	125.0	E	9	44%	125.0	E	8	25%	125.0	E	31	48%	125.0	E	16	100%	3273.1	
Total PAHs	µg/L	6	33%	0.0100	E	8	0%	< 0.0200	U	8	0%	< 0.0200	U	8	0%	< 0.0200	U	30	7%	0.0095	E	24	96%	0.1756	
cPAHs	µg/L	6	0%	< 0.0098	U	8	0%	< 0.0110	U	8	0%	< 0.0100	U	8	0%	< 0.0099	U	30	0%	< 0.0110	U	24	92%	0.0845	
LPAHs	µg/L	6	33%	0.0049	E	8	0%	< 0.0110	U	8	0%	< 0.0100	U	8	0%	< 0.0099	U	30	7%	0.0049	E	24	96%	0.0135	
HPAHs	µg/L	6	33%	0.0097	E	8	0%	< 0.0200	U	8	0%	< 0.0200	U	8	0%	< 0.0200	U	30	7%	0.0095	E	24	96%	0.1516	
Bis(2-ethylhexyl)phthalate	µg/L	6	0%	< 0.160	U	8	13%	0.085	E	8	0%	< 0.170	U	8	0%	< 0.170	U	30	3%	0.080	E	24	54%	0.340	
Triclopyr	µg/L	6	50%	0.0305	E	8	0%	< 0.0650	U	8	38%	0.0307	E	8	0%	< 0.0620	U	30	20%	0.0305	E	24	46%	0.0323	E
Nonylphenol	µg/L	6	0%	< 0.330	U	8	0%	< 0.330	U	8	0%	< 0.330	U	8	0%	< 0.340	U	30	0%	< 0.340	U	24	4%	0.160	E
Total DDTs	ng/L	6	33%	0.100	E	8	0%	< 0.210	U	8	0%	< 0.220	U	8	0%	< 0.200	U	30	7%	0.100	E	24	25%	1.250	E
Oil and Grease	mg/L	6	17%	0.20	E	8	25%	0.20	E	8	13%	0.20	E	8	25%	0.20	E	30	20%	0.20	E	24	38%	0.20	E
TPH - DOG	mg/L	6	0%	< 0.036	U	8	0%	< 0.042	U	8	13%	0.016	E	8	0%	< 0.035	U	30	3%	0.016	E	24	75%	0.075	
Conventionals																									
Total Suspended Solids	mg/L	6	33%	0.50	E	8	100%	3.00		8	100%	3.00		8	100%	2.00		30	87%	2.00		24	100%	10.00	
Total Phosphorus	mg/L	6	100%	0.058		8	100%	0.033		8	100%	0.131		8	100%	0.015		30	100%	0.038		24	100%	0.044	
Nitrate + Nitrite Nitrogen	mg/L	6	100%	0.230		8	100%	1.027		8	100%	0.216		8	100%	0.089		30	100%	0.308		24	100%	0.174	

		Storm Event															
		Residential				Agricultural				Forest/Field/Other				Combined			
			Percent	Median			Percent	Median			Percent	Median			Percent	Median	
	Units	n	Detected	Concentration	Flag	n	Detected	Concentration	Flag	n	Detected	Concentration	Flag	n	Detected	Concentration	Flag
Metals																	
Dissolved Arsenic	µg/L	24	96%	0.60		24	100%	1.14		24	100%	0.26		96	99%	0.60	
Total Arsenic	µg/L	24	100%	0.85		24	100%	1.17		24	100%	0.37		96	100%	0.81	
Dissolved Cadmium	µg/L	24	0%	< 0.02	U	24	46%	0.01	E	24	0%	< 0.02	U	96	34%	0.01	E
Total Cadmium	µg/L	24	0%	< 0.10	U	24	0%	< 0.10	U	24	0%	< 0.10	U	96	8%	0.05	E
Dissolved Copper	µg/L	24	96%	1.13		24	100%	4.07		24	100%	0.47		96	99%	2.03	
Total Copper	µg/L	24	100%	2.21		24	100%	5.19		24	100%	0.82		96	100%	3.24	
Dissolved Lead	µg/L	24	96%	0.12		24	100%	0.11		24	88%	0.05		96	96%	0.12	
Total Lead	µg/L	24	100%	0.52		24	92%	0.31		24	71%	0.13		96	91%	0.50	
Dissolved Mercury	µg/L	24	75%	0.005		24	100%	0.007		24	63%	0.002		96	81%	0.004	
Total Mercury	µg/L	24	100%	0.008		24	100%	0.011		24	96%	0.004		96	99%	0.008	
Dissolved Zinc	µg/L	24	100%	3.4		24	100%	6.7		24	71%	2.3		96	93%	5.5	
Total Zinc	µg/L	24	67%	7.3		24	92%	9.0		24	17%	2.5	E	96	69%	8.4	
Organics																	
Total PCBs	pg/L	12	83%	129.80		4	100%	275.50		12	58%	105.00		40	83%	348.00	
Total PBDEs	pg/L	16	56%	108.7		16	63%	125.0		16	44%	125.0	E	64	66%	125.0	
Total PAHs	µg/L	24	42%	0.0098	E	24	21%	0.0088	E	24	21%	0.0096	E	96	45%	0.0100	E
cPAHs	µg/L	24	21%	0.0075	E	24	4%	0.0049	E	24	0%	< 0.0200	U	96	29%	0.0095	E
LPAHs	µg/L	24	25%	0.0050	E	24	21%	0.0049	E	24	21%	0.0050	E	96	41%	0.0058	E
HPAHs	µg/L	24	25%	0.0082	E	24	8%	0.0049	E	24	0%	< 0.0200	U	96	32%	0.0095	E
Bis(2-ethylhexyl)phthalate	µg/L	24	17%	0.080	E	24	25%	0.080	E	24	25%	0.080	E	96	30%	0.080	E
Triclopyr	µg/L	24	54%	0.0310		24	29%	0.0310	E	24	21%	0.0310	E	96	38%	0.0310	E
Nonylphenol	µg/L	24	0%	< 0.330	U	24	0%	< 0.330	U	24	0%	< 0.370	U	96	1%	0.160	E
Total DDTs	ng/L	24	0%	< 2.600	U	24	4%	1.250	E	24	4%	1.250	E	96	8%	1.250	E
Oil and Grease	mg/L	24	21%	0.20	E	24	13%	0.20	E	24	17%	0.20	E	96	22%	0.20	E
TPH - DOG	mg/L	24	17%	0.016	E	24	8%	0.016	E	24	13%	0.016	E	96	28%	0.016	E
Conventionals																	
Total Suspended Solids	mg/L	24	100%	14.00		24	96%	5.50		24	92%	7.00		96	97%	9.00	
Total Phosphorus	mg/L	24	100%	0.067		24	100%	0.206		24	100%	0.024		96	100%	0.054	
Nitrate + Nitrite Nitrogen	mg/L	24	100%	0.994		24	100%	1.025		24	100%	0.228		96	100%	0.345	

Colored bars indicate relative magnitude across each row in the table

pg/L = pictograms per liter

mg/L = milligrams per liter

E = 50 percent or more of the data are non-detect values; reported values are considered estimates with relatively low accuracy.

U = All of the data are non-detect values; reported values were computed based on the maximum reporting limit.

cPAHs = carcinogenic polycyclic aromatic hydrocarbons

DDT = dichlorodiphenyltrichloroethane

HPAHs = high molecular weight polycyclic aromatic hydrocarbons

LPAHs = low molecular weight polycyclic aromatic hydrocarbons

PAHs = polycyclic aromatic hydrocarbons

PBDE = polybrominated diphenyl ethers

PCBs = polychlorinated biphenyls

TPH-DOG = total petroleum hydrocarbons, dissolved lube oil extract of oil and grease

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Table 11. Subbasin scale unit-area loads for priority parameters identified for the Phase 3 study of toxics in surface runoff to Puget Sound.

		Baseflow																Storm Event													
		Commercial/Industrial				Residential				Agricultural				Forest/Field/Other				Combined				Commercial/Industrial				Residential				Agricultural			
	Units	n	Percent Detected	Median Load	Flag	n	Percent Detected	Median Load	Flag	n	Percent Detected	Median Load	Flag	n	Percent Detected	Median Load	Flag	n	Percent Detected	Median Load	Flag	n	Percent Detected	Median Load	Flag	n	Percent Detected	Median Load	Flag	n	Percent Detected	Median Load	Flag
Metals																															
Dissolved Arsenic	g/km^2/yr	6	100%	210		8	100%	154		8	100%	258		8	100%	229		30	100%	279		24	100%	348		24	96%	186		24	100%	416	
Total Arsenic	g/km^2/yr	6	100%	212		8	100%	152		8	100%	269		8	100%	243		30	100%	287		24	100%	500		24	100%	264		24	100%	427	
Dissolved Cadmium	g/km^2/yr	6	67%	3.21		8	0%	< 4.82	U	8	0%	< 3.93	U	8	0%	< 13.5	U	30	13%	3.72	E	24	92%	16.3		24	0%	< 6.21	U	24	46%	3.65	E
Total Cadmium	g/km^2/yr	6	0%	< 16.0	U	8	0%	< 24.1	U	8	0%	< 19.7	U	8	0%	< 67.5	U	30	0%	< 37.2	U	24	33%	27.1	E	24	0%	< 31.0	U	24	0%	< 36.5	U
Dissolved Copper	g/km^2/yr	6	100%	233		8	100%	152		8	100%	289		8	100%	317		30	100%	276		24	100%	1240		24	96%	351		24	100%	1490	
Total Copper	g/km^2/yr	6	100%	302		8	100%	212		8	100%	332		8	100%	425		30	100%	361		24	100%	2090		24	100%	686		24	100%	1890	
Dissolved Lead	g/km^2/yr	6	83%	25.7		8	100%	9.63		8	88%	9.83		8	50%	13.5	E	30	80%	14.9		24	100%	125		24	96%	37.2		24	100%	40.1	
Total Lead	g/km^2/yr	6	67%	43.3		8	100%	38.5		8	50%	17.7	E	8	25%	33.7	E	30	60%	48.4		24	100%	912		24	100%	161		24	92%	113	
Dissolved Mercury	g/km^2/yr	6	50%	0.321	E	8	50%	0.482	E	8	100%	0.590		8	25%	0.675	E	30	57%	0.745		24	88%	1.63		24	75%	1.55		24	100%	2.55	
Total Mercury	g/km^2/yr	6	100%	0.321		8	88%	0.722		8	100%	0.787		8	63%	1.35		30	87%	1.12		24	100%	3.80		24	100%	2.48		24	100%	4.01	
Dissolved Zinc	g/km^2/yr	6	100%	1840		8	100%	409		8	100%	767		8	63%	810		30	90%	857		24	100%	15800		24	100%	1050		24	100%	2450	
Total Zinc	g/km^2/yr	6	100%	2550		8	25%	602	E	8	63%	1730		8	13%	1690	E	30	47%	931	E	24	100%	20200		24	67%	2270		24	92%	3280	
Organics																															
Total PCBs	mg/km^2/yr	6	100%	54.8		8	38%	43.1	E	8	63%	47.1		8	63%	81.6		30	63%	84.5		12	100%	1100		12	83%	40.3		4	100%	101	
Total PBDEs	mg/km^2/yr	6	100%	69.9		8	38%	30.1	E	9	44%	24.6	E	8	25%	84.3	E	31	48%	46.6	E	16	100%	1780		16	56%	33.7		16	63%	45.6	
Total PAHs	g/km^2/yr	6	33%	1.60	E	8	0%	< 4.82	U	8	0%	< 3.93	U	8	0%	< 13.5	U	30	7%	3.54	E	24	96%	95.3		24	42%	3.04	E	24	21%	3.19	E
cPAHs	g/km^2/yr	6	0%	< 1.57	U	8	0%	< 2.65	U	8	0%	< 1.97	U	8	0%	< 6.68	U	30	0%	< 4.10	U	24	92%	45.9		24	21%	2.33	E	24	4%	1.81	E
LPAHs	g/km^2/yr	6	33%	0.786	E	8	0%	< 2.65	U	8	0%	< 1.97	U	8	0%	< 6.68	U	30	7%	1.84	E	24	96%	7.33		24	25%	1.54	E	24	21%	1.81	E
HPAHs	g/km^2/yr	6	33%	1.56	E	8	0%	< 4.82	U	8	0%	< 3.93	U	8	0%	< 13.5	U	30	7%	3.54	E	24	96%	82.3		24	25%	2.56	E	24	8%	1.81	E
Bis(2-ethylhexyl)phthalate	g/km^2/yr	6	0%	< 25.7	U	8	13%	20.5	E	8	0%	< 33.4	U	8	0%	< 115	U	30	3%	29.8	E	24	54%	185		24	17%	24.8	E	24	25%	29.2	E
Triclopyr	g/km^2/yr	6	50%	4.89	E	8	0%	< 15.7	U	8	38%	6.04	E	8	0%	< 41.8	U	30	20%	11.4	E	24	46%	17.5	E	24	54%	9.62		24	29%	11.3	E
Nonylphenol	g/km^2/yr	6	0%	< 52.9	U	8	0%	< 79.5	U	8	0%	< 64.9	U	8	0%	< 229	U	30	0%	< 127	U	24	4%	86.9	E	24	0%	< 102	U	24	0%	< 120	U
Total DDTs	g/km^2/yr	6	33%	0.0160	E	8	0%	< 0.0506	U	8	0%	< 0.0433	U	8	0%	< 0.135	U	30	7%	0.0372	E	24	25%	0.679	E	24	0%	< 0.807	U	24	4%	0.456	E
Oil and Grease	kg/km^2/yr	6	17%	32.1	E	8	25%	48.2	E	8	13%	39.3	E	8	25%	135	E	30	20%	74.5	E	24	38%	109	E	24	21%	62.1	E	24	13%	73.0	E
TPH-DOG	kg/km^2/yr	6	0%	< 5.77	U	8	0%	< 10.1	U	8	13%	3.15	E	8	0%	< 23.6	U	30	3%	5.96	E	24	75%	40.7		24	17%	4.96	E	24	8%	5.84	E
Conventionals																															
Total Suspended Solids	kg/km^2/yr	6	33%	80.2	E	8	100%	722		8	100%	590		8	100%	1350		30	87%	745		24	100%	5430		24	100%	4340		24	96%	2010	
Total Phosphorus	kg/km^2/yr	6	100%	9.34		8	100%	7.83		8	100%	25.8		8	100%	10.1		30	100%	14.2		24	100%	23.8		24	100%	20.9		24	100%	75.2	
Nitrate + Nitrite Nitrogen	kg/km^2/yr	6	100%	36.9		8	100%	247		8	100%	42.5		8	100%	60.1		30	100%	115		24	100%	94.5		24	100%	308		24	100%	374	

		Storm Event															
		Forest/Field/Other				Combined											
	Units	n	Percent Detected	Median Load	Flag	n	Percent Detected	Median Load	Flag								
Metals																	
Dissolved Arsenic	g/km^2/yr	24	100%	164		96	99%	292									
Total Arsenic	g/km^2/yr	24	100%	234		96	100%	394									
Dissolved Cadmium	g/km^2/yr	24	0%	< 12.6	U	96	34%	4.87	E								
Total Cadmium	g/km^2/yr	24	0%	< 63.2	U	96	8%	24.3	E								
Dissolved Copper	g/km^2/yr	24	100%	297		96	99%	988									
Total Copper	g/km^2/yr	24	100%	518		96	100%	1580									
Dissolved Lead	g/km^2/yr	24	88%	31.6		96	96%	58.4									
Total Lead	g/km^2/yr	24	71%	82.2		96	91%	243									
Dissolved Mercury	g/km^2/yr	24	63%	1.26		96	81%	1.95									
Total Mercury	g/km^2/yr	24	96%	2.53		96	99%	3.89									
Dissolved Zinc	g/km^2/yr	24	71%	1450		96	93%	2680									
Total Zinc	g/km^2/yr	24	17%	1580	E	96	69%	4090									
Organics																	
Total PCBs	mg/km^2/yr	12	58%	66.4		40	83%	169									
Total PBDEs	mg/km^2/yr	16	44%	79.0	E	64	66%	60.8									
Total PAHs	g/km^2/yr	24	21%	6.07	E	96	45%	4.87	E								
cPAHs	g/km^2/yr	24	0%	< 12.6	U	96	29%	4.62	E								
LPAHs	g/km^2/yr	24	21%	3.14	E	96	41%	2.80	E								
HPAHs	g/km^2/yr	24	0%	< 12.6	U	96	32%	4.62	E								
Bis(2-ethylhexyl)phthalate	g/km^2/yr	24	25%	50.6	E	96	30%	38.9	E								
Triclopyr	g/km^2/yr	24	21%	19.6	E	96	38%	15.1	E								
Nonylphenol	g/km^2/yr	24	0%	< 234	U	96	1%	77.9	E								
Total DDTs	g/km^2/yr	24	4%	0.790	E	96	8%	0.608	E								
Oil and Grease	kg/km^2/yr	24	17%	126	E	96	22%	97.3	E								
TPH-DOG	kg/km^2/yr	24	13%	10.1	E	96	28%	7.79	E								
Conventionals																	
Total Suspended Solids	kg/km^2/yr	24	92%	4420		96	97%	4380									
Total Phosphorus	kg/km^2/yr	24	100%	15.3		96	100%	26.3									
Nitrate + Nitrite Nitrogen	kg/km^2/yr	24	100%	144		96	100%	168									

Colored bars indicate relative magnitude across each row in the table.

E = 50 percent or more of the data are non-detect values; reported values are considered estimates with relatively low accuracy.

U = All of the data are non-detect values; reported values were computed based on the maximum reporting limit.

g/km^2/yr = grams per square kilometer per year

mg/km^2/yr = milligrams per square kilometer per year

kg/km^2/yr = kilograms per square kilometer per year

cPAHs = carcinogenic polycyclic aromatic hydrocarbons

DDT = dichlorodiphenyltrichloroethane

HPAHs = high molecular weight polycyclic aromatic hydrocarbons

LPAHs = low molecular weight polycyclic aromatic hydrocarbons

PAHs = polycyclic aromatic hydrocarbons

PBDE = polybrominated diphenyl ethers

PCBs = polychlorinated biphenyls

TPH-DOG = total petroleum hydrocarbons, dissolved lube oil extract of oil and grease

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Table 12. Water quality criteria exceedances for the Phase 3 study of toxics in surface runoff to Puget Sound.

		Acute Freshwater Criteria Exceedances								Chronic Freshwater Criteria Exceedances								Human Health Freshwater Criteria Exceedances							
	n	Criterion	AG	CB	FB	RB	Storm	Base	Total	Criterion	AG	CB	FB	RB	Storm	Base	Total	Criterion	AG	CB	FB	RB	Storm	Base	Total
Metals																									
Dissolved Arsenic	126	360 µg/L	0	0	0	0	0	0	0	190 µg/L	0	0	0	0	0	0	0	NA	--	--	--	--	--	--	--
Dissolved Cadmium	126	Hardness dependent	0	0	0	0	0	0	0	Hardness dependent	0	0	0	0	0	0	0	NA	--	--	--	--	--	--	--
Dissolved Copper	126	Hardness dependent	0	2	0	0	2	0	2	Hardness dependent	4	5	1	0	9	1	10	NA	--	--	--	--	--	--	--
Dissolved Lead	126	Hardness dependent	0	0	0	0	0	0	0	Hardness dependent	0	6	0	0	6	0	6	NA	--	--	--	--	--	--	--
Total Mercury	126	2.1 µg/L	0	0	0	0	0	0	0	0.012 µg/L	1	0	2	0	3	0	3	0.14 µg/L	0	0	0	0	0	0	0
Dissolved Zinc	126	Hardness dependent	0	11	0	0	11	0	11	Hardness dependent	0	13	0	0	13	0	13	NA	--	--	--	--	--	--	--
Organics																									
Total PCBs	70	2 µg/L	0	0	0	0	0	0	0	0.014 µg/L	0	1	0	0	1	0	1	0.00017 µg/L	2	13	4	4	18	5	23
cPAHs																									
Benzo(a)anthracene	126	NA	--	--	--	--	--	--	--	NA	--	--	--	--	--	--	--	0.0028 µg/L	0	12	0	0	12	0	12
Benzo(a)pyrene	126	NA	--	--	--	--	--	--	--	NA	--	--	--	--	--	--	--	0.0028 µg/L	0	10	0	0	10	0	10
Benzo(b)fluoranthene	126	NA	--	--	--	--	--	--	--	NA	--	--	--	--	--	--	--	0.0028 µg/L	0	14	0	0	14	0	14
Benzo(k)fluoranthene	126	NA	--	--	--	--	--	--	--	NA	--	--	--	--	--	--	--	0.0028 µg/L	0	7	0	0	7	0	7
Chrysene	126	NA	--	--	--	--	--	--	--	NA	--	--	--	--	--	--	--	0.0028 µg/L	0	18	0	0	18	0	18
Indeno(1,2,3-cd)pyrene	126	NA	--	--	--	--	--	--	--	NA	--	--	--	--	--	--	--	0.0028 µg/L	0	5	0	0	5	0	5
Bis(2-ethylhexyl)phthalate	126	NA	--	--	--	--	--	--	--	NA	--	--	--	--	--	--	--	1.8 µg/L	0	0	0	1	0	1	1
Nonylphenol	126	27.9 µg/L	0	0	0	0	0	0	0	5.9 µg/L	0	0	0	0	0	0	0	NA	--	--	--	--	--	--	--
DDTs																									
4,4'-DDD	126	1.1 µg/L	0	0	0	0	0	0	0	0.001 µg/L	0	6	0	0	5	1	6	0.00083 µg/L	0	6	0	0	5	1	6
4,4'-DDE	126	1.1 µg/L	0	0	0	0	0	0	0	0.001 µg/L	0	3	0	0	3	0	3	0.00059 µg/L	0	3	0	0	3	0	3
4,4'-DDT	126	1.1 µg/L	0	0	0	0	0	0	0	0.001 µg/L	0	4	0	0	4	0	4	0.00059 µg/L	0	4	0	0	4	0	4
Conventionals																									
Nitrate + Nitrite Nitrogen	126	NA	--	--	--	--	--	--	--	NA	--	--	--	--	--	--	--	10 mg/L	3	0	0	0	3	0	3

Acute and chronic freshwater criteria from WAC 173-201A. Human health freshwater criteria from National Toxics Rule (40 CFR 131.36) and EPA National Recommended Water Quality Criteria (EPA 822-R-02-47).

mg/L = milligrams per liter

µg/L = micrograms per liter

pg/L= pictograms per liter

AG = agricultural basin

CB = commercial/industrial basin

FB = forested basin

RB = residential basin

n = sample size

NA = not applicable

PCBs = polychlorinated biphenyls

cPAHs = carcinogenic polycyclic aromatic hydrocarbons

DDD = dichlorodiphenyldichloroethane

DDE = dichlorodiphenyldichloroethylene

DDT = dichlorodiphenyltrichloroethane

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Table 13. Snohomish watershed total loading rates for priority parameters identified for the Phase 3 study of toxics in surface runoff to Puget Sound.

	Baseflow					Storm Event					Total [b]		
	n	25th Percentile	Median	75th Percentile	Flag	n	25th Percentile	Median	75th Percentile	Flag	25th Percentile	Median	75th Percentile
Dissolved Arsenic (kg/year)													
Commercial/Industrial	3	3.32	3.36	5.57		12	5.22	6.17	7.83		8.54	9.53	13.4
Residential	4	77.1	92.7	119		12	102	118	141		179	211	260
Agriculture	4	40.2	46.1	56.0		12	55.0	63.1	74.3		95.2	109	130
Forest/Field/Other	4	1030	1260	2410		12	645	791	1050		1680	2050	3460
All Land Uses [a]		1150	1400	2590			807	978	1270		1960	2380	3860
Total Arsenic (kg/year)													
Commercial/Industrial	3	3.10	3.10	5.34		12	6.80	7.91	9.17		9.90	11.0	14.5
Residential	4	77.1	90.1	115		12	137	172	214		214	262	329
Agriculture	4	46.6	55.4	66.3		12	77.7	85.8	104		124	141	170
Forest/Field/Other	4	1120	1420	2880		12	763	998	1410		1880	2420	4290
All Land Uses [a]		1250	1570	3070			985	1260	1740		2230	2830	4800
Dissolved Cadmium (kg/year)													
Commercial/Industrial	3	0.0633	0.0633	0.0633		12	0.237	0.475	0.791		0.300	0.538	0.854
Residential	4	0.00-2.90	0.00-2.90	0.00-2.90	U	12	0.00-4.09	0.00-4.09	0.00-4.09	U	0.00-6.99	0.00-6.99	0.00-6.99
Agriculture	4	0.00-0.587	0.00-0.587	0.00-0.587	U	12	0.426	0.426	0.853	E	0.426-1.01	0.426-1.01	0.853-1.44
Forest/Field/Other	4	0.00-66.1	0.00-66.1	0.00-66.1	U	12	0.00-58.8	0.00-58.8	0.00-58.8	U	0.00-125	0.00-125	0.00-125
All Land Uses [a]		0.0633-69.7	0.0633-69.7	0.0633-69.7			0.663-63.6	0.901-63.8	1.64-64.5		0.726-133	0.964-134	1.71-134
Total Cadmium (kg/year)													
Commercial/Industrial	3	0.00-0.211	0.00-0.211	0.00-0.211	U	12	0.396	0.633	1.26	E	0.396-0.607	0.633-0.844	1.26-1.47
Residential	4	0.00-14.5	0.00-14.5	0.00-14.5	U	12	0.00-20.4	0.00-20.4	0.00-20.4	U	0.00-34.9	0.00-34.9	0.00-34.9
Agriculture	4	0.00-2.93	0.00-2.93	0.00-2.93	U	12	0.00-4.26	0.00-4.26	0.00-4.26	U	0.00-7.19	0.00-7.19	0.00-7.19
Forest/Field/Other	4	0.00-331	0.00-331	0.00-331	U	12	0.00-293	0.00-293	0.00-293	U	0.00-624	0.00-624	0.00-624
All Land Uses [a]		0.00-349	0.00-349	0.00-349			0.396-318	0.633-318	1.26-319		0.396-667	0.633-667	1.26-668
Dissolved Copper (kg/year)													
Commercial/Industrial	3	1.67	1.90	2.77		12	17.3	18.7	23.5		19.0	20.6	26.3
Residential	4	91.4	102	109		12	161	213	298		252	315	407
Agriculture	4	23.8	29.0	42.2		12	89.5	142	191		113	171	233
Forest/Field/Other	4	1190	1230	1660		12	1200	1350	1580		2390	2580	3240
All Land Uses [a]		1310	1360	1810			1470	1720	2090		2770	3090	3910
Total Copper (kg/year)													
Commercial/Industrial	3	2.04	2.70	3.38		12	29.2	34.9	38.7		31.2	37.6	42.1
Residential	4	116	128	136		12	313	451	758		429	579	894
Agriculture	4	27.9	34.9	51.0		12	117	165	304		145	200	355
Forest/Field/Other	4	1490	1820	2220		12	1550	2050	3720		3040	3870	5940
All Land Uses [a]		1640	1990	2410			2010	2700	4820		3650	4690	7230
Dissolved Lead (kg/year)													
Commercial/Industrial	3	0.0211	0.0633	0.169		12	1.26	1.42	1.97		1.28	1.48	2.14
Residential	4	7.25	11.6	16.0		12	16.3	22.5	38.8		23.6	34.1	54.8
Agriculture	4	0.587	1.17	1.76		12	3.84	4.69	5.97		4.43	5.86	7.73
Forest/Field/Other	4	33.1	99.4	198	E	12	117	147	176		150	246	374
All Land Uses [a]		41.0	112	216			138	176	223		179	287	439
Total Lead (kg/year)													
Commercial/Industrial	3	0.106	0.106	0.253	E	12	6.72	10.8	15.9		6.83	10.9	16.2
Residential	4	18.9	23.2	24.7		12	88.0	131	235		107	154	260
Agriculture	4	1.47	2.64	3.81	E	12	8.53	13.2	37.5		10.0	15.8	41.3
Forest/Field/Other	4	166	298	430	E	12	147	323	471		313	621	901
All Land Uses [a]		186	324	459			250	478	759		437	802	1220
Dissolved Mercury (kg/year)													
Commercial/Industrial	3	0.00-0.00422	0.00-0.00422	0.00-0.00422	U	12	0.0159	0.0237	0.0316		0.0159-0.0201	0.0237-0.0279	0.0316-0.0358
Residential	4	0.145	0.290	0.434	E	12	0.817	1.02	1.23		0.962	1.31	1.66
Agriculture	4	0.0587	0.0587	0.0880		12	0.213	0.256	0.341		0.272	0.315	0.429
Forest/Field/Other	4	0.00-6.61	0.00-6.61	0.00-6.61	U	12	2.93	5.88	8.80		2.93-9.54	5.88-12.5	8.80-15.4
All Land Uses [a]		0.204-6.82	0.349-6.96	0.522-7.14			3.98	7.18	10.4		4.18-10.8	7.53-14.2	10.9-17.5
Total Mercury (kg/year)													
Commercial/Industrial	3	0.00422	0.00422	0.00422		12	0.0396	0.0553	0.0712		0.0438	0.0595	0.0754
Residential	4	0.290	0.434	0.581		12	1.43	1.84	2.45		1.72	2.27	3.03
Agriculture	4	0.0880	0.117	0.117		12	0.341	0.469	0.512		0.429	0.586	0.629
Forest/Field/Other	4	3.31	6.61	6.61	E	12	5.88	8.80	11.7		9.19	15.4	18.3
All Land Uses [a]		3.69	7.17	7.31			7.69	11.2	14.7		11.4	18.3	22.0
Dissolved Zinc (kg/year)													
Commercial/Industrial	3	22.8	25.9	30.8		12	205	285	350		228	311	381
Residential	4	247	276	334		12	573	695	939		820	971	1270
Agriculture	4	64.5	114	197		12	102	193	392		167	307	589
Forest/Field/Other	4	1660	2650	3970	E	12	1470	1470	5880	E	3130	4120	9850
All Land Uses [a]		1990	3070	4530			2350	2640	7560		4350	5710	12100
Total Zinc (kg/year)													
Commercial/Industrial	3	27.5	33.6	37.7		12	291	373	437		319	407	475
Residential	4	363	363	712	E	12	817	1720	2230		1180	2080	2940
Agriculture	4	135	311	1240		12	298	375	422		433	686	1660
Forest/Field/Other	4	8280	8280	16900	E	12	7340	7340	7340	E	15600	15600	24200
All Land Uses [a]		8810	8990	18900			8750	9810	10400		17500	18800	29300

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Table 13 (continued). Snohomish watershed total loading rates for priority parameters identified for the Phase 3 study of toxics in surface runoff to Puget Sound.

	Baseflow					Storm Event					Total [b]		
	n	25th Percentile	Median	75th Percentile	Flag	n	25th Percentile	Median	75th Percentile	Flag	25th Percentile	Median	75th Percentile
Total PCBs (g/year)													
Commercial/Industrial	3	0.366	0.786	2.38		6	6.90	51.4	104		7.27	52.2	106
Residential	4	1.42	2.54	30.5	E	6	20.0	56.0	235		21.4	58.5	266
Agriculture	4	0.704	2.05	6.19	E	2	3.76	4.50	5.23		4.46	6.55	11.4
Forest/Field/Other	4	61.3	209	771		6	104	145	293	E	165	354	1060
All Land Uses [a]		63.8	214	810			135	257	637		198	471	1440
Total PBDEs (g/year)													
Commercial/Industrial	3	0.702	0.899	15.0		8	10.6	25.9	227		11.3	26.8	242
Residential	4	18.6	31.8	67.8	E	8	3.15	5.01	18.3		21.8	36.8	86.1
Agriculture	4	2.34	3.75	6.04	E	8	1.50	5.34	5.36	E	3.84	9.09	11.4
Forest/Field/Other	4	297	414	3490	E	8	227	438	925		524	852	4420
All Land Uses [a]		319	450	3580			242	474	1180		561	925	4760
Total PAHs (kg/year)													
Commercial/Industrial	3	0.00-0.0422	0.00-0.0422	0.00-0.0422	U	12	1.07	1.42	1.88		1.07-1.11	1.42-1.46	1.88-1.92
Residential	4	0.00-2.90	0.00-2.90	0.00-2.90	U	12	1.53	2.00	2.04	E	1.53-4.43	2.00-4.90	2.04-4.94
Agriculture	4	0.00-0.587	0.00-0.587	0.00-0.587	U	12	0.320	0.406	0.426	E	0.320-0.907	0.406-0.993	0.426-1.01
Forest/Field/Other	4	0.00-66.1	0.00-66.1	0.00-66.1	U	12	25.7	29.3	32.3	E	25.7-91.8	29.3-95.4	32.3-98.4
All Land Uses [a]		0.00-69.6	0.00-69.6	0.00-69.6			28.6	33.1	36.6		28.6-98.2	33.1-103	36.6-106
cPAHs (kg/year)													
Commercial/Industrial	3	0.00-0.0206	0.00-0.0206	0.00-0.0206	U	12	0.484	0.621	0.746		0.484-0.505	0.621-0.642	0.746-0.767
Residential	4	0.00-1.60	0.00-1.60	0.00-1.60	U	12	1.02	1.94	2.04	E	1.02-2.62	1.94-3.54	2.04-3.64
Agriculture	4	0.00-0.290	0.00-0.290	0.00-0.290	U	12	0.212	0.406	0.411	E	0.212-0.502	0.406-0.696	0.411-0.701
Forest/Field/Other	4	0.00-32.8	0.00-32.8	0.00-32.8	U	12	0.00-58.8	0.00-58.8	0.00-58.8	U	0.00-91.6	0.00-91.6	0.00-91.6
All Land Uses [a]		0.00-34.7	0.00-34.7	0.00-34.7			1.72-60.5	2.97-61.8	3.20-62		1.72-95.2	2.97-96.5	3.20-96.7
LPAHs (kg/year)													
Commercial/Industrial	3	0.00-0.0206	0.00-0.0206	0.00-0.0206	U	12	0.0799	0.103	0.166		0.0799-0.101	0.103-0.124	0.166-0.187
Residential	4	0.00-1.60	0.00-1.60	0.00-1.60	U	12	0.998	1.07	2.00	E	0.998-2.60	1.07-2.67	2.00-3.60
Agriculture	4	0.00-0.290	0.00-0.290	0.00-0.290	U	12	0.208	0.245	0.378	E	0.208-0.498	0.245-0.535	0.378-0.668
Forest/Field/Other	4	0.00-32.8	0.00-32.8	0.00-32.8	U	12	14.4	16.9	31.9	E	14.4-47.2	16.9-49.7	31.9-64.7
All Land Uses [a]		0.00-34.7	0.00-34.7	0.00-34.7			15.7	18.3	34.4		15.7-50.4	18.3-53	34.4-69.2
HPAHs (kg/year)													
Commercial/Industrial	3	0.00-0.0422	0.00-0.0422	0.00-0.0422	U	12	0.999	1.20	1.65		0.999-1.04	1.20-1.24	1.65-1.69
Residential	4	0.00-2.90	0.00-2.90	0.00-2.90	U	12	1.02	1.94	2.04	E	1.02-3.92	1.94-4.84	2.04-4.94
Agriculture	4	0.00-0.587	0.00-0.587	0.00-0.587	U	12	0.212	0.406	0.411	E	0.212-0.799	0.406-0.993	0.411-0.998
Forest/Field/Other	4	0.00-66.1	0.00-66.1	0.00-66.1	U	12	0.00-58.8	0.00-58.8	0.00-58.8	U	0.00-125	0.00-125	0.00-125
All Land Uses [a]		0.00-69.6	0.00-69.6	0.00-69.6			2.23-61	3.55-62.3	4.10-62.9		2.23-131	3.55-132	4.10-133
BEHP (kg/year)													
Commercial/Industrial	3	0.00-0.338	0.00-0.338	0.00-0.338	U	12	1.42	3.34	7.87	E	1.42-1.76	3.34-3.68	7.87-8.21
Residential	4	11.9	12.3	876	E	12	16.3	16.3	18.4	E	28.2	28.6	894
Agriculture	4	0.00-4.99	0.00-4.99	0.00-4.99	U	12	3.33	3.41	3.41	E	3.33-8.32	3.41-8.40	3.41-8.40
Forest/Field/Other	4	0.00-564	0.00-564	0.00-564	U	12	235	235	235	E	235-799	235-799	235-799
All Land Uses [a]		11.9-581	12.3-582	876-1450			256	258	265		268-837	270-840	1140-1710
Triclopyr (kg/year)													
Commercial/Industrial	3	0.0572	0.0644	0.0644	E	12	0.245	0.253	0.281	E	0.302	0.317	0.345
Residential	4	0.00-9.44	0.00-9.44	0.00-9.44	U	12	5.94	6.32	13.9		5.94-15.4	6.32-15.8	13.9-23.3
Agriculture	4	0.772	0.895	0.895	E	12	1.29	1.31	1.34	E	2.06	2.21	2.24
Forest/Field/Other	4	0.00-202	0.00-202	0.00-202	U	12	0.00-188	0.00-188	0.00-188	U	0.00-390	0.00-390	0.00-390
All Land Uses [a]		0.829-212	0.959-212	0.959-212			7.48-195	7.88-196	15.5-204		8.30-408	8.85-408	16.5-416
Nonyphenol (kg/year)													
Commercial/Industrial	3	0.00-0.675	0.00-0.675	0.00-0.675	U	12	1.24	1.26	1.30	E	1.24-1.92	1.26-1.94	1.30-1.98
Residential	4	0.00-48.0	0.00-48.0	0.00-48.0	U	12	0.00-67.4	0.00-67.4	0.00-67.4	U	0.00-115	0.00-115	0.00-115
Agriculture	4	0.00-9.68	0.00-9.68	0.00-9.68	U	12	0.00-14.0	0.00-14.0	0.00-14.0	U	0.00-23.7	0.00-23.7	0.00-23.7
Forest/Field/Other	4	0.00-1120	0.00-1120	0.00-1120	U	12	0.00-970	0.00-970	0.00-970	U	0.00-2090	0.00-2090	0.00-2090
All Land Uses [a]		0.00-1180	0.00-1180	0.00-1180			1.24-1050	1.26-1050	1.30-1050		1.24-2230	1.26-2230	1.30-2230
Total DDTs (kg/year)													
Commercial/Industrial	3	0.00-0.000422	0.00-0.000422	0.00-0.000422	U	12	0.00-0.0237	0.00-0.0237	0.00-0.0237	U	0.00-0.0241	0.00-0.0241	0.00-0.0241
Residential	4	0.00-0.0305	0.00-0.0305	0.00-0.0305	U	12	0.00-0.531	0.00-0.531	0.00-0.531	U	0.00-0.562	0.00-0.562	0.00-0.562
Agriculture	4	0.00-0.00587	0.00-0.00587	0.00-0.00587	U	12	0.0276	0.0534	0.0534	E	0.0276-0.0335	0.0534-0.0593	0.0534-0.0593
Forest/Field/Other	4	0.00-0.661	0.00-0.661	0.00-0.661	U	12	0.00-7.63	0.00-7.63	0.00-7.63	U	0.00-8.29	0.00-8.29	0.00-8.29
All Land Uses [a]		0.00-0.698	0.00-0.698	0.00-0.698			0.0276-8.21	0.0534-8.24	0.0534-8.24		0.0276-8.91	0.0534-8.94	0.0534-8.94
Oil and Grease (MT/year)													
Commercial/Industrial	3	0.00-0.844	0.00-0.844	0.00-0.844	U	12	1.59	2.37	3.96	E	1.59-2.43	2.37-3.21	3.96-4.80
Residential	4	0.00-58.1	0.00-58.1	0.00-58.1	U	12	40.9	40.9	71.6	E	40.9-99.0	40.9-99.0	71.6-130
Agriculture	4	0.00-11.7	0.00-11.7	0.00-11.7	U	12	8.53	8.53	8.53	E	8.53-20.2	8.53-20.2	8.53-20.2
Forest/Field/Other	4	0.00-1320	0.00-1320	0.00-1320	U	12	588	588	1320	E	588-1910	588-1910	1320-2640
All Land Uses [a]		0.00-1390	0.00-1390	0.00-1390			639	640	1400		639-2030	640-2030	1400-2800
TPH-DOG (MT/year)													
Commercial/Industrial	3	0.00-0.076	0.00-0.076	0.00-0.076	U	12	0.553	0.831	1.03		0.553-0.629	0.831-0.907	1.03-1.11
Residential	4	0.00-5.22	0.00-5.22	0.00-5.22	U	12	3.07	3.27	6.15	E	3.07-8.29	3.27-8.49	6.15-11.4
Agriculture	4	0.469	0.578	0.989	E	12	0.640	0.682	0.692	E	1.11	1.26	1.68
Forest/Field/Other	4	0.00-116	0.00-116	0.00-116	U	12	43.8	47.1	88.0	E	43.8-160	47.1-163	88.0-204
All Land Uses [a]		0.469-122	0.578-122	0.989-122			48.1	51.9	95.9		48.5-170	52.5-174	96.9-218

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Table 13 (continued). Snohomish watershed total loading rates for priority parameters identified for the Phase 3 study of toxics in surface runoff to Puget Sound.

	Baseflow					Storm Event					Total [b]		
	n	25th Percentile	Median	75th Percentile	Flag	n	25th Percentile	Median	75th Percentile	Flag	25th Percentile	Median	75th Percentile
Total Suspended Solids (MT/year)													
Commercial/Industrial	3	0.00-2.11	0.00-2.11	0.00-2.11	U	12	47.5	90.9	112		47.5-49.6	90.9-93.0	112-114
Residential	4	218	290	363		12	1810	3580	7880		2030	3870	8240
Agriculture	4	58.7	88.0	161		12	132	235	587		191	323	748
Forest/Field/Other	4	6610	6610	9940		12	5880	11700	34300		12500	18300	44200
All Land Uses [a]		6890	6990	10500			7870	15600	42900		14800	22600	53300
Total Phosphorus (MT/year)													
Commercial/Industrial	3	0.0620	0.161	0.167		12	0.264	0.297	0.347		0.326	0.458	0.514
Residential	4	3.45	4.01	4.42		12	7.96	9.94	20.0		11.4	14.0	24.4
Agriculture	4	1.50	2.41	3.70		12	3.86	5.38	7.39		5.36	7.79	11.1
Forest/Field/Other	4	28.1	31.4	36.7		12	27.9	35.5	43.8		56.0	66.9	80.5
All Land Uses [a]		33.1	38.0	45.0			40.0	51.1	71.5		73.1	89.1	117
Nitrate+Nitrite Nitrogen (MT/year)													
Commercial/Industrial	3	0.515	1.89	1.95		12	1.12	1.67	2.37		1.64	3.56	4.32
Residential	4	112	144	185		12	171	192	259		283	336	444
Agriculture	4	5.67	9.04	12.0		12	13.9	38.8	50.8		19.6	47.8	62.8
Forest/Field/Other	4	155	295	377		12	483	653	840		638	948	1220
All Land Uses [a]		273	450	576			669	885	1150		942	1340	1730

[a] Values calculated by summing loading rates for all four land use types.

[b] Values calculated by summing baseflow and storm-event loading rates.

Flag:
E = 50 percent or more of the data are non-detect values; reported values are considered estimates with relatively low accuracy.
U = All of the data are non-detect values. The low value in range was calculated by assuming a zero for nondetect values; the high value in range was calculated assuming the maximum method reporting limit for non-detect values.

kg/yr = kilograms per year

g/yr = grams per year

MT/yr = metric tons per year

BEHP = Bis(2-ethylhexyl) phthalate

cPAHs = carcinogenic polycyclic aromatic hydrocarbons

DDT = dichlorodiphenyltrichloroethane

HPAHs = high molecular weight polycyclic aromatic hydrocarbons

LPAHs = low molecular weight polycyclic aromatic hydrocarbons

PAHs = polycyclic aromatic hydrocarbons

PBDE = polybrominated diphenyl ethers

PCBs = polychlorinated biphenyls

TPH-DOG = total petroleum hydrocarbons, extract of oil and grease (lube oil)

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Table 14. Puyallup watershed total loading rates for priority parameters identified for the Phase 3 study of toxics in surface runoff to Puget Sound.

	Baseflow					Storm Event					Total [b]		
	n	25th Percentile	Median	75th Percentile	Flag	n	25th Percentile	Median	75th Percentile	Flag	25th Percentile	Median	75th Percentile
Dissolved Arsenic (kg/year)													
Commercial/Industrial	3	1.36	1.97	2.07		12	2.97	3.55	3.98		4.33	5.52	6.05
Residential	4	24.2	93.4	263		12	23.9	29.1	48.2		48.1	123	311
Agriculture	4	8.85	10.5	15.0		12	18.3	21.1	26.5		27.2	31.6	41.5
Forest/Field/Other	4	140	176	187		12	156	192	252		296	368	439
All Land Uses [a]		174	282	467			201	246	331		376	528	798
Total Arsenic (kg/year)													
Commercial/Industrial	3	1.40	2.15	2.29		12	3.98	5.07	7.65		5.38	7.22	9.94
Residential	4	23.8	86.7	249		12	25.7	37.9	57.2		49.5	125	306
Agriculture	4	8.37	10.1	14.6		12	17.6	19.7	30.4		26.0	29.8	45.0
Forest/Field/Other	4	156	181	192		12	223	289	355		379	470	547
All Land Uses [a]		190	280	458			270	352	450		460	632	908
Dissolved Cadmium (kg/year)													
Commercial/Industrial	3	0.0200	0.0200	0.0400	E	12	0.190	0.190	0.253		0.210	0.210	0.293
Residential	4	0.00-0.849	0.00-0.849	0.00-0.849	U	12	0.00-0.855	0.00-0.855	0.00-0.855	U	0.00-1.70	0.00-1.70	0.00-1.70
Agriculture	4	0.00-0.285	0.00-0.285	0.00-0.285	U	12	0.345	0.345	1.04	E	0.345-0.63	0.345-0.63	1.04-1.33
Forest/Field/Other	4	0.00-10.4	0.00-10.4	0.00-10.4	U	12	0.00-14.8	0.00-14.8	0.00-14.8	U	0.00-25.2	0.00-25.2	0.00-25.2
All Land Uses [a]		0.0200-11.6	0.0200-11.6	0.0400-11.6			0.535-16.2	0.535-16.2	1.29-16.9		0.555-27.7	0.555-27.7	1.33-28.5
Total Cadmium (kg/year)													
Commercial/Industrial	3	0.00-0.200	0.00-0.200	0.00-0.200	U	12	0.317	0.317	0.317	E	0.317-0.517	0.317-0.517	0.317-0.517
Residential	4	0.00-4.25	0.00-4.25	0.00-4.25	U	12	0.00-4.28	0.00-4.28	0.00-4.28	U	0.00-8.53	0.00-8.53	0.00-8.53
Agriculture	4	0.00-1.42	0.00-1.42	0.00-1.42	U	12	0.00-3.45	0.00-3.45	0.00-3.45	U	0.00-4.87	0.00-4.87	0.00-4.87
Forest/Field/Other	4	0.00-51.8	0.00-51.8	0.00-51.8	U	12	0.00-73.9	0.00-73.9	0.00-73.9	U	0.00-126	0.00-126	0.00-126
All Land Uses [a]		0.00-57.7	0.00-57.7	0.00-57.7			0.317-81.9	0.317-81.9	0.317-81.9		0.317-140	0.317-140	0.317-140
Dissolved Copper (kg/year)													
Commercial/Industrial	3	3.04	3.53	5.44		12	10.3	12.9	16.9		13.3	16.4	22.3
Residential	4	16.6	17.9	24.6		12	34.6	63.2	98.5		51.2	81.1	123
Agriculture	4	20.9	68.0	117		12	129	201	288		150	269	405
Forest/Field/Other	4	244	322	518		12	326	533	1440		570	855	1960
All Land Uses [a]		285	411	665			500	810	1840		785	1220	2510
Total Copper (kg/year)													
Commercial/Industrial	3	4.16	4.43	6.25		12	19.8	22.9	29.8		24.0	27.3	36.1
Residential	4	26.8	33.4	41.6		12	51.8	107	145		78.6	140	187
Agriculture	4	24.0	78.7	132		12	158	255	342		182	334	474
Forest/Field/Other	4	322	388	622		12	607	1060	1670		929	1450	2290
All Land Uses [a]		377	505	802			837	1440	2190		1210	1950	2990
Dissolved Lead (kg/year)													
Commercial/Industrial	3	0.459	0.459	0.878		12	1.20	2.15	4.05		1.66	2.61	4.93
Residential	4	1.27	1.70	1.70		12	2.99	5.12	5.99		4.26	6.82	7.69
Agriculture	4	0.427	0.853	1.42		12	2.76	3.80	4.83		3.19	4.65	6.25
Forest/Field/Other	4	5.18	10.4	15.6	E	12	7.39	29.5	66.7		12.6	39.9	82.3
All Land Uses [a]		7.34	13.4	19.6			14.3	40.6	81.6		21.7	54.0	101
Total Lead (kg/year)													
Commercial/Industrial	3	0.837	0.978	1.36		12	8.92	12.8	19.7		9.76	13.8	21.1
Residential	4	5.51	6.81	13.6		12	13.7	20.5	42.8		19.2	27.3	56.4
Agriculture	4	0.712	1.71	2.99	E	12	6.21	9.97	17.6		6.92	11.7	20.6
Forest/Field/Other	4	0.00-51.8	0.00-51.8	0.00-51.8	U	12	88.8	111	148		88.8-141	111-163	148-200
All Land Uses [a]		7.06-58.9	9.50-61.3	18.0-69.8			118	154	228		125-177	164-216	246-298
Dissolved Mercury (kg/year)													
Commercial/Industrial	3	0.00598	0.00798	0.00998		12	0.0190	0.0190	0.0253		0.0250	0.0270	0.0353
Residential	4	0.0425	0.0849	0.0849	E	12	0.0428	0.171	0.257		0.0853	0.256	0.342
Agriculture	4	0.0427	0.0853	0.142		12	0.241	0.310	0.483		0.284	0.395	0.625
Forest/Field/Other	4	0.518	1.04	2.07	E	12	0.739	2.23	8.14		1.26	3.27	10.2
All Land Uses [a]		0.609	1.22	2.31			1.04	2.73	8.91		1.65	3.95	11.2
Total Mercury (kg/year)													
Commercial/Industrial	3	0.00598	0.00998	0.0120		12	0.0317	0.0443	0.0570		0.0377	0.0543	0.0690
Residential	4	0.0849	0.127	0.170		12	0.0855	0.299	0.385		0.170	0.426	0.555
Agriculture	4	0.0569	0.114	0.185		12	0.345	0.380	0.483		0.402	0.494	0.668
Forest/Field/Other	4	1.04	1.56	2.07		12	2.23	4.44	8.14		3.27	6.00	10.2
All Land Uses [a]		1.19	1.81	2.44			2.69	5.16	9.07		3.88	6.97	11.5
Dissolved Zinc (kg/year)													
Commercial/Industrial	3	16.6	21.1	39.5		12	115	165	221		132	186	261
Residential	4	55.1	68.1	93.4		12	111	154	355		166	222	448
Agriculture	4	21.4	81.2	150		12	200	314	701		221	395	851
Forest/Field/Other	4	673	1190	1660		12	2000	2290	4150		2670	3480	5810
All Land Uses [a]		766	1360	1940			2430	2920	5430		3190	4280	7370

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Table 14 (continued). Puyallup watershed total loading rates for priority parameters identified for the Phase 3 study of toxics in surface runoff to Puget Sound.

	Baseflow					Storm Event					Total [b]		
	n	25th Percentile	Median	75th Percentile	Flag	n	25th Percentile	Median	75th Percentile	Flag	25th Percentile	Median	75th Percentile
Total Zinc (kg/year)													
Commercial/Industrial	3	21.4	31.9	46.4		12	203	214	245		224	246	291
Residential	4	106	106	183	E	12	107	252	325		213	358	508
Agriculture	4	35.6	95.7	170	E	12	235	383	797		271	479	967
Forest/Field/Other	4	0.00-2580	0.00-2580	0.00-2580	U	12	1850	1850	1850	E	1850-4430	1850-4430	1850-4430
All Land Uses [a]		163-2740	234-2810	399-2980			2400	2700	3220		2560-5140	2930-5510	3620-6200
Total PCBs (g/year)													
Commercial/Industrial	3	0.498	0.619	2.18		6	4.50	12.8	16.2		5.00	13.4	18.4
Residential	4	7.59	11.8	15.7	E	6	1.07	5.24	14.3		8.66	17.0	30.0
Agriculture	4	3.98	5.77	9.09		2	16.3	18.4	20.6		20.3	24.2	29.7
Forest/Field/Other	4	62.8	118	181	E	6	81.4	244	405		144	362	586
All Land Uses [a]		74.9	136	208			103	280	456		178	417	664
Total PBDEs (g/year)													
Commercial/Industrial	6	0.252	0.889	0.981		16	8.57	23.6	104		8.82	24.5	105
Residential	8	0.620	3.00	5.30	E	16	5.36	5.39	8.67	E	5.98	8.39	14.0
Agriculture	9	0.386	1.78	1.85	E	16	0.949	4.31	24.6		1.34	6.09	26.5
Forest/Field/Other	8	0.00-135	0.00-135	0.00-135	U	16	92.5	92.5	97.1	E	92.5-228	92.5-228	97.1-232
All Land Uses [a]		1.26-136	5.67-141	8.13-143			107	126	234		109-244	131-267	243-378
Total PAHs (kg/year)													
Commercial/Industrial	3	0.0229	0.0317	0.0428		12	0.454	1.10	1.93		0.477	1.13	1.97
Residential	4	0.00-0.849	0.00-0.849	0.00-0.849	U	12	0.209	0.422	0.593	E	0.209-1.06	0.422-1.27	0.593-1.44
Agriculture	4	0.00-0.270	0.00-0.270	0.00-0.270	U	12	0.169	0.171	0.345	E	0.169-0.439	0.171-0.441	0.345-0.615
Forest/Field/Other	4	0.00-10.4	0.00-10.4	0.00-10.4	U	12	3.64	3.70	7.39	E	3.64-14	3.70-14.1	7.39-17.8
All Land Uses [a]		0.0229-11.5	0.0317-11.6	0.0428-11.6			4.47	5.39	10.3		4.50-16.0	5.42-16.9	10.3-21.8
cPAHs (kg/year)													
Commercial/Industrial	3	0.00-0.0196	0.00-0.0196	0.00-0.0196	U	12	0.231	0.574	0.913		0.231-0.251	0.574-0.594	0.913-0.933
Residential	4	0.00-0.467	0.00-0.467	0.00-0.467	U	12	0.207	0.257	0.428	E	0.207-0.674	0.257-0.724	0.428-0.895
Agriculture	4	0.00-0.142	0.00-0.142	0.00-0.142	U	12	0.00-0.690	0.00-0.690	0.00-0.690	U	0.00-0.832	0.00-0.832	0.00-0.832
Forest/Field/Other	4	0.00-5.12	0.00-5.12	0.00-5.12	U	12	0.00-14.8	0.00-14.8	0.00-14.8	U	0.00-19.9	0.00-19.9	0.00-19.9
All Land Uses [a]		0.00-5.75	0.00-5.75	0.00-5.75			0.438-15.9	0.831-16.3	1.34-16.8		0.438-21.7	0.831-22.1	1.34-22.6
LPAHs (kg/year)													
Commercial/Industrial	3	0.0123	0.0197	0.0239		12	0.0497	0.111	0.234		0.0620	0.131	0.258
Residential	4	0.00-0.467	0.00-0.467	0.00-0.467	U	12	0.209	0.213	0.340	E	0.209-0.676	0.213-0.68	0.340-0.807
Agriculture	4	0.00-0.142	0.00-0.142	0.00-0.142	U	12	0.169	0.171	0.189	E	0.169-0.311	0.171-0.313	0.189-0.331
Forest/Field/Other	4	0.00-5.12	0.00-5.12	0.00-5.12	U	12	3.64	3.66	4.07	E	3.64-8.76	3.66-8.78	4.07-9.19
All Land Uses [a]		0.0123-5.74	0.0197-5.75	0.0239-5.75			4.07	4.16	4.83		4.08-9.81	4.18-9.9	4.86-10.6
HPAHs (kg/year)													
Commercial/Industrial	3	0.0140	0.0200	0.0208		12	0.412	0.960	1.63		0.426	0.980	1.65
Residential	4	0.00-0.849	0.00-0.849	0.00-0.849	U	12	0.207	0.257	0.446	E	0.207-1.06	0.257-1.11	0.446-1.3
Agriculture	4	0.00-0.270	0.00-0.270	0.00-0.270	U	12	0.168	0.169	0.171	E	0.168-0.438	0.169-0.439	0.171-0.441
Forest/Field/Other	4	0.00-10.4	0.00-10.4	0.00-10.4	U	12	0.00-14.8	0.00-14.8	0.00-14.8	U	0.00-25.2	0.00-25.2	0.00-25.2
All Land Uses [a]		0.0140-11.5	0.0200-11.5	0.0208-11.5			0.787-15.6	1.39-16.2	2.25-17.0		0.801-27.1	1.41-27.7	2.27-28.6
BEHP (kg/year)													
Commercial/Industrial	3	0.00-0.319	0.00-0.319	0.00-0.319	U	12	0.727	2.15	3.10		0.727-1.05	2.15-2.47	3.10-3.42
Residential	4	0.00-7.23	0.00-7.23	0.00-7.23	U	12	3.34	3.43	3.98	E	3.34-10.6	3.43-10.7	3.98-11.2
Agriculture	4	0.00-2.28	0.00-2.28	0.00-2.28	U	12	2.76	2.76	3.63	E	2.76-5.04	2.76-5.04	3.63-5.91
Forest/Field/Other	4	0.00-88.2	0.00-88.2	0.00-88.2	U	12	59.3	59.3	100	E	59.3-148	59.3-148	100-188
All Land Uses [a]		0.00-98.0	0.00-98.0	0.00-98.0			66.1	67.6	111		66.1-165	67.6-166	111-209
Triclopyr (kg/year)													
Commercial/Industrial	3	0.0497	0.0608	0.0720		12	0.196	0.232	0.332		0.246	0.293	0.404
Residential	4	0.00-2.72	0.00-2.72	0.00-2.72	U	12	1.30	1.33	1.41	E	1.30-4.02	1.33-4.05	1.41-4.13
Agriculture	4	0.442	0.499	5.69	E	12	1.05	1.08	1.95	E	1.49	1.58	7.64
Forest/Field/Other	4	0.00-32.2	0.00-32.2	0.00-32.2	U	12	22.5	23.1	25.2	E	22.5-54.7	23.1-55.3	25.2-57.4
All Land Uses [a]		0.492-35.4	0.560-35.5	5.76-40.7			25.0	25.7	28.9		25.5-60.5	26.3-61.2	34.7-69.6
Nonyphenol (kg/year)													
Commercial/Industrial	3	0.00-0.658	0.00-0.658	0.00-0.658	U	12	0.00-2.08	0.00-2.08	0.00-2.08	U	0.00-2.74	0.00-2.74	0.00-2.74
Residential	4	0.00-14.0	0.00-14.0	0.00-14.0	U	12	0.00-14.1	0.00-14.1	0.00-14.1	U	0.00-28.1	0.00-28.1	0.00-28.1
Agriculture	4	0.00-4.70	0.00-4.70	0.00-4.70	U	12	0.00-11.4	0.00-11.4	0.00-11.4	U	0.00-16.1	0.00-16.1	0.00-16.1
Forest/Field/Other	4	0.00-171	0.00-171	0.00-171	U	12	0.00-275	0.00-275	0.00-275	U	0.00-446	0.00-446	0.00-446
All Land Uses [a]		0.00-190	0.00-190	0.00-190			0.00-303	0.00-303	0.00-303		0.00-493	0.00-493	0.00-493
Total DDTs (kg/year)													
Commercial/Industrial	3	0.000964	0.00325	0.00436		12	0.00791	0.0129	0.0480	E	0.00887	0.0162	0.0524
Residential	4	0.00-0.00849	0.00-0.00849	0.00-0.00849	U	12	0.00-0.111	0.00-0.111	0.00-0.111	U	0.00-0.119	0.00-0.119	0.00-0.119
Agriculture	4	0.00-0.00314	0.00-0.00314	0.00-0.00314	U	12	0.00-0.0901	0.00-0.0901	0.00-0.0901	U	0.00-0.0932	0.00-0.0932	0.00-0.0932
Forest/Field/Other	4	0.00-0.104	0.00-0.104	0.00-0.104	U	12	0.0739	0.925	0.962	E	0.0739-0.178	0.925-1.03	0.962-1.07
All Land Uses [a]		0.000964-0.117	0.00325-0.119	0.00436-0.12			0.0818-0.283	0.938-1.14	1.01-1.21		0.0828-0.399	0.941-1.26	1.01-1.33

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Table 14 (continued). Puyallup watershed total loading rates for priority parameters identified for the Phase 3 study of toxics in surface runoff to Puget Sound.

	Baseflow					Storm Event					Total [b]		
	n	25th Percentile	Median	75th Percentile	Flag	n	25th Percentile	Median	75th Percentile	Flag	25th Percentile	Median	75th Percentile
Oil and Grease (MT/year)													
Commercial/Industrial	3	0.400	0.400	0.698	E	12	1.27	1.27	1.90	E	1.67	1.67	2.60
Residential	4	8.49	12.7	17.0	E	12	8.55	8.55	8.55	E	17.0	21.3	25.6
Agriculture	4	2.85	2.85	5.69	E	12	6.90	6.90	6.90	E	9.75	9.75	12.6
Forest/Field/Other	4	104	156	492	E	12	0.00-370	0.00-370	0.00-370	U	104-474	156-526	492-862
All Land Uses [a]		116	172	515			16.7-387	16.7-387	17.4-387		132-502	189-559	533-903
TPH-DOG (MT/year)													
Commercial/Industrial	3	0.00-0.0698	0.00-0.0698	0.00-0.0698	U	12	0.101	0.291	0.651		0.101-0.171	0.291-0.361	0.651-0.721
Residential	4	0.00-1.79	0.00-1.79	0.00-1.79	U	12	0.00-1.41	0.00-1.41	0.00-1.41	U	0.00-3.20	0.00-3.20	0.00-3.20
Agriculture	4	0.00-0.499	0.00-0.499	0.00-0.499	U	12	0.553	0.553	0.559	E	0.553-1.05	0.553-1.05	0.559-1.06
Forest/Field/Other	4	0.00-18.1	0.00-18.1	0.00-18.1	U	12	0.00-35.5	0.00-35.5	0.00-35.5	U	0.00-53.6	0.00-53.6	0.00-53.6
All Land Uses [a]		0.00-20.5	0.00-20.5	0.00-20.5			0.654-37.6	0.844-37.8	1.21-38.1		0.654-58	0.844-58.2	1.21-58.6
Total Suspended Solids (MT/year)													
Commercial/Industrial	3	1.76	4.00	4.00		12	47.4	63.3	104		49.2	67.3	108
Residential	4	149	191	382		12	257	557	876		406	748	1260
Agriculture	4	28.5	42.7	49.9		12	104	241	725		133	284	775
Forest/Field/Other	4	1040	1040	2330		12	3330	5930	18500		4370	6970	20800
All Land Uses [a]		1220	1280	2770			3740	6790	20200		4960	8070	22900
Total Phosphorus (MT/year)													
Commercial/Industrial	3	0.0663	0.0985	0.125		12	0.274	0.343	0.436		0.340	0.442	0.561
Residential	4	1.61	3.64	9.61		12	2.18	3.95	5.57		3.79	7.59	15.2
Agriculture	4	2.24	2.84	3.09		12	8.04	9.33	19.4		10.3	12.2	22.5
Forest/Field/Other	4	10.6	13.2	14.7		12	19.6	24.4	54.1		30.2	37.6	68.8
All Land Uses [a]		14.5	19.8	27.5			30.1	38.0	79.5		44.6	57.8	107
Nitrate+Nitrite Nitrogen (MT/year)													
Commercial/Industrial	3	0.166	0.402	0.487		12	0.512	0.841	1.38		0.678	1.24	1.87
Residential	4	37.0	108	198		12	25.2	64.4	150		62.2	172	348
Agriculture	4	1.09	1.95	3.96		12	18.5	89.3	253		19.6	91.3	257
Forest/Field/Other	4	25.8	148	399		12	62.2	177	394		88.0	325	793
All Land Uses [a]		64.1	258	601			106	332	798		170	590	1400

[a] Values calculated by summing loading rates for all four land use types.

[b] Values calculated by summing baseflow and storm-event loading rates.

Flag:
E = 50 percent or more of the data are non-detect values; reported values are considered estimates with relatively low accuracy.
U = All of the data are non-detect values. The low value in range was calculated by assuming a zero for nondetect values; the high value in range was calculated assuming the maximum method reporting limit for non-detect values.

kg/yr = kilograms per year

g/yr = grams per year

MT/yr = metric tons per year

BEHP = Bis(2-ethylhexyl) phthalate

cPAHs = carcinogenic polycyclic aromatic hydrocarbons

DDT = dichlorodiphenyltrichloroethane

HPAHs = high molecular weight polycyclic aromatic hydrocarbons

LPAHs = low molecular weight polycyclic aromatic hydrocarbons

PAHs = polycyclic aromatic hydrocarbons

PBDE = polybrominated diphenyl ethers

PCBs = polychlorinated biphenyls

TPH-DOG = total petroleum hydrocarbons, extract of oil and grease (lube oil)

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Table 15. Toxic chemical loading rates for Puget Sound based on the Phase 3 study of toxics in surface runoff to Puget Sound.

	Baseflow					Storm Event					Total [b]		
	n	25th Percentile	Median	75th Percentile	Flag	n	25th Percentile	Median	75th Percentile	Flag	25th Percentile	Median	75th Percentile
Dissolved Arsenic (kg/year)													
Commercial/Industrial	6	42.7	56.4	68.5		24	81.6	93.5	127		124	150	196
Residential	8	564	634	2360		24	675	766	960		1240	1400	3320
Agriculture	8	223	394	471		24	340	635	824		563	1030	1300
Forest/Field/Other	8	5990	6790	8000		24	3940	4860	6370		9930	11700	14400
All Land Uses [a]		6820	7870	10900			5040	6350	8280		11900	14300	19200
Total Arsenic (kg/year)													
Commercial/Industrial	6	46.5	56.9	63.4		24	117	134	175		164	191	238
Residential	8	527	626	2170		24	791	1090	1470		1320	1720	3640
Agriculture	8	214	410	568		24	317	652	1120		531	1060	1690
Forest/Field/Other	8	6400	7200	8800		24	5070	6940	8980		11500	14100	17800
All Land Uses [a]		7190	8290	11600			6300	8820	11700		13500	17100	23400
Dissolved Cadmium (kg/year)													
Commercial/Industrial	6	0.430	0.862	1.29		24	4.38	4.38	8.75		4.81	5.24	10.0
Residential	8	0.00 - 19.9	0.00 - 19.9	0.00 - 19.9	U	24	0.00 - 25.6	0.00 - 25.6	0.00 - 25.6	U	0.00 - 45.5	0.00 - 45.5	0.00 - 45.5
Agriculture	8	0.00 - 6.00	0.00 - 6.00	0.00 - 6.00	U	24	5.57	5.57	11.1	E	5.57 - 11.6	5.57 - 11.6	11.1 - 17.1
Forest/Field/Other	8	0.00 - 400	0.00 - 400	0.00 - 400	U	24	0.00 - 373	0.00 - 373	0.00 - 373	U	0.00 - 773	0.00 - 773	0.00 - 773
All Land Uses [a]		0.430 - 426	0.862 - 427	1.29 - 427			9.95 - 409	9.95 - 409	19.9 - 418		10.4 - 835	10.8 - 835	21.1 - 846
Total Cadmium (kg/year)													
Commercial/Industrial	6	0.00 - 4.30	0.00 - 4.30	0.00 - 4.30	U	24	7.28	7.28	21.9	E	7.28 - 11.6	7.28 - 11.6	21.9 - 26.2
Residential	8	0.00 - 99.3	0.00 - 99.3	0.00 - 99.3	U	24	0.00 - 128	0.00 - 128	0.00 - 128	U	0.00 - 227	0.00 - 227	0.00 - 227
Agriculture	8	0.00 - 30.1	0.00 - 30.1	0.00 - 30.1	U	24	0.00 - 55.7	0.00 - 55.7	0.00 - 55.7	U	0.00 - 85.8	0.00 - 85.8	0.00 - 85.8
Forest/Field/Other	8	0.00 - 2000	0.00 - 2000	0.00 - 2000	U	24	0.00 - 1870	0.00 - 1870	0.00 - 1870	U	0.00 - 3870	0.00 - 3870	0.00 - 3870
All Land Uses [a]		0.00 - 2130	0.00 - 2130	0.00 - 2130			7.28 - 2060	7.28 - 2060	21.9 - 2080		7.28 - 4190	7.28 - 4190	21.9 - 4210
Dissolved Copper (kg/year)													
Commercial/Industrial	6	38.7	62.6	76.3		24	298	333	416		337	396	492
Residential	8	416	626	725		24	1010	1450	2410		1430	2080	3140
Agriculture	8	298	441	1470		24	1740	2270	3720		2040	2710	5190
Forest/Field/Other	8	7410	9400	13400		24	7680	8800	17000		15100	18200	30400
All Land Uses [a]		8160	10500	15700			10700	12900	23500		18900	23400	39200
Total Copper (kg/year)													
Commercial/Industrial	6	55.1	81.1	95.6		24	486	561	709		541	642	805
Residential	8	675	873	964		24	1830	2830	4490		2510	3700	5450
Agriculture	8	357	507	1710		24	2000	2880	5070		2360	3390	6780
Forest/Field/Other	8	10600	12600	15600		24	11600	15400	37100		22200	28000	52700
All Land Uses [a]		11700	14100	18400			15900	21700	47400		27600	35700	65700
Dissolved Lead (kg/year)													
Commercial/Industrial	6	1.29	6.90	9.91		24	24.8	33.6	49.7		26.1	40.5	59.6
Residential	8	39.7	39.7	79.5		24	89.4	153	204		129	193	284
Agriculture	8	9.00	15.0	21.1		24	44.6	61.2	78.0		53.6	76.2	99.1
Forest/Field/Other	8	200	400	800	E	24	563	937	1310		763	1340	2110
All Land Uses [a]		250	462	911			722	1180	1640		972	1650	2550
Total Lead (kg/year)													
Commercial/Industrial	6	2.15	11.6	21.1		24	163	245	379		165	257	400
Residential	8	129	159	178		24	474	663	1290		603	822	1470
Agriculture	8	15.0	27.0	48.1	E	24	100	172	311		115	199	359
Forest/Field/Other	8	999	999	1800	E	24	937	2440	3560		1940	3440	5360
All Land Uses [a]		1150	1200	2050			1670	3520	5540		2820	4720	7590
Dissolved Mercury (kg/year)													
Commercial/Industrial	6	0.0430	0.0862	0.172	E	24	0.438	0.438	0.583		0.481	0.524	0.755
Residential	8	0.993	1.99	1.99	E	24	2.56	6.38	7.66		3.55	8.37	9.65
Agriculture	8	0.600	0.900	1.80		24	3.34	3.89	5.57		3.94	4.79	7.37
Forest/Field/Other	8	20.0	20.0	40.0	E	24	18.7	37.3	75.0		38.7	57.3	115
All Land Uses [a]		21.6	23.0	44.0			25.0	48.0	88.8		46.7	71.0	133
Total Mercury (kg/year)													
Commercial/Industrial	6	0.0862	0.0862	0.215		24	0.728	1.02	1.31		0.814	1.11	1.53
Residential	8	1.99	2.97	3.97		24	6.38	10.2	12.8		8.37	13.2	16.8
Agriculture	8	1.20	1.20	2.40		24	5.00	6.12	7.23		6.20	7.32	9.63
Forest/Field/Other	8	20.0	40.0	59.9		24	56.3	75.0	150		76.3	115	210
All Land Uses [a]		23.3	44.3	66.5			68.4	92.3	171		91.7	137	238
Dissolved Zinc (kg/year)													
Commercial/Industrial	6	443	494	663		24	3090	4240	6100		3530	4730	6760
Residential	8	1490	1680	2280		24	3450	4320	7410		4940	6000	9690
Agriculture	8	450	1170	2820		24	2230	3740	7800		2680	4910	10600
Forest/Field/Other	8	9990	24000	45900		24	9370	43000	63700		19400	67000	110000
All Land Uses [a]		12400	27300	51700			18100	55300	85000		30600	82600	137000
Total Zinc (kg/year)													
Commercial/Industrial	6	516	685	800		24	4940	5420	7360		5460	6110	8160
Residential	8	2480	2480	4280	E	24	3200	9350	11400		5680	11800	15700
Agriculture	8	751	2640	4100		24	3780	5000	9190		4530	7640	13300
Forest/Field/Other	8	50100	50100	50100	E	24	46800	46800	46800		96900	96900	96900
All Land Uses [a]		53800	55900	59300			58700	66600	74800		113000	122000	134000

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Table 15 (continued). Toxic chemical loading rates for Puget Sound based on the Phase 3 study of toxics in surface runoff to Puget Sound.

	Baseflow					Storm Event					Total [b]		
	n	25th Percentile	Median	75th Percentile	Flag	n	25th Percentile	Median	75th Percentile	Flag	25th Percentile	Median	75th Percentile
Total PCBs (g/year)													
Commercial/Industrial	6	9.91	14.7	58.3		12	115	295	1300		125	310	1360
Residential	8	17.3	178	360	E	12	91.0	166	634		108	344	994
Agriculture	8	21.1	71.9	121		4	58.7	154	298		79.8	226	419
Forest/Field/Other	8	1260	2420	6940		12	928	1970	6140		2190	4390	13100
All Land Uses [a]		1310	2680	7480			1190	2590	8370		2500	5270	15900
Total PBDEs (g/year)													
Commercial/Industrial	6	13.0	18.8	21.8		16	197	478	2870		210	497	2890
Residential	8	70.0	124	217	E	16	26.9	139	161		96.9	263	378
Agriculture	9	10.3	37.5	39.1	E	16	18.0	69.6	108		28.3	107	147
Forest/Field/Other	8	2500	2500	2550	E	16	2340	2340	3760	E	4840	4840	6310
All Land Uses [a]		2590	2680	2830			2580	3030	6900		5180	5710	9730
Total PAHs (kg/year)													
Commercial/Industrial	6	0.408	0.430	0.685	E	24	16.3	25.6	34.6		16.7	26.0	35.3
Residential	8	0.00 - 19.9	0.00 - 19.9	0.00 - 19.9	U	24	6.67	12.5	13.3	E	6.67 - 26.6	12.5 - 32.4	13.3 - 33.2
Agriculture	8	0.00 - 6.00	0.00 - 6.00	0.00 - 6.00	U	24	2.75	4.87	5.57	E	2.75 - 8.75	4.87 - 10.9	5.57 - 11.6
Forest/Field/Other	8	0.00 - 400	0.00 - 400	0.00 - 400	U	24	93.1	180	187	E	93.1 - 493	180 - 580	187 - 587
All Land Uses [a]		0.408 - 426	0.430 - 426	0.685 - 427			119	223	240		119 - 545	223 - 649	241 - 667
cPAHs (kg/year)													
Commercial/Industrial	6	0.00 - 0.422	0.00 - 0.422	0.00 - 0.422	U	24	8.75	12.3	16.1		8.75 - 9.17	12.3 - 12.7	16.1 - 16.5
Residential	8	0.00 - 10.9	0.00 - 10.9	0.00 - 10.9	U	24	6.30	9.60	12.8	E	6.30 - 17.2	9.60 - 20.5	12.8 - 23.7
Agriculture	8	0.00 - 3.01	0.00 - 3.01	0.00 - 3.01	U	24	2.73	2.76	5.29	E	2.73 - 5.74	2.76 - 5.77	5.29 - 8.30
Forest/Field/Other	8	0.00 - 198	0.00 - 198	0.00 - 198	U	24	0.00 - 373	0.00 - 373	0.00 - 373	U	0.00 - 571	0.00 - 571	0.00 - 571
All Land Uses [a]		0.00 - 212	0.00 - 212	0.00 - 212			17.8 - 391	24.7 - 398	34.2 - 407		17.8 - 603	24.7 - 610	34.2 - 620
LPAHs (kg/year)													
Commercial/Industrial	6	0.211	0.211	0.427	E	24	1.21	1.97	3.57		1.42	2.18	4.00
Residential	8	0.00 - 10.9	0.00 - 10.9	0.00 - 10.9	U	24	6.22	6.34	12.4	E	6.22 - 17.1	6.34 - 17.2	12.4 - 23.3
Agriculture	8	0.00 - 3.01	0.00 - 3.01	0.00 - 3.01	U	24	2.73	2.76	4.18	E	2.73 - 5.74	2.76 - 5.77	4.18 - 7.19
Forest/Field/Other	8	0.00 - 198	0.00 - 198	0.00 - 198	U	24	91.9	93.1	166	E	91.9 - 290	93.1 - 291	166 - 364
All Land Uses [a]		0.211 - 212	0.211 - 212	0.427 - 212			102	104	186		102 - 314	104 - 316	187 - 398
HPAHs (kg/year)													
Commercial/Industrial	6	0.258	0.419	0.430	E	24	15.6	22.1	31.7		15.9	22.5	32.1
Residential	8	0.00 - 19.9	0.00 - 19.9	0.00 - 19.9	U	24	6.22	10.5	12.8	E	6.22 - 26.1	10.5 - 30.4	12.8 - 32.7
Agriculture	8	0.00 - 6.00	0.00 - 6.00	0.00 - 6.00	U	24	2.73	2.76	5.29	E	2.73 - 8.73	2.76 - 8.76	5.29 - 11.3
Forest/Field/Other	8	0.00 - 400	0.00 - 400	0.00 - 400	U	24	0.00 - 373	0.00 - 373	0.00 - 373	U	0.00 - 773	0.00 - 773	0.00 - 773
All Land Uses [a]	30	0.258 - 426	0.419 - 426	0.430 - 426			24.6 - 398	35.4 - 408	49.8 - 423		24.9 - 824	35.8 - 835	50.2 - 849
BEHP (kg/year)													
Commercial/Industrial	6	0.00 - 6.90	0.00 - 6.90	0.00 - 6.90	U	24	21.6	49.7	113		21.6 - 28.5	49.7 - 56.6	113 - 120
Residential	8	79.5	84.4	84.4	E	24	102	102	115	E	182	186	199
Agriculture	8	0.00 - 51.0	0.00 - 51.0	0.00 - 51.0	U	24	44.6	44.6	49.0	E	44.6 - 95.6	44.6 - 95.6	49.0 - 100
Forest/Field/Other	8	0.00 - 3410	0.00 - 3410	0.00 - 3410	U	24	1500	1500	1540	E	1500 - 4910	1500 - 4910	1540 - 4950
All Land Uses [a]		79.5 - 3550	84.4 - 3550	84.4 - 3550			1670	1700	1820		1750 - 5220	1780 - 5250	1900 - 5370
Triclopyr (kg/year)													
Commercial/Industrial	6	1.12	1.31	1.31	E	24	4.51	4.70	6.12	E	5.63	6.01	7.43
Residential	8	0.00 - 64.7	0.00 - 64.7	0.00 - 64.7	U	24	38.6	39.6	49.0		38.6 - 103	39.6 - 104	49.0 - 114
Agriculture	8	9.15	9.22	10.5	E	24	16.9	17.2	18.6	E	26.1	26.4	29.1
Forest/Field/Other	8	0.00 - 1240	0.00 - 1240	0.00 - 1240	U	24	572	581	599	E	572 - 1810	581 - 1820	599 - 1840
All Land Uses [a]		10.3 - 1310	10.5 - 1320	11.8 - 1320			632	643	673		642 - 1940	653 - 1960	685 - 1990
Nonyphenol (kg/year)													
Commercial/Industrial	6	0.00 - 14.2	0.00 - 14.2	0.00 - 14.2	U	24	22.6	23.3	23.6	E	22.6 - 36.8	23.3 - 37.5	23.6 - 37.8
Residential	8	0.00 - 327	0.00 - 327	0.00 - 327	U	24	0.00 - 420	0.00 - 420	0.00 - 420	U	0.00 - 747	0.00 - 747	0.00 - 747
Agriculture	8	0.00 - 99.0	0.00 - 99.0	0.00 - 99.0	U	24	0.00 - 183	0.00 - 183	0.00 - 183	U	0.00 - 282	0.00 - 282	0.00 - 282
Forest/Field/Other	8	0.00 - 6790	0.00 - 6790	0.00 - 6790	U	24	0.00 - 6940	0.00 - 6940	0.00 - 6940	U	0.00 - 13700	0.00 - 13700	0.00 - 13700
All Land Uses [a]		0.00 - 7230	0.00 - 7230	0.00 - 7230			22.6 - 7570	23.3 - 7570	23.6 - 7570		22.6 - 14800	23.3 - 14800	23.6 - 14800
Total DDTs (kg/year)													
Commercial/Industrial	6	0.00430	0.00430	0.0701	E	24	0.112	0.182	0.312	E	0.116	0.186	0.382
Residential	8	0.00 - 0.208	0.00 - 0.208	0.00 - 0.208	U	24	0.00 - 3.32	0.00 - 3.32	0.00 - 3.32	U	0.00 - 3.53	0.00 - 3.53	0.00 - 3.53
Agriculture	8	0.00 - 0.0661	0.00 - 0.0661	0.00 - 0.0661	U	24	0.0668	0.696	0.696	E	0.0668 - 0.133	0.696 - 0.762	0.696 - 0.762
Forest/Field/Other	8	0.00 - 4.00	0.00 - 4.00	0.00 - 4.00	U	24	2.02	23.4	24.4	E	2.02 - 6.02	23.4 - 27.4	24.4 - 28.4
All Land Uses [a]		0.00430 - 4.28	0.00430 - 4.28	0.0701 - 4.34			2.20 - 5.52	24.3 - 27.6	25.4 - 28.7		2.20 - 9.80	24.3 - 31.9	25.5 - 33.1
Oil and Grease (MT/year)													
Commercial/Industrial	6	8.62	8.62	8.62	E	24	29.3	29.3	58.3	E	37.9	37.9	66.9
Residential	8	199	199	297	E	24	256	256	256	E	455	455	553
Agriculture	8	60.0	60.0	60.0	E	24	111	111	111	E	171	171	171
Forest/Field/Other	8	4000	4000	5990	E	24	3730	3730	3730	E	7730	7730	9720
All Land Uses [a]		4270	4270	6360			4130	4130	4160		8390	8390	10500
TPH-DOG (MT/year)													
Commercial/Industrial	6	0.00 - 1.55	0.00 - 1.55	0.00 - 1.55	U	24	3.79	10.9	17.5		3.79 - 5.34	10.9 - 12.5	17.5 - 19.1
Residential	8	0.00 - 41.6	0.00 - 41.6	0.00 - 41.6	U	24	19.8	20.4	21.1	E	19.8 - 61.4	20.4 - 62.0	21.1 - 62.7
Agriculture	8	4.81	4.81	6.15	E	24	8.64	8.91	9.02	E	13.5	13.7	15.2
Forest/Field/Other	8	0.00 - 700	0.00 - 700	0.00 - 700	U	24	285	299	308	E	285 - 985	299 - 999	308 - 1010
All Land Uses [a]		4.81 - 748	4.81 - 748	6.15 - 749			317	339	356		322 - 1070	344 - 1090	362 - 1110

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Table 15 (continued). Toxic chemical loading rates for Puget Sound based on the Phase 3 study of toxics in surface runoff to Puget Sound.

	Baseflow					Storm Event					Total [b]		
	n	25th Percentile	Median	75th Percentile	Flag	n	25th Percentile	Median	75th Percentile	Flag	25th Percentile	Median	75th Percentile
Total Suspended Solids (MT/year)													
Commercial/Industrial	6	21.5	21.5	86.2	E	24	1020	1460	2060		1040	1480	2150
Residential	8	1990	2970	4450		24	8320	17900	32000		10300	20900	36500
Agriculture	8	600	900	1200		24	1660	3070	8500		2260	3970	9700
Forest/Field/Other	8	40000	40000	59900		24	46800	131000	247000		86800	171000	307000
All Land Uses [a]		42600	43900	65600			57800	153000	290000		100000	197000	355000
Total Phosphorus (MT/year)													
Commercial/Industrial	6	1.20	2.51	3.28		24	4.97	6.39	8.65		6.17	8.90	11.9
Residential	8	27.4	32.3	85.3		24	54.8	86.1	146		82.2	118	231
Agriculture	8	24.6	39.4	59.8		24	70.2	115	150		94.8	154	210
Forest/Field/Other	8	190	299	507		24	227	454	676		417	753	1180
All Land Uses [a]		243	373	655			357	661	981		600	1030	1630
Nitrate+Nitrite Nitrogen (MT/year)													
Commercial/Industrial	6	1.85	9.91	38.7		24	16.2	25.4	40.0		18.1	35.3	78.7
Residential	8	832	1020	2770		24	947	1270	2190		1780	2290	4960
Agriculture	8	33.9	64.8	111		24	182	571	1430		216	636	1540
Forest/Field/Other	8	999	1780	6340		24	2250	4270	5720		3250	6050	12100
All Land Uses [a]		1870	2870	9260			3400	6140	9380		5260	9010	18700

[a] Values calculated by summing loading rates for all four land use types.

[b] Values calculated by summing baseflow and storm-event loading rates.

Flag:

E = 50 percent or more of the data are non-detect values; reported values are considered estimates with relatively low accuracy.

U = All of the data are non-detect values. The low value in range was calculated by assuming a zero for nondetect values; the high value in range was calculated assuming the maximum method reporting limit for non-detect values.

kg/yr = kilograms per year

g/yr = grams per year

MT/yr = metric tons per year

BEHP = Bis(2-ethylhexyl) phthalate

cPAHs = carcinogenic polycyclic aromatic hydrocarbons

DDT = dichlorodiphenyltrichloroethane

HPAHs = high molecular weight polycyclic aromatic hydrocarbons

LPAHs = low molecular weight polycyclic aromatic hydrocarbons

PAHs = polycyclic aromatic hydrocarbons

PBDE = polybrominated diphenyl ethers

PCBs = polychlorinated biphenyls

TPH-DOG = total petroleum hydrocarbons, extract of oil and grease (lube oil)

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Table 16. Comparison of Phase 2 addendum and Phase 3 Puget Sound loading rates.

Parameter	Units	Phase 2			Phase 3				% Difference [a]
		25th	Median	75th	25th	Median	75th	Flag	
Metals									
Total Copper	kg/year	31,100	66,800	144,000	27,600	35,700	65,700		-47%
Total Zinc	kg/year	102,000	211,000	439,000	113,000	122,000	134,000		-42%
Organics									
Total PCBs	g/year	27,100	118,000	525,000	2,500	5,270	15,900		-96%
Total PBDEs	g/year	146	516	1,860	5,180	5,710	9,730		1007%
Oil and Grease	MT/year	5,960	15,200	41,700	8,390	8,390	10,500	E	-45%

[a] Percent difference in loading rates was calculated by subtracting the Phase 2 median loading rate from the Phase 3 median loading rate and dividing by the Phase 2 median loading rate.

25th = 25th percentile

75th = 75th percentile

Diff. = difference

E = 50 percent or more of the data are non-detect values; reported values are considered estimates with relatively low accuracy.

kg/yr = kilograms per year

g/yr = grams per year

MT/yr = metric tons per year

PBDE = polybrominated diphenyl ethers

PCBs = polychlorinated biphenyls

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Table 17. Comparison of Phase 2 addendum and Phase 3 total loading rates by land use for Puget Sound.

Parameter	Units	Commercial/Industrial							Residential							Agricultural							Forest/Field/Other						
		Phase 2			Phase 3			Diff. (%)[a]	Phase 2			Phase 3			Diff. (%)[a]	Phase 2			Phase 3			Diff. (%)[a]	Phase 2			Phase 3			Diff. (%)[a]
		25th	Median	75th	25th	Median	75th		25th	Median	75th	25th	Median	75th		25th	Median	75th	25th	Median	75th		25th	Median	75th	25th	Median	75th	
Total Copper	kg/yr	2,060	3,780	6,930	541	642	805	-83%	5,960	11,700	23,000	2,510	3,700	5,450	-68%	1,800	4,050	9,100	2,360	3,390	6,780	-16%	20,700	46,400	104,000	22,200	28,000	52,700	-40%
Total Zinc	kg/yr	9,880	18,100	33,300	5,460	6,110	8,160	-66%	44,700	87,800	172,000	5,680	11,800	15,700	-87%	3,610	8,100	18,200	4,530	7,640	1,3300	-6%	41,300	92,800	209,000	96,900	96,900	96,900	4%
Total PCBs	g/yr	1,180	4,530	17,500	125	310	1,360	-93%	15,200	58,500	226,000	108	344	994	-99%	2,100	8,100	31,200	79.8	2,26	419	-97%	8,600	46,400	251,000	2,190	4,390	13,100	-91%
Total PBDEs	g/yr	0.784	3.02	11.6	210	497	2,890	16,357%	42.6	117	322	96.9	263	378	125%	6.31	24.3	93.7	28.3	107	147	340%	96.3	371	1,430	4,840	4,840	6,310	1,205%
Oil and Grease	MT/yr	494	907	1,660	37.9	37.9	66.9	-96%	3,910	8,780	19,700	455	455	553	-95%	295	810	2,230	171	171	171	-79%	1,200	4,640	17,900	7,730	7,730	9,720	67%

[a] Percent difference in loading rates was calculated by subtracting the Phase 2 median loading rate from the Phase 3 median loading rate and dividing by the Phase 2 median loading rate.

25th = 25th percentile

75th = 75th percentile

Diff. = difference

kg/yr = kilograms per year

g/yr = grams per year

MT/yr = metric tons per year

PBDE = polybrominated diphenyl ethers

PCBs = polychlorinated biphenyls

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Table 18. Grab sample timing relative to hydrograph position.

Monitoring Location ID	Number of Storm Events with Single Grab Sample	Number of Storm Events with 2 Grab Samples	Average Percent of Storm Volume Passed Before Sample(s) Collected [a]	Number of Grab Samples Occurring Before 10 Percent Of Storm Passed [a]	Number of Grab Samples Occurring After 90 Percent of Storm Passed
Snohomish Watershed					
CB335	6	0	20.2	3	0
CBX	5	1	19.8	2	0
RB111	2	4	22.6	2	0
RB202	4	2	24.3	2	0
AG174	3	3	22.4	3	0
AGG	2	4	21.7	1	0
FB200	4	2	19.5	1	0
FB203	1	5	22.7	2	0
Puyallup Watershed					
CBA	2	4	17.2	2	0
CBB	1	5	15.6	1	0
RB53	2	4	18.3	0	0
RB209	4	2	20.2	2	0
AG143	2	4	18.7	1	0
AG62	1	5	18	1	0
FB130	2	4	20.8	0	0
FB372	1	5	19.1	1	0

[a] For storms with 2 grab samples the average collection time between the two samples was used in this calculation.

Table 19. Analyzed parameters that were not detected in any of the 126 study samples.

Herbicides	4,6-Dinitro-2-Methylphenol	trans-Chlordane	PCB-094
2,4,5-T	4-Bromophenyl phenyl ether	Trans-Nonachlor	PCB-096
2,4,5-TP (Silvex)	4-Chloro-3-Methylphenol	**Petroleum and Oil**	PCB-100
2,4-DB	4-Chloroaniline	#2 Diesel	PCB-104
Acifluorfen (Blazer)	4-Chlorophenyl-Phenylether	Gasoline	PCB-112
Bentazon	4-Nitroaniline	**Phthalates**	PCB-113
Bromoxynil	Bis(2-Chloroethoxy)Methane	Di-N-Butylphthalate	PCB-115/116
Clopyralid	Bis(2-Chloroethyl)Ether	**Polybrominated Diphenyl Ethers (Congeners)**	PCB-122
Dichlorprop	Hexachlorobutadiene	PBDE-010	PCB-140
Diclofop-Methyl	Hexachlorocyclopentadiene	PBDE-077	PCB-145
Dinoseb	Hexachloroethane	PBDE-119	PCB-148
Ioxynil	Isophorone	PBDE-126	PCB-150
Picloram	m-Nitroaniline	PBDE-156/169	PCB-152
LPAHs	Nitrobenzene	PBDE-184	PCB-154
Acenaphthylene	N-Nitrosodimethylamine	PBDE-205	PCB-155
Metals	N-Nitrosodi-n-propylamine	**Polychlorinated Biphenyls (Congeners)**	PCB-159
Beryllium Dissolved	**Pesticides**	PCB-002	PCB-161
Beryllium Total	Aldrin	PCB-007/009	PCB-162
Selenium Dissolved	Alpha-BHC	PCB-012/013	PCB-166
Selenium Total	Beta-BHC	PCB-014	PCB-169
Thallium Dissolved	Chlordane, technical	PCB-023	PCB-173
Tin Dissolved	cis-Chlordane	PCB-029	PCB-175
Tin Total	Cis-Nonachlor	PCB-030	PCB-181
Other Base/Neutral/Acid Extractables	DDMU	PCB-034	PCB-186
1,2,4-Trichlorobenzene	Delta-BHC	PCB-039	PCB-188
1,2-Dichlorobenzene	Endosulfan I	PCB-050	PCB-191
1,2-Diphenylhydrazine	Endosulfan II	PCB-054	PCB-197
1,3-Dichlorobenzene	Endrin	PCB-055	PCB-198
1,4-Dichlorobenzene	Endrin Aldehyde	PCB-057	PCB-199
2,3,4,5-Tetrachlorophenol	Endrin Ketone	PCB-058	PCB-200
2,4,6-Trichlorophenol	Gamma-BHC (Lindane)	PCB-062	PCB-204
2,4-Dinitrotoluene	Heptachlor	PCB-063	PCB-205
2,6-Dinitrotoluene	Heptachlor Epoxide	PCB-065	PCB-207
2-Chloronaphthalene	Methoxychlor	PCB-067	PCB-208
2-Chlorophenol	Mirex	PCB-069	
2-Nitroaniline	Oxychlordane	PCB-072	
2-Nitrophenol	Total Chlordane	PCB-078	
3,3'-Dichlorobenzidine	Toxaphene	PCB-088/121	

Table 20. Storm-event to baseflow concentration ratios for the 21 priority parameters.

Parameter	Storm/Base Median Concentration Ratio			
	Commercial/Industrial	Residential	Agricultural	Forested
Arsenic Dissolved	*0.49*	*0.94*	*0.87*	*0.77*
Arsenic Total	*0.70*	1.33	*0.86*	1.01
Cadmium Dissolved	1.32	ND	storm > base	ND
Cadmium Total	storm > base	ND	ND	ND
Copper Dissolved	1.57	1.78	2.77	*0.99*
Copper Total	2.04	2.53	3.06	1.30
Lead Dissolved	1.42	2.96	2.14	2.77
Lead Total	6.24	3.35	3.39	2.70
Mercury Dissolved	1.94	2.91	2.46	2.00
Mercury Total	2.77	2.70	2.49	1.43
Zinc Dissolved	2.54	2.00	1.73	2.04
Zinc Total	2.34	2.94	1.03	1.00
Total PCBs	5.92	*0.73*	1.15	*0.87*
Total PBDEs	7.51	*0.87*	1.00	1.00
Total PAHs	17.56	storm > base	storm > base	storm > base
Total cPAHs	storm > base	storm > base	storm > base	
Total LPAHs	2.76	storm > base	storm > base	storm > base
Total HPAHs	15.55	storm > base	storm > base	
Bis(2-Ethylhexyl) Phthalate	storm > base	*0.94*	storm > base	storm > base
Triclopyr	1.06	storm > base	1.01	storm > base
Nonylphenol	storm > base	ND	ND	ND
Total DDT	12.50	ND	storm > base	storm > base
Oil and Grease	1.00	1.00	1.00	1.00
Lube Oil (TPH-DOG)	storm > base	storm > base	1.00	storm > base
Total Suspended Solids	20.00	4.67	1.83	3.50
Total Phosphorus	*0.75*	2.07	1.57	1.61
Nitrate+Nitrite Nitrogen	*0.75*	*0.97*	4.73	2.55

Red italics text indicates that baseflow concentrations were greater than storm event.

ND indicates that the parameter was not detected during baseflow or during storm events.

"storm>base" indicates that the ratio could not be computed because the parameter was not detected in baseflow, but was detected in storm events.

Blue bars indicate relative magnitude of the storm-to-base ratio when storm concentrations were greater than baseflow concentrations.

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Table 21. Comparison of unit-area loading rates (kg/km^2/yr) for select parameters from this study to literature and Green-Duwamish values.

Units: kg/km^2/yr	Total Suspended Solids	Nitrate+ Nitrite Nitrogen	Total Phosphorus	Dissolved Copper	Total Copper	Dissolved Mercury	Total Mercury	Dissolved Zinc	Total Zinc
Forest									
Green [a]	10,960	775	31	0.5	0.8	0.002	0.0031	0.69	1.37
Literature [b]	300	30	3	NA	3	NA	NA	NA	2
This Study	5,770	200	25	0.62	0.95	0.0019	0.0041	2.26	3.27
Agricultural									
Green	5,040	1300	97	1.4	1.7	0.0018	0.0029	1.64	2.88
Literature	34,300	60	58	NA	3	NA	NA	NA	10
This Study	2,600	412	101	1.78	2.22	0.0031	0.0048	3.22	5.01
Residential									
Green	15,787	593	33	0.77	1.83	0.0023	0.0088	2.06	6.84
Literature	1,000	10	4	NA	1	NA	NA	NA	4
This Study	5,060	560	29	0.5	0.9	0.002	0.0032	1.46	2.87
Commercial/Industrial									
Green	17,195	755	67	2.4	4.65	0.0045	0.0248	17.54	33.01
Literature	42,000	200	100	NA	3	NA	NA	NA	70
This Study	5,510	131	33	1.47	2.39	0.0019	0.0041	17.64	22.75

Colored bars indicate relative magnitude in each column.

[a] Green-Duwamish Watershed Water Quality Assessment (Herrera 2007)

[b] Burton and Pitt (2002); Horner et al. (1994); Madison et al. (1979)

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Table 22. Comparison of land use-based median concentrations from other regional studies.

		Embrey and Frans (2003) [b]			Herrera (2005) [c]			River Mouths		This Study					
		Springbrook	Thornton	Fishtrap	Springbrook	Big Soos Creek	Newaukum			4 sites Commercial/Industrial		4 sites Residential		4 sites Agricultural	
Analyte [a]	Units	Commercial/ Industrial	Residential	Agricultural	Commercial/ Industrial	Residential	Agricultural	Snohomish	Puyallup	Storm	Base	Storm	Base	Storm	Base
TSS	mg/L	17	8	21	16.9	3.8	7.7	13.6	38.7	10	0.5	14	3	5.5	3
TP	mg/L	0.17	0.05	0.06	0.1	0.03	0.08	0.03	0.08	0.044	0.058	0.067	0.033	0.206	0.131
Nitrate+Nitrite	mg/L	0.43	1.26	2.8	0.395	0.89	2.33	0.28	0.31	0.174	0.23	0.994	1.027	1.025	0.216
Chlorpyrifos	mg/L	–	0.015	–	ND	ND	ND	0.0001	0.000105	0.000125	0.000165	0.000125	ND	ND	ND
2,4-D	mg/L	–	–	NC	0.235	ND	0.085	–	–	0.0333	0.0305	0.0312	ND	0.031	0.0305
Dicamba	mg/L	–	–	NC	ND	ND	ND	–	–	0.031	0.0305	0.0307	0.0307	0.0305	0.0305
MCPA	mg/L	–	NC	–	ND	ND	ND	–	–	0.0315	0.0305	0.031	ND	0.031	ND
Triclopyr	mg/L	–	NC	–	–	–	–	–	–	0.0323	0.0305	0.031	ND	0.031	0.0307

[a] Parameter list chosen based on available data in Embrey and Frans (2003) and Herrera (2005).

[b] Springbrook Creek (Duwamish River) drains a 23.4 mi^2 basin that is majority commercial/industrial. Thornton Creek (Lake Washington) drains a 12.1 mi^2 basin that is majority residential. Fishtrap Creek (Nooksack River) drains 38.1 mi^2 of predominately agricultural land.

[c] Springbrook Creek (Duwamish River) drains a 23.4 mi^2 basin that is majority commercial/industrial. Big Soos (Green River) drains a 65.6 mi^2 basin that is majority residential. Newaukum Creek (Green River) drains 27.5 mi^2 of predominately agricultural land.

MCPA = 2-methyl-4-chlorophenoxyacetic acid
ND = analyte not detected in any samples
NC = not enough data to calculate median
TSS = total suspended solids
TP = total phosphorus
mg/L = milligrams per liter
– = no data available

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Appendices

Appendices A through S are available only on the web and on CD.

On the web, they are linked to this report at www.ecy.wa.gov/biblio/1103010.html.

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