YEARS 2001–2002
WATER QUALITY DATA REPORT

Green-Duwamish Watershed
Water Quality Assessment

Prepared for

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1.0 Introduction

King County (and previously the Municipality of Metropolitan Seattle) has conducted water quality sampling in the Green-Duwamish watershed since 1970. In the past, the goal of this monitoring has been to provide information about local surface waters in the Seattle/King County metropolitan area in support of programs designed to protect water quality and abate water pollution. Fourteen sites in the Green-Duwamish Watershed have been monitored since the mid-1970s.

In 2002, King County initiated a separate comprehensive study of the Green-Duwamish watershed, called the Green-Duwamish Watershed Water Quality Assessment (GDWQA) Comprehensive Monitoring Program. The primary purpose of this program is to collect and analyze water quality data within the Green-Duwamish watershed and to use these data to support the following efforts and teams (King County 2002):

- Wastewater Treatment Division Habitat Conservation Plan (WTD HCP) team
- The WTD combined sewer overflow (CSO) control planning team
- The Water Resources Inventory Area (WRIA) 9 Planning Work Group, Technical Committee and Steering Committee
- Washington State Department of Ecology (Ecology) Total Maximum Daily Load (TMDL) efforts.

The primary goal of this monitoring program is to develop analytical tools for evaluating current and future water quality and quantity issues in the Green-Duwamish watershed, and to provide water quality information to clients both internal and external to King County's Department of Natural Resources and Parks (DNRP). For example, data from the GDWQA will be used for wastewater capital planning, Water Resource Inventory Area (WRIA) 9 salmon conservation planning, stormwater management efforts, and Washington State Department of Ecology's Total Maximum Daily Load (TMDL) program. The scope of work of this program includes water quality and hydrologic monitoring, land use/land cover modeling, water quality and quantity modeling, best management practice (BMP) evaluation, and aquatic life risk assessment.

In support of this monitoring program, Herrera Environmental Consultants, Inc. (Herrera) was retained by the County to evaluate and summarize Green-Duwamish water quality data collected from 2001 through 2003. This information will be summarized by Herrera in two water quality data reports that will be submitted to the County. This document represents the first of these water quality data reports that evaluates data collected during the 2001 and 2002 calendar years. In addition, Appendix A of this report summarizes data collected by King County during 2000, before monitoring efforts began for the GDWQA. A second water quality data report will be prepared that summarizes water quality results from the 2003 calendar year and is to be submitted to the County later in 2004. A water quality loadings report will then be prepared that presents methods, results, and detailed analyses of the 2001-2003 data including a hydrologic data analysis, pollutant loading calculations, analysis of land use loading factors, and statistical analysis. Results from water quality monitoring conducted in the Green-Duwamish watershed prior to 2000 are presented in the Habitat Limiting Factors and Reconnaissance Assessment Report (Kerwin and Nelson 2000) and are also summarized below in Section 2.2 of this report for select waterbodies.

1.1 Goals and Objectives

The objectives of the Green-Duwamish Watershed Water Quality Assessment Comprehensive Monitoring Program are to:

- Measure water quality parameter concentrations in different geographic areas of the watershed throughout the year, including at the mouths of major tributaries and at sub-watershed boundaries within the mainstem Green River

- Measure water quality parameter concentrations resulting from different land use/land cover types within select tributary subbasins

- Measure water quality parameter concentrations in the mainstem, major streams, select tributaries during both storm and baseflow conditions

- Measure water quality parameter concentrations as a function of the rise, peak, and fall of the corresponding stream hydrograph to determine the variability of parameter concentrations within a storm

- Collect sufficient data to support development and calibration of a water quality model for the Green-Duwamish watershed.

Water quality monitoring for the GDWQA was conducted according to the sampling and analysis plan (King County 2002), and involves collecting water samples at 18 sites located in the lower and middle segments of the Green-Duwamish watershed. Two of these sites are located on the mainstem of the Green River and five sites are located near the mouths of four major tributary streams including Springbrook Creek (Black River), Mill Creek, Soos Creek, and Newaukum Creek. The remaining 11 sites are located on tributaries representing different land uses including forest (three sites), agriculture (two sites), low-medium development (four sites), and high development (two sites) (King County 2002).

This report characterizes the existing conditions in the Green-Duwamish Watershed based on sampling that was conducted at GDWQA monitoring sites during the 2001 and 2002 calendar years. The specific goals of this report are as follows:

- Characterize existing water quality conditions in the Green-Duwamish Watershed based on comprehensive monitoring data collected in 2001 and 2002 for the GDWQA comprehensive monitoring program.

- Evaluate significant spatial patterns in the water quality data for the 18 monitoring locations.

- Identify sites with impaired water quality and those parameters of concern causing impairment.

1.2 Report Organization

This report is organized to include the following components:

- Introduction
- Watershed Overview
- Sampling and Laboratory Analysis Methods
- Data Management and Analysis Methods
- Data Evaluation and Results
- Conclusions
- References.

The Watershed Overview (Section 2.0) describes physical features and land use characteristics of the Green-Duwamish River and its tributaries. This section also includes a general discussion of historical water quality data collected within the watershed.

The Sampling and Laboratory Analysis Methods (Section 3.0) includes an overview of the 2001 and 2002 sampling locations, sample types and sampling frequency, sample collection procedures, sample documentation and handling procedures, sampling parameters, laboratory analysis methods, quality control procedures, and data reporting and recordkeeping procedures. The Data Management and Analysis Methods (Section 4.0) includes a description of the procedures used for data compilation and management, computation of summary statistics, comparison of results to the applicable water quality criteria, spatial pattern analysis, and a discussion of the water quality index (WQI) ranking system.

The Data Evaluation and Results (Section 5.0) summarizes water quality data collected for the GDWQA in 2001 and 2002. In order to provide some context for interpreting these data, this section begins with an evaluation of precipitation totals from the current monitoring period relative to historical precipitation totals. Results from the water quality monitoring are then presented under separate subsections for each of the following major parameter categories: in-stream measurements, conventionals, microbiological parameters, nutrients, metals, and priority pollutant organics. For each set of parameters identified, this section includes an overview discussion, summary statistics and comparison of results to the water quality criteria, and a spatial pattern analysis. The statistics include box plots exhibiting storm and base flow data for each parameter. Finally, this section presents and discusses Water Quality Index (WQI) scores for each of the monitoring sites.

The Conclusions (Section 6.0) summarizes the existing water quality conditions in the Green-Duwamish watershed. This section describes specific subbasins/streams with impaired water quality and identifies the associated parameters that are responsible for the impairment. This section also describes any significant spatial patterns that were identified through a statistical analysis of the data. The References (Section 7.0) lists all references that are cited within this document. Supporting documentation for the sections above is also provided in Appendices A through K.

2.0 Watershed Overview

This section describes the physical features and land use characteristics of the Green-Duwamish watershed and the individual stream basins studied. Also included is a general discussion of historical water quality data collected within the watershed.

2.1 Physical Features and Land Use Characteristics

This section summarizes physical features and land use patterns in the Green-Duwamish watershed and the studied stream basins as described in the WRIA 9 Habitat-limiting Factors and Reconnaissance Assessment Report completed by King County (2000).

2.1.1 Green-Duwamish Watershed

The Green-Duwamish watershed is located in Water Resource Inventory Area 9 (WRIA 9), which is located entirely within King County, Washington (Figure 1). The watershed includes a drainage area of approximately 484 square miles, consisting of the Puget lowland and Cascades ecoregions (Ecology 1995 and King County 2002). The watershed extends from the crest of the Cascade Mountains at the headwaters of the Green River, west to the mouth of the Duwamish River where the river empties into Elliot Bay at the City of Seattle. The average areal precipitation is 59 inches per year within the watershed (Ecology 1995). The Green-Duwamish watershed is comprised of the following subwatersheds (Figure 2):

- Upper Green River subwatershed covering 219.7 square miles above river mile (RM) 64.5 at Howard Hanson Dam.

- Middle Green River subwatershed covering 177.5 square miles from RM 64.5 to RM 32.0 at Auburn Narrows.

- Lower Green River subwatershed covering 63.8 square miles from RM 32.0 to RM 11.0 at Tukwila.

- Green-Duwamish Estuary subwatershed covering 22.2 square miles from RM 11.0 to RM 0.0 at Elliot Bay.

The GDWQA study area encompasses 264 square miles of the Green-Duwamish watershed that extends from Howard Hanson Dam (RM 64.5) to the mouth of the Duwamish River (RM 0) (King County 2002). The Upper Green River sub-watershed (220 square miles) above Howard Hanson Dam is not included in this study. Major cities that are located within the study area include Seattle, Renton, Kent, Auburn, Tukwila, and Enumclaw. Major streams draining to the Green River within the study area are include Soos, Newaukum, Mill (Hill), and Springbrook Creeks.

Figure 1. Location of the Green-Duwamish watershed study area in WRIA 9, Washington.

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Figure 2. Land use and cover circa 1995, WRIA 9

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Land use and cover (circa 1995) in WRIA 9 are presented in Figure 2. Designated land use in WRIA 9 is presented in Figure 3. Land use in the Upper Green River watershed (not included in the study area) is dominated by forest and forestry practices and serves as the drinking water watershed for the City of Tacoma. Land use in the Middle and Lower Green River subwatersheds is dominated by agriculture and low- to high-density residential development with some forested areas. The Green-Duwamish Estuary subwatershed is an urban industrialized area serving the City of Seattle.

2.1.2 Major Stream Basins and Tributary Subbasins

In order to address watershed variability, the monitoring study targeted major stream basins and tributary subbasins having varied land use and a wide geographic distribution across the Green River watershed (King County 2002). Based on this criterion, the major stream basins selected were Springbrook Creek (including the Black River), Mill (Hill) Creek, Soos Creek, and Newaukum Creek; and the tributary subbasins selected were Hamm Creek, Mill Creek (in Springbrook Creek basin) tributary, Panther Creek (in Springbrook basin), an unnamed Green River tributary at Lea Hill, Soosette Creek (in Soos Creek basin), Crisp Creek, four Newaukum Creek tributaries, and an unnamed Green River tributary near RM 61. These major stream basins and associated tributaries are described below.

2.1.2.1 Springbrook Creek Basin

Springbrook Creek flows via the Black River into the Lower Green River at RM 11.0 where the Green River becomes the Duwamish River. The drainage basin is approximately 24 square miles in area, and is located on the east side of the Lower Green River encompassed by the cities of Renton and Kent. Because of prior drainage modifications (diversion of Black River from Lake Washington), the major stream draining the basin is now Springbrook Creek (Kerwin and Nelson 2000). Springbrook Creek is approximately 12 miles in length and becomes the Black River at a point 0.65 miles upstream of the Green River (WDF 1975). Historically, the Black River drained Lake Washington, and combined with the Cedar River and then Springbrook Creek before it merged with the Green River to become the Duwamish River. Since construction of the Lake Washington Ship Canal in 1916, the Black River receives very little drainage besides that in Springbrook Creek.

Basin land use consists of low- to high-density development and includes portions of the cities of Kent and Renton. Panther Creek and Mill Creek are two of the largest streams within the Springbrook Creek basin. Panther Creek flows from Panther Lake into Springbrook Creek at RM 1.3 (WDF 1975). Mill (Springbrook) Creek is located entirely in the Green River valley and flows into Springbrook Creek at RM 3.8. Land use in the Panther Creek subbasin consists of low- to medium-density development, whereas land use in the Mill (Springbrook) subbasin consists of higher density development.

2.1.2.2 Mill (Hill) Creek Basin

Mill (Hill) Creek, which has been referred to as Hill Creek in various literature sources, differs from the Mill Creek located in the Springbrook Creek basin. Mill (Hill) Creek flows into the Lower Green River at RM 23.9 and is approximately 8.35 miles long (WDF 1975). The Mill (Hill) Creek drainage basin is approximately 22 square miles in size and includes portions of the Cities of Kent, Auburn, Algona, and Federal Way (Kerwin and Nelson 2000). Mill (Hill) Creek flows originate from Lake Doloff and Lake Geneva located west of the Green River Valley. Adjacent Lower Green River tributaries include Mullen Slough and Midway Creek. Prior to reaching the valley floor and flowing into the Green River, Mill (Hill) Creek flows down a steep ravine, Peasley Canyon. Land use in the Mill (Hill) Creek subbasin consists of forested areas and residential land use in the upper watershed and residential and agricultural land use in the lower parts of the basin.

2.1.2.3 Soos Creek Basin

Soos Creek flows into the Middle Green River at RM 33.7 and is 14.15 miles long (WDF 1975). The drainage basin includes over 60 miles of streams including 25 tributaries. The Soos Creek drainage basin is approximately 70 square miles in size and is located southeast of Renton and east of Kent (Kerwin and Nelson 2000). Soos Creek subbasin land use/cover consists of rural residential, agriculture, and highly urban commercial and residential areas, and includes a Washington State Department of Fish and Wildlife salmon hatchery near the mouth of Soos Creek. Soosette Creek is a tributary that enters Soos Creek at RM 1.35. Soosette Creek subbasin land use consists of low- to medium-density development. Jenkins Creek and Covington Creek are also tributaries of Soos Creek, but were not sampled as part of the GDWQA.

2.1.2.4 Newaukum Creek Basin

Newaukum Creek, the uppermost major stream included in this study, flows into the Middle Green River at RM 40.7 and is 14.35 miles long (WDF 1975). The basin is over 27 square miles in size (Kerwin and Nelson 2000). The creek flows from the mountains east of the City of Enumclaw through the Enumclaw valley and then into the Green River. Basin land use consists of high-density development, agriculture/pasture, and forest/forestry practices. Four unnamed Newaukum Creek tributaries were monitored for this study. The Newaukum Creek tributary at Enumclaw (site I322B) represents high-density development. Newaukum Creek tributaries at SE 424th Street ditch (site B322) and 236th Avenue SE (site D322) represent agriculture and pasture land use. The Newaukum Creek tributary downstream of Weyerhaeuser (site S322) represents forestry and forest practices.

2.1.2.5 Hamm Creek Basin

Hamm Creek is located immediately south of the Seattle City limits and flows into the Duwamish River at RM 4.95. The stream is less than 1 mile in length (WDF 1975). Land use in the Hamm Creek basin consists mostly of low- to medium-density development, with a forested riparian corridor in the upper basin (Kerwin and Nelson 2000).

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Figure 3. Designated land use, WRIA 9.

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2.1.2.6 Lea Hill Basin

An unnamed tributary (WRIA stream 09-0069) flows into the Green River at RM 30.15. The stream is approximately 1 mile in length, and drains the Lea Hill area located east of Auburn and consisting of low- to medium-density development.

2.1.2.7 Crisp Creek Basin

Crisp Creek is a small stream that flows into the Middle Green River at RM 40.1, just west of the City of Black Diamond. The drainage basin is approximately 4.5 square miles in size and the stream is 3.55 miles in length (Kerwin and Nelson 2000; WDF 1975). Land use in the Crisp Creek basin consists of forest/forest practices with rural zoning, as well as a salmon hatchery operated by the Muckleshoot Indian Tribe. A portion of the streamflow is contributed by springs (i.e., dominated by groundwater).

2.1.2.8 Unnamed Green River Tributary Basin

The furthest upstream tributary monitored for this study is an unnamed tributary (WRIA 09-0157) that flows into the Green River near the City of Tacoma's diversion dam at RM 61. Land use in the unnamed tributary basin consists of forest/forestry practices.

2.2 Historical Water Quality Conditions

This section summarizes historical water quality conditions in the Green-Duwamish watershed as described in the WRIA 9 Habitat Limiting Factors and Reconnaissance Assessment Report prepared by King County (2000). Water quality data collected in 2000 (since the habitat limiting factors report and before the GDWQA study) were reviewed separately and are summarized in Appendix A of this document. These historical water quality data indicate that water quality conditions vary widely throughout the watershed and among the various drainage sub-basins.

2.2.1 303(d) Water Quality Limited Water Bodies

Section 303(d) (and later revisions) of the Clean Water Act (CWA) requires all states to prepare a list of surface waters that are not expected to meet applicable water quality criteria following implementation of water quality based controls. This list, identified as the 303(d) list, is prepared by Ecology and submitted to the U.S. EPA every 2 years. The 1998 303(d) list is the most recent list prepared by Ecology approved by the U.S. EPA. A 303(d) list was not required by U.S. EPA for 2000, and the preliminary draft 303(d) list for 2002/2004 was issued by Ecology in January 2004 for public review. Further, the CWA requires states to establish Water Clean-Up Plans or Total Maximum Daily Loads (TMDLs) for parameters identified on the 303(d) list that do not meet applicable water quality criteria.

Numerous waterbodies in the Green-Duwamish watershed are included on the state's 1998 303(d) list (Figure 4). Waterbodies listed include the Duwamish Waterway and River, Lower Green River, Middle Green River, Upper Green River, Springbrook Creek, Mill (Hill) Creek, Soos Creek, Newaukum Creek, and Crisp Creek. Table 1 identifies the parameters listed on the state's 1998 303(d) list in the Green-Duwamish watershed. As part of the TMDL process, Ecology proposes to begin water clean-up planning in 2004 for the Green and Duwamish Rivers; and Big Soos, Newaukum, Springbrook and Mill (Hill) Creeks (Ecology 2003).

Table 1. Water bodies monitored for the Green-Duwamish watershed water quality assessment identified on Washington State's 1998 303(d) list.

Water Body	Listed Parameter(s) [a]
Lower Green River (RM 11.0 to 32.0)	Temperature, fecal coliform bacteria, chromium, and mercury
Middle Green River (RM 32.0 to 64.5)	Temperature and fecal coliform bacteria
Springbrook Creek	Temperature, dissolved oxygen, fecal coliform bacteria, cadmium, chromium, copper, mercury, and zinc
Mill (Hill) Creek	Temperature, dissolved oxygen, and fecal coliform bacteria.
Soos Creek, Soosette Creek	Temperature, dissolved oxygen, and fecal coliform bacteria
Newaukum Creek	Dissolved oxygen, fecal coliform bacteria, and ammonia nitrogen
Crisp Creek	Fecal coliform bacteria

Source: Kerwin and Nelson 2000 and Ecology 1998.
[a] Table shows listings for water quality parameters not meeting applicable criteria, but does not include sediment and tissue parameters.

2.2.2 Green River

Based on recent (1996 through 1999) water quality data, the Lower Green River (RM 11.0 to RM 32.2) can be characterized as having fair to good water quality. This reach of the river is listed as impaired on the state's 1998 303(d) list for temperature, fecal coliform, chromium, and mercury. Past sampling results indicate that river waters do not always meet state criteria for water temperature and dissolved oxygen during the mid- to late-summer. The river generally has low turbidity with peak values observed during storm events. River waters can also be slightly acidic and not meet the state's minimum pH criterion of 6.5. Based on samples collected in 1996 through 1999, ammonia nitrogen concentrations met state chronic and acute criteria. River waters exhibit low concentrations of metals, with the exception of aluminum, which did not meet the U.S. EPA (2002a) chronic criterion of 87 µg/L during three sampling events. (Aluminum data are compared to the U.S. EPA criteria because Washington State does not have a surface water quality criterion for aluminum [WAC 173-201A]. Because there are no state water quality criteria for aluminum, no 303(d) listing has been established).

The Middle Green River (RM 32 to RM 63.8) generally exhibits good water quality. Past sampling results indicate that river waters have reasonably moderate summer temperatures, and are generally clear and well oxygenated with occasionally elevated fecal coliform bacteria concentrations. This reach of the river is included on the state's 1998 303(d) list as impaired for temperature and fecal coliform bacteria. King County-measured ammonia-nitrogen concentrations met state criteria during all sampling events from 1996 through 2000. River waters generally met the state's pH criteria range of 6.5 to 8.5 and exhibited low metals concentrations with the exception of aluminum. However, one pH value was less than the

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Figure 4. Water bodies and parameters on the 1998 303(d) list for water, WRIA 9.

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minimum criterion of 6.5. Three sample results exceeded the U.S. EPA (2002) chronic aluminum criterion (87 µg/L) and one sample result exceeded the U.S. EPA acute criterion of 750 µg/L.

2.2.3 Major Streams and Tributary Sites

Past sampling indicates that water quality conditions in the major streams and tributary sites vary considerably throughout the watershed. Springbrook Creek, Mill (Hill) Creek, Soos Creek, Newaukum Creek and Crisp Creek are identified on the state's 1998 303(d) list as impaired waterbodies (Table 1). Historical water quality data are not available for the other tributary sites included in this study and, therefore, are not summarized in this report. Major stream and tributary water quality patterns presented below are based on sampling results summarized in the Habitat Limiting Factors and Reconnaissance Assessment Report (Kerwin and Nelson 2000) and results from sampling conducted during 2000 (see Appendix A).

2.2.3.1 Springbrook Creek

Springbrook Creek does not always meet applicable state water quality criteria (WAC 173-2-201A) for dissolved oxygen, temperature, pH, fecal coliform bacteria, and numerous metals. Stream waters have been observed to be warm, poorly oxygenated, turbid, and to exhibit elevated fecal coliform bacteria concentrations. Ammonia nitrogen concentrations met applicable state criteria during all sampling events from 1996 through 2000. However, three pH measurements did not meet the state's minimum criterion of 6.5 during this period. Three samples exceeded the U.S. EPA (2002a) chronic aluminum criterion (87 µg/L) and two samples exceeded the U.S. EPA acute aluminum criterion of 750 µg/L. Springbrook Creek is included on the state's 1998 303(d) list as impaired for dissolved oxygen, temperature, fecal coliform bacteria, and for the metals cadmium, chromium, copper, mercury, and zinc.

2.2.3.2 Mill (Hill) Creek

Mill (Hill) Creek sampling results indicate that stream waters do not always meet applicable state water quality criteria (WAC 173-2-201A) for temperature, dissolved oxygen, pH and fecal coliform bacteria. During sampling, stream waters were poorly oxygenated, turbid, and exhibited elevated fecal coliform bacteria concentrations. Erosion along the streambanks within Peasley Canyon have caused high suspended solids and turbidity downstream (Kerwin and Nelson 2000). Elevated water temperatures have been measured downstream of Peasley Canyon to the stream's mouth (Kerwin and Nelson 2000). Ammonia nitrogen concentrations met applicable state criteria during all sampling events from 1996 through 2000. However, four pH measurements did not meet the state's minimum criterion of 6.5 during sampling during this same sampling period. Three samples exceeded the U.S. EPA chronic aluminum criterion (87 µg/L) and two samples exceeded the U.S. EPA acute aluminum criterion of 750 µg/L. Mill (Hill) Creek is included on the state's 1998 303(d) list as impaired for dissolved oxygen, temperature, and fecal coliform bacteria.

2.2.3.3 Soos Creek

Soos Creek does not always meet applicable state water quality criteria (WAC 173-2-201A) for temperature, pH, dissolved oxygen, copper (chronic) and fecal coliform bacteria. Sites monitored in this subbasin include those on the mainstem as well as numerous tributaries, including Soosette Creek. Streams in the Soos Creek basin are included on the state's 1998 303(d) list for dissolved oxygen, temperature, and fecal coliform bacteria.

During sampling, Soos Creek waters were generally clear with elevated fecal coliform bacteria concentrations. Warm summer water temperature and low dissolved oxygen concentrations were recorded during summer sampling. Ammonia nitrogen met applicable state criteria during all sampling events from 1996 through 2000. Most pH measurements were within the state criteria range of 6.5 to 8.5; however, various measurements failed to meet the minimum criterion of 6.5. Sampling indicates these stream waters have low concentrations of metals with the exception of aluminum.

Historical data indicate that water quality in Soosette Creek is fair and similar to that in Soos Creek. During sampling, stream waters were generally clear with elevated fecal coliform concentrations. Low dissolved oxygen and warm water temperatures were recorded during the warm summer months. Ammonia nitrogen concentrations met applicable state criteria during all sampling events from 1996 through 2000. During this same sampling period, one pH measurement fell below the state's minimum criterion of 6.5.

2.2.3.4 Newaukum Creek

Newaukum Creek does not always meet applicable state criteria (WAC 173-2-201A) for dissolved oxygen, ammonia nitrogen, pH, and fecal coliform bacteria. During sampling, stream waters were generally cool and clear with low dissolved oxygen concentrations. Ammonia nitrogen concentrations met applicable state criteria during all sampling events from 1996 through 2000. However, three pH measurements did not meet the state's minimum state criterion of 6.5 during this same sampling period. Three samples exceeded the U.S. EPA (2002a) chronic aluminum criterion (87 µg/L) and two samples exceeded the U.S. EPA acute aluminum criterion of 750 µg/L. Newaukum Creek is included on the state's 1998 303(d) list for dissolved oxygen, ammonia-nitrogen, and fecal coliform bacteria.

2.2.3.5 Crisp Creek

Crisp Creek (also known as Keta Creek) sampling results indicate that the waters of this stream do not always meet applicable state criteria (WAC 173-2-201A) for temperature, dissolved oxygen, and fecal coliform bacteria. During sampling, stream waters were generally cool. Variable results for fecal coliform bacteria and turbidity have been recorded at two separate sampling sites located approximately one mile apart. The upper site (site F321), located upstream of the Keta Fish Hatchery, consistently exhibited lower turbidity and fecal coliform bacteria concentrations than the lower site (site 0321). Ammonia nitrogen and pH results met applicable state criteria during all sampling events from 1996 through 2000. However, two aluminum samples exceeded the U.S. EPA (2002a) chronic criterion (87 µg/L). Crisp Creek is included on the state's 1998 303(d) list for fecal coliform bacteria.

3.0 Sampling and Laboratory Analysis Methods

Sample collection, laboratory analysis, and quality control procedures used in this study are described in the comprehensive monitoring program sampling and analysis plan (SAP) prepared for the GDWQA project by King County (2002). Site locations, sample types and sampling frequency, sample collection procedures, sample documentation and handing procedures, sampling parameters, laboratory analysis methods, quality control procedures, and data reporting procedures are briefly summarized below.

3.1 Site Locations

During 2001 and 2002, a total of 18 sites were sampled by King County as part of the GDWQA comprehensive monitoring program. Sampling sites were selected to represent various boundary conditions and land use types within the watershed. Two sites are located on the Green River and five sites are located near the mouths of major streams. The remaining 11 sites are located on tributaries representing the following four categories of land use: forest, agriculture/pasture, low-medium density development, and high density development.

The location of each monitoring site is shown in Figure 5 and described briefly below. Figure 6 presents a simplified schematic showing the relative location of each monitoring site in the Green-Duwamish watershed and the associated monitoring category (i.e., river site, major stream site, or tributary site representing either forest, agriculture/pasture, low-medium density development, or high density development). More detailed information on the location and purpose of each sampling site can be found in the SAP (King County 2002). The 18 sampling site numbers, names, and associated categories include:

- A310 – Lower Green River at Fort Dent Park (RM 11.9), representing the lower boundary of the Lower Green River. It should be noted that this site is actually upstream of the confluence with the Black River to avoid perturbations resulting from tidal influences.

- E319 – Upper Green River below Howard Hanson Dam (RM 63.8), representing the lower boundary of the Upper Green River.

- A307 – Hamm Creek, representing low-medium density development.

- C317 – Black River Pump Station, representing a major stream basin.

- A317 – Springbrook Creek near mouth, representing a major stream basin.

- A326 – Panther Creek, representing low-medium density development.

- B317 – Mill Creek tributary (Springbrook basin), representing high density development.
- A315 – Mill (Hill) Creek near mouth, representing a major stream basin.
- A330 – Green tributary at Lea Hill, representing low-medium density development.
- A320 – Soos Creek above fish hatchery, representing a major stream basin.
- Y320 – Soosette Creek, representing low-medium density development.
- F321 – Crisp Creek above fish hatchery, representing forest.
- 0322 – Newaukum Creek near mouth, representing a major stream basin.
- D322 – Newaukum tributary at 236th Avenue SE, representing agriculture/pasture.
- B322 – Newaukum tributary at SE 424th Street ditch, representing agriculture/pasture.
- I322B – Newaukum tributary at Enumclaw, representing high density development.
- S322 – Newaukum tributary downstream of Weyerhaeuser, representing forest.
- A341 – Green River tributary in foothills near Tacoma Public Utilities (TPU) diversion, representing forest.

3.2 Sample Types and Sampling Frequency

Samples were collected during base flow and storm flow conditions. The sample collection protocols and frequency for each type of sampling are described briefly below. More detailed information on this topic can also be found in the SAP for the GDWQA (King County 2002). Actual sampling dates for 2001 and 2002 are presented in Table 2 with the corresponding event identification number assigned by King County. Samples were not collected at all sites for all parameters on these dates; detailed information on sample types is summarized for each site in subsequent sections of this document.

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Figure 5. Monitoring sites for the Green-Duwamish watershed water quality assessment, WRIA 9.

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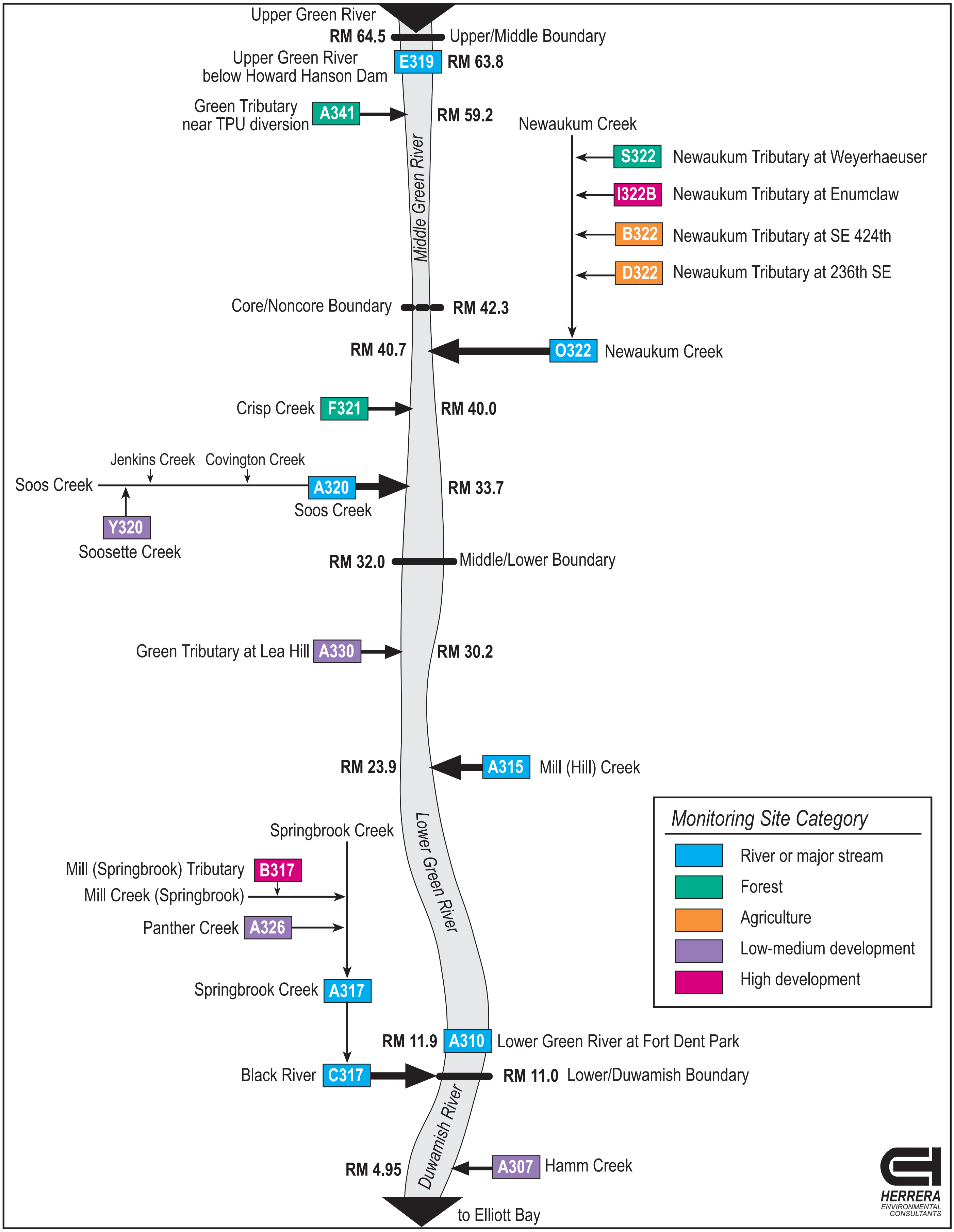


Figure 6. Schematic diagram of monitoring sites for the Green-Duwamish watershed water quality assessment.

Table 2. Sampling dates for monitoring conducted in 2001 and 2002 for the Green-Duwamish watershed water quality assessment.

Base Flow		Storm Flow	
Event ID	Sampling Dates	Event ID	Sampling Dates
B1	2/13/2002 - 2/14/2002	S1	11/14/2001 - 11/15/2001
B2	3/25/2002 - 3/26/2002	S2	11/28/2001 - 11/29/2001
B3	4/24/2002 - 4/25/2002	S3	12/13/2001 - 12/15/2001
B4	6/12/2002 - 6/13/2002	S4	1/23/2002 - 1/24/2002
B5	8/6/2002	S5	2/21/2002 - 2/22/2002
B6	10/22/2002 - 10/23/2002	S6	6/28/2002 - 6/30/2002
B7	12/3/2002 - 12/4/2002	S7	11/6/2002 - 11/8/2002
		S8	12/11/2002 - 12/13/2002

The event designations by King County shown in Table 2 were not used for defining base and storm events for each sampling site. Base and storm events were designated using hydrologic data as described under Data Management (Section 4.1).

3.2.1 Base Flow Samples

Base flow sampling targeted periods when no precipitation had occurred within at least a 2- to 3-day period, depending on the site, so that streams were sampled after the fall (recession) of the stream hydrograph following a precipitation (storm) event. According to the SAP (King County 2002), base flow sampling was to occur bimonthly (every second month) for a period of one year. A total of seven base flow events were sampled from February through December 2002 (see Table 2), which generally meets the project objective.

3.2.2 Storm Flow Samples

Storm flow sampling targeted wet periods when at least 0.5 inches of precipitation occurred within a 12-hour period. According to the SAP, between eight and ten storms were to be sampled during water year 2002, and an unspecified number of storms were to be sampled during water year 2003 depending on the data collected in 2002. To ensure that storm flow sampling occurred throughout the year, no more than two storms were to be sampled each month. A total of six storm events were sampled from November 2001 through June 2002 in water year 2002 (see Table 2). Two storm events were sampled in November and December 2002 for water year 2003. (Additional storm events were sampled in water year 2003 that are not included in this data report which covers calendar years 2001 and 2002.)

3.3 Sample Collection Procedures

Samples were collected using a combination of manual grab, auto-sequential (series of discrete samples), and auto-composite methods. In addition, field measurements were recorded for selected parameters at each monitoring site. Sample collection and field measurement procedures are described briefly in the subsections to follow. More detailed information on this topic can also be found in the SAP for the GDWQA (King County 2002). Actual sampling procedures used on each sampling date in 2001 and 2002 are shown in Tables 3 through 8 for the following major categories of parameters: field measurements, conventionals, microbiological parameters, nutrients, metals, and organics. (See Section 3.5 below for a more detailed discussion of these parameter categories.)

3.3.1 Manual Grab Samples

Grab samples were collected according to Environmental Support Services (ESS) Standard Operating Procedure (SOP) # 02-02-13 (Clean Surface Grab Sampling) protocols, which followed U.S. EPA Method 1669 (U.S. EPA 1996). Grab samples were collected while facing upstream to minimize contamination from the sampler or field equipment. Sampling personnel wore multiple layers of PVC gloves and included a pair of shoulder-length gloves to prevent possible contamination from the sampler (King County 2002). Samples for low-level metals analyses were collected using the U.S. EPA “clean hands/dirty hands” technique (U.S. EPA Method 1669). All samples were placed in a cooler with ice and transported to the laboratory for analysis.

Manual grab sampling was the only sampling method used for the following sites: Panther Creek (A326), Green tributary at Lea Hill (A330), Newaukum tributary at SE 424th Street (B322), Crisp Creek (F321), Black River (C317), Mill (Hill) Creek (A315), and Soos Creek (A320). Manual grab sampling was used as the secondary sampling method at the remaining sites, and was used exclusively at all sites for field parameters, low-level metals, and organics.

3.3.2 Auto-Sequential Samples

For auto-sequential sampling, multiple discrete samples were collected using ISCO 3700 series autosamplers during storm and base flow events. For each storm event, the autosamplers were programmed to collect one sample every four hours for a period ranging from 24 to 40 hours (collecting a total of six to 10 samples) depending on the duration of elevated stream flow. For base flow events, the autosamplers were programmed to collect one sample every four to eight hours for up to a 24-hour base flow event. Results from this type of sampling allows water quality to be examined in relation to the rise, peak, and fall of the storm hydrograph, and to assess variability during base flow events.

The autosamplers were initiated either manually or automatically by a liquid level activator switch for a specific rise in water level. The autosamplers contained 24 bottles and were programmed to fill four bottles for each sample. Thus, a second set of bottles was placed in the

Table 3. Sample types by site for field measurements, Green-Duwamish watershed water quality assessment, 2001-2002.

Event ID	Sample Date	Site A310	Site E319	Site A307	Site C317	Site A317	Site A326	Site B317	Site A315	Site A330	Site A320	Site Y320	Site F321	Site O322	Site D322	Site B322	Site I322B	Site S322	Site A341	Total Sites
S1	11/14/2001			S/GR		S/GR						S/GR	S/GR	S/GR	S/GR	S/GR	S/GR			8
S2	11/28/2001		**B/GR**	S/GR		S/GR						S/GR	S/GR	S/GR	S/GR	S/GR	S/GR			9
S3	12/14/2001		S/GR	S/GR								S/GR	S/GR	S/GR	S/GR	S/GR	S/GR		S/GR	9
S4	1/24/2002	S/GR	S/GR	S/GR			S/GR	S/GR	S/GR	S/GR		S/GR	**B/GR**	S/GR	S/GR	S/GR	S/GR		S/GR	14
B1	2/13/2002	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR		B/GR	B/GR		B/GR		B/GR	15
S5	2/21/2002	S/GR	S/GR		S/GR	S/GR	S/GR	S/GR	S/GR	S/GR	S/GR						S/GR		S/GR	11
B?	2/26/2002	B/GR	**S/GR**		B/GR	**S/GR**			B/GR		B/GR			B/GR						7
B2	3/26/2002	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR		B/GR		B/GR	B/GR	B/GR	B/GR	B/GR	B/GR		B/GR	15
B3	4/25/2002	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR			B/GR		B/GR		B/GR	14
B?	5/1/2002	B/GR	**S/GR**		B/GR	B/GR			B/GR		B/GR			B/GR						7
B4	6/12/2002	B/GR	**S/GR**	B/GR	B/GR	B/GR	B/GR	B/GR		B/GR		B/GR	B/GR	B/GR	B/GR	B/GR	B/GR		B/GR	15
S6	6/29/2002	S/GR	S/GR		S/GR	S/GR	S/GR	S/GR	S/GR	S/GR	S/GR			S/GR					S/GR	11
B5	8/6/2002	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR			**S/GR**	B/GR		B/GR			13
B6	10/22/2002	B/GR	B/GR	B/GR		B/GR	B/GR	B/GR	B/GR	B/GR	B/GR		B/GR	B/GR	B/GR			B/GR		13
S7	11/7/2002	S/GR	**B/GR**		S/GR	S/GR	S/GR	**B/GR**	S/GR	S/GR	S/GR		**B/GR**	**B/GR**				S/GR		12
B?	11/25/2002	B/GR	**B/GR**		B/GR	B/GR			B/GR		B/GR			B/GR						7
B7	12/4/2002		B/GR				B/GR		B/GR	B/GR	B/GR		B/GR					B/GR		7
S8	12/12/2002	S/GR	S/GR	S/GR	S/GR	S/GR	S/GR	S/GR		S/GR	S/GR	S/GR						S/GR		11
S8	12/13/2002															S/GR				1
	Total Base Flow	9	9	6	8	8	7	7	8	7	8	4	6	8	6	2	5	2	4	114
	Total Storm Flow	5	8	5	4	7	5	4	4	5	4	5	3	6	4	5	5	2	4	85
	Total Samples	14	17	11	12	15	12	11	12	12	12	9	9	14	10	7	10	4	8	199

S = storm flow event; B = Base flow event.

GR = grab sample; AS = autosampler sequential; AC = autosampler composite.

Values in **bold** indicate a discrepancy between the type of event identified in the field and the type of event designated by hydrologic data analysis (i.e., storm vs. base flow).

Table 4. Sample types by site for conventional parameters[a], Green-Duwamish watershed water quality assessment, 2001-2002.

Event ID	Sample Date	Site A310	Site E319	Site A307	Site C317	Site A317	Site A326	Site B317	Site A315	Site A330	Site A320	Site Y320	Site F321	Site O322	Site D322	Site B322	Site I322B	Site S322	Site A341
S1	11/14/2001			S/GR		S/GR						S/GR	S/GR		S/AS	S/GR			
S1	11/15/2001													S/AS			S/AS		
S2	11/28/2001		**B/GR**	S/GR		S/GR						S/GR	S/GR	S/GR	S/GR	S/GR	S/GR		
S2	11/29/2001											S/AS		S/AS	S/AS		S/AS		
S3	12/13/2001		S/AC	S/AC		S/AC													
S3	12/14/2001		S/AC	S/AC		S/AC							S/GR			S/GR			S/GR
S3	12/15/2001											S/AS		S/AS	S/AS		S/AS		
S4	1/23/2002		S/AC			**B/AC**													
S4	1/24/2002	S/GR		S/AC			S/GR	S/GR	S/GR	S/GR			**B/GR**			S/GR			S/GR
S4	1/25/2002		S/AC	S/AC		S/AC						S/AS		S/AS	S/AS		S/AS		
B1	2/13/2002	B/AS	B/AC	B/AS	B/GR	B/AC	B/GR	B/GR	B/GR	B/GR	B/GR	B/AC		B/AC	B/AS				B/AS
B1	2/14/2002																**S/GR**		
S5	2/21/2002		S/AC		S/GR	S/AC	S/GR	S/GR	S/GR	S/GR	S/GR	S/AC S/AC					S/GR		S/GR
S5	2/22/2002	S/AS	S/AC	S/AS		S/AC								S/AC	S/AS				
B2	3/25/2002		B/AC			B/AC		B/AC				B/AC		B/AC			B/AC		
B2	3/26/2002	B/AS		B/AS	B/GR		B/GR			B/GR			B/GR		B/AS	B/GR			B/AS
B3	4/24/2002		B/AC			B/AC		B/AC				B/AC		B/AC			B/AC		
B3	4/25/2002	B/AS	B/GR	B/AS	B/GR		B/GR		B/GR	B/GR	B/GR				B/AS				B/AS
B4	6/12/2002		**S/AC S/GR**		B/GR	B/AC	B/GR	B/AC		B/GR		B/AC	B/GR	B/AC		B/GR	B/AC		
B4	6/13/2002	B/AS		B/AS											B/AS				B/AS
S6	6/28/2002		**B/AC**			S/AC		S/AC				**B/AC**		S/AC					
S6	6/29/2002	S/GR	S/AC S/GR	**B/AS**	S/GR	S/AC	S/GR	S/AC S/GR	S/GR	S/GR	S/GR	S/AC		S/AC S/GR					S/GR
S6	6/30/2002	S/AS													**B/AS**				
B5	8/6/2002	B/GR	B/AC B/GR	B/AS	B/GR	B/AC	B/GR	B/AC	B/GR	B/GR	B/GR			**S/AC**			B/AC		
B5	8/7/2002														B/AS				
B6	10/22/2002		B/AC			B/AC	B/GR	B/AC	B/GR	B/GR	B/GR		B/GR	B/AC					
B6	10/23/2002	B/AS		B/AS											B/AS			B/AS	
S7	11/6/2002		**B/AC**					S/AC						**B/AC**					
S7	11/7/2002	S/AS	**B/AC**	S/AS	S/GR	S/AC	S/GR	**B/AC B/GR**	S/GR	S/GR	S/GR		**B/GR**	**B/AC**				S/GR	
S7	11/8/2002														**B/AS**			**B/AS**	
B7	12/3/2002		B/AC			B/AC		B/AC				B/AC		B/AC					
B7	12/4/2002	B/AS	B/GR	**S/AS**			B/GR		B/GR	B/GR	B/GR		B/GR		B/AS			B/AS	
S8	12/11/2002		**B/AC**			S/AC		S/AC				S/AC		S/AC			S/AC		
S8	12/12/2002		S/AC	S/AS S/GR	S/GR	S/AC S/GR	S/GR	S/AC		S/GR	S/GR	S/AC S/GR		S/AC	**B/AS**		**B/AC**	S/AS S/GR	
S8	12/13/2002	S/AS														S/GR			
	Total Base Flow	7	14	7	5	8	7	9	5	7	5	6	6	8	10	2	5	3	4
	Total Storm Flow	6	11	11	4	13	5	8	4	5	4	11	3	12	6	5	8	3	4
	Total Samples	13	25	18	9	21	12	17	9	12	9	17	9	20	16	7	13	6	8

Note: not all conventional parameters were sampled on each sampling date.

[a] Excludes hardness as samples for this parameter were collected concurrently with metals.

S = storm flow event; B = Base flow event.

GR = grab sample; AS = autosampler sequential; AC = autosampler composite

Values in **bold** indicate a discrepancy between the type of event identified in the field and the type of event designated by hydrologic data analysis (i.e., storm vs. base flow)

Table 5. Sample types by site for microbiological parameters, Green-Duwamish watershed water quality assessment, 2001-2002.

Event ID	Sample Date	Site A310	Site E319	Site A307	Site C317	Site A317	Site A326	Site B317	Site A315	Site A330	Site A320	Site Y320	Site F321	Site O322	Site D322	Site B322	Site I322B	Site S322	Site A341
S1	11/14/2001			S/GR		S/GR						S/GR	S/GR		S/AS	S/GR			
S1	11/15/2001													S/AS			S/AS		
S2	11/28/2001		**B/GR**	S/GR		S/GR							S/GR	S/GR		S/GR			
S2	11/29/2001											S/AS		S/AS	S/AS		S/AS		
S3	12/13/2001		S/AC	S/AC		S/AC													
S3	12/14/2001		S/AC	S/AC		S/AC							S/GR			S/GR			S/GR
S3	12/15/2001											S/AS		S/AS	S/AS		S/AS		
S4	1/23/2002		S/AC			**B/AC**													
S4	1/24/2002	S/GR		S/AC			S/GR	S/GR	S/GR	S/GR			**B/GR**			S/GR			S/GR
S4	1/25/2002		S/AC	S/AC		S/AC						S/AS		S/AS	S/AS		S/AS		
B1	2/13/2002	B/AS	B/AC	B/AS	B/GR	B/AC	B/GR	B/GR	B/GR	B/GR	B/GR	B/AC		B/AC	B/AS				B/AS
B1	2/14/2002																S/GR		
S5	2/21/2002		S/AC		S/GR	S/AC	S/GR	S/GR	S/GR	S/GR	S/GR	S/AC S/AC		S/AC			S/GR		S/GR
S5	2/22/2002	S/AS	S/AC	S/AS		S/AC								S/AC	S/AS				
B2	3/25/2002		B/AC			B/AC		B/AC				B/AC		B/AC			B/AC		
B2	3/26/2002	B/AS		B/AS	B/GR		B/GR			B/GR			B/GR		B/AS	B/GR			B/AS
B3	4/24/2002		B/AC			B/AC		B/AC				B/AC		B/AC			B/AC		
B3	4/25/2002	B/AS		B/AS	B/GR		B/GR		B/GR	B/GR	B/GR				B/AS				B/AS
B4	6/12/2002		**S/AC**		B/GR	B/AC	B/GR	B/AC		B/GR		B/AC	B/GR	B/AC		B/GR	B/AC		
B4	6/13/2002	B/AS		B/AS											B/AS				B/AS
S6	6/28/2002		**B/AC**			S/AC		S/AC				**B/AC**		S/AC					
S6	6/29/2002		S/AC	**B/AS**	S/GR	S/AC	S/GR	S/AC S/GR	S/GR	S/GR	S/GR	S/AC		S/AC					S/GR
S6	6/30/2002	S/AS													**B/AS**				
B5	8/6/2002	B/GR	B/AC	B/AS	B/GR	B/AC	B/GR	B/AC	B/GR	B/GR	B/GR			**S/AC**			B/AC		
B5	8/7/2002														B/AS				
B6	10/22/2002		B/AC			B/AC	B/GR	B/AC	B/GR	B/GR	B/GR		B/GR	B/AC					
B6	10/23/2002	B/AS		B/AS											B/AS			B/AS	
S7	11/6/2002		**B/AC**					S/AC						**B/AC**					
S7	11/7/2002	S/AS	**B/AC**	S/AS	S/GR	S/AC	S/GR	**B/AC**	S/GR	S/GR	S/GR		**B/GR**	**B/AC**				S/GR	
S7	11/8/2002														**B/AS**			**B/AS**	
B7	12/3/2002		B/AC			B/AC		B/AC				B/AC		B/AC					
B7	12/4/2002	B/AS		**S/AS**			B/GR		B/GR	B/GR	B/GR		B/GR		B/AS			B/AS	
S8	12/11/2002		**B/AC**			S/AC		S/AC				S/AC		S/AC			S/AC		
S8	12/12/2002		S/AC	S/AS	S/GR	S/AC	S/GR	S/AC		S/GR	S/GR	S/AC		S/AC	**B/AS**		B/AC	S/AS	
S8	12/13/2002	S/AS														S/GR			
	Total Base Flow	7	11	7	5	8	7	8	5	7	5	6	6	8	10	2	5	3	4
	Total Storm Flow	5	9	10	4	12	5	8	4	5	4	9	3	12	5	5	7	2	4
	Total Samples	12	20	17	9	20	12	16	9	12	9	15	9	20	15	7	12	5	8

S = storm flow event; B = Base flow event.
GR = grab sample; AS = autosampler sequential; AC = autosampler composite

Table 6. Samples types by site for nutrients, Green-Duwamish watershed water quality assessment, 2001-2002.

Event ID	Sample Date	Site A310	Site E319	Site A307	Site C317	Site A317	Site A326	Site B317	Site A315	Site A330	Site A320	Site Y320	Site F321	Site O322	Site D322	Site B322	Site I322B	Site S322	Site A341
S1	11/14/2001			S/GR		S/GR						S/GR	S/GR		S/AS	S/GR			
S1	11/15/2001													S/AS			S/AS		
S2	11/28/2001		**B/GR**	S/GR		S/GR							S/GR	S/GR		S/GR			
S2	11/29/2001											S/AS		S/AS	S/AS		S/AS		
S3	12/13/2001		S/AC	S/AC		S/AC													
S3	12/14/2001		S/AC	S/AC		S/AC							S/GR			S/GR			S/GR
S3	12/15/2001											S/AS		S/AS	S/AS		S/AS		
S4	1/23/2002		S/AC			**B/AC**													
S4	1/24/2002	S/GR		S/AC			S/GR	S/GR	S/GR	S/GR			**B/GR**			S/GR			S/GR
S4	1/25/2002		S/AC	S/AC		S/AC						S/AS		S/AS	S/AS		S/AS		
B1	2/13/2002	B/AS	B/AC	B/AS	B/GR	B/AC	B/GR	B/GR	B/GR	B/GR	B/GR	B/AC		B/AC	B/AS				B/AS
B1	2/14/2002																**S/GR**		
S5	2/21/2002		S/AC		S/GR	S/AC	S/GR	S/GR	S/GR	S/GR	S/GR	S/AC S/AC					S/GR		S/GR
S5	2/22/2002	S/AS	S/AC	S/AS		S/AC								S/AC	S/AS				
B2	3/25/2002		B/AC			B/AC		B/AC				B/AC		B/AC			B/AC		
B2	3/26/2002	B/AS		B/AS	B/GR		B/GR			B/GR			B/GR		B/AS	B/GR			B/AS
B3	4/24/2002		B/AC			B/AC		B/AC				B/AC		B/AC			B/AC		
B3	4/25/2002	B/AS		B/AS	B/GR		B/GR		B/GR	B/GR	B/GR				B/AS				B/AS
B4	6/12/2002		**S/AC**		B/GR	B/AC	B/GR	B/AC		B/GR		B/AC	B/GR	B/AC		B/GR	B/AC		
B4	6/13/2002	B/AS		B/AS											**S/AS**				B/AS
S6	6/28/2002		**B/AC**			S/AC		S/AC				**B/AC**		S/AC					
S6	6/29/2002		S/AC	**B/AS**	S/GR	S/AC	S/GR	S/AC S/GR	S/GR	S/GR	S/GR			S/AC					S/GR
S6	6/30/2002	S/AS													S/AS				
B5	8/6/2002	B/GR	B/AC	B/AS	B/GR	B/AC	B/GR	B/AC	B/GR	B/GR	B/GR			**S/AC**			B/AC		
B5	8/7/2002														**S/AS**				
B6	10/22/2002		B/AC			B/AC	B/GR	B/AC	B/GR	B/GR	B/GR		B/GR	B/AC					
B6	10/23/2002	B/AS		B/AS											B/AS			B/AS	
S7	11/6/2002		**B/AC**					S/AC						**B/AC**					
S7	11/7/2002	S/AS	**B/AC**	S/AS	S/GR	S/AC	S/GR	**B/AC**	S/GR	S/GR	S/GR		**B/GR**	**B/AC**				S/GR	
S7	11/8/2002														S/AS			**B/AS**	
B7	12/3/2002		B/AC			B/AC		B/AC				B/AC		B/AC					
B7	12/4/2002	B/AS		**S/AS**			B/GR		B/GR	B/GR	B/GR		B/GR		B/AS			B/AS	
S8	12/11/2002		**B/AC**			S/AC		S/AC				S/AC		S/AC			S/AC		
S8	12/12/2002		S/AC	S/AS	S/GR	S/AC	S/GR	S/AC		S/GR	S/GR	S/AC		S/AC	S/AS		**B/AC**	S/AS	
S8	12/13/2002	S/AS														S/GR			
	Total Base Flow	7	11	7	5	8	7	8	5	7	5	6	6	8	10	2	5	3	4
	Total Storm Flow	5	9	10	4	12	5	8	4	5	4	8	3	11	5	5	7	2	4
	Total Samples	12	20	17	9	20	12	16	9	12	9	14	9	19	15	7	12	5	8

S = storm flow event; B = Base flow event.

GR = grab sample; AS = autosampler sequential; AC = autosampler composite

Table 7. Sample types by site for metals, Green-Duwamish watershed water quality assessments, 2001-2002.

Event ID	Sample Date	Site A310	Site E319	Site A307	Site C317	Site A317	Site A326	Site B317	Site A315	Site A330	Site A320	Site Y320	Site F321	Site O322	Site D322	Site B322	Site I322B	Site S322	Site A341	Total Sites
S1	11/14/2001			S/GR								S/GR	S/GR	S/GR	S/AS S/GR	S/GR	S/GR			8
S1	11/15/2001													S/AS			S/AS			1
S2	11/28/2001		**B/GR**	S/GR								S/GR	S/GR	S/GR	S/GR	S/GR	S/GR			9
S2	11/29/2001											S/AS		S/AS	S/AS		S/AS			4
S3	12/13/2001		S/AC	S/AC		S/AC														3
S3	12/14/2001		S/AC S/GR	S/AC S/GR		S/AC						S/GR	S/GR	S/GR	S/GR	S/GR	S/GR		S/GR	12
S3	12/15/2001											S/AS		S/AS	S/AS		S/AS			4
S4	1/23/2002		S/AC			**B/AC**														2
S4	1/24/2002	S/GR	S/GR	S/AC S/GR			S/GR		S/GR	S/GR		S/GR	**B/GR**	S/GR	S/GR	S/GR	S/GR		S/GR	14
S4	1/25/2002		S/AC	S/AC		S/AC						S/AS		S/AS	S/AS		S/AS			7
B1	2/13/2002	B/AS B/GR	B/AC B/GR	B/AS B/GR	B/GR	B/AC B/GR	B/GR		B/GR	B/GR	B/GR	B/AC B/GR		B/AC B/GR	B/AS B/GR		B/GR		B/AS B/GR	22
B1	2/14/2002																**S/GR**			1
S5	2/21/2002	S/GR	S/AC S/GR		S/GR	S/AC S/GR	S/GR		S/GR	S/GR	S/GR	S/AC S/AC		S/AC			S/GR		S/GR	15
S5	2/22/2002	S/AS	S/AC	S/AS		S/AC								S/AC	S/AS					6
B2	3/25/2002		B/AC			B/AC		B/AC				B/AC		B/AC			B/AC			6
B2	3/26/2002	B/AS B/GR	B/GR	B/AS B/GR	B/GR	B/GR	B/GR	B/GR		B/GR		B/GR	B/GR	B/GR	B/AS B/GR	B/GR	B/GR		B/AS B/GR	19
B3	4/24/2002		B/AC			B/AC		B/AC				B/AC		B/AC			B/AC			6
B3	4/25/2002	B/AS B/GR	B/GR	B/AS B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR	B/GR		B/GR	B/AS B/GR		B/GR		B/AS B/GR	19
B4	6/12/2002	B/GR	**S/GR S/AC**	B/GR	B/GR	B/AC B/GR	B/GR	B/AC B/GR		B/GR		B/AC B/GR	B/GR	B/AC B/GR	B/GR	B/GR	B/AC B/GR		B/GR	21
B4	6/13/2002	B/AS		B/AS											B/AS				B/AS	4
S6	6/28/2002		**B/AC**			S/AC		S/AC				**B/AC**		S/AC						5
S6	6/29/2002	S/GR	S/AC	S/AS	S/GR	S/AC S/GR	S/GR	S/AC S/GR	S/GR	S/GR	S/GR	S/AC		S/AC					S/GR	15
S6	6/30/2002	S/AS													S/AS					2
B5	8/6/2002	B/GR	B/AC B/GR	B/AS B/GR	B/GR	B/AC B/GR	B/GR	B/AC B/GR	B/GR	B/GR	B/GR			**S/AC S/GR**			B/AC B/GR			18
B6	10/22/2002	B/GR	B/AC B/GR	B/GR		B/AC B/GR	B/GR	B/AC B/GR	B/GR	B/GR	B/GR		B/GR	B/AC B/GR	B/GR			B/GR		17
B6	10/23/2002	B/AS		B/AS											B/AS			B/AS		4
S7	11/6/2002		**B/AC**					S/AC						**B/AC**						3
S7	11/7/2002	S/AS S/GR	**B/AC**	S/AS	S/GR	S/AC S/GR	S/GR	**B/AC B/GR**	S/GR	S/GR	S/GR		**B/GR**	**B/AC**				S/GR		16
S7	11/8/2002														**B/AS**			**B/AS**		2
B7	12/3/2002		B/AC			B/AC		B/AC				B/AC		B/AC						5
B7	12/4/2002	B/AS		B/AS			B/GR		B/GR	B/GR	B/GR		B/GR		B/AS			B/AS B/GR		10
S8	12/11/2002		**B/AC**			S/AC		S/AC				S/AC		S/AC			S/AC			6
S8	12/12/2002		S/AC	S/AS	S/GR	S/AC	S/GR	S/AC S/GR		S/GR	S/GR	S/AC		S/AC	**B/AS**		**B/AC**	S/AS S/GR		15
S8	12/13/2002	S/AS														S/GR				2
	Total Base Flow	12	16	13	5	14	7	13	5	7	5	10	6	13	13	2	10	5	8	164
	Total Storm Flow	8	13	12	4	13	5	7	4	5	4	12	3	16	10	5	11	3	4	139
	Total Samples	20	29	25	9	27	12	20	9	12	9	22	9	29	23	7	21	8	12	303

S = storm flow event; B = Base flow event.

GR = grab sample; AS = autosampler sequential; AC = autosampler composite.

Values in **bold** indicate a discrepancy between the type of event identified in the field and the type of event designated by hydrologic data analysis (i.e., storm vs. base flow).

Table 8. Sample types by site for priority pollutant organics, Green-Duwamish watershed water quailty assessment, 2001-2002.

Event ID	Sample Date	Site A310	Site E319	Site A307	Site C317	Site A317	Site A326	Site B317	Site A315	Site A330	Site A320	Site Y320	Site F321	Site O322	Site D322	Site B322	Site I322B	Site S322	Site A341
B?	2/31/2002	B/GR	**S/GR**		B/GR	**S/GR**			B/GR		B/GR			B/GR B/GR					
B?	5/1/2002	B/GR	S/GR		B/GR	B/GR			B/GR		B/GR B/GR			B/GR					
S6	6/28/2002	**B/GR**	**B/GR**								**B/GR**			S/GR					
B5	8/6/2002	B/GR B/GR	B/GR		B/GR	B/GR					B/GR			S/GR					
S7	11/7/2002	S/GR S/GR	**B/GR**			S/GR								**B/GR**					
B?	11/25/2002	B/GR	B/GR B/GR		B/GR	B/GR			B/GR		B/GR			**B/GR**					
S8	12/12/2002	S/GR	S/GR		S/GR	S/GR					S/GR S/GR								
	Total Base Flow	6	5		4	3			3		6			4					
	Total Storm Flow	3	3		1	3			0		2			2					
	Total Samples	9	8		5	6			3		8			7					

S = storm flow event; B = Base flow event.

GR = grab sample; AS = autosampler sequential; AC = autosampler composite.

Values in **bold** indicate a discrepancy between the type of event identified in the field and the type of event designated by hydrologic data analysis (i.e., storm vs. base flow).

autosamplers during a sampling event if more than six samples were collected during the event. After sampling, bottles were capped, placed in coolers with ice, and transported to the laboratory for analysis.

At the laboratory, the autosampler bottles were transferred to the appropriate laboratory containers. The four autosampler bottles (representing one sample) were transferred in sequence to the laboratory containers in the following order: the first two bottles were used for filling the conventional and nutrient analysis bottles, the third bottle was used for filling the microbiological analysis bottles, and the fourth bottle was used for the filling the metals analysis bottles. Sample transfer methods are further described in detail in the SAP (King County 2002).

Auto-sequential sampling was the primary sampling method used for the following sites: Lower Green River at Fort Dent Park (A310), Hamm Creek (A307), Newaukum tributary at 236th SE (D322), Newaukum tributary downstream of Weyerhaeuser (S322), and Green tributary near TPU diversion (A341). Auto-sequential sampling was used less frequently (secondary to auto-composite sampling) at the following sites: Soosette Creek (Y320), Newaukum Creek (0322), and Newaukum tributary at Enumclaw (I322B).

3.3.3 Auto-Composite Samples

For auto-composite sampling, flow-weighted composite samples were collected during storm and base flow events. Sample collection was performed using an ISCO 3700 series autosampler filled with one 15-liter HDPE sample carboy. The autosamplers were triggered either with a timer or by a liquid level activator switch set for a specific stage level rise. A unit sample volume was then collected for each incremental unit of stream flow during the event. Two composite samples were collected if the event extended beyond 24 hours; the two collected samples were analyzed independently. Thus, analytical results for auto-composite samples represent two flow-weighted average concentrations (i.e., event mean concentration) of water samples collected during the sampling event.

The autosampler bottles were fitted with special caps to prevent contamination during the sampling process, and the special caps were replaced with standard caps for transport to the laboratory. The composite samples were transferred to appropriate laboratory containers using a Teflon siphon tube and continuous agitation at the King County Environmental Laboratory. The priority order for filling laboratory containers was conventionals, microbiological, metals, and lastly nutrients.

3.3.4 In-stream Field Measurements

In-stream field measurements for water temperature, pH, specific conductance, and dissolved oxygen were recorded either prior to or immediately following the collection of samples for laboratory analysis. In-stream field measurements were made using a Hydrolab MiniSonde® or YSI probe. Field sampling equipment were calibrated according to King County's

Environmental Support Services (ESS) Standard Operating Procedure (SOP) # 02-01-005 within 24 hours of the sampling event.

3.4 Sample Documentation and Handling Procedures

Sample documentation and handling procedures used for the GDWQA are described briefly in the subsections to follow. More detailed information on this topic can also be found in the SAP for the project (King County 2002).

3.4.1 Sample Documentation

In order to ensure collected samples are properly documented, each sampling location was assigned a unique number for sample identification purposes. Waterproof sample labels (with appropriate numbers) were generated by computer prior to each sampling event. Sampling forms and pre-printed field sheets were completed for each sampling location and each sampling event. Information recorded on field forms included: name of recorder, sample or site number, sample site locator information, date and time of sample collection, results for all field measurements (temperature, pH, dissolved oxygen, and specific conductance), and staff gauge height. Field observations and quality control information were also recorded on the data sheets. Field instrument calibration records were recorded in separate instrument logbooks.

3.4.2 Sample Handling

Sample handling procedures outlined in the SAP were used to ensure sample integrity and provide data of highest quality under the sampling conditions (King County 2002). Accordingly, the following procedures for sample containers were used during sampling:

- All samples were collected or split into pre-cleaned, laboratory-supplied containers.
- All low-level metals analysis sample bottles were double-bagged in ziplock bags in a clean-room environment at the King County Environmental Laboratory, and rebagged after sampling for transport to the laboratory.
- Information was recorded on the sample label that included sample number (or locator), sampling location, collection date, requested analyses, and any chemical used for sample preservation.

After collection, stormwater samples were stored refrigerated at a temperature of approximately 4˚C, or preserved as identified in the SAP (King County 2002). The analytical laboratory held (where practical) any unused sample that had not exceeded its holding time for 30 days after release of results.

During sampling, all sample bottles were either locked in the autosamplers or remained in the custody of sampling personnel (King County 2002). All samples were delivered to Sample Receiving at the laboratory and entered into the Logbook, as described in ESS SOP#01-01-003-001 (Sample Management). The King County Environmental Laboratory performed most of the sample analyses for this project. In instances where sample analyses were performed by a subcontracting laboratory, the associated samples were released according to ESS SOP # 11-02-002-000 (Subcontracting Samples).

3.5 Analytical Parameters

Analytical parameters for base and storm flow monitoring fall into the following five broad categories: field measurements, conventionals, microbiology, nutrients, and metals. In addition, samples for priority pollutant organics were collected during selected base and storm flow sampling. The specific analytes for each of these categories are listed below:

- Field measurements – temperature, pH, dissolved oxygen, and specific conductance.
- Conventionals – alkalinity, biochemical oxygen demand, total suspended solids, turbidity dissolved organic carbon, and total hardness (which was calculated from calcium and magnesium analyses, but is included as a conventional parameter for this document).
- Microbiology – fecal coliform bacteria, enterococci bacteria, and *E. coli* bacteria.
- Nutrients – ammonia nitrogen, total nitrogen, nitrate and nitrite nitrogen, orthophosphate, and total phosphorus.
- Metals – total and dissolved aluminum, arsenic, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, sodium, and zinc.
- Priority pollutant organics – base/neutral/acid (semivolatile) organic compounds, chlorinated pesticides/PCBs, organochlorine herbicides, and organophosphorus pesticides.

The number of data points evaluated for each of these parameter categories is presented by monitoring site in Table 9. These numbers represent the typical number of data points for a parameter category, excluding parameters that were analyzed infrequently (e.g., biochemical oxygen demand for conventionals). Also, the numbers in Table 9 do not represent the number of

Table 9. Number of data points (n) by parameter category[a] evaluated for the Green-Duwamishwatershed water quality assessment, 2001 - 2002.

Site Locator	Field Measurements	Conventional Parameters	Microbiological Parameters	Nutrients	Metals	Organics
Base Flow						
A310	9	7	7	7	12	6
E319	9	14	11	11	16	5
A307	6	7	7	7	13	0
C317	8	5	5	5	5	4
A317	8	8	8	8	14	3
A326	7	7	7	7	7	0
B317	7	9	8	8	13	0
A315	8	5	5	5	5	3
A330	7	7	7	7	7	0
A320	8	5	5	5	5	6
Y320	4	6	6	6	10	0
F321	6	6	6	6	6	0
O322	8	8	8	8	13	4
D322	6	10	10	10	13	0
B322	2	2	2	2	2	0
I322B	5	5	5	5	10	0
S322	2	3	3	3	5	0
A341	4	4	4	4	8	0
Totals	114	118	114	114	164	31
Storm Flow						
A310	5	6	5	5	8	3
E319	8	11	9	9	13	3
A307	5	11	10	10	12	0
C317	4	4	4	4	4	1
A317	7	13	12	12	13	3
A326	5	5	5	5	5	0
B317	4	8	8	8	7	0
A315	4	4	4	4	4	0
A330	5	5	5	5	5	0
A320	4	4	4	4	4	2
Y320	5	11	9	8	12	0
F321	3	3	3	3	3	0
O322	6	12	12	11	16	2
D322	4	6	5	5	10	0
B322	5	5	5	5	5	0
I322B	5	8	7	7	11	0
S322	2	3	2	2	3	0
A341	4	4	4	4	4	0
Totals	85	123	113	111	139	14

[a] Excludes specific parameters that were analyzed infrequently (e.g., biochemical oxygen demand).

Values for auto-sequential samples were flow-proportionately averaged into one data point.

samples analyzed because values for auto-sequential samples were flow-proportionately averaged into one data point for evaluation purposes (see Section 4.1 – Data Management).

3.6 Laboratory Analysis Methods

The laboratory analysis methods used for the GDWQA monitoring program are briefly described below. Two types of detection limits are associated with each chemical analysis method. The method detection limit (MDL) is the minimum concentration that can be detected by the method. The reporting detection limit (RDL) is the minimum concentration that can be reliably quantified. Typically, the RDL is 2 to 5 times higher than the MDL. Only the MDL applies to microbiological parameters. More detailed information on laboratory analysis methods and detection limits can be found in the SAP (King County 2002).

3.6.1 Conventionals

The King County Environmental Laboratory performed all conventional parameter analyses according to Standard Methods (APHA 1995). One exception is that analyses for Biochemical Oxygen Demand (BOD) were performed by the process laboratory at the West Point Treatment Plant. The specific laboratory analysis methods and detection limits for conventional parameters are listed in the SAP (see Table 5 in King County 2002).

3.6.2 Nutrients

The King County Environmental Laboratory performed all nutrient analyses according to Standard Methods (APHA 1995). The specific laboratory analysis methods and detection limits for nutrients are listed in the SAP (see Table 5 in King County 2002).

3.6.3 Microbiology

The King County Environmental Laboratory performed all analyses for microbiological parameters according to Standard Methods (APHA 1995). The specific laboratory analysis methods and detection limits for these parameters are listed in the SAP (see Table 8 in King County 2002).

3.6.4 Metal Analyses

All metals were analyzed according to methods approved by U.S. EPA. The King County Environmental Laboratory performed all metals analyses with the exception of low-level mercury (King County 2002). Low-level mercury analyses were performed by Frontier Geosciences, Inc. of Seattle, Washington using Cold Vapor Atomic Fluorescence (CVAF) (U.S. EPA Method 1631b). The King County Environmental Laboratory analyzed mercury using the less sensitive Cold Vapor Atomic Absorption (CVAA) method (U.S. EPA Method 245.1). All other metals were analyzed by the King County Environmental Laboratory using the following three methods depending on the concentration in the sample:

- Inductively-Coupled Plasma Optical Emission Spectroscopy (ICP-OES) by U.S. EPA Method 200.7.
- Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) by U.S. EPA Method 200.8.
- Pre-concentration ICP-MS by U.S. EPA Method 1638.

ICP-MS is a more sensitive method and capable of lower detection limits than ICP-OES. Mineral elements (calcium, iron, magnesium, potassium, and sodium) and other elements were determined by ICP-OES analysis. When a metal (except mineral elements) was not detected by ICP-OES in a sample, subsequent analyses were performed using ICP-MS to achieve a lower detection limit. Only grab samples collected using clean technique (EPA Method 1669) were analyzed using the most sensitive pre-concentration ICP-MS method for elements not detected using routine ICP-MS. The specific laboratory analysis methods and detection limits for metals are presented in the SAP (see Table 6 in King County 2002).

3.6.5 Organic Analyses and Detection Limits

Organic analyses were performed by the King County Environmental Laboratory with the exception of chlorinated herbicides, which were analyzed by Severn-Trent-Laboratories (STL-Seattle) of Tacoma, Washington. Laboratory analysis methods and detection limits for organics are listed in the SAP (see Table 7 in King County 2002).

3.7 Quality Control Procedures

Field and laboratory quality control procedures are briefly described below. More detailed information on this topic can be found in the SAP for the GDWQA (King County 2002).

Quality control procedures for field measurements involved the determination of post-deployment calibration drift for the target parameter (except water temperature). Calibration drift was determined by measuring the check standard solution within 12 hours of the final field measurement. Post deployment checks were conducted in the same order used for the initial instrument calibration, and were also conducted before any maintenance or calibrations were performed. Acceptable limits for post-deployment calibration checks are presented in the SAP (see Table 11 in King County 2002).

Quality control procedures for field measurements also involved taking replicate measurements at a minimum frequency of 5 percent or at a minimum of once per day. A field replicate was a separate field sample made following all the procedures typically done between individual samples. Acceptable limits for field replicate measurements are presented in the SAP (see Table 12 in King County 2002).

Various quality control samples were analyzed at a frequency of one per batch for analysis of conventional parameters, nutrients, metals, and organics. Quality control samples analyzed by the laboratories included processing blanks, replicates (duplicates or matrix spike duplicates), matrix spikes, blank spike duplicates, laboratory control standards or check standards, and surrogates (organics only). Recommended quality control limits for each quality control sample and analytical parameter are presented in the SAP (see Table 10 in King County 2002)**.**

Laboratory quality control measures for microbiological analysis included laboratory duplicates, negative controls, positive controls, and sterility controls (blanks). These measures are used to monitor the performance of each sample analysis batch for each method, as described in the SAP.

3.8 Data Reporting Procedures

Data reporting and record keeping procedures for the GDWQA are described briefly below. More detailed information on this topic can also be found in the SAP (King County 2002).

The King County Environmental Laboratory provides a 30-day turnaround for the analytical data, with the exception of metals, which is up to six months. The laboratory section responsible for each set of analyses produces a narrative describing the contents of their data package, including any notable information of interest to the client. Comprehensive data reports are prepared that consist of spreadsheets of chemical, microbiological, and field data. Where applicable, sample analysis results were presented with a method detection limit (MDL) and a reporting detection limit (RDL). The field and laboratory results (including data flags as noted below) are entered into King County's laboratory management information system (LIMS).

Chemistry, microbiology, and field measurement data underwent standard QA review within each laboratory group according to the Environmental Laboratory QA document and method specific SOPs. Data were subsequently flagged with appropriate laboratory qualifiers, as defined in the SAP (see Table 13 in King County 2002). The laboratory project manager provided a review of the quality control results and provided a summary of this information in a narrative form for project and program managers. The purpose of this review is to provide the project and program managers with the necessary level of information to interpret the data. Technical memoranda were prepared that summarize field sampling, analytical work, and interpretation of QC results. All field analysis and sampling records, custody documents, raw laboratory data, data summaries, and case narratives are stored in accordance with King County Environmental Laboratory Policy (King County 2002).

A quality assurance review memorandum was prepared separately for the metals and organics data (Appendix B). The quality assurance review memorandum for the metals data summarizes quality control issues associated with each metal and sampling event for the following quality control elements: completeness; field contamination; laboratory contamination; accuracy, precision, and bias; and sample handling. Data were complete for all metals identified in the SAP (King County 2002) and evaluated for this report, but data were not complete for many of the additional metals analyzed (which included antimony, barium, beryllium, cobalt, and molybdenum, strontium, thallium, and vanadium). Field blank contamination was frequently noted for total chromium and low-level mercury analyses, and infrequently noted for total copper, lead, and zinc analyses. Filter blank contamination was frequently noted for dissolved chromium and zinc analyses. High recovery of matrix spikes was infrequently noted for total aluminum, manganese, and zinc. High percent differences between matrix spike duplicates were infrequently noted for total arsenic and dissolved manganese. Finally, many sample values were not preserved or filtered within the recommended limit of 24 hours. The laboratory flagged metals values with a B for values within 10 times the filter blank value, and with an H for sample handling issues. Data were not flagged for issues associated with field blanks or matrix spikes. Approximately 35 percent of the metals data were flagged as estimated (and detected) values.

The quality assurance review memorandum for the organics data summarizes quality control issues associated with method blanks, spike blanks, matrix spikes, and surrogate compounds (see Appendix B). The following four phthalate compounds were detected in every method blank: butylbenzylphthalate, bis(2-ehtylhexyl)phthalate, diethylphthalate, and di-n-butylphthalate. The laboratory recommended raising the method detection limits by a factor of 10 for these four compounds, which would have resulted in undetected values for all but two sample values. However, the associated phthalate values were flagged with a B in the database rather than changed to undetected values at a raised detection limit. Spike blank or matrix spike recoveries occasionally exceeded the upper control limits for the following three compounds: 2,4-dinitrotoluene, n-nitroso-di-n-propylamine, and 1,2,4-trichlorobenzene. No data were flagged because these compounds were not detected in any of the samples. Finally, the recovery of one surrogate compound (d5-nitrobenzene) in one base flow sample from site A310 exceeded the upper control limit by 1 percent, and no data were flagged based on this surrogate recovery. Approximately 5 percent of the organics data were flagged as estimated (and detected) values.

Quality assurance review memoranda were not prepared for in-stream field measurements, conventional parameters, microbiological parameters, or nutrients. Data were flagged as estimated (and detected) values at the following frequency: 0 percent of the in-stream measurement data, 6 percent of the conventionals data, 25 percent of the microbiological data, and 9 percent of the nutrient data. All estimated values were used for the water quality data evaluation.

4.0 Data Management and Analysis Methods

This section describes the data management and analyses methods that were used in the preparation of this data report. This section is organized to include separate subsections for each of the following components of this investigation: data management, computation of summary statistics, comparison to water quality criteria, statistical spatial pattern analysis, and computation of water quality index scores.

4.1 Data Management

In order to perform the required analyses for this report, water quality data collected for GDWQA in 2001 and 2002 were obtained from the County in an electronic file format that is compatible with the Microsoft Access® software package. In addition to the data collected for the GDWQA, the County also forwarded data for ambient monitoring conducted in the Green-Duwamish watershed during the year 2000, which preceded the GDWQA. The 2000 data were reviewed and compared to data for 1996 through 1999, which were previously summarized by King County (2002). The 2000 data review is included as Appendix A to this report.

The data received were imported into a Microsoft Access® database, which served as the core data storage library for the project. In order to facilitate the efficient retrieval and analysis of these data, this core database was overlain by an environmental data tracking system called EQuIS®, which allows easy summarization of complex data sets into a variety of formats and presentation modes. Using the Microsoft Access® database and EQuIS® system in combination, separate database queries were made to obtain data for specific analysis tasks related to this assessment. In most cases, the data obtained from these queries were exported to a file format that is compatible with Microsoft Excel® and/or the Statistica® data analysis software package for further processing.

Additional processing of the data was also performed in order to evaluate those samples associated with storm or base flow events. Continuous discharge data collected in 2001 and 2002 were obtained from King County for stream gauging sites that are associated with the following water quality monitoring sites: Upper Green River (E319); Hamm Creek (A307); Springbrook Creek (A317); Mill (Springbrook) tributary (B317); Mill (Hill) Creek (A315); Soos Creek (A320); Soosette Creek (Y320); Crisp Creek (F321); Newaukum Creek (0322): Newaukum tributary at 236th SE (D322); Newaukum tributary at Enumclaw (I322B); and Newaukum tributary downstream of Weyerhaeuser (S322).

A computer algorithm was developed for this project to define intervals of the hydrograph that correspond to base and storm flow periods. This algorithm uses a sliding interval to assign a preliminary base flow rate to each hydrograph based on the minimum flow over a 3-day window. It then adjusts the base flow and identifies storm periods based on the following user input variables:

1. Starting base flow rate (cfs) if the initial flow value is missing from the hydrologic record

2. Maximum percent increase per day in base flow

3. Maximum amount (cfs) of increase per day in base flow

4. Minimum percent that the maximum daily discharge must exceed the daily average base flow rate to be categorized as a storm event.

A technical memorandum is presented in Appendix C that provides a more detailed description of the algorithm, user input variables, and discharge data processing procedures. This memo includes a table of input and output variables, and the delineated hydrographs for each of the sites listed above using daily discharge data. Event delineation was subsequently performed using hourly discharge data that required revision of the input variables. A table of the final input variables used for event delineation of the hourly discharge data is included in Appendix C.

Once periods of base and storm flow were defined in the hydrograph using this approach, samples corresponding to these periods were assigned to the same event type in the core project database. In this way, separate analyses could be performed on samples associated with base and storm flow. For sites not having an associated flow gauging site, storm and base designations were based on the type of event identified by field personnel for each sampling date and corresponding event number (e.g., B1 for base flow event 1). Sites lacking flow data that were designated by field personnel include: Lower Green River (A310), Black River (C317); Panther Creek (A326); Green tributary at Lea Hill (A330); Newaukum tributary at SE 424th (B322), and Green tributary near TPU diversion (A341).

The base flow and storm event designation of all samples in the core database were reviewed for consistency with base and storm designations made at the time of sampling. Results from this review are summarized in Tables 3 through 8 for the following major categories of parameters: field measurements, conventionals, microbiology, nutrients, metals, and organics. These results identified some discrepancies between the base flow and storm event designations using flow data versus those from field observations. Approximately 10 percent of the data points associated with those sites designated using flow data were assigned a different event type than that identified by field personnel. Percent discrepancies for each parameter category were 8 percent for field measurements, 13 percent for conventionals and nutrients, 10 percent for microbiological parameters, 10 percent for metals, and 19 percent for organics. Most of the discrepancies were for events designated as base flow using flow data, but identified as storm events by field personnel. Discrepancies were most frequently observed at the Upper Green River below Howard Hanson Dam (E319), which may be due to the regulated nature of the flows at this location (see Tables 3 through 8).

Data processing was also preformed to prevent potential bias in the evaluation of data associated with auto-sequential samples. As noted previously, results from auto-sequential sampling eventually will be examined in relation to the rise, peak, and fall of the storm hydrograph. For this report, however, the goal of the evaluation is to characterize water quality over the range of sampled base and storm flow conditions that were present at a particular monitoring site. Analyses performed based on the grab and auto-composite samples are suitable for meeting this goal because each individual sample is typically associated with a single base or storm event. In contrast, there are multiple auto-sequential samples associated with a single base or storm flow event. When analyzed in combination with grab and auto-composite samples, these auto-sequential samples would tend to bias any results by giving more weight to the water quality conditions that persisted during these more frequently sampled events.

In order to resolve this issue, available flow data from each site was used to convert water quality data from auto-sequential samples into a flow-weighted average for each sampled event. Each auto-sequential sample value was multiplied by the flow rate corresponding to the sample time and divided by the sum of the flow rates for the sample set, and then these corrected values were summed for the sample set. Where data were undetected, the method detection limit was used in the calculation of the flow-weighted average. In cases where no flow data were available for a particular site, a simple arithmetic average was computed from all auto-sequential samples associated with a particular event. The flow-weighted average or arithmetic average from the auto-sequential samples was used as one data point in the evaluations for this report.

4.2 Computation of Summary Statistics

In order to characterize water quality conditions in the Green-Duwamish watershed, data obtained from the database queries described above were imported into Microsoft Excel® and/or the Statistica® data analysis software package. These software packages were then used to calculate the following summary statistics for each site based on the data collected in 2001 and 2002:

- number of samples
- mean
- median
- minimum
- maximum
- 10^{th} percentile
- 25^{th} percentile
- 75^{th} percentile
- 90^{th} percentile
- standard deviation
- quartile range (i.e., the 75^{th} percentile minus the 25^{th} percentile)
- lower 95 percent confidence interval
- upper 95 percent confidence interval
- percentage of detected samples (for selected parameters).

Due to the large number of organic compounds that were evaluated for this study, summary statistics calculated for this category of parameters were limited to the median, minimum, maximum, and percentage of detected samples. For all parameters, separate calculations were made for storm and base flow samples from each monitoring site. These statistics were also computed using the storm and base flow data for all monitoring sites combined. Where undetected values were present in the data, the method detection limit was used in all calculations. The computed summary statistics were subsequently compiled in one table for each parameter (and one table for each group of organics). Tables of summary statistics are presented in a separate appendix for each parameter category (Appendices D through I).

In addition to these tabular data summaries, the data were also presented in graphical summaries using “box and whisker” plots. Each of these plots presents the following information: the 10th and 90th percentiles of the data as the lower and upper whiskers, respectively; the 25th and 75th percentiles of the data as the lower and upper boundaries of the box, respectively; and the median as the point in the box. Separate box plots were generated for each site using the associated base and storm flow samples, respectively. These plots are presented together in subsequent sections of this report to facilitate comparisons of monitoring data between the individual monitoring sites and between the different event types.

4.3 Comparison to Water Quality Criteria

In order to identify those subbasins/streams in the Green-Duwamish watershed exhibiting impaired water quality, data from each monitoring site were compared to various regulatory water quality criteria in the following order of priority:

1. Water Quality Standards for Surface Waters of the State of Washington (WAC 173-201A amended July 1, 2003)

2. National Recommended Water Quality Criteria: 2002 (U.S. EPA 2002a)

3. Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion II (U.S. EPA 2000)

4. Ambient Water Quality Criteria for Bacteria – 1986 (U.S. EPA 1986).

Surface water quality standards for the state of Washington vary depending on the specific designated uses that have been established for the water body in question. Designated uses that are applicable to the monitoring sites in this study are presented in Table 10, and the applicable criteria are presented in Table 11. Table 12 presents applicable water quality criteria for bacteria, nutrients, and toxic substances that are recommended by U.S. EPA (1986, 2000, 2002a) but are not regulated by Washington State. Comparisons to the U.S. EPA toxic substances criteria were based on criteria established for the protection of aquatic life and were not based on criteria for protection of human health (for consumption of water and/or organisms).

Table 10. State of Washington designated uses (WAC 173-201A) for monitoring sites associated with the Green-Duwamish water quality assessment.

Site Name	Aquatic Life Designated Use	Water Contact Recreation Designated Use
Lower Green River (A310)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Upper Green River (E319)	Salmon and Trout Spawning, **Core** Rearing, and Migration	Extraordinary Primary Contact Recreation
Hamm Creek (A307)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Black River (C317)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Springbrook Creek (A317)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Panther Creek (A326)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Mill (Springbrook) tributary (B317)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Mill (Hill) Creek (A315)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Green tributary at Lea Hill (A330)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Soos Creek (A320)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Soosette Creek (Y320)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Crisp Creek (F321)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Newaukum Creek (0322)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Newaukum tributary at 236th SE (D322)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Newaukum tributary at SE 424th (B322)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Newaukum tributary at Enumclaw (I322B)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Newaukum tributary downstream of Weyerhaeuser (S322)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Green tributary near TPU diversion (A341)	Salmon and Trout Spawning, **Core** Rearing, and Migration	Extraordinary Primary Contact Recreation

Source: WAC 173-201A

Table 11. Water quality criteria for surface waters of the state of Washington used for comparison to 2001-2002 data collected for the Green-Duwamish watershed water quality assessment.

Aquatic Life Criteria in Freshwater		
	Core Rearing	Noncore Rearing
Temperature	Shall not exceed 16.0°C	Shall not exceed 17.5°C
Dissolved oxygen	Shall exceed 9.5 mg/L	Shall exceed 8.0 mg/L
pH	Shall be within the range of 6.5 to 8.5	Shall be within the range of 6.5 to 8.5
Water Contact Recreation in Freshwater		
	Extraordinary Primary Contact Recreation	Primary Contact Recreation
Fecal coliform bacteria	Geometric mean shall not exceed 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean values exceeding 100 colonies/100 mL.	Geometric mean shall not exceed 100 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean values exceeding 200 colonies/100 mL.
Trace Metals in Freshwater		
	Acute Criteria	Chronic Criteria
Arsenic, dissolved	0.360 mg/L [c]	0.190 mg/L [d]
Cadmium, dissolved	0.0013 mg/L[c] at median hardness [e]	0.0007 mg/L [d] at median hardness [e]
Chromium, total	0.254 mg/L[c] at median hardness [e]	0.119 mg/L [d] at median hardness [e]
Copper, dissolved	0.0070 mg/L[c] at median hardness [e]	0.0075 mg/L [d] at median hardness [e]
Lead, dissolved	0.0229 mg/L[c] at median hardness [e]	0.0015 mg/L [d.]
Mercury, dissolved	0.0021 mg/L [c]	none
Mercury, total	none	0.000012 mg/L [d]
Nickel, dissolved	0.640 mg/L [c] at median hardness [e]	0.104 mg/L [d] at median hardness [e]
Selenium, total	0.020 mg/L [c]	0.005 mg/L [d]
Silver, dissolved	0.0007 mg/L [a] at median hardness [e]	none
Zinc, dissolved	0.0516 mg/L [c] at median hardness [e]	0.0692 mg/L [d] at median hardness [e]
Organic Substances in Freshwater		
	Acute Criteria	Chronic Criteria
Aldrin+Dieldrin	2.5 µg/L [a]	0.0019 µg/L [b]
Ammonia	19.7 mg/L assuming salmonids are present and typical values for temperature (15°C) and pH (7.0).	2.1 mg/L assuming salmonids are present and typical values for temperature (15°C) and pH (7.0).
Chlordane	2.4 µg/L [a]	0.0043 µg/L [b]
Chlorpyrifos	0.083 mg/L [c]	0.041 mg/L [d]
DDT (and metabolites)	1.1 µg/L [a]	0.001 µg/L [b]
Endosulfan (I or II)	0.22 µg/L [a]	0.056 µg/L [b]
Endrin	0.18 µg/L [a]	0.0023 µg/L [b]
Heptachlor	0.52 µg/L [a]	0.0038 µg/L [b]
Hexachlorocyclohexane (Lindane)	2.0 µg/L [a]	0.08 µg/L [b]
Parathion	0.065 µg/L [c]	0.013 µg/L [d]
Pentachlorophenol	9.07 µg/L [c] at pH 7.0	5.72 µg/L [d] at pH 7.0
Polychlorinated biphenyls, total	2.0 µg/L [b]	0.014 µg/L [b]

Source: WAC 173-201A

[a] An instantaneous concentration not to be exceeded at any time.
[b] A 24-hour average not to be exceeded.
[c] A 1-hour average concentration not to be exceeded more than once every three years on the average.
[d] A 4-day average concentration not to be exceeded more than once every three years on the average.
[e] Criterion varies with hardness. The acute criterion presented is based on the median hardness value of 39.1 mg/L as $CaCO_3$ for all stations during storm flow. The chronic criterion presented is based on the median hardness value of 61.5 mg/L as $CaCO_3$ for all stations during base flow.

mg/L: milligram/liter µg/L: microgram/liter mL: milliliter C: Celsius

Table 12. U.S. EPA national recommended water quality criteria for bacteria, nutrients, and toxic substances in freshwaters that are not regulated by Washington state.

Indicator Bacteria in Freshwater [a]		
	Criteria	
Enterococci	Geometric mean shall not exceed 33 colonies/100 mL	
E. coli	Geometric mean shall not exceed 126 colonies/100 mL	
Nutrients in Rivers and Streams [b]		
	Criteria	
Nitrate+nitrite nitrogen	0.26 mg/L	
Total nitrogen	0.24 mg/L	
Total phosphorus	0.0195 mg/L	
Toxic Substances in Freshwater [c]		
	Acute (CMC) Criteria	Chronic (CCC) Criteria
Aluminum, total	0.750 mg/L	0.087 mg/L
Camphechlor (toxaphene)	0.73 μg/L	0.0002 μg/L
Heptachlor epoxide	0.52 μg/L	0.014 μg/L
Malathion	none	0.1 μg/L
Methoxychlor	none	0.03 μg/L
Iron	none	1 mg/L

[a] Source: U.S. EPA 1986
[b] Source: U.S. EPA 2000; 25th percentile for Puget Sound lowlands subecoregion
[c] Source: U.S. EPA 2002a
CMC: criterion maximum concentration
CCC: criterion continuous concentration
μg/L: microgram/liter
mg/L: milligram/liter
mL: milliliter

Most toxic substances have separate criteria for acute and chronic impacts to aquatic life. In these cases, chronic criterion were used when making comparisons to data from base flow sampling and acute criteria were used for storm flow data. Criteria for some toxic substances vary with other parameters such as hardness or pH. These criteria were calculated for each sample and compared to the measured toxic substances concentrations, but only criteria for typical parameter values are presented in Tables 11 and 12.

The U.S. EPA nutrient criteria presented in Table 12 for phosphorus and nitrogen were developed for the protection of recreation and aquatic life uses in rivers and streams (U.S. EPA 2000). These criteria are intended to address the adverse effects of excessive nutrients in streams and rivers, and are empirically derived to represent conditions of surface waters that have been minimally impacted by human activities and are protective of recreational and aquatic life uses (U.S. EPA 2000).

The U.S. EPA criteria presented in Table 12 for enterococci and *E. coli* bacteria assume steady state, dry weather conditions (U.S. EPA 1986). However, these criteria were applied to both the storm and base flow data in this assessment.

Results from these comparisons were summarized based on the percentage of samples from each site that exceeded the applicable or recommended criterion for a given parameter. Nondetect samples having a detection limit greater than the applicable criterion were excluded from these calculations. The results from these calculations were tabulated along with the summary statistics described above and are presented in Appendices D through I.

4.4 Spatial Pattern Analysis

Statistical spatial pattern analyses were performed on the GDWQA data collected in 2001 and 2002 in order to meet the following study objectives:

1. Detect significant longitudinal patterns in water quality along the main stem of the Green River.

2. Determine whether there are significant differences in water quality among the five major streams that discharge to the Green River.

In order to meet the first study objective, water quality data (excluding organics) from the Upper Green River (E319) and Lower Green River (A310) were compared using a Mann-Whitney test, which is a nonparametric analog to the t test but does not require a normal distribution of data (Helsel and Hirsch 1992, Zar 1984). Results from this test indicate whether there was a significant increasing or decreasing pattern among these sites for each parameter, or no change at all. Statistical significance for this test was assessed at $\alpha = 0.05$.

The second study objective was evaluated using a statistical comparison of results for sites located near the mouths of the following four major streams: Springbrook Creek (Black River) (A317 and C317, respectively), Mill Creek (A315), Soos Creek (A320), and Newaukum Creek (0322). Specifically, the data (excluding organics) were compared using a Kruskal-Wallis (nonparametric) analysis of variance (ANOVA) to determine if there was a significant difference in water quality between these sites (Helsel and Hirsch 1992, Zar 1984). If a significant difference was detected, a nonparametric multiple comparison test was conducted to determine which monitoring sites were significantly different from the others (Zar 1984). (This test is calculated in the same manner as the Tukey test except the rank sums of the data are used instead of the means. This test uses the overall error rate for the test as opposed to the error rate for each pairwise comparison.) Statistical significance for these tests was assessed at $\alpha = 0.05$.

Results of these spatial pattern analysis tests are presented in Appendix J. These results are discussed in detail for each parameter in Section 5.2.

4.5 Computation of Water Quality Index Rating

In order to summarize water quality patterns for the GDWQA and facilitate comparisons between the monitoring sites, available data from 2002 were used to calculate a Water Quality Index (WQI) for each site using protocols developed by Ecology (2002a, b). The WQI is a unitless number ranging from 1 to 100 with higher numbers indicating better water quality. This index is calculated using data for the following suite of parameters: temperature, pH, fecal coliform bacteria, dissolved oxygen, total suspended solids, turbidity, total phosphorus, and total nitrogen. Constituent scores from these individual parameters are combined and the results aggregated over time to produce a single yearly score for each monitoring site. This score can serve as the basis for comparing water quality between monitoring sites or for assessing patterns at individual sites over time.

In general, the WQI provides an indication as to whether water quality is adequate for supporting the beneficial uses of a given waterbody as defined in WAC 173 201A. Thus, for temperature, pH, fecal coliform bacteria, and dissolved oxygen, the WQI expresses results relative to applicable water quality criteria for these parameters (see Table 11) that have been promulgated to maintain beneficial uses. For nutrient and suspended sediment measures, where criteria have not been established by Ecology, results are expressed relative to expected conditions in a given ecoregion as determined by U.S. EPA (2000). Sites scoring 80 and above likely meet expectations for water quality and are of "lowest concern," scores ranging from 40 to 80 indicate "marginal concern," and water quality at sites with scores below 40 are likely not meeting expectations and are of "highest concern" (Ecology 2002a,b).

It should be noted that the WQI contains less information by design than the raw data it summarizes. Thus, it is most useful for making broad comparisons between sites and answering general questions about the water quality in each stream (Ecology 2002a, b). The WQI is less suited to answering site-specific questions regarding water quality because this typically requires detailed analyses of the water quality data. There are at least two reasons that the WQI may fail to accurately communicate water quality information. First, the index, like most indices, is based on a pre-identified suite of water quality parameters. Therefore, a particular site may receive a good WQI score, and yet have water quality that is impaired by parameters not included in the index. Second, aggregation of data may mask short-term water quality problems. It follows that a satisfactory WQI at a particular site does not necessarily mean that water quality was always satisfactory. A good score only indicates that poor water quality was not a chronic problem. Due to these considerations, the WQI was only employed in this analysis to summarize broad patterns in the data.

5.0 Data Evaluation and Results

This section summarizes the data collected for the GDWQA in 2001 and 2002. This section begins with an evaluation of precipitation amounts for the monitoring period relative to historical precipitation data. Results from the water quality monitoring are then presented under separate subsections for each of the following major parameter categories: field measurements, conventionals, microbiological parameters, nutrients, metals, and priority pollutant organics.

5.1 Precipitation Data

In order to provide some context for interpreting the water quality data collected in 2001 and 2002 for the GDWQA, monthly and annual precipitation totals from this period were compiled and compared to historical precipitation totals. Data for the following King County rain gauges in the Green-Duwamish watershed (see Figure 5) were compiled for this analysis:

- Lower Green River (gauge 32U)
- Soos Creek (gauge 54V)
- O'Grady Creek (gauge 40U)
- Covington Creek (gauge 09U).

Monthly and annual precipitation totals for each of these gauges are summarized in Table 13 for 2001, 2002, and the historical period of record. These data indicate that precipitation totals measured over the winter of 2001/2002 were generally higher than historical averages. However, precipitation totals measured from the late spring through fall of 2002 were substantially lower than historical averages. As shown in Table 2, sampling for this project was initiated in November of 2001 with the majority of the sampling occurring in the winter, spring, and fall of 2002.

5.2 Water Quality Data

This section summarizes results from water quality sampling conducted in 2001 and 2002 for the GDWQA. The presentation of these results is organized into separate subsections for each of the following parameter categories:

- Field measurements
- Conventional parameters
- Microbiological parameters
- Nutrients
- Metals
- Priority pollutant organics.

Table 13. Monthly and annual precipitation totals (in inches) from gauges in the Green-Duwamish watershed for 2001and 2002 in comparison to historical totals.

	Lower Green River Gauge (32U)			Soos Creek Gauge (54V)			O'Grady Creek Gauge (40U)			Covington Creek Gauge (09U)		
	Historical[a]	2001	2002	Historical[b]	2001	2002	Historical[b]	2001	2002	Historical[b]	2001	2002
January	5.54	*2.76*	6.55	6.08	*3.00*	5.90	5.21	*2.30*	**7.05**	5.78	*2.60*	6.67
February	4.10	*2.59*	3.70	4.72	*2.75*	5.01	4.05	*2.44*	4.84	4.48	*2.36*	4.03
March	3.96	3.70	3.45	4.41	4.09	4.47	3.92	3.96	**5.20**	4.30	4.46	4.75
April	3.41	4.56	4.53	3.58	**4.71**	**4.89**	3.44	**5.38**	**4.25**	3.97	4.81	4.29
May	2.39	*1.95*	*1.63*	2.73	1.94	1.89	2.65	2.28	*1.72*	3.01	2.36	2.23
June	1.89	**4.12**	1.66	2.01	**4.49**	2.15	2.28	**4.16**	1.98	2.60	**5.02**	*2.10*
July	1.02	0.63	0.64	1.04	**1.40**	*0.66*	1.25	0.69	*0.59*	1.55	1.18	*0.75*
August	0.89	**1.86**	*0.11*	0.87	**2.21**	*0.19*	0.84	**2.28**	**1.56**	0.91	**2.45**	0.47
September	1.04	0.86	0.69	1.54	1.09	1.08	1.67	1.12	1.06	1.66	1.09	1.04
October	3.58	3.54	*1.26*	4.21	4.50	*1.19*	3.92	3.95	*1.56*	4.55	4.19	*1.58*
November	6.62	**10.11**	*2.67*	7.21	**11.48**	*3.04*	6.54	9.06	*2.38*	7.17	9.83	*2.56*
December	4.91	**6.00**	**5.67**	6.27	7.29	7.20	5.11	5.60	5.73	5.66	**6.32**	5.54
Total	39.10	42.68	*32.56*	44.67	48.95	*37.67*	40.88	**43.22**	37.92	45.65	46.67	*36.01*

[a] Based on average monthly and annual precipitation totals measured over the period from 1989 through 2000.

[b] Based on average monthly and annual precipitation totals measured over the period from 1992 through 2000.

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

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

Results are discussed for each water quality parameter in each subsection. This discussion begins with a brief overview of the purpose and importance of the parameter, and then summarizes any significant findings from the Habitat Limiting Factors and Reconnaissance Assessment Report (Kerwin and Nelson 2000). Results for base and storm flow sampling are then discussed for the two Green River sites, the five major stream sites, and finally the 11 tributary sites. To support these discussions, tabular summaries of the data are provided in a separate appendix for each parameter category (Appendices D through I) respectively. Results of statistical analyses are presented in Appendix J. Graphical data summaries are presented below for each monitoring parameter (excluding organics). Finally, results of the computed WQI index scores for each site are presented and discussed at the end of this section.

5.2.1 In-stream Field Measurements

This section summarizes field measurement data collected in 2001 and 2002 for the GDWQA. Summary statistics for these parameters are presented in Appendix D and results from associated statistical spatial pattern analyses are presented in Appendix J. Field measurement parameters include:

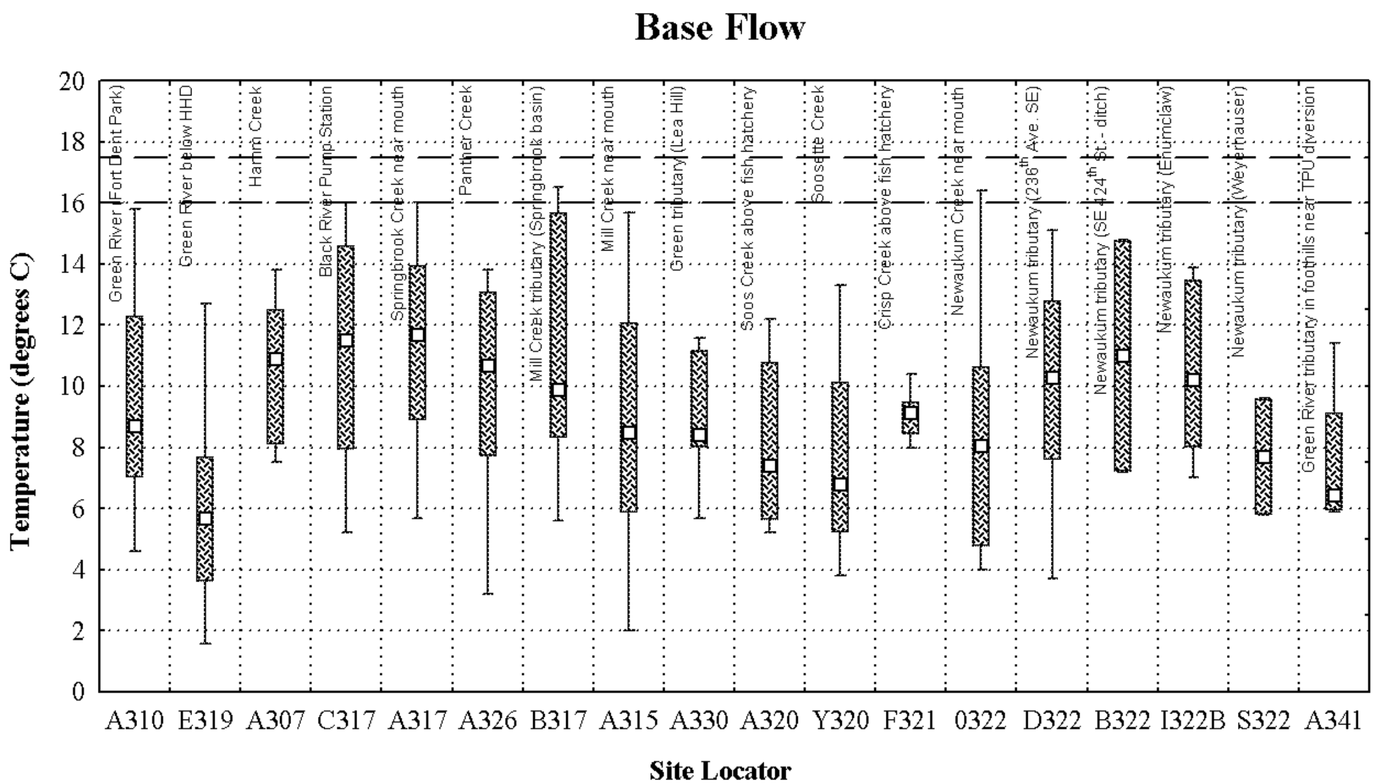
- Temperature
- Dissolved oxygen
- pH
- Specific conductance.

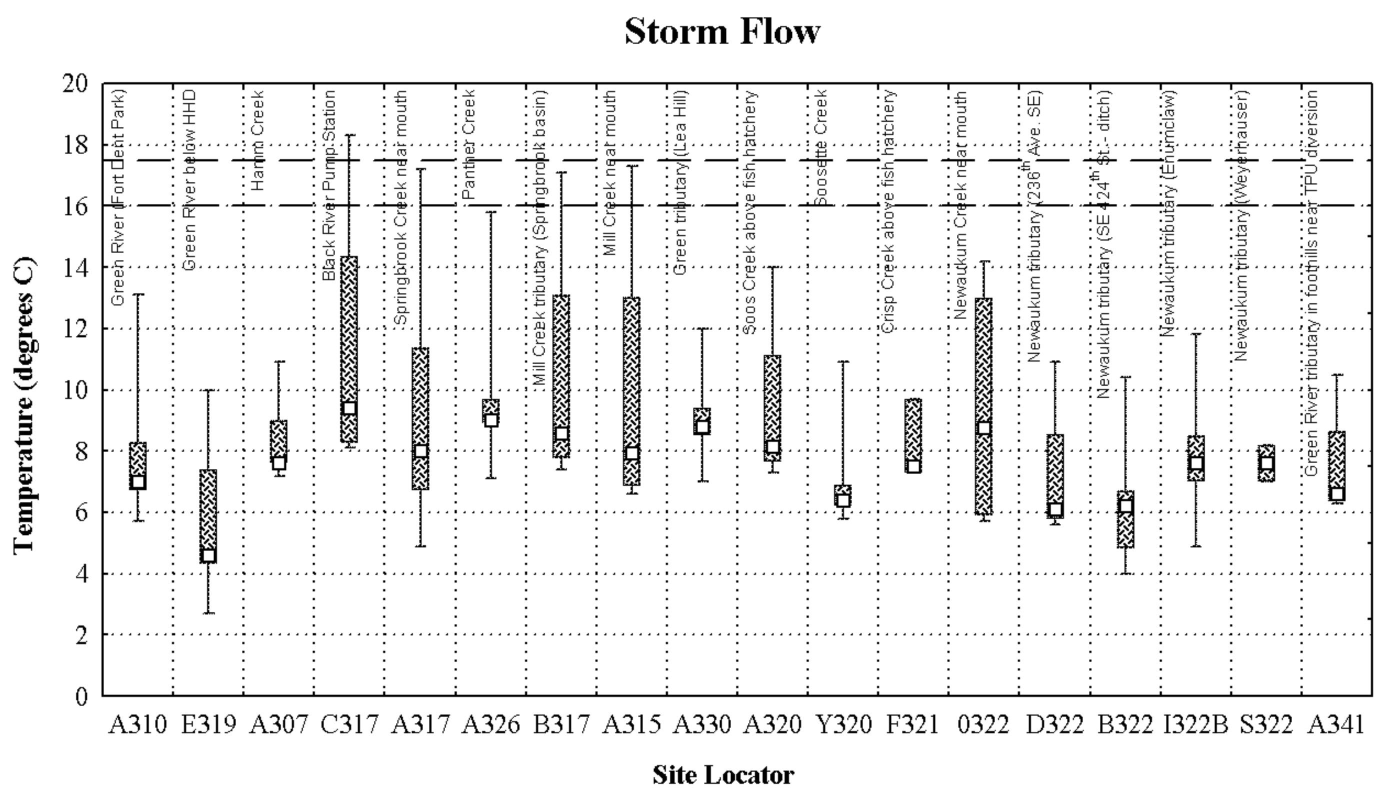
5.2.1.1 Temperature

In-stream water temperature data were collected during base flow and storm flow sampling and represent instantaneous temperature measurements. State water quality criteria for temperature (see Table 11) are based on a seven-day average daily maximum (7-DADMax). The maximum allowable 7-DADMax is 16.0°C in core salmonid rearing waters and 17.5°C in noncore salmonid rearing waters (WAC 173-201A). Waterbodies in this monitoring study that are on the state's 1998 303(d) water quality limited list for temperature are the Green River (upper and lower segments), Springbrook Creek, Mill (Hill) Creek, and Soos Creek. King County (2000) identified high temperatures as a possible factor of salmonid decline in Crisp Creek, Soos Creek, Soosette Creek, Mill (Hill) Creek, Springbrook Creek, and the Lower Green River. However, the report determined that temperature was not likely a factor in salmonid decline in Newaukum Creek and the Middle Green River.

King County is conducting a more thorough temperature study within the basin using continuous data to more accurately assess temperature patterns in the Green River and selected streams and tributaries (Taylor Associates and King County 2004). These continuous data will also allow more accurate comparisons with the 7-DADMax state temperature criteria relative to those based on discrete grab samples, and will focus on the period of most concern (i.e., summer).

Summary statistics for temperature during base and storm flow are presented in Table D1 and Figure 7. All sites exhibited water temperatures that were reasonably moderate and met





Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Dashed line = water quality standard

Figure 7. Temperature levels at sites in the Green-Duwamish watershed in 2001 and 2002.

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applicable state water quality criteria; however, it is important to emphasize that this finding is based on discrete sampling that occurred on infrequent occasions during the summer. An exception was the Black River pump station site (C317), where the criterion was exceeded during one storm event on June 29, 2002. This exceedance may be related to the impoundment at this sampling site that causes stagnation and heating of river water by solar radiation and warmer air circulating over the water surface. Base flow water temperatures ranged from 1.6°C in the Upper Green River (E319) to 16.5°C in the Mill (Springbrook) tributary (B317), and storm flow water temperatures ranged from 2.7°C in the Upper Green River (E319) to 18.3°C in the Black River (C317).

Sampling data indicate that water temperatures at both Green River sampling sites (E319 and A310) are generally cool. The maximum temperature measured at the Lower Green River (A310) was 15.8°C, compared to 12.7°C at the Upper Green River (E319). Spatial pattern analysis results for the Green River indicates that water temperature does not vary significantly between the upper (E319) and lower (A310) sites during base flow or storm flow (see Table J1). The median base flow temperature was 5.7ºC at the upper site and 8.7°C at the lower site, and the median storm flow temperature was 4.6°C at the upper site and 7.0°C at the lower site.

Spatial pattern analysis results show there are no significant differences in temperature during either base flow or storm flow for the five major stream sites (see Tables J2 and J3, respectively). Median base flow temperatures ranged from 7.4°C to 11.7°C at Newaukum Creek (0322) and Springbrook Creek (A317), respectively. Median storm flow temperatures ranged from 7.9°C to 9.4°C at Mill (Hill) Creek (A315) and Black River (C317), respectively. The maximum base flow water temperature (16.0°C) was measured at both Black River (C317) and Springbrook Creek (A317).

Among the tributaries, water temperatures were moderately cool during most sampling events. The highest maximum base flow temperature (16.5°C) was recorded in Mill (Springbrook) tributary (B317) and the highest maximum storm flow temperature (15.8ºC) was recorded in Panther Creek (A326). The Newaukum tributary at SE 424th (B322) had the highest median base flow temperature (11.0°C) and Panther Creek (A326) had the highest median storm flow temperature (9.0°C). Crisp Creek (F321) data indicate water temperatures at this site vary the least, with a 2.4°C temperature variation between the minimum and maximum base flow temperatures. This small variation is likely related to the undeveloped and forested conditions within this basin that limit direct solar warming of the stream, as well as the spring-fed (groundwater) nature of the system.

5.2.1.2 Dissolved Oxygen

Dissolved oxygen is one of the most important water quality parameters for salmonids and other aquatic life. King County (2000) identified low dissolved oxygen concentrations as a probable cause for the decline of salmonids in all four of the major streams (Springbrook, Mill, Soos, and Newaukum Creeks) draining to the Green River. Washington State surface water standards (Table 11) require that dissolved oxygen concentrations exceed 9.5 mg/L in freshwaters designated for core salmonid rearing and 8.0 mg/L in freshwaters designated for noncore salmonid rearing (WAC 173-201A). Dissolved oxygen is a 303(d) listed parameter for each of the four major streams, but not for the Upper Green River site (E319) or the Lower Green River site (A310).

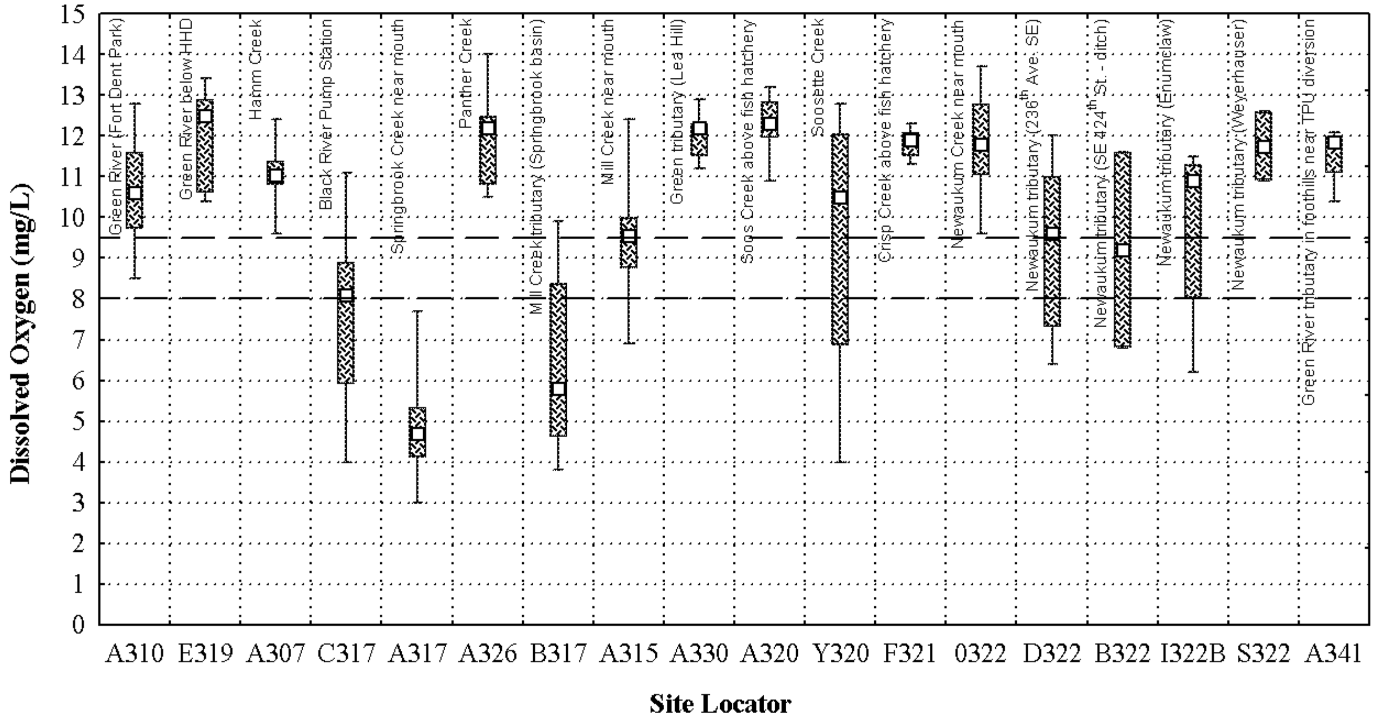
Summary statistics for dissolved oxygen concentrations during base and storm flow are presented in Table D2 and Figure 8. Among all sites, dissolved oxygen concentrations ranged from 3.0 to 13.7 mg/L during base flow and from 1.5 to 14.3 mg/L during storm flow. Between the two Green River sites (A310 and E319), dissolved oxygen concentrations showed a significant decreasing pattern downstream during base flow ($p = 0.0288$) and storm flow ($p = 0.0027$). Median dissolved oxygen concentrations at the Lower Green River (A310) were approximately 2 to 3 mg/L lower during both base and storm flow relative to those at the Upper Green River site. Dissolved oxygen concentrations did not vary substantially between base and storm flow conditions at either river site. One of 14 samples from the Lower Green River site (A310) exhibited a dissolved oxygen concentration (7.3 mg/L) that did not meet the state water quality criterion (Table 11), while all 17 measurements for the Upper Green River site met the criterion.

At the five major stream sites, median dissolved oxygen concentrations during base flow ranged from 4.7 mg/L in Springbrook Creek (A317) to 12.3 mg/L in Soos Creek (A320). During storm flow, median concentrations ranged from 7.6 mg/L in the Black River (C317) to 11.7 mg/L in Soos Creek (A320). Based on spatial pattern analysis results for these sites (Table J2), base flow dissolved oxygen concentrations were significantly lower ($p < 0.0001$) in Springbrook Creek (A317) and the Black River (C317) relative to those in Newaukum Creek (0322) and Soos Creek (A320). Significant differences ($p = 0.0038$) in storm flow dissolved oxygen concentrations were only observed between Springbrook Creek (A317) and Soos Creek (A320) that had the lowest and highest concentrations, respectively (Table J3).

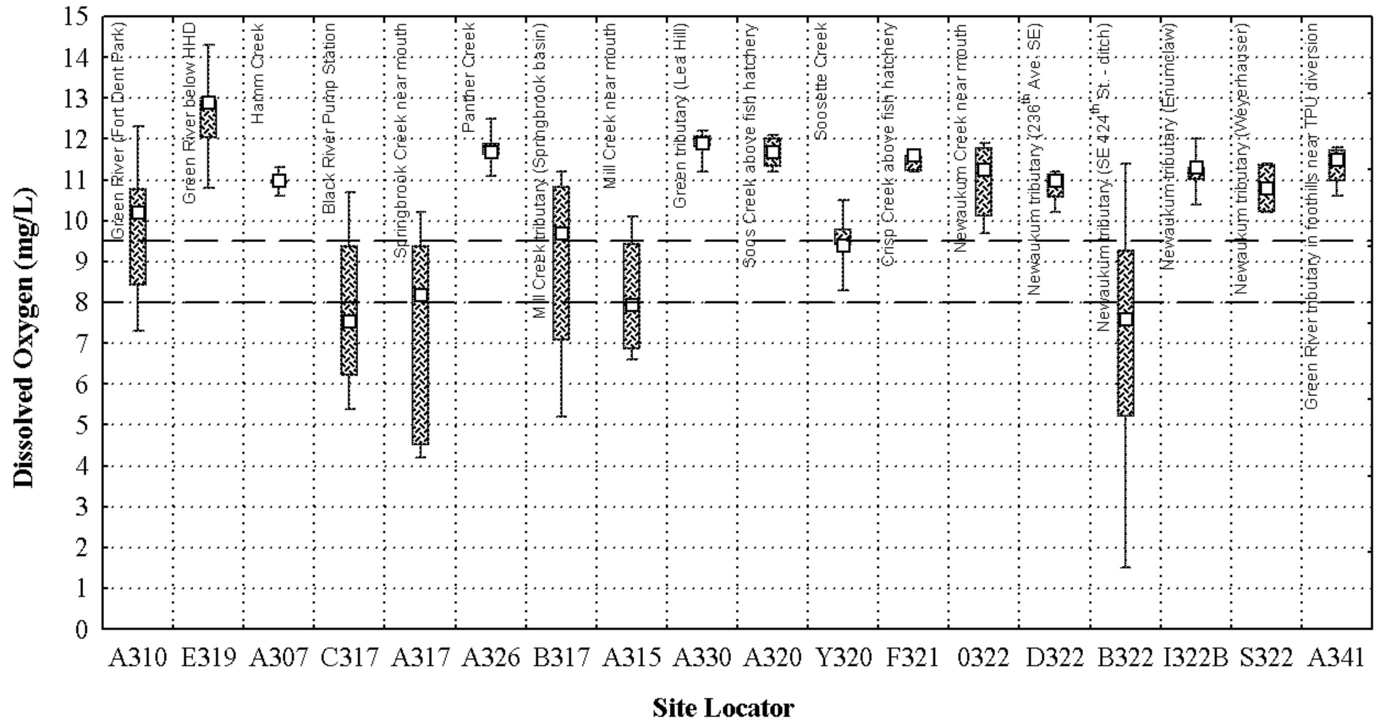
Among the five major stream sites, the dissolved oxygen criterion (Table 11) was exceeded with the greatest frequency (43 to 100 percent of collected samples) in Springbrook Creek (A317) and Black River (C317). In Mill Creek (A315), the criterion was exceeded in 12.5 percent of the base flow samples and 50 percent of the storm flow samples. The dissolved oxygen criterion was never exceeded at Soos Creek (A320) and Newaukum Creek (0322), although few samples were collected during summer base flow when the lowest dissolved oxygen concentrations would be expected.

Among the 11 tributary sites, median dissolved oxygen concentrations were lowest during base flow at the Mill Creek (Springbrook) tributary (5.8 mg/L at site B317 draining high density development) and were lowest during storm flow at the Newaukum tributary at SE 424th (7.6 mg/L at site B322 draining agriculture). Tributary sites not meeting the dissolved oxygen criterion (Table 11) include Mill (Springbrook) tributary (71 percent exceedance during base and 25 percent exceedance during storm flow at site B317), Soosette Creek (25 percent exceedance during base flow at site Y320), and three Newaukum Creek tributaries (33 percent exceedance during base flow at site D322, 50 and 60 percent exceedance during base and storm flow, respectively, at site B322, and 20 percent exceedance during base flow at site I322B).

Base Flow



Storm Flow



Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Dashed line = water quality standard

Figure 8. Dissolved oxygen concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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5.2.1.3 pH

The hydrogen ion activity in water is measured by pH, which can have a direct effect on aquatic organisms, or an indirect effect by virtue of the fact that the toxicity of various common pollutants are markedly affected by changes in pH. Waters that exhibit a pH in the range of 0.0 to 7.0 are considered acidic, while waters with pH ranging from 7.0 to 14.0 are considered alkaline. Waters measuring 7.0 are considered neutral. State surface water quality criteria for core and noncore salmonid rearing (Table 11) require pH to be within the range of 6.5 to 8.5 (WAC 173-201A). No waterbodies included in this monitoring study are included on the state's 1998 303(d) water quality limited list as impaired for pH. King County (2000) identified pH as not a likely factor for the decline of salmonids in Crisp Creek, Newaukum Creek, Soos Creek, Soosette Creek, Mill (Hill) Creek, Springbrook Creek, and the Lower and Middle Green River.

Summary statistics for pH during base and storm flow are presented in Table D3 and Figure 9. Base flow pH ranged from 6.1 to 8.2, and storm flow pH ranged from 6.2 to 8.9. The pH criterion was not met on one occasion each at Upper Green River (base flow pH of 6.1 at site E319), Soosette Creek (storm flow pH of 6.2 at Y320), and Soos Creek (storm flow pH of 8.9 at site A320).

Spatial pattern analysis results for the Green River showed a significant ($p = 0.0039$) decreasing pattern in pH downstream during base flow with the median pH levels of 7.7 and 7.1 at the upper and lower sites, respectively (Table J1). There was no significant difference in pH levels between these two sites during storm flow.

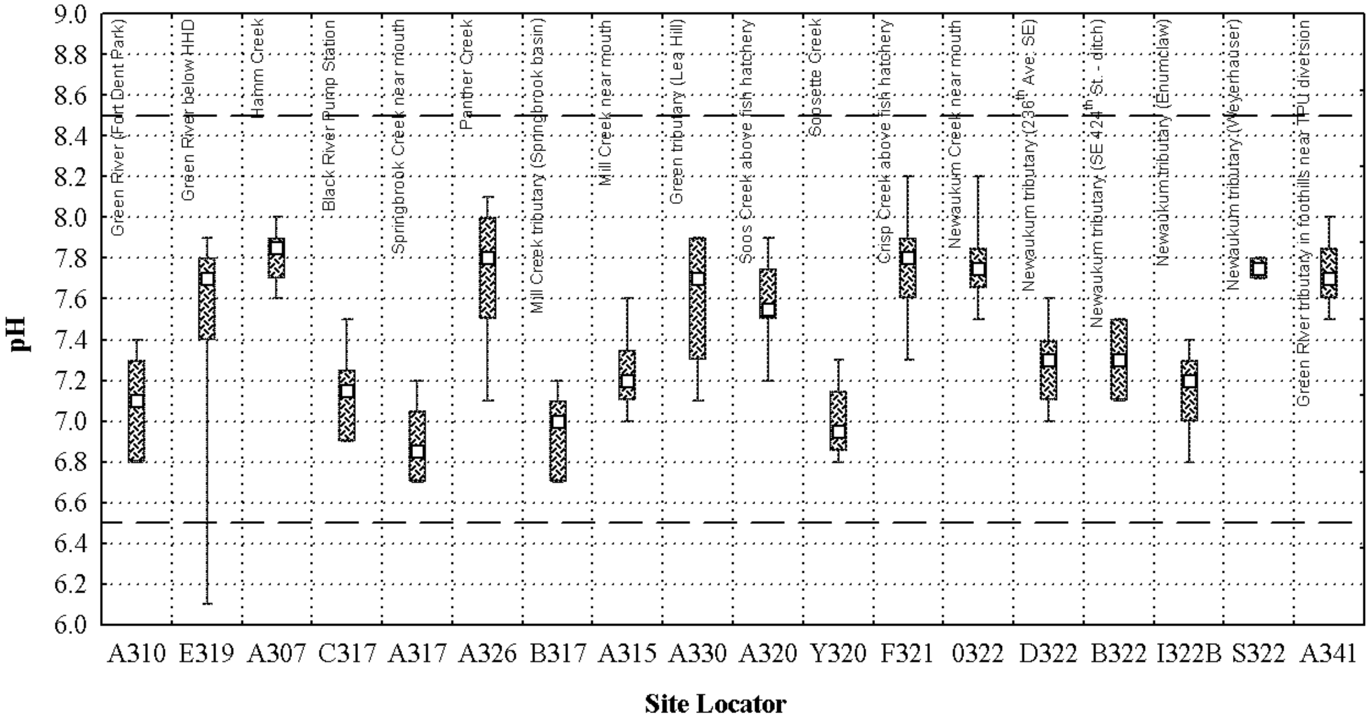
The major stream sites exhibited a wide range of median pH values during base flow and storm flow. The base flow median pH ranged from 6.8 in Springbrook Creek (A317) to 7.8 in Newaukum Creek (0322), and the storm flow median ranged from 6.6 in Springbrook Creek (A317) to 7.7 in Soos Creek (A320). Spatial pattern analysis results for the major streams showed that pH was significantly lower ($p < 0.0001$) in Springbrook Creek (A317) and Black River (C317) relative to Newaukum Creek (0322) during base flow (Table J2). Further, spatial pattern analysis results for storm flow indicate that pH was significantly lower ($p = 0.0020$) in Springbrook Creek (A317) relative to Newaukum Creek (0322) and Soos Creek (A320) (Table J3).

Among the tributary sites, the base flow median pH ranged from 6.9 in Soosette Creek (Y320) to 7.8 in Hamm Creek (A307), Crisp Creek (F321) and the Newaukum tributary downstream of Weyerhaeuser (S322), and storm flow median pH ranged from 6.6 in Soosette Creek (Y320) to 7.7 in Panther Creek (A326) and Newaukum tributary downstream of Weyerhaeuser (S322).

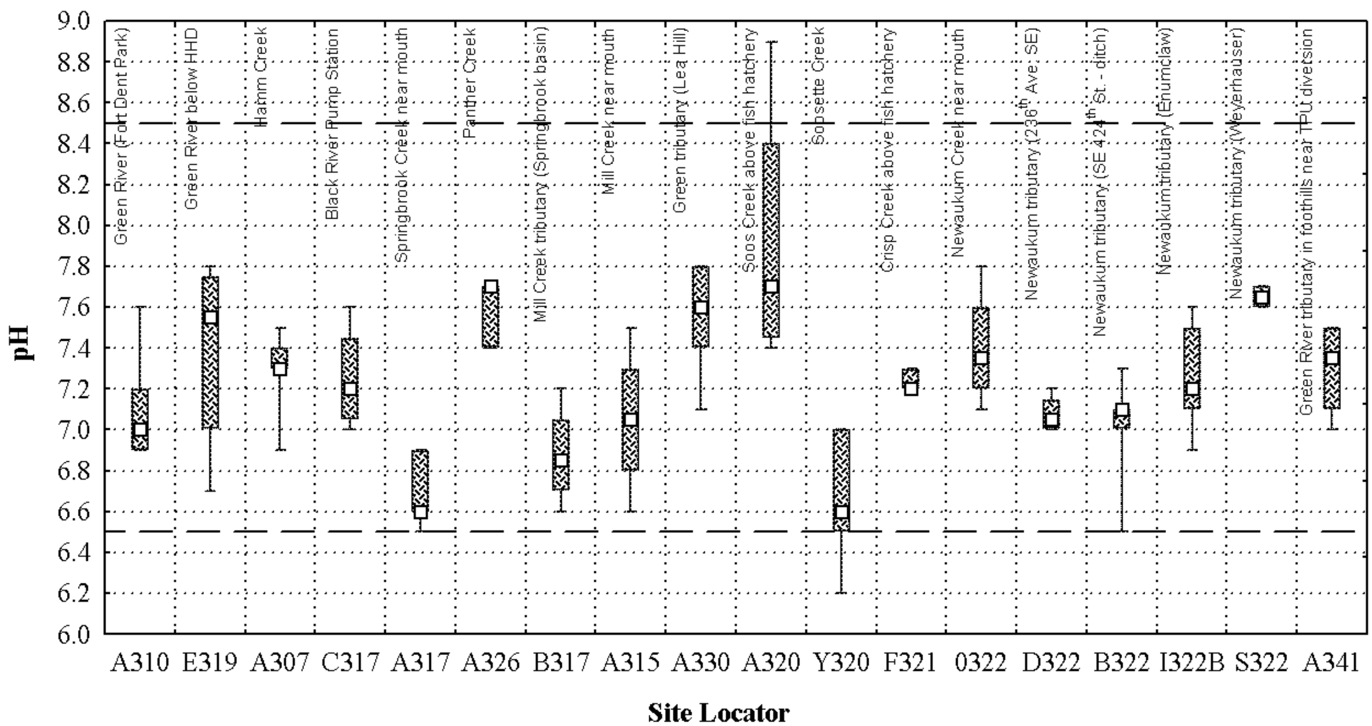
5.2.1.4 Specific Conductance

Specific conductance is a measure of the ability of water to conduct an electrical current, which is directly related to the content of dissolved ions (solids) in the water. While there is no state surface water quality criteria established for specific conductance, this measurement is useful for identifying sources of dissolved pollutants and for determining relative contributions of

Base Flow



Storm Flow



Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Dashed line = water quality standard

Figure 9. Levels of pH at sites in the Green-Duwamish watershed in 2001 and 2002.

ground water, because specific conductance is typically higher in ground water than in surface water.

Summary statistics for specific conductance during base and storm flow are presented in Table D4 and Figure 10. Among all samples, specific conductance ranged from 1.8 to 386 µmhos/cm during base flow and from 1.7 to 389 µmhos/cm during storm flow. For individual samples, median specific conductance was higher during base flow than storm flow at all sites, and the median value for all the sites combined was higher during base flow (154 µmhos/cm) than during storm flow (108 µmhos/cm). The higher base flow specific conductance likely indicates ground water is a major component of the flow at these sites. During storms, specific conductance decreases because this groundwater component of the flow is diluted by surface runoff.

Results of spatial pattern analysis for the Green River (Table J1) showed a significant increasing pattern in specific conductance from the Upper Green (E319) to the Lower Green (A310) during both base flow ($p < 0.0001$) and storm flow ($p = 0.0007$). Median specific conductance levels at the upper and lower sites were 41.4 and 104 µmhos/cm, respectively, during base flow. During storm flow, median specific conductance levels at the upper and lower sites were 34.8 and 76.0 µmhos/cm, respectively. The Upper Green River site (E319) exhibited the lowest median specific conductance of all sampling sites during base flow and storm flow.

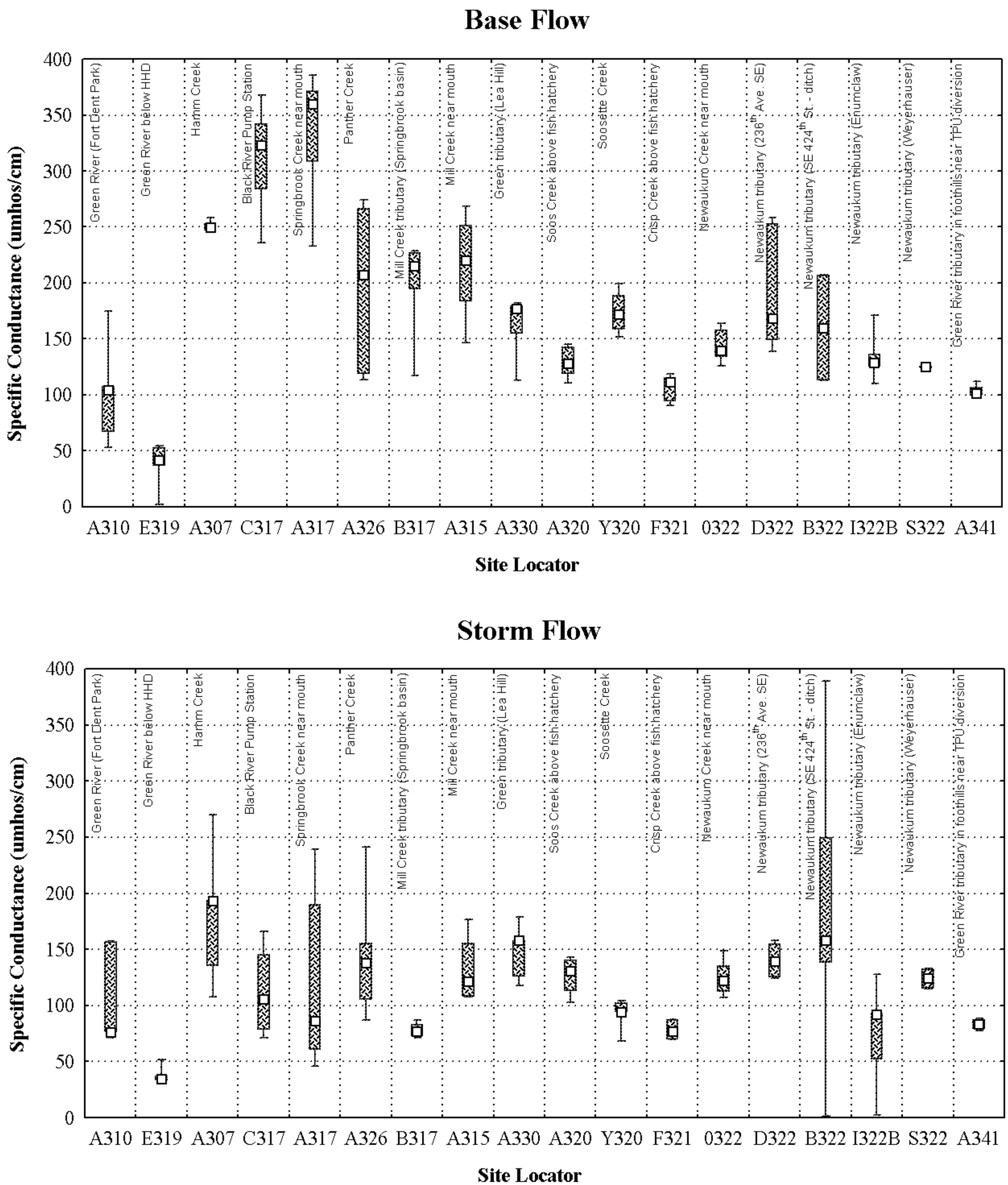
Based on results of the spatial pattern analysis for the five major stream sites (Table J2), base flow specific conductance levels were significantly lower ($p < 0.0001$) in Soos Creek (A320) and Newaukum Creek (0322) relative to Springbrook Creek (A317) and the Black River (C317). Median base flow specific conductance levels ranged from 140 µmhos/cm in Newaukum Creek (0322) to 360 µmhos/cm in Springbrook Creek (A317). Springbrook Creek (A317) also had the highest maximum base flow specific conductance (386 µmhos/cm). There were no significant differences in specific conductance between the major streams during storm flow (Table J3). Median storm flow specific conductance levels ranged from 86.0 µmhos/cm in Springbrook Creek (C317) to 131 µmhos/cm in Soos Creek (A320).

Among the tributary sites, Hamm Creek (A307) exhibited the highest median specific conductance during both base flow (250 µmhos/cm) and storm flow (193 µmhos/cm). The Green tributary near TPU diversion (A341) had the lowest median specific conductance (102 µmhos/cm) during base flow and Crisp Creek (F321) had the lowest median specific conductance during storm flow (76.7 µmhos/cm).

5.2.2 Conventionals

This section summarizes conventional parameter data collected in 2001 and 2002 for the GDWQA. Summary statistics for these parameters are presented in Appendix E and results from the associated statistical spatial pattern analyses are presented in Appendix J. Conventional parameters include:

- Alkalinity
- Turbidity
- Total suspended solids



Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 10. Specific conductance at sites in the Green-Duwamish watershed in 2001 and 2002.

- Dissolved organic carbon
- Total organic carbon
- Biochemical oxygen demand
- Hardness.

5.2.2.1 Alkalinity

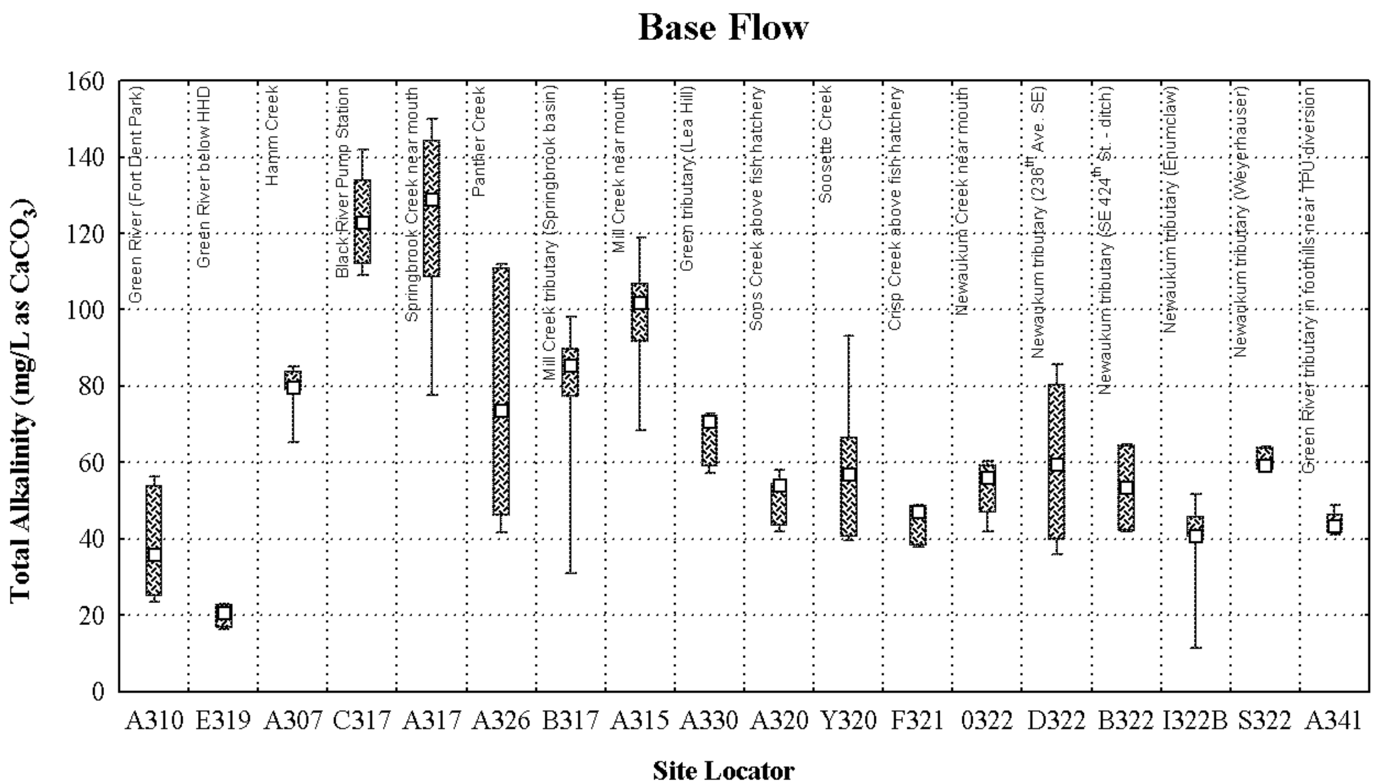
Alkalinity is a measure of the buffering capacity of water. Total alkalinity is defined as the amount of acid required to lower the pH of a water sample to the point where all of the bicarbonate [HCO_3^-] and carbonate [CO_3^{--}] have been converted to carbonic acid [H_2CO_3]. Washington State does not have surface water quality criteria for alkalinity.

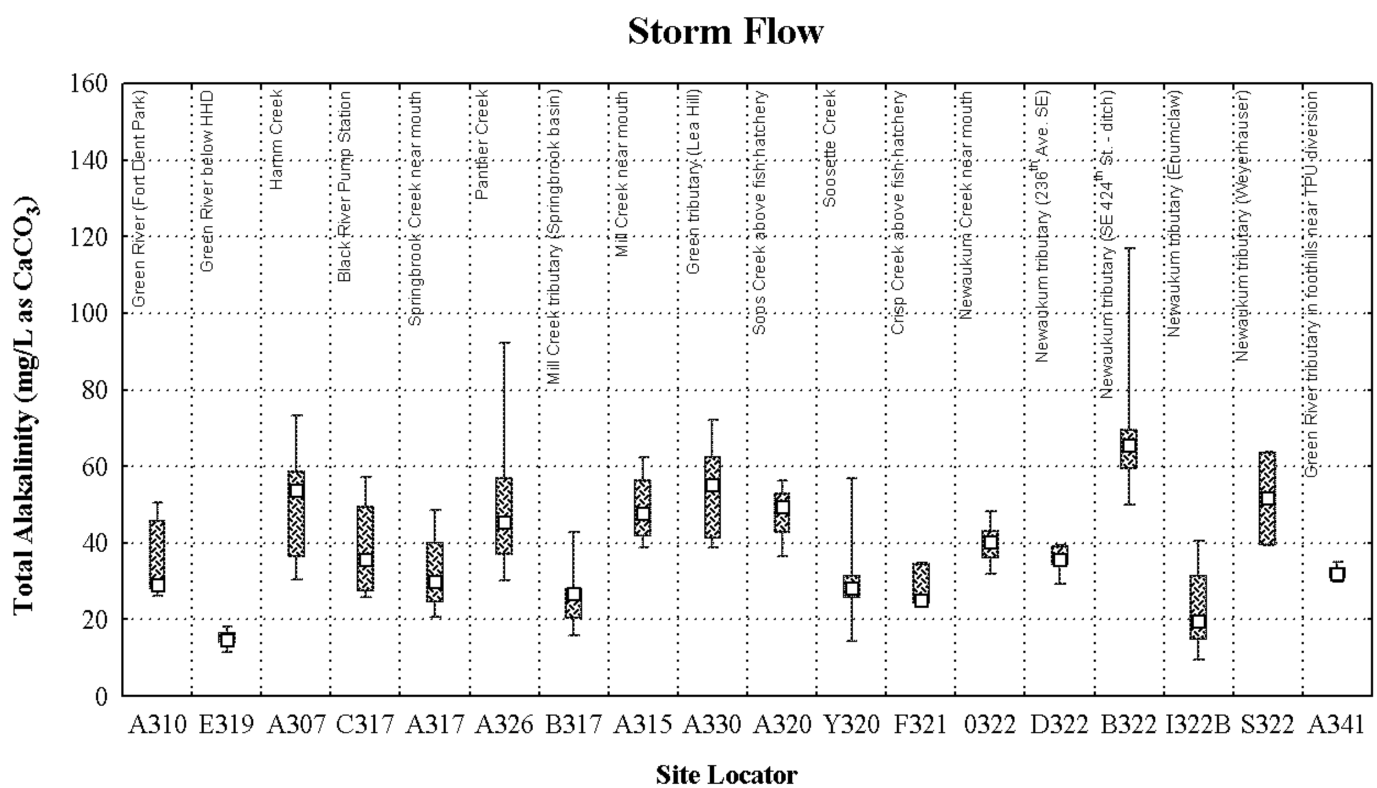
Summary statistics for alkalinity during base and storm flow are presented in Table E1 and Figure 11. Base flow alkalinity ranged from 11.4 to 150 mg/L (expressed as mg/L of $CaCO_3$), and storm flow alkalinity ranged from 9.4 to 117 mg/L. Similar to conductivity, the median alkalinity of all the sites combined was higher during base flow (57.9 mg/L) than during storm flow (35.2 mg/L), and was likely caused by the increase in surface water runoff to the streams during storm events.

Between the two Green River sites (A310 and E319), alkalinity showed a significant increasing pattern downstream during both base flow ($p = 0.0001$) and storm flow ($p = 0.0016$) sampling (see Table J4). Median alkalinity concentrations were 20.8 and 35.9 mg/L at upper and lower sites, respectively, during base flow. Similarly, median concentrations at the upper and lower sites were 14.7 and 29.1 mg/L, respectively, during storm flow. The Upper Green River site (E319) had the lowest base flow (20.8 mg/L) and storm flow (14.7 mg/L) median alkalinity values of all the sites.

For the five major stream sites, results from the spatial pattern analysis (Table J5) showed that base flow alkalinity concentrations were significantly lower ($p = 0.0001$) in Soos Creek (A320) and Newaukum Creek (0322) relative to both Springbrook Creek (A317) and Black River (C317). Median base flow alkalinity among the five sites ranged from 54.1 mg/L in Soos Creek (A320) to 129 mg/L in Springbrook Creek (A317). Springbrook Creek (A317) also had the maximum base flow alkalinity (150 mg/L) of all the sites. Spatial pattern analysis results for storm flow showed that alkalinity concentrations are significantly higher ($p = 0.0437$) in Mill (Hill) Creek (A315) relative to Springbrook Creek (A317) (Table J6). The storm flow median alkalinity ranged from 29.8 mg/L in Springbrook Creek (A317) to 47.7 mg/L in Mill (Hill) Creek.

Among the tributary sites, median base flow alkalinity ranged from 40.8 mg/L in Newaukum tributary at Enumclaw (I322B) to 85.6 mg/L in Mill (Springbrook) tributary (B317). Median storm flow alkalinity ranged from 19.6 mg/L at Newaukum tributary at Enumclaw (I322B) to 65.5 mg/L at Newaukum tributary at SE 424th (B322), which also exhibited the maximum storm flow alkalinity (117 mg/L) of all the sampling sites.





Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 11. Alkalinity concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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5.2.2.2 Turbidity

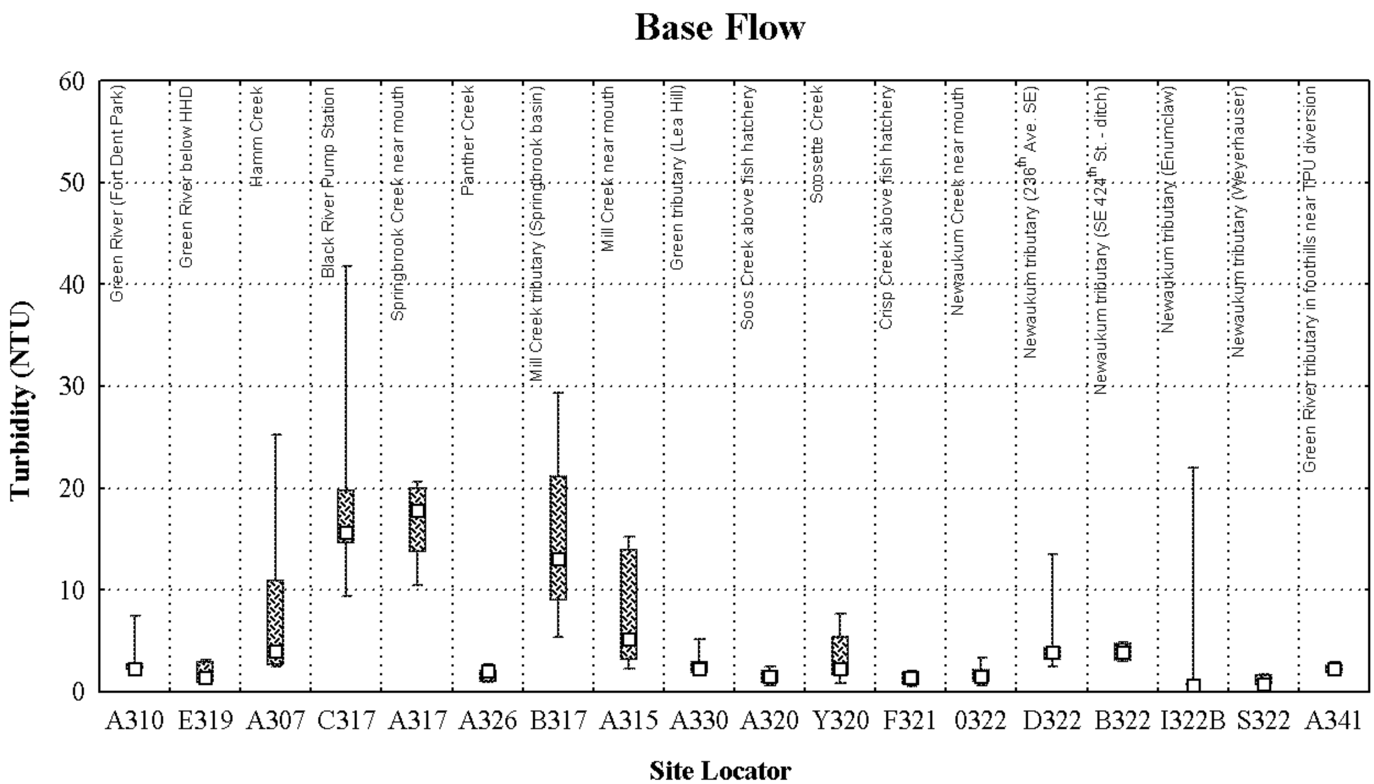
Turbidity is a measure of water clarity that is determined by how the transmission of light is scattered as it passes through water. The increase in the amount of particulate matter in water reduces clarity (or transparency) by increasing the scattering of light. Measurements of turbidity are expressed in nephelometric turbidity units (NTU). Washington State has surface water quality criteria for turbidity (WAC 173-201A) that restrict turbidity increases from human sources to a maximum of 5 NTU over background when the background is 50 NTU or less. When background turbidity is over 50 NTU, turbidity resulting from human sources cannot increase background levels by more than 10 percent. Because background data are not available for the grab samples collected during base flow and storm flow, direct comparisons with the turbidity criteria are not possible and were not made as part of this analysis. No waterbodies in this monitoring study are identified as on the state's 1998 303(d) list as water quality limited for turbidity.

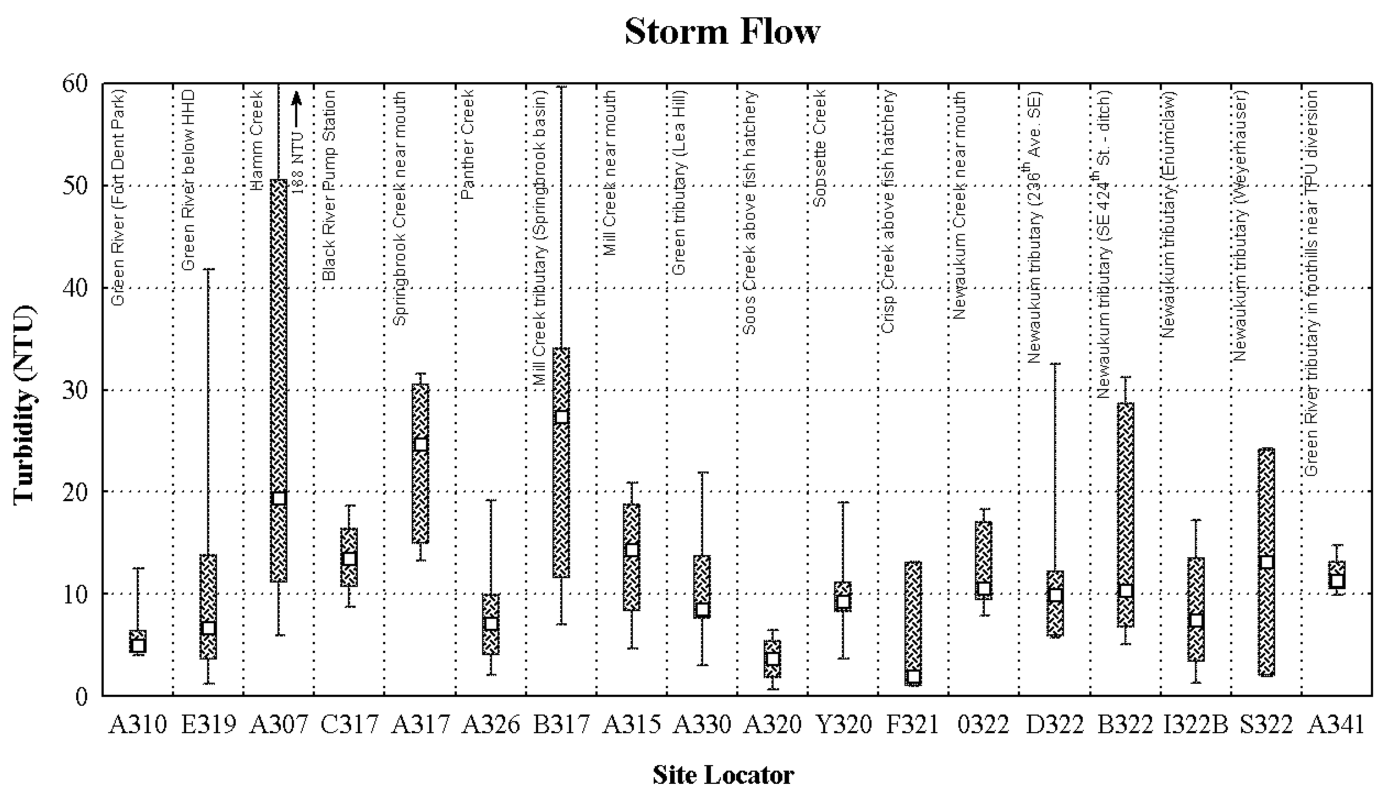
Summary statistics for turbidity during base and storm flow are presented in Table E2 and Figure 12. Base flow turbidity ranged from 0.5 to 41.8 NTU, and storm flow turbidity ranged from 0.7 to 317 NTU. The median turbidity of all the sites combined was higher during storm flow (11.1 NTU) than base flow sampling (2.6 NTU). This increase in turbidity was likely caused by the increase in surface runoff to the streams (and the associated mobilization of suspended solids from erosion or washoff from urban surfaces) during storms.

Spatial pattern analysis results for the Green River (Table J4) indicate that turbidity does not differ significantly between the upper (E319) and lower (A310) sites during either base flow or storm flow. Base flow turbidity levels were generally low with median values of 1.4 NTU at the Upper Green (E319) and 2.2 NTU at the Lower Green (A310). Storm flow turbidity levels were slightly higher with median values of 6.7 NTU at the Upper Green (E319) and 4.9 NTU at the Lower Green (A310).

Based on spatial pattern analyses for the major stream sites (Table J5), base flow turbidity levels were significantly higher ($p = 0.0001$) in Springbrook Creek (A317) and the Black River (C317) relative to Soos Creek (A320) and Newaukum Creek (0322). Median base flow turbidity levels ranged from 1.5 NTU in Newaukum Creek (0322) and Soos Creek (A320) to 17.9 NTU in Springbrook Creek (A317). The spatial pattern analysis for storm flow (Table J6) also showed that turbidity is significantly higher ($p = 0.0038$) in Springbrook Creek (A317) relative to Soos Creek (A320). Median storm flow turbidity ranged from 3.6 NTU in Soos Creek (A320) to 24.7 NTU in Springbrook Creek (A317).

Based on median values, the Newaukum tributary at Enumclaw (I322B) and Crisp Creek (F321) had lower turbidity levels during both base flow and storm flow relative to the other tributary sites. The Mill (Springbrook) tributary (B317) exhibited the highest median turbidity during base flow (13.1 NTU) and storm flow (27.4). Hamm Creek (A307) exhibited the maximum turbidity value (317 NTU) of all the sites during storm flow sampling. Other tributary sites exhibiting elevated turbidity during storm flow include three Newaukum tributary sites (D322, B322, and S322), Soosette Creek (Y320), and the Green tributary near TPU diversion (A341).





Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 12. Turbidity levels at sites in the Green-Duwamish watershed in 2001 and 2002.

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5.2.2.3 Total Suspended Solids

Total suspended solids (TSS) is a measurement of the solid materials in water that are retained on a standard glass-fiber filter. Suspended solids, especially the finer fractions, reduce light penetration in water and can have a smothering effect on fish redds and benthic biota. Suspended solids are also closely associated with other pollutants such as nutrients, bacteria, metals, and organic compounds. These pollutants tend to adsorb onto solids particles and are consequently transported in surface runoff to receiving waters if no onsite controls are implemented for solids removal. No state surface water quality criteria have been established for total suspended solids.

According to King County (2000), total suspended solids are not likely a concern for salmonids in Crisp Creek, Soos Creek, Newaukum Creek, or the Lower and Middle Green River; however, more data are needed to verify this conclusion. Elevated total suspended solids concentrations that could potentially be a problem for salmonids have been found in Mill (Hill) Creek and Springbrook Creek; however, more data on concentrations and duration are needed to determine the potential effects on salmonids (Kerwin and Nelson 2000).

Summary statistics for total suspended solids during base and storm flow are presented in Table E3 and Figure 13. Base flow TSS concentrations ranged from 0.5 mg/L (the method detection limit) to 62.2 mg/L, and storm flow TSS concentrations ranged from 0.5 to 627 mg/L. Similar to turbidity, the median total suspended solids concentration for all sites combined was higher during storm flow (14.0 mg/L) than base flow (3.7 mg/L), and was likely caused by the increase in surface runoff to these streams during storm events.

Spatial pattern analysis for the Green River sites (Table J4) show that total suspended solids concentrations increase significantly ($p = 0.0154$) between the upper (E319) and lower (A310) sites during base flow. During base flow, median total suspended solids concentrations were 1.5 and 4.1 mg/L at the upper and lower sites, respectively. There were no significant differences between these two sites during storm flow. During one storm, TSS was 147 mg/L at the Upper Green site (E319), perhaps due to effects from the accepted practice of flushing sediment from behind Howard Hanson Dam at low reservoir levels during winter storms.

Results of spatial pattern analysis for the major stream sites (Table J5) showed base flow TSS concentrations were significantly higher ($p = 0.0040$) in Springbrook Creek (A317) and the Black River (C317) relative to Newaukum Creek (0322). Among all five sites, median base flow TSS concentrations ranged from 2.0 mg/L at Newaukum Creek (0322) to 8.0 mg/L at Springbrook Creek (A317). There were no significant differences between these sites during storm flow (Table J6). Median storm flow TSS concentrations ranged from 7.5 mg/L at Soos Creek (A320) to 27.0 mg/L at Springbrook Creek (A317).

Among the tributaries, two Newaukum tributaries (I322B and S322) and Crisp Creek (F321) had low median TSS concentrations during base flow that did not exceed 1.1 mg/L. Also, Crisp Creek (F321) had the lowest median concentration (4.8 mg/L) of all the sampling sites during storm flow. Conversely, Mill (Springbrook) tributary (B317) had the highest median TSS

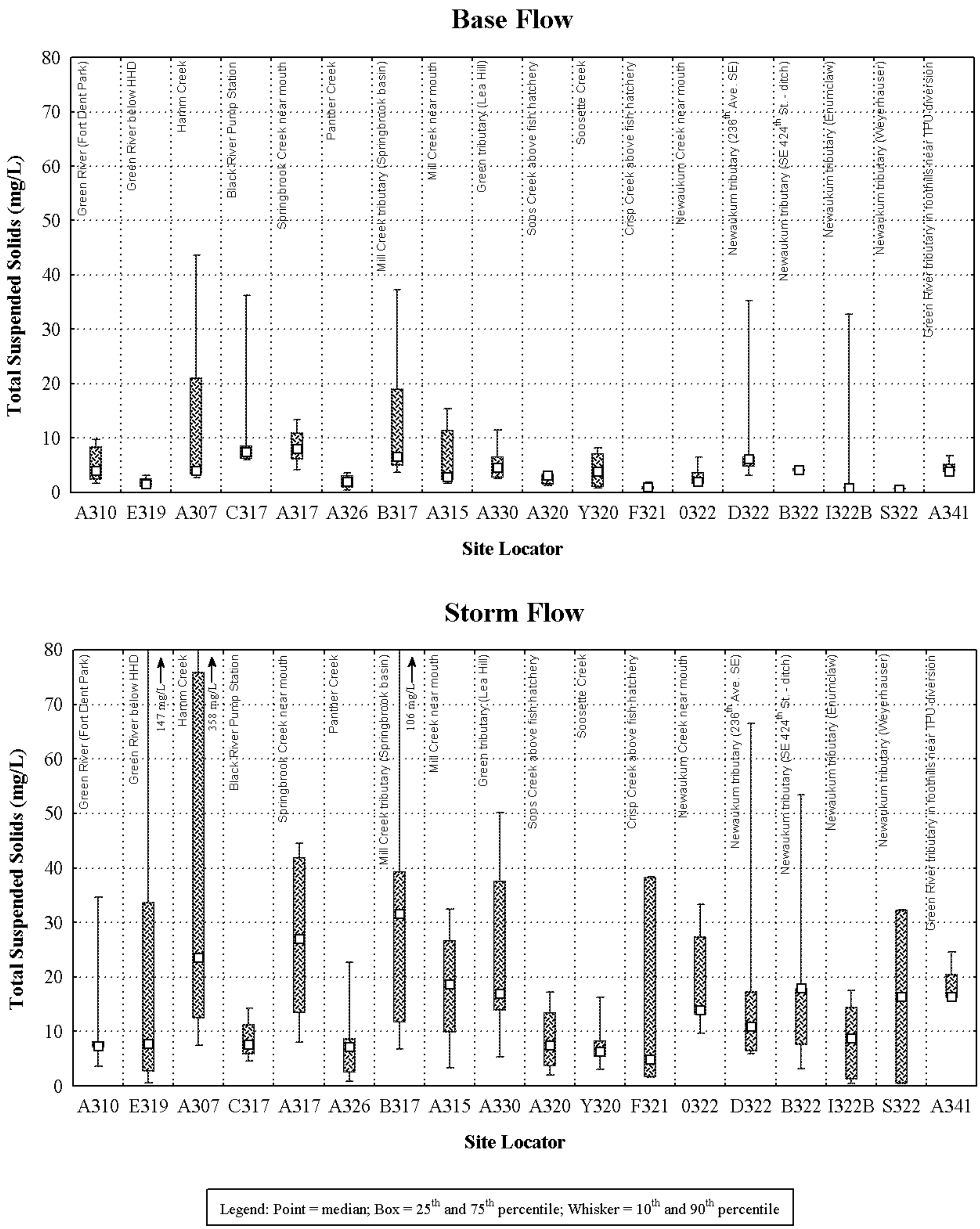

Figure 13. Total suspended solids concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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concentration of all the sites during both base flow (6.6 mg/L) and storm flow (31.5 mg/L).

Tributary sites that also had high median TSS concentrations (i.e., greater than 10 mg/L) during storm flow include Hamm Creek (A307), Green tributary at Lea Hill (A330), three Newaukum tributaries (D322, B322, and S322), and Green tributary near TPU diversion (A341). Hamm Creek (A307) had the maximum storm flow TSS concentration (627 mg/L) among all sites.

5.2.2.4 Dissolved Organic Carbon

Dissolved organic carbon (DOC) is a measure of the amount of dissolved organic matter in water. Surface water sources of dissolved organic carbon include precipitation, leaching, and organic decomposition. Dissolved organic carbon affects the attenuation of visible and ultraviolet light penetration within water and is also a key driver in stream metabolism (Larson et al. 2003). Furthermore, DOC can reduce the acute toxicity of many metals through ligand complexation with free metal ions (Bergman and Doward-King 1997). Washington State does not have surface water quality criteria for dissolved organic carbon.

Summary statistics for dissolved organic carbon during base and storm flow are presented in Table E4 and Figure 14. Base flow DOC concentrations ranged from 1.2 to 12.6 mg/L, and storm flow DOC concentrations ranged from 1.7 to 54.9 mg/L. Between the two Green River sites (A310 and E319), dissolved organic carbon concentrations showed a significant increasing pattern (see Table J4) downstream during base flow ($p = 0.0042$) and storm flow ($p = 0.0145$). Median dissolved organic carbon concentrations increased downstream from 2.0 to 2.5 mg/L during base flow and from 2.5 to 3.3 mg/L during storm flow.

Results from the spatial pattern analysis for the major stream sites (Table J5) showed that base flow DOC concentrations were significantly higher ($p = 0.0001$) in Mill Creek (A315) relative to Soos Creek (A320) and Newaukum Creek (0322). Median DOC concentrations during base flow ranged from 2.7 mg/L at Soos Creek (A320) to 9.1 mg/L at Mill Creek (A315). There were no significant differences in dissolved organic carbon concentrations between the major stream sites during storm flow (Table J6). Median storm flow DOC concentrations ranged from 5.3 mg/L at Soos Creek (A320) to 10.6 mg at Newaukum Creek (0322).

Among the tributary sites, median base flow DOC concentrations ranged from 1.6 mg/L in Crisp Creek (F321) to 7.9 mg/L in Soosette Creek (Y320). In addition, Crisp Creek had the lowest minimum base flow DOC concentration (1.2 mg/L) among all sites. Median storm flow DOC concentrations ranged from 3.3 mg/L in Green tributary near TPU diversion (A341) to 22.4 mg/L in Newaukum tributary at SE 424th (B322). Newaukum tributary at SE 424th (B322) also exhibited the maximum dissolved organic carbon concentration (54.9 mg/L) during storm flow among all sites.

5.2.2.5 Total Organic Carbon

Total organic carbon (TOC) measures the total amount of organic matter (particulate and dissolved) in water, including organic carbon. TOC affects nutrient cycling, biological

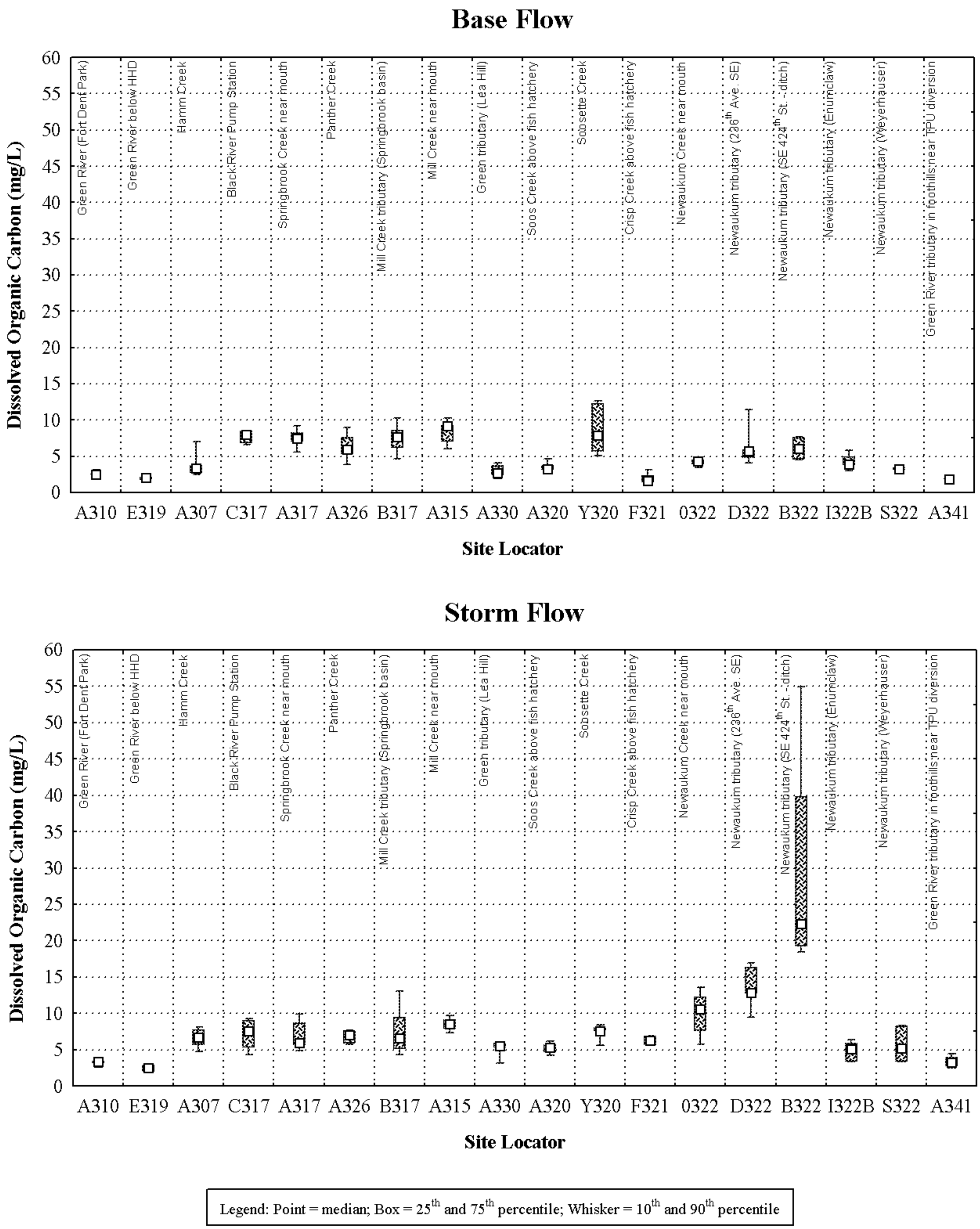

Figure 14. Dissolved organic carbon concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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availability, and chemical transport and interactions. As the amount of organic matter increases in a water body, more oxygen is consumed due to the oxidation of the more labile fractions of TOC by bacteria. Therefore, higher TOC concentrations may result in lower dissolved oxygen concentrations in a water body from this oxidation. Washington State does not have surface water quality criteria for total organic carbon.

Summary statistics for total organic carbon during base and storm flow are presented in Table E5 and Figure 15. Among all sites, base flow TOC concentrations ranged from 1.4 to 15.8 mg/L, and storm flow TOC concentrations ranged from 1.9 to 81.4 mg/L. The median TOC concentration for all the sites combined was higher during storm flow (8.1 mg/L) than during base flow (5.0 mg/L). The median base flow TOC concentration ranged from 1.8 mg/L in Crisp Creek (F321) to 9.9 mg/L in Mill Creek (A315), and the median storm flow TOC concentration ranged from 2.6 mg/L in the Upper Green River (E319) to 25.5 mg/L in the Newaukum tributary at SE 424th (B322).

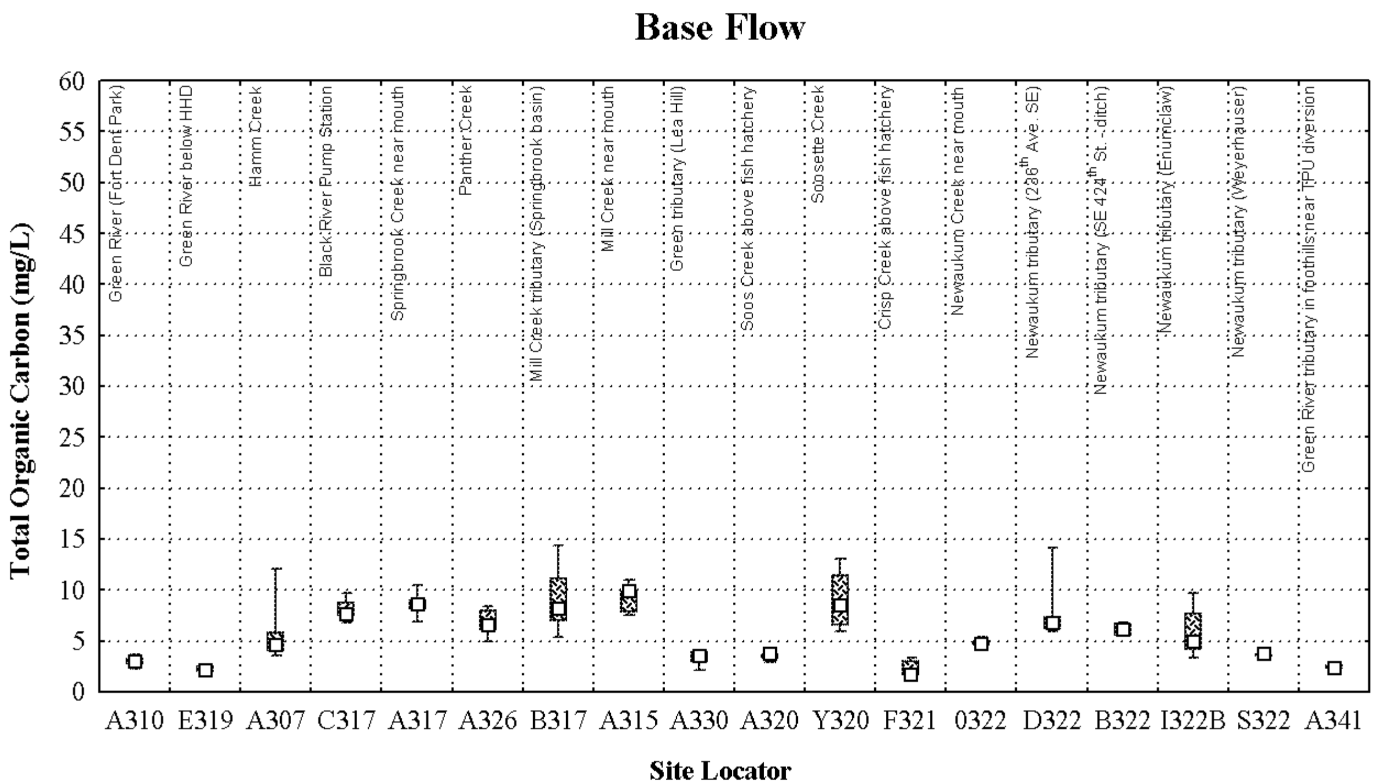
Based on the results of the spatial pattern analysis for the Green River (Table J4), total organic carbon concentrations increased significantly ($p = 0.0008$) between the upper (E319) and lower (A310) sites during base flow sampling. During base flow sampling, the median TOC concentration at the upper and lower sites was 2.2 and 3.0 mg/L, respectively. There were no significant differences in concentrations between these two sites during storm flow.

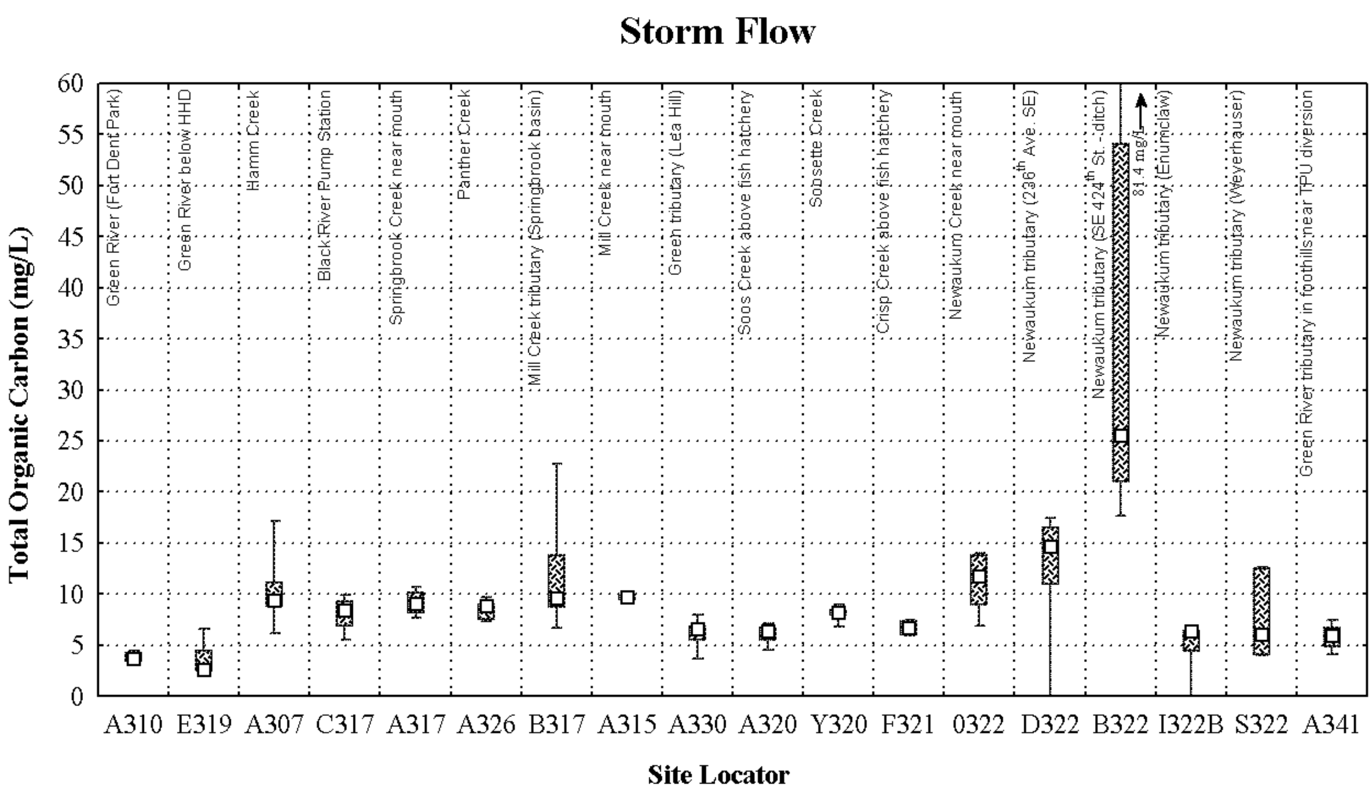
Results from the spatial pattern analysis for the major stream sites (Table J5) showed base flow TOC concentrations were significantly higher ($p = 0.0001$) in Mill Creek (A315) relative to Soos Creek (A320) and Newaukum Creek (0322). Spatial pattern analysis results for storm flow (Table J6) also showed total organic carbon concentrations were significantly higher ($p = 0.0165$) in Newaukum Creek (0322) relative to Soos Creek (A320). Median base flow TOC concentrations ranged from 3.8 mg/L at Soos Creek (A320) to 9.9 mg/L at Newaukum Creek (0322). Median storm flow TOC concentrations ranged from 6.4 mg/L at Soos Creek (A320) to 11.9 mg/L at Newaukum Creek (0322).

Among the tributary sites, median base flow TOC concentrations ranged from 1.8 mg/L in Crisp Creek (F321) to 8.5 mg/L in Soosette Creek (Y320), and median storm flow TOC concentrations ranged from 5.9 mg/L in the Green tributary near TPU diversion (A341) to 25.5 mg/L in Newaukum tributary at SE 424th (B322). Newaukum tributary at SE 424th (B322) also exhibited the maximum storm flow TOC concentration (81.4 mg/L) of all sites.

5.2.2.6 Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of the amount of oxygen required by aerobic biological processes to break down the organic matter in water. Washington State does not have surface water quality criteria for BOD. Very limited BOD data were collected during 2001 and 2002. A total of five BOD samples (only two of which were above the detection limits) were collected from three different sites during base flow, and 13 BOD samples (only seven of which were above the detection limits) were collected from 12 different sites during storm flow. Summary statistics for these data are presented in Table E6. The median base flow BOD





Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 15. Total organic carbon concentrations at sites in the Green/Duwamish watershed in 2001 and 2002.

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concentration for all base flow samples combined was 2.0 mg/L and the median for all storm samples was 8.2 mg/L. Out of all the collected samples, the maximum BOD concentration (44.0 mg/L) was measured during storm flow in the Newaukum tributary at SE 424th (B322). High BOD at this site is likely related to inputs of animal waste from agricultural/pasture land use in the basin.

5.2.2.7 Hardness

Total hardness is defined as the sum of calcium and magnesium concentrations (both expressed as calcium carbonate) in water. Hardness directly affects the toxicity of some heavy metals (i.e., some metals are more toxic at lower levels of hardness, especially divalent metals). Hardness measurements are necessary for determining compliance with state water quality criteria for dissolved cadmium, chromium, copper, lead, nickel, silver, and zinc. Washington State does not have surface water quality criteria for hardness.

Waters with low hardness are referred to as “soft” and waters with a high hardness are referred to as “hard”. The United State Geological Survey (USGS) uses the following numeric ranges (expressed as calcium carbonate) to classify hardness: 0 to 60 mg/L as soft, 61 to 120 mg/L as moderately hard, 121 to 180 mg/L as hard, and greater than 180 as very hard (USGS 2003).

Summary statistics for hardness during base and storm flow are presented in Table E7 and Figure 16. During sampling, total hardness varied from soft to hard. Base flow hardness ranged from 12.9 to 127 mg/L, and storm flow hardness ranged from 10.1 to 113 mg/L. Similar to conductivity and alkalinity, the median hardness for all the sites combined was higher during base flow (61.5 mg/L) than storm flow (39.1 mg/L) and was likely caused by dilution of the groundwater component by surface water runoff to the streams during storm events.

Waters of the Green River were soft during base and storm flow sampling. Results of the spatial patterns analysis (Table J4) showed that the hardness in the Green River increases significantly downstream during both base flow ($p < 0.0001$) and storm flow ($p < 0.0001$). Median hardness increased downstream from 17.6 to 35.3 mg/L during base flow, and increased downstream from 14.7 to 28.5 mg/L during storm flow. The Upper Green River site (E319) had the lowest median hardness of all the sites during base flow (17.6 mg/L) and storm flow (14.7 mg/L).

Among the major streams, the median hardness ranged from 57.5 mg/L in Soos Creek (A320) to 110 mg/L in Springbrook Creek (A317) during base flow, and ranged from 33.7 mg/L in Springbrook Creek (A317) to 52.8 mg/L in Soos Creek (A320) during storm flow. Base flow spatial pattern analysis results (Table J5) show that both Springbrook Creek (A317) and the Black River (C217) are significantly harder ($p < 0.0001$) relative to Soos Creek (A320) or Newaukum Creek (0322). Results of storm flow spatial pattern analysis (Table J6) show that Soos Creek (A320) has significantly higher ($p = 0.0141$) hardness relative to Springbrook Creek (A317).

The median base flow hardness among the tributary sites ranged from 43.0 mg/L in the Newaukum tributary downstream of Weyerhaeuser (S322) to 109.0 mg/L in Hamm Creek

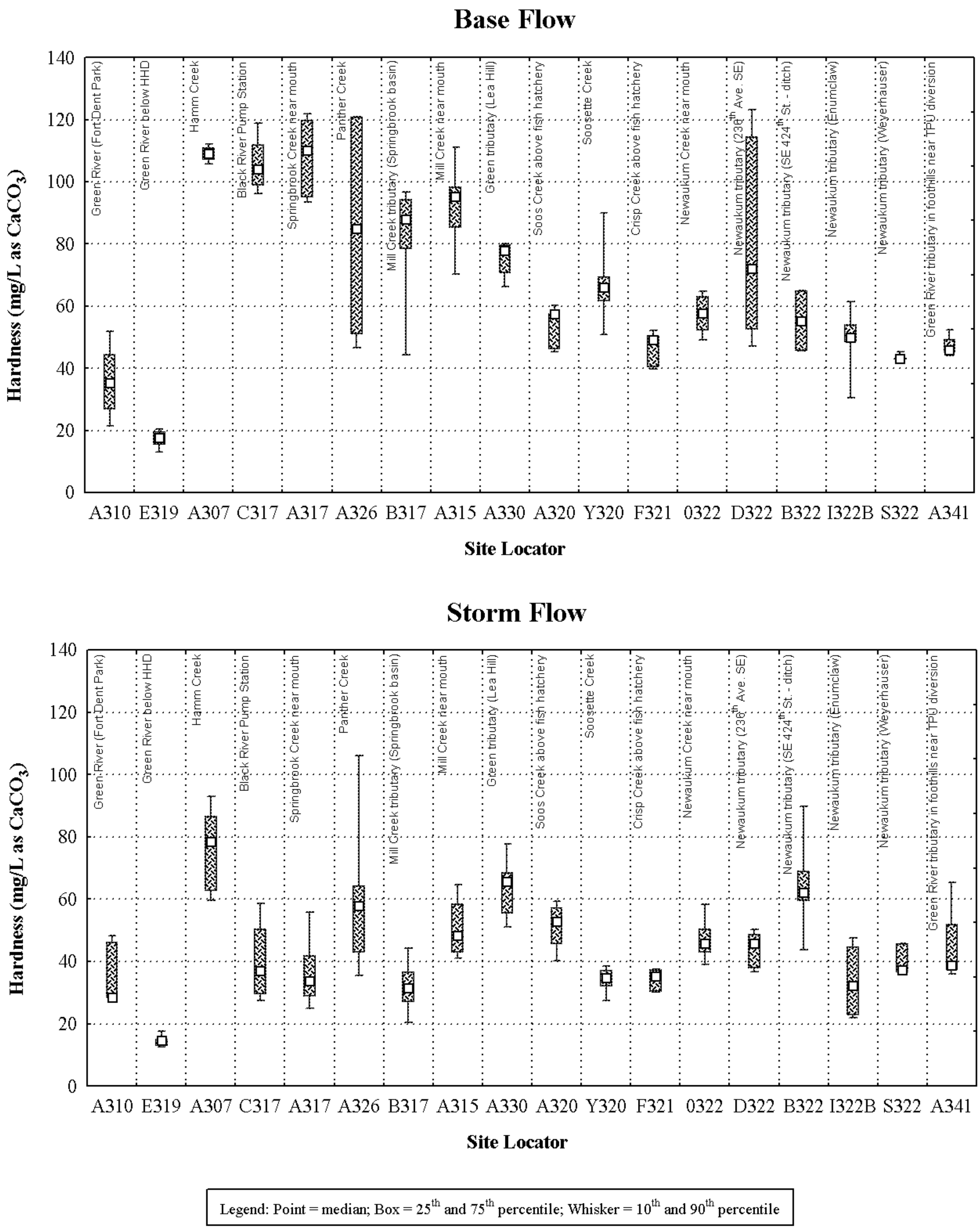

Figure 16. Hardness concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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(A307), and storm flow hardness ranged from 31.5 mg/L in Mill (Springbrook) tributary (B317) to 78.6 mg/L in Hamm Creek (A3 07). Hamm Creek (A307) exhibited the highest median storm flow hardness (78.6 mg/L) and the maximum storm flow hardness (113 mg/L) of all sites.

5.2.3 Microbiology

This section summarizes microbiological parameter data collected in 2001 and 2002 for the GDWQA. Summary statistics for these parameters are presented in Appendix F and results from associated statistical spatial pattern analyses are presented in Appendix J. Microbiological parameters include:

- Fecal coliform bacteria
- Enterococci bacteria
- *E. coli* bacteria.

5.2.3.1 Fecal Coliform Bacteria

Urban runoff characteristically contains elevated levels of fecal coliform bacteria. These organisms are used as indicators of fecal contamination from humans and other warm-blooded animals. Human sources include failing septic systems, municipal wastewater discharges, leaking wastewater conveyance systems or side sewers, and cross-connections with municipal wastewater systems. Animal sources include pets, livestock, and wildlife (e.g., birds and mammals). The simple presence of these bacteria does not necessarily indicate a threat to public health because only a small portion are likely to be pathogenic to humans. However, their use as an “indicator” of potential fecal contamination is considered important in the early detection of problems that could lead to a public health threat. Washington State surface water quality criteria (WAC 173-201A) for fecal coliform bacteria are presented in Table 11. The Lower and Middle Green River, Springbrook Creek, Mill Creek, Soos Creek, Soosette Creek, Newaukum Creek, and Crisp Creek are included on the state’s 1998 303(d) water quality limited list for fecal coliform bacteria.

Summary statistics for fecal coliform bacteria during base and storm flow are presented in Table F1 and Figure 17. Fecal coliform bacteria concentrations ranged from 0 to 9,407 colony forming units (CFU)/100 milliliters (mL) during base flow, and from 0 to 210,000 CFU/100 mL during storm flow. During base flow, the state criteria were exceeded at all sites except the Upper and Lower Green River (E319 and A310), Green tributary at Lea Hill (A330), Soos Creek (A320), Crisp Creek (F321), Newaukum Creek (0322), and Green tributary near TPU diversion (A341). During storm flow, the state criteria were exceeded at all sites except the Upper Green River (E319). The geometric mean for all sites was much higher during storm flow (556 CFU/100 mL) than base flow (55 CFU/100 mL), indicating that storm runoff is a significant source of these bacteria.

The Upper and Lower Green River sites had low to moderate fecal coliform bacteria concentrations during base flow with no exceedances of the state criteria. However, state criteria

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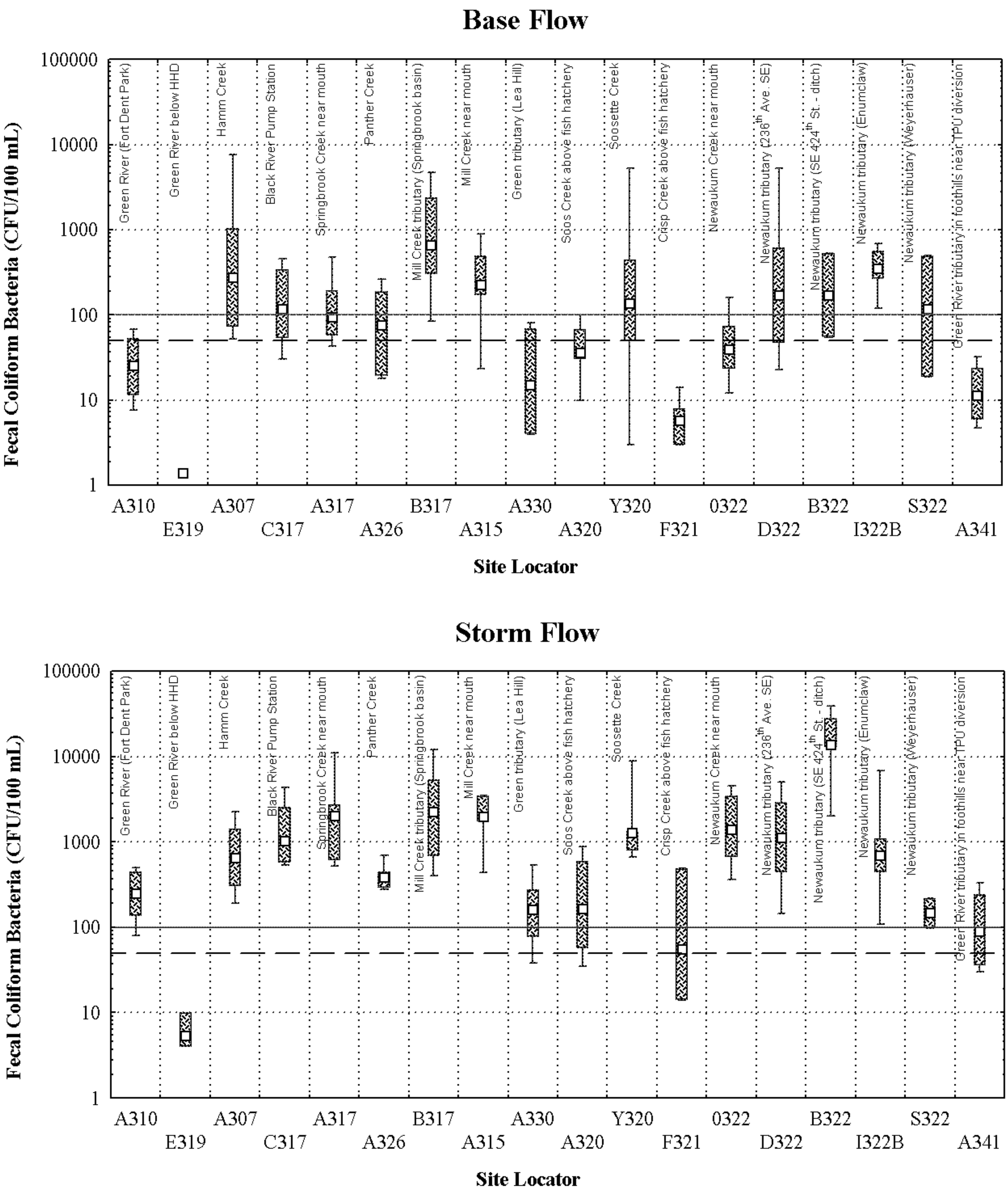

Legend: Point = geometric mean; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile
Dashed line = water quality standard for extraordinary primary contact recreation
Solid line = water quality standard for primary contact recreation

Figure 17. Fecal coliform bacteria concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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were exceeded at the lower site (A310) during storm flow. Spatial pattern analysis results show that fecal coliform bacteria concentrations increase significantly between the upper site (E319) and lower site (A310) during base flow (p = 0.0010) and storm flow (p = 0.0001) (Table J7). Between the upper site (E319) and the lower site (A310), the geometric mean fecal coliform bacteria concentration increased from 1 to 25 CFU/100 mL during base flow, and from 5 to 250 CFU/100 mL during storm flow, respectively.

Spatial pattern analysis results for the five major stream sites showed there were no significant differences in fecal coliform bacteria concentrations during either base flow or storm flow (Tables J8 and J9). Geometric mean base flow fecal coliform bacteria concentrations ranged from 36 CFU/100 mL at Soos Creek (A320) to 228 CFU/100 mL at Mill Creek (A315). Geometric mean storm flow fecal coliform bacteria concentrations ranged from 163 CFU/100 mL at Soos Creek (A320) to 2,263 CFU/100 mL at Mill Creek (A315). The state fecal coliform bacteria criteria were exceeded at Black River (C217), Springbrook Creek (A317), and Mill Creek (A315) during base flow and at all major streams during storm flow.

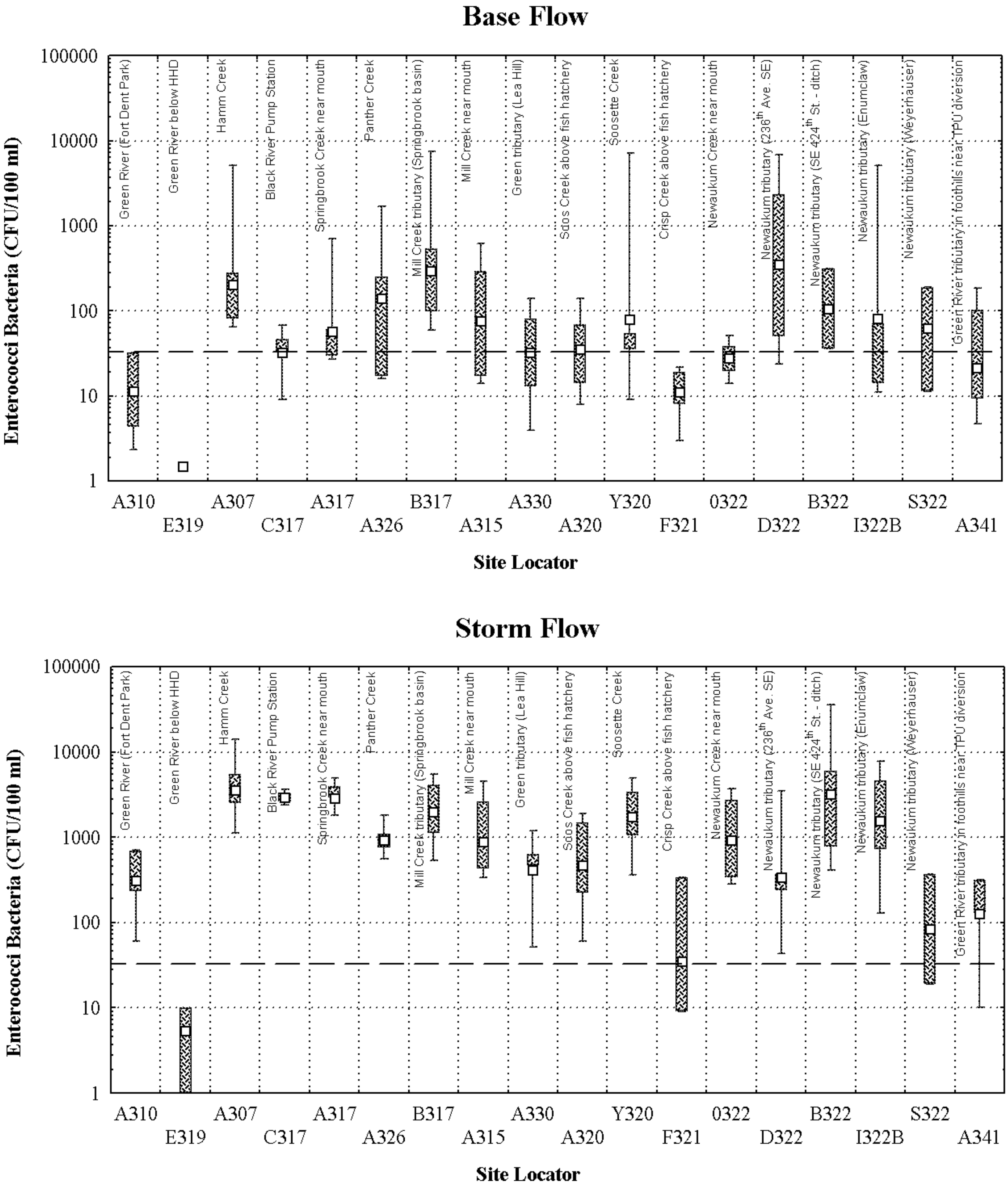
Among the tributaries, geometric mean base flow fecal coliform bacteria concentrations ranged from 6 CFU/100 mL in Crisp Creek (F321) to 662 CFU/100 mL in Mill (Springbrook) tributary (B317). All tributary sites exceeded state criteria during base flow except Green tributary at Lea Hill (A330), Crisp Creek (F321), and Green tributary near TPU diversion (A341).

The tributary storm flow geometric mean fecal coliform bacteria concentrations ranged from 55 CFU/100 mL in Crisp Creek (F321) to 13,858 CFU/100 mL in the Newaukum tributary at SE 424th (B322). All tributary sites exceeded state criteria during storm flow sampling.

5.2.3.2 Enterococci Bacteria

The measurement of enterococci bacteria is used as an indicator to determine the risk to human health in surface waters from the presence of a select sub-group of fecal streptococcus bacteria (*Streptococcus faecalis, S. faecium, S. gallinarum, and S. avium*). And, similar to fecal coliform bacteria, they are attributed to contamination from humans and other warm-blooded animals. Currently, no Washington State surface water quality criteria exist for enterococci bacteria in freshwaters. However, U.S. EPA recommends that states use either enterococci or *E. coli* as the indicator for freshwaters (U.S. EPA 2002b). U.S. EPA water quality criteria for bacteria in bathing (full body contact) recreational waters specify that the geometric mean of enterococci bacteria should not exceed 33 organisms/100 mL during steady-state conditions (U.S. EPA 1986).

Summary statistics for enterococci bacteria during base and storm flow are presented in Table F2 and Figure 18. Base flow enterococci bacteria concentrations ranged from 0 to 8,476 CFU/100 mL, and storm flow concentrations ranged from 0 to 36,000 CFU/100 mL. During base flow, the U.S. EPA criterion was exceeded at all sites except the Upper and Lower Green River (E319 and A310), Black River (C317), Green tributary at Lea Hill (A330), Crisp Creek (F321), Newaukum Creek (0322), and Green tributary near TPU diversion (A341). During storm flow, the U.S. EPA criterion was exceeded at all sites except the Upper Green River (E319). The geometric mean



Legend: Point = geometric mean; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Dashed line = water quality standard

Figure 18. Enteroccoci bacteria concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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for all sites was much higher during storm flow (691 CFU/100 mL) than base flow (45 CFU/100 mL), indicating that storm runoff is a significant source of these bacteria.

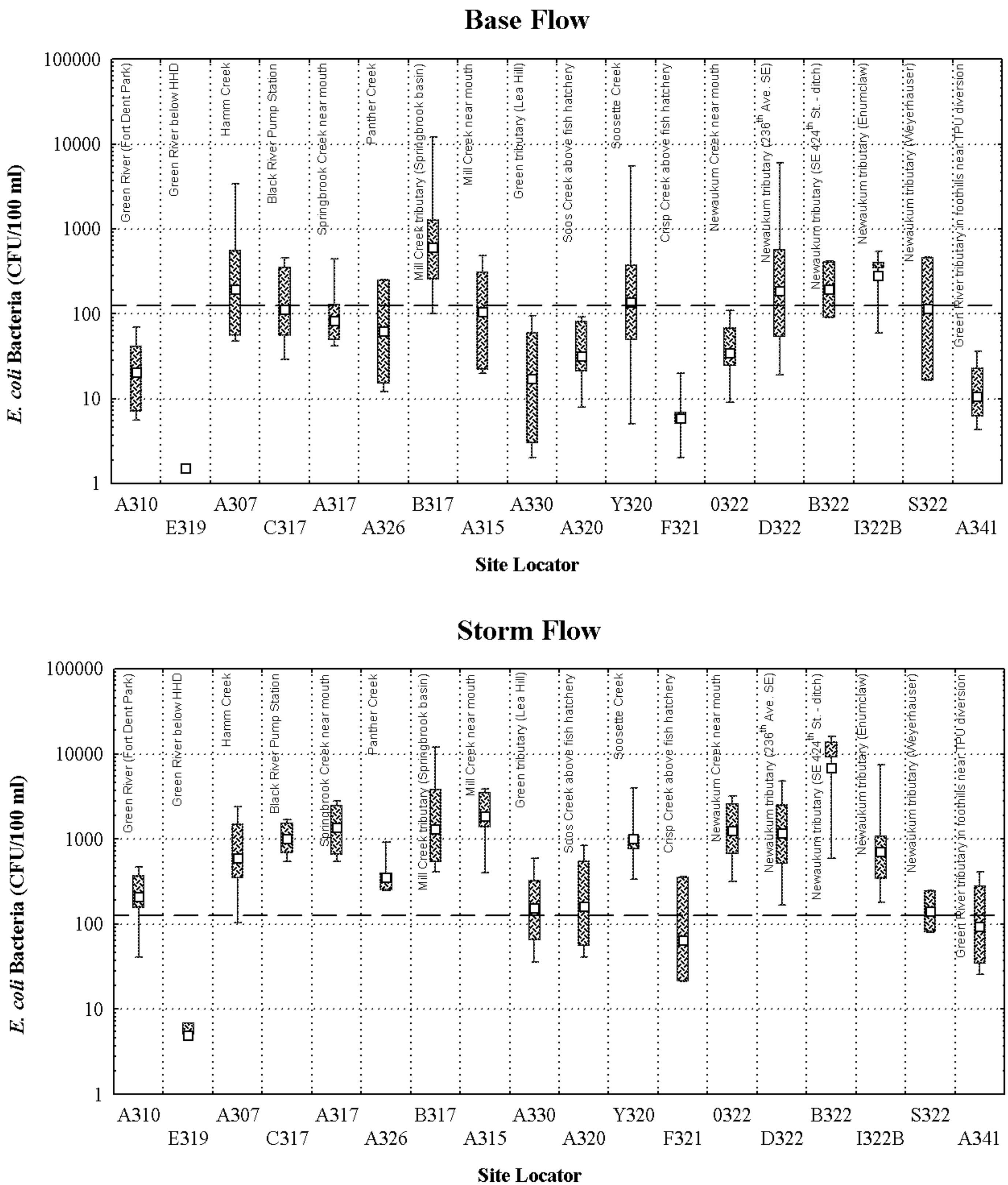
Spatial pattern analysis results for the Green River showed a significant increasing pattern downstream during base flow (p = 0.0020) and storm flow (p = 0.0004) (Table J7). Between the upper site (E319) and the lower site (A310), geometric mean enterococci concentrations increased from 1 to 11 CFU/100 mL during base flow, and from 5 to 312 CFU/100 mL during storm flow. Among the major streams, geometric mean base flow enterococci concentrations ranged from 28 CFU/100 mL in Newaukum Creek (0322) to 76 CFU/100 mL in Mill Creek (A315), and geometric mean storm flow enterococci concentrations ranged from 472 CFU/100 mL in Soos Creek (A320) to 2,943 in Black River (C317). Base flow enterococci bacteria concentrations do not differ significantly between the major streams (Table J8). However, storm flow enterococci concentrations are significantly higher (p = 0.0306) in Springbrook Creek (A317) relative to Soos Creek (A320) (Table J9). The geometric mean storm flow enterococci concentration was 472 CFU/100 mL in Soos Creek (A320) compared to 2,870 CFU/100 mL in Springbrook Creek (A317).

Enterococci concentrations varied widely among the tributary sites. For example, base flow enterococci bacteria concentrations ranged from 3 CFU/100 mL in Crisp Creek (F321) to 8,476 CFU/100 mL in Newaukum at 236th SE tributary (D322), and storm flow concentrations ranged from 9 CFU/100 mL in Crisp Creek (F321) to 36,000 in Newaukum tributary at SE 424th (B322). The Newaukum tributary at 236th SE (D322) exhibited the highest geometric mean concentration (352 CFU/100 mL) of all sites during base flow, but exhibited a similar geometric mean concentration (341 CFU/100 mL) during storm flow. Among the tributary sites, geometric mean enterococci concentrations during storm flow were highest (exceeding 3,000 CFU/100 mL) at Hamm Creek (A307) and the Newaukum tributary at SE 424th (B322).

5.2.3.3 **E. Coli *Bacteria***

A measurement of *Escherichia coli* bacteria is used as an indicator to determine the risk to human health from waterborne illnesses in surface waters from the presence of *E. coli,* a type of fecal coliform bacteria. And, similar to other fecal coliform bacteria and enterococci, these bacteria are attributed to contamination from the intestines of humans and other warm-blooded animals. Currently, no Washington State surface water quality criteria exist for *E. coli* bacteria in freshwaters. However, U.S. EPA recommends that states use either *E. coli* or enterococci as the indicator for freshwaters (U.S. EPA 2002b). U.S. EPA water quality criteria for bacteria in bathing (full body contact) recreational waters specify that the geometric mean of *E. coli* bacteria should not exceed 126 CFU/100 mL during steady-state conditions (U.S. EPA 1986).

Summary statistics for *E. coli* bacteria during base and storm flow are presented in Table F3 and Figure 19. Base flow *E. coli* concentrations ranged from 0 to 12,000 CFU/100 mL, and storm flow concentrations ranged from 0 to 16,000 CFU/100 mL. During base flow, the U.S. EPA criterion was met at all sites except Hamm Creek (A307), Mill (Springbrook) tributary (B317), Soosette Creek (Y320), and Newaukum Creek tributaries (D322, B322, and I322B). During storm flow, the U.S. EPA criterion was exceeded at all sites except the Upper Green River



Legend: Point = geometric mean; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Dashed line = water quality standard

Figure 19. *E. coli* bacteria concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

(E319), Crisp Creek (F321), and Green River tributary (A341). Similar to fecal coliform bacteria and enterococci bacteria, the geometric mean *E. coli* concentration for all the sites was higher during storm flow (471 CFU/100 mL) than during base flow (50 CFU/100 mL).

Spatial pattern analysis results for the Green River showed a significant increasing pattern downstream for *E. coli* bacteria during base flow ($p = 0.0010$) and storm flow ($p = 0.0001$) (Table J7). Between the upper site (E319) and the lower site (A310), geometric mean *E. coli* concentrations increased from 2 to 20 CFU/100 mL during base flow, and from 5 to 211 CFU/100 mL during storm flow.

Spatial pattern analysis results for the major stream sites showed there were no significant differences in *E. coli* bacteria concentrations during base flow or storm flow (Tables J8 and J9). Geometric mean base flow *E. coli* bacteria concentrations ranged from 31 CFU/100 mL in Soos Creek (A320) to 113 CFU/100 mL in Black River (C317). Geometric mean storm flow concentrations ranged from 160 CFU/100 mL in Soos Creek (A320) to 1,841 CFU/100 mL in Mill Creek (A315).

Of the tributary sites, Mill (Springbrook) tributary (B317) had the maximum base flow *E. coli* concentration (12,000 CFU/100 mL) and the highest geometric mean base flow *E. coli* concentration (597 CFU/100 mL). Other tributary sites with elevated base flow *E. coli* concentrations include all the Newaukum Creek tributary sites (D322, B322, I322B, and S322), Soosette Creek (Y320) and Hamm Creek (A307). The lowest geometric mean base flow *E. coli* concentrations among the tributary sites were observed at Crisp Creek (6 CFU/100 mL at F321) and Green tributary near TPU diversion (11 CFU/100 mL at A341). During storm flow, Newaukum tributary at SE 424th (B322) had the highest geometric mean *E. coli* concentration (6,798 CFU/100 mL) and Crisp Creek (F321) had the lowest geometric mean *E. coli* concentration (65 CFU/100 mL) among the tributary sites.

5.2.4 Nutrients

This section summarizes results for nutrients based on the data collected in 2001 and 2002 for the GDWQA. Summary statistics for these parameters are presented in Appendix G and results from associated statistical spatial pattern analyses are presented in Appendix J. Nutrients analyzed for the GDWQA include:

- Ammonia nitrogen
- Nitrate+nitrite nitrogen
- Total nitrogen
- Orthophosphate phosphorus
- Total phosphorus.

5.2.4.1 Ammonia Nitrogen

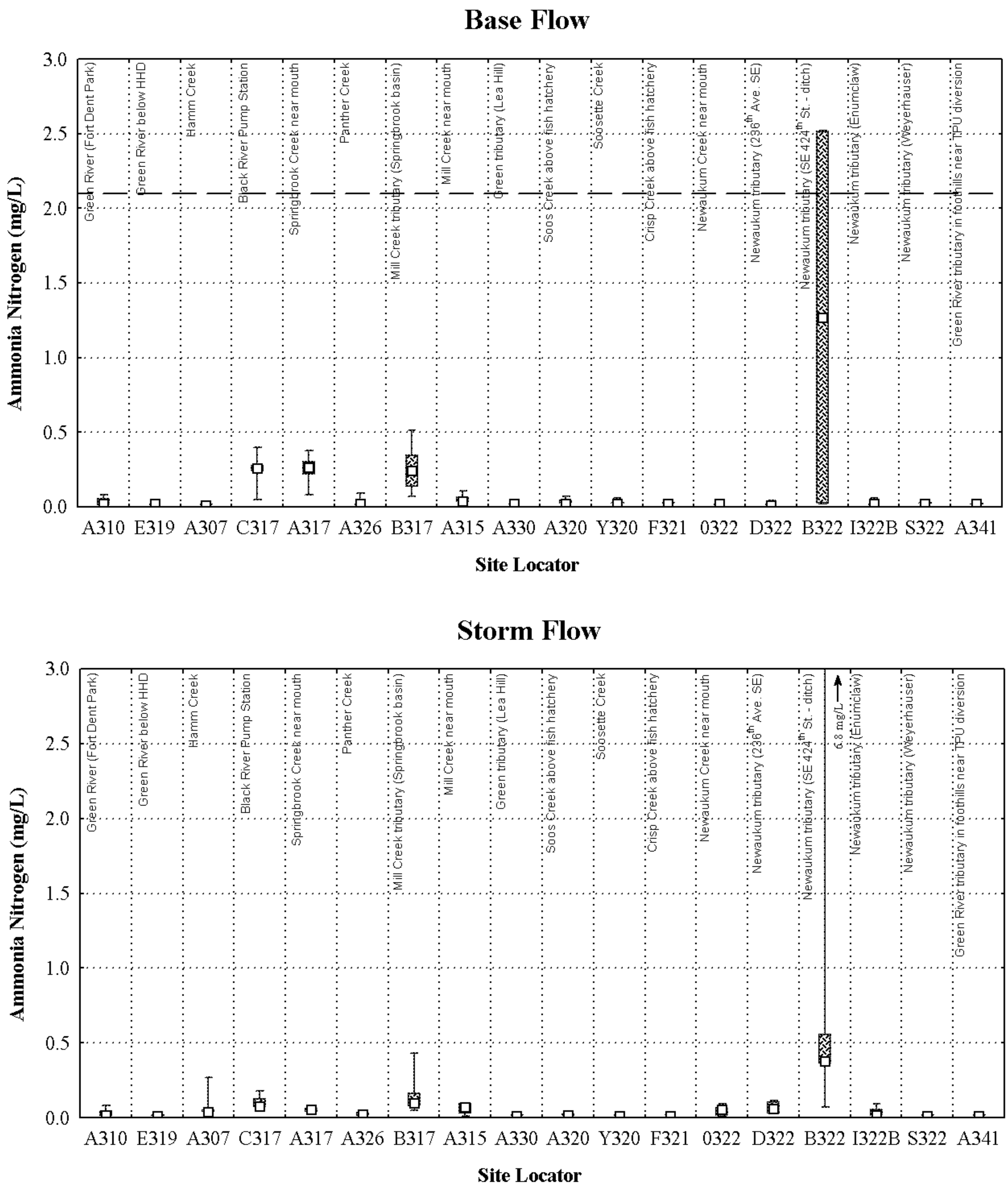
Ammonia nitrogen is of concern in freshwater systems due to its toxicity to aquatic life. Within most freshwater systems ammonia is readily converted to nitrate when oxygen is present. Washington State has surface water quality criteria for chronic and acute ammonia toxicity (WAC 173-201A) that vary depending on the ambient water temperature, pH, and the presence of salmonids (see Table 11). In the following discussion, base flow data are compared to chronic criteria and storm flow data are compared to acute criteria. King County (2000) did not identify ammonia as a possible factor contributing to salmonid decline in Crisp Creek, Newaukum Creek, Soos Creek, Soosette Creek, Mill (Hill) Creek, Springbrook Creek, and the lower and Middle Green River.

Summary statistics for ammonia nitrogen during base and storm flow are presented in Table G1 and Figure 20. Base flow ammonia nitrogen concentrations ranged from below detection (0.01 mg/L) to 2.52 mg/L, and storm flow ammonia nitrogen concentrations ranged from below detection to 6.82 mg/L. The ammonia nitrogen chronic criterion was exceeded on one occasion during base flow for the Newaukum tributary at SE 424th (2.52 mg/L at B322).

In general, ammonia nitrogen concentrations in the Green River are low. The maximum ammonia concentration (0.08 mg/L) was observed at the lower site during both base flow and storm flow. Spatial pattern analysis results for the Green River (Table J10) indicate that there is a significant ($p = 0.0346$) increasing pattern in ammonia concentrations downstream during base flow, but there were no significant differences during storm flow. For both the upper and lower sites, the median ammonia concentration was 0.02 mg/L during base flow and 0.01 mg/L during storm flow.

Among the major stream sites, median base flow ammonia concentrations ranged from 0.02 mg/L in Soos Creek (A320) and Newaukum Creek (0322) to 0.27 mg/L in Springbrook Creek (A317), and median storm flow ammonia concentrations ranged from 0.02 mg/L in Soos Creek (A320) to 0.08 mg/L in the Black River (C317). The spatial pattern analysis results for base flow (Table J11) show that Springbrook Creek (A317) had significantly higher ($p = 0.0001$) ammonia nitrogen concentrations relative to Newaukum Creek (0322) and Soos Creek (A320). During storm flow (Table J12), the Black River (C317) had significantly higher ($p=0.0484$) ammonia nitrogen concentrations relative to Soos Creek (A320).

Among the tributary sites, median ammonia concentrations ranged from 0.01 mg/L in Newaukum tributary at 236th SE (D322) to 1.27 mg/L in Newaukum tributary at SE 424th (B322) during base flow, and ranged from 0.01 mg/L in seven tributaries to 0.38 mg/L in Newaukum tributary at SE 424th (B322) during storm flow. The Newaukum tributary at SE 424th (B322) exhibited the maximum ammonia nitrogen concentration of all sites during base flow (2.52 mg/L) and storm flow (6.82 mg/L). High ammonia nitrogen concentrations at this site are likely related to inputs of animal waste from agricultural/pasture land use in the basin.



Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Dashed line = water quality standard

Figure 20. Ammonia concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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5.2.4.2 Nitrate+nitrite Nitrogen

Washington State does not have surface water quality criteria for nitrate+nitrite nitrogen. However, nitrate nitrogen is a regulated parameter in state ground water standards (WAC 173-200-040) and state drinking water standards (WAC 246-290-310) for protection of human health. To prevent a potentially fatal blood disorder in infants called "blue baby syndrome", both standards specify that nitrate nitrogen concentrations shall not exceed 10 mg/L. Nitrate nitrogen is also a concern in freshwater because it may contribute to the overgrowth of plant life and decline of the biological community. The U.S. EPA (2000) has recommended a nutrient criterion of 0.26 mg/L for nitrate+nitrite nitrogen in Puget Sound lowland rivers and streams that was used for comparison to the sampling results. This criterion represents a reference condition that is equivalent to the median of 25th percentiles for four seasons using all data compiled from up to 129 rivers and streams in the Puget Sound lowlands subecoregion.

Summary statistics for nitrate+nitrite nitrogen during base and storm flow are presented in Table G2 and Figure 21. Base flow nitrate+nitrite concentrations ranged from 0.07 to 6.19 mg/L, and storm flow nitrate+nitrite concentrations ranged from 0.06 to 14.70 mg/L. The U.S. EPA criterion (0.26 mg/L) was exceeded at least once at all sites during both base flow and storm flow, with the exception of the Upper Green River (E319) where samples did not exceed the U.S. EPA criterion during storm flow. The U.S. EPA criterion for nitrate+nitrite nitrogen (0.26 mg/L) was exceeded in all base flow samples at 13 sites and in all storm flow samples at 12 sites (see Table G2), suggesting that nitrate+nitrite nitrogen concentrations were moderate to high at most sites during sampling. The median nitrate+nitrite concentration for all the sites combined was 0.65 mg/L during base flow and 0.70 mg/L during storm flow.

Spatial pattern analysis results show a significant increasing pattern downstream for nitrate+nitrite nitrogen concentrations in the Green River during base flow ($p=0.0012$) and storm flow ($p=0.0040$) (Table J10). Between the upper site (E319) and the lower site (A310), median nitrate+nitrite concentrations increased from 0.08 to 0.37 mg/L during base flow, and from 0.15 to 0.46 mg/L during storm flow.

Among the major stream sites, nitrate+nitrite nitrogen concentrations ranged from 0.71 mg/L in the Black River (C317) to 2.85 mg/L in Newaukum Creek (0322), and storm flow concentrations ranged from 0.64 mg/L in Springbrook Creek (A317) to 3.92 mg/L in Newaukum Creek (0322). Spatial pattern analysis results for the major stream sites show that base flow nitrate+nitrite concentrations were significantly higher ($p < 0.0001$) in Newaukum Creek relative to the Black River (C317), and storm flow nitrate+nitrite concentrations were significantly higher ($p<0.0001$) in Newaukum Creek (0322) relative to Springbrook Creek (A317) and the Black River (C317) (Tables J11 and J12). All samples collected from the major stream sites exceeded the U.S. EPA criterion for nitrate+nitrite nitrogen (0.26 mg/L) during base flow and storm flow.

Among the tributary sites, base flow nitrate+nitrite nitrogen concentrations ranged from 0.15 mg/L in the Newaukum tributary downstream of Weyerhaeuser (S322) to 6.19 mg/L in the Newaukum tributary at SE 424th (B322), and storm flow concentrations ranged from 0.14 mg/L in the Newaukum Creek tributary S322 to 14.70 mg/L in the Newaukum tributary at SE 424th

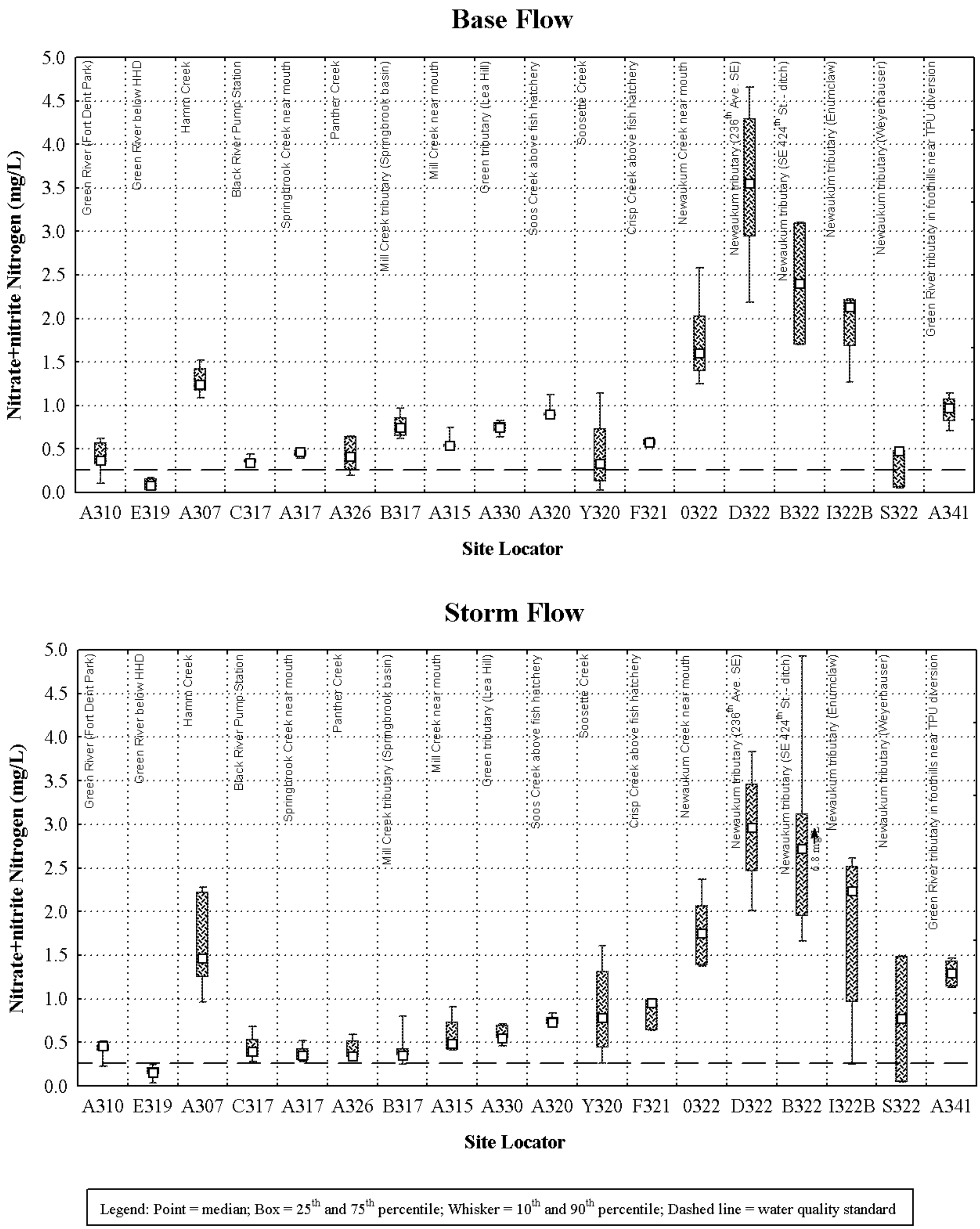

Figure 21. Nitrate+nitrite nitrogen concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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(B322). This maximum concentration exceeds the state drinking water criterion of 10 mg/L established for human health purposes. The U.S. EPA criterion for nitrate+nitrite nitrogen (0.26 mg/L) was exceeded for at least 50 percent of the samples at each site, and was exceeded in all base flow samples at eight sites and in all storm flow samples at 7 sites (see Table G2). High nitrate+nitrite nitrogen concentrations at Newaukum tributary at SE 424th (B322) are likely related to inputs of animal waste from agricultural/pasture land use in the basin.

5.2.4.3 Total Nitrogen

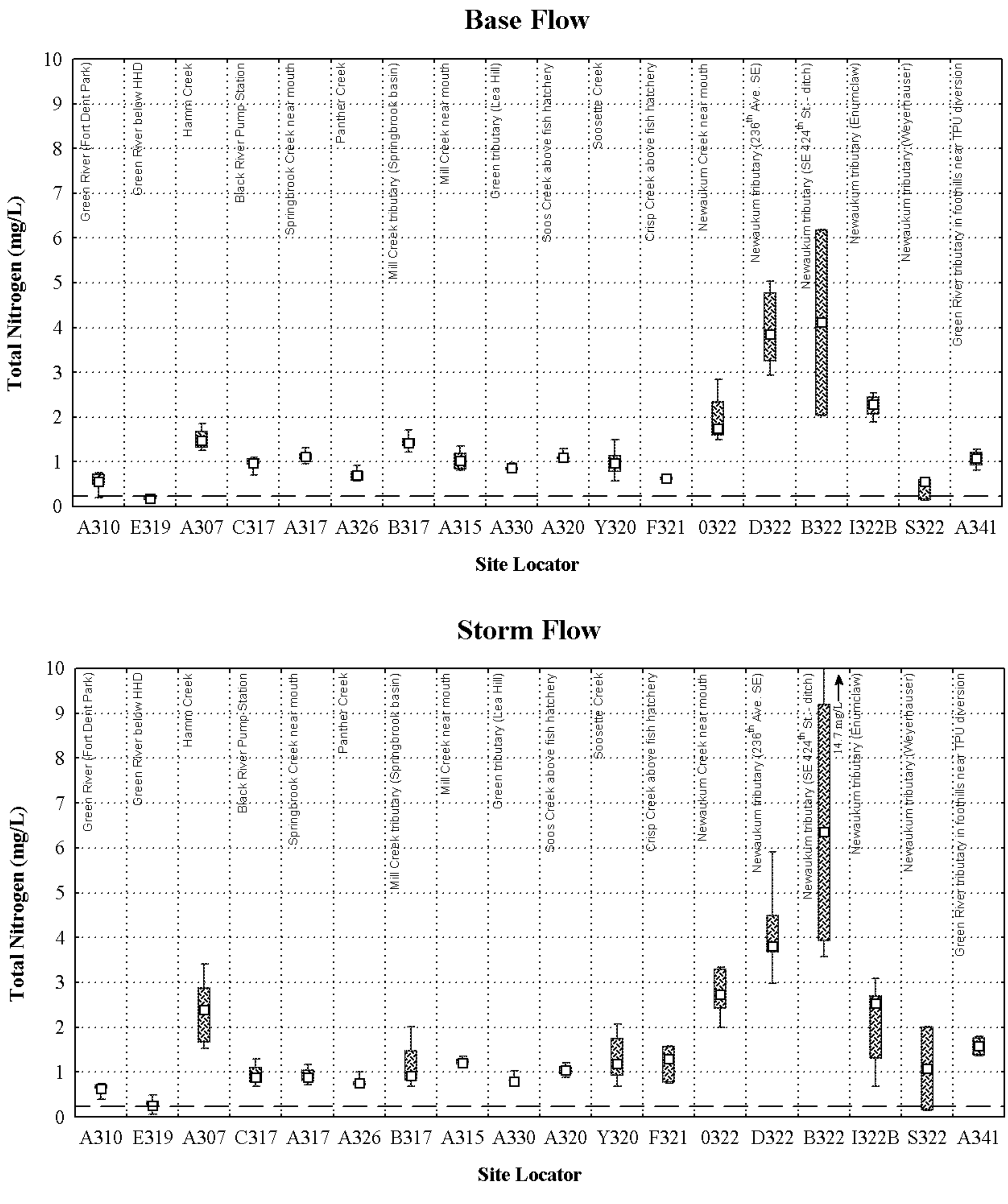
Currently, Washington State does not have surface water quality criteria for total nitrogen. However, the U.S. EPA (2000) has established a nutrient criterion of 0.24 mg/L for total nitrogen in Puget Sound lowland rivers and streams that was used for comparison to the sampling results. This criterion represents a reference condition that is equivalent to the median of 25th percentiles for four seasons using all data from up to 37 rivers and streams in the Puget Sound lowlands subecoregion.

Summary statistics for total nitrogen during base and storm flow are presented in Table G3 and Figure 22. Base flow total nitrogen concentrations ranged from 0.07 to 6.19 mg/L, and storm flow total nitrogen concentrations ranged from 0.06 to 14.70 mg/L. The U.S. EPA criterion for total nitrogen was exceeded at least once at every site during both base flow and storm flow, and was exceeded in all base flow samples at 15 sites and in all storm flow samples at 16 sites (see Table G3). The median total nitrogen concentration for all the sites was 1.07 mg/L during base flow and 1.17 mg/L during storm flow.

Spatial pattern analysis results for the Green River show that total nitrogen concentrations increase significantly downstream during base flow (p=0.0004) and storm flow (p=0.0040) (Table J10). Between the upper site (E319) and the lower site (A310), the median total nitrogen concentration increased from 0.18 to 0.56 mg/L during base flow, and from 0.26 to 0.63 mg/L during storm flow.

Among the major streams, base flow total nitrogen concentrations ranged from 0.71 mg/L in the Black River (C317) to 2.85 mg/L in Newaukum Creek (0322), and storm flow concentrations ranged from 0.64 mg/L in Springbrook Creek (A317) to 3.92 mg/L in Newaukum Creek (0322). Spatial pattern analysis results for the major streams show that total nitrogen concentrations in Newaukum Creek (0322) were significantly higher (p = 0.0008) relative to the Black River (C317) during base flow, and that Newaukum Creek total nitrogen concentrations were significantly higher relative to Springbrook Creek (A317) and the Black River (B317) during storm flow (Tables J11 and J12). All samples collected from the major stream sites exceeded the U.S. EPA criterion for total nitrogen (0.24 mg/L) during base flow and storm flow.

Among the tributary sites, base flow median total nitrogen concentrations ranged from 0.56 mg/L in Newaukum tributary downstream of Weyerhaeuser (S322) to 4.12 mg/L in Newaukum tributary at SE 424th (B322), and storm flow median concentrations ranged from 0.75 mg/L in Panther Creek (A326) to 6.35 mg/L in Newaukum tributary at SE 424th (B322). All samples collected from the tributary sites exceeded the U.S. EPA criterion for total nitrogen (0.24 mg/L)



Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Dashed line = water quality standard

Figure 22. Total nitrogen concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

during base flow and storm flow, with the exception of Newaukum tributary downstream of Weyerhaeuser (S322). As with ammonia nitrogen, the high total nitrogen concentrations for Newaukum tributary at SE 424th (B322) are likely related to agricultural/pasture land use in the basin.

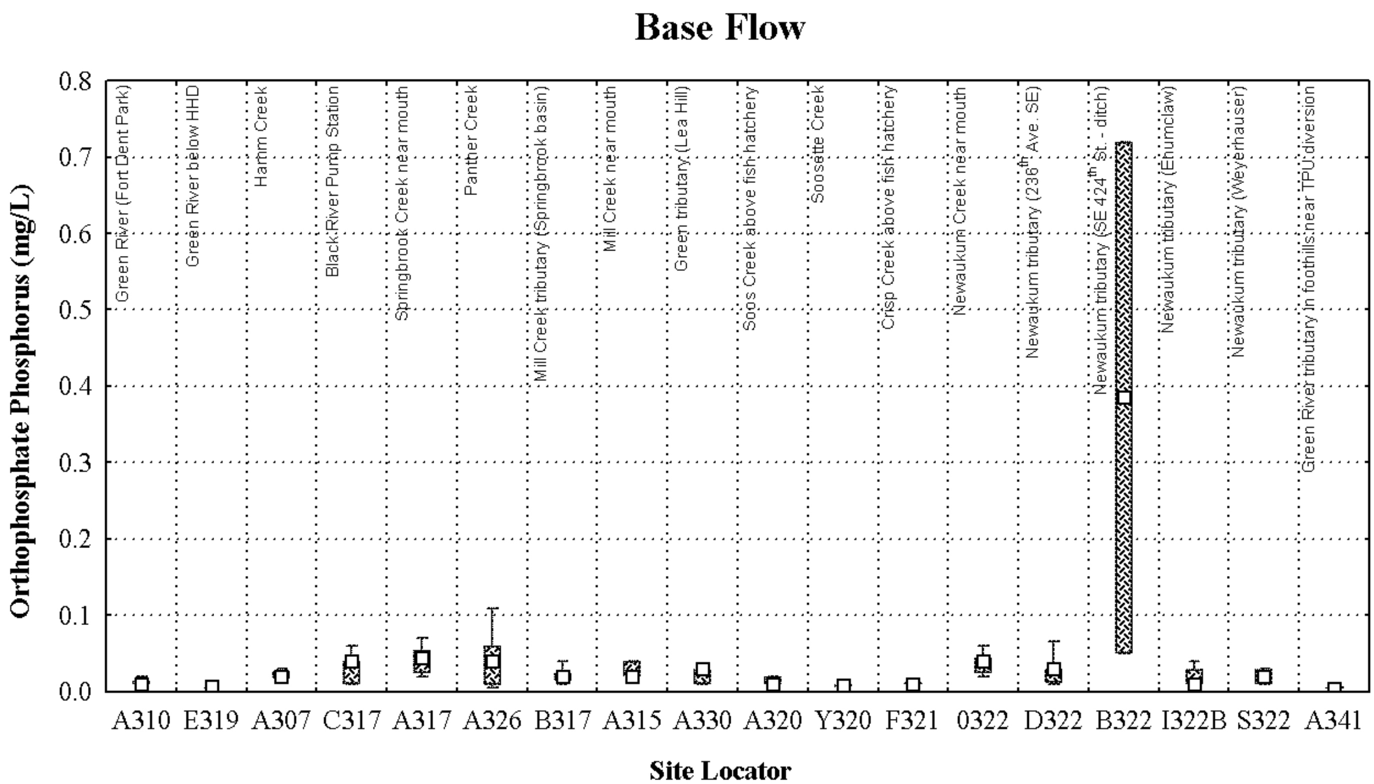
5.2.4.4 Orthophosphate Phosphorus

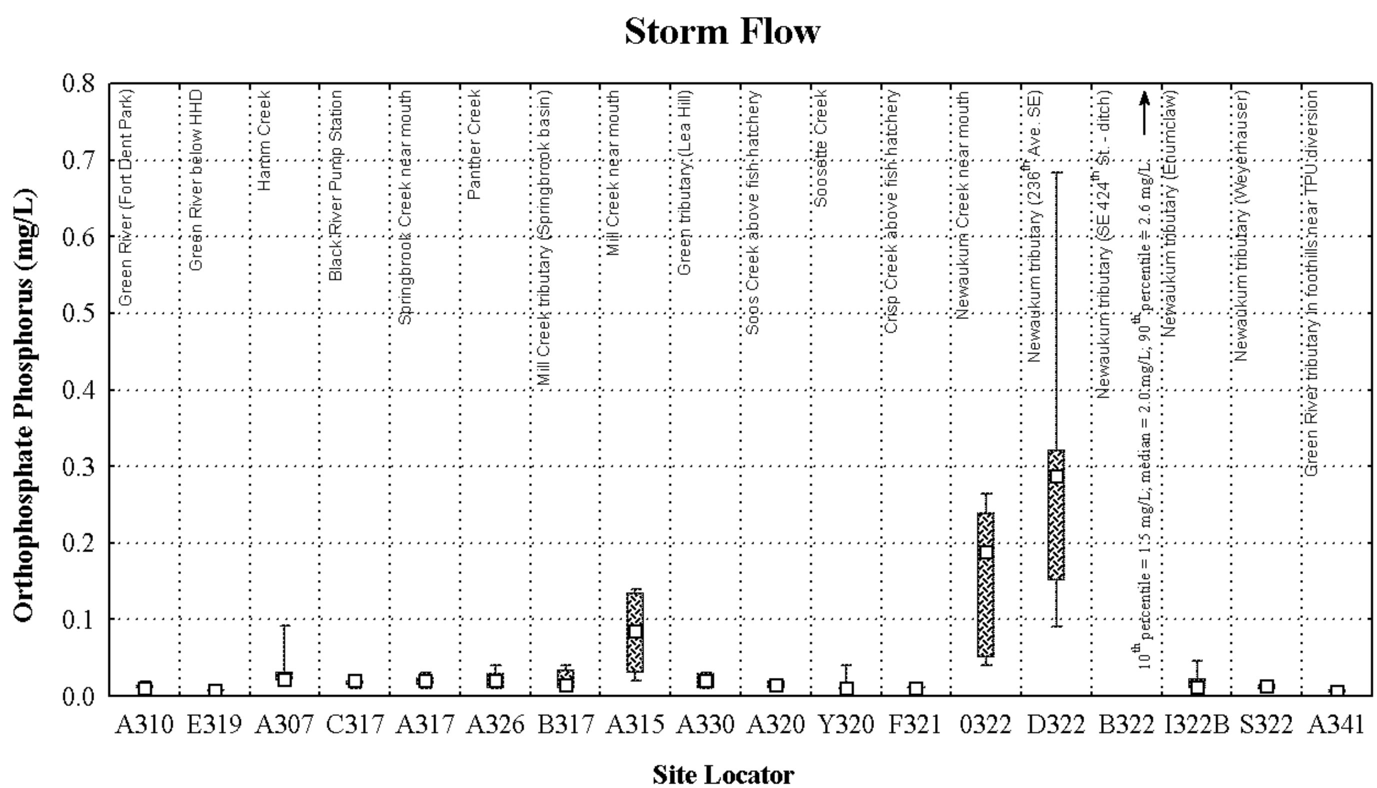
Washington State does not have surface water quality criteria for orthophosphate phosphorus, nor does the U.S. EPA have a criterion for orthophosphate phosphorus in streams and rivers. Summary statistics for orthophosphate phosphorus during base and storm flow are presented in Table G4 and Figure 23. Base flow orthophosphate phosphorus concentrations ranged from 0.002 to 0.720 mg/L, and storm flow concentrations ranged from 0.002 to 2.57 mg/L. The median orthophosphate phosphorus concentration for all the sites combined was 0.020 mg/L during base flow and storm flow. At most sites, orthophosphate phosphorus concentrations were moderately low with the exception of the Newaukum tributary at SE 424th (B322), which had the maximum concentration during both base flow and storm flow (Table G3). Like the other nutrients discussed above, the high orthophosphate phosphorus concentration at this site are likely related to agricultural/pasture land use in this subbasin.

Orthophosphate phosphorus concentrations were generally low in the Green River during base flow and storm flow. Spatial pattern analysis results show that orthophosphate phosphorus concentrations increase significantly downstream during base flow ($p=0.0003$) and storm flow ($p=0.0010$) (Table J10). Between the upper site (E319) and the lower site (A310), median concentrations increased from 0.007 to 0.010 mg/L during both base flow and storm flow.

Among the major streams, base flow orthophosphate phosphorus concentrations ranged from 0.010 mg/L in Soos Creek (A320) and Black River (C317) to 0.070 mg/L in Springbrook Creek (A317), and storm flow concentrations ranged from 0.010 mg/L at three sites (Springbrook Creek [A317], Black River [C317], and Soos Creek [A320]) to 0.270 mg/L in Newaukum Creek (0322). The spatial pattern analyses results show that base flow orthophosphate phosphorus concentrations are significantly higher ($p = 0.0357$) in Springbrook Creek (A317) relative to Soos Creek (A320), and storm flow orthophosphate phosphorus concentrations in Newaukum Creek (0322) are significantly higher ($p=0.0001$) relative to Springbrook Creek (A317), Black River (C317) and Soos Creek (A320) (Tables J11 and J12).

Among the tributaries, median base flow orthophosphate phosphorus concentrations ranged from 0.005 mg/L in the Green tributary near TPU diversion (A341) to 0.385 mg/L in the Newaukum tributary at SE 424th (B322), and median storm flow concentrations ranged from 0.007 mg/L in the Green tributary near TPU diversion (A341) to 2.020 mg/L in the Newaukum tributary at SE 424th (B322). Newaukum tributary at SE 424th (B322) exhibited the maximum orthophosphate phosphorus concentrations of all sampling sites during base flow (0.720 mg/L) and storm flow (2.57 mg/L).





Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 23. Orthophosphate phosphorus concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

5.2.4.5 Total Phosphorus

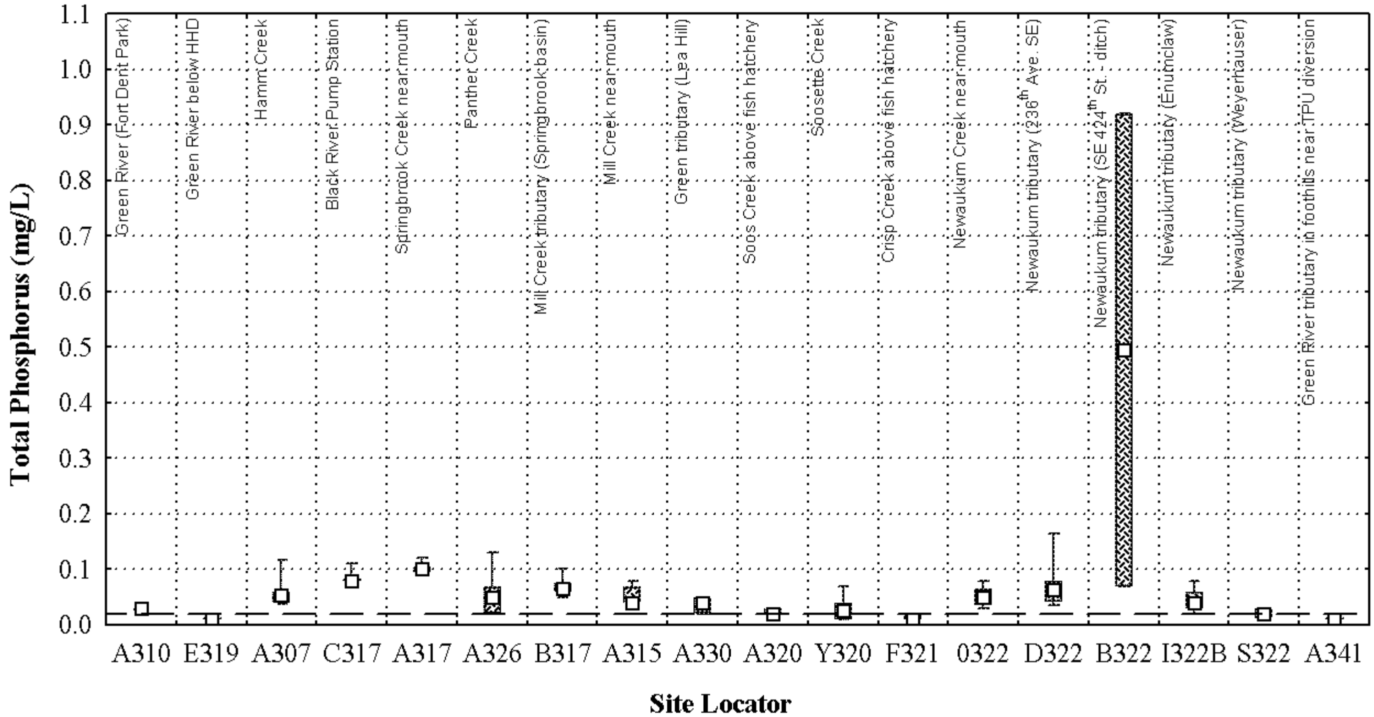
Total phosphorus is a concern in freshwater because it can contribute to hypereutrophication. Currently, Washington State does not have surface water quality criteria for total phosphorus in rivers and streams; however, state criteria have been established for lakes. The U.S. EPA (2000) has established a total phosphorus criterion of 0.0195 mg/L for Puget Sound lowland rivers and streams that was used for comparison to the sampling results. This criterion represents a reference condition that is based on the 25th percentile of all data compiled for the Puget Sound lowland ecoregion.

Summary statistics for total phosphorus during base and storm flow are presented in Table G5 and Figure 24. Base flow total phosphorus concentrations ranged from 0.010 to 0.920 mg/L, and storm flow total phosphorus concentrations ranged from 0.010 to 3.350 mg/L. All sites exceeded the U.S. EPA total phosphorus criterion (0.0195 mg/L) at least once during both base flow and storm flow with the exception of the Green tributary near TPU diversion (A341), which did not exceed the criterion during base flow. The median total phosphorus concentration for all sites combined was lower during base flow (0.040 mg/L) than storm flow (0.080 mg/L).

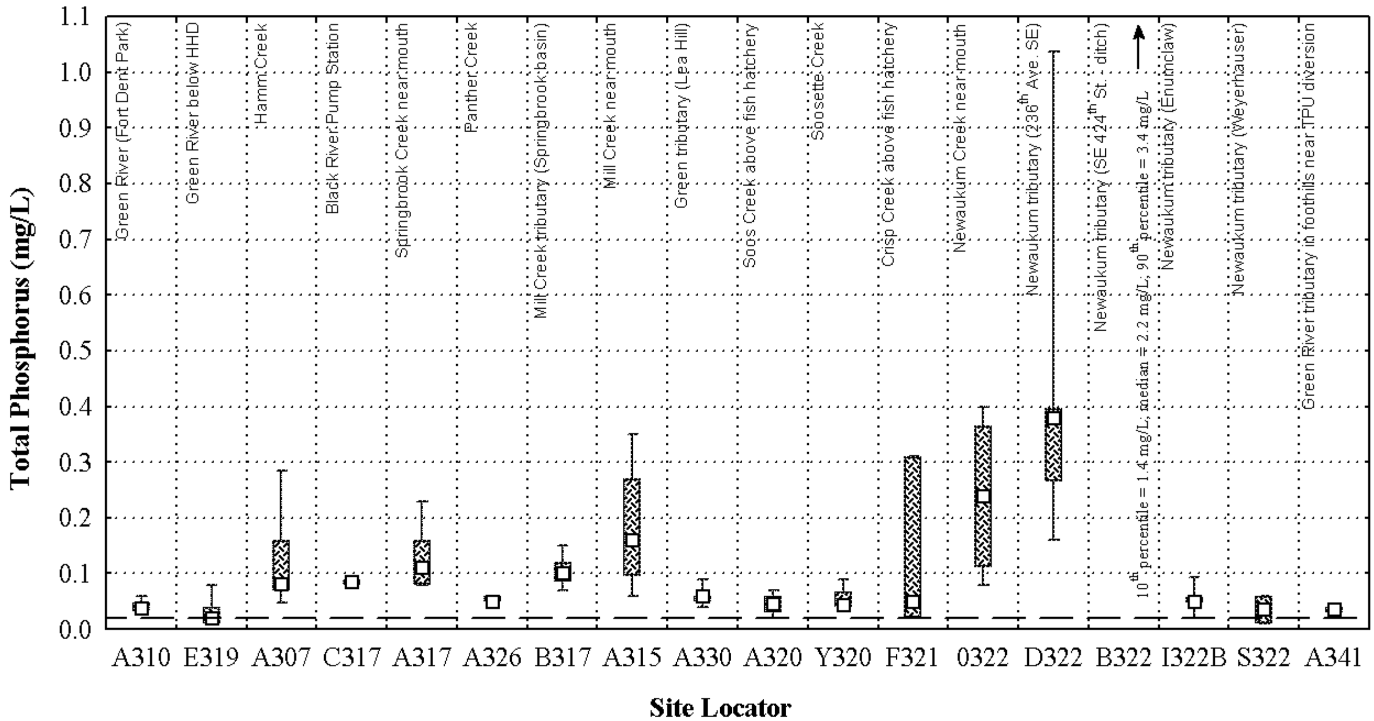
Spatial pattern analysis results for the Green River show a significant increasing pattern downstream for that total phosphorus concentrations during base flow (p=0.0001), but not during storm flow (Table J10). Between the upper site (E319) and the lower site (A310), median total phosphorus concentrations increased from 0.010 to 0.030 mg/L during base flow, and increased from 0.020 and 0.038 mg/L during storm flow. Among the major stream sites, base flow total phosphorus concentrations ranged from 0.020 mg/L in Soos Creek (A320) to 0.120 mg/L in Springbrook Creek (A317), and storm flow concentrations ranged from 0.020 mg/L (Soos Creek) to 0.483 mg/L in Newaukum Creek (0322). Spatial pattern analysis results show that Springbrook Creek (A317) has significantly higher (p=0.0001) total phosphorus concentrations relative to Soos Creek (A320) and Newaukum Creek (0322) during base flow; and that Newaukum Creek has significantly higher (p=0.0078) total phosphorus concentrations relative to Soos Creek (A320) during storm flow (Tables J11 and J12). Median base flow concentrations ranged from 0.020 mg/L in Soos Creek (A320) to 0.100 mg/L in Springbrook Creek (A317), and median storm flow concentrations ranged from 0.045 mg/L in Soos Creek (A320) to 0.240 mg/L in Newaukum Creek (0322). All base and storm flow samples collected at the major stream sites exceeded the U.S. EPA criterion of 0.0195 mg/L.

Among the tributary sites, base flow median total phosphorus concentrations ranged from 0.010 mg/L in Crisp Creek (F321) and the Green tributary near TPU diversion (A341) to 0.495 mg/L in the Newaukum tributary at SE 424th (B322), and storm flow median concentrations ranged from 0.035 mg/L in the Newaukum tributary downstream of Weyerhaeuser (S322) and the Green tributary near TPU diversion (A341) to 2.220 mg/L in the Newaukum tributary at SE 424th (B322). Newaukum tributary at SE 424th (B322) exhibited the maximum total phosphorus concentration during base flow (0.920 mg/L) and storm flow (3.350 mg/L) of all the sites. Seven tributary sites exceeded the U.S. EPA criterion 100 percent of the time during base flow sampling (see Table G5). All but one tributary site (Newaukum Creek tributary S322) exceeded the U.S. EPA criterion 100 percent of the time during storm flow.

Base Flow



Storm Flow



Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Dashed line = water quality standard

Figure 24. Total phosphorus concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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5.2.5 Metals

This section summarizes results for metals based on the data collected in 2001 and 2002 for the GDWQA. Summary statistics for these parameters are presented in Appendix H and results from associated statistical spatial pattern analyses are presented in Appendix J. Metals analyzed for the GDWQA include:

- Aluminum
- Arsenic
- Cadmium
- Calcium
- Chromium
- Copper
- Iron
- Lead
- Magnesium
- Manganese
- Mercury
- Nickel
- Potassium
- Selenium
- Silver
- Sodium
- Zinc.

5.2.5.1 Aluminum

Summary statistics for dissolved aluminum during base and storm flow are presented in Table H1 and Figure 25. Summary statistics for total aluminum during base and storm flow are presented in Table H2 and Figure 26. Aluminum is not included in the Washington State surface water quality standards (WAC 173-201A). However, the U.S. EPA (2002a) has established surface water quality criteria for total aluminum that include an acute criterion of 0.750 mg/L and a chronic criterion of 0.087 mg/L (see Table 12), which were used for comparison to storm flow and base flow results, respectively. It is important to recognize that EPA acknowledges that these criteria may be overprotective because the digestion procedure for analyzing total aluminum includes some aluminum that is not toxic and would not likely be converted to a toxic form under natural conditions (U.S. EPA 1988).

Dissolved aluminum concentrations ranged from less than 0.002 to 0.040 mg/L during base flow, and from less than 0.002 to 0.120 mg/L during storm flow. Total aluminum concentrations ranged from 0.010 to 1.39 mg/L during base flow, and from 0.010 to 19.8 mg/L during storm flow. During base flow sampling, the chronic criterion for total aluminum was exceeded in all samples from the Green tributary at Lea Hill (A330) and the Green tributary near TPU diversion (A341), but was never exceeded at Crisp Creek (F321) or the Newaukum tributary downstream of Weyerhaeuser (S322). During storm flow sampling, the acute criterion was always exceeded on at least one occasion at all sites except Soos Creek (A320). The median total aluminum concentration for all sites combined was higher during storm flow (0.550 mg/L) than during base flow (0.090 mg/L).

Spatial pattern analysis results for the Green River show that dissolved aluminum concentrations significantly ($p = 0.0159$) decreased from the Upper Green (E319) to the Lower Green (A310) during storm flow, but not during base flow (Table J13). Conversely, total aluminum concentrations significantly ($p = 0.0373$) increased from the upper to lower site during base flow,

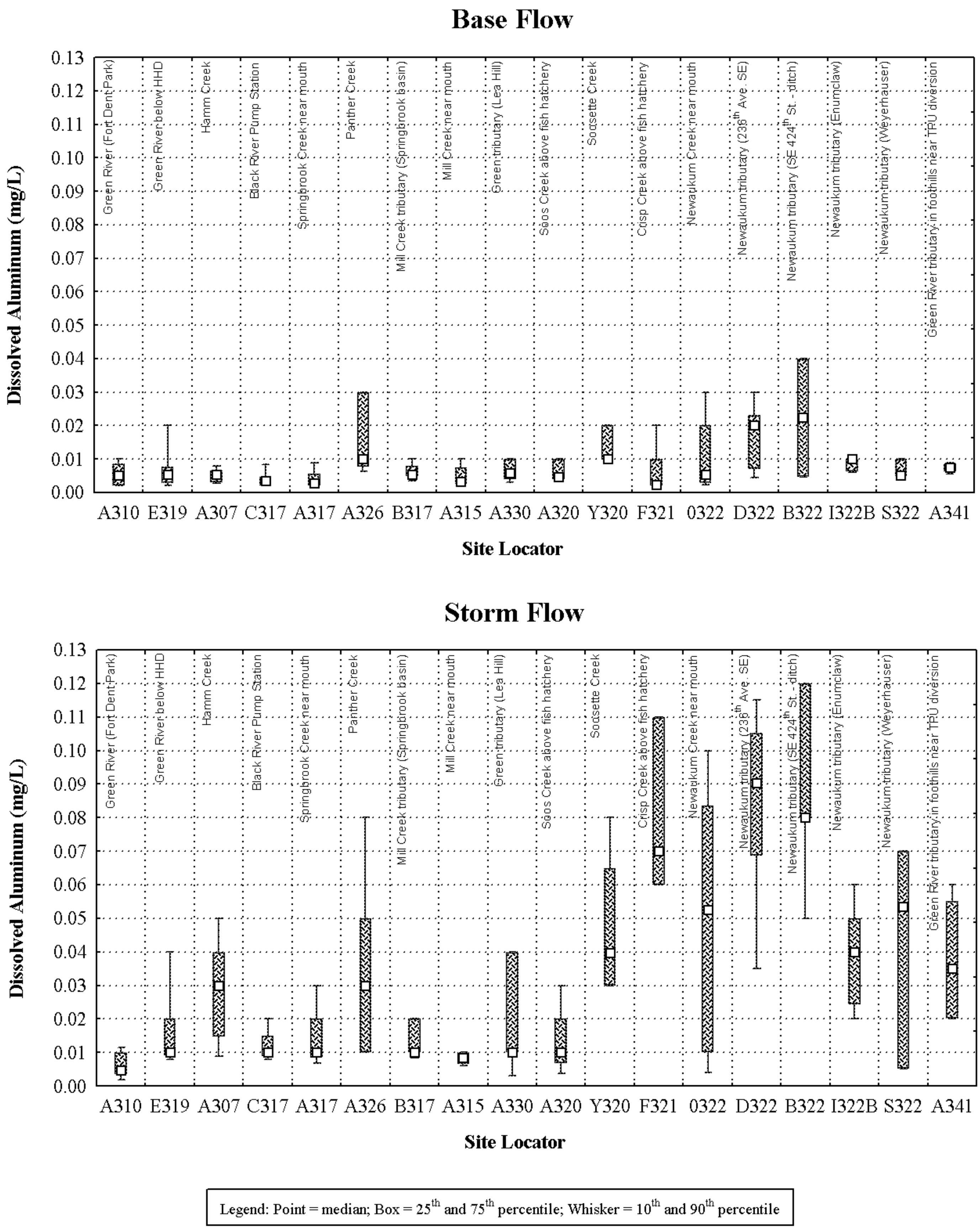

Figure 25. Dissolved aluminum concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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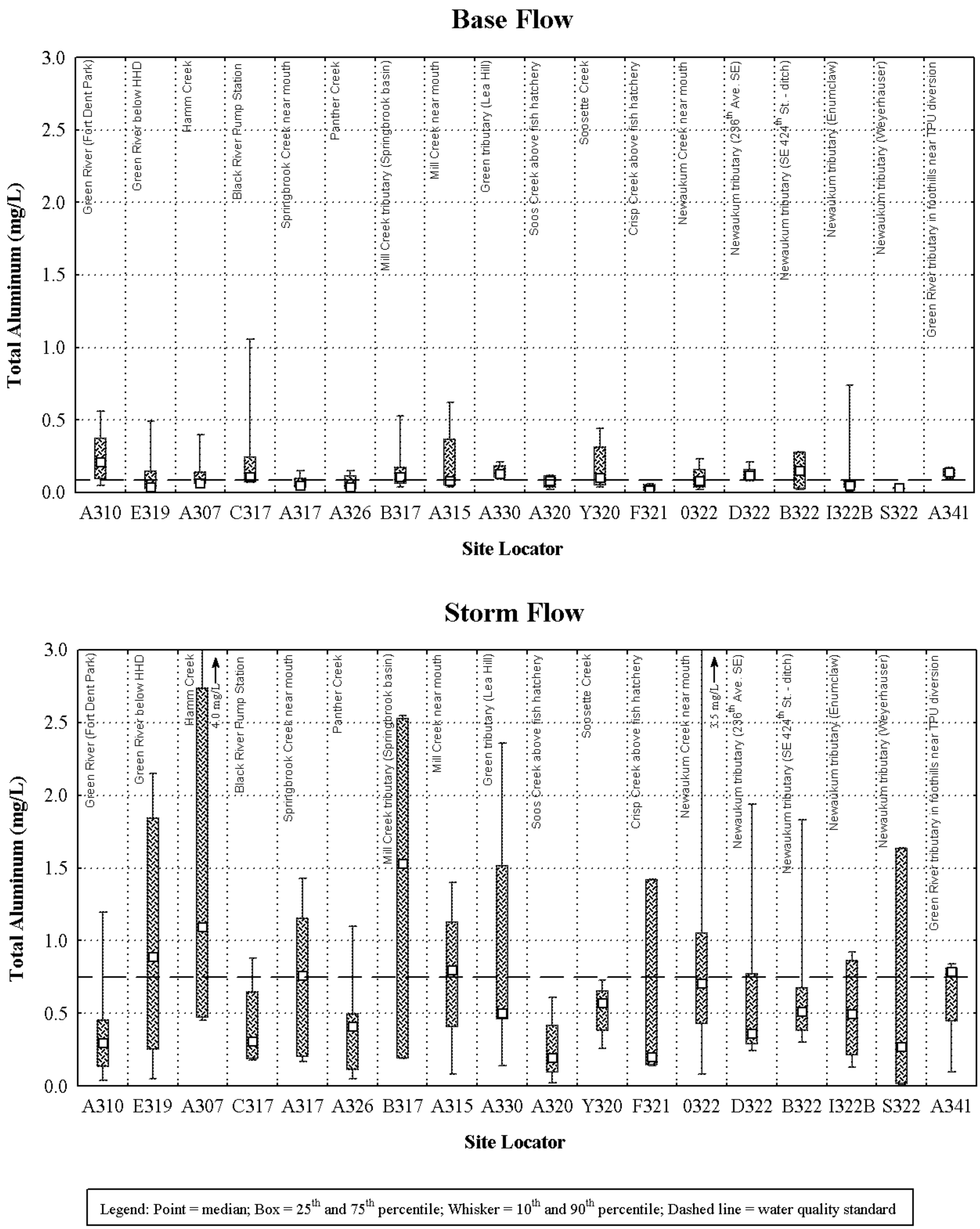

Figure 26. Total aluminum concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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but not during storm flow. From the Upper Green (E319) and Lower Green (A310), median dissolved aluminum concentrations decreased from 0.010 and 0.005 mg/L during storm flow, and median total aluminum concentrations increased from 0.040 to 0.212 mg/L during base flow. Among all sites, the Lower Green (A310) exhibited the maximum base flow total aluminum concentration (1.39 mg/L) and the highest median base flow total aluminum concentration (0.212 mg/L).

Among the major stream sites, there were no significant differences in total or dissolved aluminum concentrations during either base flow or storm flow (Tables J14 and J15). Among the tributary sites, median dissolved aluminum concentrations were highest during storm flow at two Newaukum tributaries (D322 and B322) and Crisp Creek (F321), and median total aluminum concentrations were highest during storm flow at Mill (Springbrook) tributary (B317) and Hamm Creek (A307).

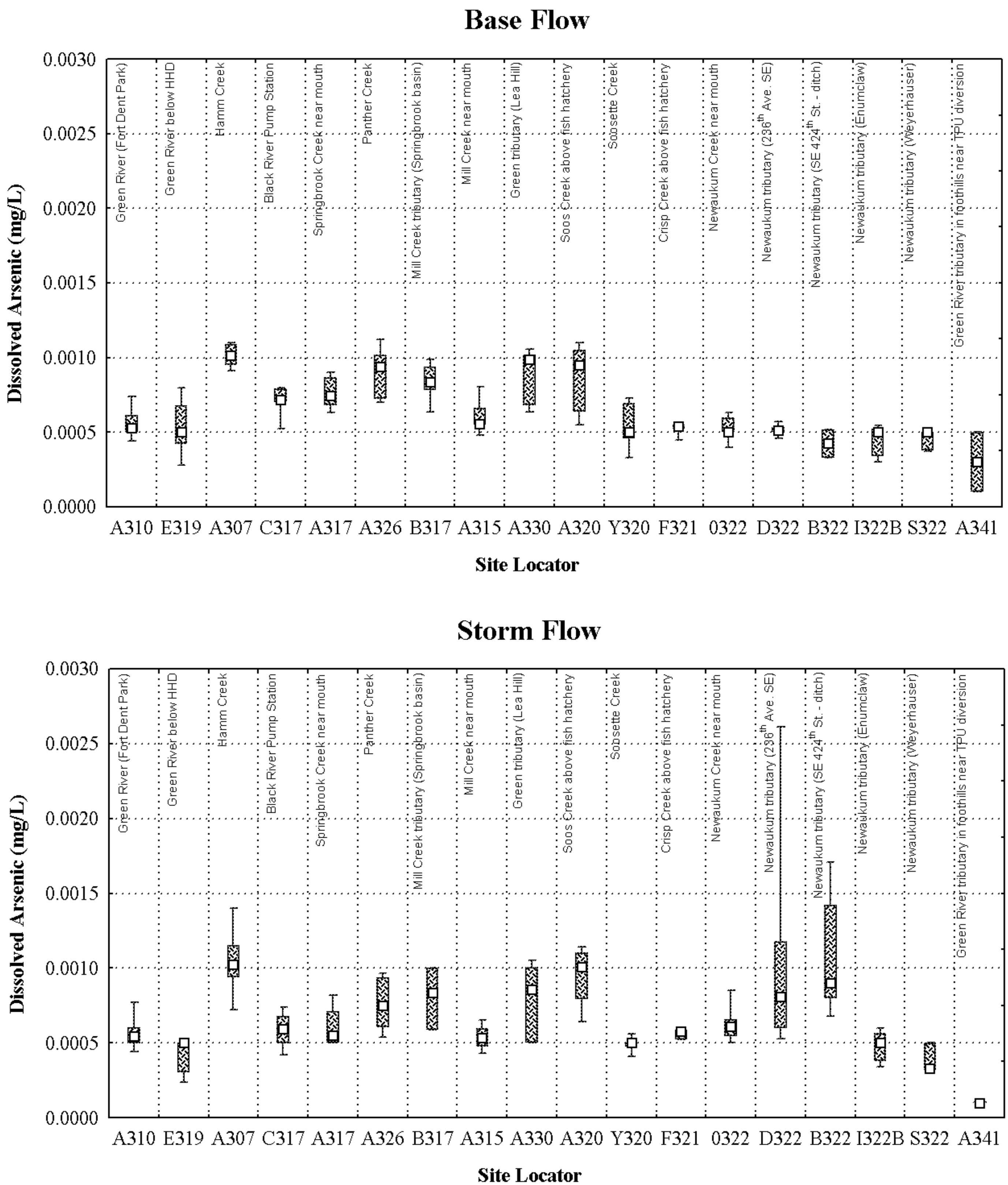
5.2.5.2 Arsenic

Summary statistics for dissolved arsenic during base and storm flow are presented in Table H3 and Figure 27. Summary statistics for total arsenic during base and storm flow are presented in Table H4 and Figure 28. Washington State surface water quality standards (WAC 173-201A) for arsenic include an acute criterion of 0.360 mg/L and a chronic criterion of 0.190 mg/L for dissolved arsenic that were used for comparison to storm flow and base flow results, respectively (Table 11). Dissolved arsenic concentrations did not exceed the criteria at any site during either base flow or storm flow.

Dissolved arsenic concentrations ranged from less than 0.00010 to 0.00112 mg/L during base flow, and ranged from less than 0.00010 to 0.00303 mg/L during storm flow. Total arsenic concentrations ranged from less than 0.0001 to 0.0020 mg/L during base flow, and ranged from 0.0001 to 0.0100 mg/L during storm flow. The median total arsenic concentration for all sites combined was slightly higher during storm flow (0.00085 mg/L) than during base flow (0.00073 mg/L).

Spatial pattern analysis results for the Green River showed a significant ($p = 0.0126$) increase in dissolved arsenic from the upper to lower sites during storm flow, but not during base flow. (Table J13) Median dissolved arsenic concentrations for the upper (E319) and lower (A310) sites were 0.00050 and 0.00054 mg/L, respectively, during storm flow. Total arsenic concentrations showed a significant increasing pattern downstream during base flow ($p = 0.0421$) and storm flow ($p = 0.0034$). The median total arsenic concentration increased downstream from 0.00050 to 0.00072 mg/L during base flow, and from 0.00050 to 0.00077 mg/L during storm flow.

Results of the spatial pattern analysis for the major stream sites (Tables J14 and J15) showed that Springbrook Creek (A317) and Soos Creek (A320) had significantly higher ($p = 0.0002$) dissolved arsenic concentrations relative to Newaukum Creek (0322) during base flow, but dissolved arsenic concentrations did not differ significantly among the major streams during storm flow. Total arsenic concentrations were significantly higher ($p < 0.0001$) at the Black



Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Water quality standard off scale

Figure 27. Dissolved arsenic concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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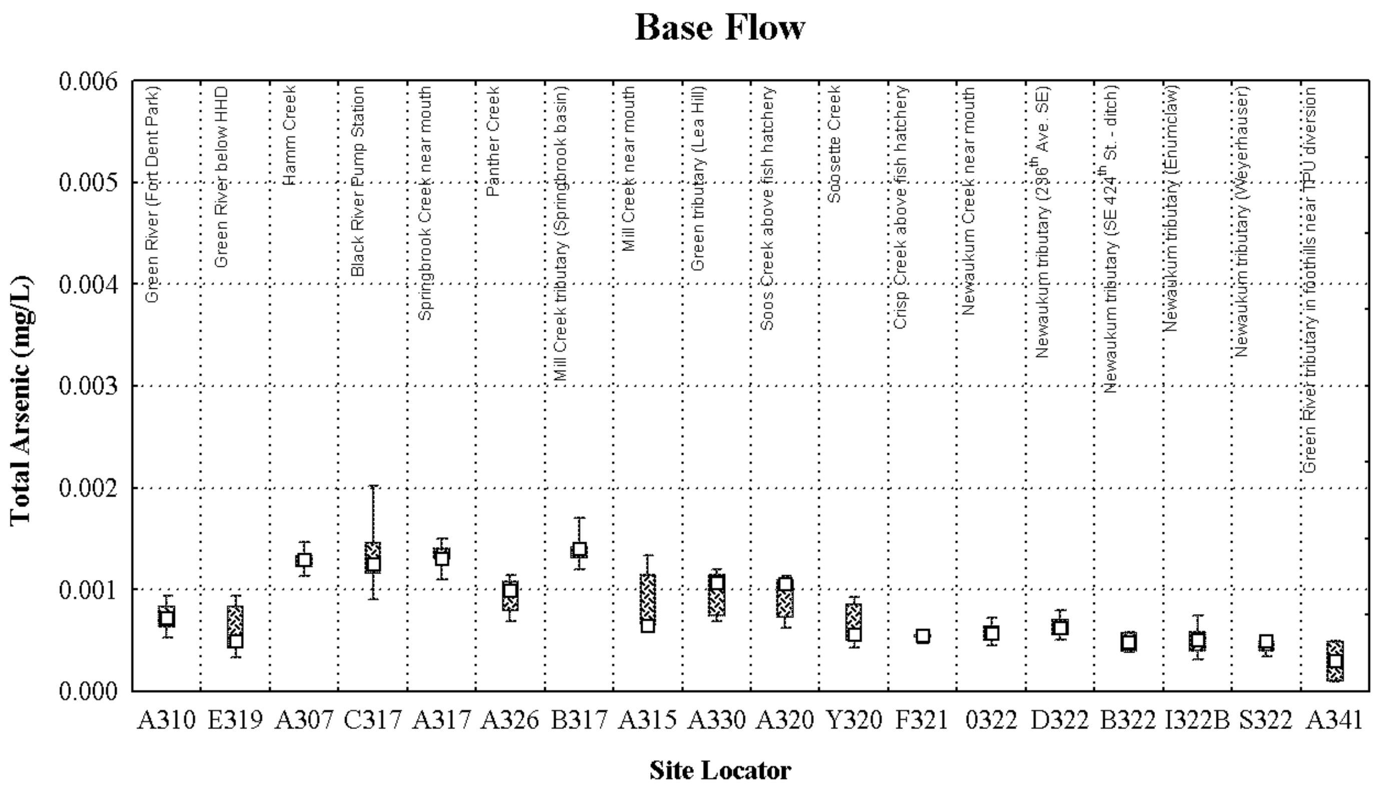

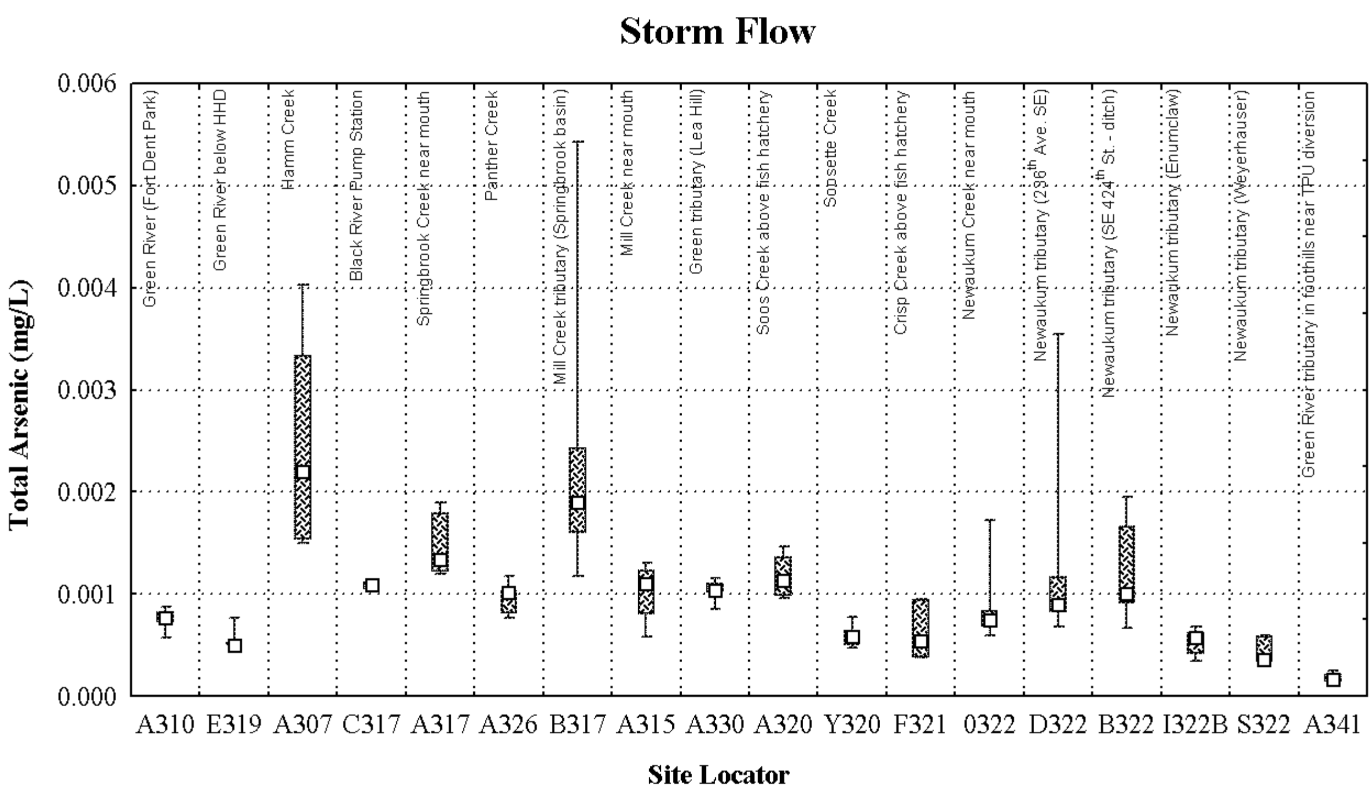

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 28. Total arsenic concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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River (C315) and Springbrook Creek (A317) sites relative to Newaukum Creek (0322) during base flow, and were significantly higher (p = 0.0004) in Springbrook Creek (A317) relative to Newaukum Creek (0322) during storm flow.

The tributary sites exhibited dissolved arsenic concentrations that were similar to those for the major stream sites. Median total arsenic concentrations were highest during storm flow at Hamm Creek (A307) and Mill (Springbrook) tributary (B317).

5.2.5.3 Cadmium

Summary statistics for dissolved cadmium during base and storm flow are presented in Table H5 and Figure 29. Summary statistics for total cadmium during base and storm flow are presented in Table H6 and Figure 30. Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for dissolved cadmium that vary with hardness (see Table 11).

None of the sample values exceeded the state chronic criterion during base flow or the acute criterion during storm flow.

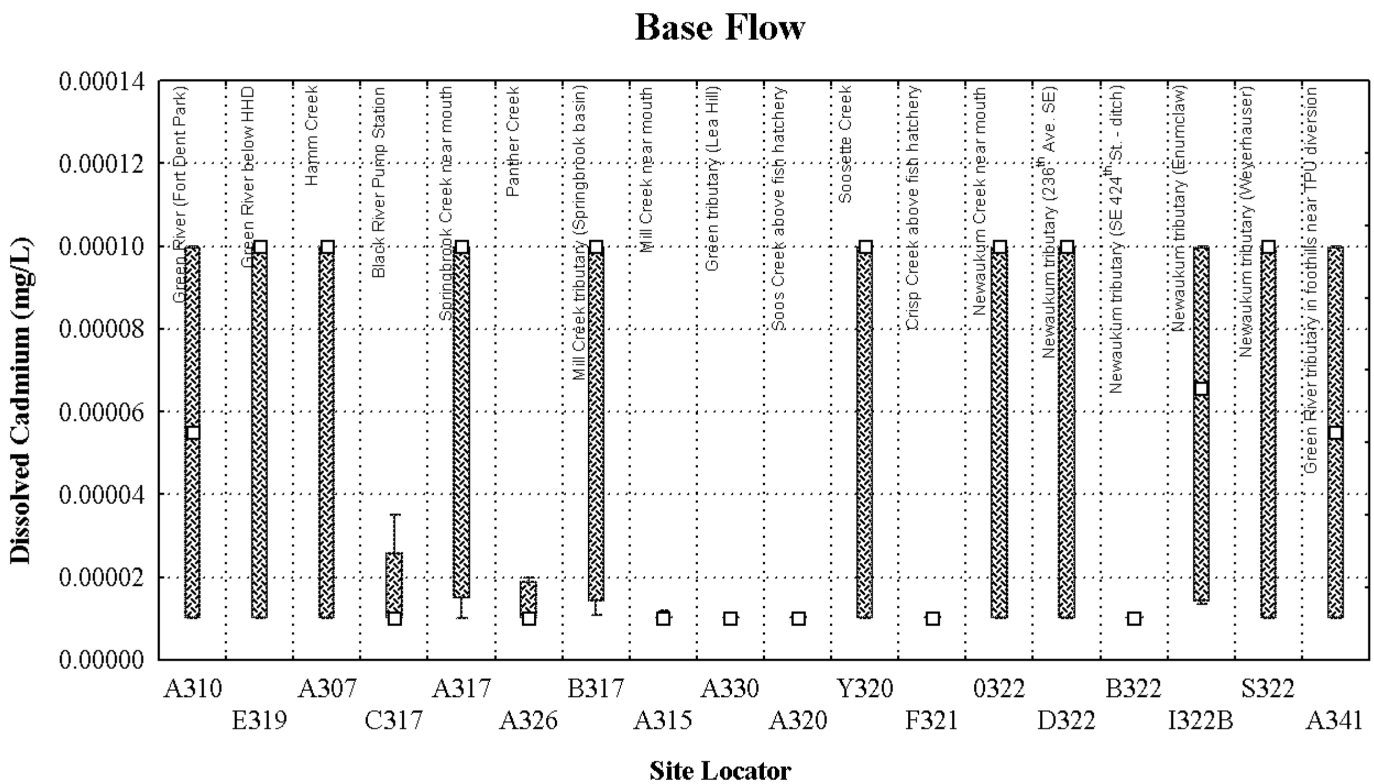
Dissolved cadmium concentrations ranged from less than 0.00001 to 0.00016 mg/L during base flow, and from less than 0.00001 to 0.00012 mg/L during storm flow. Total cadmium concentrations ranged from less than 0.00001 to 0.00034 mg/L during base flow, and less than 0.00001 to 0.00081 mg/L during storm flow. The median dissolved cadmium concentration for all sites combined was slightly higher during storm flow (0.00004 mg/L) than base flow (0.00002 mg/L).

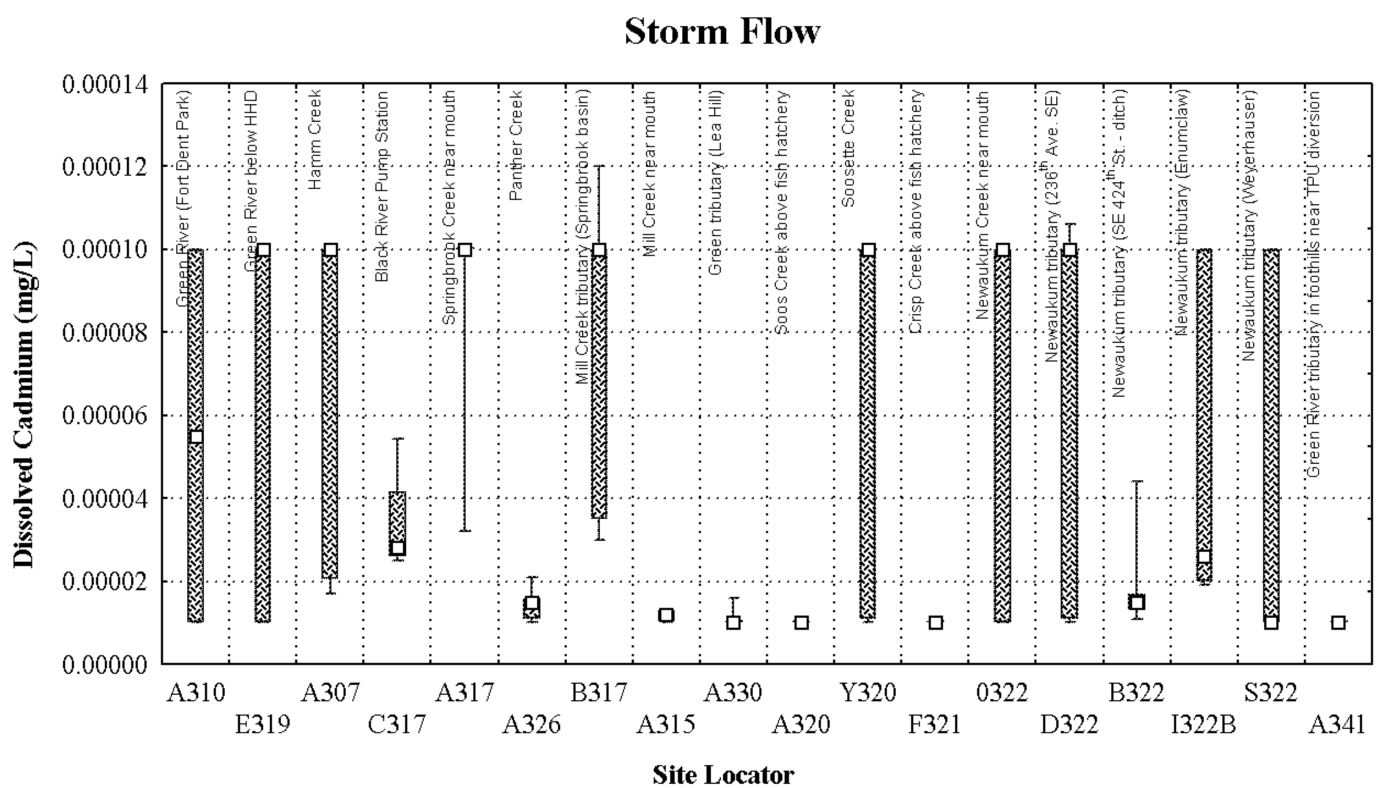
Spatial pattern analysis results for the Green River show that total and dissolved cadmium concentrations did not differ significantly between the upper and lower sites during base flow or storm flow (Table J13). Results from the spatial pattern analysis for the major streams show that dissolved cadmium concentrations were significantly higher in Springbrook Creek (A317) relative to Soos Creek (A320) during both base flow (p = 0.0037) and storm flow (p = 0.0015) (Tables J14 and J15). Concentrations of total cadmium were also significantly (p = 0.0039) higher in Springbrook Creek (A317) relative to Soos Creek (A320) during base flow. Finally, total cadmium concentrations were significantly (p = 0.0002) higher in Springbrook Creek (A317) relative to both Soos Creek (A320) and Mill Creek (A315) during storm flow.

The tributary sites exhibited cadmium concentrations that were similar to those for the major stream sites with the exception of a high median concentration of total cadmium (0.00037 mg/L) at Mill (Springbrook) tributary (B317) during storm flow.

5.2.5.4 Calcium

Summary statistics for dissolved calcium during base and storm flow are presented in Table H7 and Figure 31. Summary statistics for total calcium during base and storm flow are presented in Table H8 and Figure 32. Washington State does not have surface water quality criteria for total or dissolved calcium (WAC 173-201A).





Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Water quality standard off scale

Figure 29. Dissolved cadmium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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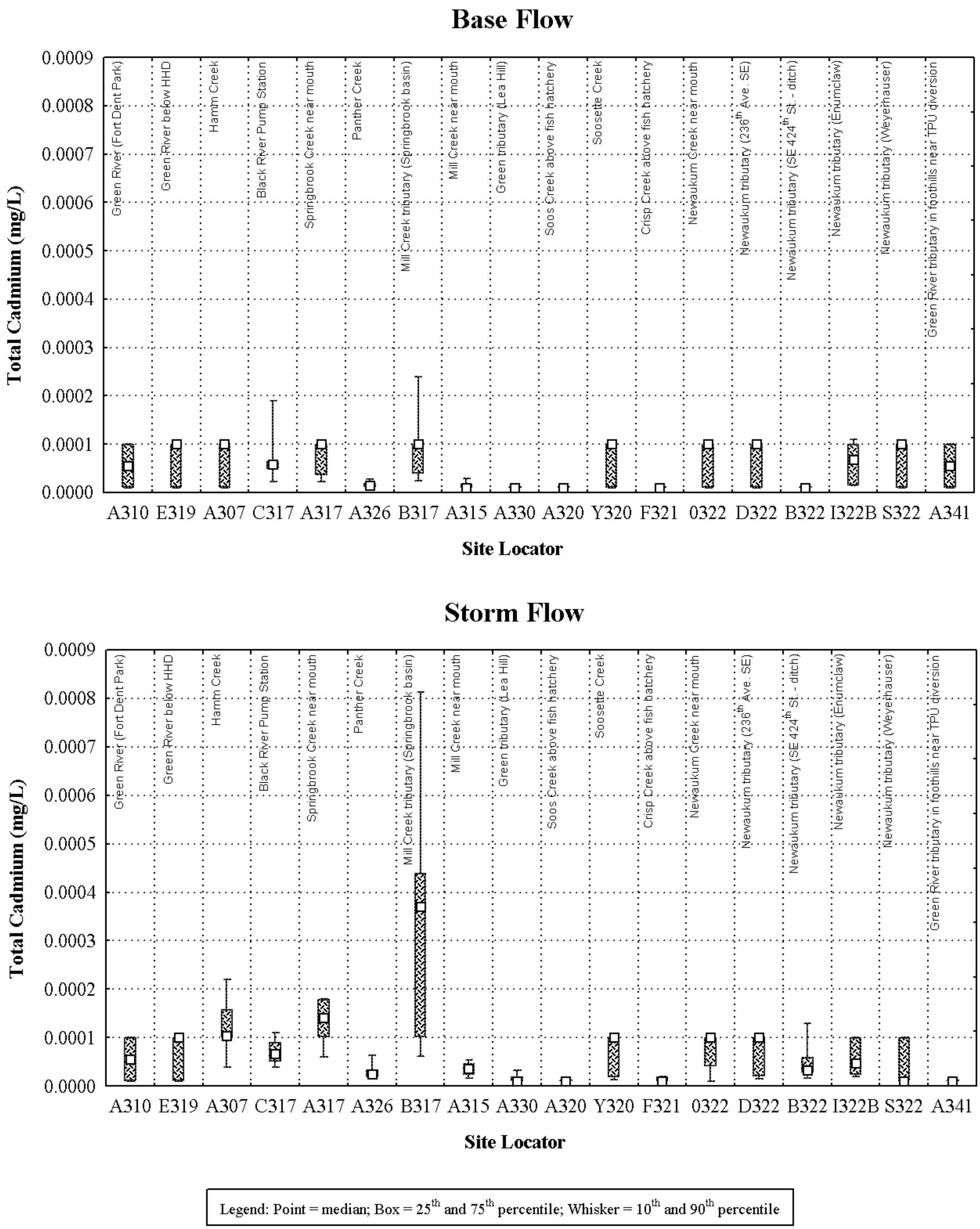

Figure 30. Total cadmium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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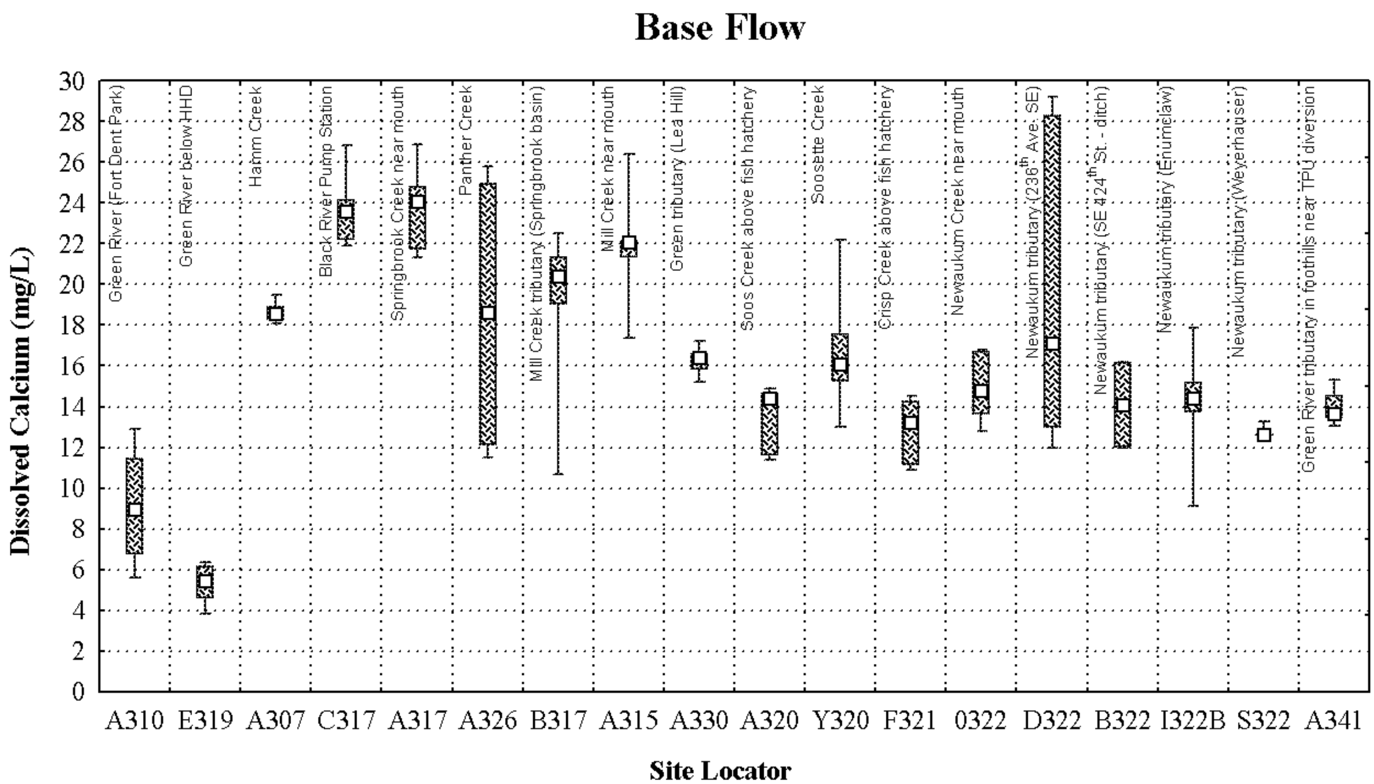

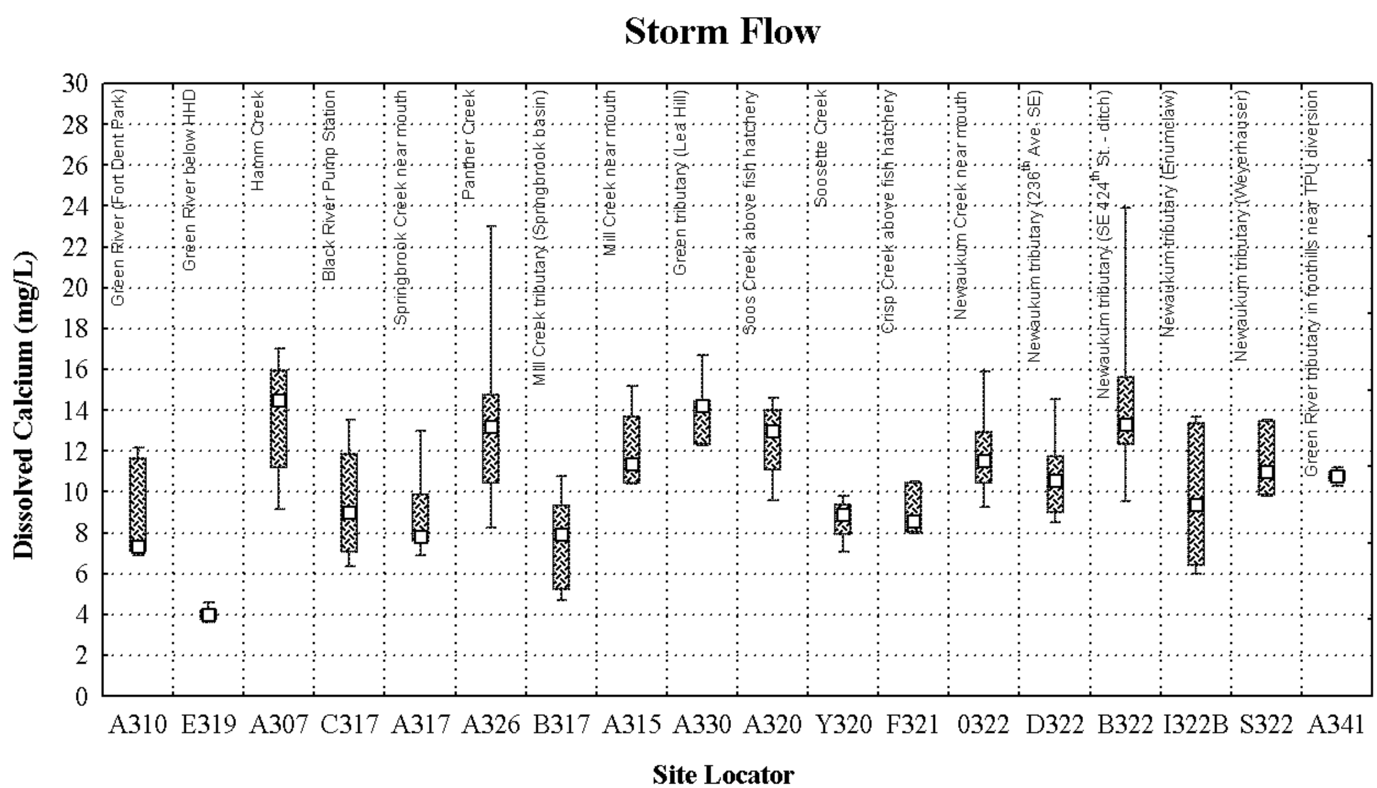

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 31. Dissolved calcium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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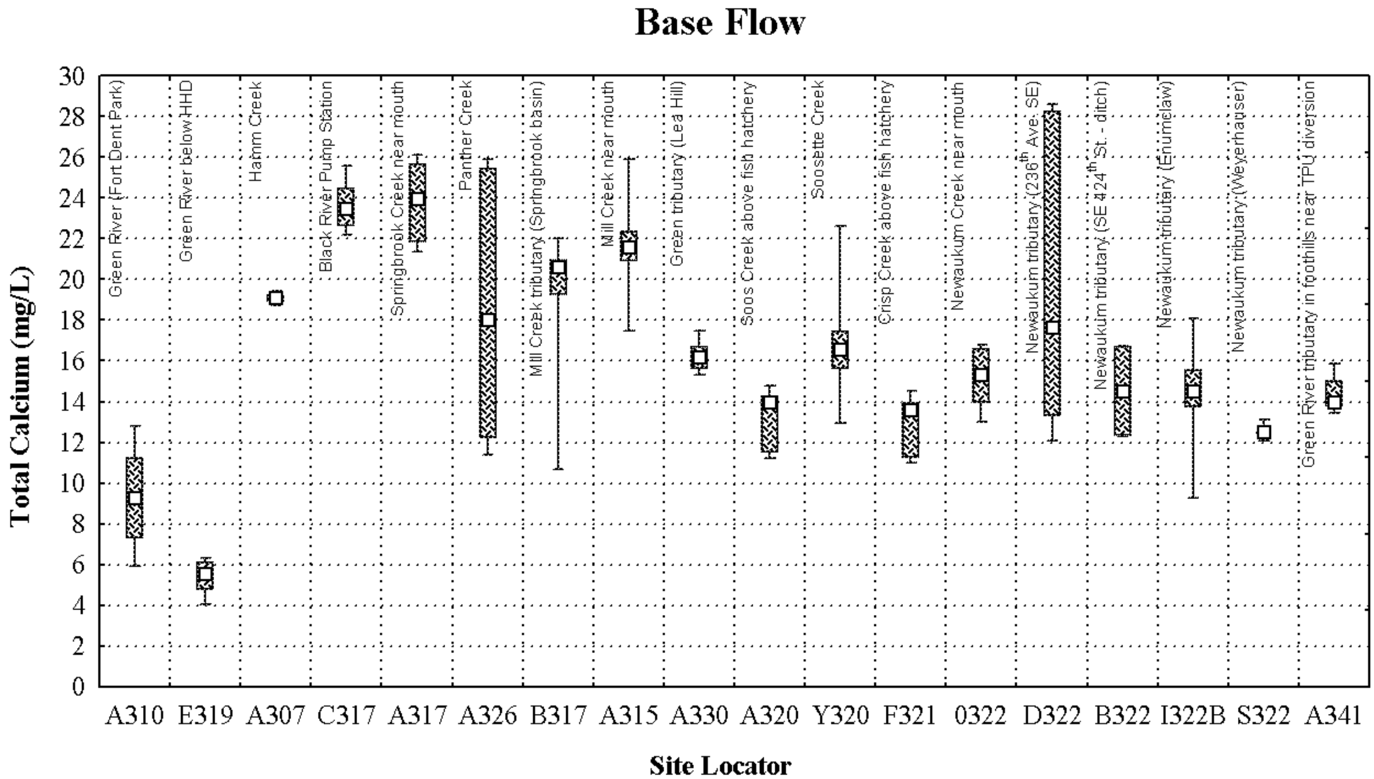

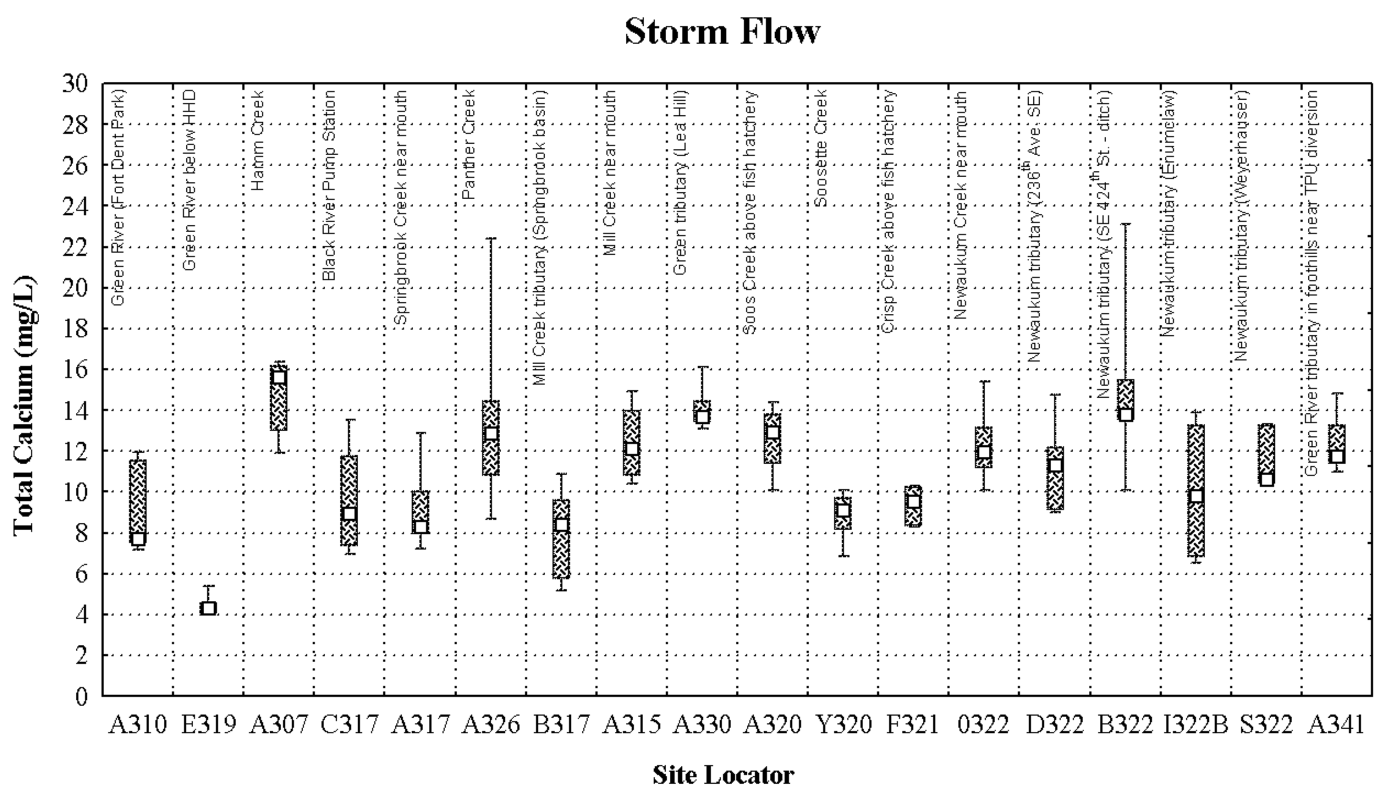

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 32. Total calcium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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Dissolved calcium concentrations ranged from 3.78 to 29.33 mg/L during base flow, and ranged from 2.91 to 23.90 mg/L during storm flow. Total calcium concentrations ranged from 3.97 to 29.20 mg/L during base flow, and ranged from 3.18 to 23.10 mg/L during storm flow. The median total calcium concentration for all sites combined was higher during base flow (15.60 mg/L) than storm flow (10.60 mg/L).

Spatial pattern analysis results for the Green River show that dissolved calcium concentrations increased significantly downstream from the upper to lower site during base flow ($p = 0.0001$) and storm flow ($p < 0.0001$) (Table J13). Total calcium concentrations also increased significantly downstream in the Green River during base flow ($p < 0.0001$) and storm flow ($p < 0.0001$). The median total calcium concentration increased downstream from 5.54 to 9.31 mg/L during base flow, and from 4.33 to 7.72 mg/L during storm flow.

Spatial pattern analysis results for the major stream sites showed that dissolved calcium concentrations during base flow were significantly ($p < 0.0001$) higher in the Black River (C317) and Springbrook Creek (A317) relative to Newaukum Creek (0322) and Soos Creek (A320), and that dissolved calcium concentrations during storm flow were significantly ($p = 0.0186$) higher in Soos Creek (A320) relative to Springbrook Creek (A317) (Tables J14 and J15). Total calcium concentrations during base flow were significantly ($p < 0.0001$) higher in the Black River (C317) and Springbrook Creek (C317) relative to Newaukum Creek (0322) and Soos Creek (A320), and total calcium concentrations during storm flow were significantly ($p = 0.0087$) higher in Soos Creek (A320) relative to Springbrook Creek (A317).

The tributary sites exhibited calcium concentrations that were similar to those for the major stream sites.

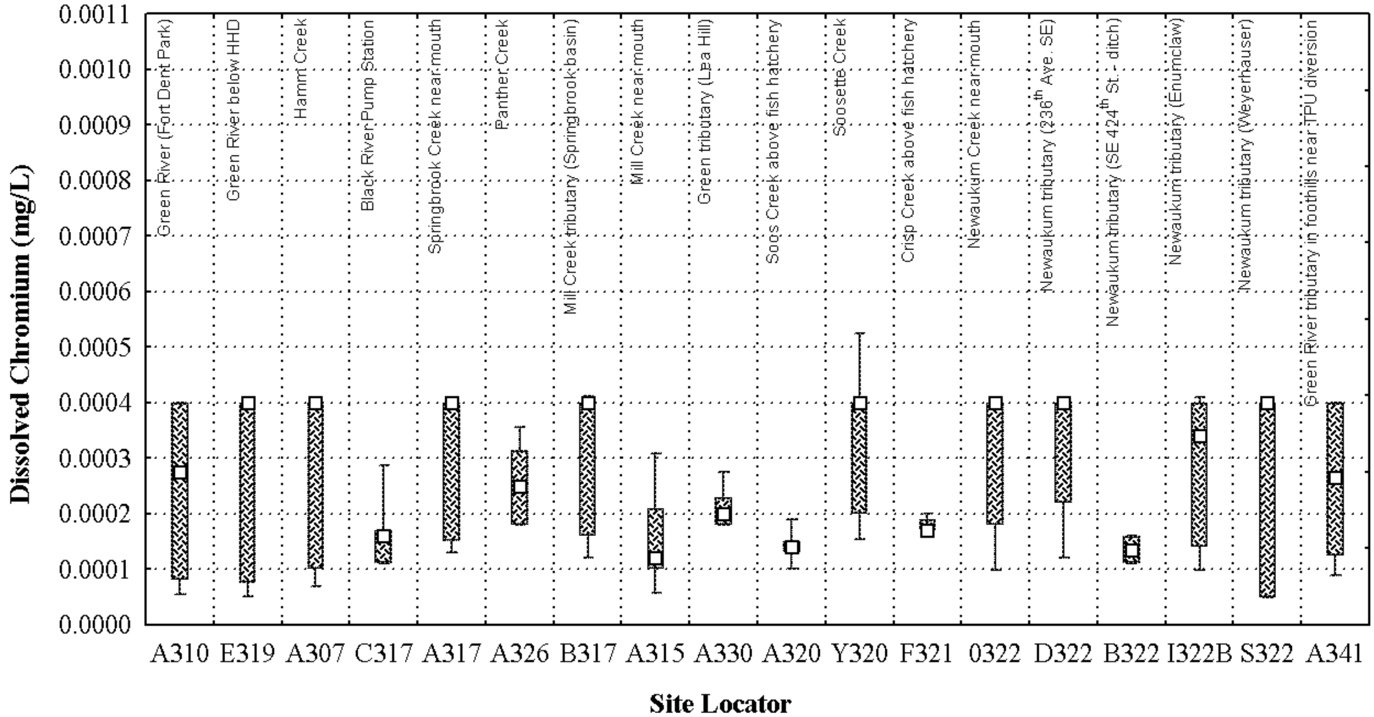
5.2.5.5 Chromium

Summary statistics for dissolved chromium during base and storm flow are presented in Table H9 and Figure 33. Summary statistics for total chromium during base and storm flow are presented in Table H10 and Figure 34. Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for total chromium (or trivalent chromium if available) that vary with hardness (see Table 11). None of the sample values exceeded the state chronic criterion during base flow or the acute criterion during storm flow.

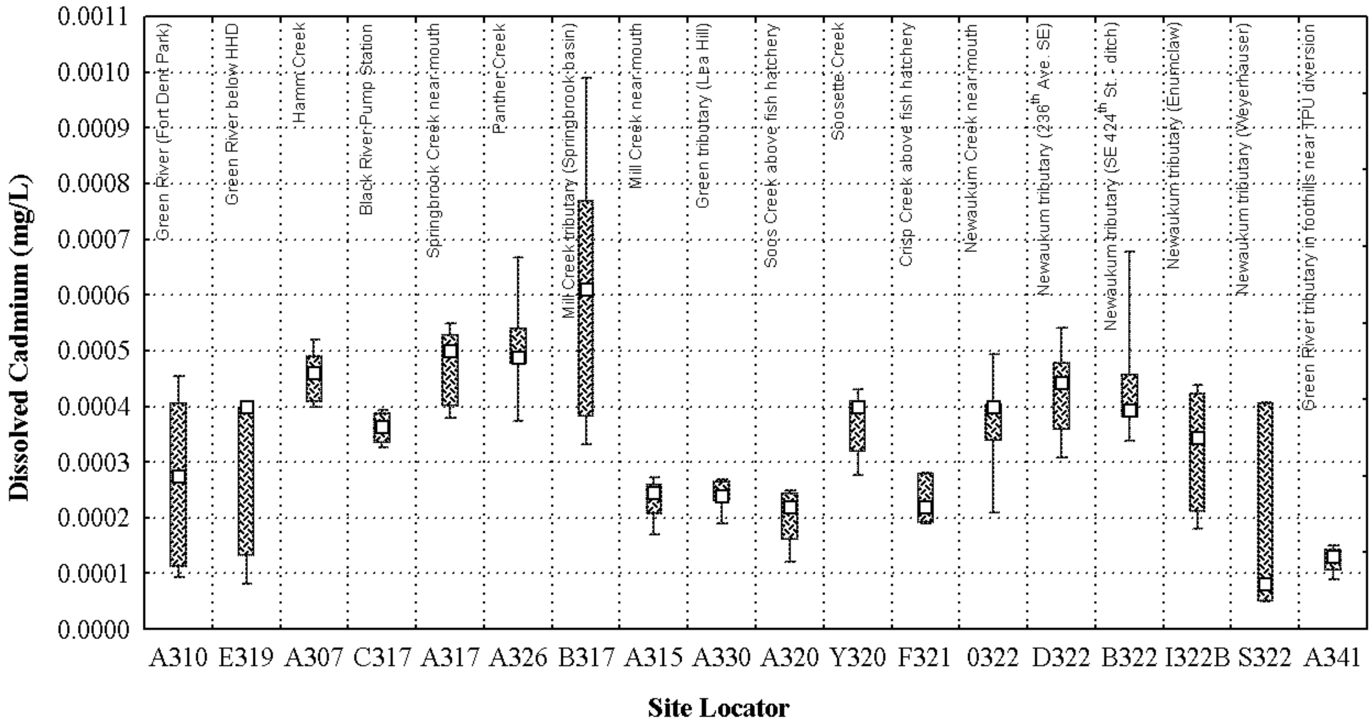
Dissolved chromium concentrations ranged from less than 0.0005 to 0.00100 mg/L, and ranged from less than 0.00005 to 0.00099 mg/L during storm flow. Total chromium concentrations ranged from less than 0.00005 to 0.00247 mg/L during base flow, and ranged from 0.00005 to 0.03000 mg/L during storm flow. The median total chromium concentration for all sites combined was higher during storm flow (0.00079 mg/L) than during base flow (0.00040 mg/L).

Spatial pattern analysis results for the Green River showed no significant differences in dissolved chromium concentrations between the upper and lower sites during base flow or storm flow (Table J13). Total chromium concentrations significantly ($p = 0.0226$) increased from the upper to lower site during base flow, but not during storm flow.

Base Flow



Storm Flow



Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 33. Dissolved chromium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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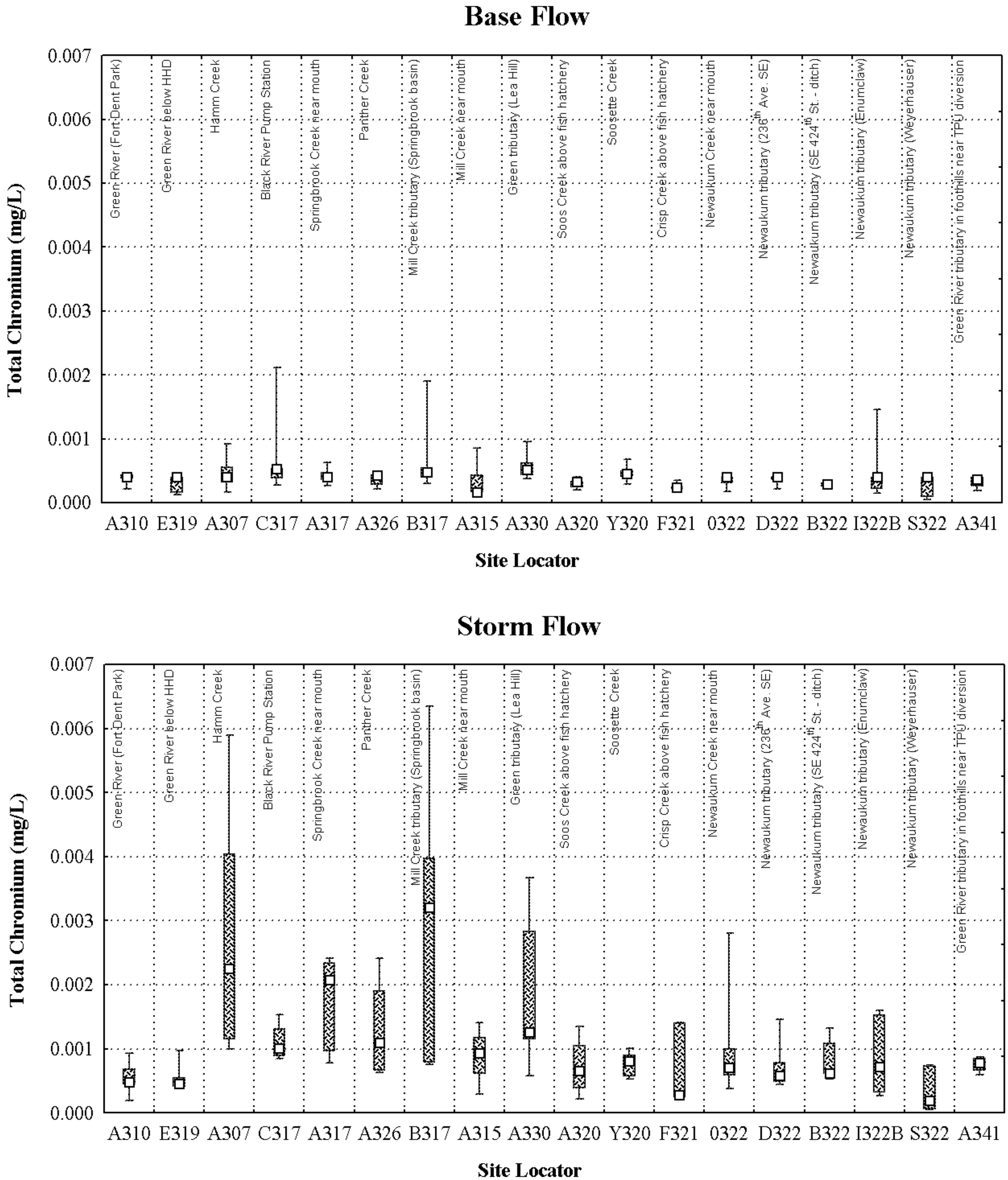

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Water quality standard off scale

Figure 34. Total chromium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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Among the major streams, dissolved chromium concentrations were significantly higher ($p = 0.0477$) in Springbrook Creek (A317) relative to Mill Creek (A315) during base flow, and were significantly higher ($p = 0.0003$) in Springbrook Creek (A317) relative to Soos Creek (A320) and Mill Creek (A315) during storm flow (Tables J14 and J15). Total chromium concentrations did not differ significantly among the major streams during base flow, but were significantly higher ($p = 0.0180$) during storm flow at Springbrook Creek (A317) relative to Soos Creek (A320).

The tributary sites exhibited chromium concentrations that were similar to those observed at the major stream sites with the exception that Mill (Springbrook) tributary (B317) and Hamm Creek (A307) exhibited the highest median total chromium concentrations during storm flow.

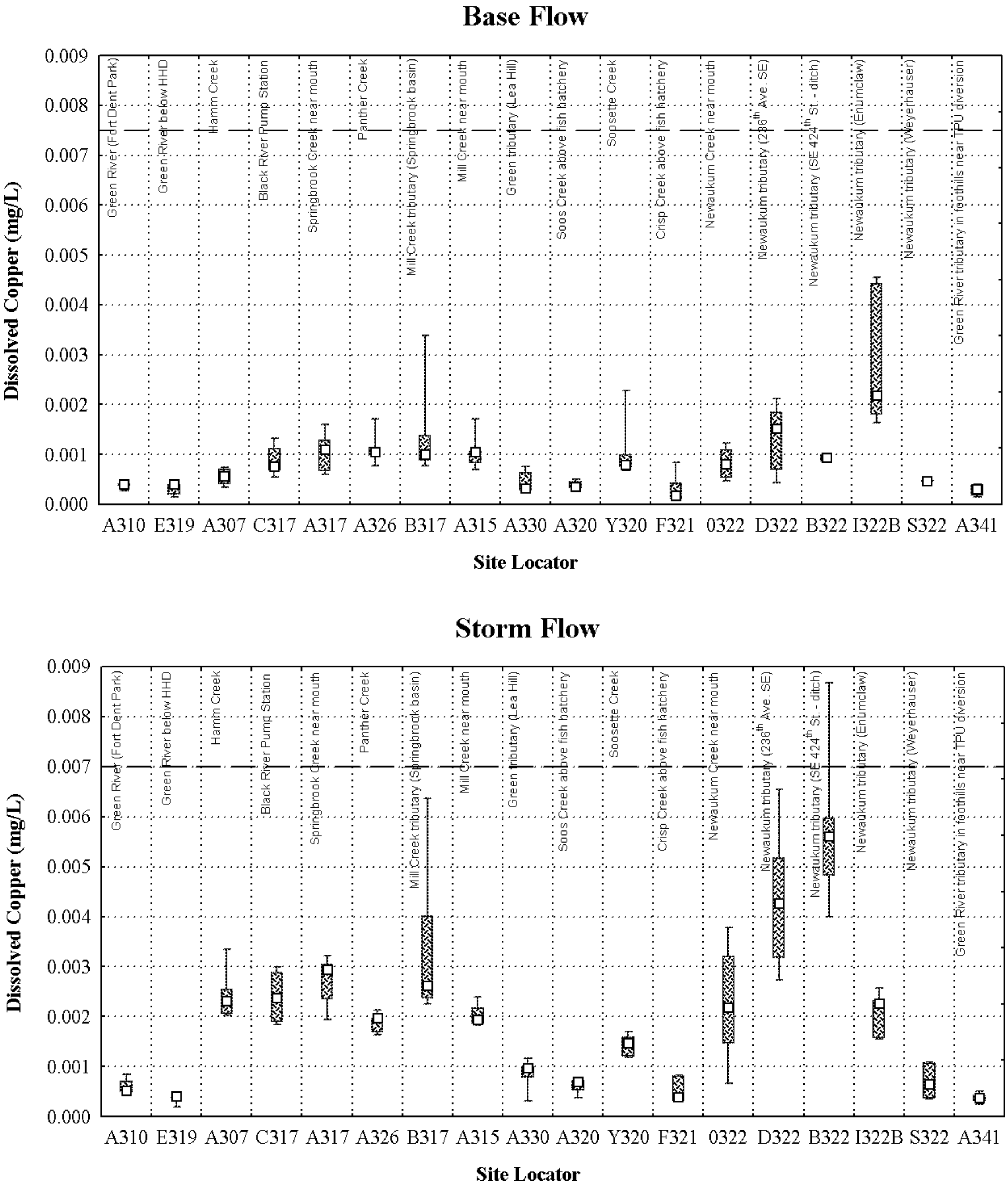
5.2.5.6 Copper

Summary statistics for dissolved copper during base and storm flow are presented in Table H11 and Figure 35. Summary statistics for total copper during base and storm flow are presented in Table H12 and Figure 36. Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for dissolved copper that vary with hardness (see Table 11). The chronic criterion was exceeded on one occasion during base flow at Mill (Springbrook) tributary (0.0056 mg/L dissolved copper at site B317). The acute criterion was exceeded on one occasion during storm flow at Newaukum tributary at 236th SE (0.0072 mg/L dissolved copper at site D322).

Dissolved copper concentrations ranged from less than 0.0001 to 0.0056 mg/L during base flow, and ranged from 0.0001 to 0.0087 mg/L during storm flow. Total copper concentrations ranged from 0.0001 to 0.0091 mg/L during base flow, and ranged from less than 0.0002 to 0.0400 mg/L during storm flow. Among all sites, the median dissolved copper concentration was higher during storm flow (0.0020 mg/L) than during base flow (0.0007 mg/L), and the median total copper concentration was also higher during storm flow (0.0033 mg/L) than during base flow (0.0010 mg/L).

Spatial pattern analysis results for the Green River show that dissolved copper concentrations significantly increased downstream from the upper site to lower site during base flow ($p = 0.0197$) and storm flow ($p < 0.0001$), (Table J13). However, median dissolved copper concentrations did not differ by more than 0.0001 mg/L between the two sites. Total copper concentrations significantly ($p < 0.0001$) increased downstream during base flow, but not during storm flow. The median total copper concentration increased downstream from 0.0004 and 0.0007 mg/L during base flow.

Among the major streams, dissolved copper concentrations were significantly ($p = 0.0112$) higher in Springbrook Creek (A317) and Mill Creek (A315) relative to Soos Creek (A320) during base flow, and Springbrook Creek (A317) exhibited significantly ($p = 0.0161$) higher dissolved copper concentrations relative to Soos Creek (A320) during storm flow (Tables J14 and J15). Total copper concentrations were significantly ($p = 0.0008$) higher during base flow in Springbrook Creek (A317) and the Black River (C317) relative to Soos Creek (A320), and were



Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Dashed line = water quality standard

Figure 35. Dissolved copper concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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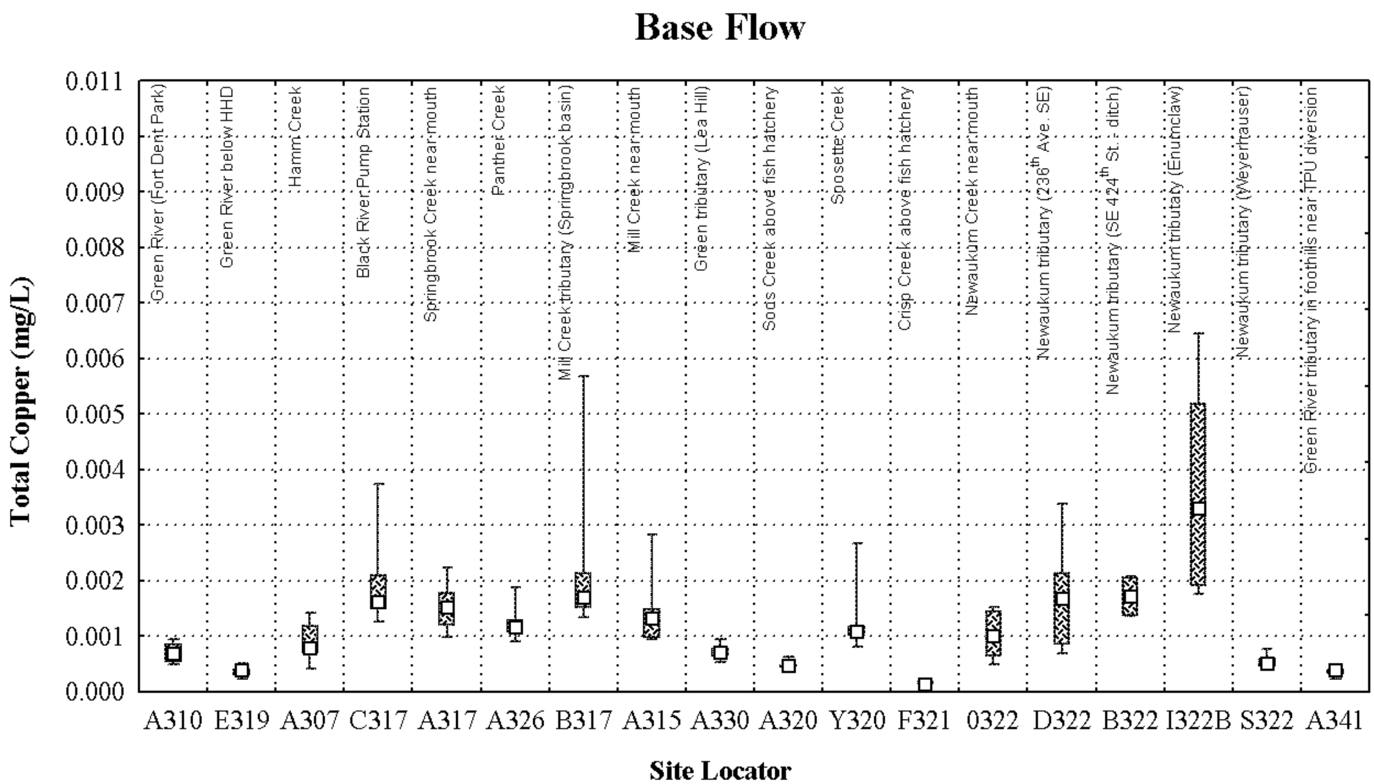

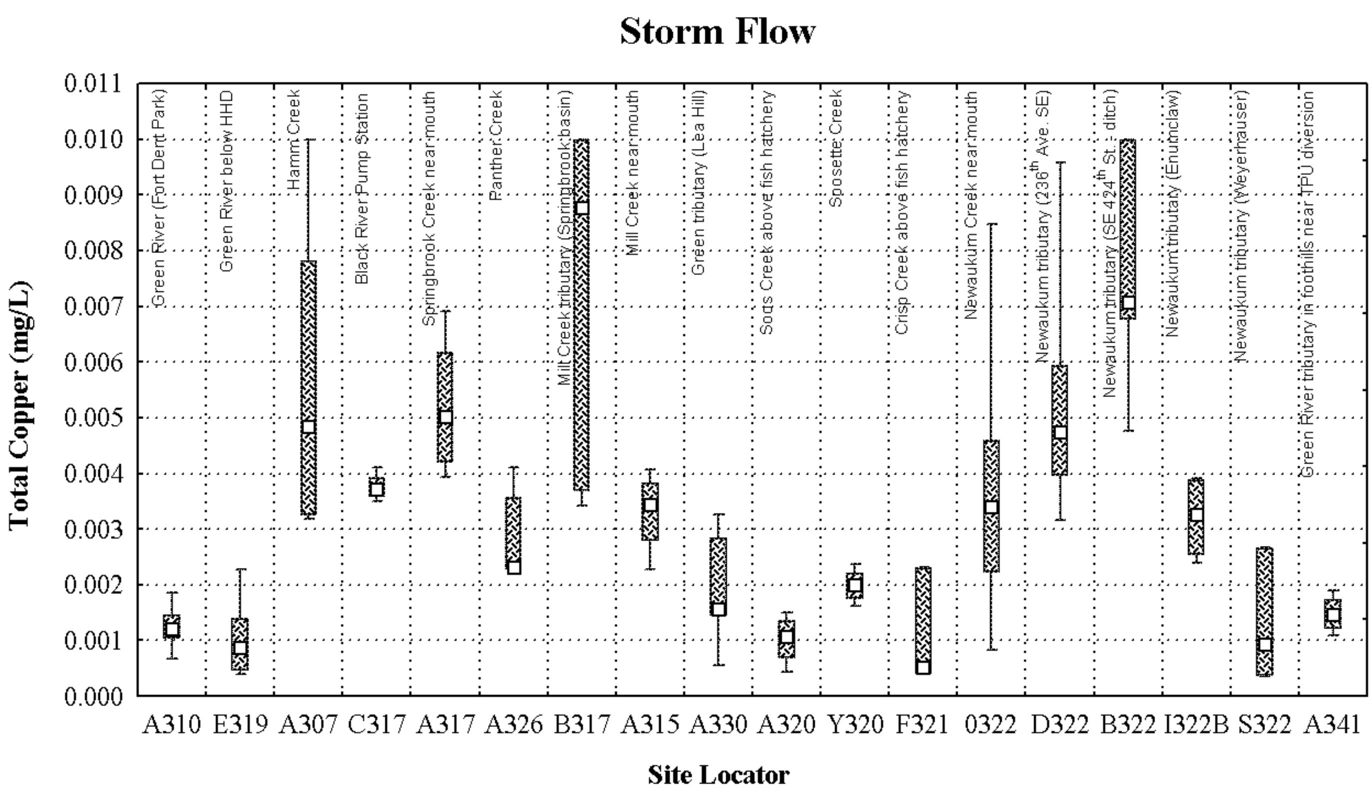

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 36. Total copper concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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significantly ($p = 0.0012$) higher during storm flow in Springbrook Creek (A317) relative to Soos Creek (A320).

Among the tributary sites, median dissolved and total copper concentrations during base flow were highest at Newaukum tributary at Enumclaw (I322B). During storm flow, median dissolved copper concentrations were highest at Newaukum tributary at SE 424th (B322) and Newaukum tributary at 236th SE (D322), and median total copper concentrations were highest at Mill (Springbrook) tributary (B317) and Newaukum tributary at SE 424th (B322).

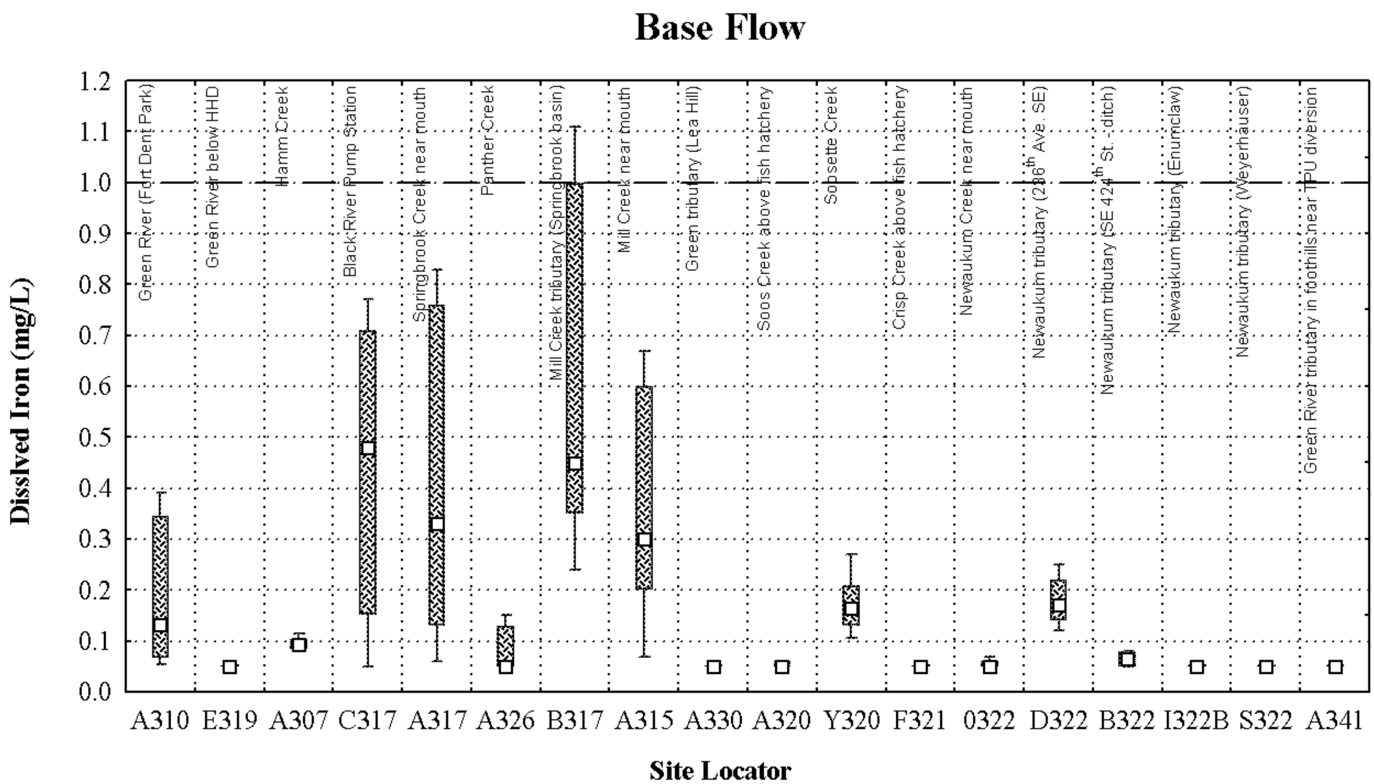
5.2.5.7 Iron

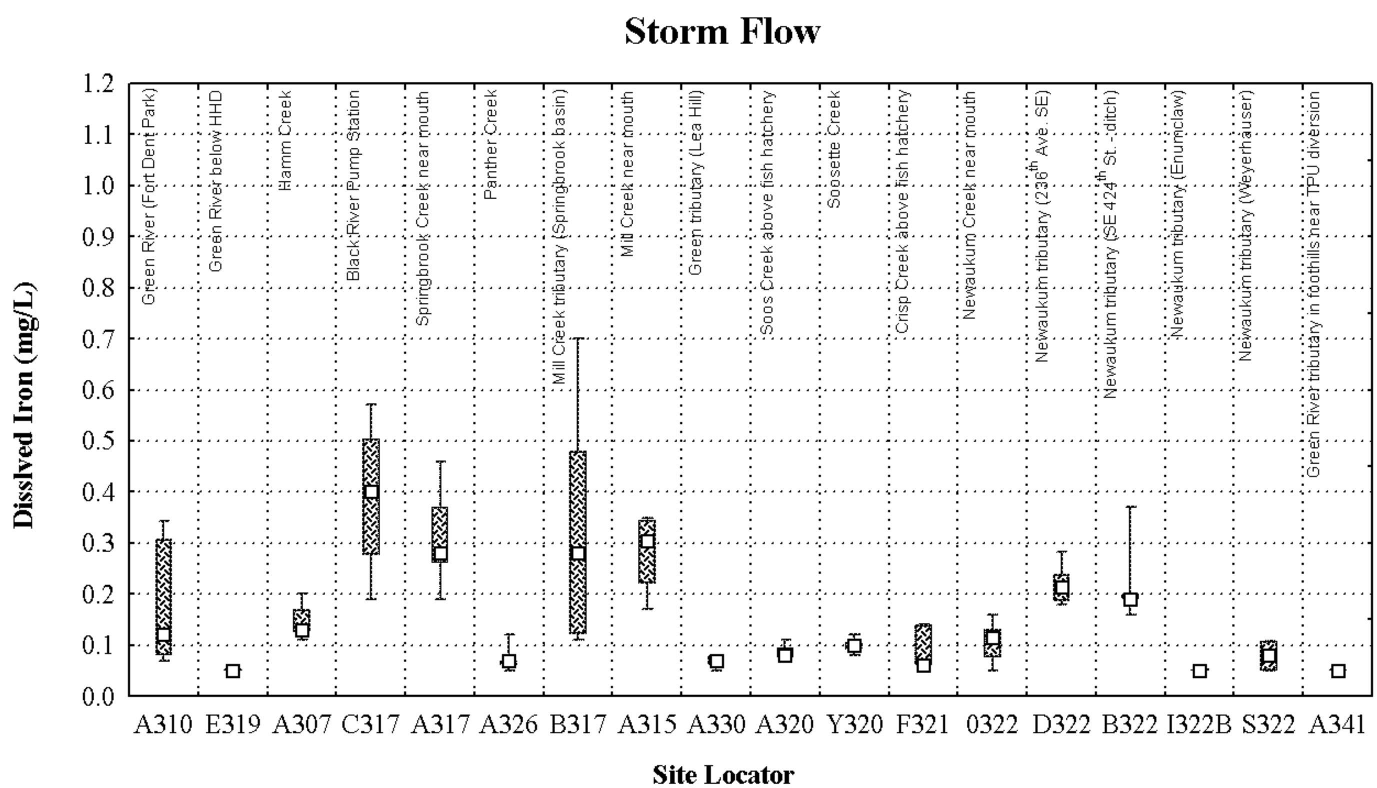
Summary statistics for dissolved iron during base and storm flow are presented in Table H13 and Figure 37. Summary statistics for total iron during base and storm flow are presented in Table H14 and Figure 38. Washington State does not have surface water quality criteria for dissolved or total iron (WAC 173-201A). However, the U.S. EPA (2002a) has established a chronic criterion of 1.0 mg/L for iron.

Dissolved iron concentrations ranged from less than 0.05 to 1.15 mg/L during base flow, and ranged from 0.05 to 0.70 mg/L during storm flow. Total iron concentrations ranged from 0.05 to 4.31 mg/L during base flow, and from 0.06 to 26.70 mg/L during storm flow. Dissolved iron concentrations occasionally exceeded the chronic criterion during base flow at Springbrook Creek (A317) and Mill (Springbrook) tributary (B317). Total iron concentrations exceeded that chronic criterion in at least on sample collected at eight sites, and in most (greater than 80 percent) samples collected at Black River (C317), Springbrook Creek (A317), and Mill (Springbrook) tributary (B317). The median total iron concentration for all sites combined was higher during storm flow (0.79 mg/L) than during base flow (0.37 mg/L).

Based on results of the spatial pattern analysis for the Green River, dissolved iron concentrations significantly increased downstream during base flow ($p < 0.0001$) and storm flow ($p < 0.0001$) (Table J13). Median dissolved iron concentrations increased downstream from 0.05 to 0.13 mg/L during base flow and increased from 0.05 to 0.12 mg/L during storm flow. Total iron concentrations significantly increased downstream during base flow ($p < 0.0001$), but not during storm flow. The median total iron concentration increased downstream from 0.14 to 0.64 mg/L during base flow.

Among the major streams, results of the spatial pattern analysis showed that dissolved iron concentrations were significantly ($p = 0.0001$) higher during base flow in Mill Creek (A315) relative to Soos Creek (A320), and that dissolved iron concentrations were significantly ($p < 0.0001$) higher during storm flow in Springbrook Creek (A317) and the Black River (C317) relative to Soos Creek (A320) and Newaukum Creek (0322) (Tables J14 and J15). Total iron concentrations were significantly ($p < 0.0001$) higher during base flow in Springbrook Creek (A317) and the Black River (C317) relative to Soos Creek (A320) and Newaukum Creek (0322), and total iron concentrations were significantly ($p = 0.0004$) higher during storm flow in Springbrook Creek (A317) relative to Soos Creek (A320) and Newaukum Creek (0322).





Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Dashed line = water quality standard

Figure 37. Dissolved iron concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

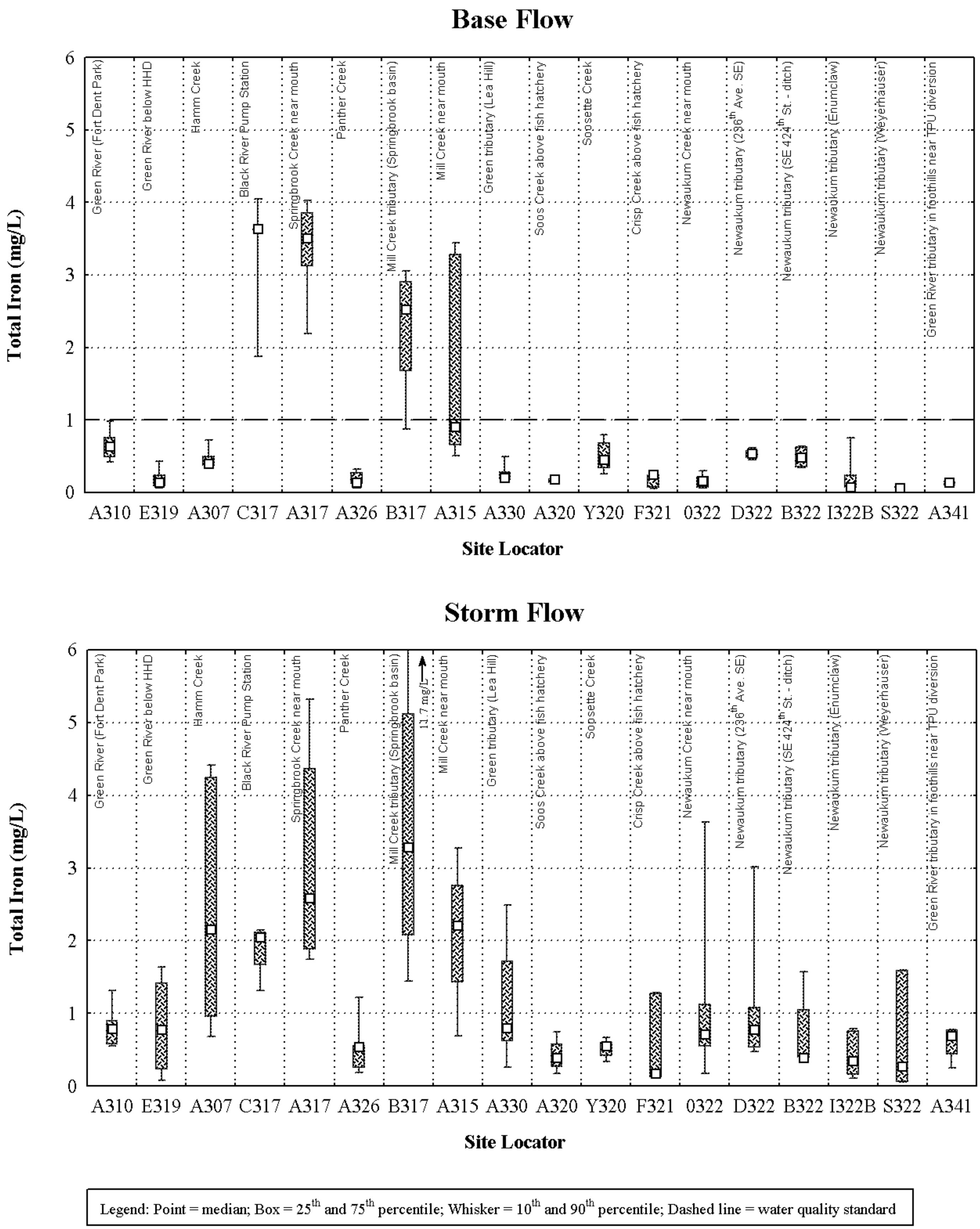


Figure 38. Total iron concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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The tributary sites exhibited iron concentrations that were similar to those observed for the major stream sites.

5.2.5.8 Lead

Summary statistics for dissolved lead during base and storm flow are presented in Table H15 and Figure 39. Summary statistics for total lead during base and storm flow are presented in Table H16 and Figure 40. Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for dissolved lead that vary with hardness (see Table 11). None of the sample values exceeded the state chronic criterion during base flow or the acute criterion during storm flow.

Dissolved lead concentrations ranged from less than 0.000025 to 0.000870 mg/L during base flow, and from 0.000025 to 0.000673 mg/L during storm flow. Total lead concentrations ranged from less than 0.000025 to 0.008760 mg/L during base flow, and from less than 0.000025 to 0.060000 mg/L during storm flow. Among all sites, the median dissolved lead concentration was higher during storm flow (0.000200 mg/L) than base flow (0.000081 mg/L), and the median total lead concentration was also higher during storm flow (0.000575 mg/L) than base flow (0.000200 mg/L).

Spatial pattern analysis for the Green River sites showed that dissolved lead concentrations did not differ significantly between the upper and lower sites (Table J13). Total lead concentrations increased significantly ($p = 0.0060$) downstream during storm flow, but not during base flow.

Median total lead concentrations increased downstream from 0.000200 to 0.000495 mg/L during storm flow.

Based on results of the spatial pattern analysis for the major streams, there were no significant differences in dissolved lead concentrations during base flow (Tables J14 and J15). However, dissolved lead concentrations were significantly ($p < 0.0001$) higher during storm flow in Springbrook Creek (A317) relative to Soos Creek (A320). Total lead concentrations were significantly ($p = 0.0004$) higher during base flow in the Black River (C317) relative to Soos Creek (A320), and total lead concentrations were significantly ($p = 0.0001$) higher during storm flow in Springbrook Creek (A317) relative to Soos Creek (A320) and Newaukum Creek (0322).

The tributary sites exhibited lead concentrations that were similar to those for the major stream sites with the exception that Mill (Springbrook) tributary (B317) and Hamm Creek (A307) exhibited the highest median total lead concentrations during storm flow.

5.2.5.9 Magnesium

Summary statistics for dissolved magnesium during base and storm flow are presented in Table H17 and Figure 41. Summary statistics for total magnesium during base and storm flow are presented in Table H17 and Figure 42. Washington State does not have surface water quality criteria for dissolved or total magnesium (WAC 173-201A).

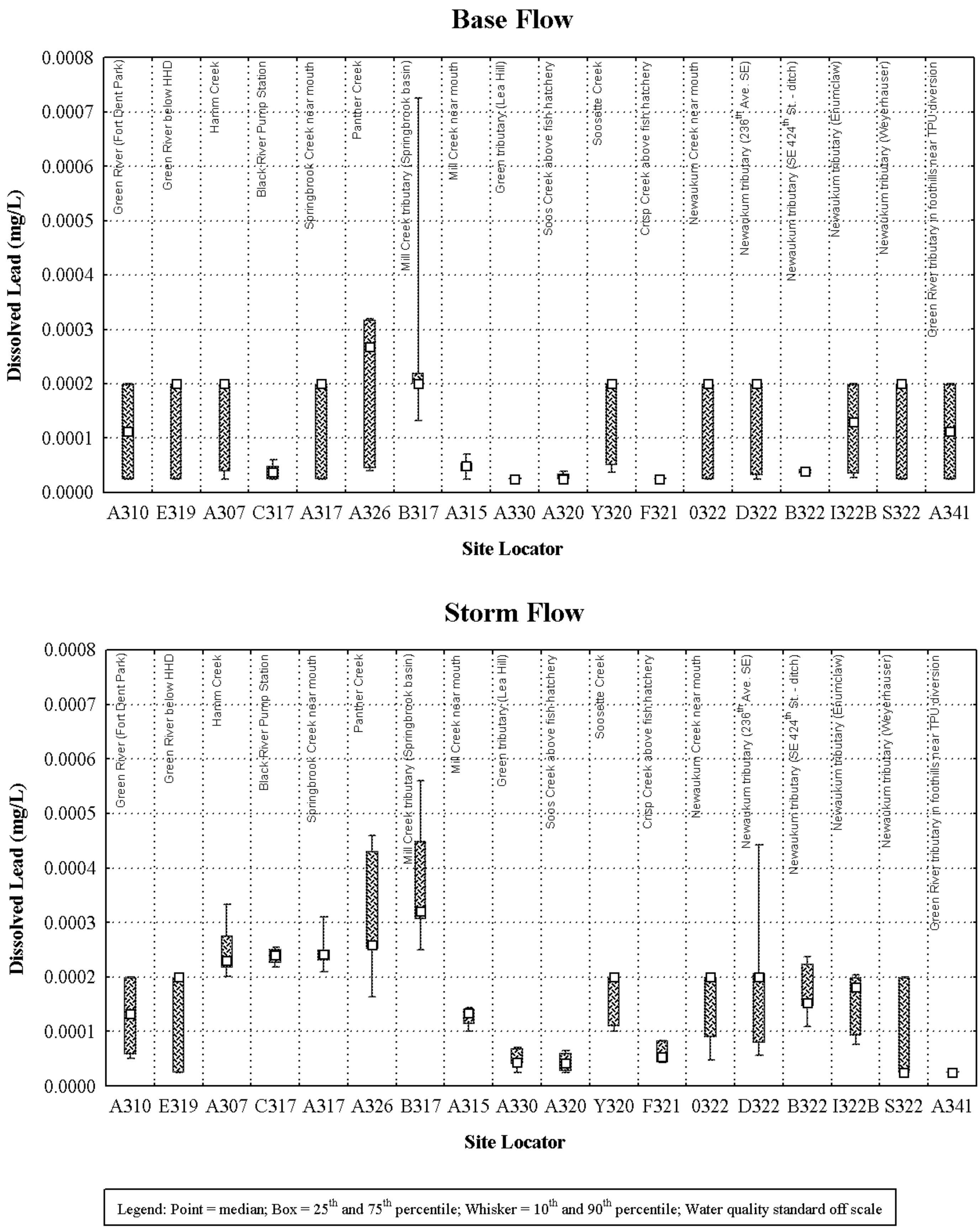

Figure 39. Dissolved lead concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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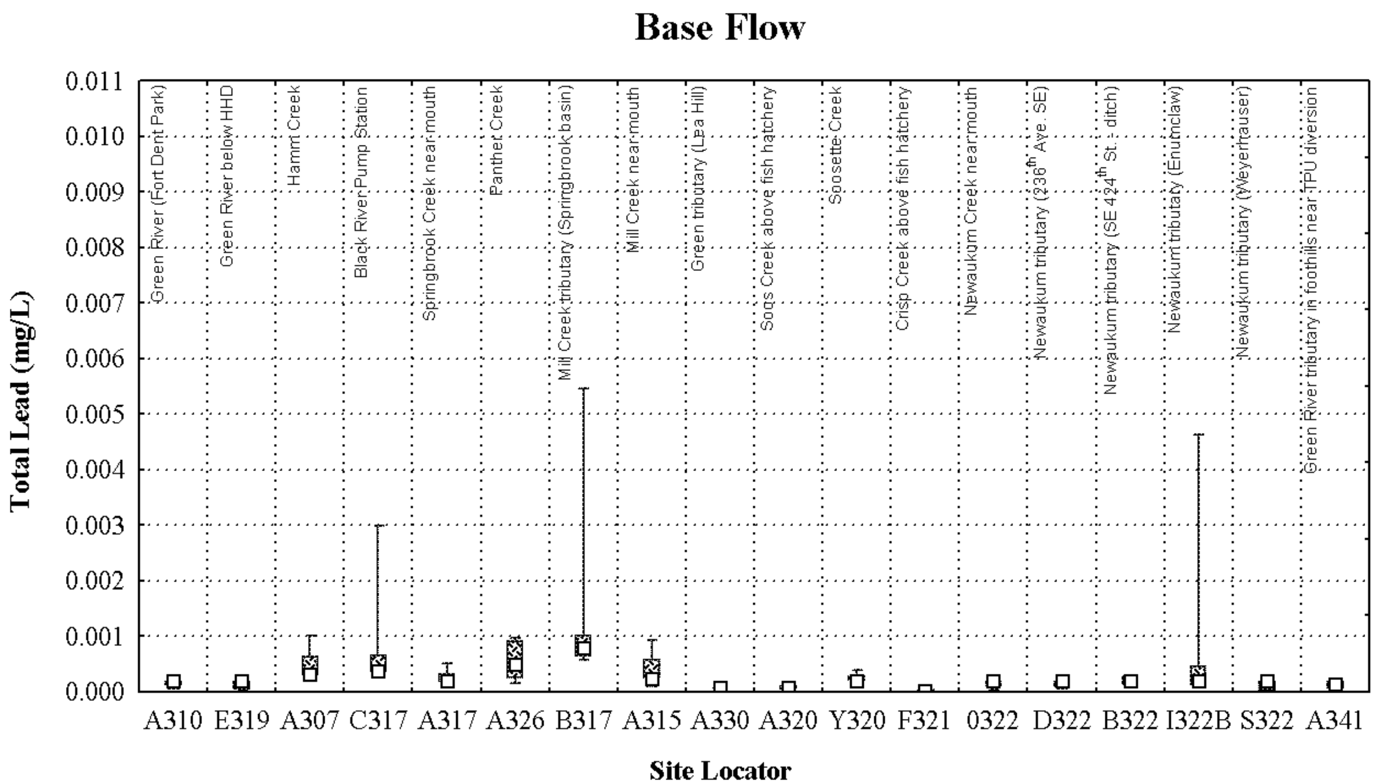

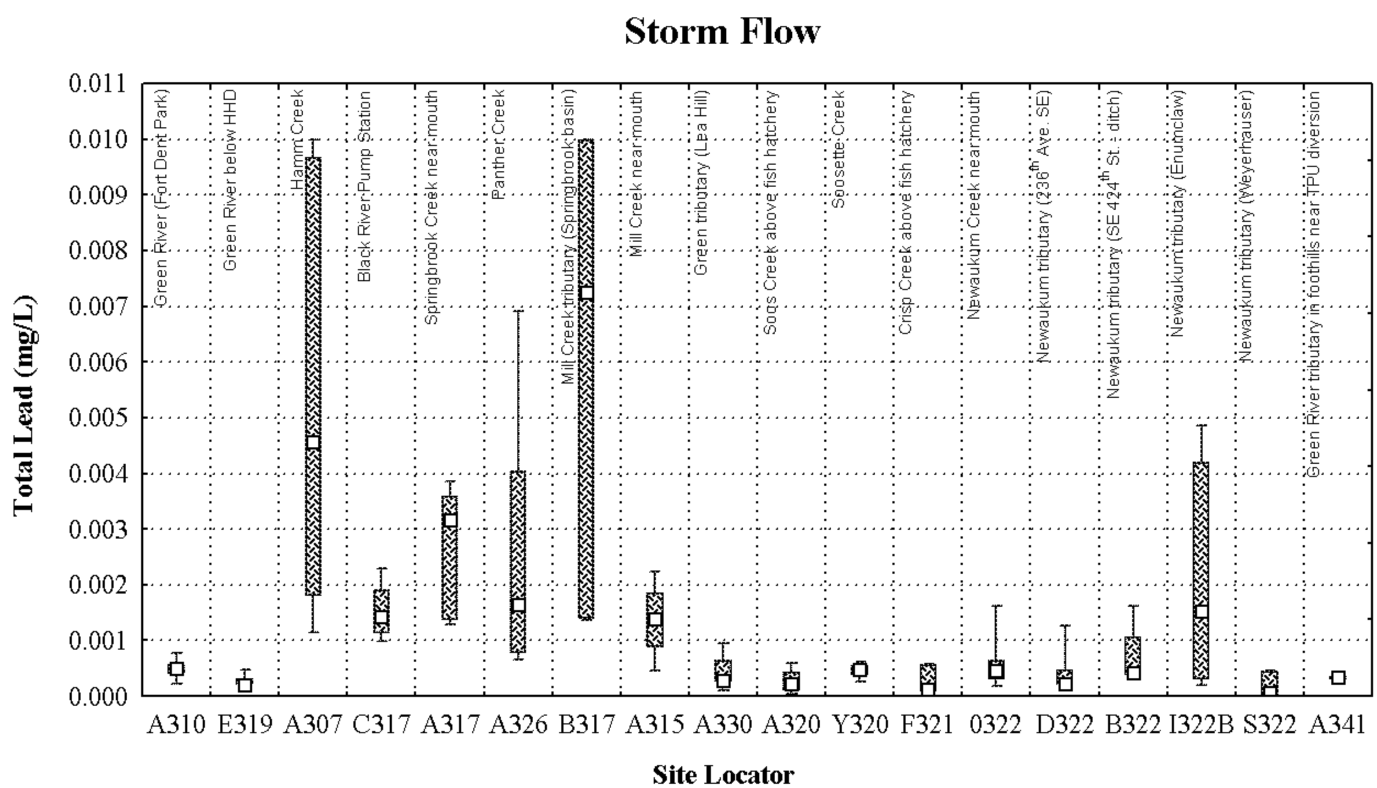

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 40. Total lead concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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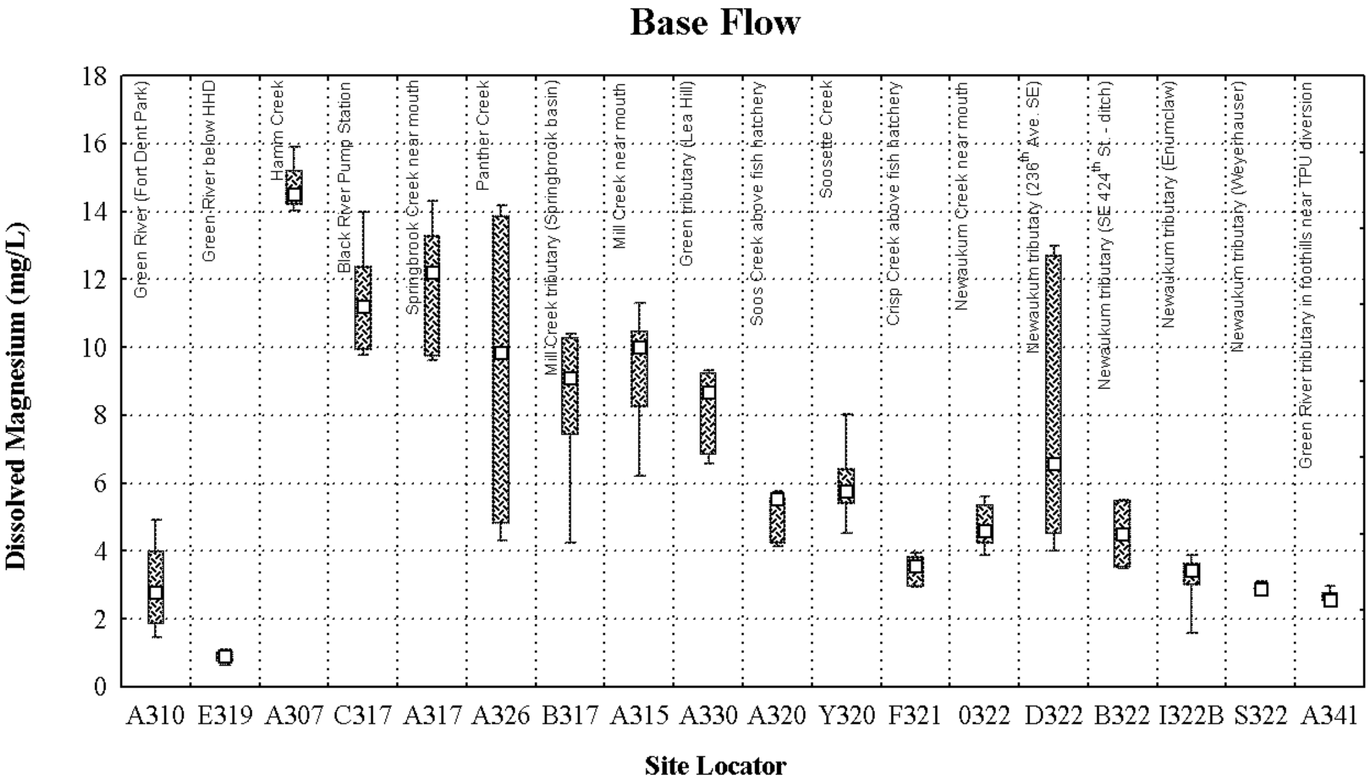

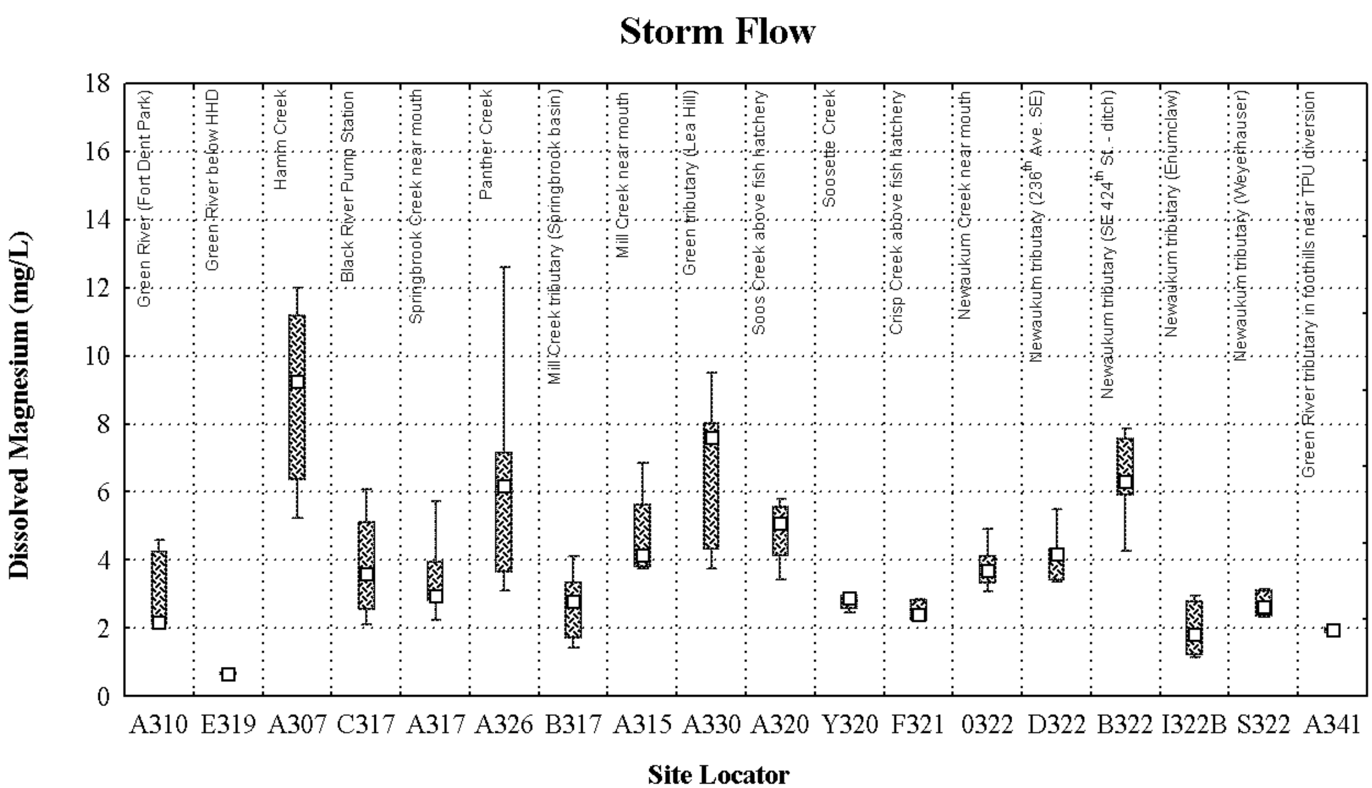

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 41. Dissolved magnesium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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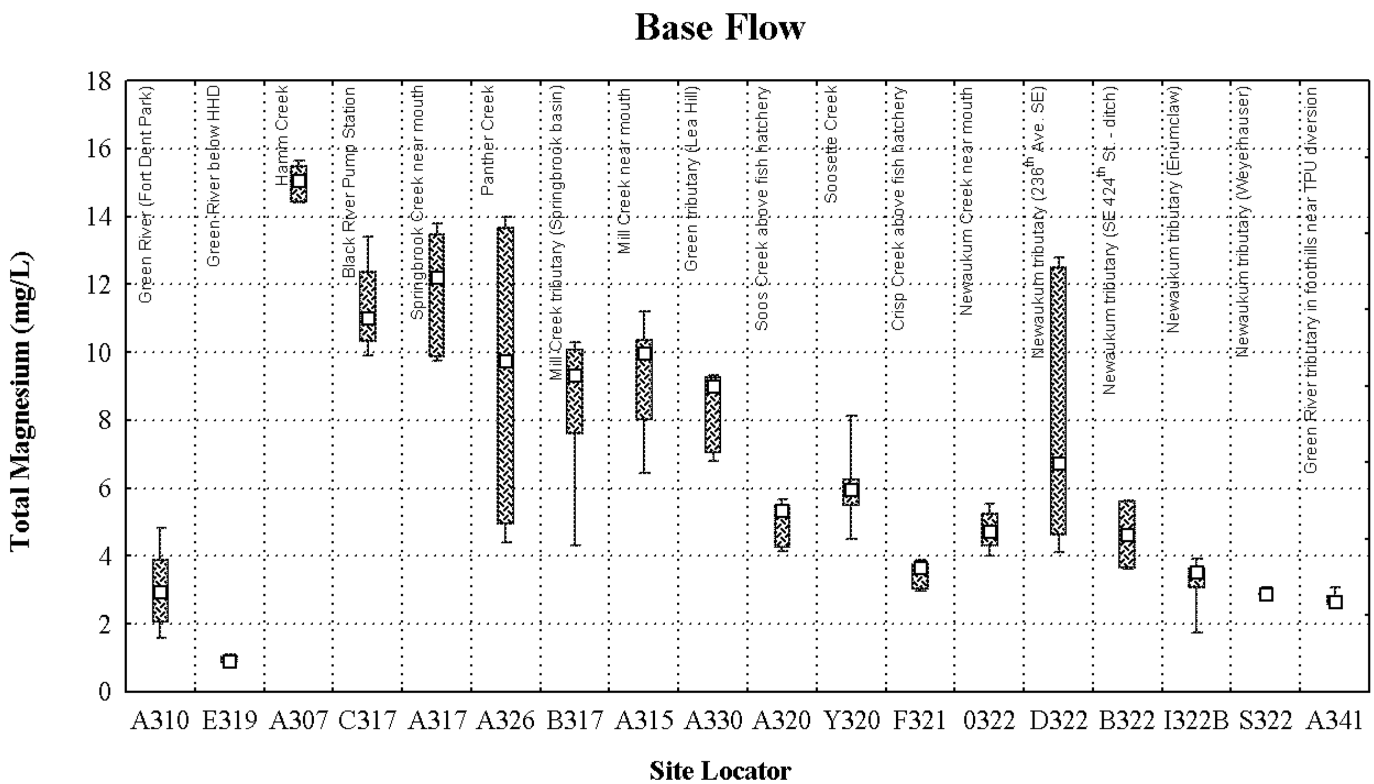

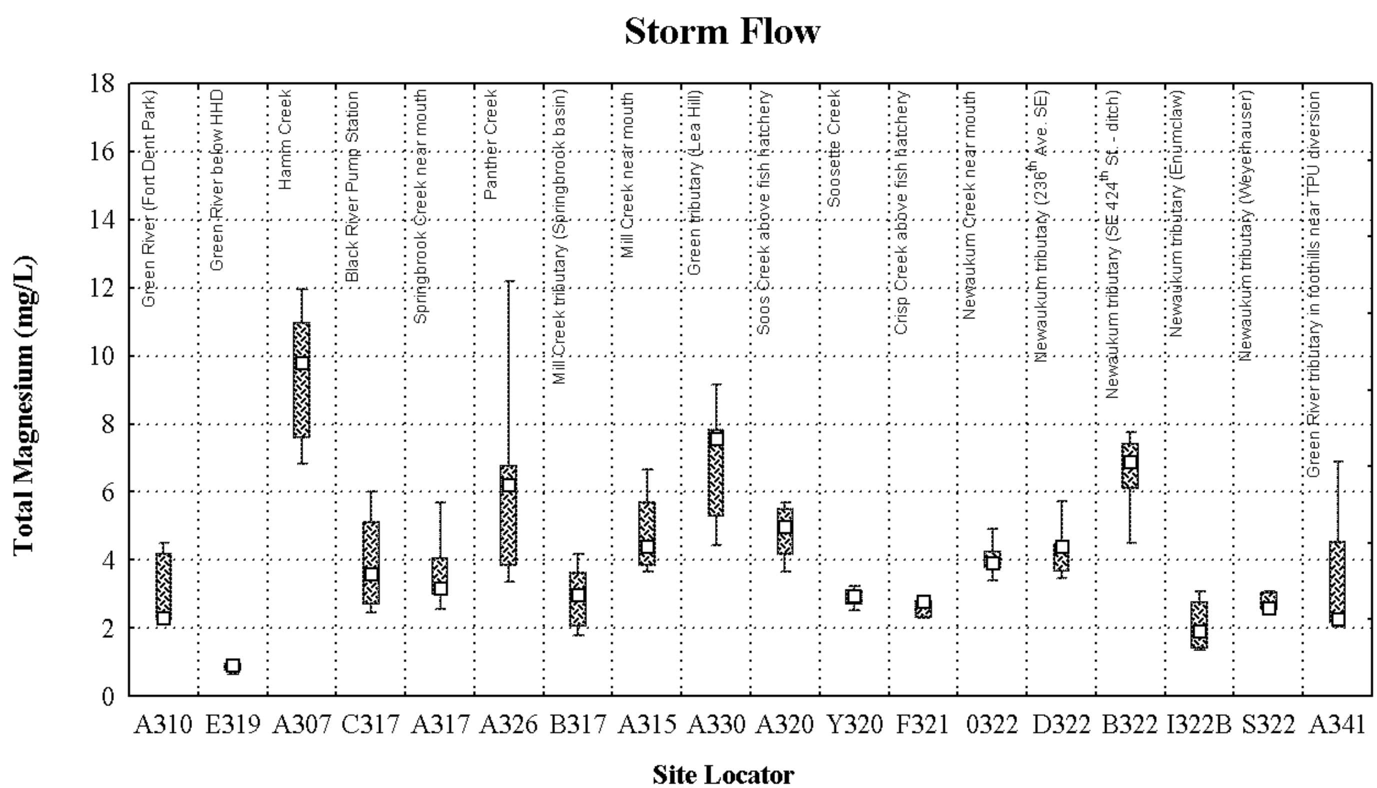

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 42. Total magnesium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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Dissolved magnesium concentrations ranged from 0.63 to 16.55 mg/L during base flow, and from 0.30 to 12.84 mg/L during storm flow. Total magnesium concentrations ranged from 0.68 to 16.27 mg/L during base flow, and from 0.52 to 12.73 mg/L during storm flow. The median total magnesium concentration for all sites combined was higher during base flow (5.29 mg/L) than storm flow (3.49 mg/L).

Based on results of the spatial pattern analysis for the Green River, dissolved magnesium concentrations were significantly higher downstream during base flow ($p < 0.0001$) and storm flow ($p < 0.0001$) (Table J13). The median dissolved magnesium concentration increased downstream from 0.90 to 2.78 mg/L during base flow, and from 0.65 to 2.17 mg/L during storm flow. Total magnesium concentrations were also significantly higher downstream during base flow ($p < 0.0001$) and storm flow ($p < 0.0001$). Median total magnesium concentrations increased downstream from 0.91 to 2.93 mg/L during base flow, and from 0.90 to 2.29 mg/L during storm flow.

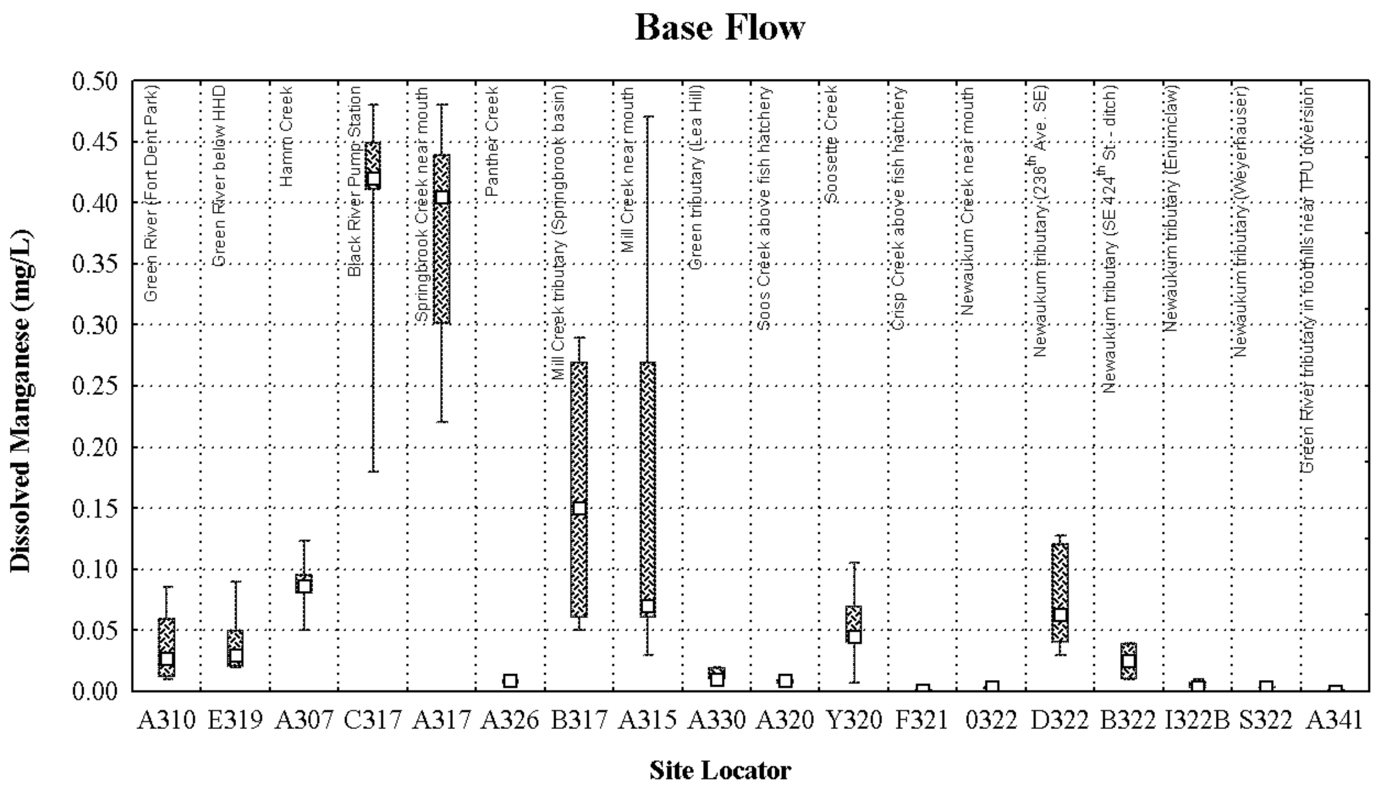
Spatial pattern analysis results for the major streams showed that dissolved magnesium concentrations were significantly ($p < 0.0001$) higher during base flow in Springbrook Creek (A317) relative to Soos Creek (0322) (Tables J14 and J15). Total magnesium concentrations were significantly ($p < 0.0001$) higher during base flow in Springbrook Creek (A317) relative to Newaukum Creek (0322). There were no significant differences in dissolved or total magnesium concentrations between the major stream sites during storm flow. The tributary sites exhibited magnesium concentrations that were similar to those for the major stream sites with the exception that median dissolved and total magnesium concentrations were highest at Hamm Creek (A307) during base and storm flow.

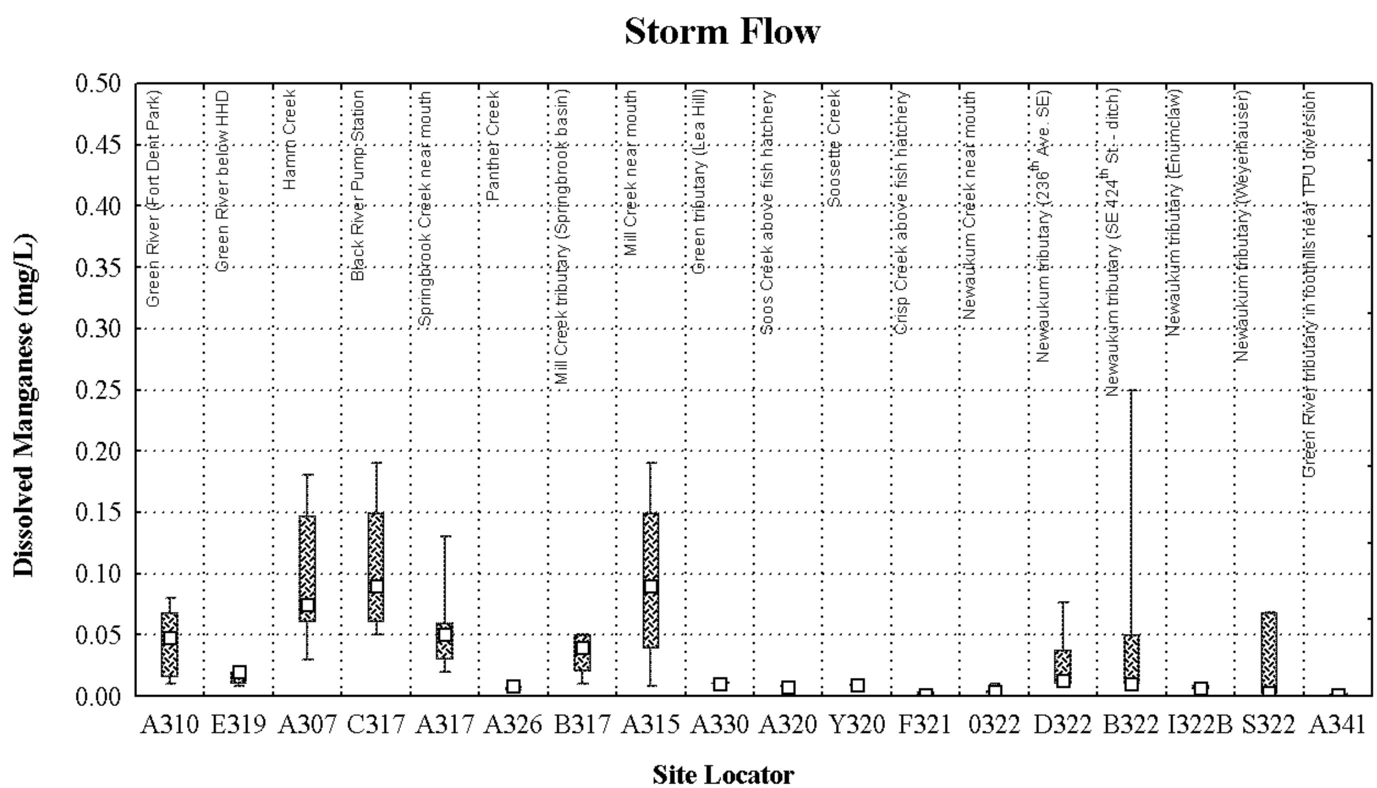
5.2.5.10 Manganese

Summary statistics for dissolved manganese during base and storm flow are presented in Table H19 and Figure 43. Summary statistics for total manganese during base and storm flow are presented in Table H20 and Figure 44. Washington State does not have surface water quality criteria for dissolved or total manganese (WAC 173-201A).

Dissolved manganese concentrations ranged from 0.0003 to 0.5500 mg/L during base flow, and ranged from 0.0006 to 0.2837 mg/L during storm flow. Total manganese concentrations ranged from 0.0009 to 0.5400 mg/L during base flow, and ranged from 0.0028 mg/L to 2.2900 mg/L during storm flow. The median total manganese concentration for all sites combined was higher during base flow (5.29 mg/L) than storm flow (3.49 mg/L).

Results of the spatial pattern analyses for the Green River (Table J13) showed a significant ($p = 0.0368$) increase in dissolved manganese concentrations downstream during storm flow, but not during base flow. The median dissolved manganese concentration increased downstream from 0.0200 to 0.0473 mg/L during storm flow. There were no significant differences in total manganese concentrations between the upper and lower sites during base flow or storm flow.





Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 43. Dissolved manganese concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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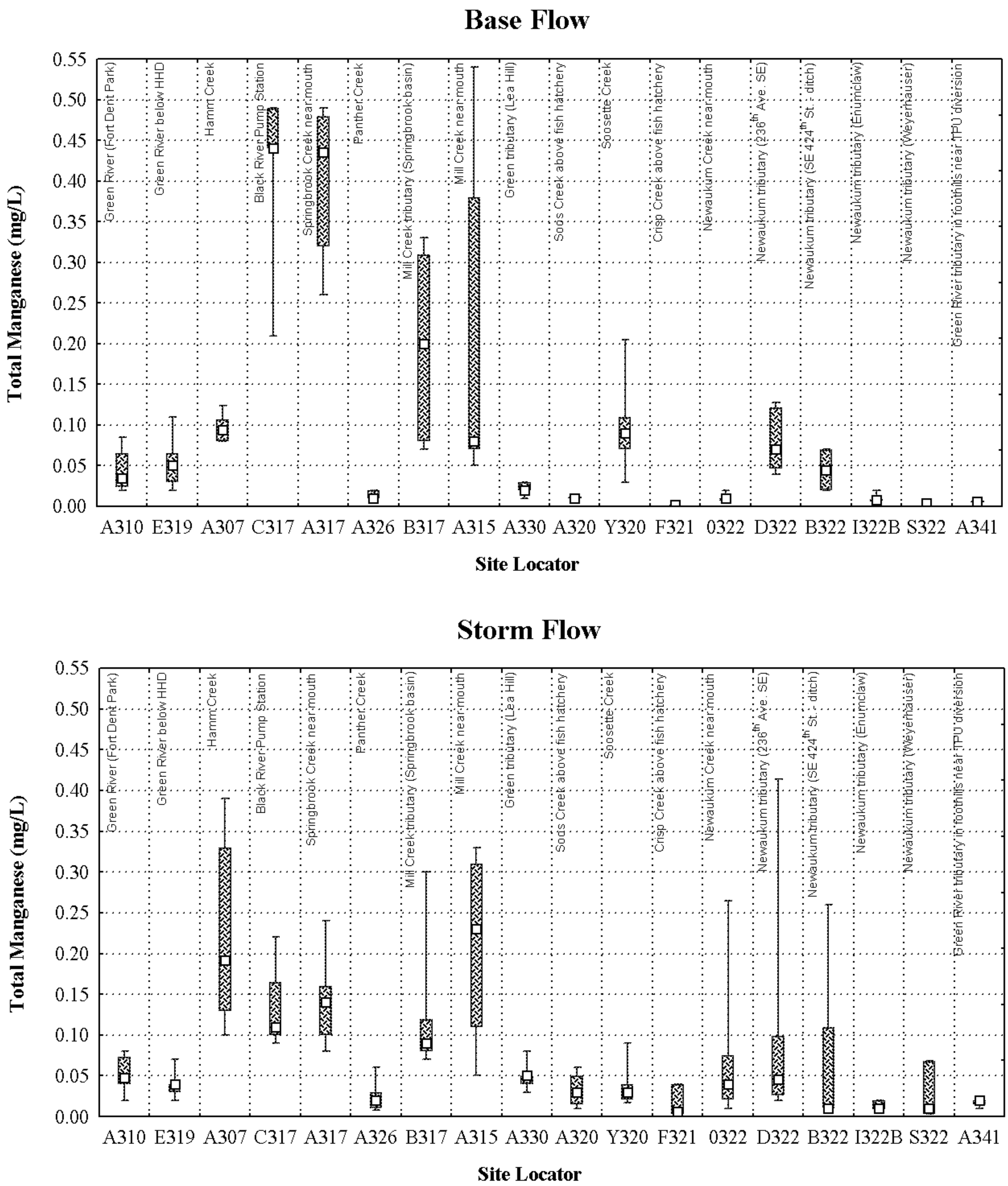

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 44. Total manganese concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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Among the major stream sites, results of the spatial pattern analysis (Tables J14 and J15) showed that the dissolved manganese concentrations were significantly ($p < 0.0001$) higher during base flow in Springbrook Creek (A317) and the Black River (C317) relative to Soos Creek (A320), and were significantly ($p < 0.0001$) higher during storm flow in the Black River. Total manganese concentrations were significantly ($p < 0.0001$) higher during base flow in the Black River (C317) and Springbrook Creek (A317) relative to Soos Creek (0322), and were significantly ($p = 0.0024$) higher during storm flow in Mill Creek (A315) relative to Soos Creek (A320).

The tributary sites exhibited manganese concentrations that were similar to those for the major stream sites.

5.2.5.11 Mercury

Summary statistics for dissolved mercury during base and storm flow are presented in Table H21 and Figure 45. Summary statistics for total mercury during base and storm flow are presented in Table H22 and Figure 46. Washington State has established an acute criterion of 0.0021 mg/L for dissolved mercury and a chronic criterion of 0.000012 mg/L for total mercury (WAC 173-201A) (see Table 11). The chronic criterion for total mercury was slightly exceeded during base flow on one occasion at the Lower Green River (0.0000127 mg/L total mercury at site A310) and Mill (Springbrook) tributary (0.0000130 mg/L total mercury at site B317). The acute criterion for dissolved mercury was not exceeded during storm flow (or base flow). Dissolved mercury concentrations ranged from less than 0.0000001 to 0.00000050 mg/L during base flow, and ranged from less than 0.0000004 to 0.0000101 mg/L during storm flow. Total mercury concentrations ranged from 0.0000002 to 0.0000130 mg/L during base flow, and ranged from 0.0000006 to 0.0002440 mg/L during storm flow. The median dissolved mercury concentration for all sites combined was higher during storm flow (0.0000050 mg/L) than base flow (0.0000019 mg/L), and the median total mercury concentration was higher during storm flow (0.0000064 mg/L) than base flow (0.0000032 mg/L).

Spatial pattern analysis results for the Green River showed there were no significant differences in dissolved and total mercury concentrations between the upper and lower sites during either base flow or storm flow (Table J13). Among the major streams, dissolved mercury concentrations were significantly ($p = 0.0049$) higher during base flow in Newaukum Creek (0322) relative to Mill Creek (A315), and were significantly ($p = 0.0002$) higher during storm flow in Newaukum Creek (0322) relative to Soos Creek (A320) (Tables J14 and J15). There were no significant differences in total mercury concentrations between the major stream sites during base flow, but total mercury concentrations were significantly higher ($p=0.0182$) during storm flow Springbrook Creek (A317) relative to Soos Creek (A320).

The tributary sites exhibited mercury concentrations that were similar to those for the major stream sites with the exception that median dissolved and total mercury concentrations were highest during storm flow at Hamm Creek (A307).

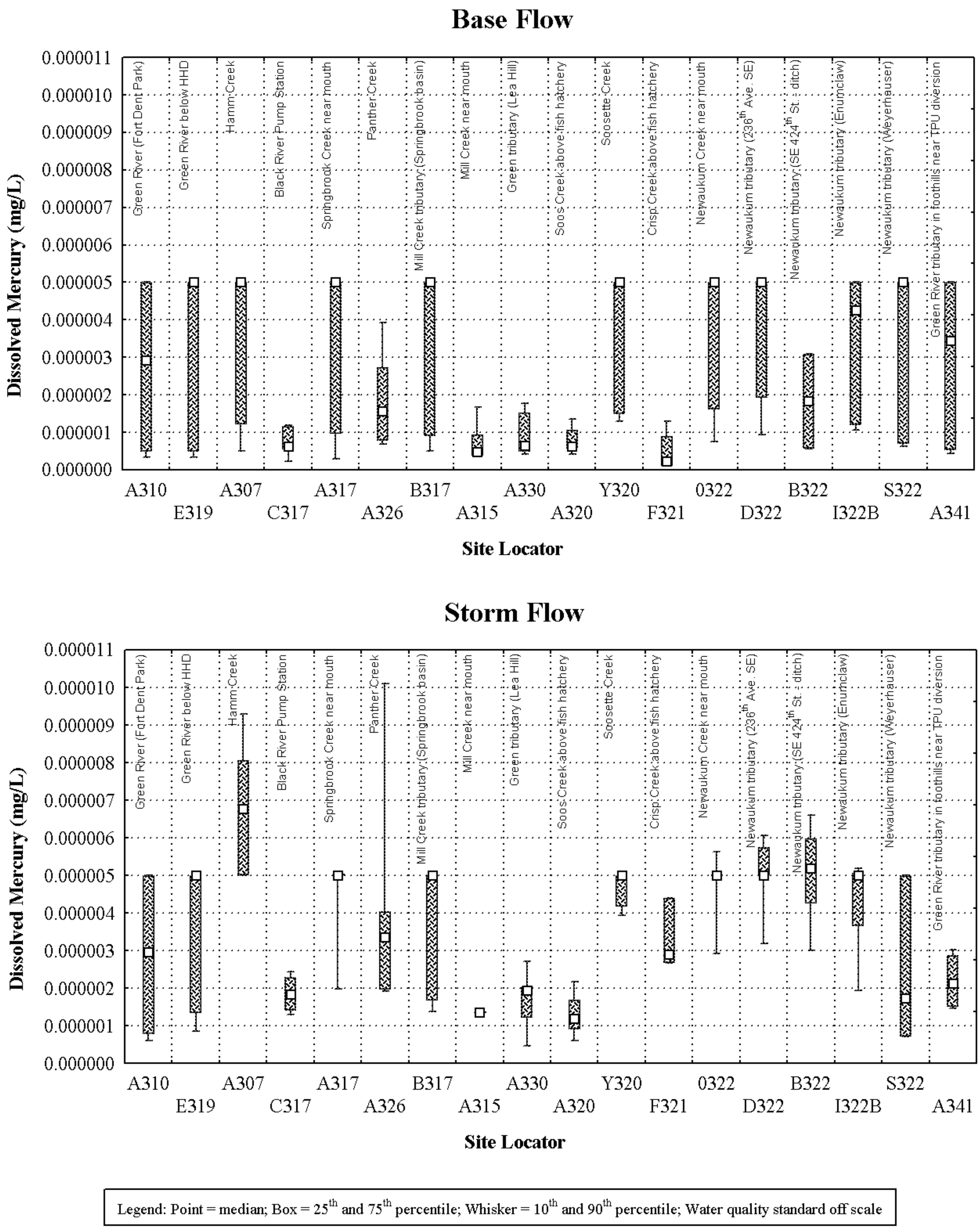

Figure 45. Dissolved mercury concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

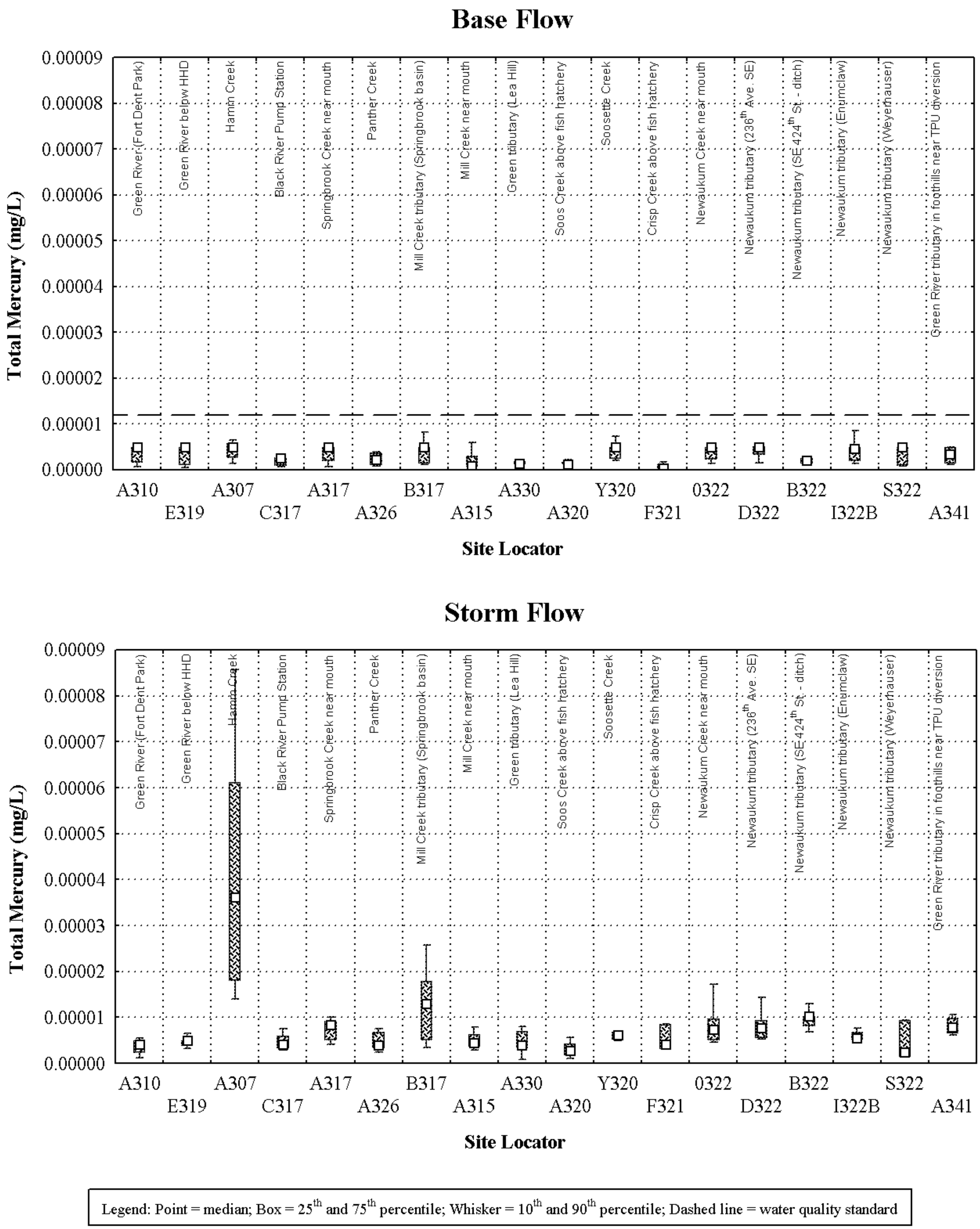

Figure 46. Total mercury concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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5.2.5.12 Nickel

Summary statistics for dissolved nickel during base and storm flow are presented in Table H23 and Figure 47. Summary statistics for total nickel during base and storm flow are presented in Table H24 and Figure 48. Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for dissolved nickel that vary with hardness (Table 11). None of the sample values exceeded the state chronic criterion during base flow or the acute criterion during storm flow.

Dissolved nickel concentrations ranged from less than 0.00008 to 0.00189 mg/L during base flow, and ranged from 0.00007 to 0.00205 mg/L during storm flow. Total nickel concentrations ranged from 0.00011 to 0.00288 mg/L during base flow, and ranged from 0.00014 to 0.050 mg/L during storm flow. Median dissolved nickel concentrations for all sites combined were similar during storm flow (0.00071 mg/L) and base flow (0.00065 mg/L), but the median total nickel concentration was higher during storm flow (0.00116 mg/L) than base flow (0.00076 mg/L).

Based on results of the spatial pattern analysis for the Green River, dissolved nickel concentrations significantly ($p = 0.0373$) increased downstream during base flow, but not during storm flow (Table J13). However, median dissolved nickel concentrations for the upper (E319) and lower (A310) sites were similar at during base flow (0.00030 and 0.00031 mg/L, respectively). Total nickel concentrations significantly increased downstream during base flow ($p < 0.0001$) and storm flow ($p = 0.0060$). The median total nickel concentration increased downstream from 0.00030 to 0.00049 mg/L during base flow, and from 0.00036 to 0.00055 mg/L during storm flow.

Spatial pattern analysis for the major streams showed that dissolved nickel concentrations were significantly higher during base flow ($p < 0.0001$) and storm flow ($p = 0.0046$) in Springbrook Creek (A317) relative to Soos Creek (A320) and Newaukum Creek (0322) (Tables J14 and J15). Total nickel concentrations were significantly ($p < 0.0001$) higher during base flow in the Black River (C317) and Springbrook Creek (A317) relative to Newaukum Creek (0322), and were significantly ($p = 0.0198$) higher during storm flow in Springbrook Creek (A317) relative to Newaukum Creek (0322).

The tributary sites exhibited nickel concentrations that were similar to those for the major stream sites with the exception that median dissolved and total nickel concentrations were highest during storm flow at Hamm Creek (A307).

5.2.5.13 Potassium

Summary statistics for dissolved potassium during base and storm flow are presented in Table H25 and Figure 49. Summary statistics for total potassium during base and storm flow are presented in Table H26 and Figure 50. Washington State does not have surface water quality criteria for dissolved or total potassium (WAC 173-201A).

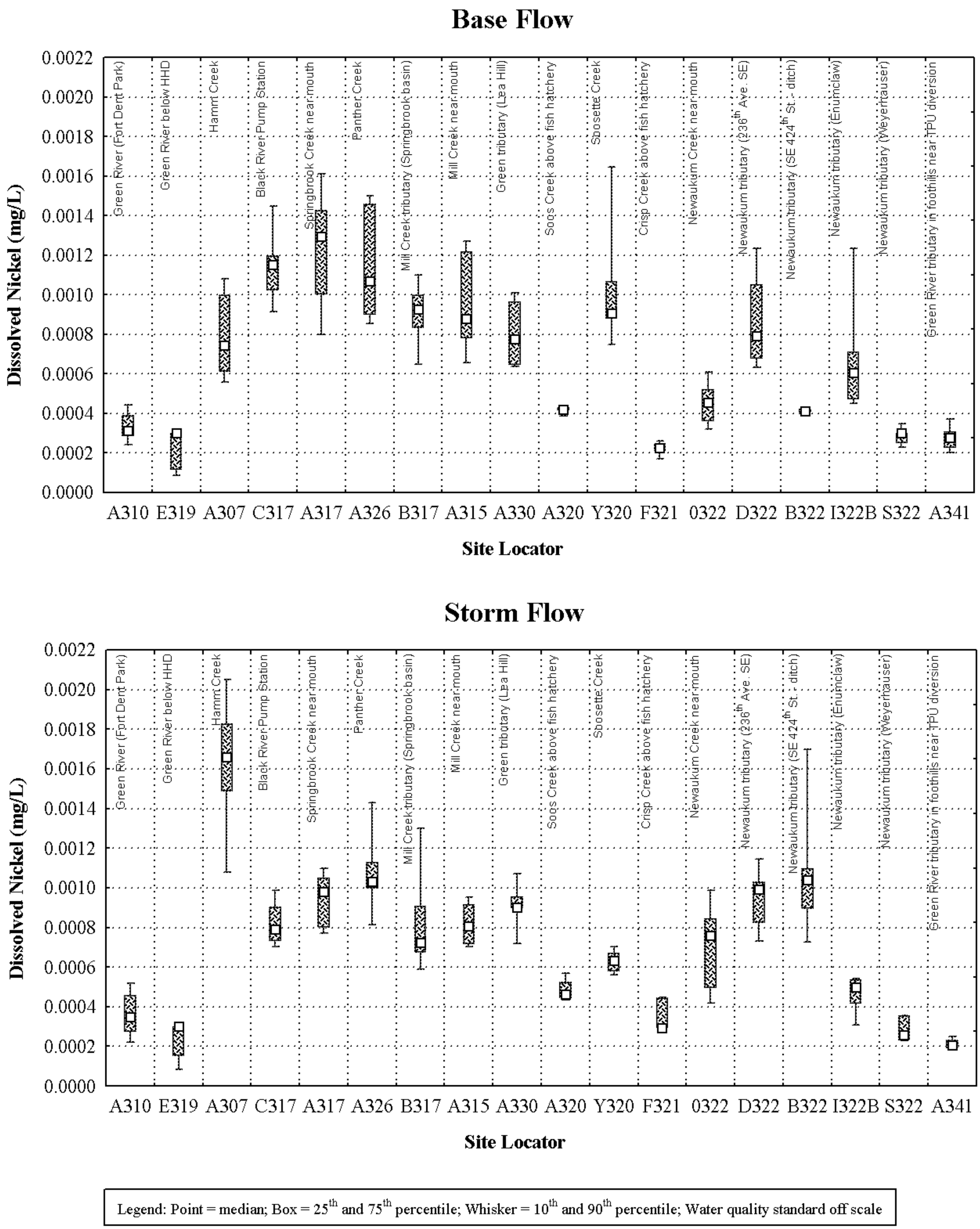
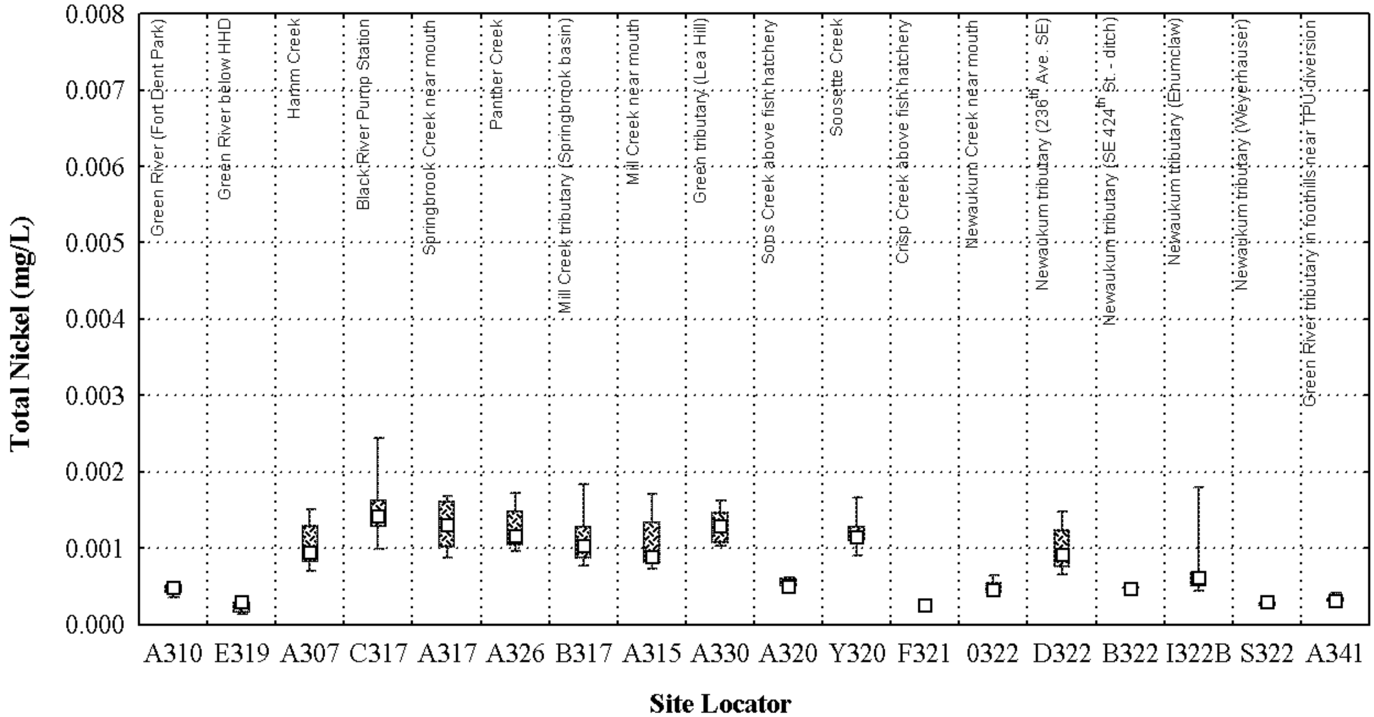
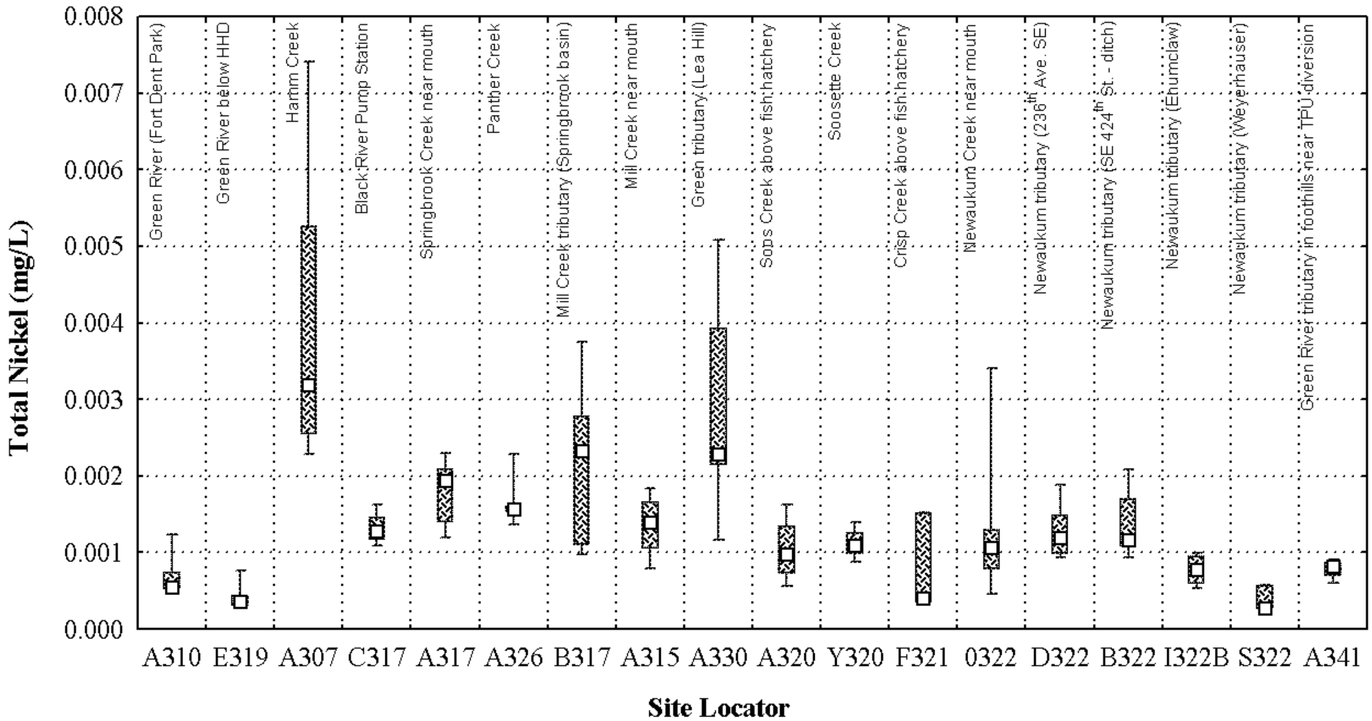


Figure 47. Dissolved nickel concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

Base Flow



Storm Flow



Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 48. Total nickel concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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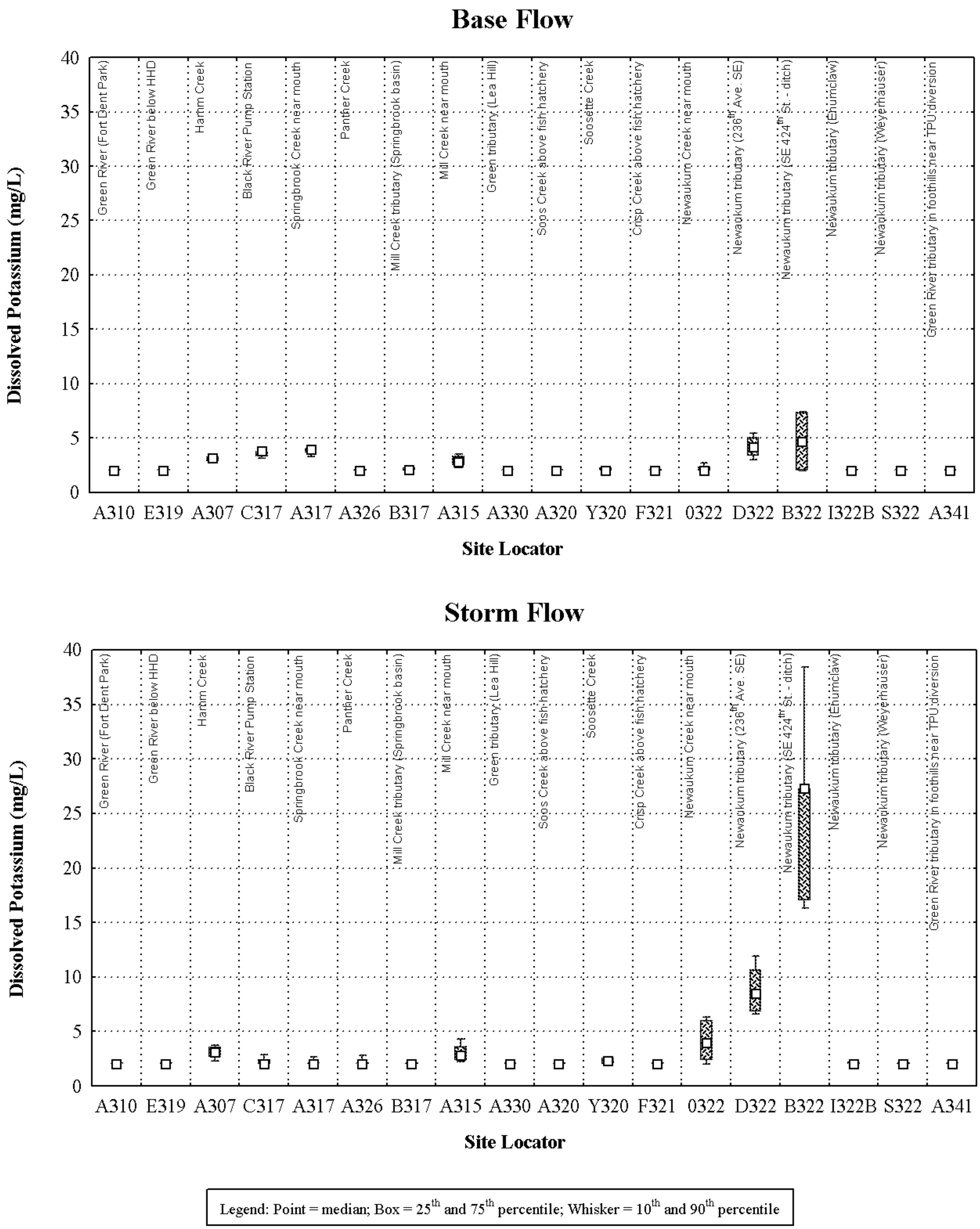


Figure 49. Dissolved potassium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

HERRERA ENVIRONMENTAL CONSULTANTS

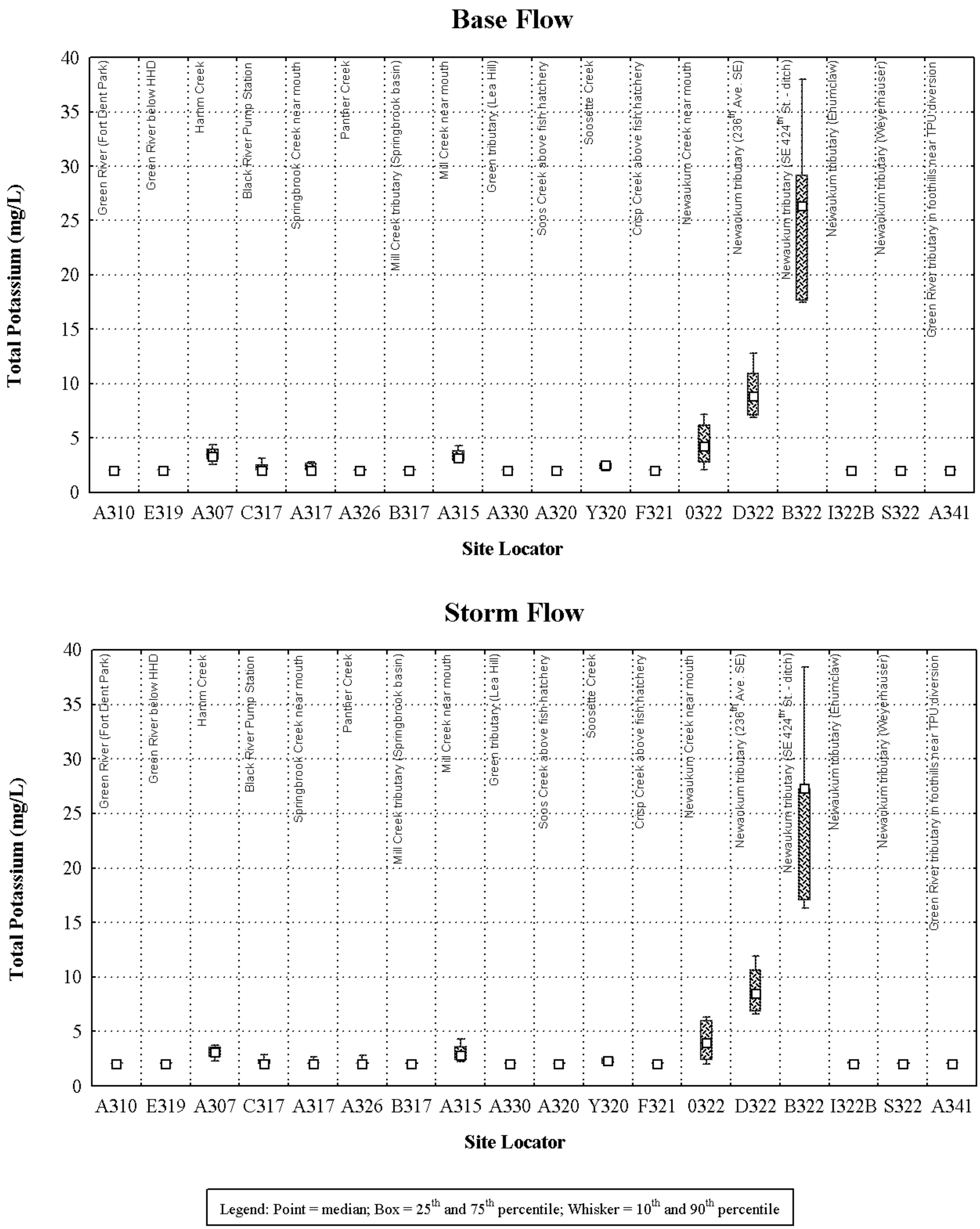


Figure 50. Total potassium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

Dissolved potassium concentrations ranged from less than 2 to 9 mg/L during base flow, and ranged from less than 2 mg/L to 38 mg/L during storm flow. Total potassium concentrations ranged from less than 2 to 9 mg/L during base flow, and ranged from less than 2 mg/L to 38 mg/L during storm flow.

Results of the spatial pattern analysis for the Green River showed that there were no significant differences in dissolved and total potassium concentrations between the upper and lower sites during base flow or storm flow (Table J13). Spatial pattern analysis results for the major stream sites showed that dissolved potassium concentrations were significantly ($p < 0.0001$) higher during base flow in the Black River (C317) and Springbrook Creek (A317) relative to Newaukum Creek (0322) and Soos Creek (A320), and were significantly ($p = 0.0003$) higher during storm flow in Newaukum Creek (0322) relative to Soos Creek (A320) (Tables J14 and J15). Total potassium concentrations were significantly higher ($p < 0.0001$) during base flow in Springbrook Creek (A317) relative Soos Creek (A320) and Newaukum Creek (0322), and were significantly higher ($p = 0.0002$) during storm flow in Newaukum Creek (0322) relative to Soos Creek (A320).

Median dissolved and total potassium concentrations were consistently highest during base and storm flow at Newaukum tributary at SE 424th (B322), followed by Newaukum tributary at 236th SE (D322). These two tributary sites represent agriculture/pasture land use.

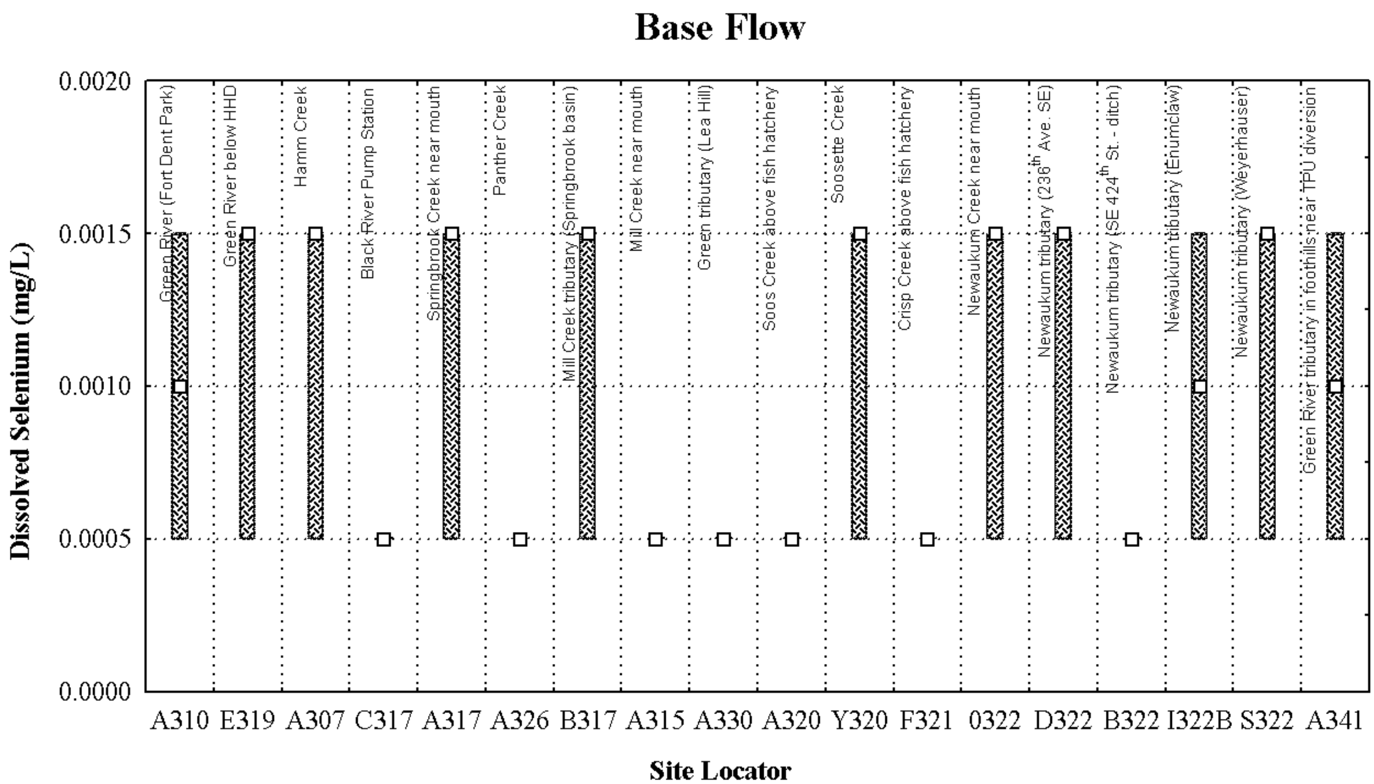
5.2.5.14 Selenium

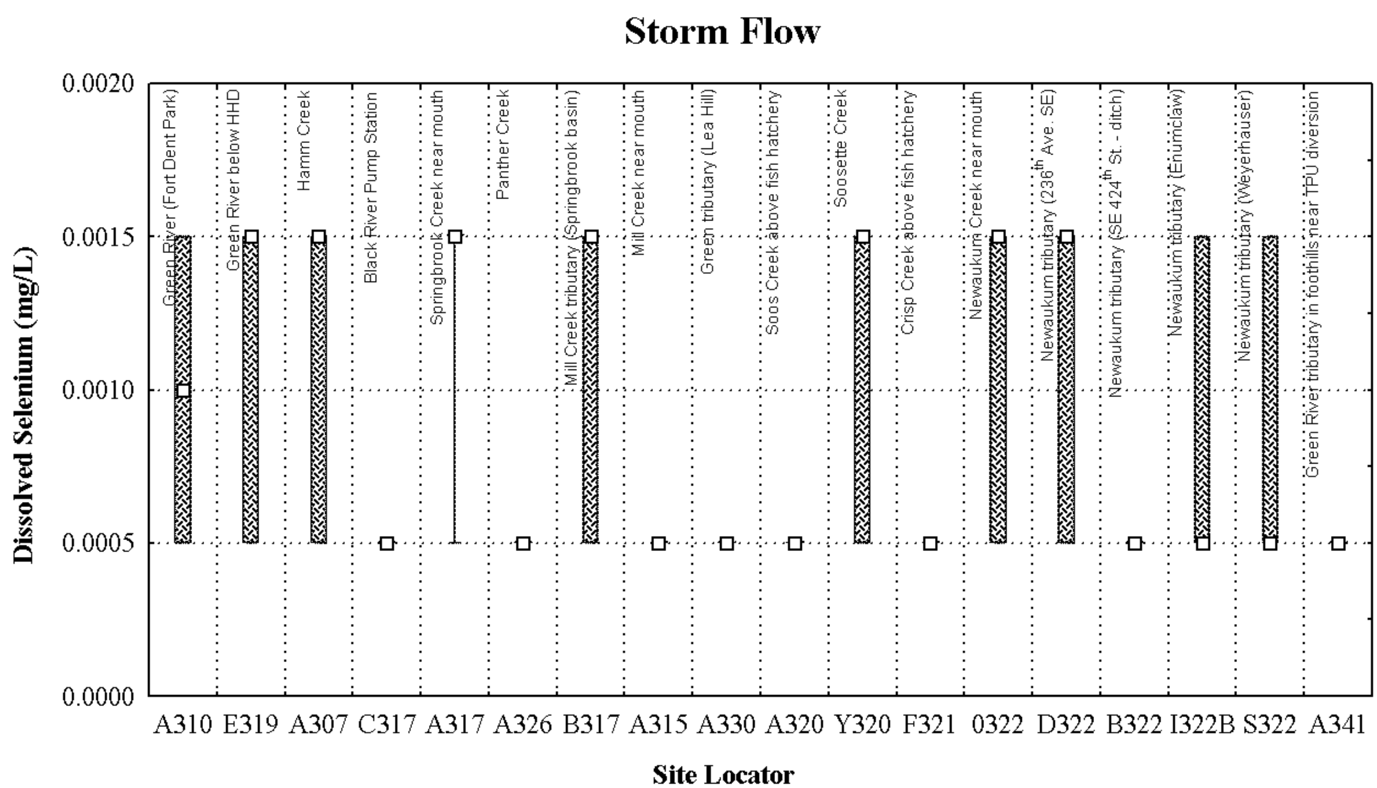
Summary statistics for dissolved selenium during base and storm flow are presented in Table H27 and Figure 51. Summary statistics for total selenium during base and storm flow are presented in Table H28 and Figure 52. Washington State surface water quality standards (WAC 173-201A) include an acute criterion of 0.020 mg/L and a chronic criterion of 0.005 mg/L for total selenium (Table 11) that were used for comparison to storm flow and base flow results, respectively. Total selenium concentrations (and detection limits) did not exceed the criteria at any site during either base flow or storm flow.

Dissolved and total selenium were not detected in any of the base flow or storm flow samples with the exception of dissolved selenium in one base flow sample collected from the Black River (0.0005 mg/L at site C317). Method detection limits for dissolved and total selenium ranged from 0.0005 to 0.0015 mg/L. There were no significant differences in selenium concentrations (or detection limits) between the Green River sites (Table J13). Spatial pattern analysis was not performed for the major stream sites because of the lack of detected values.

5.2.5.15 Silver

Summary statistics for dissolved silver during base and storm flow are presented in Table H29 and Figure 53. Summary statistics for total silver during base and storm flow are presented in Table H30 and Figure 54. Washington State surface water quality standards (WAC 173-201A) include an acute criterion for dissolved silver that varies with hardness (Table 11). None of the sample values (or detection limits) exceeded the acute criterion during base flow or storm flow.

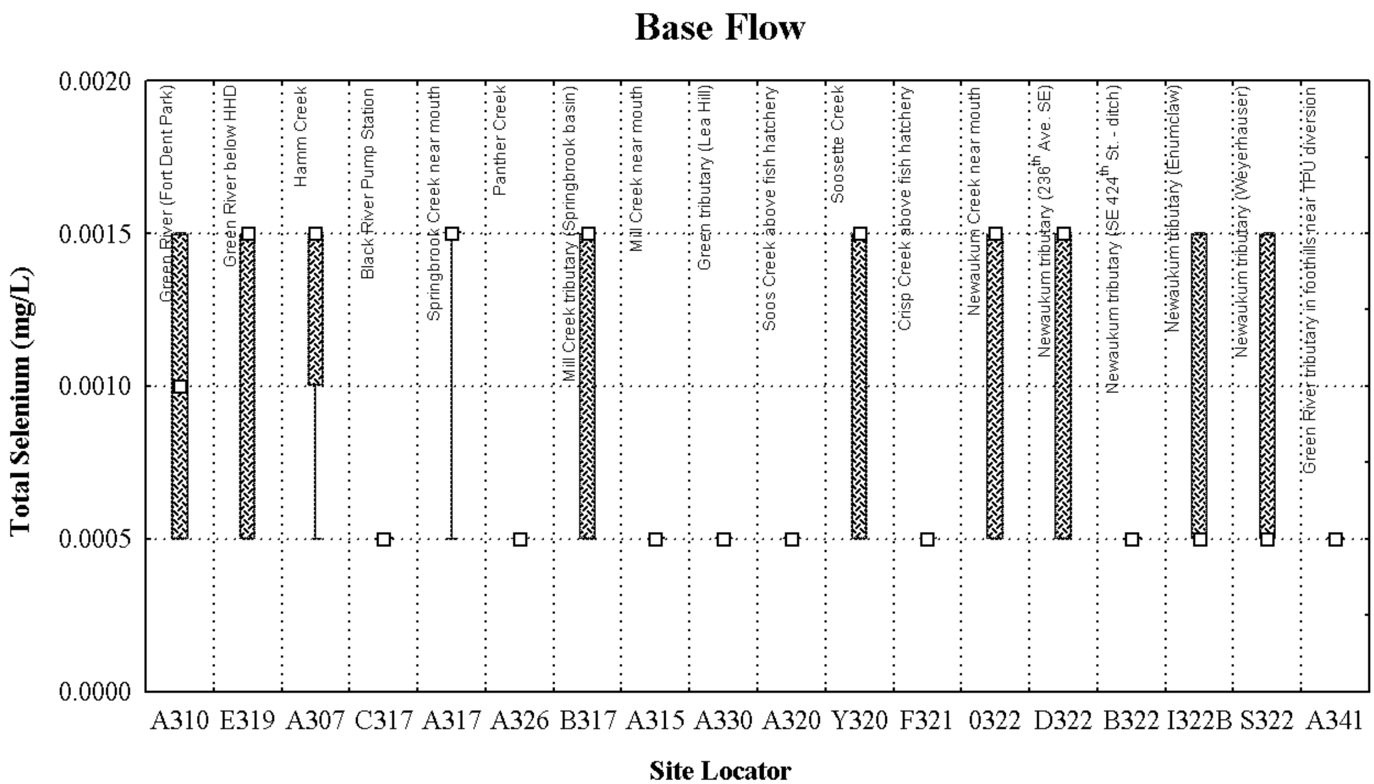


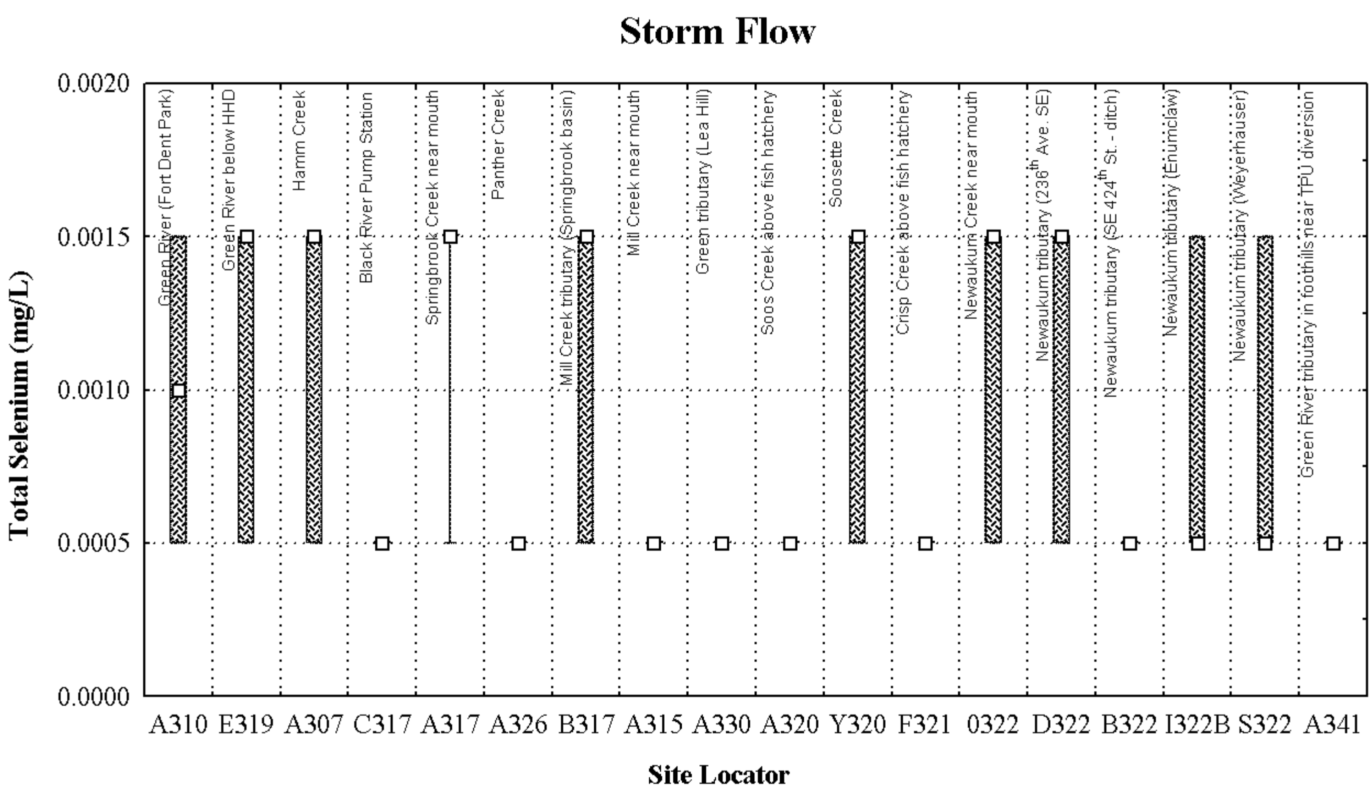


Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 51. Dissolved selenium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

HERRERA ENVIRONMENTAL CONSULTANTS





Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Water quality standard off scale

Figure 52. Total selenium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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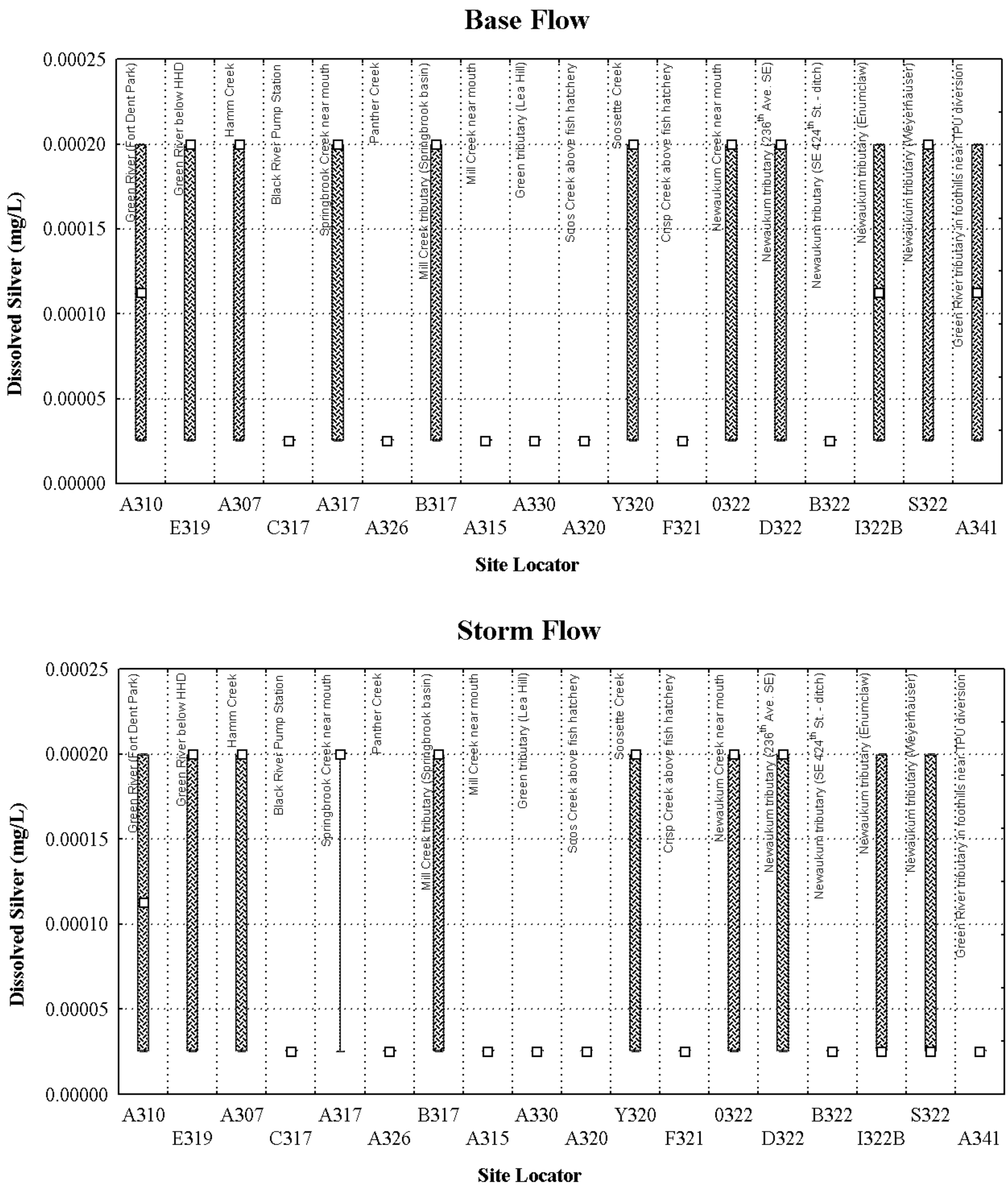

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile; Water quality standard off scale

Figure 53. Dissolved silver concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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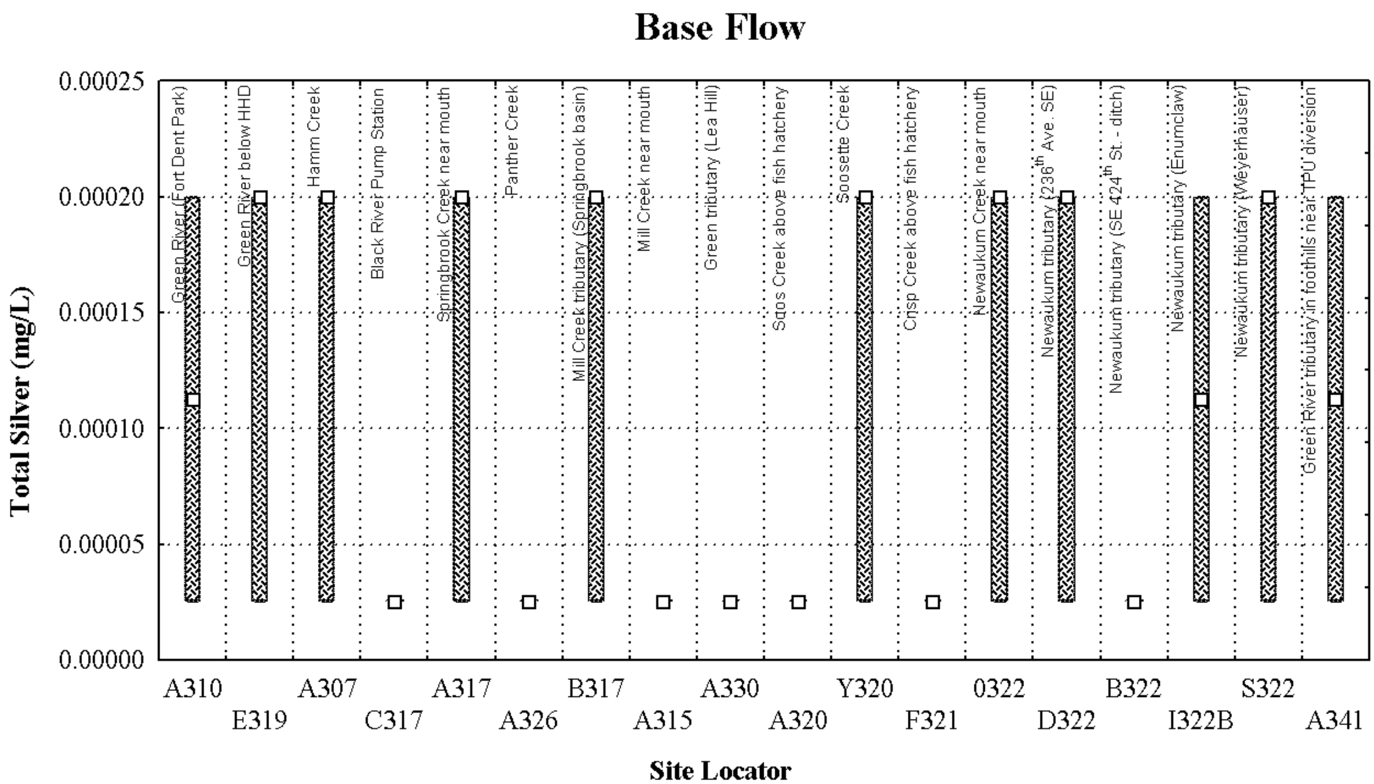

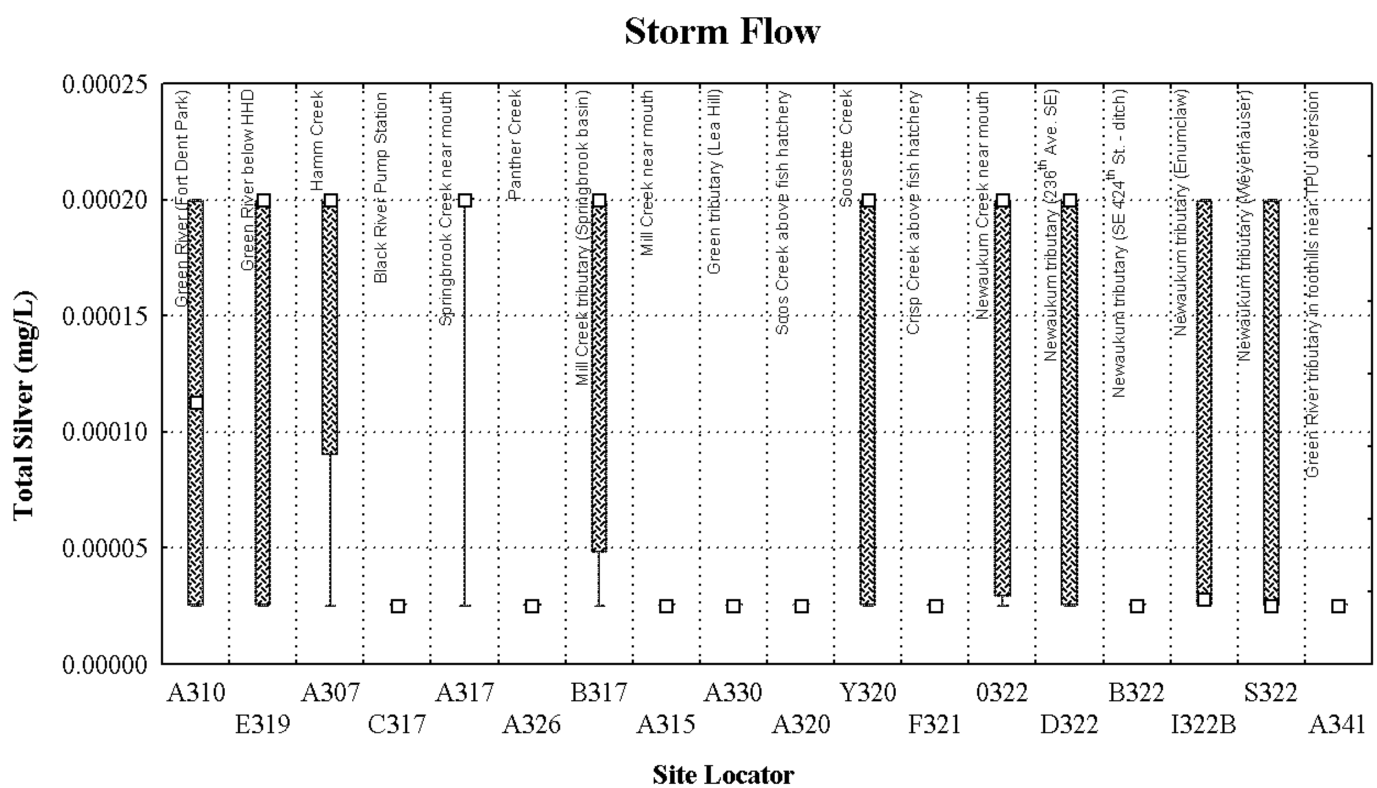

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 54. Total silver concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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Dissolved and total silver was not detected in any of the base flow and storm flow samples. Method detection limits for dissolved and total silver ranged from 0.000025 to 0.000200 mg/L. There were no significant differences in silver concentrations (or detection limits) between the Green River sites (Table J13). Spatial pattern analysis was not performed for the major stream sites because of the lack of detected values.

5.2.5.16 Sodium

Summary statistics for dissolved sodium during base and storm flow are presented in Table H31 and Figure 55. Summary statistics for total sodium during base and storm flow are presented in Table H32 and Figure 56. Washington State does not have surface water quality standards for dissolved or total sodium (WAC 173-201A).

Dissolved sodium concentrations ranged from 1.4 to 39.2 mg/L during base flow, and ranged from 0.8 to 13.4 mg/L during storm flow. Total sodium concentrations exhibited similar ranges (i.e., from 1.5 to 38.2 mg/L during base flow and from 0.9 to 12.5 mg/L during storm flow).

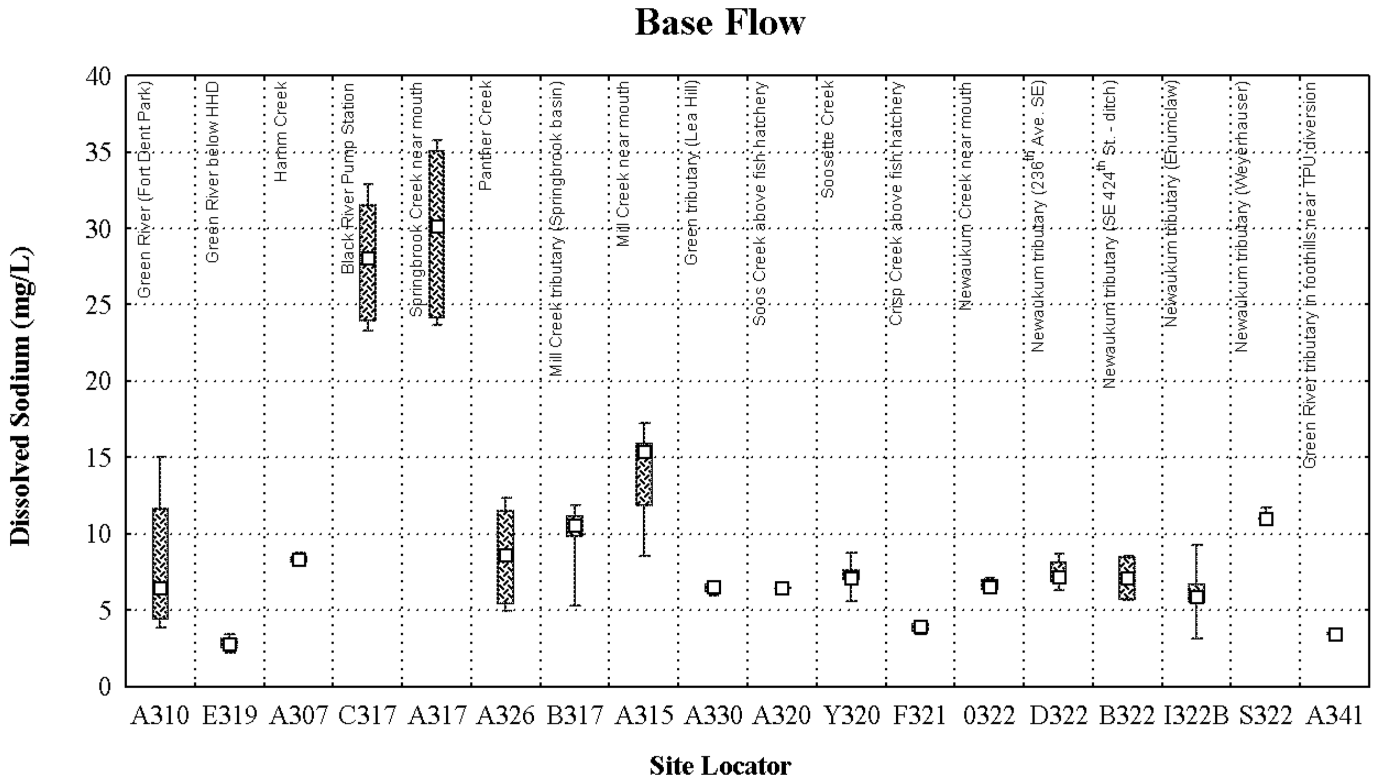
Spatial pattern analysis results for the Green River sites showed that both dissolved and total sodium concentrations significantly increased downstream during base flow ($p < 0.0001$) and storm flow ($p < 0.0001$) (Table J13). Median total sodium concentrations increased downstream from 2.8 to 6.7 mg/L during base flow, and increased downstream from 2.4 to 5.5 mg/L during storm flow.

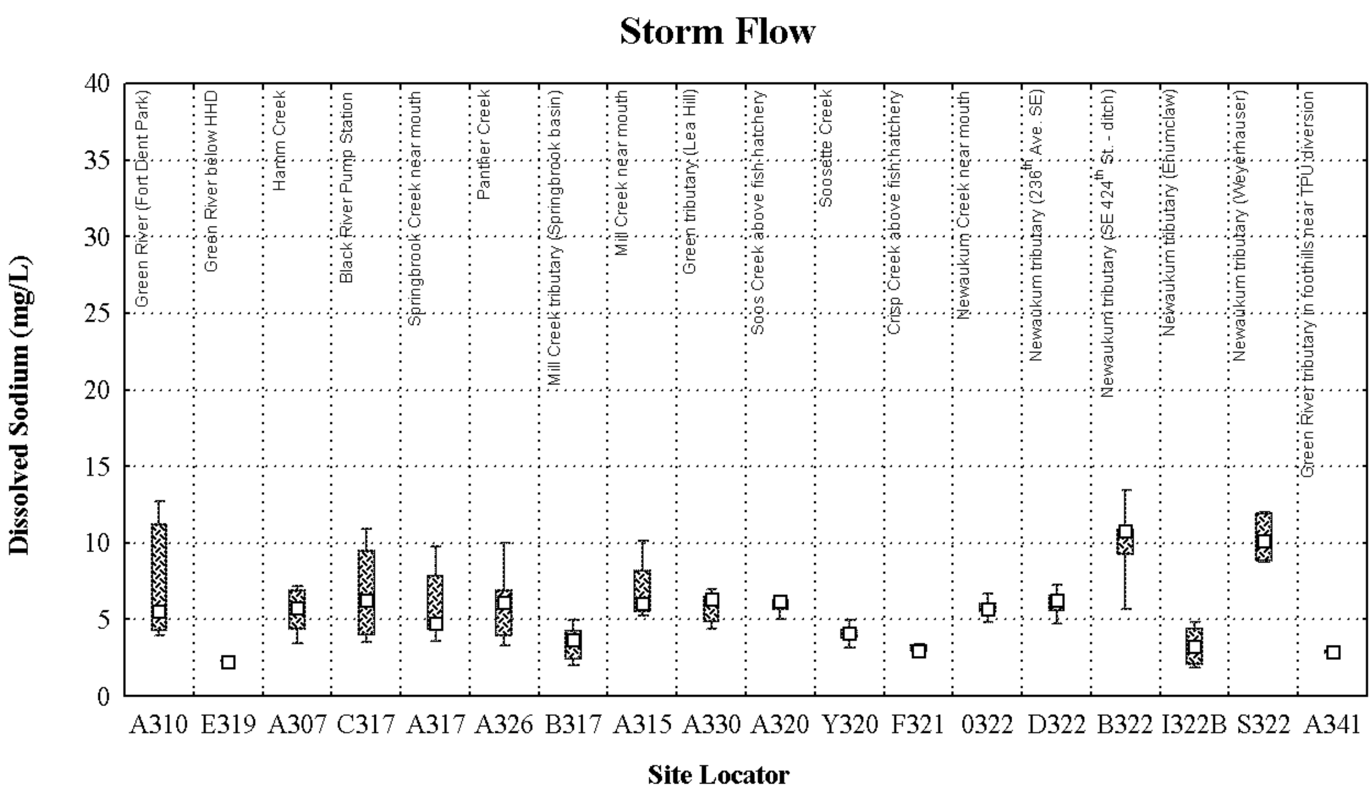
Results of the spatial pattern analysis for the major stream sites showed that dissolved sodium concentrations were significantly higher during base flow and storm flow in the Black River (C317) and Springbrook Creek (A317) relative to Soos Creek (A320) and Newaukum Creek (0322) (Tables J14 and J15). There were no significant differences in dissolved or total sodium concentrations during storm flow among the major stream sites.

The tributary sites exhibited sodium concentration that were similar to those for the major stream sites with the exception that median dissolved and total sodium concentrations during storm flow were highest at Newaukum tributary at SE 424th (B322) and Newaukum tributary downstream of Weyerhaeuser (S322).

5.2.5.17 Zinc

Summary statistics for dissolved zinc during base and storm flow are presented in Table H33 and Figure 57. Summary statistics for total zinc during base and storm flow are presented in Table H34 and Figure 58. Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for dissolved zinc that vary with hardness (see Table 11). The chronic criterion was exceeded on one occasion during base flow at Mill (Springbrook) tributary (0.050 mg/L dissolved zinc at site B317). The acute criterion was exceeded on one occasion during storm flow at the Green tributary at Lea Hill (0.550 mg/L dissolved zinc at site A330).





Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 55. Dissolved sodium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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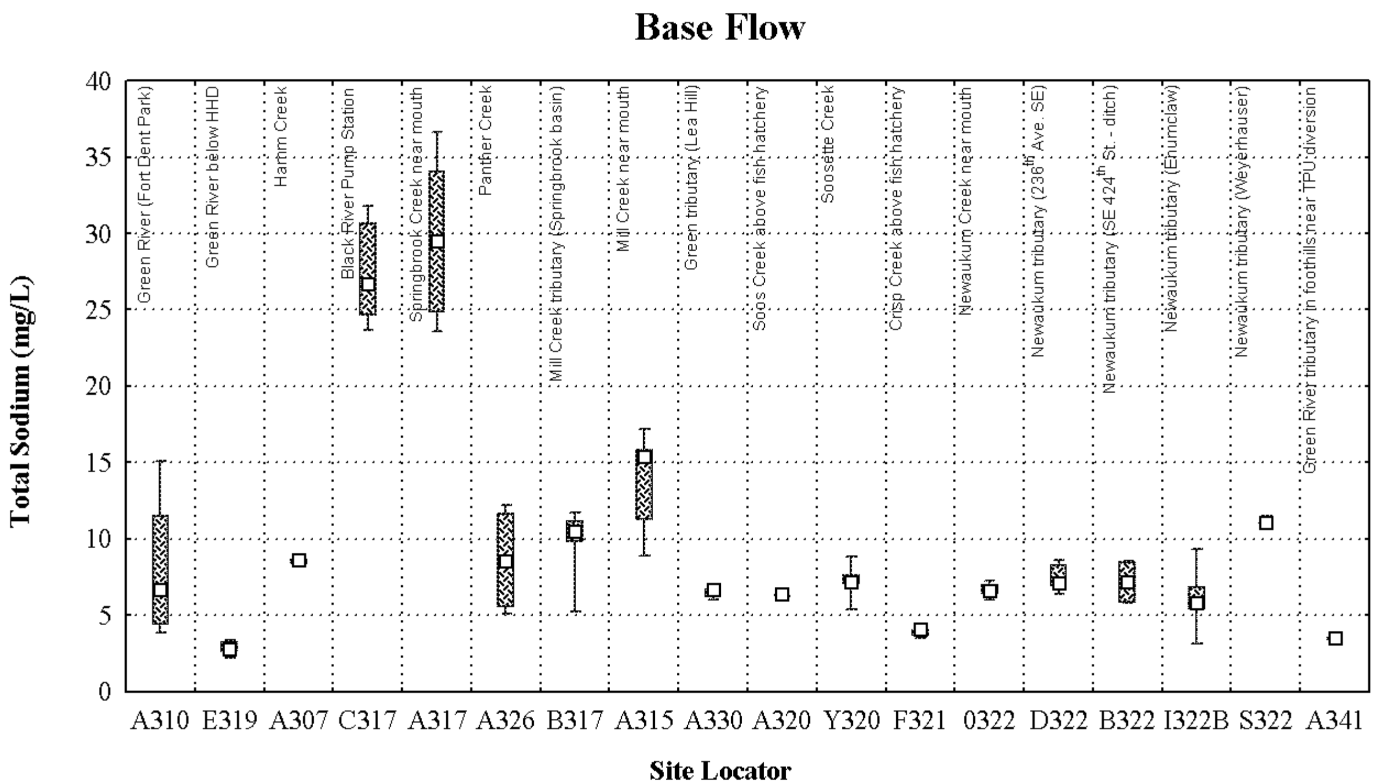

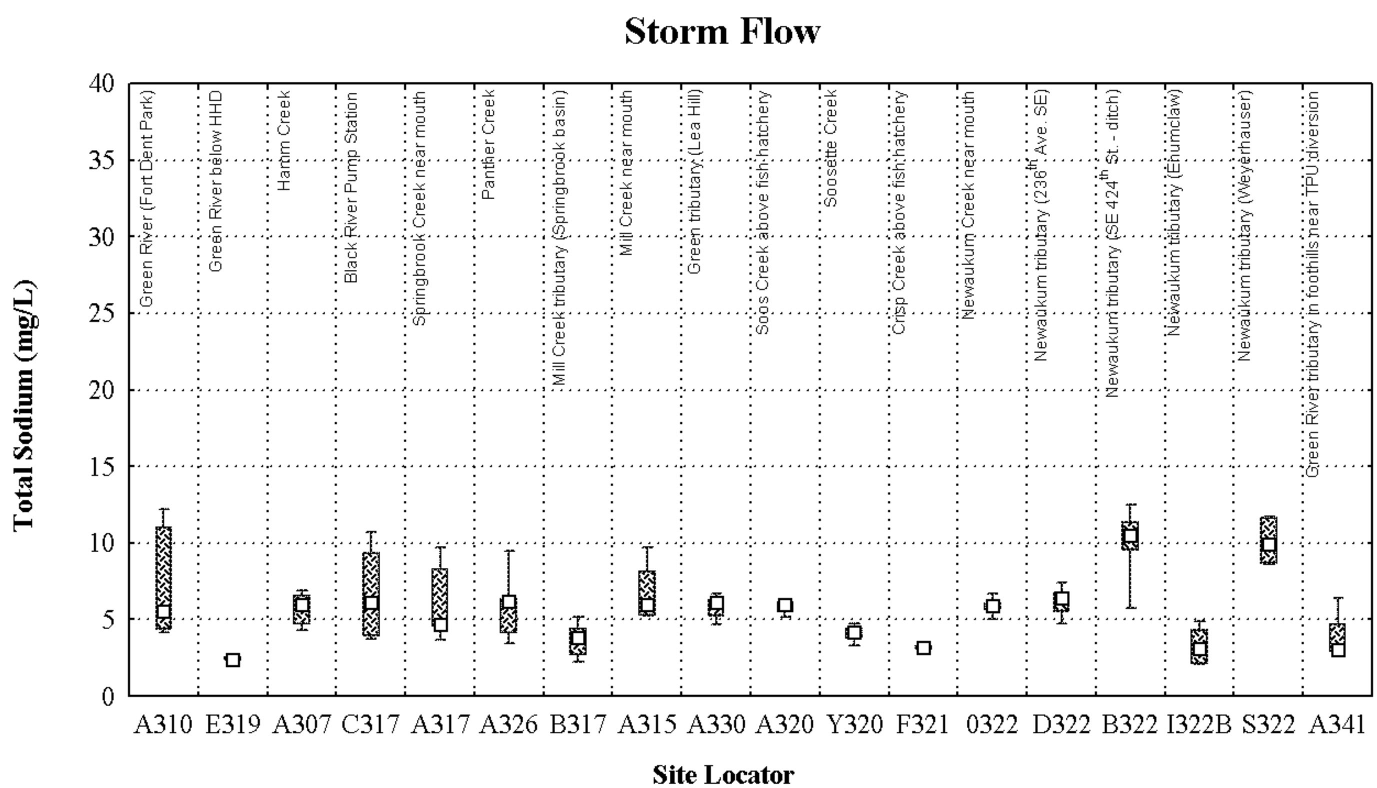

Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 56. Total sodium concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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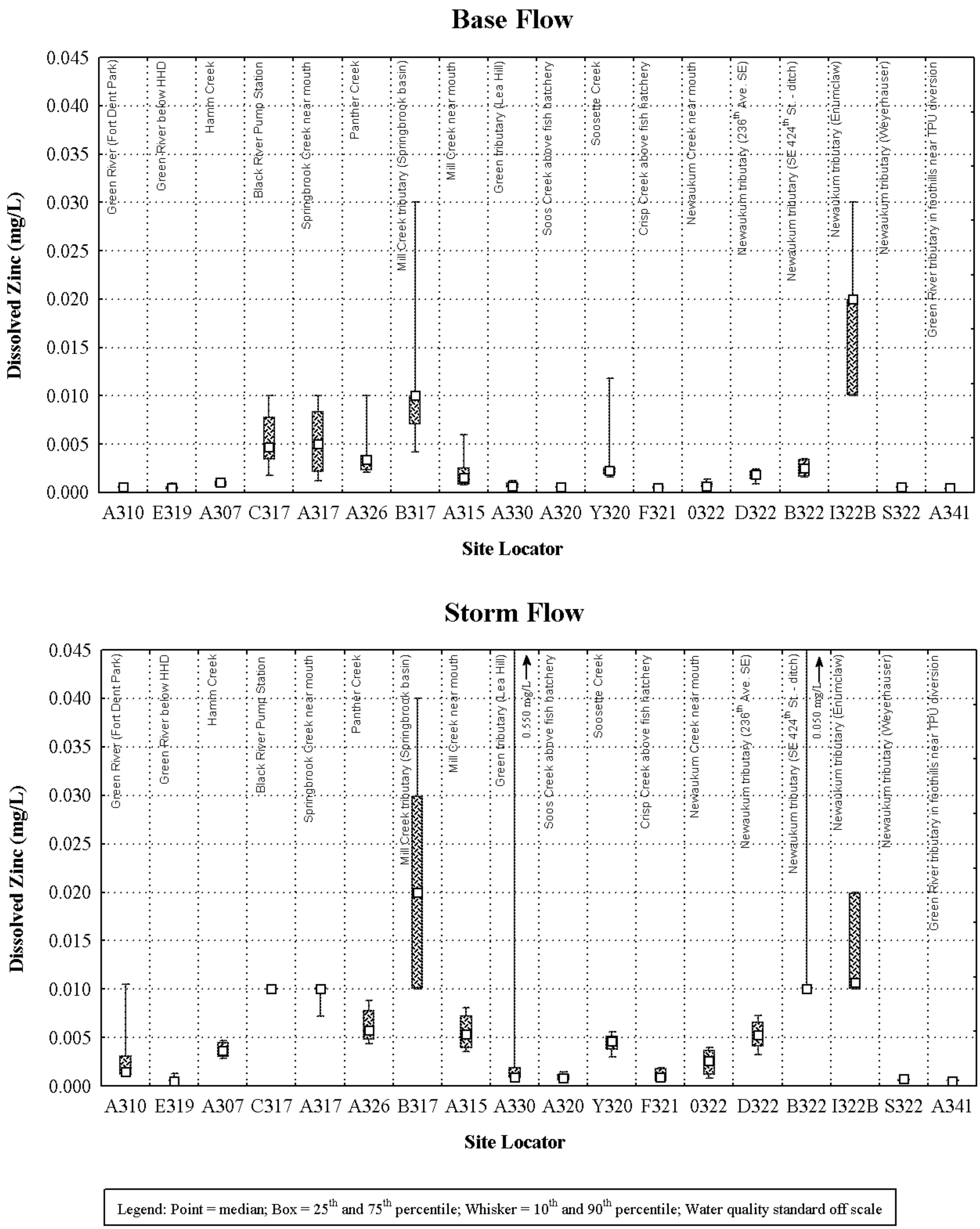

Figure 57. Dissolved zinc concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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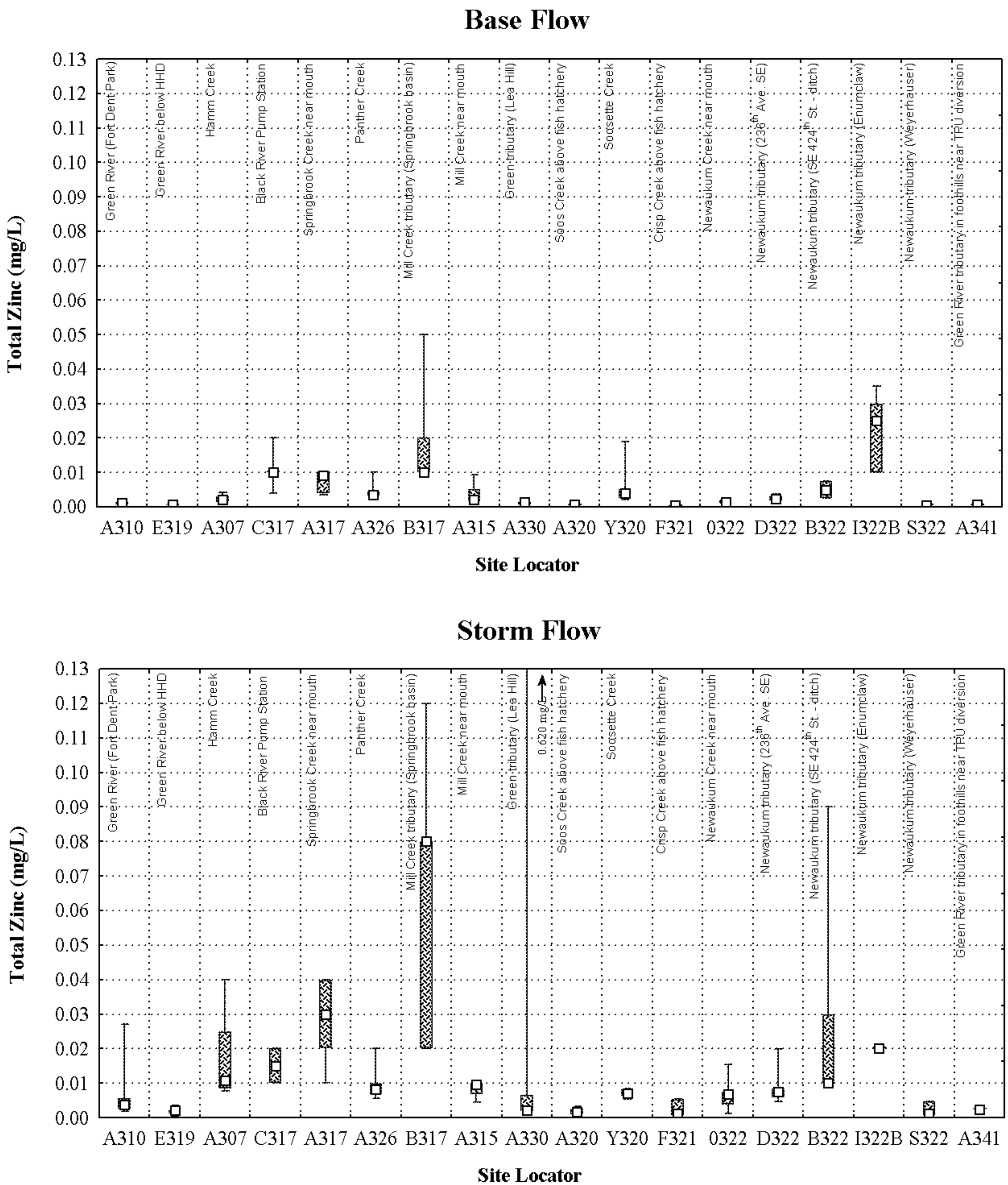
JL\Zinc Total Box Plot.stg



Legend: Point = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile

Figure 58. Total zinc concentrations at sites in the Green-Duwamish watershed in 2001 and 2002.

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Dissolved zinc concentrations ranged from less than 0.00021 to 0.05000 mg/L during base flow, and ranged from less than 0.00026 to 0.55000 mg/L during storm flow. Total zinc concentrations ranged from 0.00016 to 0.08000 mg/L during base flow, and ranged from 0.00020 mg/L to 0.62000 mg/L during storm flow. The median dissolved zinc concentration for all sites combined was substantially higher during storm flow (0.00418 mg/L) than during base flow (0.00118 mg/L).

Based on results of the spatial pattern analysis for the Green River sites, dissolved zinc concentrations significantly ($p = 0.0004$) increased downstream during storm flow, but not during base flow (Table J13). The median dissolved zinc concentration increased downstream during storm flow from 0.00050 to 0.00145 mg/L. Total zinc concentrations significantly increased downstream during base flow ($p = 0.0061$) and storm flow ($p = 0.0126$). Median total zinc concentrations increased downstream from 0.00058 to 0.00107 mg/L during base flow, and from 0.00204 to 0.00381 mg/L during storm flow.

Results of the spatial pattern analysis for the major streams showed that dissolved zinc concentrations were significantly higher during base flow ($p < 0.0001$) and storm flow ($p < 0.0001$) in the Black River (C317) and Springbrook Creek (A317) relative to Soos Creek (A320) and Newaukum Creek (0322) (Tables J14 and J15). Total zinc concentrations were significantly ($p < 0.0001$) higher during base flow in the Black River (C317) and Springbrook Creek (C317) relative to Soos Creek (A320) and Newaukum Creek (0322). Total zinc concentrations were significantly ($p < 0.0001$) higher during storm flow in Springbrook Creek (A317) relative to Soos Creek (A320) and Newaukum Creek (0322).

Median dissolved and total zinc concentrations were highest at Newaukum tributary at Enumclaw (I322B) during base flow, and were highest at Mill (Springbrook) tributary (B317) during storm flow.

5.2.6 Organics

This section summarizes results for organic compounds based on the data collected in 2001 and 2002 for the GDWQA. Summary statistics for these parameters are presented in Appendix I, but are not presented graphically due to the infrequency with which organic contaminants were detected. Presentation of these results is organized into separate subsections for the following categories of priority pollutant organic compounds:

- Halogenated hydrocarbons
- Phenols
- Phthalates
- Polycyclic aromatic hydrocarbons (PAHs)
- Polychlorinated biphenyls (PCBs)
- Miscellaneous semivolatile organics
- Chlorinated and organophosphorus pesticides
- Chlorinated herbicides.

5.2.6.1 Halogenated Hydrocarbons

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following halogenated hydrocarbons:

- 1,2,4-Trichlorobenzene
- 1,2-Dichlorobenzene
- 1,3-Dichlorobenzene
- 1,4-Dichlorobenzene
- 2-Chloronaphthalene
- 3,3'-Dichlorobenzidine
- 4-Bromophenylphenylether
- 4-Chloroaniline
- 4-Chlorophenylphenylether
- Bis(2-chloroethoxy)methane
- Bis(2-chloroethyl)ether
- Bis(2-chloroispropyl)ether
- Hexachlorobenzene
- Hexachlorobutadiene
- Hexachloroethane.

None of these compounds are regulated by Washington State (WAC 173-201A) or U.S. EPA (2002a) for toxicity to aquatic organisms in surface waters.

None of the halogenated compounds were detected in the collected samples (see Table I1). Detection limits ranged from 0.01 to 0.02 µg/L (with the exception of 3,3'-dichlorobenzidine where detection limits ranged from 0.74 to 0.82 µg/L).

5.2.6.2 Phenols

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following phenols:

- 2,4,5-Trichlorophenol
- 2,4,6-Trichlorophenol
- 2,4-Dichlorophenol
- 2,4-Dimethylphenol
- 2,4,-Dinitrophenol
- 2-Chlorophenol
- 2-Methylphenol
- 2-Nitrophenol
- 4,6-Dinitro-2-methylphenol
- 4-Chloro-3-methylphenol
- 4-Methylphenol
- 4-Nitrophenol
- Pentachlorophenol
- Phenol.

Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for pentachlorophenol (see Table I1), which vary with pH but are well above the method detection limit.

None of these analyzed parameters were detected with the exception of phenol and pentachlorophenol (see Table I2). Phenol concentrations ranged from less than 0.09 to 0.54 µg/L, and was detected in one or two samples collected from all sites except lower Green River (A310) and Soos Creek (A320). Pentachlorophenol was detected at low concentrations (i.e., less than 0.25 µg/L and not exceeding state criteria) in two storm flow samples and one base flow sample from Springbrook Creek (A317), and in one storm sample from Black River (C317).

5.2.6.3 Phthalates

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following phthalates:

- Bis(2-ethylhexyl)phthalate
- Butylbenzylphthalate
- Diethylphthalate
- Dimethylphthalate
- Di-n-butylphthalate
- Di-n-octylphthalate.

None of these compounds are regulated by Washington State (WAC 173-201A) or U.S. EPA (2002a) for toxicity to aquatic organisms in surface waters.

Phthalate concentrations ranged from less than 0.01 to 0.30 µg/L, with the exception of bis(2-ethylhexyl)phthalate which exhibited a maximum concentration of 5.4 µg/L. Bis(2-ethylhexyl)phthalate, butylbenzylphthalate, diethylphthalate, and di-n-butylphthalate were frequently detected at all sites (see Table I3). Dimethylphthalate was detected only once during storm flow at Lower Green River (A310), Black River (C317), Springbrook Creek (A317), and Newaukum Creek (0322). Di-n-octylphthalate was detected only once during storm flow at Lower Green River (A310), Black River (C317), and Springbrook Creek (A317). However, as noted in the QA Review memorandum (Appendix B), blank contamination was observed for all phthalate parameters, and it was recommended that the MDLs be raised by a factor of ten. Although the phthalate MDLs were not raised in the database, all phthalate concentrations should be regarded as undetected with the exception of two values for deithylphthalate.

5.2.6.4 Polycyclic Aromatic Hydrocarbons (PAHs)

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following polycyclic aromatic hydrocarbons (PAHs):

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

None of these compounds are regulated by Washington State (WAC 173-201A) or U.S. EPA (2002a) for toxicity to aquatic organisms in surface waters.

The range of detected PAH concentrations was from less than 0.01 to 0.04 µg/L. Detection limits for 2-methylnaphthtalene, benzo(g,h,i)perylene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene all varied and exceeded this range of detected concentrations. Detected PAHs included acenaphthene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, fluoranthene, naphthalene, phenanthrene, and pyrene (see Table I4). Fluoranthene, fluorene, phenanthrene, and pyrene were detected most frequently (in at least three samples) at Black River (C317) and Springbrook Creek (A317), and were detected infrequently (in one or two samples) at Lower Green River (A310). Acenaphthene was also detected frequently at Springbrook Creek (A317), but not at the other sites. Benzo(b)fluoranthene, benzo(k)fluoranthene, and chrysene were detected infrequently (in one or two samples) at Black River (C317) and Springbrook Creek (A317).

5.2.6.5 Polychlorinated biphenyls (PCBs)

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following polychlorinated biphenyls (PCBs):

- Aroclor 1016
- Aroclor 1221
- Aroclor 1232
- Aroclor 1242
- Aroclor 1248
- Aroclor 1254
- Aroclor 1260.

Washington State surface water quality standards (WAC 173-201A) include an acute criterion of 2.0 µg/L and a chronic criterion of 0.014 µg/L for total PCBs.

None of the PCBs were detected in the collected samples at a detection limit of 0.05 µg/L (see Table I5). This detection limit is well below the acute criterion, but exceeds the chronic criterion for total PCBs.

5.2.6.6 Miscellaneous Semivolatile Organics

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following miscellaneous semivolatile organics:

- 2,4-Dinitrotoluene
- 2,6-Dinitrotoluene
- 3,5,5-Trimethyl-2-cyclohexene-1-one
- 2-Nitroaniline
- 3-Nitroaniline
- 4-Nitroaniline
- Caffeine
- Carbazole
- Dibenzofuran
- Nitrobenzene
- N-nitroso-di-methylamine
- N-nitroso-di-n-propylamine
- N-nitrosodiphenylamine
- Phorate.

None of these compounds are regulated by Washington State (WAC 173-201A) or U.S. EPA (2002a) for toxicity to aquatic organisms in surface waters.

Caffeine was detected at all sites except Upper Green River (E391) at concentrations ranging from 0.02 to 1.41 µg/L (see Table I6). The highest caffeine concentrations were observed during storm flow at Black River (C317) and Springbrook Creek (A317). The only other compound detected was 3,5,5-trimethyl-2-cyclohexane-1-one, which was detected in only two samples at concentrations within two times the detection limit of 0.01 ug/L. The remaining semivolatile organics were not detected at detection limits ranging from 0.01 to 0.05 µg/L (with the exception of elevated detection limits ranging from 0.25 to 0.55 µg/L for 3-nitroaniline, 4-nitroaniline, and n-nitrosodiphenylamine).

5.2.6.7 Chlorinated and Organophosphorus Pesticides

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for chlorinated and organophosphorus pesticides. Chlorinated pesticides include:

- 4,4'-DDD
- 4,4'DDE
- 4,4,'DDT
- Aldrin
- Alpha-BHC
- Beta-BHC
- Delta-BHC
- Gamma-BHC (lindane)
- Chlordane
- Dieldrin
- Endosulfan I
- Endosulfan II
- Endosulfan sulfate
- Endrin
- Endrin aldehyde
- Heptachlor
- Heptachlor epoxide.

Organophosphorus pesticides include:

- Camphechlor (toxaphene)
- Chlorpyriphos
- Diazinon
- Disulfoton
- Malathion
- Methoxychlor
- Methyl parathion
- Parathion.

Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for 4,4'DDT, (and the metabolites 4,4'DDD and 4,4'DDE), aldrin (and the metabolite dieldrin), gamma-BHC (lindane or hexachlorocyclohexane), chlordane, chlorpyriphos, endosulfan (I and II), endrin, heptachlor, and parathion (see Table 11). U.S. EPA (2002) water quality criteria include acute and chronic criteria for camphechlor (toxaphene) and heptachlor epoxide, and include chronic criteria for malathion and methoxychlor (see Table 12).

None of the pesticides were detected in the collected samples at a detection limit of 0.005 µg/L for the chlorinated pesticides and detection limits ranging from 0.02 to 0.05 µg/L for the organophosphorus pesticides (see Table I7). These detection limits are less than acute criteria, but exceed chronic criteria for 4,4’DDT (and the metabolites 4,4’DDD and 4,4’DDE), aldrin (and the metabolite dieldrin), camphechlor (toxaphene), chlordane, endrin, heptachlor, and parathion.

5.2.6.8 Chlorinated Herbicides

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following chlorinated herbicides:

- 2,2-Dichloropropionic acid
- 2,4-D
- 2,4-DB
- 2,4,5-T
- Dicamba
- Dichlorprop
- Dinoseb
- MCPA
- MCPP
- Silvex.

None of these compounds are regulated by Washington State (WAC 173-201A) or U.S. EPA (2002a) for toxicity to aquatic organisms in surface waters.

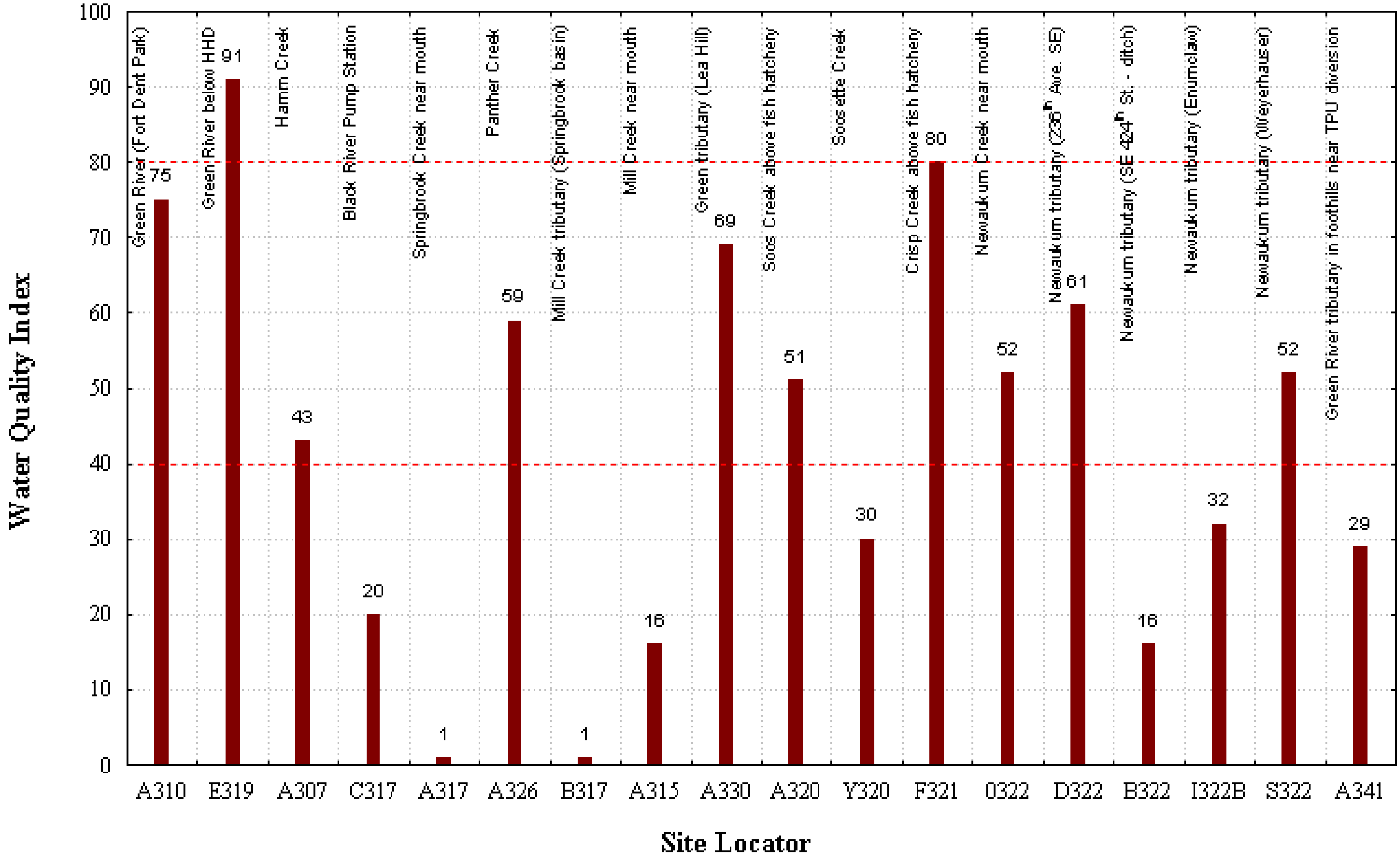
None of the herbicides were detected at detection limits ranging from 0.01 to 0.08 µg/L, with the following two exceptions (see Table I8). The herbicide 2,4-D was detected in two samples (0.10 µg/L in a base flow sample and 0.37 µg/L in a storm sample) collected from Springbrook Creek (A317), and two samples (0.08 and 0.19 µg/L in storm samples) collected from Newaukum Creek (0322). The herbicide dichlorprop was detected in one storm sample (0.08 µg/L) collected from Newaukum Creek (0322).

5.2.7 Water Quality Index (WQI) Scores

Calculated water quality index (WQI) scores for each site are summarized in Figure 59. More detailed tabular summaries for the WQI scores are presented in Appendix K. These tabular summaries include WQI scores for individual samples and parameters from each site. Sites scoring 80 and above likely meet expectations for water quality and are of "lowest concern," scores between 40 and 79 indicate "marginal concern," and water quality at sites with scores below 40 are likely not meeting expectations and are of "highest concern" (Ecology 2002a,b). Based on these criteria, the following sites were identified as being a high concern due to impairment from the indicated parameters (see Section 4.5 for results of the eight parameters included in the WQI score):

- **Black River (C317):** low dissolved oxygen, high total nitrogen

- **Springbrook Creek (A317):** low dissolved oxygen, high total phosphorus, high total nitrogen



Scores less than 40 indicate that water quality may not meet designated uses as defined in WAC 173-201A. Scores of 40 to 79 indicate moderate concern, and scores of 80 and greater indicate water quality likely meets designated uses (Ecology 2002).

Figure 59. Water quality index (WQI) scores for sampling locations in the Green/Duwamish Watershed in 2002.

- **Mill (Springbrook) tributary (B317):** high fecal coliform bacteria, low dissolved oxygen, high total nitrogen
- **Mill (Hill) Creek (A315):** high fecal coliform bacteria, high total nitrogen
- **Soosette Creek (Y320):** low dissolved oxygen, high total nitrogen
- **Newaukum tributary at SE 424th (B322):** high fecal coliform bacteria, low dissolved oxygen, high total phosphorus, high total nitrogen
- **Newaukum tributary at Enumclaw (I322B):** high total nitrogen
- **Green tributary near TPU diversion (A341):** high total nitrogen.

With the exception of Green tributary near TPU diversion (A341) and Newaukum tributary at SE 424th (B322), all of the above sites have a substantial amount of medium to high density residential and urban development in their associated drainage basins. Accordingly, the specific sources of water quality impairment at these sites (e.g., high fecal coliform bacteria, low dissolved oxygen, and high nutrients) are related to specific activities that occur in association with these types of land use. For example, common sources of fecal coliform bacteria contamination from urban and residential land use include failing septic systems, municipal wastewater discharges, leaking wastewater conveyance systems or side sewers, cross-connections with municipal wastewater systems, and pet and other animal wastes. Low dissolved oxygen concentrations in urban and residential settings can be related to flow reductions as a result of decreased groundwater recharge, riparian canopy alterations that reduce shading and increase water temperatures (colder water retains more oxygen), inputs of organic matter from animal wastes or municipal wastewater discharges (oxygen is depleted during the decomposition of organic matter), and nutrient inputs from stormwater runoff that contribute to increased algae growth and eutrophication. Fertilizer applications are common sources of nitrogen and phosphorus contamination in stormwater runoff arising from residential areas.

The drainage basin associated with the Green tributary near TPU diversion (A341) contains a significant amount of land area that is utilized for commercial forestry. Therefore, impairment at this site is likely related to forest management activities, increased erosion of nutrient-containing soils, the washoff of excess forest fertilizers, or the secondary growth of nitrogen fixing alders.

The drainage basin associated with Newaukum tributary at SE 424th (B322) contains a significant amount of land area that is utilized for agricultural purposes. Therefore, impairment at this site from fecal coliform bacteria is likely related to livestock waste. Similarly, high nutrient concentrations at this site are also likely related to the erosion of nutrient-containing soils from cultivated fields. The decomposition of organic matter in water and sediment also depletes dissolved oxygen levels.

The following sites were identified as being of moderate concern due to impairment from high total nitrogen:

- Hamm Creek (A307)
- Panther Creek (A326)
- Green tributary at Lea Hill (A330)
- Soos Creek (A320)
- Newaukum Creek (0322)
- Newaukum tributary at 236th SE (D322)
- Newaukum tributary downstream of Weyerhaeuser (S322).

With the exception of Newaukum tributary at 236th SE (D322) and Newaukum tributary downstream of Weyerhaeuser (S322), all the above sites have varying amounts of residential and urban development in their associated drainage basins. The drainage basin for Newaukum tributary at 236th SE (D322) contains a significant amount of land area that is utilized for agricultural purposes; whereas, Newaukum tributary downstream of Weyerhaeuser (S322) contains a significant land area that is utilized for commercial forestry.

Only two sites were identified as being a low concern for water quality impairment:

- Upper Green River (E319)
- Crisp Creek (F321).

The high WQI scores for these sites are related to the relatively undisturbed, forested condition in their associated drainage basins that resulted in high scores for all parameters except pH at the Upper Green River (E319) and total nitrogen at Crisp Creek (F321)

6.0 Conclusions

Results from water quality monitoring conducted during 2001 and 2002 for the Green-Duwamish Watershed Water Quality Assessment are summarized below for select monitoring parameters, followed by a summary for the monitoring sites.

6.1 Monitoring Parameters

This section summarizes results for select monitoring parameters based on exceedances of the applicable water quality criteria and general patterns relating to storm and base flow concentrations.

6.1.1 In-stream Field Measurements

Temperature. During sampling, water temperatures at all river, stream, and tributary sites were generally cool and met applicable state water quality criteria with the exception of one sample collected from the Black River (C317) during one summer storm event. However, the Comprehensive GDWQA Sampling Program measured temperature on an infrequent basis during the summer. Therefore, these data likely do not reflect maximum summer daily conditions. The reader is directed to consult the *Green-Duwamish Watershed Water Temperature Report* (Taylor Associates and King County 2004) for a more thorough temperature analysis.

Dissolved Oxygen. Low dissolved oxygen concentrations not meeting applicable state criteria were observed at Lower Green River (A310), Black River (C317), Springbrook Creek (A317), Mill (Hill) Creek (A315), and at the following tributary sites: Mill Creek (Springbrook) tributary (B317), Soosette Creek (Y320), Newaukum tributary at 236th SE (D322), Newaukum tributary at SE 424th (B322), and Newaukum tributary at Enumclaw (I322B). Minimum dissolved oxygen concentrations observed at these sites ranged from 3.0 to 6.9 mg/L during base flow conditions and 1.5 to 7.3 mg/L during storm conditions.

6.1.2 Conventionals

Turbidity. The median turbidity value for all river, stream, and tributary sites was higher during storm flow (11.1 NTU) than during base flow (2.6 NTU). The highest turbidity levels during base and storm flow were observed at Black River (C317), Springbrook Creek (A317), Mill (Hill) Creek (A315), and at the following tributary sites: Mill (Springbrook) Tributary (B317) and Hamm Creek (A307).

Total Suspended Solids. The median total suspended solids concentration for all river, stream, and tributary sites was higher during storm flow (14.0 mg/L) than during base flow (3.7 mg/L).

The highest total suspended solids concentrations during storm flow were observed at Upper Green River (E319), Springbrook Creek (A317), and Newaukum Creek (0322), and at the following tributary sites: Hamm Creek (A307), Mill (Springbrook) tributary (B317), and Newaukum tributary at 236th SE (D322).

6.1.3 Microbiological

Fecal Coliform Bacteria. The geometric mean fecal coliform bacteria concentration for all river, stream, and tributary sites was higher during storm flow (556 CFU/100 mL) than during base flow (55 CFU/100 mL). During base flow, fecal coliform bacteria concentrations exceeded state criteria at three major stream sites (C317, A317, and A315) and eight tributary sites (A307, A326, B317, Y320, D322, B322, I322B, and S322). During storm flow, fecal coliform bacteria concentrations exceeded state criteria at all sites except the Upper Green River (E319). The highest geometric mean fecal coliform bacteria concentrations during storm flow were observed at major stream sites Mill (Hill) Creek (A315) and Springbrook Creek (A317), and at tributary sites Mill (Springbrook) tributary (B317) and Newaukum tributary at SE 424th (B322). The Newaukum tributary at SE 424th (B322) exhibited a particularly high geometric mean concentration (13,858 CFU/100 mL).

6.1.4 Nutrients

Ammonia Nitrogen. Ammonia nitrogen concentrations at all sites were less than 0.5 mg/L and met applicable water quality criteria with the exception of one sample collected from the Newaukum tributary at SE 424th (B322) during a base flow event that exhibited an ammonia nitrogen concentration of 2.5 mg/L.

Nitrate+nitrite and Total Nitrogen: Newaukum Creek (0322), Newaukum tributary at 236th SE (D322), Newaukum tributary at SE 424th (B322), Newaukum tributary at Enumclaw (I322B), and Hamm Creek (A307) exhibited high nitrate+nitrite nitrogen and total nitrogen concentrations during both base flow and storm flow sampling. The Newaukum tributary at SE 424th (B322) exhibited the highest total nitrogen concentration (14.7 mg/L during storm flow).

Phosphorus. Newaukum Creek (0322), Newaukum tributary at 236th SE (D322), and Newaukum tributary at SE 424th (B322) had high orthophosphate phosphorus and total phosphorus concentrations during both base flow and storm flow sampling. The Newaukum tributary at SE 424th (site B322 which drains agriculture) exhibited very high orthophosphate and total phosphorus concentrations (greater than 1.4 mg/L) that exceeded the maximum total phosphorus concentration (1.0 mg/L) for all other sites.

6.1.5 Metals

Aluminum. Median dissolved and total aluminum concentrations for all the sites combined were higher during storm flow than during base flow. On at least one occasion at all sites, total aluminum concentrations exceeded either the U.S. EPA chronic criterion during base flow or the acute criterion during storm flow.

Cadmium and Lead. Median concentrations of cadmium and lead for all the sites combined were higher during storm flow than during base flow. Lead and cadmium concentrations were generally low at all sampling sites and did not exceed applicable state criteria for the dissolved fraction during base or storm flow sampling.

Copper and Zinc. Median concentrations of copper and zinc for all the sites combined were higher during storm flow than during base flow. Copper and zinc concentrations were generally low during base and storm flow sampling, and did not exceed state criteria in the Green River and major streams. However, state criteria for dissolved copper were not met for one base flow sample from Mill (Springbrook) tributary (B317) and one storm flow sample from Newaukum tributary at 236th SE (D322). In addition, state criteria for dissolved zinc were not met for one base flow sample from Mill (Springbrook) tributary (B317) and one storm flow sample from Green tributary at Lea Hill (A330).

Mercury. Median concentrations of dissolved and total mercury for all sites combined were higher during storm flow than during base flow. The acute criterion for dissolved mercury was not exceeded in any of the samples, but the chronic criterion for total mercury was slightly exceeded in one base flow sample from the Lower Green River (A310) and Mill (Springbrook) tributary (B317).

6.1.6 Priority Pollutant Organics

Halogenated Hydrocarbons. Halogenated hydrocarbons were not detected at any site during base or storm flow sampling. (Samples from tributary sites were not analyzed for priority pollutant organics.)

Phenols. Pentachlorophenol was detected at low concentrations in Springbrook Creek (A317) during base and storm flow, and in the Black River (C317) during base flow. Phenol was detected during storm flow in the Upper Green River (E319), the Black River (C317), Springbrook Creek (A317), Mill (Hill) Creek (A315), and Newaukum Creek (0322). Phenol was also detected in one base flow sample from Newaukum Creek (0322).

Phthalates. Low concentrations of bis (2-ethylhexyl) phthalate, butylbenzylphthalate, diethylphthalate, and di-n-butylphthalate were detected at all river and major stream sites during both base and storm flow sampling. However, all but two phthalate values should be considered undetected due to blank contamination.

Polycyclic Aromatic Hydrocarbons. Polycyclic aromatic hydrocarbons (PAHs) were detected in the Lower Green River (A310), the Black River (C317), and Springbrook Creek (A317) during both base and storm flow sampling.

Polychlorinated Biphenyls. Polychlorinated biphenyls (PCBs) were not detected at any river or major stream site during base or storm flow sampling.

Miscellaneous Semivolatile Organics. Caffeine was detected at all river and major streams sites except the Upper Green River (E319). 3,5,5-Trimethyl-2-cyclohexane-1-one was detected during base flow in the Lower Green River (A310), the Black River (C317), and Springbrook Creek (A317).

Pesticides and Herbicides. Chlorinated and orthophosphorus pesticides were not detected in any site during base or storm flow sampling. The herbicide 2,4-D was detected in two samples from Springbrook Creek (A317) and the herbicide dichlorprop was detected in one sample from Newaukum Creek (0322).

6.2 Monitoring Sites

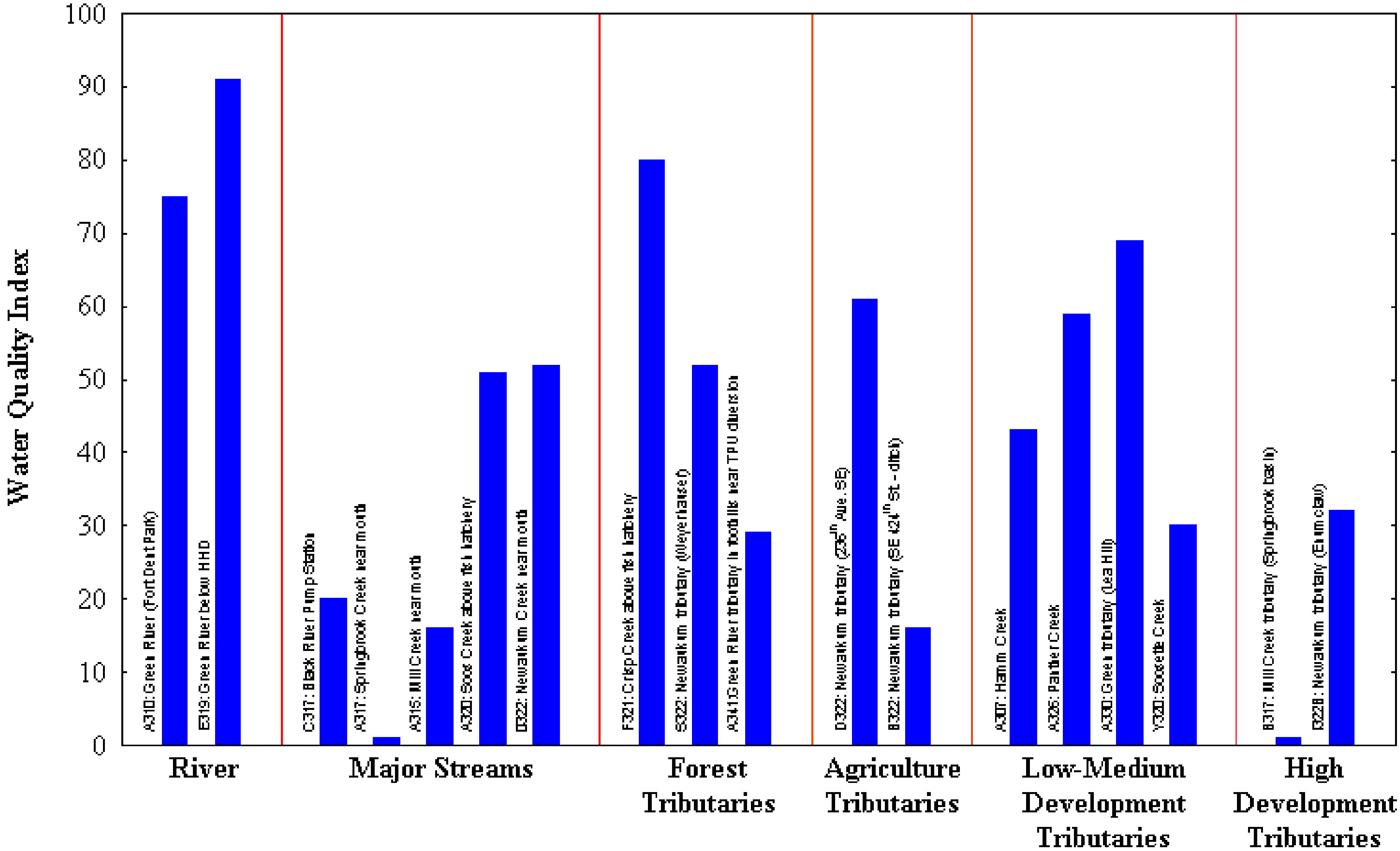
This section summarizes water quality observations for the two sites on the Green River, the five major stream sites, and the 11 tributary sites using comparisons to applicable state or federal water quality criteria and the water quality index scores presented in Figure 60.

6.2.1 Green River

Concentrations of most parameters increased significantly moving downstream in the Green River from site E319 below Howard Hanson Dam to site A310 at Fort Dent Park. State or federal water quality criteria for the following six parameters were exceeded at the upstream site (E319): pH, total nitrogen, nitrate+nitrite nitrogen, total phosphorus, enterococci bacteria, and total aluminum. At the downstream site (A310), state or federal criteria were exceeded for the following nine parameters: dissolved oxygen, fecal coliform bacteria, enterococci bacteria, *E. coli* bacteria, nitrate+nitrite nitrogen, total nitrogen, total phosphorus, total aluminum, and total mercury. The water quality index decreased downstream from 91 to 75, which indicates that beneficial uses are likely supported at the upstream site on the Green River, but may be impaired at the downstream site.

6.2.2 Major Streams

Data analyses conducted for the five major stream sites indicated that concentrations of most parameters were significantly higher at Black River (C317), Springbrook Creek (A317), and Mill Creek (A315) than at Soos Creek (A320) and Newaukum Creek (0322). State or federal water quality criteria were exceeded at one or more of these three streams sites for the following parameters: temperature, dissolved oxygen, fecal coliform bacteria, enterococci bacteria, *E. coli* bacteria, nitrate+nitrite nitrogen, total nitrogen, total phosphorus, and total aluminum. Water quality index scores for these three stream sites ranged from 1 to 20, which indicates that the associated beneficial uses are most likely not supported. Water quality impairment in these streams is most likely related to residential and urban development within the respective stream drainage basins.



Scores less than 40 indicate that water quality may not meet designated uses as defined in WAC 173-201A. Scores of 40 to 79 indicate moderate concern, and scores of 80 and greater indicate water quality likely meets designated uses (Ecology 2002).

Figure 60. Water quality index (WQI) scores for the Green-Duwamish watershed in 2002 by monitoring site categories including river, major streams, and tributaries.

Concentrations of most parameters were significantly lower in Soos Creek (A320) and Newaukum Creek (0322) than in the other three stream sites noted above. The only notable exceptions to this pattern were significantly higher nutrient concentrations in Newaukum Creek (0322) that are likely related to agricultural land use that occurs in the drainage basin. State or federal criteria were exceeded at one or both of these two stream sites for the following parameters: fecal coliform bacteria, enterococci bacteria, *E. coli* bacteria, nitrate+nitrite nitrogen, total nitrogen, total phosphorus, and total aluminum. The water quality index scores for Soos Creek (A320) and Newaukum Creek (0322) were 51 and 52 respectively, which indicates that beneficial uses may not be supported in these streams.

6.2.3 Tributaries

Water quality varied widely among the 11 tributary sites and was not always closely related to land use activities in the associated drainage basins. Five tributary sites (Mill [Springbrook]) (B317), Soosette (Y320), Newaukum tributary at SE 424th (B322), Newaukum tributary at Enumclaw (I322B), and Green River tributary near TPU (A341)) exhibited water quality index scores of less than 40, which indicates that beneficial uses are most likely not supported. Two of the sites (B317 and I322B) drain high density development, one site (Y320) drains low to medium density development, one site (B322) drains agriculture, and one site (A341) drains forest. Based on water index scores, the predominant sources of water quality impairment at these five tributary sites were: high fecal coliform bacteria concentrations, high total nitrogen concentrations, and low dissolved oxygen concentrations.

Water quality index scores for tributary sites Hamm Creek (A307), Panther Creek (A326), Green River tributary at Lea Hill (A330), Newaukum tributary at 236th SE (D322), and Newaukum tributary downstream of Weyerhaeuser (S322) were within the range of 40 to 79, which indicates that beneficial uses may not be supported in these streams. The predominant cause of water quality impairment at these five sites was high total nitrogen. Nutrients are common in runoff from the following land use categories associated with these sites: low to medium density development (sites A307, A326, and A330), agriculture (site D322), and commercial forestry (site S322).

Only one tributary site (Crisp Creek, F321) had a water quality index score that exceeded 79, which indicates that beneficial uses are likely supported by land use activities in this subbasin. The high WQI score for this stream appears to be related to the relatively undisturbed, forested condition of its watershed.

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