Comprehensive Clackamas County NPDES MS4 Stormwater Monitoring Plan

December 2022
Revised May 2023
Implementation start: July 1, 2023

Comprehensive Clackamas County
NPDES MS4 Stormwater Monitoring Plan

Prepared for

Clackamas County
City of Gladstone, Oregon
City of Milwaukie, Oregon
City of Oregon City, Oregon
City of West Linn, Oregon
City of Wilsonville, Oregon
City of Happy Valley, Oregon
City of Rivergrove, Oregon
Clackamas Water Environment Services
Oak Lodge Water Services

December 2022
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List of Abbreviations

°C	degree(s) Celsius
μg/L	microgram(s) per liter
2021 permit	2021 NPDES MS4 permit
ACWA	(Oregon) Association of Clean Water Agencies
BMP	best management practice
BOD	biochemical oxygen demand
$CaCO_3$	calcium carbonate
CCCSMP	Comprehensive Clackamas County Stormwater Monitoring Plan
CFR	Code of Federal Regulations
cm	centimeter(s)
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorophenyltrichloroethane
DEQ	(Oregon) Department of Environmental Quality
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
JFA	Joint Funding Agreement
mg/L	milligram(s) per liter
mL	milliliter(s)
MPN	most probable number
MS4	Municipal Separate Storm Sewer System
NPDES	National Pollutant Discharge Elimination System
OLWS	Oak Lodge Water Services
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
Plan	Comprehensive Clackamas County NPDES MS4 Stormwater Monitoring Plan
QA/QC	quality assurance/quality control
RSAT	Rapid Assessment Technique
SM	Standard Methods
SOP	standard operating procedure
SWMP	stormwater management plan
TMDL	total maximum daily load
UIC	underground injection control
USGS	U.S. Geological Survey
WES	Clackamas Water Environment Services

Section 1 Introduction

As part of the National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit requirements, Clackamas County co-permittees are required to develop and implement a stormwater monitoring program. Stormwater monitoring requirements and objectives are outlined in Schedule B of the Clackamas County NPDES MS4 permit (101348), originally issued September 15, 2021, effective October 1, 2023, and modified with a revised effective date of May 5, 2023 (2021 permit). The 2021 permit provides the basis for monitoring activities described in this 2023 Comprehensive Clackamas County NPDES MS4 Stormwater Monitoring Plan (2023 Plan)[1].

In accordance with deadlines outlined in the 2021 permit, this 2023 Plan was originally submitted to DEQ in December 2022 and has been updated in accordance with the permit modification and updated effective date of the permit.

NPDES stormwater monitoring programs require two components. The first component is ***program monitoring***, which involves the tracking and assessment of programmatic activities, as described in the individual permittees' stormwater management plans (SWMPs). The second component is ***environmental monitoring,*** which includes the actual collection and analysis of samples. The purpose of this 2023 Plan is to address the following environmental monitoring elements as outlined in Schedule B.1.c of the 2021 permit:

- Identification of how the monitoring objectives are addressed and sources of information used.
- Discussion of how the monitoring program is related to adaptive management and a long-term monitoring program strategy.
- Description of documentation and recordkeeping procedures.
- Documentation of monitoring sites, parameters, and sample collection frequency and methods.
- Identification of the analytical methods.
- Protocols for quality assurance and quality control (QA/QC).
- Discussion of data management, review, validation, and verification.

Following this introductory Section 1, this 2023 Plan is organized into the following sections:

- Section 2. Objectives- Summarizes objectives of the 2023 Plan, specifically related to the six objectives listed in Schedule B of the 2021 permit.
- Section 3. Development and Implementation of the Plan- Provides background information related to the development of the 2023 Plan.
- Section 4. Data Gathering Strategies- Outlines various data gathering and data collection strategies and describes how collected data will be used in the adaptive management of the individual stormwater programs and in the development of a long-term monitoring program strategy.
- Section 5. Monitoring Activities- Describes environmental monitoring activities including monitoring frequency and locations.
- Section 6. Sampling Parameters, Analytical Methods, and Quality Assurance and Control- Provides a summary of sampling parameters, sampling procedures, and analytical methods including applicable QA/QC.
- Section 7. Monitoring Data Management and Plan Modifications- Summarizes data analyses, interpretation, and management activities.

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[1] The major permit modification of Schedule B.1 resulted in an updated effective date of the permit (May 5, 2023), updated monitoring requirements for pesticides, and formalization of a July 1, 2023 implementation start date.

Section 2 Objectives

Schedule B.1 of the 2021 permit lists six specific monitoring objectives to be addressed with the stormwater monitoring program. The six objectives are listed below:

Objective 1: Evaluate the source(s) of and means for reducing the pollutants of concern applicable to the co-permittees' permit area, including the 2018/2020 303(d) listed pollutants, as applicable;

Objective 2: Evaluate the effectiveness of Best Management Practices (BMPs) in order to help determine BMP implementation priorities;

Objective 3: Characterize stormwater based on land use type, seasonality, geography, or other catchment characteristics;

Objective 4: Evaluate status and long-term trends in receiving waters associated with MS4 stormwater discharges;

Objective 5: Assess the chemical, biological, and physical effects of MS4 stormwater discharges on receiving waters; and,

Objective 6: Assess progress towards reducing total maximum daily load (TMDL) pollutant loads.

Each of the environmental monitoring activities listed in Section 5 of this plan will be conducted to attempt to answer specific questions in support the monitoring objectives listed above. These questions are listed for each monitoring activity. Descriptions of the monitoring activities also include a narrative describing how the monitoring objectives will be addressed.

Section 3 Development and Implementation of the Plan

Because of the wide range of variability in stormwater data, collecting and analyzing sufficient data to address environmental monitoring requirements and objectives requires significant resources to obtain statistically valid and robust data sets. The Oregon Department of Environmental Quality (DEQ) has acknowledged this issue and provided the following clause in the 2021 permit (Schedule B.1.e) to allow for a coordinated monitoring approach:

> *Environmental monitoring conducted to meet a permit condition in Table 3 may be coordinated among co-permittees or conducted on behalf of a co-permittee by a third party. Co-permittees are responsible for environmental monitoring in accordance with Schedule B requirements. Each co-permittee may utilize data collected by another permittee, a third party, or in another co-permittee's jurisdiction to meet a permit condition in Table 3 provided the co-permittee establishes an agreement prior to conducting coordinated environmental monitoring.*

3.1 Development and Participation in the CCCSMP

Development of a coordinated monitoring program stemmed from the need to address monitoring objectives when they were newly included in the 2004 NPDES MS4 permit (2004 permit). Before the 2004 permit, jurisdictions were collecting samples based primarily on locations and frequencies as specified in the permit. Smaller jurisdictions with less significant environmental monitoring requirements did not have the resources to address all the new monitoring objectives without substantial additional effort beyond the "maximum extent practicable" requirement.

The original Plan was developed in 2006 by eight Clackamas County co-permittees and was implemented beginning in July 2007. In 2017, coverage was expanded to include two additional co-permittees, Oak Lodge Water Services (OLWS), formerly Oak Lodge Sanitary District and the City of Wilsonville. OLWS and the City of Wilsonville's participation was reflected in the previous 2017 Plan. This 2023 Plan reflects a total of 10 co-permittees in accordance with the 2021 permit (Lake Oswego and Johnson City currently implement their own individual monitoring programs).

The 2006 Plan was developed by reviewing and compiling each participating co-permittee's existing monitoring efforts (through annual reports). Information compiled included monitoring locations, sample collection methods, sample collection frequencies, water bodies, TMDL/303(d) list status, and contributing land uses. Jurisdictions participated in a series of workshops to evaluate existing activities combined as a whole. Monitoring activities were then refined to (1) address the identified implementation gaps, (2) minimize duplication of monitoring efforts, and (3) ensure that data collected contained information that was sufficiently comprehensive to make progress towards addressing the permit-required monitoring objectives.

Since 2006, the Plan has been updated to reflect adjustments in monitoring locations, adjustments in monitoring parameters and detection limits, the inclusion of new participating co-permittees, additional detail related to sampling and quality assurance procedures, and changes for consistency with monitoring requirements per the 2012 and 2021 permits.

3.2 Implementation of the 2023 CCCSMP

This 2023 Plan reflects refinement of monitoring locations, parameters, and activities in accordance with the 2021 permit. Eight topic-specific workshops were held with participants from February to September 2022 to collectively discuss, and address, modifications required to the 2017 Plan, as well as discuss collaboration efforts, training needs, and implementation challenges. Workshop outcomes have been integrated into this document.

Key features of the 2023 Plan include the following:

- Inclusion of a coordinated mercury monitoring effort, based on the collective instream and stormwater monitoring requirements detailed in Table 3 of the 2021 permit.
- Inclusion of pesticide monitoring activities, as detailed in Table 3 of the 2021 permit.
- Adjustment of monitoring locations in accordance with the required number of locations per Table 3 of the 2021 permit and identified safety and technical limitations related to sample collection at certain locations. Locations still ensure geographic distribution of data and continued ability to assess trends.
- Adjustment of pollutant parameters from the analyte list, in accordance with Table 3 of the 2021 permit.
- Adjustment of analytical methods and reporting limits based on consistency with Code of Federal Regulations (CFR) Title 40 and current laboratory capabilities.
- Updated standard operating procedures (SOPs) for the field collection and quality assurance of samples (see Appendix A) to incorporate expanded quality control procedures outlined in U.S. Environmental Protection Agency (EPA) Method 1669, as required for mercury sample collection.
- Minor editorial updates to improve clarity and consistency with current practices.

This 2023 Plan reflects the outcome from the permit modification application submitted to DEQ August 29, 2022. The permit modification application was submitted to 1) request the adjustment of pesticide monitoring requirements to proportional align with other Phase I NPDES MS4 permittee obligations and consider Clackamas County co-permittee's previous pesticide monitoring efforts, and 2) request an implementation start date for this CCCSMP of July 1, 2023, to support the timing, fiscal, and contractual considerations associated with implementation of coordinated monitoring activities (per Schedule B.1.e). As a result of the permit modification application and process, the 2021 permit was reissued with an effective date of May 5, 2023. Updated pesticide monitoring requirements are reflected in this 2023 Plan. The 2017 Plan remains in effect until July 1, 2023, and the 2023 Plan takes effect July 1, 2023.

This 2023 Plan serves as an established agreement to conduct a coordinated monitoring effort. The ten current participating co-permittees include the cities of Gladstone, Milwaukie, Oregon City, Wilsonville, and West Linn; OLWS; and Clackamas Water Environment Services (WES). WES conducts monitoring on behalf of Clackamas County and the cities of Happy Valley and Rivergrove, and they are included as participants in this 2023 Plan as well.

Section 4 Data Gathering Strategies

As described in Section 3, development of the original (2006) Plan and subsequent iterations to the Plan have applied adaptive management principles to refine individual monitoring activities into a coordinated program and work towards addressing monitoring objectives. This 2023 Plan reflects the results of these adaptive management efforts.

Three primary strategies are outlined in this 2023 Plan to obtain and review data and information necessary to support the six monitoring objectives of the 2021 permit. These strategies include the following:

1. Collect water quality data and macroinvertebrate data to address the specified monitoring objectives:
    a. Monitoring locations, frequencies, and parameters were reviewed by the co-permittees as providing beneficial information for the city/jurisdiction to support the current permit monitoring objectives, as well as adhere to requirements outlined in Table 3 of the 2021 permit.
    b. For some jurisdictions, a change in monitoring location required consensus amongst participating co-permittees to ensure the collective intent of monitoring is maintained. Selection of the monitoring locations, frequencies, and parameters generally reflect historic data collection efforts so that adequate data will be available to assess trends in the future.
2. Conduct literature reviews to track relevant technical information related to stormwater quality that is collected by others, yet representative of co-permittee activities:
    a. The scientific community, public agencies, and private organizations interested in stormwater management continue to conduct research related to stormwater characterization and treatment. This costly research is often beyond the means of any one co-permittee to conduct an equivalent type of study.
    b. Organizations such as the Oregon Association of Clean Water Agencies (ACWA), Bay Area Stormwater Management Association, Water Environment Research Foundation, state transportation departments, vendors of proprietary stormwater treatment systems, colleges and universities, and others continually conduct this type of research and examine complex stormwater-related issues.
    c. Continuing participation in these groups and following current research, co-permittees can realize greater benefits from labor and capital investment than if they were to attempt such studies on their own. As such, the co-permittees plan to rely on information garnered by these organizations to address some of the more complex and costly objectives of the permit, especially with respect to understanding the effectiveness of BMPs. One example is the research activities related to porous pavement applications, led by the porous pavement subcommittee of the Association of Clean Water Agencies (ACWA) Stormwater Committee. The City of Gresham and City of Milwaukie recently partnered on water quality sampling for the Lake Road (Milwaukie) porous pavement pilot study.

3. Review and evaluate the monitoring results and other information (literature and stormwater management program tracking measures) collected by the co-permittees to support future decisions related to adaptive management and refinement of both the SWMP and environmental monitoring plan:
    a. The compilation of monitoring data during the annual reporting periods and at permit renewal will allow co-permittees to ensure that data are being collected as required and that the data are providing useful information to support adaptive management goals.
    b. In conjunction with the monitoring objectives and adaptive management approach submitted to DEQ by the co-permittees in November 2012 and again with permit renewal in March 2017, the monitoring data can potentially provide rationale for co-permittees in making decisions related to the allocation of resources among stormwater management activities.
    c. Monitoring activities are then revised to better address needs. The intent of the stormwater monitoring program is to provide data to support conclusions related to implementation of the co-permittee’s SWMPs (e.g., what are the trends) and NPDES MS4 permit requirements and to ensure that the data continue to provide value as questions are answered or new questions arise.

Section 5 Monitoring Activities

This section describes the coordinated environmental monitoring efforts for the participating Clackamas County co-permittees. This section is organized according to the following monitoring activities:

- Instream monitoring efforts (routine and targeted)
- Stormwater system monitoring efforts (including pesticide monitoring)
- Mercury monitoring efforts
- Biological monitoring efforts
- BMP effectiveness monitoring

The questions to be answered and objectives addressed by each monitoring activity are listed at the beginning of each subsection.

5.1 Instream Monitoring

Instream monitoring throughout the Clackamas MS4 permit area addresses objectives 2, 4 and 5 from Schedule B.1.a of the 2021 permit:

> **Objective 2:** Evaluate the effectiveness of Best Management Practices (BMPs) in order to help determine BMP implementation priorities.
>
> **Objective 4:** Evaluate status and long-term trends in receiving waters associated with MS4 stormwater discharges; and
>
> **Objective 5:** Assess the chemical, biological, and physical effects of MS4 stormwater discharges on receiving waters.

Instream monitoring activities will attempt to address the following questions:

- What is the ambient water quality status of the water body?
- What are the trends in water quality observed for the water body?
- How is stormwater runoff impacting receiving water quality?
- How does instream water quality change from an upstream location to a downstream location within an urbanized area?

The following sections describe the instream monitoring locations (Section 5.1.1), sample collection methods (Section 5.1.2), and additional instream sample collection efforts (Section 5.1.3).

5.1.1 Description of Instream Monitoring Locations

Instream monitoring efforts conducted by the participating Clackamas County co-permittees as part of this 2023 Plan include a total of 20 sampling locations representing 18 water bodies.

Instream monitoring site selection was conducted to prioritize locations with water quality impairment, meaning they have a TMDL in place or are 303(d)-listed for a specific parameter. Within the Clackamas County area, the TMDL water bodies and effective and pending 303(d)-listed water bodies are listed in Table 1.

Table 1. Summary of Clackamas County TMDL and 303(d) Listed Water Bodies

Monitored water body	Bacteria[a]	Temperature	Dissolved oxygen (DO)	Phosphorus	pH/chlorophyll a	Mercury[b]	PCBs[c]	PAHs	DDE/DDT	Pesticides[d]	Copper	Iron	BioCriteria, HABs	Aquatic Weeds/Algae	Cyanide	Ethylbenzene	Tetrachloroethylene
TMDLs																	
Willamette River (and tributaries) (2006) (2019)	✓	✓				✓											
Johnson Creek (2006) (2019)	✓	✓				✓			✓	✓							
Tualatin River (2001) (2019)	✓	✓	✓	✓	✓	✓											
2018/2020 (effective) 303(d) list																	
Willamette River (and tributaries)			✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Johnson Creek							✓	✓				✓	✓				✓
Tualatin River/Fanno Creek			✓								✓	✓	✓				
Abernethy Creek	✓		✓										✓				
Clackamas River			✓														
Kellogg Creek					✓												

DDE = dichlorodiphenyldichloroethylene

DDT = dichlorophenyltrichloroethane

PAH = polycyclic aromatic hydrocarbon

PCB = polychlorinated biphenyl

HAB = Harmful algal bloom

a. Bacteria includes E. coli and/or Enterococci

b. Mercury includes Total Mercury

c. PCBs include Dioxin

d. Pesticides include Aldrin, Chlordane, Dieldrin, Eldrin Aldehyde, Endosulfan, Hexachlorobenzene, and/or Pentachlorophenol

Instream monitoring site selection was also based on the length of record of historical data. Locations are primarily consistent with those included in the 2006 Plan and subsequent updates, to ensure a long enough period of record to inform future trends analyses. Finally, site selection was made to ensure geographic coverage of the participating co-permittees' MS4 permit areas.

Paired instream monitoring locations were selected when possible. Paired monitoring locations include one upstream location that represents more baseflow and/or rural conditions, generally located close to the co-permittee's MS4 permit area boundary, and one downstream location that represents urban MS4 stormwater runoff and baseflow conditions generated inside of the co-permittee's MS4 permit boundary. Paired monitoring was selected to help identify the effects of urban development on receiving water quality.

Figure 1 identifies the instream monitoring locations and includes the specific water body, responsible jurisdiction, and type of sampling method employed (see Section 5.1.2). Table 2 summarizes the total number of locations and the total number of data points (product of monitoring location and frequency) collected by participating co-permittees each year. Please note that instream monitoring locations may adjust because of adaptive management, but the number of data points identified in Table 2 will remain the same over the 2023 Plan implementation period.

Table 2. Summary of the Clackamas County Co-permittee Instream Monitoring Efforts

Jurisdiction	Total number of monitoring locations	Data points/year
WES[a]	4	36
Milwaukie	1	4
Oregon City	6	24
West Linn	3	15
Gladstone	1	3
OLWS	3	12
Wilsonville	2	8
Total	20	102

a. Clackamas WES conducts monitoring on behalf of Clackamas County and the cities of Happy Valley and Rivergrove.

5.1.2 Sample Collection Methods

Instream sample collection methods vary by jurisdiction and include either storm-targeted sample collection efforts or routine sample collection efforts. A description of both methods is provided below.

5.1.2.1 Targeted Sample Collection

The 2006 Plan's instream monitoring efforts were focused on collecting ambient water quality data during both dry weather and wet weather conditions. As instream water quality tends to vary during storm events, sample collection that is targeted during storm events and during dry weather conditions allows jurisdictions that conduct monitoring less frequently to assess water quality impacts associated with MS4 discharges. For this 2023 Plan, select jurisdictions (Milwaukie and OLWS) opted to continue targeting storm events as well as dry weather events to meet their instream sampling requirements. Other jurisdictions have opted for routine (i.e., scheduled) instream sampling which occurs regardless of the weather (see Section 5.1.2.2).

Targeted instream sampling procedures applicable to this 2023 Plan are as follows:

1. Instream water quality samples will be collected during both dry and wet weather conditions, to support future trends analyses and evaluate differences in receiving water quality due to weather conditions and MS4 stormwater runoff. A select (varies by jurisdiction) number of samples will be collected during targeted storm events (see Table 3 of this Plan).
2. Samples collected during a targeted storm event will be collected as time-composited grab samples, which will require grab samples to be collected at a defined frequency and combined prior to analysis. Rationale related to the use of a time-composite sampling approach was previously submitted to DEQ in 2012.
3. A minimum of 72 hours shall be maintained between consecutive instream sampling events.
4. Individual grab samples (during dry weather conditions) will be collected in accordance with the field collection methods outlined in Appendix A. Time-spaced grab samples (during wet weather conditions) will be combined into a single time-composited sample in accordance with the field collection methods outlined in Appendix A.

Table 3 outlines the targeted instream monitoring locations, frequencies, and responsible jurisdiction. As shown in Table 3, a total of 16 individual samples are planned for collection via the targeted instream sampling method per year, representing 4 water bodies. Eight of those samples are planned to be time-composited samples collected during storm events.

NOTE: The most resource-intensive element of water quality monitoring is sampling during storm events. Because of the difficulty in identifying suitable storms, the uncertainty associated with weather forecasts, and the need to mobilize in a timely manner to allow for characterizing the duration of the storm, storm-targeted sampling requires a significant time commitment. Staff conducting the sampling are assigned other responsibilities in addition to stormwater monitoring. To ensure that monitoring does not consume inordinate resources at the expense of activities that reduce pollution, the following limitations apply to the commitments made in this 2023 Plan related to storm event sample collection.

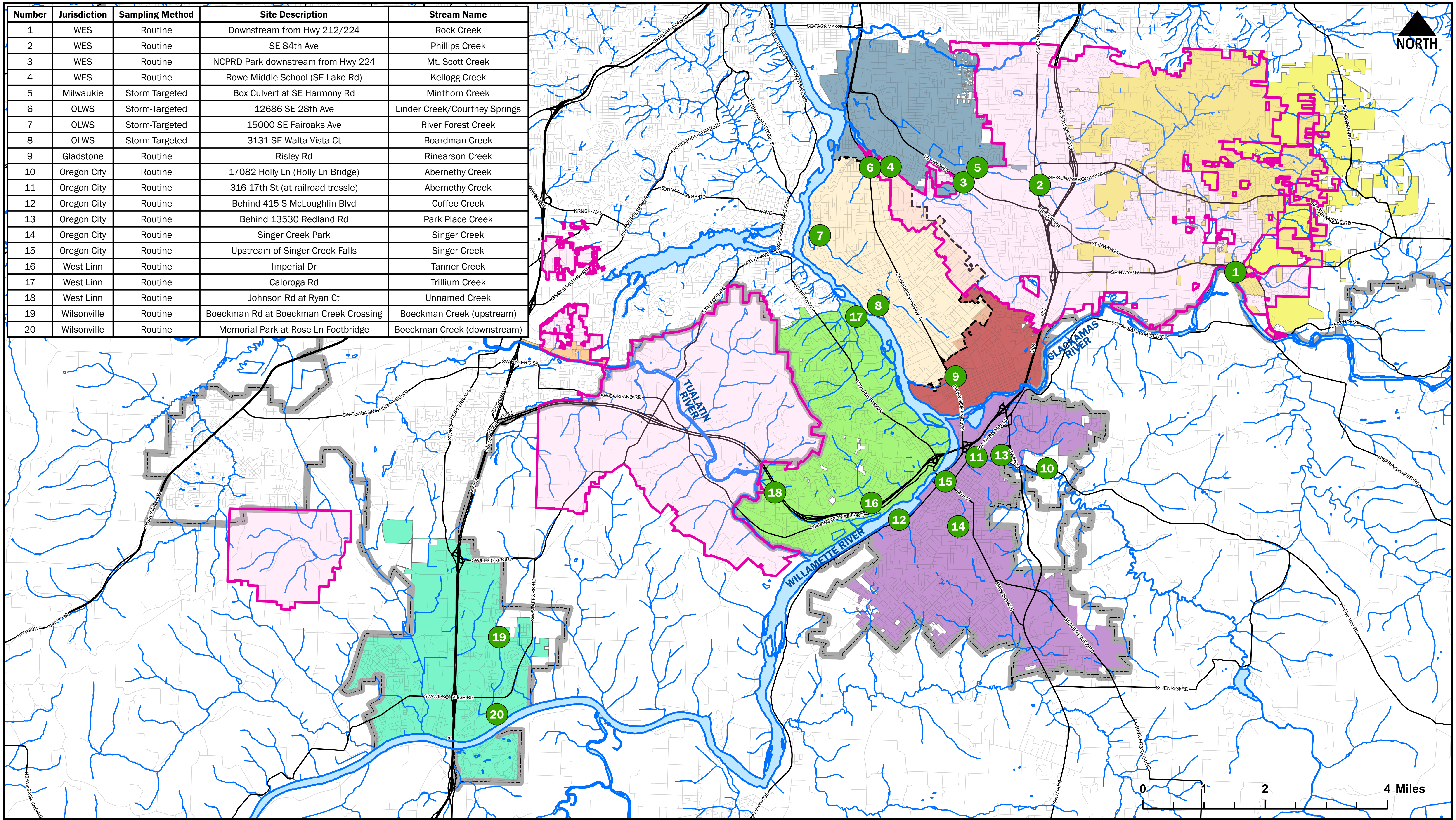
- Storms will not be sampled on major holidays including Thanksgiving Day, Christmas Eve, Christmas Day, New Year's Eve, New Year's Day, President's Day, Independence Day, Labor Day, Memorial Day, and Easter.
- Storm events shall be a minimum of 0.1 inch of rainfall and of a size for which, once a crew is mobilized, runoff is anticipated to occur for a minimum of 2 hours.
- For time-composite sample collection, the duration of time between the collection of individual grab samples will vary as necessary to meet the goal of obtaining at least three grab samples per storm event (these three grab samples will then be combined into one composited sample for analyses). In some cases, a storm may not last long enough to collect three individual grab samples. In these cases, the samples that are collected will be composited and analyzed; no minimum number of samples is specified.

Table 3. Targeted Instream Monitoring Site Summary

Monitored water body	Responsible party	Number of locations	Sampling Event Frequency	Parameters monitored (field/lab)[a]	Storm events targeted
Minthorn Creek	Milwaukie	1	4/year	Field and lab	Y (2 of 4)
River Forest Creek	OLWS	1	4/year	Field and lab	Y (2 of 4)
Boardman Creek	OLWS	1	4/year	Field and lab	Y (2 of 4)
Kellogg Creek	OLWS	1	4/year	Field and lab	Y (2 of 4)
Total		4	16 samples collected/ year	Field and lab	8 samples collected/ year

a. The term "field" indicates samples that are analyzed using meters in the field–typically for temperature, conductivity, DO, and pH.

Number	Jurisdiction	Sampling Method	Site Description	Stream Name
1	WES	Routine	Downstream from Hwy 212/224	Rock Creek
2	WES	Routine	SE 84th Ave	Phillips Creek
3	WES	Routine	NCPRD Park downstream from Hwy 224	Mt. Scott Creek
4	WES	Routine	Rowe Middle School (SE Lake Rd)	Kellogg Creek
5	Milwaukie	Storm-Targeted	Box Culvert at SE Harmony Rd	Minthorn Creek
6	OLWS	Storm-Targeted	12686 SE 28th Ave	Linder Creek/Courtney Springs
7	OLWS	Storm-Targeted	15000 SE Fairoaks Ave	River Forest Creek
8	OLWS	Storm-Targeted	3131 SE Walta Vista Ct	Boardman Creek
9	Gladstone	Routine	Risley Rd	Rinearson Creek
10	Oregon City	Routine	17082 Holly Ln (Holly Ln Bridge)	Abernethy Creek
11	Oregon City	Routine	316 17th St (at railroad tressle)	Abernethy Creek
12	Oregon City	Routine	Behind 415 S McLoughlin Blvd	Coffee Creek
13	Oregon City	Routine	Behind 13530 Redland Rd	Park Place Creek
14	Oregon City	Routine	Singer Creek Park	Singer Creek
15	Oregon City	Routine	Upstream of Singer Creek Falls	Singer Creek
16	West Linn	Routine	Imperial Dr	Tanner Creek
17	West Linn	Routine	Caloroga Rd	Trillium Creek
18	West Linn	Routine	Johnson Rd at Ryan Ct	Unnamed Creek
19	Wilsonville	Routine	Boeckman Rd at Boeckman Creek Crossing	Boeckman Creek (upstream)
20	Wilsonville	Routine	Memorial Park at Rose Ln Footbridge	Boeckman Creek (downstream)



Brown AND Caldwell

NOVEMBER 2022

FIGURE 1. INSTREAM MONITORING LOCATIONS

WES, Clackamas County, Happy Valley, Rivergrove, Gladstone, Milwaukie, OLWS, Oregon City, West Linn, and Wilsonville

- ● Instream Monitoring Locations
- ▭ Urban Growth Boundary
- ▭ WES SWM Service Area
- ▭ OLWS
- 🟥 Gladstone
- 🟨 Happy Valley
- ▨ Milwaukie
- 🟪 Oregon City
- 🟧 Rivergrove
- 🟩 West Linn
- ▨ Wilsonville

5.1.2.2 Routine Sample Collection Methods

Routine instream monitoring efforts are focused on collecting ambient water quality data year-round during both dry weather and wet weather seasons in accordance with a predetermined schedule.

For this 2023 Plan update, select jurisdictions (Wilsonville, Oregon City, Gladstone, WES and West Linn) opted to conduct routine instream monitoring instead of specifically targeting dry weather events and storm events to meet their instream sampling requirements. Routine sampling provides a more unbiased and comprehensive picture of ambient water quality conditions. Routine sampling requires prescheduling of sampling activities, reflective of consistent timing and frequency over the monitoring year. When prescheduled, samples will presumably be collected during both dry weather and wet weather conditions to allow for assessment of water quality impacts associated with MS4 discharges.

As with the targeted instream sampling method, grab samples will be collected instream during dry weather conditions. During qualifying storm events, multiple time-spaced grab samples will be collected throughout the storm event to provide a single time-composited sample. If rainfall starts while sample collection efforts are in progress, continuation of single grab sampling is permissible.

Instream sampling procedures applicable to this 2023 Plan are as follows:

- Prior to the start of the monitoring year, the co-permittee shall establish an instream sampling schedule, based on frequencies shown in Table 4. Deviation from the predetermined schedule during the monitoring year is to be avoided to the extent possible.
- Instream water quality samples will be scheduled and collected during both the dry and wet weather seasons. A minimum of 50 percent of the samples will be collected during the wet weather season (September 1 to April 30).
- If it is raining (i.e., minimum of 0.1 inch of rainfall over a 2-hour duration) on a prescheduled sampling day, samples shall be collected as time-composited grab samples, which will require grab samples to be collected at a defined frequency and then combined prior to analysis. A minimum of 72 hours shall be maintained between consecutive instream sampling events. Refer to Section 5.1.2.1 for applicable instream sampling procedures during rainfall events.
- Individual grab samples (during dry weather conditions) will be collected in accordance with the field collection methods outlined in Appendix A. Time-spaced grab samples (during wet weather conditions) will be combined into a single time-composited sample in accordance with the field collection methods outlined in Appendix A.

Table 4 outlines the routine instream monitoring locations, frequencies, and responsible jurisdiction. As shown in Table 4, a total of 86 individual samples are planned for collection via the routine instream sampling method per year, representing 16 locations across 13 water bodies.

Table 4. Routine Instream Monitoring Site Summary

Monitored water body	Responsible party	Number of locations[a]	Sampling Event Frequency	Parameters monitored (field/lab)[b]
Kellogg Creek	WES	1	9/year	Field and lab
Mt Scott Creek	WES	1	9/year	Field and lab
Phillips Creek	WES	1	9/year	Field and lab
Rock Creek	WES	1	9/year	Field and lab
Abernethy Creek	Oregon City	2	4/year	Field and lab
Coffee Creek	Oregon City	1	4/year	Field and lab
Park Place Creek	Oregon City	1	4/year	Field and lab
Singer Creek	Oregon City	2	4/year	Field and lab
Rinearson Creek	Gladstone	1	3/year	Field and lab
Summerlinn Creek	West Linn	1	5/year	Field and lab
Tanner Creek	West Linn	1	5/year	Field and lab
Trillium Creek	West Linn	1	5/year	Field and lab
Boeckman Creek	Wilsonville	2	4/year	Field and lab
Total		16	86 samples collected/year	

a. Two locations on the same monitored water body reflects paired sampling sites.

b. The term "field" indicates samples that are analyzed using meters in the field–typically for temperature, conductivity, DO, and pH.

5.1.3 Additional Instream Monitoring Efforts

Since 1998, the City of Milwaukie has participated in a cooperative Johnson Creek watershed study with the U.S. Geological Survey (USGS) and other partners (Gresham, Portland, etc.). The project objectives included the following:

- Assess hydrologic hazards: Analysis of real-time flow and water surface elevations will allow for assessment of flooding conditions as a result of ongoing, significant changes in land use and groundwater discharges.
- Assess water quality: Analysis of stream temperature and turbidity data will provide insight into the effects of land use practices and pollutant sources.
- Assess the interaction between surface water and groundwater: The study provides data and analyses that relate directly to the inter-related nature of the surface and groundwater systems.

As part of this ongoing project, multiple technical reports and publications have been developed. Publications are available for public use and include topics such as: (1) pesticide contributions and transport, (2) overall system hydrology, and (3) suspended sediment loading and the relationship to turbidity levels.

In 2021, the City of Milwaukie agreed to extend participation through September 2022. Joint Funding Agreements (JFAs) are prepared by USGS annually to ensure each partner provides funds (in part) to operate and monitor continuous flow gauges on Johnson Creek. This monitoring effort is identified in Table 3 of the 2021 permit specific for Milwaukie and helps support monitoring objective 4 by assessing ambient conditions in Johnson Creek. Because of the variable nature of the funding of this study and because future participation is unknown, this effort is referenced separately as an additional instream monitoring activity. The City of Milwaukie anticipates continued participation if USGS remains a partner.

5.2 Stormwater System Monitoring Efforts

Stormwater monitoring throughout the Clackamas County MS4 permit area addresses objectives 1, 2, 3, 5, and 6 from Schedule B.1.a of the 2021 permit:

Objective 1: Evaluate the source(s) of and means for reducing the pollutants of concern applicable to the co-permittees' permit area, including the 2018/2020 303(d) listed pollutants, as applicable;

Objective 2: Evaluate the effectiveness of Best Management Practices (BMPs) in order to help determine BMP implementation priorities;

Objective 3: Characterize stormwater based on land use type, seasonality, geography, or other catchment characteristics;

Objective 5: Assess the chemical, biological, and physical effects of MS4 stormwater discharges on receiving waters; and

Objective 6: Assess progress towards reducing TMDL pollutant loads.

Stormwater monitoring activities will attempt to address the following questions:

- Are stormwater-related sources of 303(d) pollutants discharging to receiving waters?
- How do stormwater pollutant concentrations vary based on land use?
- How do stormwater pollutant concentrations vary based on BMP implementation upstream?
- Are pollutant loads from stormwater being reduced over time?
- Specific for pesticides, do pesticide concentrations vary seasonally?

The following sections describe stormwater outfall monitoring locations (Section 5.2.1), sample collection methods (Section 0), and additional stormwater monitoring efforts for pesticides (Section 0).

5.2.1 Description of Stormwater Monitoring Locations

Stormwater monitoring efforts conducted by the participating Clackamas County co-permittees as part of this 2023 Plan represent a total of 11 sampling locations and five land use categories. As with the instream monitoring locations, stormwater outfall monitoring locations were originally selected as part of the 2006 Plan development and have been continually refined based on site accessibility and safety.

In 2006, stormwater monitoring locations were originally selected based on the distribution and consistency of the upstream land use type or category (i.e., residential, commercial, industrial, and mixed use). Classification of stormwater quality by land use allows for estimation and evaluation of the sources of specific pollutants. Additionally, the classification of stormwater quality based on land use can be used for pollutant load modeling efforts, and the identification and application of specific BMPs to address specific pollutant loading from a particular land use. Monitoring locations were also selected based on avoiding non-stormwater flow (e.g., baseflow from groundwater) given that samples collected during a storm event from locations with significant baseflow would not be entirely representative of MS4 discharges.

Figure 2 identifies the selected stormwater monitoring locations and includes the associated receiving water, upstream contributing land use, and sampling frequency. Table 5 summarizes the total number of locations and total number of data points (product of monitoring location and frequency) collected by participating co-permittees each year. Please note that stormwater monitoring locations may adjust because of adaptive management, but the number of data points identified in Table 5 will remain the same over the monitoring period.

Table 5. Summary of the Clackamas County Co-permittee Stormwater Monitoring Efforts

Upstream land use	Number of outfalls monitored	Annual samples collected
Residential	4	12
Multifamily residential	1	3
Commercial	2	6
Mixed use	3	9
Industrial	1	3
Total	11	33

5.2.2 Sample Collection Methods

Stormwater monitoring efforts are focused on capturing storm-specific data from select outfall locations representing drainage from various land use categories. In conjunction with the monitoring objectives, collection of stormwater samples allows for the identification of pollutant sources, characterization of stormwater (based on land use), and indication of the effects that stormwater runoff may have on instream water quality.

Samples will generally be collected as time-composite grab samples. Given the number of stormwater monitoring sites and the geographic coverage of sites, a time-composite sampling method is preferred for participants in the Comprehensive Clackamas County Monitoring Program. Composited samples (either time- or flow-composited samples) collected during storm events allow for capture of a larger portion of the storm hydrograph. As fluctuations of pollutant concentrations vary throughout a storm event, use of composite sampling techniques will better represent those variations during storm events.

Stormwater sampling procedures are as follows:

- Qualifying stormwater monitoring events must be associated with a storm event resulting in greater than 0.1 inch of rainfall.
- As possible, qualifying stormwater monitoring events shall occur after a minimum 12-hour antecedent dry period with intra-event dry periods not exceeding 6 hours.
- Stormwater samples will be collected during three storm events per monitoring year (July 1st to June 30th) per location.
- For each sampling event and for the composite-able parameters/pollutants, a minimum of three time-spaced grab samples will be collected throughout the storm event. As possible, based on the number and location of stormwater monitoring sites, sample collection will be initiated toward the beginning of the storm event and individual grab samples will be collected throughout the storm event, but no more frequently than one sample per 30 minutes.
- The time-spaced grab samples collected will be combined into a single time-composited sample in accordance with the field collection methods outlined in Appendix A.

The discussion in Section 5.1.2.1 regarding limitations on the commitments for storm event sampling for instream monitoring efforts is also applicable to stormwater monitoring efforts. In addition, if less than three time-spaced grab samples are collected, the sample will still be composited and utilized.

Number	Jurisdiction	Site Description	Receiving Water	Associated Land Use	Sampling Frequency
1	WES	Sunnyside Village Outfall at 13944 SE Hines Dr	Rose Creek	Residential	3 / Year
2	WES	Sunnyside Village Apartments	Unnamed tributary to Rose Creek	Multi-family Residential	3 / Year
3	WES	Clackamas Promenade Shopping Mall	Phillips Creek	Commercial	3 / Year
4	WES	Carli Creek Stormwater Treatment Facility Outfall	Carli Creek	Industrial	3 / Year
5	WES	Outfall #12 at SE Pheasant Ct	Mt Scott Creek	Mixed Use	3 / Year
6	Milwaukie	Outfall #23003 at Roswell St	Johnson Creek	Residential	3 / Year
7	OLWS	SE Naef Rd (Stringfield Park)	Boardman Creek	Mixed Use	3 / Year
8	Oregon City	Oregon City Shopping Center	Clackamas River	Commercial	3 / Year
9	Oregon City	Clackamette Cove at Agnes Ave	Clackamas River	Industrial	3 / Year
10	West Linn	Summit St & Horton Rd	Barlow Creek	Residential	3 / Year
11	Wilsonville	Library Detention Pond Inlet at Memorial Park	Tributary to Boeckman Creek	Mixed Use	3 / Year

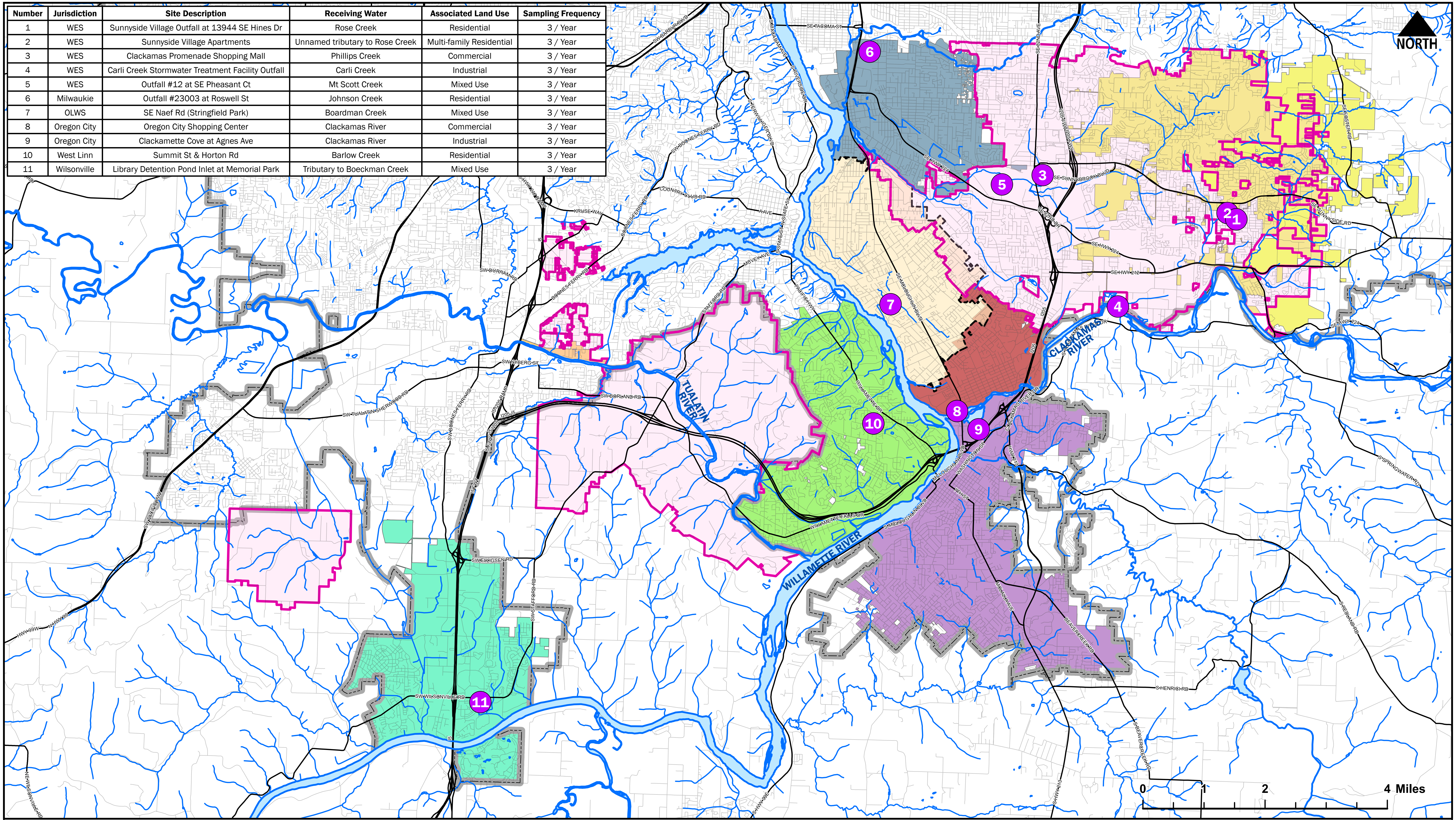


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FIGURE 2. OUTFALL MONITORING LOCATIONS

WES, Clackamas County, Happy Valley, Rivergrove, Gladstone,
Milwaukie, OLWS, Oregon City, West Linn, and Wilsonville

● Outfall Monitoring Locations
▭ Urban Growth Boundary
▭ WES SWM Service Area
▭ OLWS
▭ Gladstone
▭ Happy Valley
▭ Milwaukie
▭ Oregon City
▭ Rivergrove
▭ West Linn
▭ Wilsonville

For each monitored storm event, the contributing storm event rainfall depth will be estimated based on local rainfall gauge records. In lieu of storm event rainfall depth estimates, the flow rate in the pipe may be estimated. Flow rate may be estimated using the average depth of flow measurement taken in the pipe (or outfall) during sample collection activities, the pipe (or outfall) slope and diameter, and Manning's equation2.

Each stormwater monitoring location is listed in Table 6, along with a reference regarding the sampling frequency and parameters monitored.

Table 6. Stormwater System Monitoring Site Summary

Upstream land use	Outfall description	Receiving water	Responsible party	Sampling Event Frequency	Parameters monitored (field/lab)
Residential[a]	Sunnyside Village Outfall at 13944 SE Hines Dr.	Rose Creek	WES	3/year	Field and lab
Residential	Outfall 23003 at Roswell Street	Johnson Creek	Milwaukie	3/year	Field and lab
Residential	Summit Street and Horton Road	Barlow Creek	West Linn	3/year	Field and lab
Multifamily residential	Sunnyside Village Apartments	Unnamed tributary to Rose Creek	WES	3/year	Field and lab
Mixed use (industrial, highway, commercial, residential)	Outfall 12: SE Pheasant Court	Mt. Scott Creek	WES	3/year	Field and lab
Mixed use (park, school, commercial, residential)	Inlet to Library Detention Pond at Memorial Park	Unnamed tributary to Boeckman Creek	Wilsonville	3/year	Field and lab
Mixed use (park, highway, commercial, residential)	SE Naef Road at Stringfield Park	Boardman Creek	OLWS	3/year	Field and lab
Commercial[a]	Clackamas Promenade Shopping Mall	Phillips Creek	WES	3/year	Field and lab
Commercial	Oregon City Shopping Center	Clackamas River	Oregon City	3/year	Field and lab
Industrial	Clackamette Cove at Agnes Avenue	Clackamas River	Oregon City	3/year	Field and lab
Industrial[a]	Carli Creek Stormwater Treatment Facility outfall	Carli Creek	WES	3/year	Field and lab

a. New stormwater monitoring location compared to 2017 Plan.

5.2.3 Additional Stormwater Monitoring Efforts (Pesticides)

Clackamas co-permittees submitted a permit modification letter to the Oregon Department of Environmental Quality (DEQ) on August 25, 2022, related to the prescribed pesticide monitoring requirements in the originally issued 2021 permit. DEQ reissued the Clackamas NPDES MS4 permit effective on May 5, 2023. The reissued permit maintains the expiration date of September 30, 2026. This 2023 Plan reflects the updated pesticide monitoring requirements per the reissued permit. The reissued permit is still referred to as the 2021 permit for purposes of this 2023 Plan..

5.2.3.1 2015 Clackamas and USGS Pesticide Monitoring Study

In 2013, Clackamas co-permittees (including those jurisdictions participating in the Comprehensive Clackamas County Stormwater Monitoring Plan/CCCSMP) entered into an agreement with United States Geological Survey (USGS) to conduct a coordinated pesticide monitoring study to provide a baseline

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[2] Various online resources for Manning's formula for pipe flow may be referenced. One option: http://www.sd-w.com/civil/mannings_formula.html

characterization of pesticides in stormwater, receiving waters, and bed sediment within Clackamas County and build on past USGS pesticide monitoring efforts. Specific objectives of the study included:

- Characterize pesticide concentrations in stormwater runoff from streams and stormwater outfalls in areas covered by the Clackamas County MS4 permit;
- Characterize pyrethroids and other current use pesticide concentrations in streambed sediment during low flow conditions and in sediments accumulated within stormwater outfall pipes;
- Use Geographic Information System (GIS) data to examine the relations between urban land cover characteristics and pesticide occurrence.
- Relate pesticide occurrence to the quality of benthic invertebrate assemblages using existing data; and
- Present findings in a peer-reviewed scientific journal.

Data collection associated with the USGS study occurred in August and September 2013. Sampling occurred at 12 urban stream locations, three streams draining some agricultural land use, and five stormwater outfalls representing primarily residential and commercial land use. Sampling at stormwater outfalls occurred for one summer storm event (September 5-6, 2013), which represented first flush conditions.

Pesticides selected were ultimately determined based on use of the USGS Pesticide Fate and Research Laboratory in Sacramento, California, which specializes in “current use” pesticides and uses methods to achieve ultra-low detention limits. The study analyzed a total of 91 pesticides dissolved in water and 118 pesticides on sediment. Compounds selected for the USGS study included a subset of pesticides identified for consideration in the 2012 NPDES MS4 permit.

The USGS study identified bifenthrin (insecticide), fipronil (insecticide), and metolachlor (herbicide) as the most frequently detected pesticides in stormwater discharges (detection in more than 60 percent of stormwater samples). Bifenthrin, pendimethalin (herbicide), and trifluralin (herbicide) were the most frequently detected pesticides in stormwater sediment and in streambed sediment. Conclusions from the USGS pesticide study were considered in the development of the pesticide monitoring approach outlined herein.

The USGS study was published in 2015 and is provided in Appendix B.

5.2.3.2 Pesticide Monitoring Goals

Pesticide monitoring conducted for the 2021 permit will build off the results of the USGS study, specifically objectives #1 and #3 from the original USGS study. Efforts will focus on stormwater monitoring locations and contributing land uses not previously evaluated as part of USGS study, as well as consider an expanded list of pesticide parameters in accordance with those listed for consideration in the 2021 permit. Frequently detected pesticides in stormwater discharges as noted in the 2015 USGS study will continue to be evaluated to assess continued presence, seasonality, and potential trending.

5.2.3.3 Pesticide Monitoring Activities

Specific pesticide activities for the 2023-2026 NPDES MS4 monitoring period include:

- Utilize local/regional laboratories and screening-level analyses to detect pesticides in stormwater runoff at identified stormwater monitoring locations;
- Establish pesticide presence within the CCCSMP coverage area for contributing land uses not previously evaluated (i.e., industrial or mixed use).
- Compare seasonality of pesticides, as available, in stormwater discharges (i.e., spring versus summer storm events).

Responsible jurisdictions (i.e., jurisdictions per the 2021 permit with a stormwater monitoring requirement) will each collect a total of six data points (i.e., combination of monitoring location and sampling event) for pesticides over the permit term (from July 2023 through September 2026). In accordance with Table 3 of the 2021 permit, Clackamas County, WES, and the cities of Happy Valley and Rivergrove are required to sample for pesticides at two monitoring locations during three events over the permit term whereas the other responsible jurisdictions are required to sample for pesticides at one monitoring location during six events over the permit term. For responsible jurisdictions with more than one current stormwater monitoring location (see Figure 2), more than one pesticide monitoring location may be used to adhere to the requirement to collect six data points over the permit term.

Sample collection will be targeted in the spring, summer, or fall, in accordance with anticipated presence of pesticides in stormwater runoff. The sampling approach is outlined in Table 7.

Table 7. Pesticide Monitoring Summary

Responsible party	Stormwater Monitoring Locations	Stormwater Monitoring Location (by upstream land use)	Receiving water	Reflected in 2015 USGS Study? (Y/N)	Pesticide Sampling Activities		
					Sampling Locations	Sampling Event Frequency	Notes
WES[c]	5	Residential	Rose Creek		X	3/permit term	Two locations to be sampled per event. Each location to be sampled at least once over the permit term.
		Commercial	Phillips Creek		X		
		Industrial	Carli Creek		X		
		Multifamily residential	Unnamed tributary to Rose Creek		X		
		Mixed use	Mt. Scott Creek		X		
Wilsonville[a, b]	1	Mixed use	Unnamed tributary to Boeckman Creek	Y	X	6/permit term	Sampling to reflect varying seasons
OLWS[b]	1	Mixed use	Boardman Creek		X	6/permit term	Sampling to reflect varying seasons
Oregon City[c]	2	Commercial	Clackamas River		X	3/permit term	Both locations to be sampled for each event.
		Industrial	Clackamas River		X		
Milwaukie[b]	1	Residential	Johnson Creek		X	6/permit term	Sampling to reflect varying seasons
West Linn[b]	1	Residential	Barlow Creek		X	6/permit term	Sampling to reflect varying seasons

a. *The 2015 USGS study considered this monitoring location as commercial.*

b. *Responsible jurisdictions with only one stormwater monitoring location will vary seasonality for their respective pesticide monitoring events.*

c. *Responsible jurisdictions with multiple stormwater monitoring locations will monitor a minimum of two locations for the respective pesticide monitoring events (for land use comparison purposes).*

Pesticides listed for consideration in the 2021 permit that were not evaluated as part of the 2015 USGS study include 2,4-D, 2,6-dichlorobenzamide, diuron, glyphosate and degradate (AMPA), sulfometuron methyl, dieldrin, and imidacloprid. As stated in Section 5.2.3.1, bifenthrin (insecticide), fipronil (insecticide), and meto lachlor were the pesticides most readily detected by the 2015 USGS study in stormwater runoff. As such, a multi-residue pesticide screen will be employed by all co-permittees for all sampling events to assess the presence of some of the permit-listed pesticides, as well as those readily detected from the 2015 USGS study. Additional screening analyses will be employed at the discretion of co-permittees to assess the presence of additional pesticides[3].

Sample collection methods are consistent with stormwater monitoring procedures outlined in Section 5.2.2.

5.3 Mercury Monitoring Efforts

Mercury monitoring throughout the Clackamas MS4 permit area addresses objectives 1, 2, 3, 5, and 6 from Schedule B.1.a of the 2021 Permit:

Objective 1: Evaluate the source(s) of and means for reducing the pollutants of concern applicable to the co-permittees' permit area, including 2018/2020 303(d) listed pollutants, as applicable;

Objective 2: Evaluate the effectiveness of Best Management Practices (BMPs) in order to help determine BMP implementation priorities;

Objective 3: Characterize stormwater based on land use type, seasonality, geography, or other catchment characteristics;

Objective 5: Assess the chemical, biological, and physical effects of MS4 stormwater discharges on receiving waters; and,

Objective 6: Assess progress towards reducing TMDL pollutant loads.

Mercury monitoring activities will attempt to address the following questions:

- Are stormwater-related sources of mercury discharging to receiving waters?
- How do stormwater mercury concentrations vary based on land use, season, and location?
- What are the potential impacts of stormwater runoff on receiving water quality?

The following sections describe the mercury monitoring locations (Section 5.3.1) and sample collection methods (Section 5.3.2).

5.3.1 Description of Mercury Monitoring Locations

The 2021 Permit requires mercury monitoring for the collective Clackamas County co-permittees per Schedule B, Table 3 of the 2021 permit. A total of eight instream sampling locations representing four different basins and four stormwater sampling locations are required. Lake Oswego is included in the collective mercury monitoring requirement and monitoring locations in Lake Oswego are reflected as part of the collective mercury monitoring approach in this plan.

Mercury monitoring sites were selected during a series of workshops with Clackamas County co-permittees held from February through April 2022. Existing (current) instream and stormwater monitoring locations were reviewed to identify those that could be accessed safely, and to ensure feasibility of compliance with the performance-based provisions of EPA Method 1669. Locations near heavily traveled roads, metal supports, bridges, and poles were avoided to reduce the potential for sample contamination. Locations where previous mercury monitoring efforts were conducted were prioritized. Site selection included consideration of geographic coverage across the four major basins and individual co-permittee NPDES MS4 permit coverage area, as well as equity in effort amongst co-permittees.

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[3] Separate, additional screening analyses to be considered include the Chlorinated Herbicides in Water (Modified EPA 8151A for 2,4-D and triclopyr), Sulfometuron-methyl in Water (DuPont Method), and Glyphosate and AMPA in Water (Modified EPA 547).

Figure 3 identifies the selected instream and stormwater mercury monitoring locations, the associated receiving water for stormwater locations, and the specific water body and basin for instream locations. Table 8 summarizes the instream mercury monitoring locations by participating co-permittee and watershed. Table 9 summarizes the stormwater mercury monitoring locations by participating co-permittee and respective land use.

Table 8. Clackamas County Co-permittee Instream Mercury Monitoring Locations

Jurisdiction	Instream Locations (#)	Stream Name	Basin	Sampling Event Frequency
WES	1	Rock Creek	Clackamas River	4/year
	1	Sieben Creek	Clackamas River	
Milwaukie	1	Minthorn Creek	Lower Willamette	
Lake Oswego	1	Nettle Creek	Lower Willamette	
	1	Carter Creek	Tualatin River	
West Linn	1	Unnamed Creek	Tualatin River	
Oregon City	1	Singer Creek	Middle Willamette	
Wilsonville	1	Boeckman Creek	Middle Willamette	
Total	8			32 samples collected/year

Table 9. Clackamas County Co-permittee Stormwater Mercury Monitoring Efforts

Jurisdiction	Stormwater Locations (#)	Receiving Water	Associated land use	Stormwater Sampling Event Frequency
WES	1	Phillips Creek	Commercial	3/year
WES	1	Carli Creek	Industrial	
West Linn	1	Barlow Creek	Residential	
OLWS	1	Boardman Creek	Mixed-Use	
Total	4			12 samples collected/year

5.3.2 Sample Collection Methods

Mercury monitoring will be conducted using a coordinated approach with a single entity (jurisdiction or coordinated jurisdictions) sampling on behalf of all co-permittees. Instream mercury monitoring efforts will use a routine method where ambient data are collected year-round during both dry weather and wet weather seasons in accordance with a predetermined schedule (see Section 5.1.2.2). Stormwater mercury monitoring efforts are focused on capturing storm-specific data from select outfall locations representing drainage from various land use categories.

Mercury sample collection methods will follow the “clean hands/dirty hands” method as outlined in Appendix A. All mercury samples will be collected as grab samples rather than composite samples to limit the risk of sample contamination. All mercury sampling will be paired with TSS sampling.

Instream mercury sampling procedures applicable to this 2023 Plan are as follows:

1. Prior to the start of the monitoring year, the co-permittees shall establish an instream mercury sampling schedule, based on frequencies shown in Table 8. Deviation from the predetermined schedule during the monitoring year is to be avoided to the extent possible.
2. Instream water quality samples will be scheduled and collected during both the dry and wet weather seasons. A minimum of 50 percent of the samples will be collected during the wet weather season (September 1 to April 30).

3. A minimum of 72 hours shall be maintained between consecutive instream sampling events.
4. Instream samples will be collected during four events per year per location.

Stormwater mercury sampling procedures are as follows:

1. Qualifying stormwater monitoring events must be associated with a storm event resulting in greater than 0.1 inch of rainfall.
2. As possible, qualifying stormwater monitoring events shall occur after a minimum 12-hour antecedent dry period.
3. Stormwater samples will be collected during three storm events per year per location.

The discussion in Section 5.1.2.1 regarding limitations on the commitments for storm event sampling is also applicable to stormwater mercury monitoring efforts with the exception that all mercury samples are collected as grab samples rather than composite samples to limit the risk of sample contamination.

For each monitored storm event, the contributing storm event rainfall depth will be estimated based on local rainfall gauge records. In lieu of storm event rainfall depth estimates, the flow rate in the pipe may be estimated. Flow rate may be estimated using the average depth of flow measurement taken in the pipe (or outfall) during sample collection activities, the pipe (or outfall) slope and diameter, and Manning's equation.

Outfall Monitoring Locations

Number	Jurisdiction	Site Description	Receiving Water
3	WES	Clackamas Promenade Shopping Mall	Phillips Creek
4	WES	Carli Creek Stormwater Treatment Facility Outfall	Carli Creek
7	OLWS	SE Naef Rd (Stringfield Park)	Boardman Creek
10	West Linn	Summit St & Horton Rd	Barlow Creek

Instream Monitoring Locations

Number	Jurisdiction	Site Description	Stream Name	Basin
1	WES	Downstream from Hwy 212/224	Rock Creek	Clackamas River
5	Milwaukie	Box Culvert at SE Harmony Rd	Minthorn Creek	Lower Willamette
14	Oregon City	Singer Creek Park	Singer Creek	Middle Willamette
18	West Linn	Johnson Rd at Ryan Ct	Unnamed Creek	Tualatin River
20	Wilsonville	Memorial Park at Rose Ln Footbridge	Boeckman Creek (downstream)	Middle Willamette
21	WES	Hwy 212/224	Sieben Creek	Clackamas River
22	Lake Oswego	Nettle Creek above Tryon	Lower Willamette	Lower Willamette
23	Lake Oswego	Carter Creek above Bangy	Fanno Creek/Tualatin River	Tualatin River

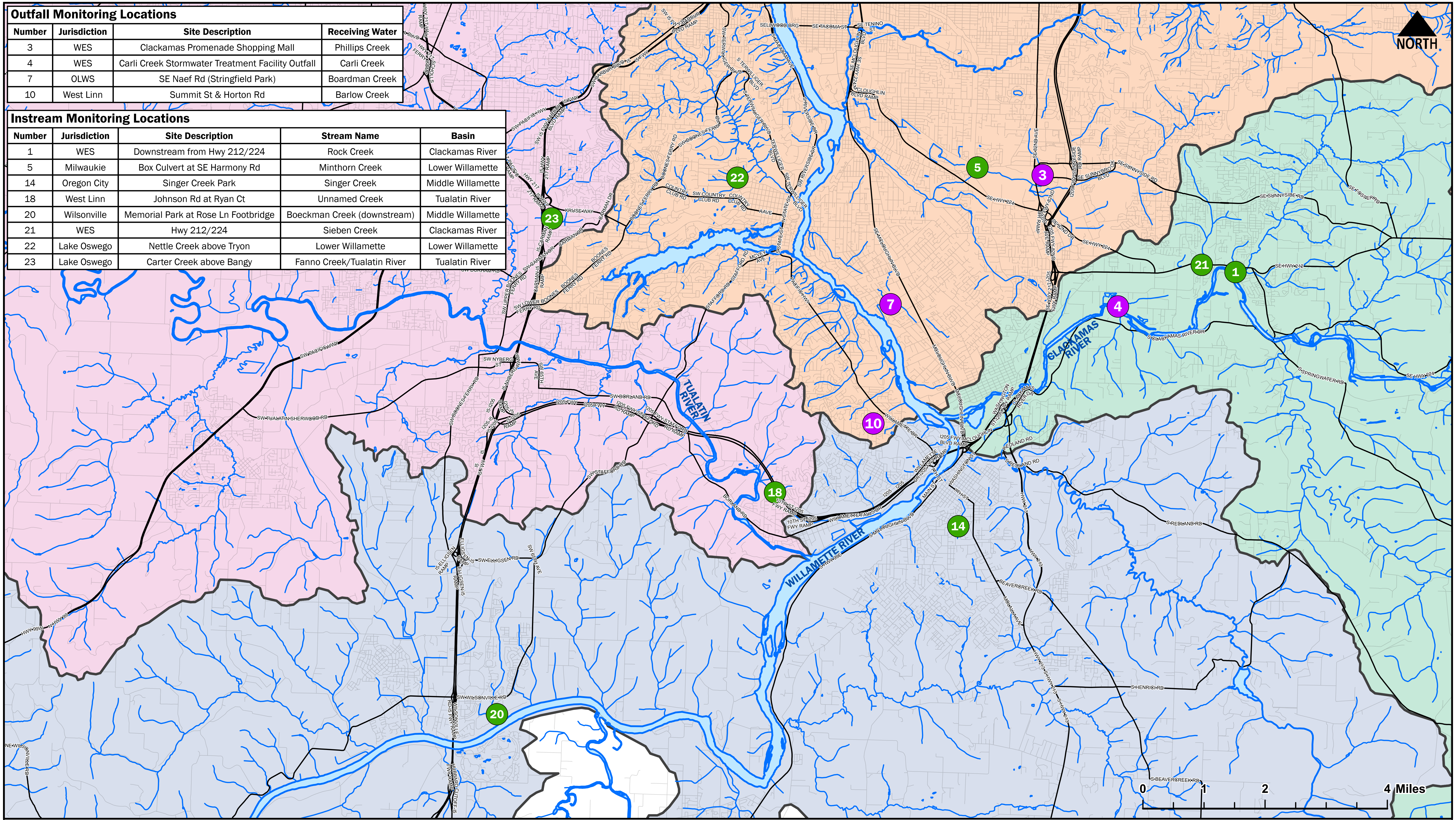

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FIGURE 3. MERCURY MONITORING LOCATIONS

WES, Clackamas County, Happy Valley, Rivergrove, Gladstone,
Milwaukie, OLWS, Oregon City, West Linn, and Wilsonville

🟩	Clackamas River	▨	Middle Willamette	●	Outfall Monitoring Locations
🟧	Lower Willamette	▨	Tualatin River	●	Instream Monitoring Locations

5.4 Biological Monitoring Efforts

Biological monitoring throughout the Clackamas County MS4 permit area addresses objective 5 from Schedule B.1.a of the 2021 permit:

> **Objective 5**: Assess the chemical, biological, and physical effects of MS4 stormwater discharges on receiving waters.

Biological monitoring activities will attempt to address the following questions:

- What are the biologic conditions of receiving waters?
- Based on past macroinvertebrate sampling activities, are there noticeable trends of improvement or impairment in receiving waters?

The following sections describe the macroinvertebrate monitoring site locations (Section 5.4.1), sample collection methods (Section 5.4.2), and connection to physical condition monitoring (Section 5.4.3).

5.4.1 Description of Biological Monitoring Locations

Biological monitoring efforts conducted by the participating Clackamas County co-permittees as part of this 2023 Plan include a total of 20 sampling locations representing 15 water bodies.

Biological monitoring sites reflect locations where biologic and water quality sampling has historically been conducted. In some cases, the locations are consistent with previous pesticide monitoring activities and/or ongoing instream water quality monitoring. Conclusions and recommendations from previous biological monitoring efforts related to site conditions and site adjustments were considered for this 2023 Plan.

For WES, biological monitoring locations reflect WES's clustered monitoring approach, and locations of detailed, instream physical condition assessments are not directly included in this 2023 Plan. WES's clustered monitoring approach is internal to WES and is intended to allow for a more comprehensive assessment of watershed conditions at specific sites.

The biological monitoring locations are described in Table 10 and shown graphically in Figure 4.

Table 10. Biologic Monitoring Site Summary					
Jurisdiction	**Target monitoring date**	**Site description**	**Receiving water**	**Past biologic monitoring efforts?**	**Current instream water quality monitoring location?**
WES	2024	Rowe Middle School (SE Lake Road)	Kellogg Creek	Y (2009, 2011, 2014, 2017, 2020)	Y
WES	2024	Carli Creek Stormwater Treatment Facility (formally Downstream of 11814 Jennifer Street)	Carli Creek	Y (2007, 2009, 2011, 2014, 2017, 2020)	N[a]
WES	2024	Downstream from Highway 212/224	Sieben Creek	Y (2002, 2007, 2009, 2011, 2014, 2017, 2020)	Y[b]
WES	2024	SE Troge Road and SE Foster Road	Rock Creek	Y (2009, 2011, 2014, 2017, 2020)	N
WES	2024	SE Rusk Road	Kellogg Creek	Y (2011, 2014, 2017, 2020)	N[c]
WES	2024	NCPRD Park downstream from Highway 224	Mt. Scott Creek	Y (2011, 2014, 2017, 2020)	Y[d]
WES	2024	Downstream from Highway 212/224	Rock Creek	Y (2002, 2007, 2009, 2011, 2014, 2017, 2020)	Y[e]
WES	2024	Downstream of SE Dean Drive	Cow Creek	Y (2011, 2014, 2017, 2020)	N
Gladstone	2024	River Road (Brookside Village Apartments)	Rinearson Creek	Y (2018)	N[f]
Milwaukie	2024	Box culvert at SE Harmony Road	Minthorn Creek	Y (2013, 2018)	Y
Oregon City	2024	Singer Creek Park	Singer Creek	Y (2013, 2018)	Y
Oregon City	2024	Lower Coffee Creek	Coffee Creek	Y (2013, 2018)	Y
West Linn	2024	Imperial Drive	Tanner Creek	Y (2013, 2018)	Y
West Linn	2024	Caloroga Road	Trillium Creek	Y (2013, 2018)	Y
Wilsonville	2024	Memorial Park at Rose Lane footbridge	Boeckman Creek	Y (2013, 2018)	Y
Wilsonville	2024	Kolbe Lane Bridge	Boeckman Creek	Y (2004, 2013, 2018)	N
Wilsonville	2024	Boeckman Creek footbridge	Boeckman Creek	Y (2004, 2013, 2018)	N
OLWS	2024	2350 SE Swain Avenue	River Forest Creek	Y (2013, 2018)	N
OLWS	2024	SE Naef Road at Stringfield Park	Boardman Creek	Y (2013, 2018)	N
OLWS	2024	4507 SE Boardman Avenue	Boardman Creek	Y (2013, 2018)	N

a. *The Carli Creek biological monitoring location was relocated approximately 200 meters downstream from the previous location in 2017. Record of past biological monitoring activities also correspond with the historical WES instream monitoring location at SE 120th Avenue and Carpenter Drive. No significant tributaries or other potential influences occur in the intervening distance; therefore, comparisons with previous years' results are valid.*

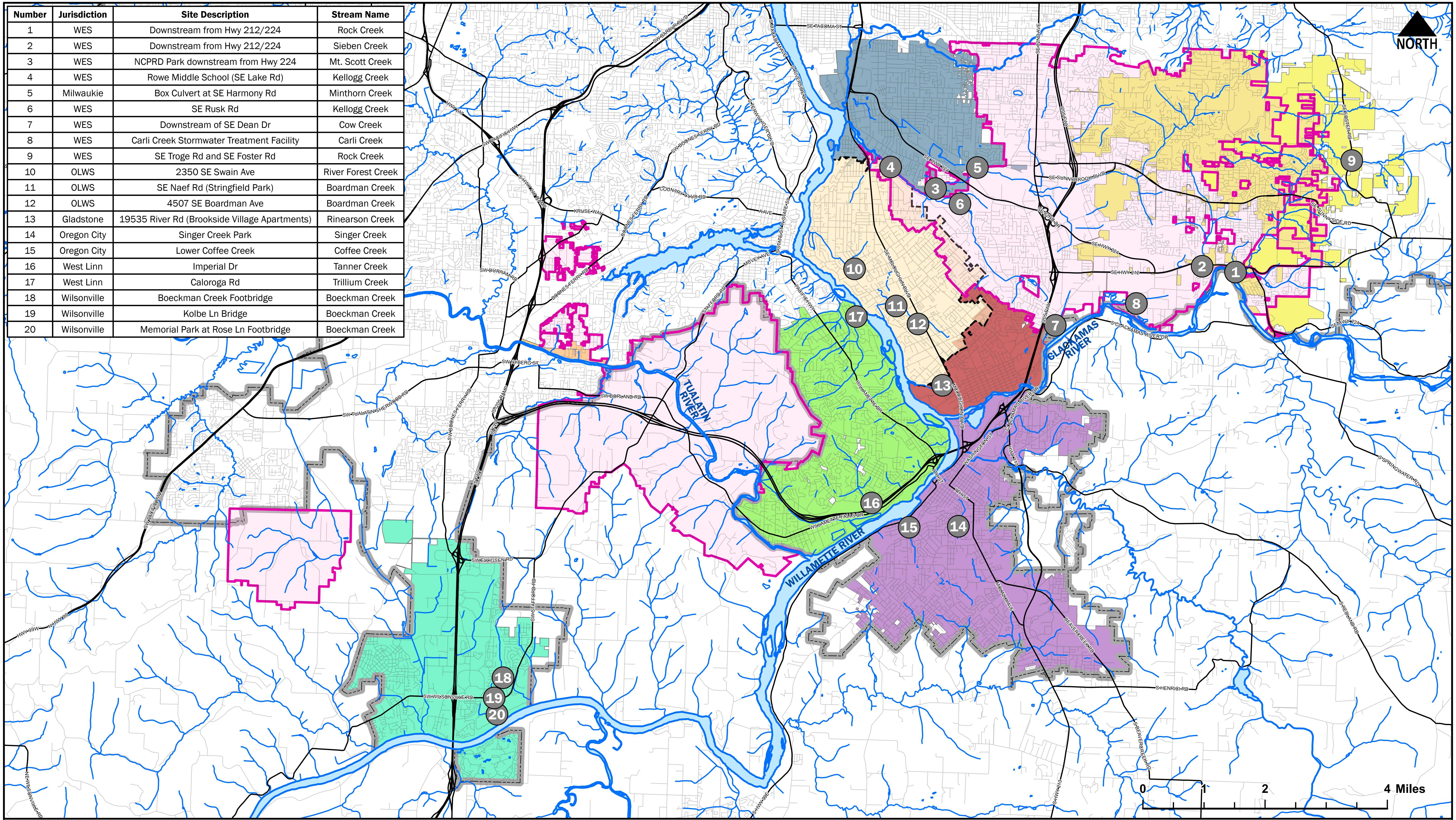
b. *The Sieben Creek biologic monitoring location corresponds to the historical WES instream monitoring location at Highway 212/224 and current instream mercury monitoring location.*

c. *The SE Rusk Road Kellogg Creek biologic monitoring location corresponds to the historical WES instream monitoring location at SE Rusk Road.*

d. *The Mt. Scott Creek biologic monitoring location corresponds to the historical WES instream and biologic monitoring location at North Clackamas Park. The past biologic monitoring efforts refer to the North Clackamas Park location. The instream and biologic monitoring site was relocated to Highway 224 for the 2013–14 monitoring year.*

e. *Shifted reach location in 2014, but not by more than 200m.*

f. *This site was relocated from the Risley Road instream monitoring location based on recommendations following Gladstone's 2013 biological monitoring effort.*



Number	Jurisdiction	Site Description	Stream Name
1	WES	Downstream from Hwy 212/224	Rock Creek
2	WES	Downstream from Hwy 212/224	Sieben Creek
3	WES	NCPRD Park downstream from Hwy 224	Mt. Scott Creek
4	WES	Rowe Middle School (SE Lake Rd)	Kellogg Creek
5	Milwaukie	Box Culvert at SE Harmony Rd	Minthorn Creek
6	WES	SE Rusk Rd	Kellogg Creek
7	WES	Downstream of SE Dean Dr	Cow Creek
8	WES	Carli Creek Stormwater Treatment Facility	Carli Creek
9	WES	SE Troge Rd and SE Foster Rd	Rock Creek
10	OLWS	2350 SE Swain Ave	River Forest Creek
11	OLWS	SE Naef Rd (Stringfield Park)	Boardman Creek
12	OLWS	4507 SE Boardman Ave	Boardman Creek
13	Gladstone	19535 River Rd (Brookside Village Apartments)	Rinearson Creek
14	Oregon City	Singer Creek Park	Singer Creek
15	Oregon City	Lower Coffee Creek	Coffee Creek
16	West Linn	Imperial Dr	Tanner Creek
17	West Linn	Caloroga Rd	Trillium Creek
18	Wilsonville	Boeckman Creek Footbridge	Boeckman Creek
19	Wilsonville	Kolbe Ln Bridge	Boeckman Creek
20	Wilsonville	Memorial Park at Rose Ln Footbridge	Boeckman Creek

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NOVEMBER 2022

FIGURE 4. MACROINVERTEBRATE MONITORING LOCATIONS

WES, Clackamas County, Happy Valley, Rivergrove, Gladstone, Milwaukie, OLWS, Oregon City, West Linn, and Wilsonville

5.4.2 Sample Collection Methods

Biological monitoring efforts will be conducted by each participating co-permittee a minimum of once over the permit term (i.e., July 2023 through September 2026). Efforts include macroinvertebrate sampling and associated physical habitat, riparian assessment, and water chemistry sampling that accompanies the sample collection. Historically, the co-permittees have used a contractor to conduct the sampling and prepare the documentation in a separate report.

Sampling efforts are typically targeted for summer or early fall, low-flow conditions.

Sample collection processes and methods summarized below are consistent with methods previously employed. Detailed documentation of methods can be referenced in the *Clackamas County NPDES MS4 Co-permittees 2018 Coordinated Macroinvertebrate Assessment* (January 2019), prepared by Cole Ecological, Inc. on behalf of the cities of Gladstone, Lake Oswego, Milwaukie, Oregon City, West Linn, Wilsonville and OLWS. At the time of sampling, sampling methods may be slightly adjusted to conform to new technologies. Such changes will be documented in a final assessment report at the conclusion of the monitoring event.

Macroinvertebrate community sampling will be conducted using the *Benthic Macroinvertebrate Sampling Protocol for Wadeable Rivers and Streams* (DEQ 2003). Samples are sorted and identified to the level of taxonomic resolution recommended for Level 3 macroinvertebrate assessments. Level 3 protocols include duplicate composite sampling for quality assurance. Both glide and riffle samples are assessed using a multi-metric analysis and using a predictive model.

As required per the protocol, water temperature, DO, and specific conductivity will be measured at each site. SOPs and calibration procedures will be provided to participating co-permittees by the contractor prior to field sampling efforts.

5.4.3 Connection to Physical Condition Monitoring

With urbanization and increased development along the stream corridor, the timing and magnitude of discharge to stream channels often results in changes to the geomorphic character of the channel. This physical change to the stream channel can be observed through changes to stream channel width and depth and changes to the riparian vegetation.

During macroinvertebrate community sampling activities, habitat surveys and riparian assessments are likely to be conducted to inform the presence or lack of macroinvertebrates. Habitat surveys and riparian assessments are a type of physical condition monitoring that also help to locate areas of erosion, incision, and migration, and other changes to the stream corridor.

The physical conditions of the stream corridor can be assessed using the modified Rapid Stream Assessment Technique (RSAT), which includes data collection from channel habitat units (a sample reach equal to 20 times the wetted width or 75 meters, whichever length is greater), channel cross sections, and the adjacent riparian zone. Habitat surveys are conducted to measure or visually estimate the number, length, gradient, and depth of pools and riffles instream; the percent of eroding or downcutting banks; woody debris characteristics; and substrate characteristics. Riparian assessment efforts include identification of riparian plant community type and percent vegetative cover present in the riparian area.

5.5 BMP Monitoring Efforts

Monitoring to analyze the effectiveness of BMPs is conducted to address monitoring objectives 2 and 6 from Schedule B.1.a of the 2021 permit:

Objective 2: Evaluate the effectiveness of Best Management Practices (BMPs) in order to help determine BMP implementation priorities; and,

Objective 6: Assess progress towards reducing TMDL pollutant loads.

BMP monitoring activities will attempt to address the following questions:

- What are the relative pollutant removal capabilities of BMPs being used/implemented in the jurisdiction?
- Has implementation of programmatic BMPs provided information to validate whether stormwater quality improvement is being made, based on defined schedules, and frequencies in the SWMP?

BMP is a broad term that can be used to describe structural water quality facilities and source control/programmatic activities (as reported in the co-permittees' SWMPs). Both are implemented to achieve a net water quality benefit. The monitoring of a structural BMP facility (e.g., detention and retention ponds, swales, constructed wetlands, proprietary systems) would represent an environmental monitoring effort, while monitoring (tracking) of source control/ programmatic activities (erosion and sediment control, stormwater conveyance system cleaning and maintenance, industrial and business inspection programs, and public education and outreach) would represent a program monitoring effort.

This 2023 Plan focuses on environmental monitoring efforts. However, program monitoring is referenced because it also addresses objective 2 from Schedule B.1.a of the 2021 permit. Additionally, the evaluation of stormwater monitoring data, when combined with programmatic monitoring information, may help to quantify the water quality benefit of BMPs.

BMP monitoring also helps indirectly to address monitoring objective 6: *Assess progress towards reducing TMDL pollutant loads*. BMP effectiveness data are used in pollutant load modeling and the development of pollutant load reduction estimates in order to meet requirements for TMDL compliance. Evaluating BMP effectiveness allows for refinement of these effectiveness values used in the model and allows for the pollutant load modeling to reflect current conditions more accurately.

The following sections describe BMP monitoring efforts pertaining to environmental monitoring (Section 5.5.1) and program monitoring (Section 5.5.2).

5.5.1 BMP Monitoring (Environmental)

Limited environmental monitoring is currently being conducted by Clackamas County co-permittees associated with the performance of structural or source control BMPs. Structural BMP monitoring can be a very time- and cost-intensive activity, while the results apply only to the specific characteristics of the sampled BMP. Sampling of stormwater for purposes of evaluating BMPs that are source control activities often provides inconclusive results because of the variability of stormwater runoff, pollutant sources, and implementation efforts.

As stormwater management and stormwater treatment are continually changing and evolving fields, extensive literature regarding the environmental monitoring of various treatment technologies and practices (structural and source control BMPs) is being generated by researchers, public entities, and private companies to meet both regulatory and non-regulatory needs. Clackamas co-permittees collect effectiveness information and cost information for various BMPs in conjunction with implementation of their stormwater programs. When made available from local, regional, and national sources, Clackamas County co-permittees obtain information that aids their individual stormwater management efforts and influences future decision making regarding appropriate levels of treatment technology to require for new development and redevelopment. Review and application of these findings provides a more cost-effective means of addressing monitoring objective 2.

A number of Clackamas County co-permittees are actively involved in ACWA, which provides an open forum for stormwater management discussions and provides additional educational opportunities for local officials regarding stormwater quality and treatment. Participation in ACWA will continue to support literature tracking efforts.

5.5.2 BMP Monitoring (Programmatic)

Clackamas County co-permittees currently conduct a variety of program monitoring efforts, generally related to implementation of their SWMPs. Qualitative information is currently collected in the form of tracking measures. These tracking measures provide valuable information to assist in the assessment of BMPs. Examples of BMP categories that are assessed for effectiveness through the use of tracking measures include the following:

- Illicit discharge detection and elimination (e.g., have the number of illicit discharge incidents decreased?)
- Public education (e.g., is there increased public awareness related to the jurisdiction’s stormwater program and overall stormwater management?)
- Maintenance of structural controls (e.g., based on inspection records, is maintenance being performed more regularly? Are facilities operating more consistently?)

Specific tracking measures for these BMP categories are described in each of the co-permittees’ SWMPs and are reported on with annual reports.

Quantitative effectiveness data for the programmatic elements outlined in the SWMP are currently not collected, but efforts to look at the effectiveness of these source control activities may occur as discussed above under Section 5.5.1.

Section 6 Sampling Parameters, Analytical Methods, and Quality Assurance and Quality Control

This section includes a summary of sampling parameters and analytical methods (Section 6.1) and a summary of QA/QC procedures (Section 6.2).

6.1 Sampling Parameters and Analytical Methods

The purpose of both instream and stormwater outfall monitoring efforts is to assess the degree to which ambient water quality is impacted by stormwater runoff. Therefore, consistent pollutant parameters are monitored for both instream and outfall (stormwater) sampling locations.

Pollutant parameters for this 2023 Plan are based on Table 3 of the 2021 permit and are listed below in Table 11. A suggested analytical method is also identified in Table 11; however, use of an alternative, EPA-approved method listed in the most recent publication of 40 CFR 136 is permissible. The suggested analytical methods documented in Table 11 include both EPA and Standard Methods (SM) and are consistent with provisions of 40 CFR 136.

Table 11. Pollutant Parameters and Analytical Methods

Type (field or lab)	Analyte	Sample type (grab or time-spaced composite)[b]	Unit	Suggested analytical method	Target MDL	Notes
Field	Specific conductivity	Grab	µmhos/cm	SM 2510 B	1	Method assumes use of probe
Field	pH	Grab	Standard units	SM 4500-H B	0.1	Method assumes use of probe
Field	Temperature	Grab	°C	SM 2550 B	0.1	Method assumes use of probe
Field	DO	Grab	mg/L	SM 4500-O G or H	0.1	Method assumes use of probe
Lab	Total alkalinity	Grab or Composite	mg $CaCO_3$/L	SM 2320 B	1	
Lab	Copper, total	Grab or Composite	µg/L	EPA 200.8	0.1	
Lab	Copper, dissolved	Grab or Composite	µg/L	EPA 200.8	0.1	Field filtration recommended; lab filtration acceptable
Lab	DO[a]	Grab	mg/L	SM 4500-O-C	0.02	Conducted to verify field reading
Lab	Dissolved organic carbon	Grab or Composite	mg C/L	SM 5310 C	0.14	Field filtration may be required (lab dependent)
Lab	*E. coli*	Grab	MPN/100 mL	SM 9223 B	1.0	
Lab	Total hardness	Grab or Composite	mg $CaCO_3$/L	SM 2340 C	5	
Lab	Lead, total	Grab or Composite	µg/L	EPA 200.8	0.02	
Lab	Lead, dissolved	Grab or Composite	µg/L	EPA 200.8	0.02	Field filtration recommended; lab filtration acceptable
Lab	Total mercury	Grab	ng/L	EPA 1631E	0.5	Must be paired with TSS sampling
Lab	Nitrogen: ammonia	Grab or Composite	mg/L	SM 4500-NH_3 G	0.025	Manual distillation can be omitted if turbidity is controlled by filtration

Table 11. Pollutant Parameters and Analytical Methods

Type (field or lab)	Analyte	Sample type (grab or time-spaced composite)[b]	Unit	Suggested analytical method	Target MDL	Notes
Lab	Nitrogen: nitrate	Grab or Composite	mg/L	SM 4500-NO_3 F	0.0625	Method is run twice: once with cadmium reduction (NO_3+NO_2), once without (NO_2) = NO_3
Lab	Phosphorus, total	Grab or Composite	mg/L	SM 4500-P B, F or EPA 365.3	0.02	
Lab	Phosphorus, ortho-phosphate	Grab or Composite	mg/L	SM 4500-P F	0.025	Field filtration may be required (lab dependent)
Lab	Solids: total suspended	Grab or Composite	mg/L	SM 2540 D	1.0	
Lab	Zinc, total	Grab or Composite	µg/L	EPA 200.8	2.0	
Lab	Zinc, dissolved	Grab or Composite	µg/L	EPA 200.8	2.0	Field filtration recommended; lab filtration acceptable

a. The Winkler Titration Method is employed to verify field DO readings in accordance with field sampling procedures outlined in Appendix A. Some jurisdictions may opt to analyze DO using only the Winkler Titration Method instead of collecting field samples.

b. Time-composite sampling pertains to the collection of stormwater samples or the collection of instream samples during wet-weather conditions only.

°C = degrees Celsius; µg/L = micrograms per liter; CaCO3 = calcium carbonate; cm = centimeters; mg/L = milligrams per liter; mL = milliliters; MPN = most probable number; ng/L = nanograms per liter.

Water quality monitoring conducted as part of the macroinvertebrate sampling will conform to documented SOPs and may deviate from the approved methods listed in 40 CFR 136.

6.2 Quality Assurance and Quality Control Procedures

For purposes of this 2023 Plan, QA/QC procedures for field analysis are initiated directly by the jurisdiction. QA/QC procedures for laboratories are developed by the individual laboratories and available on request.

Field QA/QC procedures are outlined in Appendix A and included in the SOPs for field sample collection (SOP A-1), chain of custody (SOP A-2), sample handling and transportation (SOP A-3), and field filtration (SOP A-5). General sampling procedures for parameters analyzed in the field are provided in SOP A-4. ACWA developed detailed QA/QC procedures for stormwater data collection and sample handling and custody as part of the ACWA UIC [Underground Injection Control] Monitoring Study. Provisions from this ACWA study have been incorporated into the field QA/QC procedures in Appendix A as appropriate.

Co-permittees will use laboratories that have comprehensive QA programs and are accredited by the National Environmental Laboratory Accreditation Program (NELAP) or Oregon Environmental Laboratory Accreditation Program (ORELAP). The WES Water Quality Laboratory, which currently conducts laboratory analysis for samples collected by some Clackamas County co-permittees operating under this 2023 Plan, is NELAP accredited and operates under the WES *Water Quality Assurance Manual* (May 17, 2007). This manual outlines the pertinent test methods, validation, and reporting limits; equipment calibration and maintenance procedures; sample handling and storage procedures; sample acceptance and results reporting procedures; and data qualification and validation procedures. This manual is available by request from the WES Water Quality Laboratory.

Contracted monitoring activities related to biologic monitoring employ field procedures and protocols unique to the monitoring effort. A description of study methods and QA/QC guidelines will be documented in the final assessment report provided to each jurisdiction at the conclusion of the monitoring event.

Section 7 Monitoring Data Management and Plan Modifications

This section includes a summary of data management procedures (Section 7.1) and procedures for modifying this 2023 Plan (Section 7.2).

7.1 Data Management

Participants in this 2023 Plan individually (or through an intergovernmental agreement) collect samples and are responsible for the quality control of their samples prior to delivery at the laboratory. Field sample collection procedures are outlined in Appendix A. Sample validation and verification is conducted at the laboratory and, following analysis, the monitoring results are provided to the responsible jurisdiction to validate and verify that the findings are consistent with their expectations. Questionable monitoring results will be flagged for further review and possible follow-up in the field. If data quality indicators (i.e., field blanks, field duplicates) suggest that contamination or corruption of the sample occurred, data may be discarded and sampling would be conducted again, and the cause of the failure would be evaluated. If the cause is found to be equipment failure, calibration and/or maintenance techniques will be assessed and improved; if the cause is found to be with the sample collection process, field techniques will be assessed, revised, and retrained as appropriate.

Individual jurisdictions are responsible for the compilation of instream and stormwater monitoring data in database or spreadsheet format. Monitoring data are compiled by monitoring location and monitoring event, and data include times, concentrations, and indication of whether a sample represents a grab- or time-composited sample. Statistics (i.e., mean, maximum, minimum) may be calculated on the data by an individual jurisdiction for its own use. A summary of monitoring results may be provided to DEQ with submittal of the individual jurisdiction's NPDES MS4 annual reports. Compiled monitoring data will be submitted to DEQ in accordance with the DEQ-approved Data Submission template.

Technical reports documenting results of the biologic monitoring effort shall be maintained by individual jurisdictions and results shall be summarized or attached to the associated NPDES MS4 annual report.

A water quality trends analysis will be conducted during the last year of this 2023 Plan implementation, based on the instream monitoring data collected to date. The benefit of a coordinated monitoring program is that resources can be distributed more widely to produce data that will provide comprehensive information for Clackamas County as a whole. As a result, data analyses will be conducted specific to each jurisdiction and water body, but assessment and interpretation can be associated at a watershed scale too. As part of the water quality trends analysis effort, previously collected monitoring data specific to the water body will be reviewed.

7.2 Plan Modifications

Modifications to monitoring locations and frequency as outlined in this 2023 Plan are permissible as long as the number of monitoring data points collected on an annual basis (the product of monitoring location and frequency) is not reduced. Additionally, if on an annual basis a participating co-permittee is not able to collect the required samples because of climatic conditions, sampling conditions, equipment malfunction, monitoring location inaccessibility, etc., such inability is not directly reflective of a need to modify the monitoring plan.

Currently, as required in the 2021 permit, if a modification to this 2023 Plan is requested or required, such need will be documented in the subsequent annual report by describing the rationale for the modification and how the modification will allow the monitoring program to remain compliant with the permit conditions.

Appendix A: Field QA/QC Procedure

Appendix A:

Field Quality Assurance and Control Procedures for Sample Collection, Handling, and Custody

SOP A-1: Field Sample Collection Procedures

Field crews are responsible for collecting samples, recording information, and transferring collected samples.

Prior to sample collection, field crews shall verify that adequate sample collection bottles, personal protective equipment, and sample storage equipment are obtained. Sample collection bottles shall be of adequate size and appropriate material, per requirements of the applicable sampling and analytical methods. Most sample collection bottles are pre-preserved by the laboratory for the appropriate analytical test. If necessary to meet preservation requirements, additional preserving agents will be added to samples by the laboratory upon receipt of the samples.

Upon arrival at the site, field crews shall establish a safety zone for sample collection if necessary (this may include the placement of traffic cones, etc.). Site conditions and other sampling notes shall be recorded in a monitoring log and/or on the Monitoring Field Data Sheet.

1. Clean Sampling Rules

Sample collection personnel should adhere to the following rules while collecting stormwater and instream samples to reduce potential contamination.

- Do not eat, drink, or smoke during sample collection.
- Do not park vehicles in immediate sample collection area. Do not sample near a running vehicle.
- Always wear clean, disposable, nontalc polyethylene, latex, vinyl, or PVC gloves when handling all sampling equipment and sample bottles. At a minimum, gloves will be changed prior to sampling at each location.
- Never touch the inside surface of a sample container or lid or allow them to be contacted by any material other than the sample water.
- Do not breathe, sneeze, or cough in the direction of an open sample container.
- Never allow any object or material to fall into or contact the collected sample water.
- Avoid allowing rainwater to drip from rain gear or other surfaces into sample bottles.

Total mercury sampling collection procedures require stringent adherence to clean-sampling protocols described herein. Specific mercury sampling requirements, when different from other parameters, are identified with an italicized "*Mercury Sampling ONLY*" phrase to emphasize special procedures. Specific pesticide sampling requirements are also identified, where required, with an italicized "*Pesticide Sampling ONLY*" phrase to emphasize special procedures.

2. Tools and Equipment

Depending on the site characteristics, samples can be obtained by hand or with the aid of tools. Tools may include grab poles, beakers, bailers, etc. Plastic tools (e.g., Teflon, polyethylene, etc.) are recommended for general and ionic parameters such as TSS, metals, and nutrients. Stainless steel tools are recommended for organics such as pesticides. All tools used for metal samples including mercury must be nonmetallic and free of material that may contain metal.

3. Grab Sampling Procedures

Grab sample collection methods shall be employed for all dry weather instream monitoring activities. Grab sample collection methods shall be employed for wet weather instream and stormwater (outfall) monitoring activities for bacteria and mercury only.

3.1. Bottle preparation

Obtain clean sample bottles from the laboratory conducting the water quality analyses. Each monitoring site requires a minimum number of sample bottles such that separate sample bottles are obtained based on the analytical test methods to be employed by the laboratory. Bottles shall be pre-labeled to include the site number and monitoring parameter.

- Bottles for duplicate sampling and field blanks shall be obtained from the laboratory conducting the water quality analyses as required. Based on the number of analytical test methods to be employed, the appropriate number of bottles should be obtained for the collection of duplicate samples and field blanks at a site. Bottles for duplicate and field blank samples shall also be pre-labeled with the designated duplicate site number and monitoring parameter.
- Procedures related to the collection of grab sample duplicates and field blanks are outlined under SOP A-1, Section 5. QA/QC Sampling Procedures.

3.2. Grab sampling technique

Grab sampling activities may be conducted in a one- or two-person team. Procedures are outlined below in accordance with Section 3.2 numbering.

3.2.1. Put on clean gloves. Consider using multiple layers of clean gloves to reduce disruption to sample collection if the outer pair of gloves needs to be quickly removed.

3.2.2. *Mercury Sampling ONLY*: If required, collect the Mercury Field Blank. If not required, proceed to the next step. Remove the cap from the lab-provided Field Blank bottle and protect the cap from being contaminated. Handle the Field Blank as a Sample; the Field Blank should contact any tools and/or equipment being used. If no tools and/or equipment are used, keep the Field Blank cap off and the bottle located near the sampling location during Sample collection. Cap the Field Blank after an equivalent time as the time for a single sample collection has passed.

3.2.3. For sample collection directly into the sample container:

- From a flowing surface water body: the Sample should be collected from the middle of the flow stream in a well-mixed location if possible. Care must be taken to avoid collecting particulates that are suspended because of bumping the bottle on the streambed. The sample location should be approached from down current and downwind to minimize contamination of the sample if possible.
- From a surface water outfall: the Sample should be collected, if possible, at the point where the flow leaves the pipe.

3.2.4. Fill the bottle to the appropriate level. When sampling from a surface water body, if possible, submerge the bottle into the water to fill the sample container and replace the lid while the bottle is submerged. When sampling from a surface water outfall, fill the bottle and recap as quickly as possible. Take care not to overfill bottles and flush out sample preservative. Complete the Monitoring Field Data Sheet with required information related to sample collection (i.e., time, sampling conditions, date, etc.).

3.2.5. *Mercury Sampling ONLY:* Table 1 protocols reflecting provisions of EPA Method 1669 and clean hands/ dirty hands (CH/DH) procedures must be strictly adhered to when sampling for mercury to minimize contamination. These protocols assume the lab-provided bottle for analytical method EPA 1631E is double-bagged. When conducting Mercury sampling in conjunction with in-stream or outfall sampling for other parameters, always collect mercury samples first when arriving at a site. If Mercury is collected in a separate effort, TSS **must** be collected at the same time as mercury samples.

Mercury Sampling ONLY

Table 1: One- and Two-Person Grab Sampling Procedures for Mercury Sample Collection

Two-Person Team	
In-stream grab sampling	Outfall grab sampling
a) CH and DH don two pairs of clean, disposable, nontalc gloves. CH only touches the inner bag and sample bottle. DH touches coolers, outer bag, and other necessary equipment to aid CH. b) DH opens the outer bag, carefully pushing up the inner bag and bottle for CH to reach without touching either the inner bag or bottle. c) CH opens inner bag and removes sample bottle. DH secures inner bag inside of outer bag. d) CH removes the cap, holds the cap upside down, and discards the dilute acid solution into a waste carboy or discards the reagent water directly into the water body. e) If sufficient flow exists, CH submerges bottle underwater and triple rinses the sample container, keeping the container submerged during all rinses. After the third rinsing, CH carefully fills the bottle and recaps it underwater. If insufficient flow, the bottle is uncapped above the surface. While the cap is held in hand, the bottle is lowered and filled, then re-capped as quickly as possible. f) DH reopens the outer bag. CH returns the bottle to the inner bag and seals the inner bag. DH seals the outer bag.	a) CH and DH don two pairs of clean, disposable, nontalc gloves. CH only touches inner bag and sample bottle. DH touches coolers, outer bag, and other necessary equipment to aid CH. b) DH opens the outer bag, carefully pushing up the inner bag and bottle for CH to reach without touching either the inner bag or the bottle. c) CH opens inner bag and removes sample bottle. DH secures inner bag inside of outer bag. d) CH removes the cap, holds the cap upside down, and discards the dilute acid solution into a waste carboy or discards the reagent water directly into the water body. e) CH triple rinses the sample container. After the third rinsing, CH fills the bottle and re-caps the bottle as quickly as possible. f) DH reopens the outer bag. CH returns the bottle to the inner bag and seals the inner bag. DH seals the outer bag.

One-Person Team	
In-stream grab sampling	Outfall grab sampling
a) Segregate mercury sample bottles in a dedicated cooler prior to deploying in the field. b) Sampler dons two pairs of clean, disposable, nontalc gloves. c) Leaving the double-bagged bottle in the cooler, open the outer bag and push up the inner bag and bottle. Discard outer pair of gloves. d) Open inner bag, remove bottle, and push inner bag down into outer bag. e) Remove the cap, hold the cap upside down, and discard the dilute acid solution into a waste carboy or discard the reagent water directly into the water body. f) If sufficient flow exists, submerge bottle underwater and triple rinse the sample container, keeping the container submerged during all rinses. After the third rinsing, carefully fill the bottle and recap it underwater. If insufficient flow, the bottle is uncapped above the surface. While the cap is held in hand, the bottle is lowered and filled, then re-capped as quickly as possible. Return the bottle to the inner bag, seal the inner bag, then seal the outer bag.	a) Segregate mercury sample bottles in a dedicated cooler prior to deploying in the field. b) Sampler dons two pairs of clean, disposable, nontalc gloves. c) Leaving the double-bagged bottle in the cooler, open the outer bag and push up the inner bag and bottle. Discard outer pair of gloves. d) Open inner bag, remove bottle, and push inner bag down into outer bag. e) Remove the cap, hold the cap upside down, and discard the dilute acid solution into a waste carboy or discard the reagent water directly into the water body. f) Triple rinse the sample container. After the third rinsing, fill the bottle and re-cap the bottle as quickly as possible. g) Return the bottle to the inner bag, seal the inner bag, then seal the outer bag

3.2.6. When no sample is collected because of lack of flow (e.g., enter “NEF” for not enough flow) or any other circumstances beyond the sampler’s control, the associated condition should be noted in the appropriate entry point on the Monitoring Field Data Sheet.

3.2.7. As directed by the laboratory, filter or preserve samples as necessary in accordance with laboratory-issued standard operating procedures. As an example, the WES laboratory requires field filtration of ortho-phosphate and dissolved organic carbon at the time of sample collection (See SOP A-5).

3.2.8. Samples should be stored for transport to the laboratory in a cooler at a maximum of 4°C using ice or an ice substitute that has been frozen.

3.2.9. If a Field Duplicate is to be obtained at a particular sampling site, the Field Duplicate will be obtained by completing the normal grab sampling procedures and documenting information on the Monitoring Field Data Sheet consistent with collection of the Sample.

3.2.10. For samples that are collected for the analysis of bacteria, samples must be transported to the lab within 6 hours of sample collection.

3.2.11. Ensure that all elements of the Monitoring Field Data Sheet are complete prior to relinquishing the samples to the laboratory.

4. Composite Sampling Procedures

Composite sample collection methods shall be employed for wet weather instream (except for jurisdictions choosing to pre-schedule instream events) and stormwater (outfall) monitoring activities for all laboratory parameters except for bacteria and Total Mercury as outlined in Table 11 of the Comprehensive Clackamas County NPDES MS4 Stormwater Monitoring Plan.

4.1. Bottle preparation

Obtain clean sample bottles from the laboratory for collection of the individual samples and one carboy (i.e., large glass or plastic vessel) to combine the individual samples and mix the composited sample. The bottle(s) and the carboy shall be pre-labeled to include the site number. For outfall Pesticide sampling, compositing should occur within the sample bottles themselves. No additional glass carboys should be used for Pesticide samples to minimize contamination and biased results.

Each monitoring site requires a minimum number of sample bottles such that separate sample bottles are obtained based on the analytical test methods to be employed by the laboratory. Bottles shall be pre-labeled to include the site number and monitoring parameter.

- Based on the number of sampling sites, obtain the same number of sample bottles as outlined above for the collection of a composite duplicate samples and field blank samples. Bottles for duplicate sampling and field blanks shall also be obtained from the laboratory conducting the water quality analyses as required.
- Procedures related to the collection of composite duplicate samples and field blank samples are outlined under SOP A-1, Section 5. QA/QC Sampling Procedures.

4.2. Composite sampling technique

Grab sample collection methods, steps 3.2.1 through 3.2.4 as documented above, should be employed for each of the minimum three individual grab samples collected prior to pouring in the carboy.

Composite samples are collected at timed intervals and/or on a sampling rotation. Following collection of the minimum three individual grab samples that will compose the composited sample, the following procedures should be followed in accordance with Section 4.2 numbering:

4.2.1. Ensure equal portions from individual grab samples are poured into the pre-labeled carboy. This effort shall occur in a closed or covered environment.

4.2.2. Properly mix the composited sample and pour a sufficient quantity of the composited sample into each pre-labeled sample bottle that is to be relinquished to the lab for analysis.

4.2.3. When no sample is collected because of lack of flow (e.g., enter “NEF” for not enough flow) or any other circumstances beyond the sampler’s control, the associated condition should be noted in the appropriate entry point on the Monitoring Field Data Sheet.

4.2.4. As directed by the laboratory, filter or preserve samples as necessary in accordance with laboratory-issued standard operating procedures. As an example, the WES laboratory requires field filtration of ortho-phosphate and dissolved organic carbon at the time of sample collection (See SOP A-5).

4.2.5. Samples should be stored for transport to the laboratory in a cooler at a maximum of 4°C using ice or an ice substitute that has been frozen.

4.2.6. If a composite Field Duplicate is to be obtained at a particular sampling site, the composite Field Duplicate will be obtained by completing the normal grab sampling procedures, compositing as indicated in steps 4.2.1 through 4.2.2, and documenting information on the Monitoring Field Data Sheet consistent with collection of the Sample.

4.2.7. Update the Monitoring Field Data Sheet to document completion of the composite sample collection efforts. Ensure that all elements of the Monitoring Field Data Sheet are complete prior to relinquishing the samples to the laboratory.

Pesticide Sampling ONLY: If possible, collect separate, individual grabs which will comprise a composite into the final bottles in equal portions. For example, if three individual grabs will be combined and mixed to comprise the composite sample, fill the lab-provided sample bottles approximately one-third of the way during each grab. This technique prevents pesticide analytes from adhering to separate grab bottles prior to mixing/compositing, and biasing low results. If sampling circumstances are challenging (e.g., high flow rate) at a particular outfall, a dry, cleaned glass beaker may be used to collect the three individual grabs prior to transferring to the final bottle. A separate beaker should be used for each outfall and QA/QC sample.

5. QA/QC Sampling Procedures

The use of field blanks and grab and composite field duplicates will help to identify potential sources of error in the stormwater sampling process, specifically those associated with sample collection, transportation, and analytical procedures.

For grab and composite samples for all parameters, field blanks and grab or composite field duplicates shall be collected at a minimum of 10 percent of the total number of monitoring locations for a single event and for samples collected by a single sampling crew. For example, if samples are to be collected at 10 sites or less for one monitoring event, then one field blank and one duplicate sample shall be obtained for that monitoring event. If individual grab samples are to be collected at 12 sites for one monitoring event, then two field blanks and two grab sample duplicates shall be obtained for that monitoring event. A minimum of one field blank and one duplicate shall be obtained for a single monitoring event.

Mercury Sampling ONLY:

Per sampling method EPA 1669, one field blank and field duplicate is required for each mercury site. As EPA 1669 is a performance-based method, and all mercury samples will be collected as grabs, Field Blank/Duplicate pairs of QC samples for each in-stream and outfall site the first permit year will be collected and evaluated for contamination and reproducibility. If QA/QC targets are acceptable (i.e., blanks showing less-than the detection limit and duplicates showing ≤ 20% Relative Percent Difference), then Field Blanks and Duplicates will be collected at the frequency described above. If targets are not met, the “every-site frequency” will continue until source(s) of contamination are corrected.

Guidelines related to the collection of a field blank and duplicate sample are outlined below:

5.1. Procedures for collection of field blank samples should follow the appropriate grab or composite sampling procedures with the exception that the analyte bottle (in the case of grab sample collection) or half-gallon sample bottles (in the case of composite sample collection) are instead filled with deionized (DI) water as provided by the lab. The field blanks shall be transported to all sampling sites associated with a monitoring event in the storage containers with other sample bottles. This will assist with identifying any potential contamination that may occur with the sample collection and transportation of samples.

Mercury Sampling ONLY: For low-level Total Mercury required in the MS4 permit, it is recommended to purchase and use commercially available ASTM Type 1 Reagent Water to fill Field Blank bottles. This water should be transported into the field with sample bottles and be dedicated for Mercury sampling field blanks only.

5.2. Procedures for collecting the duplicate sample should follow the appropriate grab or composite sample procedures. The duplicate sample bottles shall be pre-labeled with the designated duplicate site number and monitoring parameter. These duplicate samples will assist with identifying any potential contamination that may occur with sample collection or analytical procedures.

5.3. Per Bacteria methods used at the WES Water Quality Lab (SM 9223 E, “IDEXX Colilert”), additional sample duplicates are necessary for quality control beyond the field duplicates collected in Step 5.2 above. The requirement is one additional sample duplicate per ten samples (QA/QC inclusive). For example, if nine field samples and two QA/QC samples are collected in a single sampling event, two additional sample duplicates must be collected and analyzed for Bacteria.

SOP A-2: Field Data Sheets and Chain-of-Custody Records

Monitoring Field Data Sheets are completed by field staff conducting the monitoring activities during sample collection activities. Monitoring Field Data Sheets are maintained with the samples during transport to the laboratory.

A chain-of-custody (COC) record is a legal document generated at the laboratory based on information contained in the Monitoring Field Data Sheet. The COC is prepared either prior to or during the delivery of the samples and identifies the person(s) responsible for the sample bottles during all elements of monitoring activity.

The Monitoring Field Data Sheet(s) shall be completed for each sampling location and event. The COC shall be maintained for each sampling event.

The procedures for filling out these forms are as follows.

Before and during Sample Collection

Before sample collection activities, field staff shall document the following general information on a Monitoring Field Data Sheet, unless otherwise documented on the COC:

- Source/location
- Site code or ID
- Person(s) sampling
- Type of sample (instream dry weather/season, instream wet weather/season, or stormwater outfall)
- Number of sample (if applicable): pertains to collection of multiple individual grab samples to compile as a time-composite sample
- Parameters submitted for analysis and reporting

During sample collection, the Monitoring Field Data Sheet should remain with the sample bottles. During sampling, staff should add to the Monitoring Field Data Sheet for each individual grab sample to document the time and date that the sample was collected.

The Monitoring Field Data Sheets should remain with the samples for the duration of sampling.

After Sample Collection

If composite sampling methods are used, the Monitoring Field Data Sheet should be updated to include the time and date at which the individual grab samples were composited. If a separate Monitoring Field Data Sheet is completed for the composite sample, any Monitoring Field Data Sheets associated with individual grab samples used to generate the composite sample should be maintained (e.g., stapled to the back) of the composite sample Monitoring Field Data Sheet.

At the Laboratory

The person responsible for completion of the Monitoring Field Data Sheets should be the one to relinquish this paperwork to laboratory personnel or other staff, as necessary. At the time of transfer, information contained on the Monitoring Field Data Sheets shall be entered into the laboratory's tracking database (e.g., Clackamas County Water Environment Services Labworks program). In addition to information contained on the Monitoring Field Data Sheets, any special instructions and information related to the transfer of responsibility is also documented.

Using the laboratory's tracking system, the COC is recorded and internal tracking labels may be generated.

SOP A-3: Transporting, Packaging, and Shipping Samples from Field to Lab

Procedures for handling and transportation of samples to the applicable water quality laboratory are as follows:

1. Keep the Monitoring Field Data Sheet with the samples at all times.
2. Pack samples well within ice chest to prevent breakage or leakage.
3. As stated previously, samples should be packed in ice or an ice substitute with a goal to maintain a sample temperature of 4°C during transport. Acquire more ice or ice substitute, as necessary.
4. Samples must be delivered to the water quality laboratory within 6 hours (standard for bacteria analysis) or in accordance with required holding times for other parameters (refer to 40 CFR Part 136.3, Table II).
5. Most samples will be collected in pre-preserved bottles. Some samples may require additional preservation agents to meet preservation requirements. If needed, additional preserving agents will be added to samples by the laboratory personnel upon receipt of the samples.

SOP A-4: Sampling Procedures for Parameters Analyzed in the Field

Sampling procedures for field parameters (i.e., dissolved oxygen [DO]/temperature, conductivity, and pH) are outlined below.

Field Dissolved Oxygen/Temperature Procedure

Meter preparation

1. Check the device for damage.
2. Check and replenish the field supply of deionized (DI) water.
3. Calibrate the device for DO (refer to current manufacturer's calibration instructions). Record calibration in a Calibration Logbook. As necessary, have experienced personnel calibrate the device prior to field sampling event.
4. Verify the device's temperature reading to a National Institute of Standards and Technology (NIST) thermometer. The temperature reading should be within ± 0.5 degree Celsius to meet DEQ Data Quality Level A data. Record the temperature verification in a Calibration Logbook.

Analysis timeline

1. All temperature and DO samples are obtained in the field.
2. Samples must be obtained in a fresh glass or plastic bottle or beaker.
3. Sample analysis is performed on site.

Technique

1. Immerse the probe directly in the sample. The probe is not to be moved around in the sample. Depending on the device used, measurement may occur in a pre-rinsed sample beaker or bottle or directly in the flow path.
2. Record the DO and temperature readings on the Monitoring Field Data Sheet.
3. Remove the device from the sample and rinse with DI water prior to storage or analysis of the next sample.

QA/QC

1. In order to verify DO concentrations obtained in the field, employ the Winkler Titration Method (as approved in 40 CFR 136.3) for one sample collected per event. A separate grab sample shall be collected and analyzed at the laboratory, and results shall be compared to the instrument analysis from the same location.
2. In accordance with the rationale outlined in SOP B-1, duplicate samples shall be collected.
3. Monitoring Field Data Sheets are completed during field sample collection and during grab sample collection (when conducting the Winkler test).

Field pH Procedure

Meter preparation

1. Set up the field pH meter(s).
2. Check the device for damage.
3. Check and replenish the buffer solution (pH 4, 7, 10) and DI water.
4. Calibrate the device using at least two pH buffers (4 and 7) and document (refer to current manufacturer's calibration instructions). As necessary, be sure to remove the device's filling solution vent plug before making any pH measurements.

Analysis timeline

1. All pH samples are obtained in the field as grab samples.
2. Samples must be obtained in fresh glass or plastic bottles or beaker.
3. Sample analysis shall be performed on site within 15 minutes of grab time.

Technique

1. Remove probe from the field storage solution. Do not remove from storage solution until water sample is ready for analysis.
2. Pre-rinse the sample bottle or beaker with sample water prior to obtaining the actual sample.
3. Collect a 200-milliliter (mL) sample (minimum).
4. Thoroughly rinse the device tip with DI water, pat dry with clean paper towel, and immerse the probe into the sample.
5. Once the device is immersed in the sample, slowly rotate in a circular pattern until the reading stabilizes (30 seconds).
6. Record the pH (to nearest 0.1 unit).
7. Enter the pH data on the Monitoring Field Data Sheet.
8. Remove the device from the sample and rinse with DI water prior to storage or analysis of the next sample.

QA/QC

1. Monitoring Field Data Sheets are completed in the field as the samples are collected.
2. After the completion of each day's sampling, device calibration(s) must be verified and checked for accuracy. The verified pH readings shall be recorded in the pH Calibration Logbook. Post-event pH verifications should agree within ± 0.2 S.U. to meet DEQ Data Quality Level A data. Devices should be cleaned with DI water and stored in the correct storage solution.
3. A low ionic strength pH probe and an automatic temperature compensation (ATC) probe should be used (e.g., low-maintenance pH/ATC Triode probe Orion 8107BNURCA).

Field Conductivity Procedure

Meter preparation

1. Set up the field conductivity meter.
2. Check the device for damage.
3. Calibrate the device according to current manufacturer's calibration instructions.
4. Check and replenish the field supply of DI water for rinsing the device following sampling.

Analysis timeline

1. All conductivity samples are obtained in the field as grab samples.
2. Samples must be obtained in fresh glass or plastic bottles or beakers.
3. Sample analysis is performed on site within 15 minutes of grab time.

Technique

1. Pre-rinse the sample bottle with sample water prior to obtaining the actual sample.
2. Collect 200 mL sample (minimum).
3. Ensure that the meter is reading in conductivity mode, if necessary.
4. Rinse device with DI water and pat dry with clean paper towel.
5. Immerse the probe in the sample and do not allow the device to touch the bottom of the container or any solid object.
6. Enter the conductivity data on the Monitoring Field Data Sheet.
7. Remove the probe from the sample and rinse with DI water prior to storage or the next analysis.

QA/QC

1. Monitoring Field Data Sheets are completed in the field as the samples are collected.
2. After the completion of each day's sampling, device calibration(s) must be verified, checked for accuracy, and recorded.
3. Devices should then be cleaned with DI water and stored appropriately.

SOP A-5: Field Filtering

Filtering specific parameters is required based on the analytical method or filtering requirements found in 40 CFR 136.3 Table II, Footnote 7. Applicable parameters include Orthophosphate, Dissolved Organic carbon, and Dissolved Metals (i.e., Copper, Lead, and Zinc). Samples are either not preserved in the field and filtered at the laboratory or filtered in the field and immediately preserved. Field filtering is recommended pending QA/QC issues.

Recommended materials and procedures related to field filtration of samples are described for each parameter group. Grab samples should be filtered as soon as possible after collection, or within 15 minutes, whichever is shorter. Composite samples should be filtered as soon as possible after the composite sample is created by combining grabs into one container. Field Blanks and Field Duplicates should be evaluated for each parameter for contamination generated from the filtering materials and reproducibility of the filtering technique, respectively. De-ionized water used for Field Blanks should be evaluated or certified (via a Certificate of Analysis) as having non-detects for the parameters of interest.

1. <u>Orthophosphate Field Filtering Procedure</u>

1.1. Materials and Equipment

1.1.1. Nonsterile disposable syringes, 60mL Luer-Lok®, BD 301035 or equivalent

1.1.2. Membrane syringe filters, 0.45μm pore size, Sartorius Minisart 16533Q or equivalent

1.1.3. Glass fiber pre-filters, 1μm pore size, Thermo Target2 F2500-19 or equivalent

1.1.4. 18.2 MΩ DI Water or ASTM Type I DI water

1.1.5. Large (1-L) clean Glass Beaker or container

1.2. Filter Preparation

1.2.1. Wash membrane filters by soaking in 18.2 MΩ DI water before use to reduce phosphorous contributions to low level samples. Place washed filters into clean Ziplock bags. Provide washed filters to Field Staff to have on hand for sampling events.

1.2.2. The preferred washing procedure is to soak in 2L 18.2 MΩ DI water for 24 hours followed by allowing to air dry, covered under paper towels.

1.2.3. Record washing date for each set of filters on storage bags.

1.2.4. An alternate washing procedure is to soak in 2L UltraPure DI water for 1 hour, change water, and then soak filters for an additional 3 hours, for a total soaking time of 4 hours.

1.3. Field Filtration

1.3.1. For single grab samples, fill a 60mL syringe with sample either from the surface water or from a well-mixed non-preserved sample container, such as the 2L solids sample bottles. Attach a 0.45μm membrane syringe filter to the Luer-Lok® fitting on the syringe. Filter sufficient sample into the lab-provided bottle, typically a 60 mL Amber glass bottle.

1.3.2. For time-weighted composites, fill a 60mL syringe from a well-mixed non-preserved sample container, such as the 2L solids sample bottles. The filtrate is taken from the final composite sample after all grab samples for a given site have been combined and mixed well. Attach a 0.45μm membrane syringe filter to the Luer-Lok® fitting on the syringe. Filter sufficient sample into the lab-provided bottle.

1.3.3. More than one filter may be needed for filtration of turbid samples. If a filter clogs, back off the syringe to relieve pressure, then place a new syringe filter on the Luer-Lok® fitting on the syringe and continue filtering.

1.3.4. A 1µm pore size glass fiber pre-filter may be placed in series before the membrane filter to aid in filtering difficult samples. Pre-filters should only be used when necessary to reduce the risks of contamination and sample alteration. If time allows, it is preferable to use multiple membrane filters for a difficult sample rather than a pre-filter.

1.3.5. Use a new syringe and syringe filter(s) for each sample.

1.3.6. Place filtrates in a cooler with ice for transport to the laboratory.

1.3.7. Upon receipt at the laboratory, samples must be cooled to 4°C until time of analysis.

2. Dissolved Organic Carbon Field Filtering Procedure

2.1. Materials and Equipment

2.1.1. Nonsterile disposable syringes, 60mL Luer-Lok®, BD 301035 or equivalent

2.1.2. Cyanoacetate (CA) Membrane disposable syringe filters, 0.45µm pore size, Whatman 25 mm 6880-2504 or equivalent

2.1.3. ASTM Type I DI water

2.2. Field Filtration

2.2.1. For single grab samples, fill a 60mL syringe with sample either from the surface water or from a well-mixed non-preserved sample container, such as the 2L solids sample bottles. Attach a 0.45µm membrane syringe filter to the Luer-Lok® fitting on the syringe. Filter sufficient sample into the lab-provided bottle, typically a 40 mL Sulfuric Acid-preserved VOA vial.

2.2.2. For time-weighted composites, fill a 60mL syringe from a well-mixed non-preserved sample container, such as the 2L solids sample bottles. The filtrate is taken from the final composite sample after all grab samples for a given site have been combined and mixed well. Attach a 0.45µm membrane syringe filter to the Luer-Lok® fitting on the syringe. Filter sufficient sample into the lab-provided bottle.

2.2.3. More than one filter may be needed for filtration of turbid samples. If a filter clogs, back off the syringe to relieve pressure, then place a new syringe filter on the Luer-Lok® fitting on the syringe and continue filtering.

2.2.4. Use a new syringe and syringe filter(s) for each sample.

2.2.5. Place filtrates in a cooler with ice for transport to the laboratory.

2.2.6. Upon receipt at the laboratory, samples must be cooled to 4°C until time of analysis.

3. Dissolved Metals Field Filtering Procedure

3.1. Materials and Equipment

3.1.1. Portable Peristaltic Pump and silicone tubing

- Pump Geotech Geopump™ Series I Portable Peristaltic with easy-load II™ Pump Head (Cat #: 91352023) or equivalent
- Tubing: ½” OD by ⅜” ID flexible (Shore 70 hardness) silicone tubing. (Grainger Cat# 742V88) or equivalent

3.1.2. 0.45-micron capsule filter, Waterra medium turbidity 0.45-micron inline capsule filters (Cat #: FMT300X-45) or equivalent

3.1.3. Simple Green D Pro 3 Plus concentrate

3.1.4. 1 L plastic bottle

3.2. Materials Preparation

3.2.1. Dedicated, reusable 3-foot lengths of silicone tubing are cleaned by first rinse of the tubing with tap water.

3.2.2. Follow with a rinse of Simple Green D Pro 3 Plus cleaner. Rinse thoroughly clean.

3.2.3. Soak the tubing in a dilute HCl bath for a minimum 4 hours.

3.2.4. Carefully remove tubing and rinse with 18.2 MΩ Ultrapure water.

3.2.5. Store in polyethylene, plastic Ziploc type bags until needed.

3.3. Field Filtration

3.3.1. Set-up the peristaltic pump. Connect the portable battery to the pump or plug into an outlet and confirm the pump rotates and the rotation direction.

3.3.2. Don a pair of clean gloves.

3.3.3. Load a 3-foot length of silicone tubing in the pump head, with approximately 2 feet on the suction side and 1 foot on the filter side. Follow the manufacturer's instructions for loading the easy-load pump head. CAUTION: Take extreme care to not touch the ends of the tubing which will contact sample or filter during this step.

3.3.4. Unbag and attach a capsule filter to the discharge-end of the tubing, paying attention to the correct direction of flow, as indicated with an arrow, or marking on the filter.

3.3.5. Pump approximately 500 mL of sample from the 1 L bottle through the filter, discarding the filtrate. While pumping, point the filter outlet at an upward incline so as much of the filter media is contacted by the filtrate as possible.

3.3.6. Uncap the sample bottle and continue pumping to fill the lab-provided bottle taking care not to touch the bottle with the filter. Cap the bottle and store on ice.

3.3.7. Remove the suction end of from the bottle and turn off the pump.

3.3.8. If not enough resistance was felt while pumping (i.e., the flow rate appeared good) and the sample was suspected of not containing high metals concentration, remove the capsule filter and store it either in a new polyethylene bag or the original packaging bag the filter came in until the next sample use.

3.3.9. Unload the pump tubing and store away from the unused segments to be cleaned and re-used at a later date.

3.3.10. Filter subsequent samples with a new un-used tubing portion and the old filter if it has not clogged. Open a new filter if it has. Do not re-use a filter at more than three sites.

Appendix B: 2015 USGS Pesticide Study

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Storm-event-transport of urban-use pesticides to streams likely impairs invertebrate assemblages

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Abstract Insecticide use in urban areas results in the detection of these compounds in streams following stormwater runoff at concentrations likely to cause toxicity for stream invertebrates. In this 2013 study, stormwater runoff and streambed sediments were analyzed for 91 pesticides dissolved in water and 118 pesticides on sediment. Detections included 33 pesticides, including insecticides, fungicides, herbicides, degradates, and a synergist. Patterns in pesticide occurrence reveal transport of dissolved and sediment-bound pesticides, including pyrethroids, from upland areas through stormwater outfalls to receiving streams. Nearly all streams contained at least one insecticide at levels exceeding an aquatic-life benchmark, most often for bifenthrin and (or) fipronil. Multiple U.S. EPA benchmark or criterion exceedances occurred in 40 % of urban streams sampled. Bed sediment concentrations of bifenthrin were highly correlated ($p < 0.001$) with benthic invertebrate assemblages. Non-insects and tolerant invertebrates such as amphipods, flatworms, nematodes, and oligochaetes dominated streams with relatively high concentrations of bifenthrin in bed sediments, whereas insects, sensitive invertebrates, and mayflies were much more abundant at sites with no or low bifenthrin concentrations. The abundance of sensitive invertebrates, % EPT, and select mayfly taxa were strongly negatively correlated with organic-carbon normalized bifenthrin concentrations in streambed sediments. Our findings from western Clackamas County, Oregon (USA), expand upon previous research demonstrating the transport of pesticides from urban landscapes and linking impaired benthic invertebrate assemblages in urban streams with exposure to pyrethroid insecticides.

Keywords Urban streams · Pesticides · Source · Transport · Bifenthrin · Fipronil · Benthic invertebrates

Introduction

Reductions in the abundance or diversity of aquatic insects can have important consequences for aquatic ecosystems, particularly for young salmon and steelhead that consume aquatic invertebrates (National Marine Fisheries Service 2012), but also birds and bats that feed on the adult insects that hatch from streams (Baxter et al. 2005). Many urban streams in the greater Portland, Oregon, metropolitan area once

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supported native salmonid populations, but populations have since declined substantially (Oregon Department of Fish and Wildlife 2010). The low numbers reflect combined habitat and water quality impairment and changes in the base of the food web, including reduced numbers of insects and dominance by less desirable organisms such as oligochaetes, nematodes, and flatworms (Waite et al. 2008). Severely disturbed aquatic invertebrate populations have been found in many of the urban streams in and around Portland (Mulvey et al. 2009; Waite et al. 2008) and in Clackamas County (Cole 2014; Lemke et al. 2013; Dewberry et al. 1999). Although the specific causes for their impaired condition have not been fully evaluated, exposure to insecticides could play a role.

Frequent detection of insecticides at high concentrations in urban streams nationally (Stone et al. 2014) suggests that exposure to these compounds is another stressor likely to impact aquatic invertebrates. Previous studies of urban and rural/agricultural streams in the nearby Clackamas River Basin (Carpenter 2004; Carpenter et al. 2008) found numerous pesticides in stormwater runoff (11 compounds per sample, on average), with several pesticides exceeding U.S. EPA chronic benchmarks for invertebrates (U.S. Environmental Protection Agency 2014), oftentimes for multiple insecticides simultaneously. Since then, new types of insecticides have increased in use, particularly pyrethroids (bifenthrin in particular), and fipronil, a phenyl pyrazole insecticide. Now, residues of these insecticides are showing up in some of California's urban streams at levels of concern (Weston et al. 2014; Ensminger et al. 2013).

While fipronil's high water solubility allows transport of the dissolved compound from the landscape to receiving stream, bifenthrin and other hydrophobic pyrethroids demonstrate a strong tendency to associate with fine sediment and organic matter (Gan et al. 2005a). Pyrethroid compounds transported in stormwater runoff may settle out into streambed sediments (Kuivila et al. 2012) and cause harm to benthic invertebrates (Nowell et al. 2013; Moran et al. 2012). While these new pesticides tend to be less toxic to mammals (U.S. EPA 2011), they are very toxic to aquatic organisms (Siegfried 1993 and references cited therein). Their high frequency of detection in streams highlights the importance of understanding the sources, transport mechanisms, and factors affecting toxicity, including properties of the sediments (organic carbon and (or) sand content) and water temperature (Holmes et al. 2008; Weston et al. 2011), so that strategies can be developed to minimize potential impacts on aquatic life.

Study background and objectives

This study was conducted, in part, to satisfy the Oregon Department of Environmental Quality (ODEQ's) requirement for the new National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permits issued to the Clackamas County Co-permittees in 2012. Our scientific objectives were to evaluate the sources, transport, and fate of current-use insecticides in these streams and assess possible adverse effects on benthic invertebrates using measured pesticide concentrations and existing invertebrate data (Lemke et al. 2013; Cole 2014) collected as part of the MS4 permit.

Methods

Site selection and data collection

Sites were selected to represent the range of urban development, with priority given to sites where invertebrate monitoring was completed. Stormwater and sediment samples were collected from 12 urban streams, 5 paired stormwater outfalls, and 3 streams draining mixed basins including some agricultural land (Table 1, SI 1, and SI 2). Although these 3 were included in the study for comparison, one site (Rock Creek) was included along with the other predominantly urban streams in some of the analyses given the high-density development in the watershed and the availability of comparable invertebrate community data.

Pesticide samples were collected August–September 2013, starting with fine-grained streambed sediment sampling at 14 streams during the late summer low-flow period. Stream-deposited sediments were targeted for sampling and care was taken to avoid sediments derived from adjacent eroding banks. Sampling and processing equipment were cleaned with Liquinox™ soap, rinsed with distilled/deionized water, methanol, and certified organic-free water. Streambed sediment subsamples were collected with a stainless-steel spoon from the top 2 cm of sediment from 10 to 15 locations at each site and composited. The sediment slurry was homogenized and sieved (2-mm stainless steel) into clean 250-mL glass jars.

Samples of stormwater runoff were collected on September 5–6, 2013, following about an inch of rain. Whole-water samples were collected by directly filling

Table 1 List of stormwater outfall and stream sampling sites, basin characteristics, select pesticide concentrations in stormwater runoff and streambed sediments, and benthic invertebrate assemblage disturbance class

Map no.	Site	% urban	% impervious area	Storm runoff SSC (mg/L)	Stormwater runoff concentrations[a] for pesticides exceeding aquatic-life benchmarks or criteria				Streambed sediment concentrations (μg/kg)		
					Bifenthrin	Fipronil	Malathion	DDE + DDD	Total pyrethroids	Total DDT degradates	Invertebrate assemblage disturbance class[b]
Stormwater outfalls and receiving streams											
1	Outfall to Tanner Creek	97	42	68	120*	30*	<	<	1700	–	–
2	Tanner Creek	77	40	136	97*	127**	<	<	34	<	Severe
3	Outfall to Lost Dog Creek	65	27	85	31*	59*	<	<	246	–	–
4	Lost Dog Creek	52	21	102	24*	16*	<	1.1***	73.9	2.3	Severe
5	Outfall to Rose Creek/Sieben Creek	100	78	104	32*	<	<	<	304	–	–
6	Sieben Creek	62	35	545	39*	10	<	9.2***	1.7	0.9	Moderate
7	Outfall to Kellogg Creek	94	43	6.2	<	6.1	<	<	240	1.7	–
8	Kellogg Creek	76	42	76	21*	10.5	<	<	3.1	1.2	Moderate
9	Outfall to detention pond, Wilsonville[c]	65	66	152	29*	<	<	<	190	–	–
Other predominantly urban streams											
11	Ball Creek	83	35	89	21*	19*	<	<	4.1	<	Severe
10	Boeckman Creek (lower)	39	20	32	<	<	<	<	1.2	<	Severe
13	Carli Creek	96	74	105	23*	<	<	<	8.8	<	Severe
14	Coffee Creek	82	39	200	23*	6.7	<	<	1	0.7	Slight
16	Minthorn Spring Creek	92	47	339	24*	6.4	<	<	3.5	4	Severe
18	Singer Creek	83	37	247	<	<	457**	<	30.4	1.1	Slight-moderate
19	Singer Creek tributary	77	34	31	<	20*	<	<	<	<	nd
20	Trilium Creek	68	29	162	24*	12*	<	<	30.3	1.1	Moderate-severe
Streams draining some agricultural land											
12	Boeckman Creek (upper)	29	15	1770	31*	<	<	<	<	<	nd
15	Deep Creek	8	4	138	22*	<	<	2.7***	<	0.8	nd
17	Rock Creek	26	12	34	<	12*	<	<	<	0.7	Moderate-severe

Map is shown in SI 1. Percent urban and impervious areas from National Land Cover Data (NLCD; Fry et al. 2011; impervious area data updated in 2014). Urban area includes NLCD classes 22, 23, and 23 (low-, medium-, and high-intensity urban). Pesticide exceedances indicated with asterisk(s) according to: * Exceeds the U.S. EPA Office of Pesticide Programs 21-day chronic benchmark for invertebrates of 1.3 ng/L bifenthrin or 11 ng/L fipronil; ** Exceeds the U.S. EPA Office of Pesticide Programs acute benchmark for invertebrates of 110 ng/L fipronil or 300 ng/L malathion; *** Exceeds water-quality criterion of 1 ng/L for total DDT plus degradates established by the Clean Water Act for the protection of aquatic life

SSC suspended sediment concentration, *mg/L* milligrams per liter, *nd* no data; <, less than MDL (see Table SI 4); –, not applicable

[a] Stormwater runoff values are whole-water concentrations (sum of the dissolved and suspended fractions) in ng/L

[b] Based on the Oregon Department of Environmental Quality invertebrate metric scores presented in Lemke et al. (2013) and Cole (2014)

[c] This outfall does not discharge to Boeckman Creek

1-L baked amber-glass bottles using a width-integrated method for streams and point-grab samples for stormwater outfalls. Based on continuous monitoring data from nearby Fanno Creek (SI 3), this storm was considered a "first flush" event for the season, producing a characteristic peak in turbidity that subsided with additional rainfall, presumably through dilution and decreased mobilization of sediments.

Prior to the storm, stainless steel Screened Inline Flow-Through (SIFT©) sediment traps designed by the City of Portland (Fig. 1) were deployed in 3 outfalls: Rose Creek/Sieben Creek outfall, Kellogg Creek outfall, and the outfall in Wilsonville (SI 1), in a pilot effort to monitor for pesticides on sediments transported in stormwater from the "pipe-shed." The samplers collected time-integrated samples of sediments >226 μm (Randy Belston, City of Portland, written communication, 2013). Samplers were deployed on July 17 and sediments retrieved from all three outfalls on September 13, a week after the September 5–6 storm. Due to low volumes of sediment retrieved from the Rose Creek/Sieben Creek and Kellogg Creek outfalls, SIFT sediment traps were redeployed for another 38 days until October 21, when a second set of post-storm samples was retrieved.

Invertebrate assemblage data (and community metrics) were assessed alongside pesticide concentrations to examine for possible effects. Benthic macroinvertebrate samples were collected at all sites in either 2011 or 2013 using Oregon DEQ's protocol for wadeable rivers and streams (ODEQ 2009). Specific details are presented in Lemke et al. (2013) and Cole (2014). Briefly, targeted riffle samples (8-kick composites) were collected using a 500-μm mesh D-frame net. Samples were sorted to remove a 500-organism subsample. Identifications were performed by Michael Cole and Ann Gregoire, Cole Environmental, Inc. Most aquatic insects, including Ephemeroptera, Plecoptera, and Tricoptera, and other arthropods were identified to genus or species. Mollusks were identified to family or genus, oligochaetes were identified to class, and chironomids were identified to subfamily/tribe.

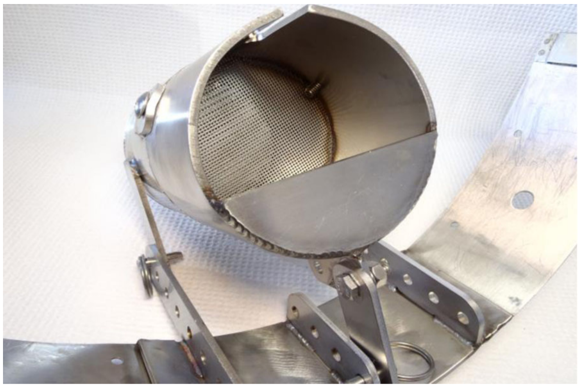

Fig. 1 Screened Inline Flow-Through (SIFT) sediment trap

Pesticide analyses and quality assurance

Analyses included 91 pesticides dissolved in water and 118 compounds on sediment (SI 4). Pesticide samples were analyzed at the USGS Organic Chemistry Laboratory in Sacramento, CA, using methods for water (Hladik et al. 2008), suspended sediment (Hladik et al. 2009), and streambed sediment (Hladik and McWayne 2012). Stormwater samples were processed through 0.7-μm glass-fiber filters in the laboratory, with dissolved and suspended fractions analyzed separately using gas chromatography–mass spectroscopy (GC/MS). Method detection limits were 0.9 to 10.5 ng/L for water and 0.5 to 3.1 μg/kg for sediment (SI 4).

Percent organic carbon concentrations were determined for streambed and SIFT sediments at the USGS Organic Chemistry Laboratory using a PerkinElmer CHNS/O analyzer (Perkin Elmer Corporation, Waltham, MA). Before analysis, sediments were dried to a constant weight at 110 °C for 3 h. Sediments were combusted at 925 °C in silver boats after being exposed to concentrated hydrochloric acid fumes in a desiccator for 24 h to remove inorganic carbon. Acetanilide was used for instrument calibration for carbon.

Quality assurance samples included one field blank, three replicates, four matrix spikes, plus two surrogate matrix spikes for each sample analyzed. There were no QA issues identified; the blank sample was clean (SI 5), and relative percent differences (RPD) between replicate samples were < 20 %, with an average RPD of 8.5 % (SI 6). Percent recoveries were 70–121 % (SI 7). Percent recoveries for surrogate spikes for atrazine (84–112 %) and permethrin (76–107 %) averaged 100 and 95 %, respectively (SI 8).

Site basin characteristics

Stream and outfall basin areas were delineated for each site using light imaging detection and ranging (LiDAR), 10-m digital elevation maps, or hand delineation with guidance from staff with local jurisdictions. GIS was used to derive basin statistics from USGS Streamstats (U.S. Geological Survey 2012), the 2006 National Land Cover Data (NLCD, Fry et al. 2011), 2013 census data, and SSERGO soils data (Natural Resources Conservation Service 2014). Percent impervious area was derived using the 2001, 2006, and 2011 NLCD (posted October 2014).

Stormwater outfalls drained the most densely urbanized areas with the exception of the outfall to Lost Dog Creek, which contains some "unpiped" areas (see footnote in Table 2). These basins were 93–100 % urban, with substantial impervious areas (Table 1). The outfall to Rose Creek/Sieben Creek drains a basin that is 100 % commercial/retail, whereas other outfalls drained basins with higher amounts of residential property. Streams drain mixed basins containing low-, medium-, and high-density development, with some industrial land (SI 2). Three sites (upper Boeckman, Rock, and Deep Creeks) also contained some agricultural land (row crops and nurseries) (SI 2).

Several sites (Tanner, Lost Dog, Trillium, and Coffee Creeks) drain steep, highly dissected hill slopes with high drainage density (stream miles per mi^2) that rapidly

Table 2 Pesticide concentrations in stormwater outfall discharge and SIFT sediments

Pesticide (type)	Detection frequency (%)	Outfall to Lost Dog Creek[a]	Outfall to Tanner Creek	Outfal to Rose Creek/Sieben Creek		Outfall to Kellogg Creek		Outfall to detention pond, Wilsonville
Stormwater discharge								
Bifenthrin (I)	80	37 (240)	120 (1697)	32 (304)	–	<	–	29 (190)
Fipronil (I)	60	59	30	<	–	6.1	–	<
Metolachlor (H)	60	<	13	<	–	6	–	72
Carbaryl (I)	40	50	13	<	–	<	–	<
Fipronil sulfide (D)	40	9.4	3.5	<	–	<	–	<
Iprodione (F)	40	15 (145)	<	<	–	<	–	<
Kresoxim-methyl (F)	40	6 (58)	<	<	–	<	–	12 (76)
Zoxamide (F)	40	9 (91)	<	<	–	<	–	28 (187)
Boscalid (F)	20	8.6	<	<	–	<	–	<
Esfenvalerate (I)	20	6.2	<	<	–	<	–	<
Fenbuconazole (F)	20	7.2	<	<	–	<	–	<
Fipronil desulfinyl (D)	20	<	<	<	–	10.5	–	<
Flusilazole (F)	20	6.3	<	<	–	<	–	<
Piperonyl butoxide (S)	20	18	<	<	–	<	–	<
SIFT sediments				Sample 1	Sample 2	Sample 1	Sample 2	Sample 1
Bifenthrin (I)	100	–	–	24	436	12.1	11.5	179
Pendimethalin (H)	100	–	–	20	849	4.9	6.2	380
Trifluralin (H)	80	–	–	<	40	21	1.6	49
Dithiopyr (H)	60	–	–	12	244	<	<	176
Prodiamine (H)	40	–	–	<	39	<	<	92
DDE (D)	20	–	–	<	<	1.7	<	<
Pentachloroanisole (D)	20	–	–	1.2	<	<	<	<
Oxyfluorfen (H)	20	–	–	<	<	12.5	<	<
Methoprene (I)	20	–	–	<	<	<	25	<

Whole-water pesticide concentrations in stormwater outfall discharge in ng/L; suspended sediment concentrations in stormwater outfall discharge in μg/kg (shown in parens).

SIFT sediment pesticide concentrations in μg/kg

Pesticide types: *F* fungicide, *H* herbicide, *I* insecticide, *S* synergist, *D* pesticide degradate. <, less than MDL (see Table SI 4); –, no data

[a] Although this sampling site is classified as an outfall, about 27 % (40 acres) of the upstream watershed is "unpiped" area drained by surface channels

transport stormwater runoff. These include the bluffs in Lake Oswego and West Linn, which have residential landscaping that might be subject to pesticide applications. This combination of factors may present the right conditions for pesticides to mobilize to streams during storm runoff.

Data reduction and statistical analysis

Pesticide concentrations in stormwater runoff—whole-water sums of dissolved and suspended fractions—were evaluated against U.S. EPA Office of Pesticide Programs (OPP) chronic and acute benchmarks for invertebrates and, for DDT degradates, water quality criteria set forth in the Clean Water Act for the protection of aquatic life. Benchmark quotient (BQ) values were calculated for each detection in water: BQ = sample concentration/benchmark or criteria. Based on this screening process, bifenthrin, fipronil, malathion, and the sum of DDT degradates (compounds with BQ >1) were identified as having the greatest potential for affecting invertebrate assemblages in these streams. Pesticide concentrations in streambed sediments were compared against benchmarks proposed by Nowell et al. 2016. Analyses were performed using both raw and organic-carbon-normalized bifenthrin concentrations in bed sediment to examine for potential effects on invertebrates.

Pesticide variables (concentrations, OC-normalized concentrations, and pesticide class sums) were collated with the site basin statistics and data on benthic invertebrates, water quality (temperature, dissolved oxygen, and specific conductance), and habitat conditions (riparian buffer width, bank stability, large wood, and substrate size and embeddedness) reported in Lemke et al. (2013) and Cole (2014). Most sites were sampled for benthic invertebrates a few weeks prior to the storm sampling, but four streams included in the analysis—Carli, Sieben, Rock, and Kellogg Creeks—were sampled in September 2011 (Lemke et al. 2013).

Non-metric multidimensional scaling (NMDS) ordinations, Bio-Env Stepwise (BEST) analyses, and spearman rank correlations were performed using the multivariate statistical package PRIMER (Clarke and Gorley 2006). Analyses were conducted separately on (1) all sites and (2) the predominantly urban streams without 2 of the 3 agriculturally affected sites (SI 2). As described above, Rock Creek was included as an urban affected stream in the analyses involving the invertebrates.

NMDS ordination was used to portray the pattern in the invertebrate species assemblage data based on Bray-Curtis similarity using square-root-transformed abundance data. Invertebrate assemblage traits and metrics were then examined for correlation with NMDS axes scores to understand the underlying patterns among sites. Associations between the invertebrate species composition and pesticide/environmental data matrix were examined using BEST to identify possible factor(s) that may relate to or explain the distribution of samples in the ordination. Overlay bubble plots were made to visualize relationships between the invertebrate assemblages and pesticide concentrations and other environmental variables.

Results and discussion

Overall, 33 pesticide compounds, including 9 insecticides, were detected. Pesticides were detected at all sites in one or more sample types/phases, with up to 12 pesticides detected per site. Four compounds—bifenthrin, fipronil, a DDT degradate, and metolachlor—composed half of all detections (Tables 2 and 3).

Twenty samples of stormwater runoff from outfalls and streams resulted in the detection of 18 pesticides, mostly fungicides and insecticides (Tables 2 and 3). The most frequently detected pesticides were two insecticides, bifenthrin and fipronil, which occurred in 80 and 60 % of samples from stormwater outfalls, respectively, and 73 and 67 % of samples from streams (Tables 2 and 3). The highest concentration of bifenthrin (120 ng/L) occurred in the outfall to Tanner Creek, with the next highest concentration in Tanner Creek. Tanner Creek also contained the highest concentration of fipronil (127 ng/L), with the next highest concentration occurring in the outfall to Lost Dog Creek (Table 1). These outfall-stream systems drain relatively high-elevation neighborhoods with large single-family houses, often with large lawns and manicured landscaping; the latter stream site drains a mixed basin containing residential and commercial land, and a golf course (SI 2). These watersheds are also relatively steep, making for rapid transport of runoff during storms that is often highly turbid.

The frequent detection of bifenthrin and fipronil is consistent with their use in urban environments (SI 9) and their relatively long half-lives (many months to over 1 year; SI 10). Although bifenthrin and fipronil are less toxic to mammals (U.S. EPA 2011), they are much more

Table 3 Pesticide concentrations in streams during stormwater runoff and in streambed sediments

Pesticide (type)	Predominantly urban streams												Streams draining some agricultural land		
	Detection frequency (%)	Tanner Cr.	Lost Dog Cr.	Sieben Cr.	Kellogg Cr.	Ball Cr.	Boeckman Creek (lower)	Carli Cr.	Coffee Cr.	Minthorne Spg. Cr.	Singer Cr.	Singer Cr. tributary	Trillium Cr.	Boeckman Creek (upper)	Deep Cr.	Rock Cr.
Stormwater runoff [a]																
Bifenthrin (I)	73	97 (672)	24 (284)	39 (72)	21 (277)	21 (235)	<	23 (218)	23 (114)	24 (70)	<	<	24 (146)	31 (17)	22 (159)	<
Fipronil (I)	67	127	16	10	11	19	<	<	6.7	6.4	<	20	12	<	<	12
Metolachlor (H)	67	9.1	<	7.2	7.2	10.2	11	<	14	5.4	45	<	7.8	22	<	<
Carbaryl (I)	27	135	15	66	<	<	<	<	<	<	<	<	9	<	<	<
DDE (D)	20	<	1 (13)	4 (7)	<	<	<	<	<	<	<	<	<	<	3 (20)	<
Pendimethalin (H)	20	<	<	25 (46)	<	<	<	<	<	<	<	<	<	36 (20)	39 (279)	<
Propiconazole (F)	20	<	<	<	57	<	<	215	<	<	<	<	<	<	83	<
Iprodione (F)	13	<	<	21 (39)	<	<	<	<	<	<	<	<	<	<	26.9	<
Zoxamide (F)	13	<	<	14 (25)	<	<	<	<	<	<	<	<	<	<	<	22
Azoxystrobin (F)	7	<	<	<	<	<	<	<	<	<	<	<	<	<	63	<
DCPA (H)	7	<	<	<	<	<	<	10	<	<	<	<	<	<	<	<
Kresoxim-methyl (F)	7	<	<	8 (15)	<	<	<	<	<	<	<	<	<	<	<	<
Malathion (I)	7	<	<	<	<	<	<	<	<	<	457	<	<	<	<	<
Malathion-oxon (D)	7	<	<	<	<	<	<	<	<	<	47	<	<	<	<	<
DDD (D)	7	<	<	5 (9)	<	<	<	<	<	<	<	<	<	<	<	<
Simazine (H)	7	<	<	<	<	<	<	<	<	<	<	<	108	<	<	<
Streambed sediments																
Bifenthrin (I)	71	34	27	1.7	3.1	4.1	1.2	8.8	1	3.5	<	–	2.5	<	<	<
DDE (D)	64	<	2.3	0.9	1.2	<	<	<	0.7	2.7	1.1	–	1.1	<	0.8	0.7
Trifluralin (H)	29	6.4	3.1	1.5	<	2	<	<	<	<	<	–	<	<	<	<
Dithiopyr (H)	29	2.8	1.4	<	<	<	<	2.2	<	<	<	–	1	<	<	<
Metalaxyl (F)	21	<	<	<	<	<	21	<	<	20	392	–	<	<	<	<
Cypermethrin (I)	14	<	<	<	<	<	<	<	<	<	30	–	28	<	<	<
Pentachloroanisole (D)	14	<	2.8	<	<	<	<	3.7	<	<	<	–	<	<	<	<
Cyfluthrin (I)	7	<	47	<	<	<	<	<	<	<	<	–	<	<	<	<
Fenpyroximate (I)	7	15.1	<	<	<	<	<	<	<	<	<	–	<	<	<	<
Pendimethalin (H)	7	<	<	<	<	<	<	32	<	<	<	–	<	<	<	<
Prodiamine (H)	7	<	<	<	<	<	<	8.4	<	<	<	–	<	<	<	<
Oxyfluorfen (H)	7	<	<	<	68	<	<	<	<	<	<	–	<	<	<	<
DDD (D)	7	<	<	<	<	<	<	<	<	1.3	<	–	<	<	<	<

Stormwater runoff pesticide concentrations in ng/L (suspended sediment concentrations in µg/kg in parens). Streambed sediment pesticide concentrations in µg/kg

Pesticide types: *F* fungicide, *H* herbicide, *I* insecticide, *D* degradate; <, less than MDL (see Table SI 4); –, no data

[a] Stormwater runoff values are whole-water concentrations (sum of the dissolved and suspended fractions)

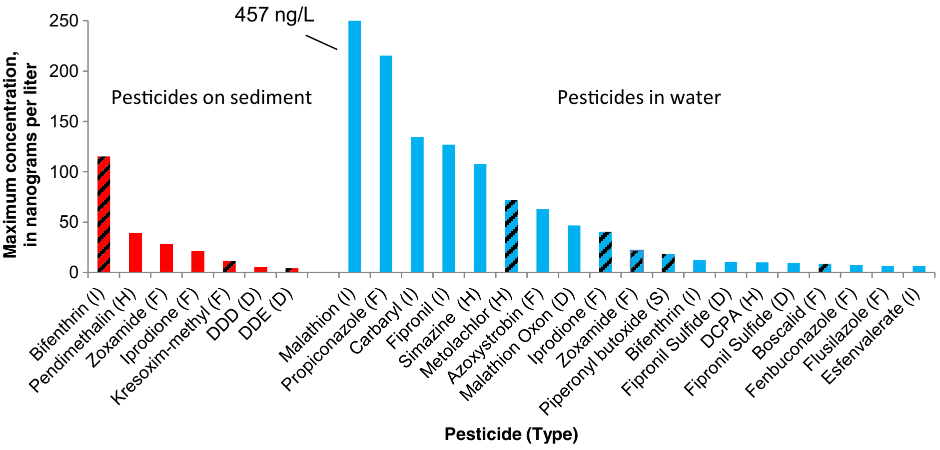

Fig. 2 Maximum concentrations of pesticides in stormwater runoff. Sampling included 15 streams and 5 outfall sites, each sampled once. Bar cross hatches indicate pesticides with maximum concentrations in stormwater outfalls. Pesticide types: *F*, fungicide; *H*, herbicide; *I*, insecticide; *S*, synergist; *D*, degradate

toxic to cold-blooded aquatic invertebrates, which may have consequences for stream life, including the small organisms that fish and other creatures feed upon.

Changes in pesticide use over the past decade have likely resulted in bifenthrin and fipronil replacing organophosphate insecticides such as diazinon, which was banned for urban use in 2005 (Ryberg et al. 2010; U.S. Environmental Protection Agency 2012). While diazinon was not detected in our current study, it was found in 25 % of samples during a previous Clackamas River Basin study conducted in 2000–2005 (Carpenter et al. 2008), including Carli, Sieben, and Rock Creeks sampled for the current study.

The most frequently detected herbicide was metolachlor, which occurred in about two thirds of stormwater samples collected from the outfalls and streams. In Oregon, metolachlor is only used by licensed applicators, for control of grasses and small-seeded broadleaf weeds. Its high frequency of detection is consistent with a previous study in the Clackamas River basin (Carpenter et al. 2008) that found metolachlor in nearly half of over 100 samples, including detection in raw and finished (treated) drinking water.

Partitioning of pesticides in stormwater runoff

Samples of stormwater runoff were filtered to allow analyses of dissolved and suspended (filter retained) fractions (SI 11 and SI 12). Seven pesticides partitioned onto suspended sediment, with one or more insecticides occurring on sediment in nearly three quarters of samples (Tables 2 and 3). Nearly three times as many dissolved pesticides were detected and at higher concentrations (Fig. 2), despite the high concentrations of total suspended sediments (Table 1). Differences in method detection limits for dissolved versus sediment (SI 4), however, may also affect detection frequencies.

Fipronil, metolachlor, carbaryl, and propiconazole occurred exclusively in the dissolved phase, whereas bifenthrin, kresoxim-methyl, DDT degradates, pendimethalin, and zoxamide had their greatest frequency of detection on suspended sediments (Fig. 3). The partitioning of these pesticides into dissolved and sediment phases is consistent with their water solubilities and Koc values (SI 10), and points to the importance of both fractions in transporting pesticides during storms.

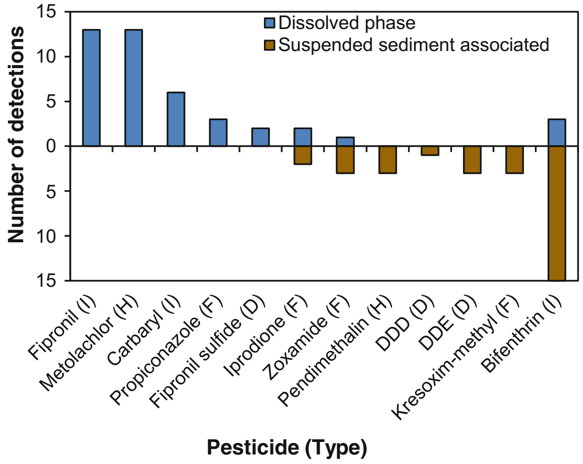

Fig. 3 Comparison of dissolved and suspended sediment associated pesticides in stormwater. Includes compounds detected in >1 sample ($n = 20$ samples). Pesticide types: *F*, fungicide; *H*, herbicide; *I*, insecticide; *D*, pesticide degradate

Transport of pesticides from outfalls to streams

The nested design of the study with four outfall-stream pairs allowed for comparison of pesticide concentrations in outfalls (stormwater runoff and SIFT device sediments) with those in receiving streams (stormwater runoff and streambed sediments) (Fig. 4a–c). In all of the nested pairs, there were some compounds detected in both the outfall and receiving stream, and some compounds detected in one but not the other (SI 13). This could represent compound-specific differences in their upstream sources, timing of pesticide transport relative to sample collection, as well as dilution and fractionation (partitioning to sediment, for example), and, for streambed and SIFT sediments, sediment dilution and (or) degradation.

There were 14 pesticides detected in water in the outfalls, with bifenthrin, fipronil, and metolachlor occurring in over half of samples. In addition, there were 9 pesticides detected in 5 SIFT samples (Table 2). The highest concentrations were for pendimethalin and bifenthrin, which occurred in all 5 SIFT samples; their 100 % detection points to these highly urbanized watersheds as important source areas for these compounds. Most of the pesticides detected in the receiving streams were also discharged by stormwater outfalls. Exceptions included insecticides (cyfluthrin and fenpyroximate) and the fungicide propiconazole, which were detected in one and three streams each, respectively, but not in any outfalls, pointing to other upstream sources.

Thirteen pesticides were detected in streambed sediments, with one to six compounds per stream (Table 3). Bed sediments contained bifenthrin in 71 % of streams, overall, and nearly two thirds contained one or more DDT degradates. With the exception of Tanner and Lost Dog Creeks, these bifenthrin concentrations are similar to those reported by Weston et al. (2011) for streams in the Pacific Northwest, including Kellogg Creek, which was sampled again during our study.

The highest concentrations of bifenthrin occurred in the outfall to Tanner Creek (Table 2), where the concentration more than accounted for that found downstream in the creek (Table 3), pointing to the outfall as an important source. Tanner Creek and the outfall are situated in a neighborhood in close proximity to large residential properties with extensive turf and manicured landscaping that may be treated with bifenthrin and other pesticides. The high concentration in the outfall relative to other sites may reflect recent/fresh applications on upland areas in the neighborhood.

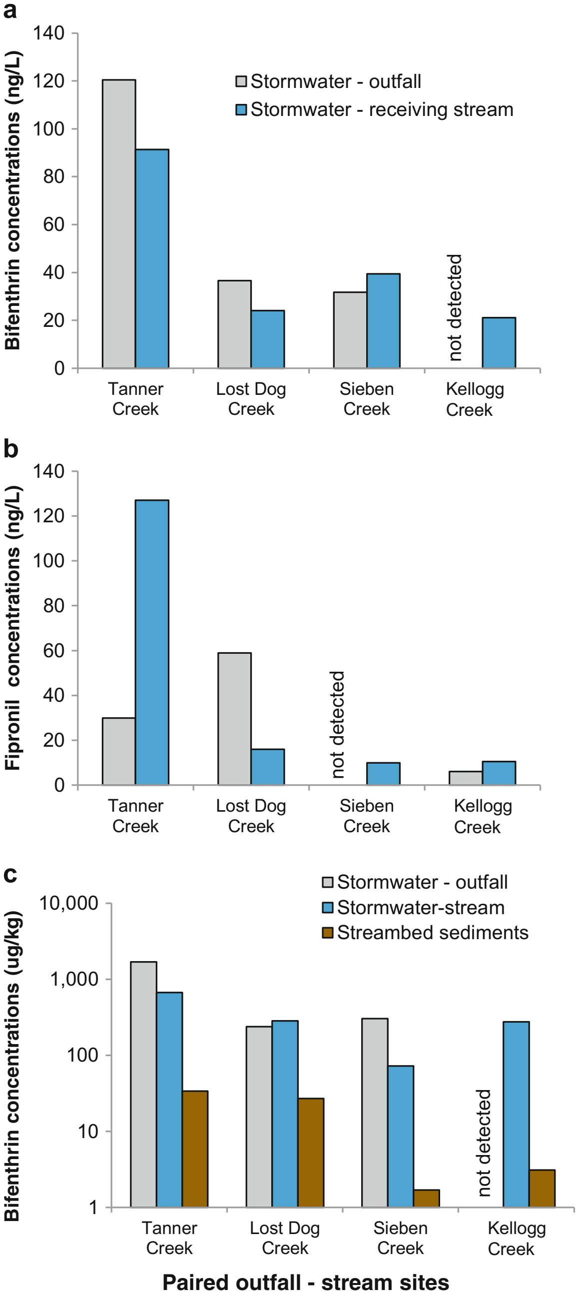

Fig. 4 Stormwater runoff concentrations of **a** total bifenthrin and **b** dissolved fipronil in paired stormwater outfalls and receiving streams, and **c** mass-per-unit-mass bifenthrin concentrations in outfalls, streams, and streambed sediments. Note log scale of *y axis* in panel **c**. Lost Dog Creek outfall contains 40 acres of "unpiped" area drained by surface channels

Bifenthrin was also found in Tanner Creek bed sediments (Fig. 4c), at a concentration 20 times lower than that on storm-derived suspended sediment and 50 times lower than the concentration on suspended sediments from the outfall. Taken together, these results indicate the importance of recent inputs of bifenthrin to Tanner Creek from this outfall.

The outfall to Lost Dog Creek and downstream site contained similar concentrations of mostly sediment-associated bifenthrin (Fig. 5a), which similarly originates from the outfall's upstream watershed mostly comprised of residential properties, a golf course, and other possible areas where bifenthrin and other insecticides may be applied. Dissolved concentrations of fipronil and carbaryl were about 3.5 times higher in the outfall compared with the downstream site. The timing of runoff relative to sample collection in this steep watershed may have contributed to such differences in concentrations between the outfall and stream site.

The bifenthrin concentration in bed sediments in Lost Dog Creek was an order of magnitude lower than that found in runoff in both the stream and outfall (Fig. 4c), indicating, once again, fresh inputs as the primary source. In similar fashion, DDE transported on suspended sediments was six times more concentrated than that found in the creek bed sediments. Other pesticides such as cyfluthrin, dithiopyr, pentachloranisole (PCA), and trifluralin were also found in the bed sediments, but not in the upstream outfall, suggesting other sources for these pesticides.

The outfall to Rose Creek was a source of bifenthrin, pendimethalin, and trifluralin to Sieben Creek (Table 2); three other pesticides—dithiopyr, prodiamine, and PCA—were detected in the outfall but not downstream. This outfall drains a shopping center that is nearly 100 % commercial/retail (Andrew Swanson, Clackamas County Water Environmental Services, written commun., 2013), and pesticides applied to landscaping may be washed onto pavement and carried through storm drains to the outfall, which discharges to surface water about 1 mi upstream from the Sieben Creek sampling site (SI 1). The drainage basin for this outfall is small, however, making up just 0.6 % of Sieben Creek's basin area, which limits its influence on downstream pesticide concentrations. Sieben Creek drains into the lower Clackamas River upstream from four major drinking water intakes, and was previously identified as an important pesticide source (Carpenter et al. 2008).

Although the whole water concentration of bifenthrin at the outfall was slightly lower compared with Sieben Creek downstream, the bifenthrin concentrations on the suspended sediments were four times greater in the outfall (Fig. 4c), suggesting downstream dilution by sediments having, on average, lower bifenthrin concentrations.

Pendimethalin was also detected in the outfall—only in SIFT sediments—at concentrations of 20 μg/kg following the first storm (sample 1) and 849 μg/kg in sample 2 (Table 2). The concentration on suspended sediments in Sieben Creek during the storm was intermediate (46 μg/kg). Three other compounds, dithiopyr, prodiamine, and PCA, were detected in SIFT sediment from the outfall, but not in Sieben Creek downstream, and eight other pesticides, including fipronil, carbaryl, and DDT degradates, were detected in Sieben Creek

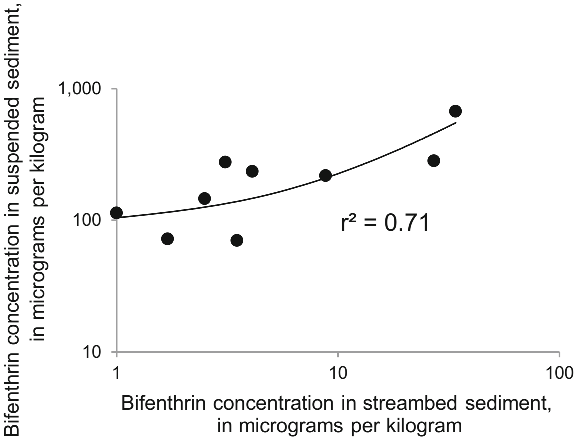

Fig. 5 Regression of bifenthrin concentrations on suspended sediments (in runoff) and those in streambed sediments. Note log scale in *x* and *y axes*

stormwater, but not in the outfall. These results are not unexpected, as discharge from the outfall makes up only a small fraction of the flow in the creek, and pesticide runoff from residential properties in other parts of the basin are likely occurring.

The outfall to Kellogg Creek was a source of bifenthrin, fipronil, pendimethalin, trifluralin, DDE, and four other pesticides. While bifenthrin was detected in both SIFT sediment samples (Table 2), bifenthrin was below detection in the stormwater runoff sample collected at the outfall. This may have resulted from sampling the outfall after the major flush of sediments had already occurred. The water sample did contain dissolved fipronil (plus a degradate) and metolachlor (Table 3, Fig. 4b), and these moderately-to-highly water-soluble compounds (SI 10) might be expected to linger in the receding stormwater more so than sediment-associated pesticides that settle out when runoff velocities decline. Three of the four pesticides detected in Kellogg Creek bed sediments, bifenthrin, oxyfluorfen, and DDE, were also detected in the stormwater outfall. In addition to the outfall, Minthorne Spring Creek was another source of bifenthrin, fipronil, and metolachlor (Table 3) to downstream Kellogg Creek (SI 1).

Sources, transport, and fate of bifenthrin, fipronil, and DDT degradates

Bifenthrin, fipronil, and a DDT degradate (DDE) were the insecticide compounds most commonly detected in this study. They represent three chemically distinct classes and have different modes of action upon target organisms, though all have potential to cause adverse effects on aquatic invertebrates in streams.

Bifenthrin

Bifenthrin was the most frequently detected pesticide in our study, transported primarily sorbed to suspended sediments (Fig. 3). Almost all (97 %) of the bifenthrin mass transported during the storm was associated with suspended sediments. Bifenthrin was detected in all five outfalls in stormwater or SIFT sediments and in the bed sediments of > 90 % of streams sampled.

Bifenthrin concentrations in streambed sediments were on average 50 times (up to 270 times) lower than those in stormwater runoff, though concentrations were positively correlated ($r^2 = 0.71$, $p < 0.001$; Fig. 5). While resuspension of sediment-bound bifenthrin in the streambed may occur during storms, the higher concentrations in four out of five outfalls suggest that inputs of fresh chemical from the landscape to receiving streams enriches streambed sediments, but that degradation and (or) sediment dilution result in lower concentrations.

Bifenthrin and DDE were the only compounds detected in both suspended and streambed sediments, a finding that is likely due to their high organic carbon partitioning coefficient (Koc) values and relatively long half-lives (Weston et al. 2011; Saran and Kamble 2008; Gan et al. 2005b; SI 10). Although no data are available to assess the local use of bifenthrin, high non-agricultural use of bifenthrin-containing products was shown for the Puget Sound counties (Washington State Department of Agriculture 2014). Bifenthrin is widely used for control of structural pests—carpenter ants and termites—but it is also approved to control insect pests on residential lawns, golf course turf, and as a broad-spectrum insecticide for landscape ornamentals.

Fipronil

Fipronil, a phenyl pyrazole insecticide, was detected in about two thirds of outfalls and streams—all in the dissolved phase—along with a few detections of degradates in outfall samples. Fipronil is often used by professional applicators for structural pests, especially termites and carpenter ants, and for control of larvae and adult cockroaches, mosquitos, locust, ticks, and fleas. Because it has a unique mode of action, fipronil is considered effective for pests that may have become resistant to other insecticides such as pyrethroids, organophosphates, or carbamates (Bobe et al. 1997).

During 2008, fipronil was the most common insecticide applied in Oregon, making up 35 % of the total reported use statewide (Oregon Department of Agriculture 2008). Its frequent detection in our study suggests that fipronil use continues to be important in northwestern Oregon. Fipronil is used exclusively in urban areas and is not applied to agricultural crops (Gunasekara and Troung 2007). Fipronil is moderately soluble and has a relatively low Koc; none was detected on sediments. But, like bifenthrin, fipronil has a relatively long half-life, which, along with its common use, contributes to its frequent detection in urban stormwater.

DDT degradates

DDT degradates (DDD and DDE) were commonly detected in these streams, almost entirely associated with sediments—from outfalls, streams, and streambeds (Table 1, Table 2, and Table 3). Though banned in 1972, DDT degradates—toxic, hydrophobic, and bioaccumulative—continue to be detected; in this study, they were found in two thirds of streams, revealing their persistence across much of the study area. For streams where DDE was detected in both the suspended and streambed sediments, concentrations were 5–25 times lower in streambed sediment, suggesting mobilization of higher-concentration sediments from upland sources or possibly bank erosion during high discharge.

Detections of DDE in the Kellogg Creek watershed, including the outfall to Kellogg Creek (Table 2), Minthorne Spring, and Kellogg Creek bed sediments (Table 3), suggest continued transport of these compounds on sediments eroded from the watershed with subsequent deposition in the creeks. Their slow degradation provides opportunity for long-term exposure that may affect stream life.

Pesticides exceeding benchmarks for invertebrates and water quality criteria

Nearly all stormwater runoff samples (14 of 15 streams) contained one or two insecticide(s) at levels exceeding U.S. EPA OPP chronic benchmarks for invertebrates (Table 1). Concentrations of fipronil and malathion in Tanner and Singer Creeks exceeded U.S. EPA acute benchmarks for invertebrates with respective BQ values of 1.15 and 1.5. While these one-time samples may or may not have characterized peak concentrations, exceedances of acute benchmarks suggest that levels were sufficiently high in these streams to impair invertebrates, at least for a period of time.

Many more insecticide detections potentially exceeded U.S. EPA chronic benchmarks for invertebrates, with bifenthrin and fipronil exceedances in 80 and 46 % of streams, respectively (Table 1). These EPA chronic benchmarks are based on 21-day average water concentrations, not instantaneous concentrations during peak stormwater runoff as reported here. Thus, comparisons to these chronic benchmarks may overestimate actual toxicity to aquatic life if exposures are shorter lived.

Some of these exceedances were, however, well above chronic benchmarks, and likely exceeded chronic values for some time after the storm, depending on the sources, transport, and flushing rates, among other factors. In addition, our screening process used standard single-compound benchmark quotient (BQ) values as potential indicators of invertebrate toxicity, and did not consider possible cumulative effects of mixtures. But, in reality, stream biota are exposed to multiple pesticides (Carpenter et al. 2008) and other pollutants in stormwater including metals and poly-aromatic hydrocarbons (McIntyre et al. 2014), which may collectively produce toxicity for aquatic life. These perspectives support the use of lower, chronic benchmarks as a potentially useful, albeit conservative, screening approach. Taking this approach, there were two to three insecticides (bifenthrin, fipronil, and (or) a DDT degradate) in 40 % of urban streams exceeding chronic benchmarks or water-quality criteria (Table 1).

Potential effects of bifenthrin on invertebrates

In addition to the potential exceedances of aquatic-life benchmarks in stormwater, other lines of evidence suggest that bifenthrin in particular may be altering invertebrate assemblages in these urban streams. The Bio-ENV BEST multivariate analyses identified bifenthrin concentrations in streambed sediments as the most important variable in the solution (rho = 0.59; $p < 0.001$), explaining a significant amount of variation in the benthic invertebrate similarity matrix. Sites with relatively high concentrations of bifenthrin in bed sediments were dominated by tolerant organisms including amphipods, flatworms, oligochaetes, blackflies, and midges. All of them had severely disturbed invertebrate assemblages (Table 1). Although stormwater concentrations of bifenthrin were higher in runoff compared with bed sediments, runoff concentrations were not significant in the BEST analysis ($p > 0.05$).

Consistent with these BEST results, bifenthrin in streambed sediments was significantly correlated with NMDS axis 1 (rho = 0.75, $p < 0.01$, Fig. 6). NMDS Axis 1 scores were also significantly correlated (rho = –0.82, $p < 0.001$) with % sensitive EPT (mayflies [but not including those in the *Baetis tricaudatus* complex], stoneflies, and caddisflies). NMDS Axis 2 was significantly correlated (rho = 0.63–0.69, $p < 0.05$) with total invertebrate abundance (insect and non-insects), reflecting the high densities of tolerant organisms at sites such as Carli Creek, with low total abundances overall in Lost Dog and Ball Creeks (Fig. 6, also see Lemke et al. 2013; Cole 2014).

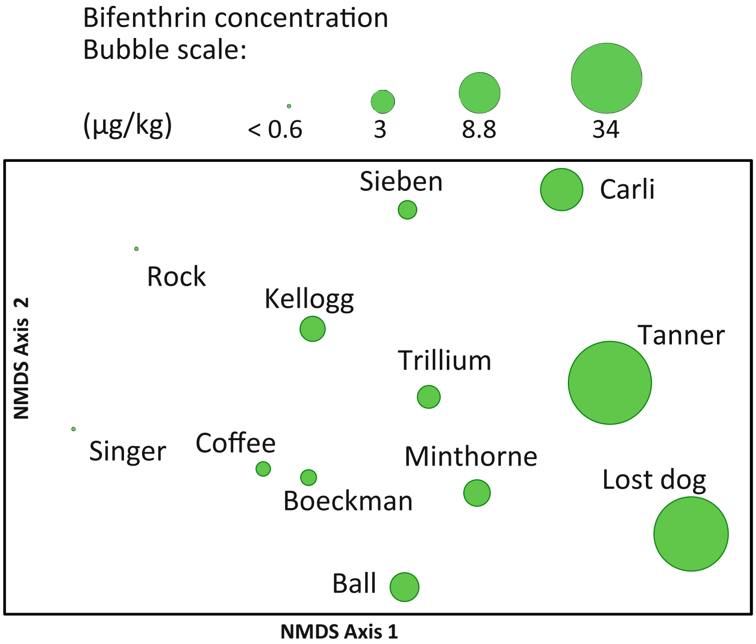

Fig. 6 Ordination of creek benthic invertebrate samples with bubble plot overlay of bifenthrin concentrations in streambed sediments

In addition, a strong negative response in the total abundance of sensitive benthic invertebrates occurred with increasing bifenthrin (organic-carbon-normalized concentrations) in streambed sediments (Fig. 7a), based on U.S. EPA tolerance values for the Pacific Northwest Region (Barbour et al. 1999). A similar decline in % EPT abundance (not including *Baetis*) and declines in three mayfly taxa were observed with higher bifenthrin concentrations in bed sediments (Fig. 7b, c). *Baetis* (swimming mayflies), including those in the *B. tricaudatus* complex, are often found in disturbed urban streams (Waite et al. 2008). They were removed from the % EPT metric because, unlike most EPT, which are relatively sensitive to environmental conditions, *Baetis* mayflies are more tolerant (Barbour et al. 1999). High abundances of *B. tricaudatus* (complex) can develop due to their relatively short generation time (~30 days), and because they are common in the drift, they are effective colonizers and may occur in high abundances despite poor water quality or sediment contaminants.

The highest bifenthrin concentration in bed sediments (34 µg/kg) occurred in Tanner Creek, where the invertebrate assemblage disturbance class was rated “severe” (Table 1, also see Cole 2014), with dominance by fast colonizers (*B. tricaudatus* complex) or tolerant non-insect taxa, including flatworms, amphipods, and oligochaete worms. Lost Dog Creek, which had the second highest bifenthrin concentrations in bed sediments (27 µg/kg), had low abundance of invertebrates and an exclusively tolerant assemblage dominated by amphipods, flat worms, oligochaete worms, and midges. Carli Creek had much higher densities of invertebrates despite the third highest bifenthrin concentration (8.8 µg/kg), but was also dominated by tolerant organisms—isopods, black flies, oligochaetes, and *B. tricaudatus* complex.

The negative relationship between bifenthrin concentrations in streambed sediments with indicators of healthy invertebrate populations suggests that bifenthrin could be causing community declines and shifts, but other insecticides such as fipronil, DDT degradates, and other pyrethroids may also contribute to degrading invertebrate populations in these streams (Table 1). In addition, fine sediment and warm water temperatures (Lemke et al. 2013; Cole 2014), or other pollutants, including copper, zinc, and lead, commonly found in urban streams at levels exceeding water quality criteria (Hobbs et al. 2015), also may contribute to the cumulative degradation in these streams.

Bifenthrin is highly toxic to aquatic invertebrates, affecting the central and peripheral nervous system by delaying the closure of the sodium ion channels leading to paralysis and death (Johnson et al. 2010). In addition, sub-lethal toxic effects of pyrethroids, such as reduced growth, altered behavior and endocrine/reproductive effects have also been documented that could affect

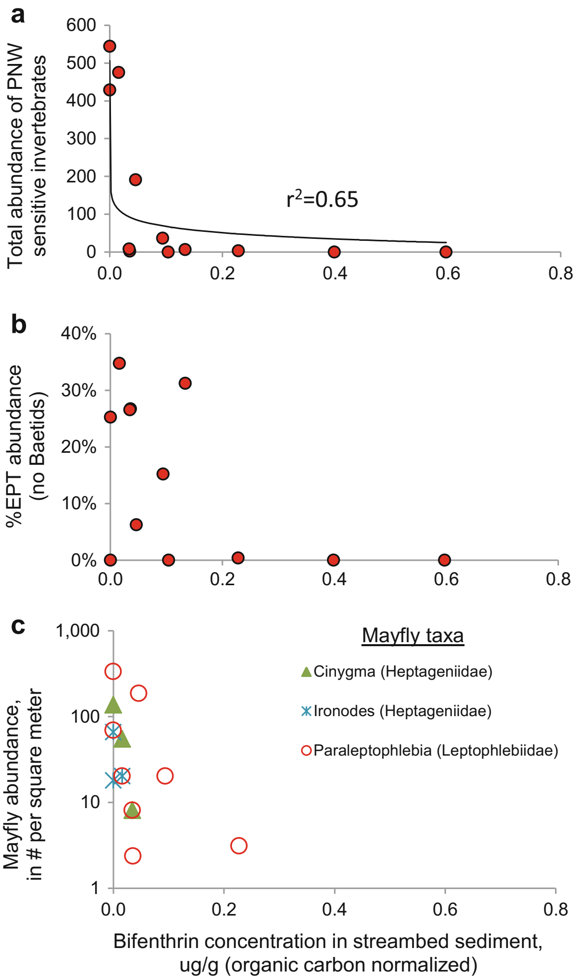

Fig. 7 Biplots of organic-carbon-normalized bifenthrin concentrations in streambed sediments and **a** abundance of sensitive invertebrate taxa, **b** percent EPT abundance (see text), and **c** abundance of select mayfly taxa. Includes only streams with comparable invertebrate data. Pacific Northwest [PNW] sensitive invertebrate scores based on tolerance values from Barbour et al. (1999)

survival, growth, or reproduction of benthic organisms (Werner and Moran 2008).

A national study of urban streams (Nowell et al. 2013; Moran et al. 2012) examined 108 contaminants in bed sediment and found bifenthrin to be the best single predictor of toxicity to the benthic invertebrates. A recent study by Weston et al. (2014) found that water-column bifenthrin concentrations in the 10–20 ng/L range were enough to impair normal movements in about one third of the dozen invertebrate taxa tested. In many studies, the predicted toxicity of bifenthrin in streambed sediments alone was enough to explain a large proportion of the observed toxicity in experimental tests using amphipods (Weston et al. 2005, 2009, 2011; Amweg et al. 2006; Hintzen et al. 2009). A later study found evidence that amphipod populations in some Californian streams have developed resistance and become desensitized to pyrethroids (Weston et al. 2013), which may explain prevalence of these organisms in some of the more impacted streams, including in this study.

Pyrethroids such as bifenthrin are also more toxic at lower water temperatures (Weston et al. 2011; Holmes et al. 2008). The relatively warm water temperatures that often plague urban streams may, ironically, reduce toxicity of pyrethroids to stream invertebrates; this presents challenges for water and land managers working to re-establish riparian vegetation and shading with the goal of reducing water temperatures.

The occurrence of high numbers of tolerant crustaceans, including isopods, amphipods, and decapods, in streams where bifenthrin and other persistent pesticides occur also raises the potential for these organisms, while tolerating moderate to high concentrations of pesticides in urban streams, to bioaccumulate and (or) transfer these contaminants into the food web. Bifenthrin has been found in tissue samples from amphibians (Smalling et al. 2013a, 2015), fish (Smalling et al. 2013b), crab embryos (Smalling et al. 2010), and brown trout (Bonwick et al. 1996) in other watersheds, but studies are needed to evaluate whether sensitive life stages of endangered salmonids are being affected. Recent research by Weston et al. (2014) in the American River, CA, found that while typical concentrations of bifenthrin and other pyrethroids were not directly toxic to steelhead, rainbow trout, or Chinook salmon, their invertebrate prey were affected, and they concluded that food-web effects are of greatest concern for these fish populations. More study is therefore needed to fully understand the effects of pyrethroids and other pesticides on aquatic life in these streams.

Potential effects of fipronil on invertebrates

Fipronil was also frequently detected in stormwater runoff, exceeding its chronic benchmark for invertebrates in nearly half of the creeks sampled. Repeated exposures to fipronil may also contribute to degraded invertebrate assemblages in some of these streams. Fipronil is a broad-spectrum insecticide that blocks gamma-aminobutyric acid (GABA)-gated chloride channels in the central nervous system of invertebrates, eventually causing paralysis and death (Jackson et al. 2009). Weston and Lydy (2014) proposed that the largest threat from fipronil to aquatic invertebrates is not solely by causing death directly but also by affecting their movement, swimming, and clinging behaviors, which are important for survival and reproduction.

Two fipronil degradates, fipronil sulfide and fipronil desulfinyl, were also detected—but only in outfall samples (Table 2). Fipronil degradates, especially fipronil sulfide, can be more toxic to aquatic invertebrates than the parent compound (U.S. EPA 1996; Weston and Lydy 2014), and while there are no existing aquatic-life benchmarks for these degradates, their presence and toxicity suggest that it would be worthwhile to include these degradates in future monitoring studies.

Basin characteristics as predictors of pesticide occurrence

Although none of the pesticide variables correlated with total percent urban or percent impervious area, the highest pesticide concentrations and (or) largest numbers of compounds detected occurred in Tanner and Lost Dog Creeks and their upstream outfalls, and in Sieben, Singer, and Carli Creeks, which all drain highly developed basins (52–96 % urban, Table 1). Tanner and Lost Dog Creek watersheds are generally steeper and have relatively high drainage densities—conditions that produce rapid runoff that transports pesticides to streams.

Housing density was not significantly correlated with any of the pesticide variables except total fungicide concentrations, which were positively correlated with high-density development ($p < 0.001$) and negatively correlated with low-density development ($p < 0.05$). Considering just the urban streams, bifenthrin, fipronil, and carbaryl concentrations in stormwater runoff were positively correlated ($p < 0.05$) with the percentage of developed open space, defined as "vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes" (Fry et al. 2011). This category also includes lawns associated with large-lot single-family houses, parks, golf courses, and cemeteries; impervious areas represent less than 20 %. This suggests that applications to grass turf and (or) landscaping in developed open spaces may be important sources of these insecticides.

Conclusions

This study was the first to examine a broad range of pyrethroid insecticides and other current-use pesticides in stormwater runoff and streambed sediments in urban streams in northwest Oregon. Numerous pesticides were detected in stormwater runoff and (or) streambed sediments, with two insecticides—fipronil and malathion—occurring at concentrations exceeding EPA acute benchmarks for aquatic invertebrates. Concentrations of bifenthrin exceeded the EPA 21-day chronic benchmark for invertebrates, though reported concentrations were instantaneous values that may overestimate potential toxicity if these elevated concentrations were short lived. Comparing bifenthrin and other insecticides to chronic benchmark values is conservative because benchmarks do not take into account the typical pattern of exposure to multiple pesticides. Applying these chronic benchmarks, 40 % of stream potentially exceeded two aquatic-life benchmarks or the DDT-plus-degradate water quality criterion simultaneously. The potential effects of DDT degradates on aquatic life have not been investigated in detail in this part of Oregon, but their frequent occurrence in stormwater and streambed sediments, combined with their relatively high toxicity, suggests that additional monitoring may be warranted in some of these basins.

Comparisons of pesticide occurrence and concentrations between outfalls and streams provided by the paired sampling design begin to shed light on the contributions from stormwater outfalls to streams during runoff periods, although only one storm event was sampled, and at a limited number of sites. Higher concentrations in the outfalls compared with streams suggest dilution downstream, whereas higher concentrations in streams compared with their paired outfall suggest additional sources upstream that were not sampled, including other outfalls and nonpoint sources.

Streams in the cities of Lake Oswego and West Linn generally had the highest concentrations of bifenthrin and fipronil. This is likely attributable to rapid transport of pesticide-laden runoff from application areas, a process facilitated by relatively steep slopes, high amounts of impervious surfaces, and relatively high drainage density. This, combined with the relatively long half-lives, allows these pesticides to reach streams prior to degradation.

The poor quality of the invertebrate assemblages in the MS4 streams in 2011 and 2013 (Lemke et al. 2013; Cole 2014) indicates a substantial degree of impairment, consistent with multiple stressors that likely include pesticides. Bifenthrin concentrations in streambed sediments were negatively correlated with several benthic invertebrate metrics that suggest impairment to both abundance and composition of sensitive types of invertebrates (e.g., EPT taxa) that are important prey for salmonids and other fish, birds, bats, and other animals. While the statistically significant correlations presented herein do not prove or demonstrate cause and effect, especially considering the small number of samples, they suggest that bifenthrin may have substantial effects. While the limited duration and scope of our study preclude reaching unequivocal conclusions about the effect of bifenthrin on invertebrates in these streams, our results contribute to a growing body of scientific research linking pyrethroid insecticides—bifenthrin in particular (Moran et al. 2012; Weston et al. 2014)—to toxic effects on stream invertebrates.

Given the strong tendency for pyrethroids to sorb strongly to sediments, analysis of dissolved compounds alone will not be effective at detecting these current-use pesticides except at very high concentrations. The SIFT devices were effective for sampling sediments in the outfalls, producing a 100 % detection rate for bifenthrin. Future monitoring of sediment-bound bifenthrin could examine sources of these hydrophobic insecticides in more detail; such knowledge could enhance existing stormwater management infrastructure and inform future development of Best Management Practices (BMPs) aimed at reducing pesticide occurrence in these and other urban streams in the USA and across the globe.

Because of the temperature dependence on the toxicity of pyrethroid insecticides—with greater toxicity at lower temperatures (Holmes et al. 2008; Weston et al. 2011)—it is important that laboratory studies evaluating toxicity to aquatic life be conducted at ambient stream temperatures to obtain real-world results. The organic carbon content and (or) the mineral/biological character of sediments (Weston et al. 2011) may also play an important role in the transport, bioavailability, and toxicity of bifenthrin and other pesticides to invertebrates. Deciphering these details could lead to a better understanding of how and where pyrethroids are most likely to be transported in urban watersheds, and the effects they may have on stream invertebrates at ambient temperatures.

Stormwater management is an ongoing endeavor in temperate urban areas. Despite strategies and regulations to reduce pollution during stormwater runoff, sediment and pollutants including pesticides continue to enter streams where they appear to have substantial effects on benthic invertebrates. Because these organisms are an important food resource for endangered fish and other wildlife, it is critical to better determine the full impact from these current-use insecticides on aquatic life so that mitigation solutions can be implemented.

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