FINAL

Summary of Published Science, Caltrans Monitoring Results, and Treatment Approaches Related to 6PPD-Q in Stormwater

CTSW-TM-24-425.20.01
Agreement No.: 43A0425 | Task Order 20

December 2024

California Department of Transportation
Office of Hydraulics and Stormwater Design
1120 N Street
Sacramento, California 95814
https://dot.ca.gov/programs/design/hydraulics-stormwater

Caltrans Technical Report Documentation Page

1.	Report No.:	CTSW-TM-24-425.20.01
2.	Type of Report:	Technical Memorandum
3.	Title and Subtitle:	Summary of Published Science, Caltrans Monitoring Results, and Treatment Approaches Related to 6PPD-Q in Stormwater
4.	Report Date:	December 2024
5.	Copyright Owner(s):	California Department of Transportation
6.	Caltrans Project Coordinator(s):	Charlow Arzadon
7.	Performing Organization Names and Addresses:	Brown and Caldwell 201 N. Civic Drive, Suite 300 Walnut Creek, CA 94596-3864
8.	Contract No.:	43A0425
9.	Task Order No.:	20
10.	Sponsoring Agency Name and Address:	California Department of Transportation Office of Hydraulics and Stormwater Design OHSD MS-28 1120 N Street Sacramento, CA 95814 https://dot.ca.gov/programs/design/hydraulics-stormwater
11.	Caltrans Functional Reviewer(s):	Sean Penders, Bhaskar Joshi, Charlow Arzadon, Alison Pommerenck
12.	Supplementary Notes:	
13.	External Reviewer(s):	
14.	Key Words:	6PPD-Q, 6PPD-Quininone, stormwater, toxicity
15.	Distribution Statement:	
16.	No. of pages:	74

17. Abstract: This technical memorandum provides an overview of scientific literature of 6PPD-Q sources, transport, treatability, toxicity, and related information needed to guide monitoring design and evaluate stormwater treatment design guidance updates.

Acknowledgements

The following individuals are acknowledged for their contributions in preparing the Summary of Published Science, Caltrans Monitoring Results, and Treatment Approaches Related to 6PPD Q in Stormwater.

Specifically, the project team recognizes the following personnel for their efforts:

- Sean Penders, Caltrans Office of Stormwater Hydraulics and Design (OHSD), Office Chief
- Charlow Arzadon, Caltrans OHSD
- Alison Pommerenck, Caltrans OHSD
- Bhaskar Joshi, Caltrans Office of Stormwater Program Development (OSWPD), Office Chief
- Benhur Batoon, Caltrans Division of Maintenance
- Gerardo Dominguez, Caltrans Office of Drainage and Stormwater Management, Office Chief
- Pete Riegelhuth, Caltrans District 5 Design Stormwater Coordinator / NPDES Coordinator
- Ken Murray, Caltrans Office of Standards and Procedures, Office Chief
- Shawna-Leigh Pampinella, Caltrans Division of Biological Studies, Office Chief

The project team members included:

- Khalil Phelan Abusaba, Brown and Caldwell (BC)
- Michael Flake, BC
- Wes Faubel, BC
- Erica Cruz, BC
- Christian Kocher, Kinnetic Environmental Incorporated (KEI)
- Steen Trump, KEI

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List of Abbreviations, Terms

AADT	annual average daily traffic
BMP	best management practice
Biostrip	biofiltration strip
Bioswale	biofiltration swale
CDA	contributing drainage area
CWA	Clean Water Act
DOC	dissolved organic carbon
DPP	design pollution prevention
DPPIA	design pollution prevention infiltration area
EDF	Evaluation Documentation Form
ESA	Endangered Species Act
hr	hour(s)
IQR	interquartile range
LC_{50}	legal concentration 50
LID	low-impact development
MEP	Maximum Extent Practicable
ng/L	nanograms per liter
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
OGFC	open graded friction course
PE	project engineer
Porter-Cologne	Porter-Cologne Water Quality Control Act
PPDG	Project Planning and Design Guide
Q	quinone
ROW	right-of-way
RWQCB	Regional Water Quality Control Board
SSC	suspended sediment concentration
SWRCB	State Water Resources Control Board
TBMP	(stormwater) treatment best management practice
TDC	targeted design constituent
TMDL	total maximum daily load
TOC	total organic carbon
TRWP	tire and road-wear particles
USC	United States Code
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
Washington	Washington State Ecology Department of Ecology
WDR	waste discharge requirements
WQAR	water quality assessment report

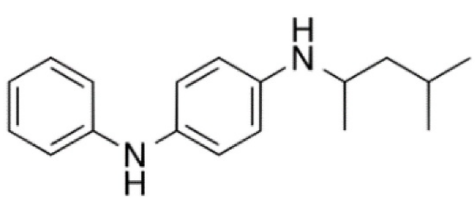
Executive Summary

The California Department of Transportation (Caltrans) has prepared this report to address a pollutant of emerging concern affecting the endangered coho salmon shown in Figure ES-1. When exposed to air, the rubber tire additive 6PPD reacts with ozone to create 6PPD-quinone (6PPD-Q). Figure ES-2 shows their chemical structures and formal names. Research published in 2021 pointed to 6PPD-Q as the cause of recurrent coho salmon mortality in lowland Puget Sound urban streams (Tian et al., 2021; 2022). This report will explore the linkage between tire rubber, roadways, and 6PPD-Q with focused attention in California and stormwater discharges from Caltrans' roads. The coho salmon's status as a culturally, commercially, and recreationally important fish species make addressing 6PPD-Q sources a high priority for Caltrans, regulatory and resource agencies, and the public.

Figure ES-1. Spawning-age coho salmon (*Oncorhynchus kisutch*)

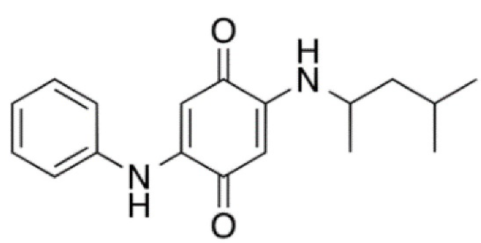
Public domain image courtesy https://www.usgs.gov/media/images/coho-salmon

Tire additive, 6PPD



N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD)

Reaction product of 6PPD with ozone, 6PPD-Q



N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine quinone (6PPD-Q)

Figure ES-2. Chemical structures for 6PPD and 6PPD-Q

Regulatory Setting

Caltrans implements Clean Water Act (CWA) and Endangered Species Act (ESA) mandates at the direction of the State Water Resources Control Board (SWRCB) and in consultation with the National Marine Fisheries Services (NMFS). Both agencies have expressed concerns to Caltrans about 6PPD-Q in stormwater. Caltrans has engaged both agencies in partnering meetings to hear concerns and share information. This report documents findings from a literature review of 6PPD-Q scientific publications, summarizes results of Caltrans stormwater monitoring for 6PPD-Q, and explains Caltrans' process for incorporating post-construction stormwater treatment best management practices (BMP) into Caltrans projects.

Problem Statement

Vehicles traveling on roadways generate tire and road-wear particles (TRWP) containing 6PPD and 6PPD-Q. The additive 6PPD rapidly degrades to 6PPD-Q. Stormwater carries TRWP and 6PPD-Q into receiving waters where, without adequate dilution, coho salmon can potentially encounter lethal 6PPD-Q levels. In the Seattle area where recurrent coho salmon mortality occurred, dilution of stormwater by non-roadway runoff appeared to be about 10-fold.

Literature review identified three thresholds for evaluating 6PPD-Q concentrations. They are:

- **1,000 nanograms per liter (ng/L)** – the level lethal to half of rainbow trout exposed (i.e., the rainbow trout LC_{50})
- **95 ng/L** – the coho salmon LC_{50}
- **11 ng/L** – the U.S. Environmental Protection Agency (USEPA) screening level to protect sensitive species. This screening level is not an enforceable guidance, nor is it an established numeric criterion for attainment of water quality standards.

None of the above thresholds is a water quality objective adopted by the SWRCB. Instead, the thresholds are useful for comparing against stormwater and receiving water monitoring results. The literature review showed that roadway runoff frequently exceeds the coho salmon LC_{50} (95 ng/L). In contrast, surface waters of 13 states surveyed by the U.S. Geological Survey during wet and dry weather were generally below the coho salmon LC_{50} (except for maximum values observed in Colorado and Washington). Median concentrations of this mixed wet and dry weather sampling data set were below the USEPA screening level (11 ng/L). The review identified studies showing that bioretention and porous pavement overlays are effective at reducing 6PPD-Q in stormwater.

Caltrans Monitoring and Treatment Best Management Practice (TBMP) Evaluations

Caltrans stormwater monitoring shows that 6PPD-Q increases with increasing traffic volumes. More than 200 6PPD-Q measurements at 18 sites across California were analyzed with average annual daily traffic (AADT) data provided by Caltrans. The results help estimate 6PPD-Q stormwater concentrations where monitoring results are not available (Table ES-1). This finding helps guide receiving water monitoring studies and facilitate Caltrans project development consultations with NMFS.

Caltrans-approved TBMPs effectively remove 6PPD-Q below the coho salmon LC_{50}. A media filter, a pilot test of porous asphalt overlays, and three Biofiltration Swales (bioswales) all showed effective removal below the coho salmon LC_{50} for 6PPD-Q (95 ng/L) for all storms monitored. One of the bioswales monitored discharged to a bioretention basin that infiltrated all stormwater received in the monitored storms; samples collected from upstream of the bioretention basin showed removal of 6PPD-Q to below 95 ng/L by stormwater transiting the bioswale. Two other bioswales monitored were 100 percent effective in that they infiltrated the entire volume of stormwater generated, so there was no outflow to sample. For comparison with Table ES-1, treated concentrations at all TBMPs monitored had a median 6PPD-Q concentration of 33 ng/L and a maximum of 81 ng/L.

Table ES-1. Median and Upper Limit of 6PPD-Q Concentrations (ng/L) in Stormwater from Caltrans Roadways Based on Annual Average Daily Traffic

Traffic Volume	AADT (vehicles/day)	Untreated Median (ng/L)	Untreated Upper Limit = 75th percentile + 1.5 X IQR (ng/L)
Low (n=37)	AADT < 1,000	3.5	21
Medium (n=85)	AADT = 1,000 to 10,000	100	260
High (n=55)	AADT > 10,000	400	830

Values rounded to 2 significant figures

AADT = Annual Average Daily Traffic

IQR = interquartile range (difference between the 75th percentile and the 25th percentile)

The 75th percentile + 1.5 x IQR is a commonly accepted definition of the threshold for upper outliers in a box and whiskers plot.

n = number of samples in each group

Caltrans Treatment BMP Program

Caltrans' process for incorporating post-construction stormwater treatment follows a disciplined approach to select appropriate TBMPs. The approach can be tailored to address 6PPD-Q as a targeted design constituent as sufficient data become available.

Findings

1. Caltrans operates within a well-defined regulatory program to implement CWA and ESA mandates at the direction of SWRCB and in consultation with NMFS.
2. Current scientific information about 6PPD-Q in stormwater shows that although 6PPD-Q frequently exceeds lethal levels in roadway runoff, surface water monitoring results are generally below lethal levels. In many cases, median surface water 6PPD-Q concentrations are below the EPA screening level (11 ng/L).
3. Caltrans' stormwater management program is monitoring stormwater runoff characterization and TBMP effectiveness for 6PPD-Q.
4. Caltrans TBMPs are effective at reducing 6PPD-Q below the 95 ng/L LC_{50} for coho salmon and infiltrate where possible to reduce stormwater discharge volumes.
5. The assessment of TBMP effectiveness is based on monitoring to date. Findings will be re-evaluated as effectiveness more data are generated.
6. The PPDG's T-1 checklist selection process incorporates TBMPs to MEP, in accordance with CWA.
7. Caltrans uses the natural environmental as a treatment area (NEAT) in the Lake Tahoe Basin as an effective stormwater runoff treatment to protect receiving water bodies.

Section 1

Introduction

This report describes actions by the California Department of Transportation (Caltrans) in response to new information on a pollutant of emerging concern affecting the endangered coho salmon (*Oncorhynchus kisutch,* Figure 1-1). When exposed to air, the rubber tire additive 6PPD reacts with ozone to create 6PPD-quinone (6PPD-Q). Figure 1-2 shows the chemical structures and formal names of 6PPD and 6PPD-Q. Research published in 2021 pointed to 6PPD-Q as the cause of recurrent coho salmon mortality in lowland Puget Sound urban streams (Tian et al., 2021; 2022). This report will explore the linkage between tire rubber, roadways, and 6PPD-Q with focused attention in California and stormwater discharges from Caltrans' roadways.

The coho salmon's status as a culturally, commercially, and recreationally important fish species make this a high priority for Caltrans, regulatory and resource agencies, and the public. According to the California Department of Fish and Wildlife[1], coho salmon in California fall into two populations with different listing statuses. The Central California Coast Evolutionarily Significant Unit (ESU) is listed as endangered, whereas the Southern Oregon / Northern California ESU is listed as threatened.

Figure 1-1. Spawning-age coho salmon

Public domain image courtesy https://www.usgs.gov/media/images/coho-salmon

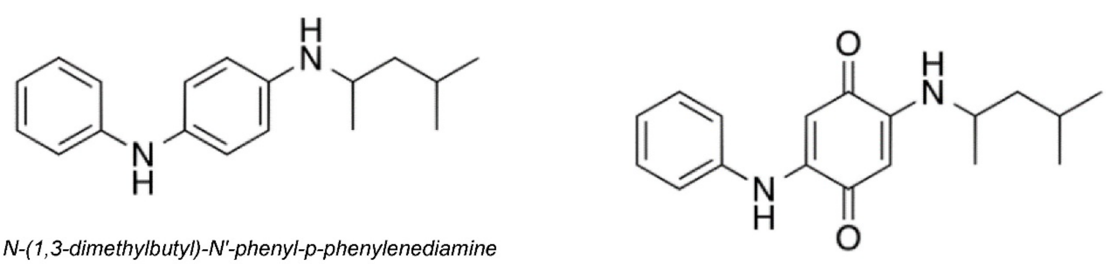
The National Marine Fisheries Service (NMFS) recognizes Caltrans' assignment of responsibilities as federal lead under the National Environmental Policy Act (NEPA). The Federal Highway Administration (FHWA) has assigned Caltrans the responsibility under 23 United States Code (USC) 327 and 23 USC 326. The Endangered Species Act (ESA) Section 7 requires federal agencies to consult with the appropriate ESA lead agency over actions that may affect threatened or endangered species. The purpose of this report is to provide a review of science related to 6PPD-Q and a summary of Caltrans stormwater management actions

[1] https://wildlife.ca.gov/Conservation/Fishes/Coho-Salmon

related to 6PPD-Q. This will assist with partnering discussions and consultations with NMFS and other regulatory agencies.

The report begins with an overview of the regulatory setting (Section 2). Section 3 presents a summary of relevant science of 6PPD-Q based on a scientific literature review. Relevant published science provides a basis for comparing Caltrans 6PPD-Q monitoring results to levels of concern. Monitoring data presented in Section 4 characterizes 6PPD-Q in stormwater across a range of California highways and demonstrates the effectiveness of approved Caltrans treatment best management practices (TBMPs). Section 5 describes Caltrans' process to include post-construction stormwater TBMPs. Findings and recommendations in Section 6 summarize potential next steps from a stormwater management perspective for Caltrans, partnering agencies, and the public to consider.

Tire additive, 6PPD | **Reaction product of 6PPD with ozone, 6PPD-Q**



N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD)

N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine quinone (6PPD-Q)

Figure 1-2. Chemical structures for 6PPD and 6PPD-Q

Section 2

Regulatory Setting

This section summarizes the regulations and agencies that require Caltrans to protect water quality and consider risks to endangered species. Caltrans' mission is to "provide a safe, and reliable transportation network that serves all people and respects the environment." Regulations establish a framework for Caltrans to respect the environment by monitoring pollutants of concern in stormwater discharges and by treating stormwater to reduce pollutants of concern to the maximum extent practicable (MEP).

Figure 2-1 shows the three primary regulatory/resource agencies that direct Caltrans to implement policies compliant with the 1972 Federal Clean Water Act (CWA) and the 1973 ESA:

- The U.S. Environmental Protection Agency (USEPA)
- The National Marine Fisheries Service (NMFS)
- The California State Water Resources Control Board (SWRCB) and affiliated Regional Water Quality Control Boards (RWQCB).

The sections below describe policies that affect Caltrans' approach to managing 6PPD-Q under two federal laws, the CWA, and the ESA, as shown in Figure 2-1. The State of California's Porter-Cologne Water Quality Control Act (Porter-Cologne) is described concurrently with SWRCB activities along with the CWA summary in Section 2.1.

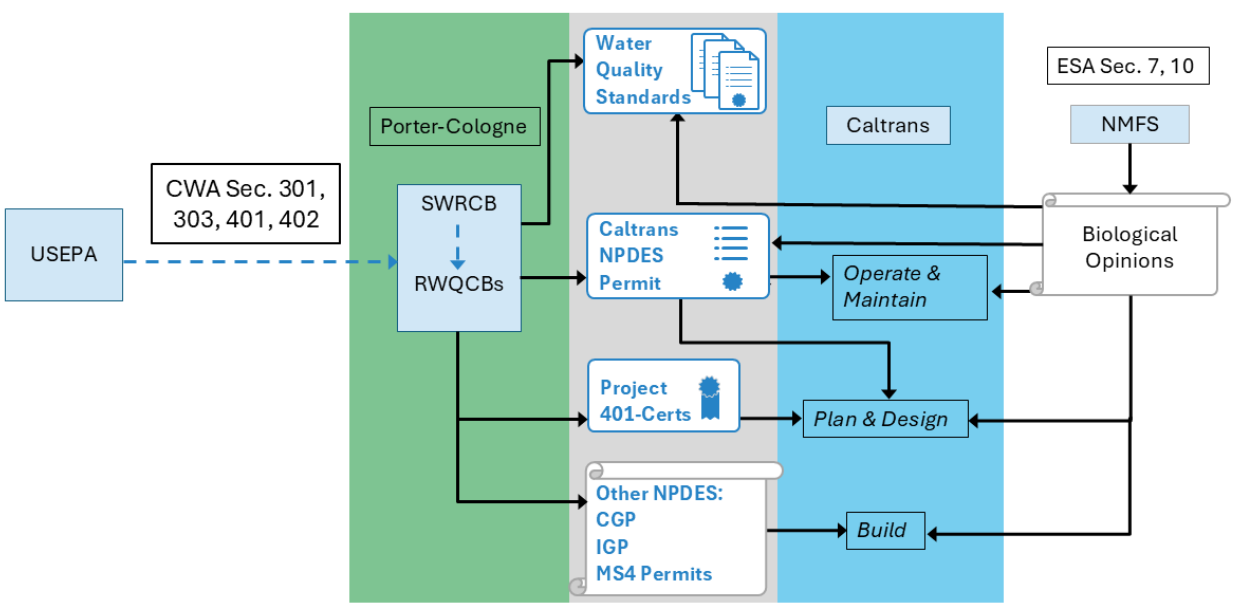


Figure 2-1. Regulatory setting requiring Caltrans to protect water quality and endangered species

CGP = Construction General Permit; IGP = Industrial General Permit; NPDES = National Pollutant Discharge Elimination System

Dashed lines indicate delegation of authority

2.1 Clean Water Act, Porter-Cologne, and the California Fish and Game Code

The CWA sets forth the laws that guide Caltrans' approach to managing stormwater. The USEPA delegates CWA authority to the SRWCB. Specific CWA programs are further delegated by SWRCB to the RWQCBs. Specific CWA sections relevant to 6PPD-Q in Caltrans stormwater discharges relate to stormwater permitting, water quality standards, and water quality certifications for proposed projects, as described below.

CWA Section 301 establishes the National Pollutant Discharge Elimination System (NPDES) and prohibits the discharge of pollutants into navigable water except in compliance with the CWA. The section provides SWRCB authority as a delegated agency to issue, administer, and enforce the *NPDES Statewide Stormwater Permit and Waste Discharge Requirements for State of California Department of Transportation* (Order 2022-0033-DWQ, aka Caltrans Permit). The Caltrans Permit requires stormwater monitoring as described in Section 4 and post-construction stormwater TBMPs as described in Section 5.

Porter-Cologne is a California law that authorizes the SWRCB and RWQCBs to issue Waste Discharge Requirement permits under state law, which is why the formal title of the Caltrans NPDES Permit includes state-issued waste discharge requirements (WDR) as defined in Porter-Cologne. Porter-Cologne enhances the SWRCBs' authorities, e.g., provisions 13267 and 13383 that authorize the SWRCB and RWQCBs to request monitoring information related to discharges. Porter-Cologne also names groundwater and wetlands as waters of the state, whereas CWA defines its regulatory jurisdiction as navigable waters of the United States.

California Fish and Game Code Section 1602 requires Caltrans (and any other person or public entity) to notify the California Department of Fish and Wildlife prior to beginning any activity that may:

- Divert or obstruct the natural flow of any river, stream, or lake.
- Change the bed, channel, or bank of any river, stream, or lake.
- Use material from any river, stream, or lake.
- Deposit or dispose of material into any river, stream, or lake.

Fish and Game Code Section 1610 allows emergency work to proceed, conditioned on notifying CDFW within 14 days of beginning work.

CWA Section 404 grants the United States Army Corps of Engineers (USACE) the authority to issue, deny or condition permits for projects that involve dredging and / or filling waters of the U.S. Application for a 404 permit can trigger a requirement for certification of water quality under CWA Section 401.

CWA Section 401 requires applicants for federal permits or licenses governing projects that may discharge pollutants into U.S. waters to obtain a state or interstate water quality certification. The 401-certification describes measures and conditions to provide reasonable assurance that the project will comply with all applicable water quality standards. Caltrans project 401-certifications are typically issued by the RWQCB with jurisdiction over the watershed containing the Caltrans construction project. RWQCB 401-certifications may include additional requirements ranging from no additional action required, to monitoring requirements accompanied by trigger levels with associated response actions, to individual project WDRs issued under Porter-Cologne.

CWA Section 303 describes the federal program of water quality standards. Sub-section 303(c) requires states to adopt water quality standards, including water quality criteria. Water quality standards under the CWA are comprised of designated uses of water and numeric or narrative water quality criteria indicating attainment of designated uses. States are required to adopt an anti-degradation policy as part of their water quality standards program. Relevant examples of designated uses, known as beneficial uses under Porter-Cologne, include cold water fisheries habitat, fish spawning, municipal water supply, and water contact recreation, to name a few. The concern over 6PPD-Q stems from its potential threat to cold water fisheries habitat and fish spawning.

There are no existing federal 6PPD-Q numeric water quality criteria ("water quality criteria" are named "water quality objectives" in Porter-Cologne). California has adopted a narrative objective for toxicity that states that "waters of the state shall be free from toxic substances in toxic amounts." The narrative water quality objective may be translated to numeric thresholds by the SWRCB using relevant scientific information.

CWA Section 304 defines the process to translate scientific data on pollutant toxicity into water quality criteria. Development of water quality criteria requires considerable amounts of toxicity data (Stephen et al., 1985). Data from at least eight taxonomic families of aquatic life plus one freshwater alga or vascular plant are required. According to the Washington State Department of Ecology (Washington Ecology, 2024), acceptable 6PPD-Q toxicity data from three of the required eight taxonomic families are currently available for purposes of establishing an acute water quality criterion in the State of Washington. According to USEPA, quantitative data representing four of the eight taxonomic families are available (United States Environmental Protection Agency, 2024). The difference between the Washington Ecology and USEPA approach is Washington Ecology excluded studies of zebrafish because it is not a resident in North America and does not serve as a surrogate for native North American aquatic species.

Porter-Cologne Section 13241 requires SWRCB to consider several factors when adopting water quality objectives (quoted as written):

- *Past, present, and probable future beneficial uses of water*
- *Environmental characteristics of the hydrographic unit under consideration, including the quality of water available thereto*
- *Water quality conditions that could reasonably be achieved through the coordinated control of all factors which affect water quality in the area*
- *Economic considerations*
- *The need for developing housing within the region*
- *The need to develop and use recycled water*

2.2 Caltrans Statewide Stormwater Management Plan

The Caltrans Statewide Stormwater Management Plan (SWMP) implements stormwater-related requirements of Porter-Cologne and the CWA (California Department of Transportation, 2024). Figure 2-2 illustrates the relationship between the Caltrans Permit, the SWMP, and Caltrans policies, manuals, and guidance.

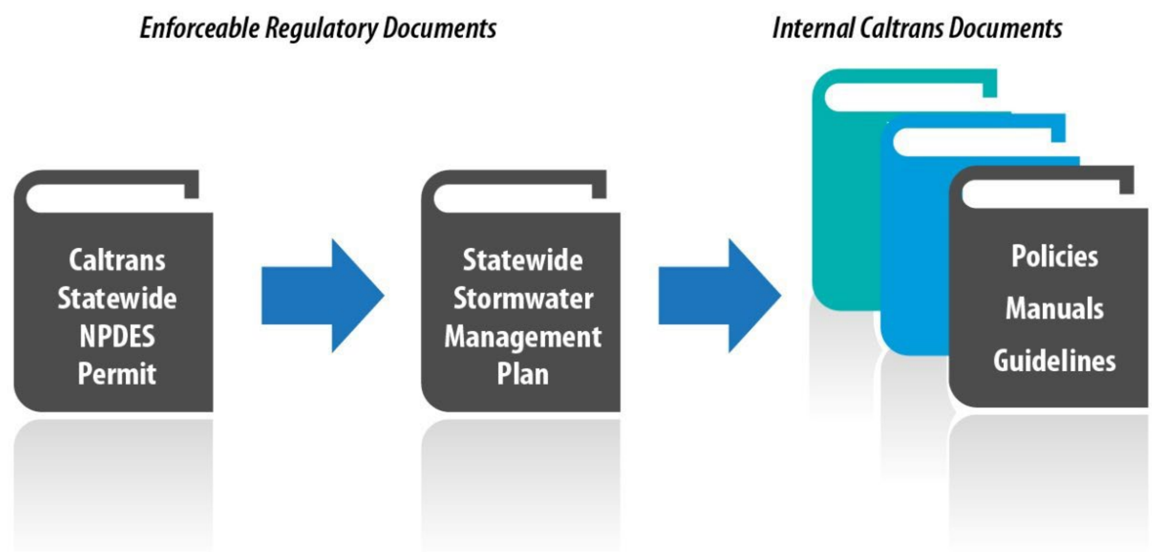


Figure 2-2. Relationship of Caltrans NPDES Permit, SWMP, and Caltrans Documents

From Figure 1-1 of the Caltrans SWMP

The Caltrans Permit establishes prohibitions, limitations, and requirements for Caltrans to demonstrate that stormwater discharges do not cause pollution. The SWMP provides a road map for compliance with the Caltrans Permit by describing stormwater pollution controls related to Caltrans activities, including planning, design, construction, maintenance, and operation of roadways and facilities, as well as monitoring to characterize pollutants of concern and effectiveness of treatment and other mitigation measures. The SWMP informs the content of Caltrans policies, manuals, and guidelines. Examples of key Caltrans manuals and guidance relevant to 6PPD-Q include:

- Stormwater Monitoring Guidance Manual
- BMP Pilot Study Guidance Manual
- Project Planning and Design Guide (PPDG)
- Maintenance Staff Guide

Findings in this report on 6PPD-Q characterization in stormwater and TBMP effectiveness at reducing 6PPD-Q come from monitoring programs implemented following the Stormwater Monitoring and TBMP Pilot Study Guidance Manual. Results from TBMP effectiveness evaluations inform selection of TBMPs to address pollutants of concern as documented in the PPDG. Implementation of TBMPs requires ongoing inspection and maintenance following procedures in the Maintenance Staff Guide.

2.3 Endangered Species Act

ESA Section 7 requires federal agencies to consult with NMFS when any action that the agency carries out, funds, or authorizes may affect either a species listed as threatened or endangered under the Act, or any critical habitat designated for listed species. As illustrated in the right-hand side of Figure 2-1, consultations provide NMFS standing to influence Caltrans requirements under the CWA. Biological opinions issued following agency consultations pursuant the ESA over adoption of water quality standards, total maximum daily loads (TMDLs), or NPDES permits have a federal nexus due to USEPA's ultimate approval authority over SWRCB actions.

Caltrans also consults directly with NMFS on projects and plans that may affect threatened or endangered species at the project level and programmatically. Caltrans is currently in programmatic consultation with NMFS with the goal of proposing conservation measures to address the potential for direct impacts on listed endangered coho salmon resulting from 6PPD-Q in stormwater.

In this consultation, Caltrans is the federal lead assigned by FHWA. Section 7(a)(1) of the ESA charges federal agencies with helping in the conservation of listed species, and section 7(a)(2) requires the agencies to ensure their activities are not likely to jeopardize the continued existence of federally listed species or destroy or adversely modify designated critical habitat. If NMFS determines via the Caltrans Regional Programmatic consultation that actions may jeopardize threatened or endangered species, the Regional Programmatic Biological Opinion would likely include reasonable and prudent alternatives to avoid jeopardy.

In summary, Caltrans operates within a well-defined regulatory program to implement CWA and ESA mandates at the direction of SWRCB and in consultation with NMFS. The USACE and CDFW also have regulatory authority over Caltrans projects. The USACE permitting authority under Section 404 may trigger Section 401 water quality certifications, and also creates a federal nexus for Section 7 consultations with NMFS.

The United States Fish and Wildlife Services (USFWS) also conducts Section 7 consultations over threatened and endangered species. For the purposes of 6PPD-Q management, NMFS is the most prominent lead agency because of the sensitivity of coho salmon. CDFW also has an interest in protecting coho salmon. To date, CDFW has elected to let NMFS take lead in discussions with Caltrans over 6PPD-Q management.

Federal Register (FR) Volume 66 Number 36 (February 22, 2001) documents the Memorandum of Agreement memorialized in the federal register that was written to streamline the development of water quality standards in compliance with the Endangered Species Act. Therefore, the current water quality standards are protective of endangered species.

2.4 National Environmental Policy Act and California Environmental Quality Act (NEPA/CEQA)

Title I of NEPA contains a Declaration of Environmental Policy that "requires the federal government to use all practicable means to create and maintain conditions under which man (sic) and nature can exist in productive harmony." (*National Environmental Policy Act,* 1970). Section 102 of NEPA requires that federal agencies may conduct a systematic interdisciplinary approach to incorporate environmental considerations in planning and decision-making. The NEPA requirements extend to Caltrans. The California Environmental Quality Act (CEQA) requires similar environmental review by Caltrans as a state agency (*California Environmental Quality Act,* 1970).

Caltrans performs NEPA/CEQA review as lead agency on Caltrans projects that have potential to impact the environment. The purpose of reviews is to document potential impacts and, if needed, mitigation measures to reduce impacts to less than significant. Where significant impacts are unavoidable NEPA/CEQA review must document the overriding need for the project or action.

Highway maintenance is considered an activity that causes less than significant impacts, according to Section 15300 of the California Environmental Quality Act (CEQA) guidelines (*California Environmental Quality Act,* 1970). Maintenance activities exempt under CEQA consist of the operation, repair, maintenance, permitting, leasing, licensing, or minor alteration of existing public or private structures, facilities, mechanical equipment, or topographical features, involving negligible or no expansion of use beyond that existing at the time of the lead agency's determination.

The key consideration for exemption is whether the project involves negligible or no expansion of an existing use. Examples include but are not limited to existing highways and streets, sidewalks, gutters, bicycle and pedestrian trails, and similar facilities. This includes road grading for the purpose of public safety. The maintenance exemption is critical to Caltrans' discussion with NMFS over project permitting because environmental review of the multitude of small maintenance projects executed by Caltrans would be infeasible for Caltrans or reviewing agencies from the standpoint of time and staff resources.

2.5 Summary of Regulatory Setting

Table 2-1 summarizes the applicable regulations and implementing authorities described herein.

Table 2-1. Summary of Applicable Regulations and Implementing Authorities

Regulation	Scope	Implementing Authority
CWA Section 301	Discharge permits	USEPA, SWRCB
Porter-Cologne	Water quality protection in waters of the State of California	SWRCB, RWQCB
Fish and Game Code Section 1602	Lake or streambed alteration agreements (LSAs)	CDFW
CWA Section 404	Permits to dredge and / or fill waters of the U.S.	USACE
CWA Section 401	State-issued water quality certifications	SWRCB, RWQCB
CWA Section 303	Water quality standards	USEPA, SWRCB
CWA Section 304	Adoption of numeric criteria for toxic pollutants	USEPA
ESA Section 7	Consultations to protect endangered species	NMFS, USFWS
FR Vol 66 No 36	Water quality standards protect endangered species	SWRCB, USEPA
NEPA / CEQA	Incorporate environmental considerations in planning	Caltrans

Note: The SWRCB as an implementing authority includes the delegated authorities of the RWQCBs.

Section 3

Relevant Science of 6PPD-Q

This section summarizes current knowledge from a literature review of 6PPD-Q sources; impacts and levels of concern; concentrations of 6PPD-Q in stormwater and surface waters compared to levels of concern; fate and transport; and treatability with stormwater TBMPs.

3.1 Sources of 6PPD-Q

Tire and road-wear particles (TRWP) generate 6PPD-Q in stormwater (Tian et al., 2021). TRWP particles range in size up to 350 microns, as shown on Figure 3-1. For comparison, a single grain of sand is 63 microns, and a single silt particle is 4 to 10 microns. Rubber tires contain 6PPD and other related phenyl-phenylene-diamine (PPD) compounds that protect rubber from premature aging and cracking due to oxidation by ozone (J. Xu et al., 2022). The protective effect of these antioxidants enhances driving safety. The antioxidants move freely within the rubber matrix, and so migrate to the outer surface of rubber tires (and tire particles) to replenish antioxidants as they are consumed by oxidation. Stormwater transports TRWP and associated 6PPD, 6PPD-Q, and other anti-oxidants and reaction products into receiving waters (Nicomel and Li, 2023).

Figure 3-1. TRWP generation from tire friction on pavement

Image generated by artificial intelligence

Caltrans faces a new stormwater challenge with 6PPD-Q. Unlike many other pollutants of concern, 6PPD-Q is predominantly a roadway-generated pollutant, by virtue of the sheer numbers of tires in use. Most of the early 6PPD-Q stormwater research has focused on high traffic volume roadways (Tian et al., 2022; H.-Y. Zhang et al., 2023). Caltrans monitoring data presented herein provides a more complete picture of the relationship between 6PPD-Q in stormwater and annual average daily traffic (AADT, in vehicles per day) and other traffic metrics.

Source control, where feasible, generally yields more effective solutions compared to treating stormwater to remove pollutants. Product replacement lessons learned from leaded gasoline (Needleman, 2000) and the copper brake pad partnership (Gautier di Confiengo and Faga, 2022) suggest that removing 6PPD from rubber tires may be an important long-term solution for 6PPD-Q. In March 2024, the U.S. Tire Manufacturers Association released an alternatives analysis report for compounds that can replace 6PPD in tires while maintaining the protective properties needed for safe driving (Gradient, 2024).

The California Department of Toxics Substances Control (DTSC) requires the alternatives analysis work of the consortium via the safter Consumer Products program (DTSC, 2024). On October 1, 2023, DTSC finalized a regulation to list 6PPD as a new Priority Product. This action required manufacturers using 6PPD to submit an alternatives analysis by March 29, 2024. The above-cited alternatives analysis report by the U.S. Tire Manufacturers Association was submitted in response to that DTSC requirement. The report also identified seven potential alternatives to 6PPD. Four alternatives are PPD compounds, three are not PPDs.

Final alternatives analysis reports are expected by August 2026. Source control by product replacement would take additional time to implement if suitable alternatives are identified. The time to replace the entire U.S. inventory of tires in use and available for replacement is also likely a matter of years. Therefore, monitoring and management strategies for 6PPD-Q will be needed for the foreseeable future.

3.2 Aquatic Life Impacts of 6PPD-Q and Thresholds of Concern

Toxicity testing identifies levels of concern for emerging pollutants of concern such as 6PPD-Q that lack numeric water quality objectives. Since the new public awareness as of 2021 that 6PPD-Q causes coho salmon fish kills, academic and government researchers have tested numerous fish species for 6PPD-Q toxicity. The literature review supporting this report (Caltrans, 2024) includes peer-reviewed publications on 6PPD-Q toxicity studies of aquatic organisms. Table 3-1 summarizes lethal concentrations from 18 studies. The concentration of 6PPD-Q lethal to half of the adult coho salmon exposed (the LC_{50}) is 95 nanograms per liter (ng/L). In contrast, the rainbow trout LC_{50} for 6PPD-Q is 1,000 ng/L, 10-fold higher compared to the coho LC_{50}. Figure 3-2 shows examples of both fish species.

Coho salmon LC_{50} = 95 ng/L
Public domain image from https://www.fws.gov/media

Rainbow trout LC_{50} = 1,000ng/L
Public domain image from https://www.usgs.gov/media

Figure 3-2. Coho salmon and rainbow trout, salmonid species with very different 6PPD-Q sensitivities

As noted in the regulatory setting described previously in Section 2.1, toxicity studies inform water quality standards. Although the USEPA has not yet established enforceable numeric water quality criteria for 6PPD-Q, the agency has released non-regulatory screening-level guidance (USEPA, 2024). The USEPA-proposed screening value is 11 ng/L for 1 hour (hr) exposure duration, not to be exceeded more frequently than once every three years.

Washington Ecology updated water quality criteria in 2024, including a new acute exposure (1-hr duration) criterion of 12 ng/L for 6PPD-Q (Washington Ecology, 2024). The Washington Ecology criterion does not specify a maximum exceedance frequency. The new criteria would become effective for CWA purposes upon EPA approval at a date not yet determined. Washington Ecology based the criterion on the screening-level approach that USEPA adopted in its 2024 water quality criteria screening-level guidance. Table 3-1 summarizes key toxicity studies that Washington Ecology used to adopt a 6PPD-Q criterion.

Toxicology research on 6PPD-Q continues, so Table 3-1 is an incomplete list of current toxicity data. Ongoing research includes evaluation of other species and different species life stages. Chronic effects are not well characterized yet, and difficult to study because 6PPD-Q decomposes rapidly in the environment. The shaded rows in Table 3-1 showing lethal concentrations to rainbow trout / steelhead salmon (the same species), coho salmon, and the EPA screening guideline span three orders of magnitude of environmentally relevant concentrations and so are sufficient to make the points of this report.

Table 3-1. Lethal Concentrations of 6PPD-Q to Aquatic Organisms

Fish Species	LC_{50} (ng/L)	Time (hr)	Citations
All – USEPA Screening Guideline = 11 ng/L[a]	N/A	1 hr	USEPA (2024)
Oncorhynchus kisutch (juvenile coho salmon)	41	24	Lo et al. (2023)
Oncorhynchus kisutch (adult coho salmon)[a]	95	24	Tian et al. (2022)
Oncorhynchus kisutch (coho salmon)	80	24	Greer et al. (2023)
Salvelinus fontinalis (brook trout fry)	200	24	Philibert et al. (2024)
Salvelinus fontinalis (brook trout fingerlings)	500	24	Philibert et al. (2024)
Salvelinus namaycush (lake trout)	500	96	Roberts et al. (2024)
Salvelinus leucomaenis Pluvius (spotted char)	510	24	Hiki and Yamamoto (2022)
Salvelinus fontinalis (brook trout)	590	24	Brinkmann et al. (2022)
Oncorhynchus mykiss (rainbow trout)[a]	1,000	72	Brinkmann et al. (2022)
Oncorhynchus mykiss (rainbow trout / steelhead salmon)	2,260	96	Di et al. (2022)
Pimephales promelas (adult fathead minnows)	>9400[b]	96	Anderson-Bain et al. (2023)
Salvelinus curilus (Southern Asian dolly varden)	>10,000[b]	24	Hiki and Yamamoto (2022)
Oncorhynchus masou masou (masu salmon)	>10,000[b]	24	Hiki and Yamamoto (2022)
Salvelinus alpinus (artic char)	>12,700[b]	24	Brinkmann et al. (2022)
Acipenser transmontanus (white sturgeon)	>12,700[b]	24	Brinkmann et al. (2022)
Pimephales promelas (fathead minnow embryo)	>39,970[b]	168	Anderson-Bain et al. (2023)
Oncorhynchus tshawytscha (chinook salmon)	>80,000[b]	24	Greer et al. (2023)

a. *Shaded cells indicate levels used for comparison to water concentrations in this report.*

b. *Value is greater than the highest concentration tested.*

The normal procedure to develop aquatic life criteria for toxic substances following USEPA guidelines (Stephen et al.,1985) involves gathering data from peer-reviewed toxicology studies that represent at least eight taxonomic families. Washington Ecology lacked complete data that supported the eight-family procedure and so relied on alternative procedures. The alternative procedures are enabled by coho salmon's extreme sensitivity to 6PPD-Q relative to other species, as well as its commercial and cultural importance. USEPA criteria development guidance (Stephen et al., 1985) notes under Part IV.A that:

> "...if the Species Mean Acute Value of a commercially or recreationally important species is lower than the calculated Final Acute Value, then that Species Mean Acute Value replaces the calculated Final Acute Value in order to provide protection for that important species."

In essence, results from the eight-species approach can be trumped by a sensitive commercially or recreationally important species. Washington Ecology's approach was premised on findings that coho salmon are commercially and recreationally important, and that coho salmon represent the most sensitive commercially and recreationally important species.

The Washington Ecology criteria evaluation focused on establishing a criterion that was below threshold effect levels. After evaluating and rejecting two other alternative approaches, Washington Ecology concluded that USEPA's screening-level approach provided protective levels for coho salmon. Washington Ecology removed one data source for a species of zebrafish not found in North America and included more recent data sources to arrive at the 12 ng/L acute criterion, which is comparable to the USEPA-established 11 ng/L screening level.

3.3 Stormwater and Surface Water Concentrations of 6PPD-Q

Stormwater monitoring identifies source areas and potential areas of risk for sensitive species. Surface water monitoring provides more direct information about exposure of aquatic organisms to 6PPD-Q. Stormwater and surface water concentrations are linked by stormwater transportation, 6PPD-Q attenuation during transport, and dilution in receiving surface waters. This section summarizes stormwater and surface water 6PPD-Q concentrations from peer-reviewed science articles and compares them to three levels of concern identified in Section 3.2.

Recent science literature on stormwater monitoring understandably focuses on heavily urbanized areas. Studies conducted in the Pearl River Delta Region of China, and in urbanized areas of Seattle and Los Angeles showed concentrations in roadway runoff that generally exceeded the 95 ng/L lethal level for coho salmon, as shown on Figure 3-3. Median stormwater concentrations were generally below lethal levels for rainbow trout (1,000 ng/L), though maximum values exceeded this level in some instances.

Studies from the Pearl River Delta region provide examples of stormwater from source areas that were not transportation corridors. The courtyard samples on Figure 3-3 represent paved courtyards in high-density apartment block residential areas, and therefore indirect 6PPD-Q sources from wind and lower-density vehicle traffic. The farm runoff samples represent open spaces with very low roadway density.

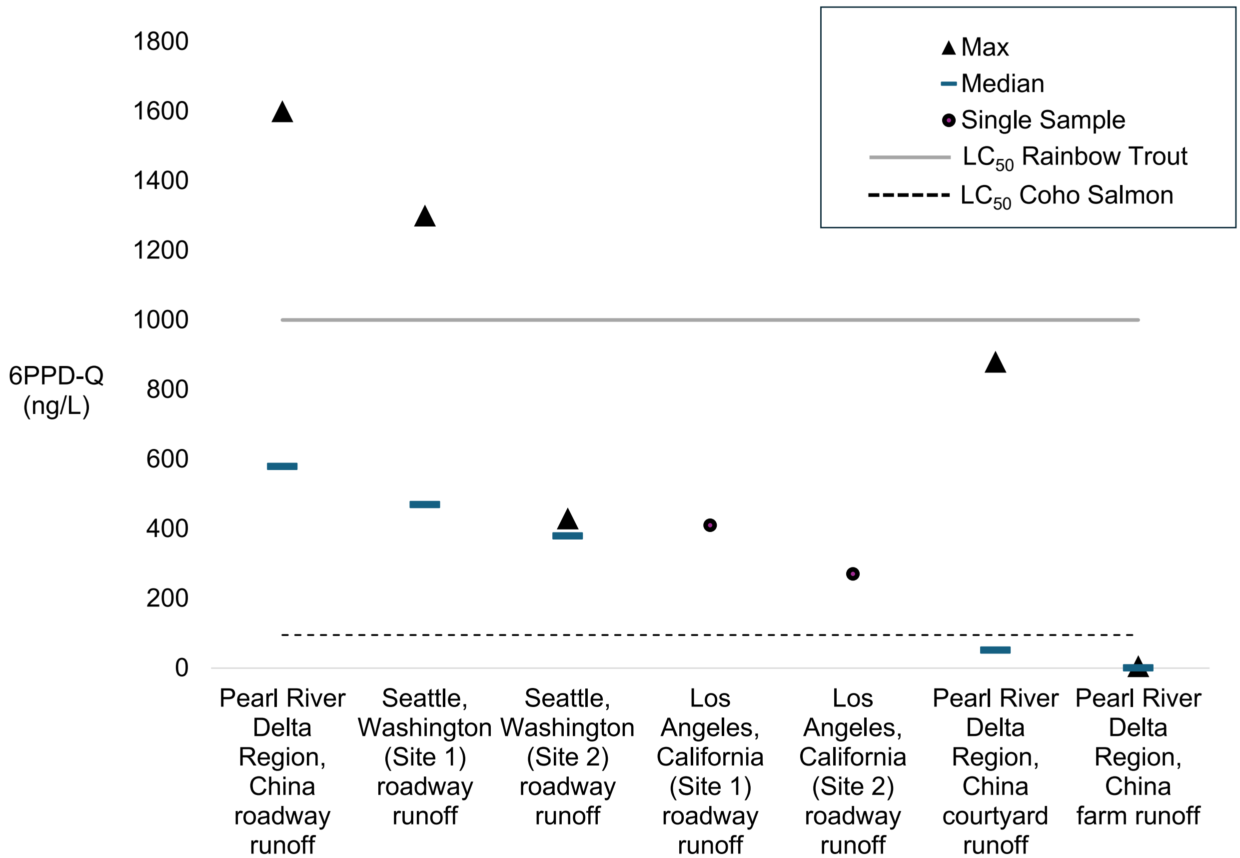


Figure 3-3. Stormwater concentrations of 6PPD-Q from urban areas

Data Sources: Pearl River Delta (R. Zhang et al., 2023); Seattle and Los Angeles (Tian et al., 2022)

Organisms are generally exposed to 6PPD-Q in surface waters, not stormwater discharges. Reported surface water concentrations near urban areas are generally lower compared to stormwater concentrations because of dilution from non-roadway areas. In the San Francisco Bay Area, five out of nine urban drainages assessed by Tian et al., (2022, 2022) were non-detect, two were below 95 ng/L levels lethal to coho salmon, and two exceeded 95 ng/L, as shown on Figure 3-4. The Bay Area urban drainages sampled are described by Tian et al. (2022) as "runoff-affected" receiving waters, most of which are lined channels.

The two Bay Area drainages with the highest 6PPD-Q concentrations, Rodeo Creek (233 ng/L) and Elmhurst Creek (173 ng/L), are predominantly urban stormwater as noted in Figure 3-4. Rodeo Creek at the location sampled receives direct discharges from State Route 4. Elmhurst Creek is surrounded by dense urban and roadway areas and is entirely underground and/or channelized.

Examining details from the original Seattle area studies (Tian et al., 2021; 2022) provides insight into evaluating 6PPD-Q risks from stormwater to receiving water organisms. The ratios of median Seattle area stormwater sources (370 and 380 ng/L) to the median receiving water concentration (35 ng/L) range from 11 to 13, i.e., an 11-fold to 13-fold dilution. In California, streams where roadway stormwater discharges may be diluted in receiving waters by less than 20-fold (i.e., 5% roadway density) to 50-fold (i.e., 2% roadway density) could potentially be at risk for 6PPD-Q effects on sensitive species, because California highways with moderate to high traffic typically have 100 to 400 ng/L 6PPD-Q in stormwater discharges (as shown in Section 4). These dilution examples assume the management endpoint is maintaining 6PPD-Q concentrations about 10-fold lower than the coho salmon LC_{50} (95 ng/L), i.e., in the range of the 11 ng/L EPA screening guidance. This understanding, combined with knowledge of how 6PPD-Q varies with traffic volumes, can help prioritize monitoring and intervention.

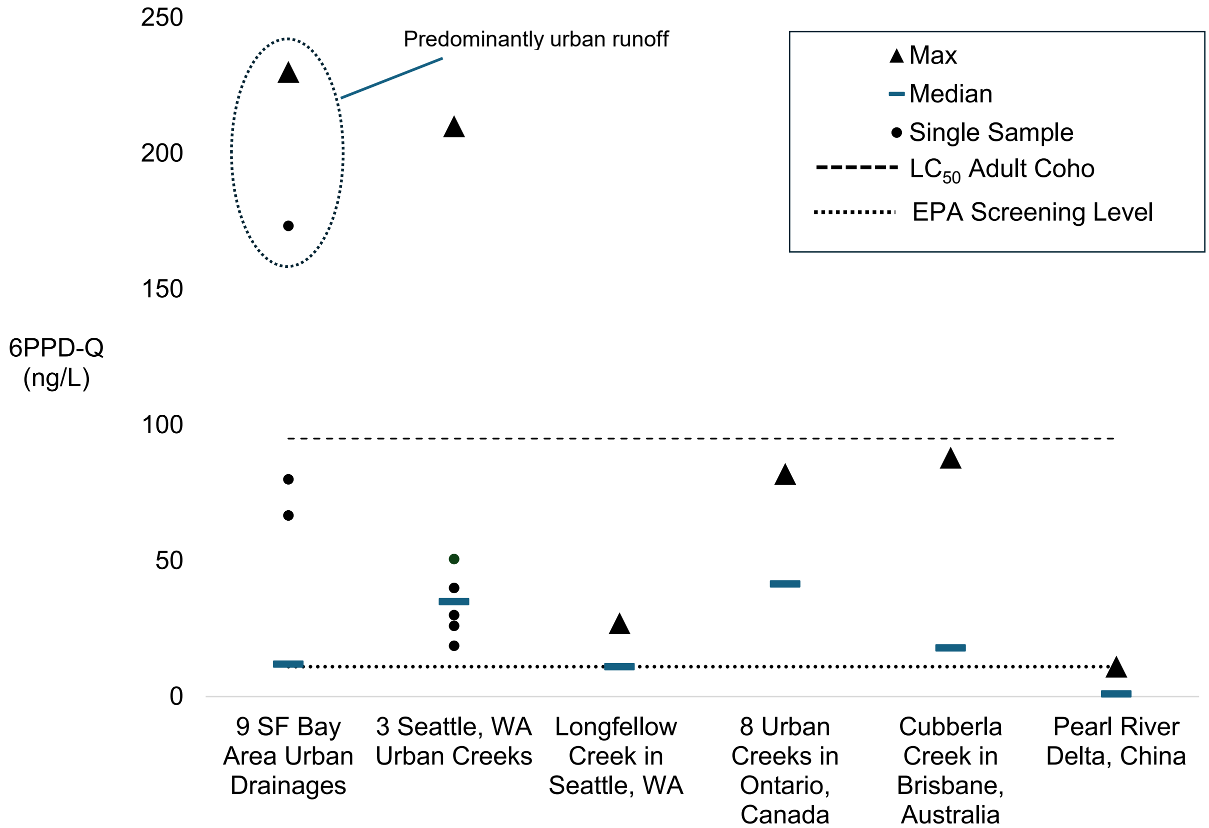


Figure 3-4. Surface water concentrations of 6PPD-Q near urban areas

Data Sources: San Francisco Bay Area and Seattle (Tian et al., 2022); Longfellow Creek (Halama et al., 2024); Ontario, Canada (Helm et al,. 2024); Brisbane, Australia (Rauert et al., 2022); Pearl River Delta, China (R. Zhang et al., 2023)

A recent survey (Lane et al., 2024) of surface waters in 13 states conducted by the United States Geological Survey (USGS) affirms the importance of receiving water concentrations to assessing ecological risks. Surface water concentrations from a mix of wet and dry weather sampling in these 13 states are shown on Figure 3-5. The states with the highest maximum 6PPD-Q concentrations in Figure 3-5 were the ones sampling storm events. This underscores that 6PPD- risk is primarily a wet weather problem because it degrades, and therefore does not persist in surface waters through the dry season.

Median surface water 6PPD-Q concentrations in all states surveyed were below the USEPA 11 ng/L screening guideline. In 12 of 13 states surveyed, 75 percent of samples collected were below 11 ng/L. Maximum concentrations exceeded the 11 ng/L screening guideline in six states, and in two states (Colorado and Washington) maximum surface concentrations exceeded the 95 ng/L lethal level for coho salmon.

These findings potentially explain why recurrent urban runoff mortality due to 6PPD-Q has heretofore only been documented in the unique setting of the Seattle area and Puget Sound, where roadway stormwater runoff enters receiving waters with apparently low dilution and inhabited by coho salmon, a large sensitive species whose mortality is easily observed. Note that concentrations observed in midwestern, and east coast surface waters may not necessarily predict conditions in west coast streams, where AADT in surrounding roadways can be higher in urbanized areas.

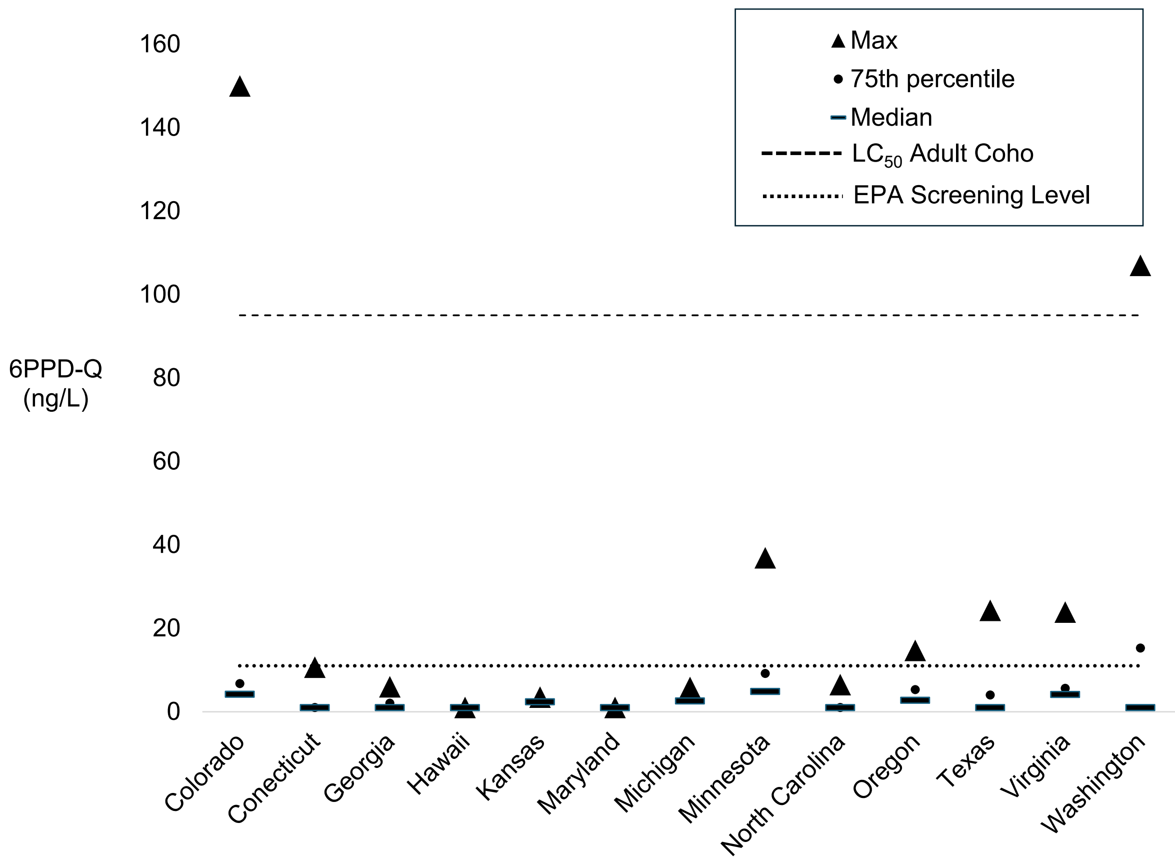


Figure 3-5. Surface water concentrations of 6PPD-Q in 13 U.S. states

Figure prepared using public data release from Lane et al. (2024), downloaded from: https://www.usgs.gov/index.php/data/concentrations-6ppd-and-6ppd-quinone-a-united-states-reconnaissance-stormwater-surface-water#:~:text=Data%20Releases.%20Concentrations%20of%206PPD%20and, last accessed 9/9/2024

Table 3-2 shows how the sampling approach varied by state. In some states many sites were sampled (spatial replication), in some states one site was sampled many times (temporal replication). Temporal replicates were collected in all states but Kansas. The report does not include traffic volume information. The sites sampled generally represented urban/suburban areas. Not all states targeted wet weather for sampling.

California's SWRCB included 6PPD-Q measurement as part of a pilot monitoring project for emerging contaminants conducted across the state. During the dry weather conditions of Spring 2023, water samples were collected from 18 sites and analyzed using semi-quantitative non-target methods. The results showed that all but one sample were non-detects. However, the detected sample could not be quantified. The study also included the collection and analysis of sediment samples. Out of the 18 sites, 6PPD-Q was detected in sediment at two locations, with concentrations of 6.38 ng/L and 2.29 ng/L. It is important to note that the study did not specifically target areas where 6PPD-Q was expected to be present, as it was designed to assess a broad range of constituents of emerging concern. (M. Romano De Orte, SWRCB, personal communication of 12/13/2024). Thus, California streams monitored once in the dry season achieved the 11 ng/L screening level, as in other states. Wet weather data downstream of highway stormwater discharges in California surface waters inhabited by coho salmon remains a substantial data gap.

Table 3-2. Summary of Sampling Approach by State for USGS Surface Water Sampling

State	# Locations	# Samples	Spatial replicates?	Temporal replicates?
Colorado	16	38	Yes	Yes
Connecticut	1	23	No	Yes
Georgia	1	16	No	Yes
Hawaii	16	26	Yes	Yes
Kansas	1	5	Yes	No
Maryland	1	6	No	Yes
Michigan	1	9	No	Yes
Minnesota	1	21	No	Yes
North Carolina	1	17	No	Yes
Oregon	4	25	Yes	Yes
Texas	9	71	Yes	Yes
Virginia	1	14	No	Yes
Washington	10	94	Yes	Yes
Totals	72	365		

Summary statistics for public data release from Lane et al. (2024)

3.4 Transport and Transformation of 6PPD-Q

Four key concepts of 6PPD-Q transport and transformation discussed in this section help understand treatability and risks to aquatic life. They are:

- The role of particle size and aging
- 6PPD and 6PPD-Q degradation rates
- Microbial transformations
- Partitioning between solid (particulate) and liquid (dissolved) states

3.4.1 The role of particle size and aging

Particle size directly affects the release of rubber additives and transformation products from TRWP. Smaller particle sizes (<100 microns) release additives and transformation products three to five times faster compared to particles larger than 710 microns (T. Zhang et al., 2024). This is because the ratio of particle surface to particle mass increases as particle size decreases, and constituent release occurs at the surface-water interface. Ultraviolet irradiation (i.e., artificial sunlight) accelerates release of tire additives (T. Zhang et al., 2024).

Artificial sunlight simulating six months' exposure caused TRWP to lose about 40 percent of its mass, presumably caused by losing surface mineral incrustations (Weyrauch et al., 2023). The study by Weyrauch et al., (2023) also showed that the parent compound 6PPD decreased by 93 to 98 percent under artificial sunlight, while the transformation product 6PPD-Q only increased by about 1 percent. The study findings indicate that transformation of 6PPD and other additives is a continuous process occurring during aging and leaching of TRWP.

3.4.2 6PPD and 6PPD-Q Degradation Rates in Water

Once TRWP are mobilized, degradation rates become an important factor affecting 6PPD-Q concentrations in stormwater and surface waters. The design function of 6PPD is to persist stably in the rubber matrix of a tire until it reacts with ozone. After 6PPD leaves the rubber tire matrix, it degrades more rapidly than 6PPD-Q, as suggested by roughly equal concentrations of 6PPD and 6PPD-Q in road dust (Y. Zhang et al., 2024) compared to non-detect 6PPD where 6PPD-Q was detected in surface waters (Lane et al., 2024).

The degradation rate of 6PPD-Q in water, although slower than 6PPD, is still relatively fast when exposed to sunlight. For example, the 6PPD degradation half time, i.e., the time it takes for half of the starting 6PPD concentration to degrade, was about 49 minutes under natural conditions (Yan et al., 2024). The 6PPD degraded in water to five transformation products but yielded no detectable 6PPD-Q. This led the authors to challenge the prevailing concept that natural aquatic-based attenuation of 6PPD generates 6PPD-Q. In that same study, loss of 6PPD-Q by bacterial activity, adsorption, and abiotic degradation were found to be minimal in the absence of sunlight. Dissipation of 6PPD-Q was mainly achieved by photodegradation under the study conditions. With sunlight irradiation, the 6PPD-Q degraded with a half time of 2.6 hours. For comparison, the 6PPD-Q degradation half-time in natural river water was found to be 13-16 days (Di et al., 2022).

A 1979 study of 6PPD degradation, reported by the Oslo and Paris Commission (OSPAR Commission) in 2006, showed a 6PPD degradation half-time of less than 1 day in water (OSPAR Commission, 2006). A follow-up 1981 study cited in the OSPAR Commission report determined a 6PPD degradation rate of 3 to 9 hours in water.

In summary, formation of 6PPD-Q from 6PPD and subsequent 6PPD-Q degradation affect 6PPD-Q concentrations in receiving waters. Formation and degradation pathways and rates can vary according to site-specific conditions.

3.4.3 Microbial transformations

Bacteria can both degrade 6PPD-Q and create it by degrading 6PPD. Bacterial degradation of 6PPD-Q is the reason stormwater samples must be preserved on ice with no headspace (Lane et al., 2024). In flooded wetlands, biodegradation was found to be the predominant loss pathway for 6PPD-Q in soils, but low-oxygen conditions caused a nearly four-fold increase of 6PPD-Q (Q. Xu et al., 2023). Thus, design of natural treatment systems should consider ponding, saturation times, and the potential to develop low oxygen conditions in standing or stagnant water.

3.4.4 Adsorption and desorption: implications for treatment and crumb rubber

Adsorption, defined as binding a molecule to a particle surface, can allow pollutant removal via particle removal. Pollutants with a high affinity for particles are more readily removed by particle settling and removal, either through treatment or through natural processes. Desorption, defined as the release of a molecule from the particle surface, is also important to the question of treatment effectiveness for 6PPD-Q. Treatment effectiveness can diminish in flow-through systems reliant on particle removal for pollutants that readily desorb (i.e., detach from particles).

Adsorption and desorption are important to understanding TRWP and potentially rubberized asphalt may serve as 6PPD-Q sources. A study of compacted rubberized asphalt found that desorption of 6PPD-Q in purified water resulted in 10 to 90 ng/L and in synthetic stormwater yielded 25 ng/L to 50 ng/L 6PPD-Q in the leachates (Lokesh et al. 2023). The report finds that adsorption/desorption of 6PPD-Q from rubber in rubberized asphalt can increase or decrease 6PPD-Q concentrations in water, depending on the starting 6PPD-Q concentrations in the water. The report found higher desorption releases from non-compacted rubberized asphalt. In discussing the potential role of compacted rubberized asphalt as a 6PPD-Q sink due to adsorption, the report did not address the potential for compacted rubberized asphalt to generate uncompacted TRWP with elevated rubber content compared to TRWP generated on non-rubberized asphalt, potentially acting as a 6PPD-Q source.

Recognizing concerns that crumb rubber asphalt could potentially leach 6PPD-Q, the Michigan State Department of Ecology (Michigan Ecology) monitored surface water 6PPD-Q concentrations near roadways paved with crumb rubber asphalt (Nedrich, 2022). Of seventeen surface water samples collected, 15 were non-detect (<3 ng/L). A creek downstream of a crumb rubber stockpile had 12 ng/L 6PPD-Q. The report notes that this may be an underestimate as the sample was collected post peak storm conditions. A detention basin for roadway runoff showed 37 ng/L 6PPD-Q in the same Michigan Ecology study.

Thus, 6PPD-Q can be detected in water potentially affected by crumb rubber asphalt, but the environmental significance of this process is not well understood. Understanding whether rubberized asphalt increases 6PPD-Q concentrations in stormwater compared to non-rubberized asphalt is a critical information gap, because Caltrans has a goal of 35 percent crumb rubber in asphalt for projects.

In summary, the processes of particle aging, weathering, solid-liquid partitioning, microbially mediated formation, and light-induced degradation interact to establish 6PPD-Q concentrations in water. The relevance of these processes to treatment is highlighted by a study of detention basin treatment systems for tunnel wash water (Meland et al., 2024). The study found minimal 6PPD-Q removal by detention (0 to 22 percent), and actual increases of some tire-derived chemicals and transformation products. The minimal loss of 6PPD-Q may be attributed to possible microbial 6PPD-Q formation under low oxygen conditions and the absence of light in the detention systems. These transport and transformation concepts provide useful reference points for interpreting monitoring results from characterization and treatment studies.

3.5 Stormwater Treatment for 6PPD-Q

Research by others on stormwater TBMPs' removal effectiveness for 6PPD-Q yields insights that support Caltrans monitoring studies. Two studies of bioretention suggest effective removal occurs when water infiltrates through the root zones of plants. Bioretention treats stormwater by infiltration, sometimes utilizing detention within a vegetated basin with an underdrain. This provides an alternative to other infiltration TBMPs in settings where tight soils reduce infiltration rates. Note from the above discussion that anoxic conditions can promote formation of 6PPD-Q, which could be a potential risk factor for bioretention systems.

A small-scale (22 square meters) bioretention cell yielded 98 percent 6PPD-Q removal from inflow to underdrains (Rodgers et al., 2023). The test simulated a rain event by discharging water spiked with 6PPD-Q into the bioretention cell. The authors augmented the small pilot cell with a contaminant fate and transport model to advocate that bioretention can mitigate most 6PPD-Q under the most frequent storm conditions, i.e., the 2-year return interval.

A follow-up modeling study by the same authors concluded that having the largest possible area for bioretention systems optimizes their performance (Rodgers et al., 2024). The treatment area required is a substantive challenge for bioretention implementation across the California landscape, especially near roadways in coho salmon watersheds. Rural roads in the North Coast, where roadways are close to coho salmon habitat, are often configured such that bioretention is infeasible. In addition to physical constraints of geography, environmentally sensitive areas often abut North Coast roadways, further limiting space for bioretention. In contrast, multi-lane highways with ample surrounding open space, which are common in California's Central Valley, do not always align with coho salmon habitat.

A study of porous pavement overlays and full-depth porous pavement on an urban arterial roadway in Gresham, Oregon showed greater than 75 percent removal of 6PPD-Q, along with suspended solids, particulate lead, and particulate copper (Holzer and Poor, 2024). The University of California Pavement Research Center (UCPRC) performed a literature review of the water quality benefits of open grade friction course (OGFC), a porous asphalt overlay covering non-porous dense graded material (Kayhanian and Harvey, 2020). The study found that OGFC is effective at reducing sediments and sediment-associated metals from stormwater runoff. The report proposes further evaluation of different OGFC mixes to optimize water quality improvement.

These examples make useful reference points for understanding the results of Caltrans TBMP effectiveness evaluation. The examples discussed above, bioretention and OGFC, are two of a dozen different approved Caltrans TBMPs. The full range of approved Caltrans TBMPs will be needed to protect coho salmon.

Section 4

Caltrans 6PPD-Q monitoring

This section describes Caltrans' program of water quality monitoring, presents characterization and TBMP effectiveness results, and concludes with a description of data gaps.

4.1 Caltrans 6PPD-Q Monitoring Approach

4.1.1 Caltrans Monitoring Program Overview

Caltrans water quality monitoring generates information needed to support water quality management questions. Consequential management questions are related to Caltrans' role in impaired watersheds. In watersheds where Caltrans is named as a stormwater discharger under a TMDL, the SWRCB assigns Caltrans waste load allocation (WLA). The SWRCB expects Caltrans to take actions that achieve pollutant load reductions to meet the WLA. The TMDL management question is, therefore, "What set of actions would result in load reductions sufficient to achieve the WLA?"

The Caltrans NPDES permit Attachment F defines TMDL-specific reporting requirements for Caltrans established by the RWQCB with jurisdiction over the impaired watershed. Monitoring must target either characterization to document pollutant loads from Caltrans stormwater discharges, and/or effectiveness of TBMPs for reducing pollutant loads.

Caltrans today implements a monitoring program that responds to TMDL mandates across the state where Caltrans is named as a discharger. The program is executed by Caltrans Division of Environmental Analysis, Office of Stormwater Program Development and their contractors who provide experienced project managers, scientists, field crews, and support staff to implement Caltrans' direction.

4.1.2 Pivoting Caltrans Monitoring Program to 6PPD-Q

In August 2022, 18 months after the original 6PPD-Q story came out in the journal *Science* (Tian et al., 2021), Caltrans requested a quote for laboratory analysis of 6PPD-Q from commercial laboratory. At that time, the draft EPA-approved 6PPD-Q analytical method had not been established. The laboratory selected was involved in the methods development and validation and expressed confidence in its method and the likelihood that it would be the basis for an EPA-approved method.

Caltrans directed monitoring contractors to begin 6PPD-Q monitoring effective January 2023. By December 2023, Caltrans had finalized a 6PPD-Q Quality Assurance Project Plan (QAPP) (Caltrans, 2023), and USEPA had approved a draft Method 1634 for 6PPD-Q analysis (USEPA, 2023). Washington Ecology also approved its own 6PPD-Q monitoring QAPP in November 2023. The draft EPA Method 1634 and the Caltrans QAPP for 6PPD-Q monitoring are the latest official guidance available for Caltrans monitoring. In summary, Caltrans pivoted its water quality monitoring program as quickly as possible within the time constraints for establishing a commercially available, validated analytical method and developing accepted standards of practice for sample collection and handling.

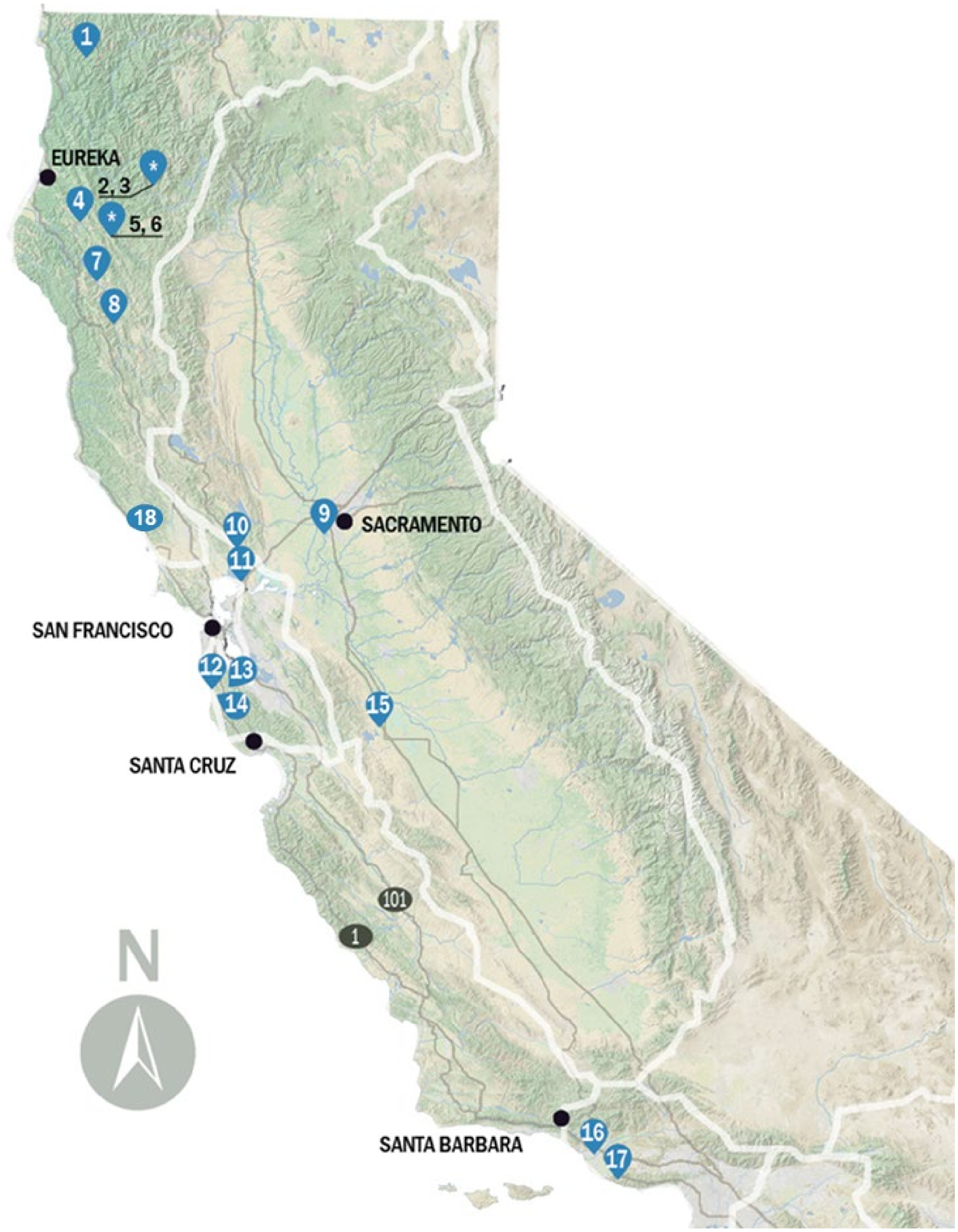


Figure 4-1. Caltrans 6PPD-Q monitoring locations 2023 – present

White boundaries indicate RWQCB jurisdictions.

Figure 4-1 shows the geographic locations of 18 sites sampled for 6PPD-Q between January 2023 and May 2024 (the rainy season typically ends in April – May in California). Table 4-1 provides site details and monitoring goals. Additional details on sampling site characteristics are provided in Appendix A. The 18 sites yield 25 monitoring stations, because five of the sites are TBMP evaluation sites with multiple sampling locations.

Each of the 18 locations required two people to sample. Although it normally does not rain at all locations across California simultaneously, for any given storm front there were up to 16 workers sampling, often overnight. Their efforts produced over 230 6PPD-Q measurements distributed across 25 monitoring stations resulting in 49 station/storm event combinations successfully sampled (Appendix B). Site 18 included receiving water monitoring (Stations 1-354 and 1-355) to assist with 6PPD-Q dilution assessments in receiving waters.

Table 4-1. Summary of Caltrans 6PPD-Q Monitoring Locations 2023 – Present

Map #	Station Codes	Site Name	Watershed	Treatment Type
1	1-321	Wilson Creek	Wilson Creek	NA
2	1-351 and 352	Lord Ellis Summit	Redwood Cr.	Bioswale
3	1-344 and 345	Circle Point Curve	Redwood Cr.	Bioswale
4	1-343	Carlotta	Van Duzen R.	NA
5	1-341	North Weott	S. Fork Eel R.	NA
6	1-347	Founders Grove	S. Fork Eel R.	NA
7	1-346	Richardson Grove	S. Fork Eel R.	NA
8	1-348 and 349	McCoy Creek	S. Fork Eel R.	Bioswale
9	3-412	I-5 Sacramento	Sacramento R.	NA
10	4-445	Napa	Napa R.	NA
11	4-434 and 435	Carquinez	San Francisco Bay	Sand Filter
12	5-314	Big Basin	San Lorenzo Cr.	NA
13	5-313	San Lorenzo Park	San Lorenzo Cr.	NA
14	4-446	Whitehouse Creek	Whitehouse Cr.	NA
15	10-306 and 307	Santa Nella	San Joaquin R.	OGFC Pavement
16	5-312	Rincon Creek	Rincon Cr.	NA
17	7-426	Malibu Lagoon	Malibu Cr.	NA
18	1-353, 354 and 355	Fish Rock Gulch	Fish Rock Gulch	NA

NA = characterization only, no treatment effectiveness data at these stations

4.1.3 Sampling Approach

The normal Caltrans method for stormwater sampling uses flow meters and autosamplers to collect a large-volume whole-storm composite, as shown on Figure 4-2. The programmable autosampler uses real-time flow meter data to pull samples more frequently as flow rate increases. Auto sampling equipment is typically powered by batteries that are recharged using solar panels, and a rain tipping bucket gauge is typically located on site, as shown on Figure 4-3. The 6PPD-Q monitoring program required a different approach based on discrete grab sampling at several evenly rainfall intensity intervals across the storm event (hyetograph monitoring).

Figure 4-2. Example of typical Caltrans automated sampling equipment

Equipment listed clockwise from top left: voltage regulator (black box); autosampler pump (round grey box); flow meter/autosampler controller (tan box); 20-liter sample carboy for whole-storm composite sample collection (clear bottle in yellow box). Example is from the Carquinez media filter effluent (Station 4-435, Figure 4-1 Map Location #9)

Figure 4-3. Solar panel (left) and rain gauge (right, top of cabinet)

Grab sampling approach details can vary by site. Figure 4-4 illustrates the general approach for edge-of-pavement grab sampling. In the examples below, water flows along a curb and into a cut in the curb made for sampling. Techniques for sampling curb-cut flow focus on getting a sample bottle beneath a free-falling stream of water. Typically, a sheet of cleaned Teflon or polycarbonate is rolled into a cylinder or cone to direct flow.

Figure 4-4. Examples of grab sampling edge-of-pavement flows

The left side shows examples of curb-cuts at stations 1-347 (Founders Grove, top) and 4-445 (Napa, bottom).
The right side shows examples of grab sampling from the curb-cuts at those same locations.

Crews monitored weather ahead of a storm to determine expected start of rainfall and time of peak rainfall intensity. The monitoring goal was to collect a minimum of three samples, and preferably six, spaced at varying rainfall intensity intervals to capture the storm's first wash-off followed by rising, peak, and falling stormwater flow rates from the area sampled. Sampling for 6PPD-Q commenced in January 2023. Concurrent samples for suspended sediment concentration (SSC) were collected effective January 13, 2024, and concurrent total organic carbon (TOC), and dissolved organic carbon (DOC) samples were collected effective February 12, 2024. Samples for 6PPD-Q were collected into 250 milliliter amber glass bottles with no headspace, sealed with Teflon-lined caps, and immediately put on ice. Monitoring crews prepared a post-storm technical memorandum for each storm event sampled that documented storm intensity, duration, antecedent rainfall, sampling success/challenges, and unusual occurrences.

4.2 Caltrans 6PPD-Q Characterization Monitoring Results

Arranging results in descending order of AADT validates the working hypothesis that 6PPD-Q concentrations in stormwater increase with traffic volumes, as shown on Figure 4-5. The group of stations from 4-434 to 10-306 all have AADTs above 10,000, as well as the highest median 6PPD-Q concentrations of the stations monitored. The group from 1-341 to 1-343 have intermediate 6PPD-Q concentrations, and the pair of 5-314 and 1-348 have the lowest.

Station 4-434 appears to be an anomaly compared to its peers above 10,000 AADT in that it has the highest AADT of all stations but the lowest 6PPD-Q concentration of the high AADT group. Station 4-434, the influent to the Carquinez media filter, is different from other locations monitored because it is not edge-of-pavement monitoring. Stormwater from the I-80 freeway surface commingles with water from a vegetated slope and a low-traffic parking lot within the toll plaza service area, and so may dilute 6PPD-Q concentrations at the influent location. There is also OGFC along I-80 in the area, constructed in 2015. So, the area represents a treatment train combining OGFC with a media filter. Station 4-434 inflow represents sampling mid-point in a treatment train rather than untreated freeway conditions and is therefore not included in analysis of 6PPD-Q concentrations vs. AADT.

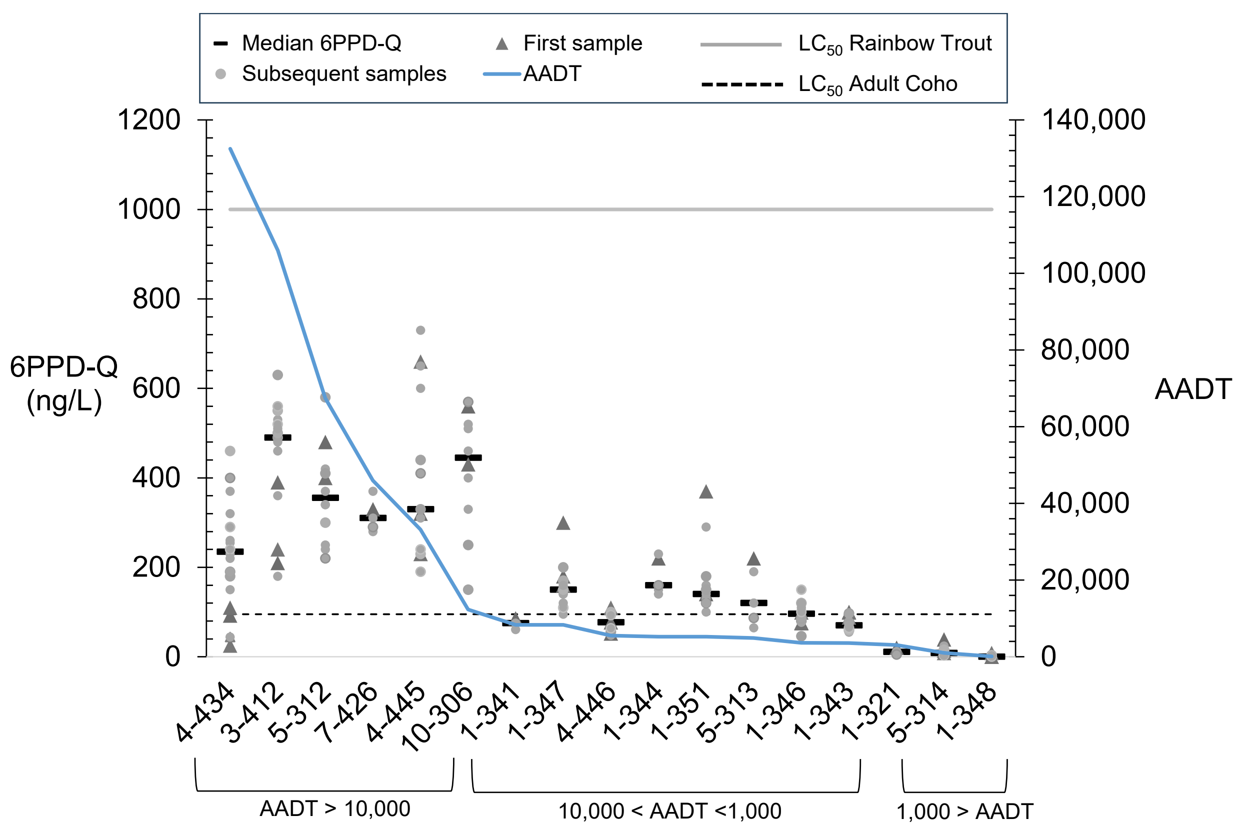


Figure 4-5. Summary of Caltrans 6PPD-Q characterization data

AADT data from https://gisdata-caltrans.opendata.arcgis.com/datasets/d8833219913c44358f2a9a71bda57f76_0/about

The triangle data points at each station indicate the first sample of the storm. Some stations were monitored for multiple storm events, indicated by multiple triangles at the same stations. The multiple grab sampling approach, as opposed to composite sampling, was intended to evaluate whether 6PPD-Q concentrations are elevated in the first flush from a rain event and at other critical points within a storm such as peak flow.

In some instances, e.g., stations 10-306, 1-347, 4-446, 1-351, 5-313, and 1-343, the first samples of the storm (triangles) had higher 6PPD-Q concentrations compared to the station median for all storms (bars). However, of those stations, only at 10-306 was the difference between the first sample of the storm and the remaining samples statistically significant ($p < 0.05$, t test)*. There is not consistent evidence for a "pollutograph" effect whereby elevated concentrations are encountered early in the storm or at peak flow (the first flush phenomenon). Twenty of the 47 station/storm events monitored showed a statistically significantly higher concentration in the first sample compared to the rest, and 12 showed a lower concentration in the last sample compared to preceding samples. Results of statistical analysis by storm are available in Appendix B.

There were inconsistent correlations with SSC, TOC, and dissolved organic carbon (DOC). Not all storm events had SSC, TOC, or DOC data paired with 6PPD-Q measurements. Table 4-2 shows that where data were available for correlation, about a fourth of the storm events sampled showed a significant correlation by simple linear regression.

Table 4-2. Summary of Significant Correlations Between 6PPD-Q and SSC, TOC, and DOC

Constituent	No. of Events Correlated with 6PPD-Q	No. of Events Evaluated
SSC	9	37
TOC	6	23
DOC	7	23

The inconsistent correlations between 6PPD-Q and SSC, TOC, and DOC are not surprising. To the extent that increased AADT is a direct underlying cause of increased 6PPD-Q concentrations, that process does not necessarily apply to SSC, TOC, or DOC. Those constituents are more affected by surrounding watershed conditions and transport of sediment onto the roadway by erosion, wash-off, vehicle tracking, and wind than by AADT. The exceptions where 6PPD-Q and SSC are correlated may indicate areas where TRWP make up a greater fraction of roadway suspended sediments. Correlations between 6PPD-Q and SSC concentrations may be a clue when investigating the potential impacts of rubberized asphalt on 6PPD-Q concentrations in stormwater. Also, paired treatment / control TBMP effectiveness evaluations may show some correlation between 6PPD-Q and SSC to the extent that both are removed by treatment.

Figure 4-6 shows a plot of 6PPD-Q vs. AADT emphasizing the strong association. The data points follow the general trend of 6PPD-Q increasing with AADT. The dashed lines illustrate two different approaches to establishing a best fit line by linear regression – calculating the y-intercept (black) and setting the y-intercept to zero (grey). The AADT explains 41 percent of the variability in 6PPD-Q concentrations for all 17 locations monitored ($r^2 = 0.41$, simple linear regression). Excluding the two circled outliers, AADT explains 86 percent of the 6PPD-Q variability ($r^2 = 0.86$, simple linear regression). Outliers are indicated by large circles.

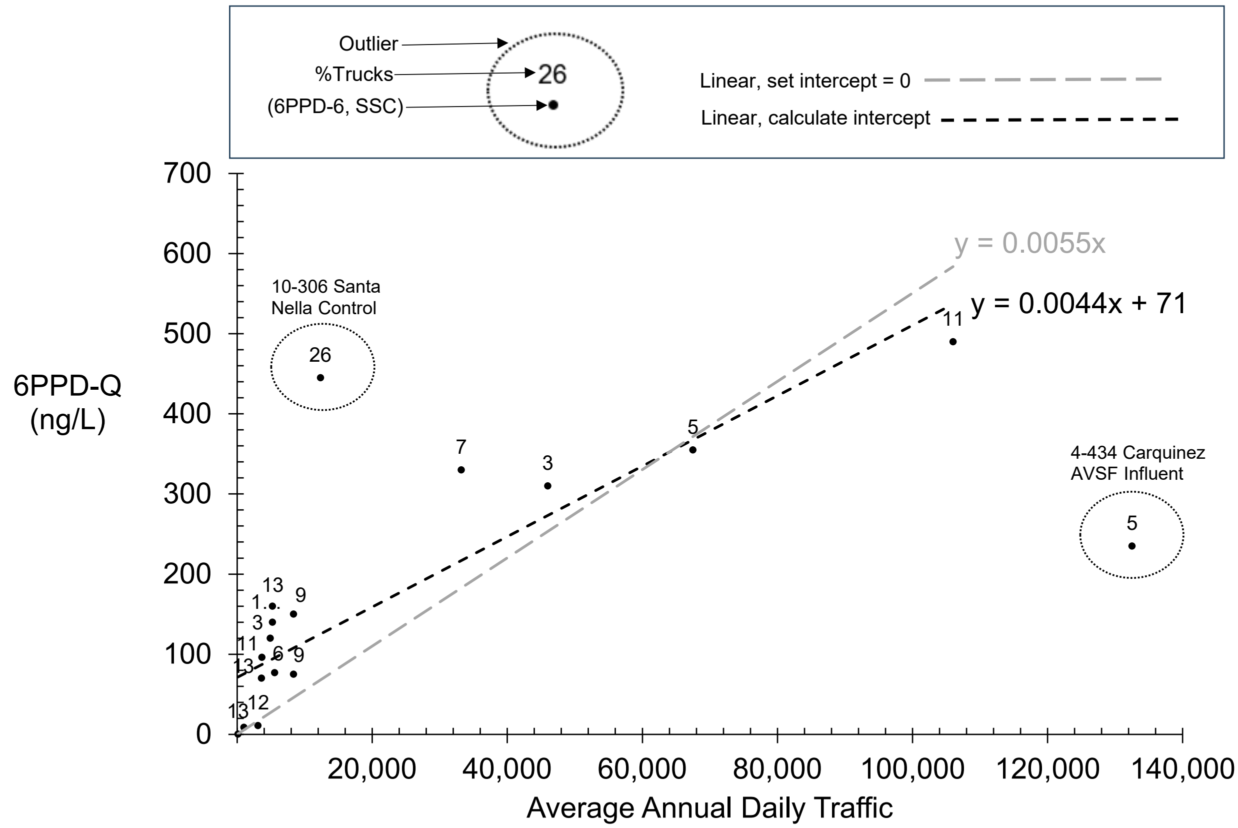


Figure 4-6. Relationship between station median 6PPD-Q concentrations and AADT

Truck AADT data from https://gisdata-caltrans.opendata.arcgis.com/datasets/c079bdd6a2c54aec84b6b2f7d6570f6d_0/about

As noted above, station 4-434 (Carquinez media filter influent) is a low outlier because it is sampled mid-way in a treatment train and included non-roadway runoff. Station 10-306, in contrast, appears to be a high outlier. Plotting the percentage of AADT that is trucks offers one explanation for the high outlier. Of all the stations sampled, 10-306 has the highest percentage of truck traffic. Station 10-306 is located on Hwy 33 in Merced County, a popular truck connector between I-5 and State Route (SR)-152. While a single outlier is not proof of process, it makes sense given that trucks are heavier than cars and have more tires per vehicle and larger contact surface area per tire.

The demonstrative linear regression shown previously on Figure 4-6 shows that, omitting the two outliers 10-306 and 4-434, AADT explains about 86 percent of the variability in 6PPD-Q concentrations. Setting the regression intercept to zero underestimates the 6PPD-Q concentrations for the middle AADT group (1,000 – 10,000 AADT). Allowing the regression to calculate the intercept more closely estimates the middle group but overestimates the lowest group by setting a minimum 71 ng/L 6PPD-Q concentration on very low AADT stations where measured concentrations are much lower.

The Figure 4-6 regression is called "demonstrative" because linear regression is probably not the right model for the data. Linear regression assumes a normal data distribution, which does not apply to this stormwater data set. In some situations, log transformation of the measured values can address non-normally distributed data. Data were still non-normal after log transformation. Regardless of the details of the regression approach, the findings remain consistent that 6PPD-Q generally increases with AADT, and stations 10-306 and 4-434 deviate from the observed relationship between 6PPD-Q and AADT.

The value of the demonstrative regression model is identifying the outliers in the scatter plot and exploring the limits of regression modeling for predicting 6PPD-Q concentrations from AADT. The regression model shows that there is a general relationship between AADT and 6PPD-Q. The low outlier shows the importance of understanding what a sample represents. The high outlier suggests that gathering more data from areas with high and low percentages of trucks in the AADT may improve understanding of where the highest risks of elevated 6PPD-Q will be found on California roadways.

The box and whiskers plot on Figure 4-7 shows a helpful use of the 6PPD-Q data. The 6PPD-Q concentrations of the three AADT groups identified represent different populations ($P<0.01$[2], Kruskal-Wallis test). Follow-up pairwise Mann-Whitney tests show that the difference of medians between each group is also significant ($P <0.01$).

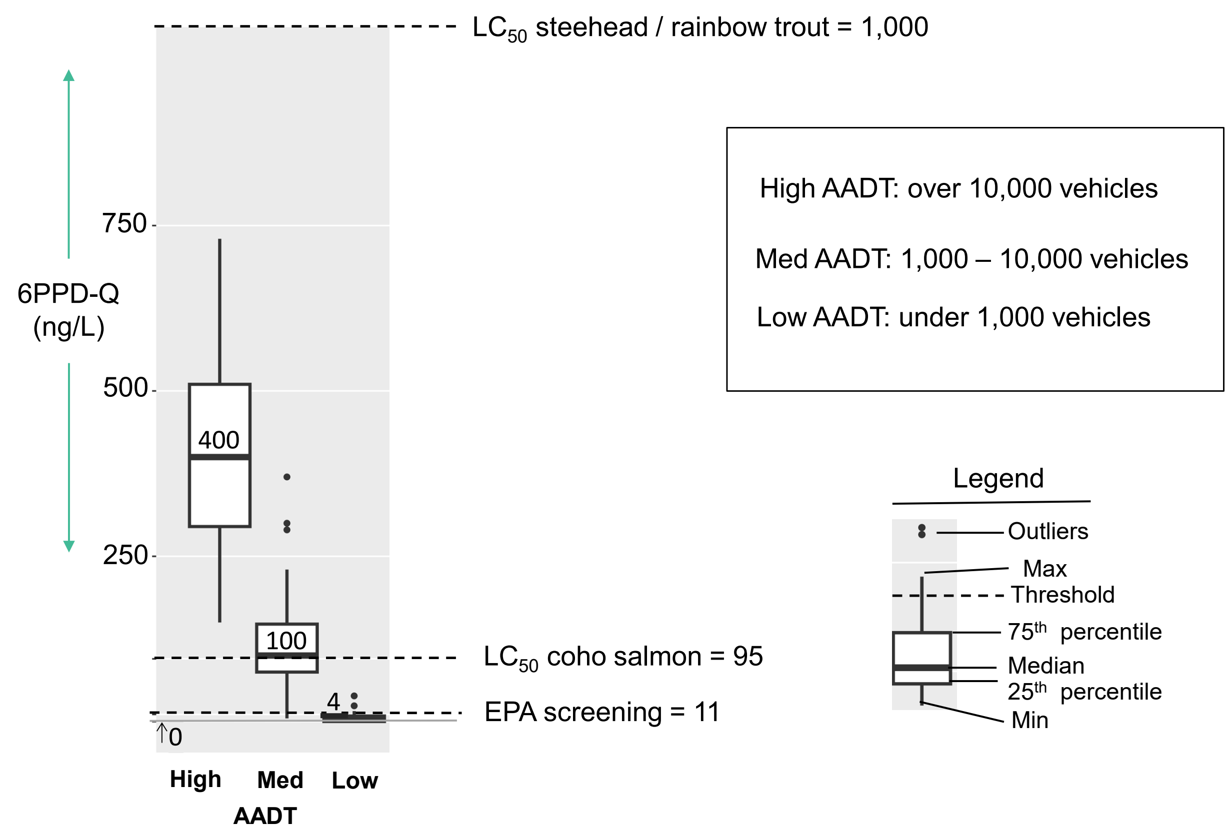


Figure 4-7. Box and whiskers plot showing how 6PPD-Q concentrations vary by AADT

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[2] *The notation "p <0.05" in statistical analysis means that when a statistical test is applied and a difference is found between populations, the probability that the declared difference is false is less than 5 percent. A false difference means the perceived difference is due to chance alone.*

The box and whiskers plot shows the median (line within the box), 25th and 75th percentile (height of box), and outliers (filled circles) above the upper limit shown by whiskers. The upper limit is defined as the 75th percentile plus 1.5 x the interquartile range (IQR). When outliers are not shown the whiskers indicate the range rather than 1.5 x IQR.

A predictive model for 6PPD-Q concentration helps identify 6PPD-Q risks to aquatic life. For example, Washington Ecology proposes to carry out a stakeholder-led prioritization of watersheds for monitoring and interventions (Washington Ecology, 2022). According to Washington Ecology, their approach will involve spatial analysis using GIS to intersect 6PPD-Q roadway concentrations with coho salmon habitat, coho salmon mortality connectivity to receiving waters, and stormwater treatment. The SWRCB is developing a predictive tool to plan receiving water monitoring studies.

The summary in Table 4-3 provides a useful starting point for estimating 6PPD-Q by AADT. It is not the final word in California, nor is it proven to be applicable in other states. Station 4-434 influent was excluded from Table 4-3 and Figure 4-7 as an outlier not representing 100% roadway runoff, as explained above. Station 10-306 was included. Hence, the summary applies to the range of traffic (<1,000 AADT to 106,000 AADT) and truck (3 to 26 percent) conditions in the monitoring data.

Table 4-3. Median and Upper Limit of 6PPD-Q Concentrations (ng/L) in Stormwater from Caltrans Roadways Based on Annual Average Daily Traffic

Traffic Volume	AADT (vehicles/day)	Untreated Median (ng/L)	Untreated Upper Limit = 75th percentile + 1.5 X IQR (ng/L)
Low (n=32)	AADT < 1,000	3.5	21
Medium (n=90)	AADT = 1,000 to 10,000	100	260
High (n=55)	AADT > 10,000	400	830

Values rounded to 2 significant figures. AADT = Annual Average Daily Traffic. n = number of samples in each group.

IQR = interquartile range (difference between the 75th percentile and the 25th percentile); 1.5 x IQR is a commonly accepted definition of the threshold for outliers in a box and whiskers plot.

The low group in Table 4-3 is represented by two tourist roads: Avenue of the Giants (SR-271) in Mendocino County, and Big Basin Way (SR-236) in Santa Cruz County. The AADT for Big Basin Way (Station 5-314) was estimated because traffic counts are not available for that roadway. The estimated AADT of less than 1,000 vehicles at that location is based on historical annual attendance[3]. Thus, the upper limit of 1,000 vehicles for the low AADT group is nominal and may be refined as more data are gathered.

[3] *Visitor attendance prior to wildfires in 2020 was estimated at 250,000 per year. The park re-opened in 2022, but visitor access has been much lower since that time. Other than visitors and park workers there is little reason to travel SR-236. See: https://www.kqed.org/news/11919474/as-big-basin-finally-reopens-indigenous-stewardship-key-among-plans-for-parks-rebirth.*

The summary data are consistent with reported stormwater 6PPD-Q concentrations from heavily traveled roadways. As summarized in Figure 3-3, 6PPD concentrations range from 400 ng/L to 600 ng/L stormwater discharged from freeways in the Pearl River Delta region of China (R. Zhang et al. 2023) and in Seattle, Washington (Tian et al. 2021; 2022).

Table 4-3 helps quantify a general relationship between 6PPD-Q and the readily available metric AADT. The medians and upper limits provide information about uncertainty of estimates from Table 4-3. To account for uncertainties, Caltrans project planners may choose to use the upper limits to evaluate project risks based on worst-case scenarios. In contrast, SWRCB staff and others planning receiving water monitoring may choose to use the medians because resulting estimates would have a higher probability of being closer to actual conditions. Undoubtedly the model will be refined over time as more sites are monitored and more granular detail emerges regarding effects of trucks, roadway conditions, and other factors.

The data in Table 4-3 represent storms typically ranging from 6 to 36 hours duration. Shorter storms rarely generate sufficient runoff to sample. Caltrans ends monitoring after 36 hours for this characterization program. As noted above, evidence for elevated 6PPD-Q concentrations early in the storm was inconsistent. To the extent that there is a first flush effect at certain times and locations, that variability is captured by the upper limit in each group.

4.3 Caltrans 6PPD-Q Treatment BMP Effectiveness Results

Approved Caltrans TBMPs monitored were effective at reducing 6PPD-Q below lethal levels to coho salmon, as shown in Figure 4-8. All treatments reduced 6PPD-Q from above the coho salmon LC_{50} to below the coho salmon LC_{50}. Differences between influent and effluent, or between control (HMA) and OGFC (HMA-O) treatments, were statistically significant in all comparisons ($p < 0.01$, Mann-Whitney u test). Performance details are described below by treatment type.

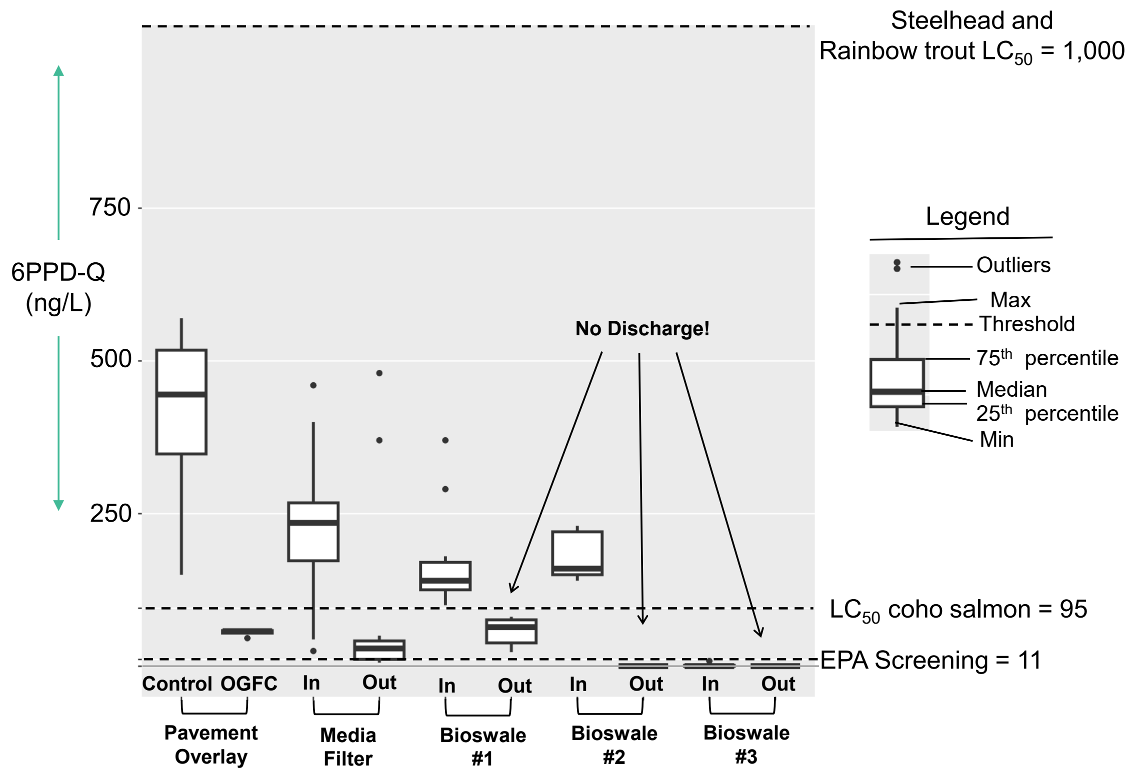

Figure 4-8. Caltrans stormwater treatment BMP effectiveness for reducing 6PPD-Q

Note: Bioswale #1 conveys water to a basin that infiltrated all water during monitored storms. Samples were collected from the end of the bioswale to quantify treatment by passage through the bioswale, even though 100% of the treated water infiltrated.

4.3.1 Porous Pavement Overlay

Treatment with OGFC decreases 6PPD-Q in comparison to untreated (control) pavement. Asphalt OGFC layers are made with aggregate that is selected for coarse (large) gravel size, creating pore space in the asphalt. Pavement treated with OGFC absorbs stormwater in pore spaces of the coarse-graded material (Figure 4-9). Stormwater is shunted laterally through the pore spaces to the freeway edge. The result is decreased standing water on the freeway surface, which reduces the possibility of hydroplaning and improves visibility. Studies have demonstrated the efficacy of OGFC and other types of pervious pavement for reducing sediments and sediment-associated pollutants (Alam et al., 2019; Eck et al., 2012) and 6PPD-Q (Holzer and Poor, 2024).

Caltrans monitoring stations for OGFC evaluation are located along SR-33 adjacent to sections of freeway treated with different types of asphalt. The control section (Station 10-306) has dense-grade hot mix asphalt base with no overlay, while Station 10-307 has a non-rubberized form of OGFC. The OGFC installation was relatively new (less than six months old) at the start of monitoring in the winter of 2023.

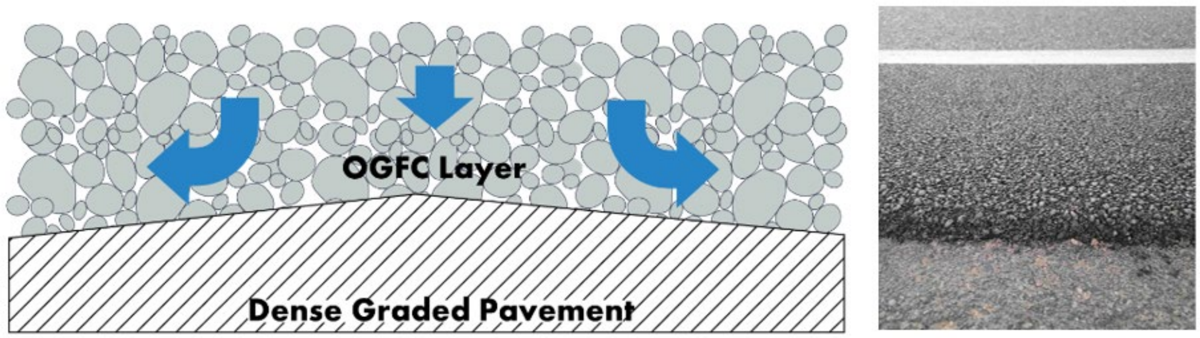

Figure 4-9. Conceptual diagram and closeup of OGFC (Station 10-307)

Figure 4-8 shows that pavement treated with OGFC had median 6PPD-Q concentrations of 58 ng/L compared to 445 ng/L in the untreated control, a statistically significant reduction ($p<0.01$, Mann-Whitney u test). These are preliminary findings, based on two storms sampled at the control site and one storm at the OGFC test site.

4.3.2 Carquinez Media Filter

The Carquinez media filter collects water from the toll plaza area in the eastbound and westbound lanes of I-80 near Vallejo in the general area shown in Figure 4-10. As noted, the system also treats non-freeway runoff from the toll plaza service area and vegetated area located in the freeway median. The media is sand augmented with biochar and iron filings. Commingled freeway and non-freeway stormwater flow through the sand media shown in Figure 4-11. Treated water is discharged into the Carquinez Straits of San Francisco Bay at a high dilution.

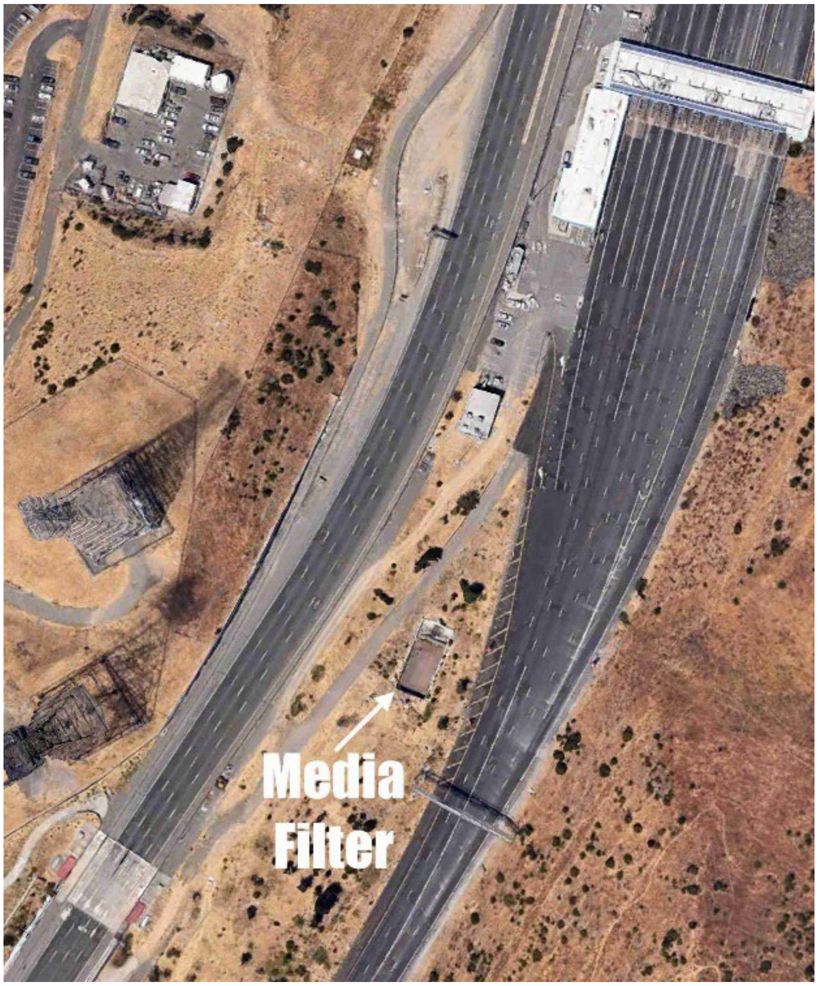

Figure 4-10. Treatment area for Carquinez media filter

Media filter treatment reduced median 6PPD-Q concentrations from 235 ng/L down to 28 ng/L. These are preliminary findings, based on four storms each sampled at the influent and effluent. With dilution, 6PPD-Q would likely be non-detect after mixing in the tidal Carquinez Straits. All but two treated samples were below the 6PPD-Q LC_{50} for coho salmon. Those two exceeding samples were the first two samples collected on commencement of 6PPD-Q monitoring at station 4-434 and were very likely compromised by commingling with untreated runoff from a nearby Caltrans drainage area. Field methods for collecting an un-commingled sample were not perfected until the third sampling event at this site.

Figure 4-11. Media filter at I-80 Carquinez toll plaza (Station 4-434 and 4-435)

Stormwater flows through the sand media in the foreground before discharging to San Francisco Bay at the Carquinez Straits.

4.3.3 Bioswales

Three bioswale examples in Figure 4-12 through Figure 4-17 show bioswales infiltrating and filtering stormwater while conveying it to drainage inlets or bioretention areas.

Bioswale Example 1: Lord Ellis Summit

In the first example from a site at Lord Ellis Summit, stormwater flows from the SR-299 shoulder through a bioswale, and into a bioretention basin. In this example, crews collected water from the bioswale influent and from the bioswale effluent before it flowed into the bioretention basin. The basin infiltrated all the runoff (i.e., did not discharge) during the two storm events monitored. The bioswale conveyance prior to the basin reduced median 6PPD-Q concentrations in SR-299 runoff from 140 ng/L, above the 95 ng/L coho LC_{50}, to 64 ng/L, which is below this lethal threshold.

Figure 4-12. Influent for the bioswale at Station 1-351 (Lord Ellis Summit)

Figure 4-13. Sampling effluent from the bioswale at Station 1-352 (Lord Ellis Summit)

Flow from bioswale at sampling point (foreground) ponds in a bioretention basin (background) that did not overflow during any of the storms sampled.

Bioswale Example 2: Circle Point Curve

In this second example, edge-of-pavement flow from SR-299 at Circle Point Curve flows from the shoulder into a grassy bioswale (Figure 4-14) toward a culvert inlet (Figure 4-15). A small channel was created to concentrate edge-of-pavement flow for sampling. During the single event sampled, approximately 0.6 inches of rain fell over 24 hours, yet stormwater did not traverse through the bioswale and reach the drainage culvert. The bioswale appears to be so effective that flow will only occur on events greater than 0.6 inches over 24 hours.

Figure 4-14. Edge-of-pavement stormwater influent to bioswale at Station 1-344 (Circle Point Curve)

Channel installed to facilitate sampling. Inflow is sampled from the Teflon sheeting to the right of the bottles.

Figure 4-15. Effluent location of bioswale at Station 1-344 (Circle Point Curve)

Stormwater did not reach the outflow during the storm sampled on 4/16/2023 – 4/17/2023.

Stormwater flowing into the Circle Point Curve bioswale at Station 1-344 and into the bioswale at the nearby Lord Ellis Summit (Station 1-351) comes from SR-299, a two-lane rural road with moderate AADT (5,250 each). Trucks using this connecting highway from I-5 to US-101 comprise 13 percent of the AADT, which is mid-range for percent trucks in this data set. The median influent concentrations at Lord Ellis Summit and Circle Point Curve, 140 ng/L and 160 ng/L, respectively, are above the median (100 ng/L) for the middle AADT group (shown previously in Figure 4-7, but they are not outliers.

These Caltrans-approved TBMP's infiltrated all of the monitored storm flow, leading to no discharge of 6PPD-Q. Bioswale conveyance alone at Lord Ellis Summit reduced 6PPD-Q below the 95 ng/L LC_{50}. These two examples of a bioswale at Circle Point curve and a treatment train combining a bioswale and a bioretention basin at Lord Ellis Summit highlight the effectiveness of TBMPs for addressing 6PPD-Q in relevant ecological context.

At McCoy Creek, stormwater flows from the shoulder of SR-271 (Avenue of the Giants) into a bioswale (Figure 4-16). The bioswale conveys stormwater to a bioretention basin (Figure 4-17) This site represents the lowest (<0.7 ng/L) 6PPD-Q measurements from the lowest AADT station (Station 1-348). The roadway mostly serves locals and service vehicles, having an AADT of 125, thirteen percent of which are light trucks, mostly (~80 percent) less than three axles. Similar to Circle Point Curve, there was no stormwater discharge observed from the bioswale during the three storms monitored. During the original site reconnaissance 2.7 inches of rain had fallen prior to arriving onsite with no discharge from the bioswale observed.

4.3.4 Summary of Caltrans TBMP Effectiveness Monitoring

These treatment examples (OGFC, media filter, bioswales, bioretention) tell quantitative stories of how Caltrans-approved TBMPs effectively reduce 6PPD-Q to below the adult coho salmon LC_{50}. The stories, in the context of rural California roads near coho salmon habitat streams, show how Caltrans existing program of stormwater monitoring and treatment meets the needs of 6PPD-Q risk management for coho salmon.

Bioswale Example 3: McCoy Creek

Figure 4-16. Flow into bioswale at Station 1-348 (McCoy Creek)

Figure 4-17. Flow into bioretention basin at Station 1-349 (McCoy Creek)

Flow completely infiltrated with no discharge during all three events monitored.

4.4 Receiving Water Monitoring

Caltrans performed monitoring in the vicinity of a Caltrans' fish passage project. The project would remove a barrier to fish passage where SR-1 in Mendocino County crosses Fish Rock Gulch (Location 18 in Figure 4-1). Figure 4-18 shows the site setting, and Figure 4-19 shows the downstream receiving water monitoring location.

Figure 4-18. Setting of Fish Rock Gulch on SR-1 in Mendocino County

Figure 4-19. Downstream sampling location in Fish Rock Gulch

Caltrans monitored 6PPD-Q concentrations in roadway runoff that discharges into Fish Rock Gulch (Station 1-353) and at locations in the receiving water upstream (Station 1-354) and downstream (Station 1-355) of the discharge. The storm monitored on 10/12/2024 was a light, early season storm that totaled 0.55 inches of rain over its 23 hours duration. Two samples were collected at each station during the most intense rainfall period, when 0.36 inches of precipitation occurred over two hours.

Figure 4-20 shows 180 and 240 ng/L 6PPD-Q measured in in roadway runoff. The AADT at this location was 3,100 vehicles, placing this location in the medium group of Figure 4-7 and Table 4-3. Both measured roadway runoff concentrations are above the median for the medium group but are not outliers. Receiving water concentrations were 2.5 to 3.6 ng/L upstream of the roadway runoff discharge point, and 2.0 to 4.8 ng/L downstream of the roadway runoff discharge point. Thus, there was no discernible change in receiving water 6PPD-Q concentrations resulting from the roadway runoff. Receiving water 6PPD-Q concentrations were below the 11 ng/L USEPA 6PPD-Q screening level in all four samples.

This first look at receiving water 6PPD-Q concentrations in a rural California stream with potential coho salmon habitat stream highlights the point made in Section 3.3. The urban runoff mortality syndrome observed in lowland Puget Sound urban streams appears to be caused by roadway runoff discharges into urban streams with low dilution, resulting in 6PPD-Q concentrations exceeding levels lethal to coho salmon. This example of a coastal highway where Caltrans is working to restore fish habitat provides reassurance that the alarming results published by Tian et al (2021) may not apply to all coho salmon streams.

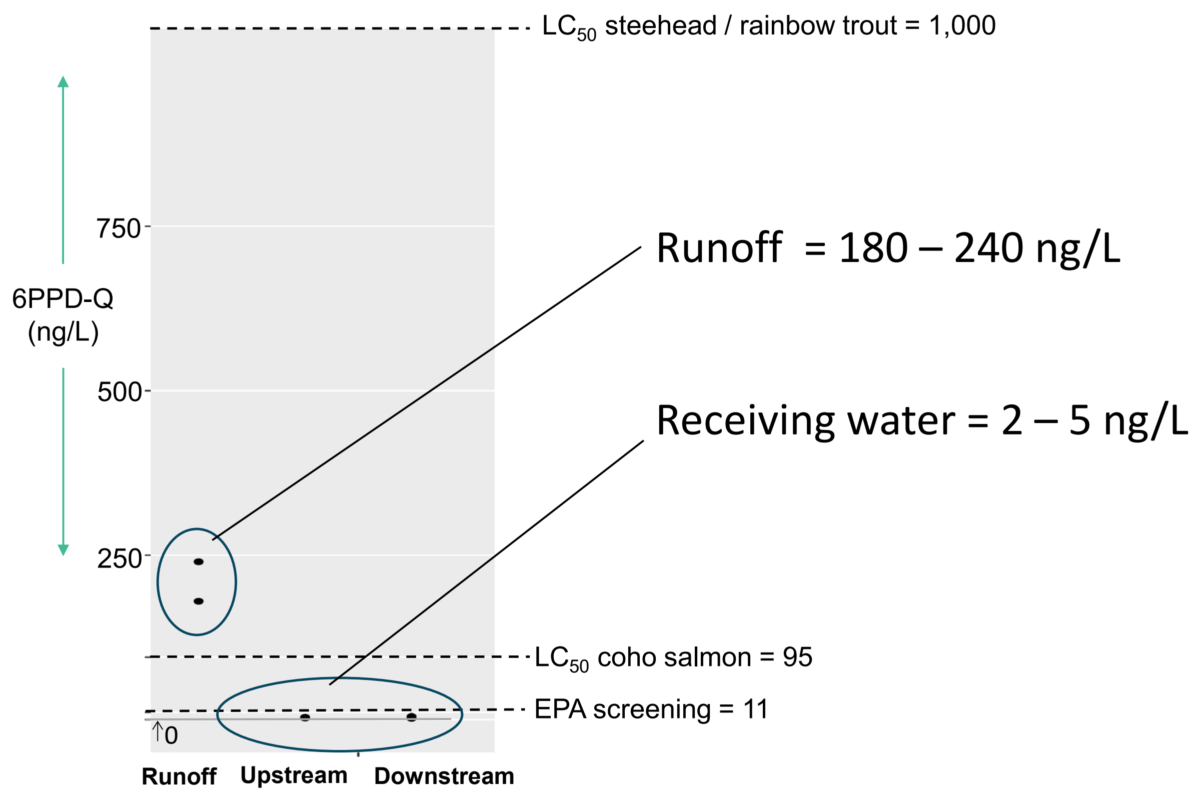

Figure 4-20. 6PPD-Q concentrations in stormwater and receiving waters of Fish Rock Gulch, 10/12/2024

4.5 Summary of Caltrans 6PPD-Q Monitoring

Caltrans' statewide stormwater quality monitoring program provides essential information to address concerns about 6PPD-Q risks to coho salmon. The results allow for prediction of 6PPD-Q based on AADT, at least to a level of precision needed to guide monitoring and risk assessment. The findings show the effectiveness of a range of Caltrans-approved TBMPs, including a media filter, OGFC application, bioswales, and bioretention basins. Initial findings from receiving water monitoring near a planned fish passage restoration project showed concentrations below the USEPA 11 ng/L screening level. Data gaps include:

- Data from North Coast highways at higher AADT near coho salmon streams
- Data from low AADT, low-threat roadways
- Data from a broader range of AADT and percent truck conditions and combinations
- Data from rubberized asphalt and non-rubberized asphalt pavements
- Data from roadways representing a variety of driving conditions
- Effectiveness data from more TBMP examples
- More receiving water studies comparable to the approach at Fish Rock Gulch

Section 5

Caltrans Approach to Stormwater Treatment

This section presents Caltrans' approach to TBMP evaluation and selection. Caltrans implements TBMPs to protect water quality to the maximum extent practicable (MEP), minimize life-cycle maintenance costs and resources, provide adequate site access, and maximize worker and public safety. Design pollution prevention (DPP), treatment, and specific construction site TBMPs are incorporated into project plans and specifications. Construction, operation, and maintenance costs are considered when selecting permanent TBMPs, so adequate cost is estimated, and funding is allocated. The MEP analysis is accomplished by using the processes in Caltrans' Project Planning and Design Guide (PPDG).

Project-specific TBMP selection is an iterative process that begins with initial project planning activities. As the project progresses into detailed design, the project engineer (PE) revisits the TBMP selection process. The TBMP selection and project design proceed together with a detailed analysis of the roadway and drainage facilities.

5.1 Documenting Potential Stormwater Impacts

Water quality objectives are identified in the basin plans developed by each of the nine RWQCBs to identify designated beneficial uses and water quality objectives for each jurisdictional region. Caltrans considers potential water quality impacts as part of each project's NEPA/CEQA review which is included in the environmental document. As part of this review, Caltrans identifies any watershed specific requirements (i.e., TMDLs, 404(d) impaired waterbodies, etc.) to determine which TBMPs, if any, are necessary to target specific pollutants.

The Caltrans PPDG has an established BMP selection criteria based on pollutant as shown in the below Figure 5-1. As emerging pollutants are added to the Caltrans NPDES Permit and SWMP, Caltrans would adapt the stormwater management program and TBMP selection process as needed.

Approved Caltrans Treatment BMPs by Pollutant	TSS	TDS	Nutrients	Pesticides	Metals	Bacteria	Trash	BOD	Turbidity	Temp	Hg
Bioretention	✓			✓	✓		✓	✓	✓	✓	✓
Biofiltration Systems	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Media Filters	✓		✓	✓	✓		✓	✓	✓	✓	
Open Grade Friction Course (OGFC)	✓		✓	✓					✓	✓	✓
DPPIA (Infiltration Area)	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Infiltration Devices	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Detention Devices	✓		✓	✓		✓	✓		✓	✓	✓
Dry Weather Flow Diversion	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Trash Capture							✓				
Multi-Chambered Treatment Train	✓		✓	✓	✓		✓		✓		
Wet Basin	✓		✓	✓		✓	✓			✓	
Traction Sand Traps	✓						✓		✓		

Figure 5-1. Caltrans TBMPs Based on Pollutants of Concern
Modified table based on PPDG, Table 3-1
TSS = total suspended solids; TDS = total dissolved solids; BOD = biochemical oxygen demand; Hg = mercury
Order of appearance does not signify order of importance.

5.2 TBMP Selection Process

In general, TBMPs are selected based on the following criteria:

- Feasibility: Safety, ROW, design/siting, construction, environmental compliance
- Operations and maintenance requirements
- Treatment performance
- Life-cycle costs

The level of detail for the selection process may differ depending on the complexity of the TBMP. Proximity to salmonid watersheds and dilution of stormwater in receiving waters would be a new criterion relevant to 6PPD-Q evaluations.

Section 5 of the PPDG promotes a consistent approach to protect water quality on all Caltrans projects by using site design techniques and implementing permanent treatment in accordance with permit requirements. A permanent TBMP strategy must consider both DPP and TBMPs to treat runoff and manage impervious and pervious areas within the project limits. A project site may require that multiple TBMPs be placed within project limits, and each TBMP sized to treat flows from its contributing drainage area.

5.3 BMP Strategy

Figure 5-2 illustrates the objectives of the Caltrans permanent TBMP strategy:

- **Maximize infiltration**. All projects with disturbed soil area, independent of location or treatment requirements, consider maximizing infiltration of stormwater runoff. This includes using low-impact site design principles and infiltration-type DPP BMPs during site development and design.
- **Prioritize TBMPs**. In some cases, infiltration is infeasible or limited to less than the required volume. These situations require consideration and selection of TBMPs best suited for the targeted design constituent. This is where watershed specific requirements, including consideration of coho salmon habitat, comes into the process.
- **Provide detailed documentation of treatment.** The PE documents specific TBMP information and design decisions made for the purposes of reporting compliance, implementing asset management, and supporting long-term maintenance where needed.

Selection of Caltrans-approved TBMPs for individual projects is principally conducted by answering two questions:

- **Step 1:** Does the project require TBMPs to be deployed? If "yes" then,
- **Step 2:** Which TBMPs are feasible and effective for the project site and pollutants of concern?

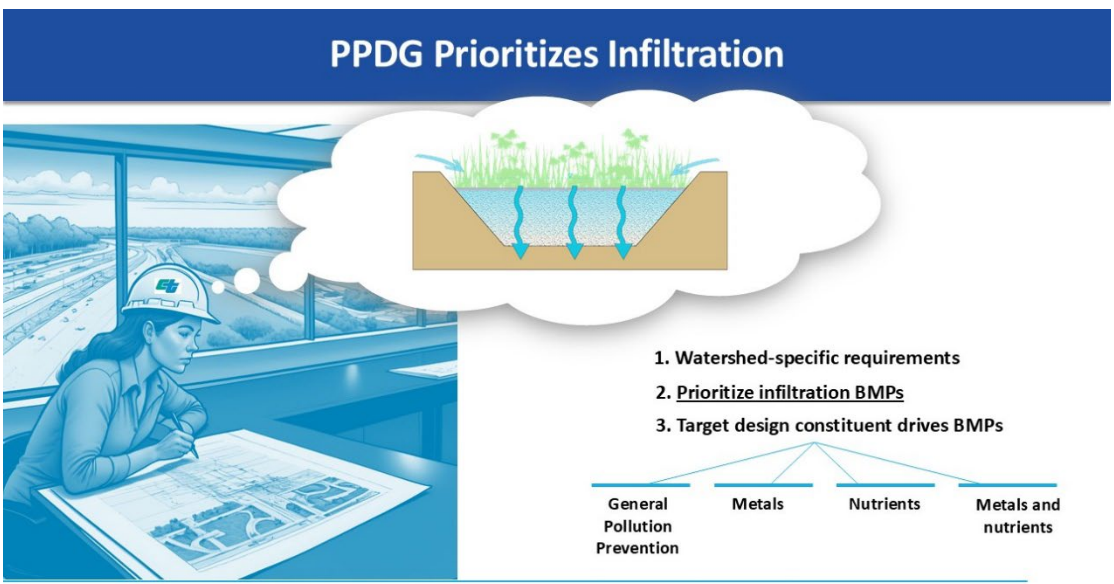

Figure 5-2. Conceptual illustration of the Caltrans TBMP strategy

5.4 Lake Tahoe NEAT Study

Natural Environment as Treatment (NEAT) has been used successfully in Lake Tahoe to improve water quality. This is a low-impact development concept that uses natural environment as vegetated buffers without disturbing the existing natural conditions. Pollutants transported by stormwater runoff are either infiltrated or absorbed by natural existing vegetation. This strategy considers the distance and topography of the down gradient land to determine if a NEAT segment may be reasonable assumed to be incapable of discharging stormwater runoff generated from the roadway surface to a receiving water body. Where adequate NEAT segments are not available, minor environment modifications, low impact improvements, or Caltrans approved TBMPs would be implemented.

Figure 5-3. Example of a Lake Tahoe NEAT Area

Section 6

Findings, Recommendations, and Uncertainties

The information summarized in this report leads to the following findings and recommendations. The section concludes with a summary of uncertainties and information gaps, including a brief description of how to address unknowns.

6.1 Findings

1. Caltrans operates within a well-defined regulatory program to implement CWA and ESA mandates at the direction of SWRCB and in consultation with NMFS.
2. Current scientific information about 6PPD-Q in stormwater shows that although 6PPD-Q frequently exceeds lethal levels in roadway runoff, surface water monitoring results are generally below lethal levels. In many cases, median surface water 6PPD-Q concentrations are below the EPA screening level (11 ng/L), most indicating non-detect 6PPD-Q concentrations.
3. Caltrans' stormwater management program is monitoring stormwater runoff characterization and TBMP effectiveness for 6PPD-Q.
4. Caltrans TBMPs are effective at reducing 6PPD-Q below the 95 ng/L LC_{50} for coho salmon and infiltrate where possible to reduce stormwater discharge volumes.
5. The assessment of TBMP effectiveness is based on monitoring to date. Findings will be re-evaluated as effectiveness more data are generated.
6. The PPDG's T-1 checklist selection process incorporates TBMPs to MEP, in accordance with CWA.
7. Caltrans uses the natural environmental as a treatment area (NEAT) in Lake Tahoe as an effective stormwater runoff treatment to protect receiving water bodies.

6.2 Recommendations

1. Use the findings of this report to support a risk management approach for Caltrans ESA consultations with NMFS on projects.
2. Use Caltrans SWMP and the Lake Tahoe NEAT study to propose 6PPD-Q TBMPs and other solutions to the maximum extent practicable.
3. Address data gaps discussed in Section 4.4 and detailed below through Caltrans' stormwater monitoring program.
4. Use the AADT estimating tool (Table 4-3) to assist regional monitoring collaborations and Caltrans project delivery.
    a. Caltrans understands that SWRCB is developing a receiving water monitoring program that could use Table 4-3 to estimate 6PPD-Q information from roadways to support GIS-based prioritization of monitoring sites.
    b. Caltrans project developers can use Table 4-3 to inform water quality assessment reports during the project development phase.

5. Provide information on Caltrans monitoring site locations to SWRCB to allow better alignment of SWRCB receiving water monitoring with highway runoff locations.
6. As more data are available from Caltrans and other sources, this white paper should be amended with appendices to update the best available science for monitoring data.
7. Work with SWRCB, Regional Boards, and other regulatory agencies to demonstrate using the NEAT methodology from Lake Tahoe for areas where standard TBMPs are infeasible.

6.3 Uncertainties and Information Gaps

1. There are limited data on 6PPD-Q concentrations in California receiving waterbodies that provide habitat for coho salmon and other aquatic species. Key questions include:
    a. What other aquatic species are sensitive to 6PPD-Q at relevant concentrations?
    b. Which of the most sensitive species are threatened or endangered?
    c. What are the worst-case scenarios whereby sensitive species may be exposed?
2. In addition to AADT, what other factors affect 6PPD-Q concentrations in roadway runoff?
    a. Potentially important factors include presence/absence of rubberized asphalt, percentage of AADT that is truck traffic, driving conditions that increase road wear, and seasonally peaking traffic volumes vs. more constant year-round traffic.
    b. Most of these factors can be addressed through refinements to the stormwater monitoring approach and / or retrospective review of existing monitoring data. Future monitoring stations can be selected to cover a range of truck volumes, driving conditions, seasonal and non-seasonal roadways, and rubberized vs. non-rubberized asphalt. The eighteen locations monitored for this report can be reviewed retrospectively to identify whether or not asphalt in the roadway sampled is rubberized.
    c. Some insights may be gained from retrospective review of pavement types in areas already monitored.
    d. Using select projects located within coho salmon watersheds as case studies can advance understanding of factors besides AADT.
3. How effective are bioswales and biostrips at 6PPD-Q attenuation?
    a. Infiltration TBMPs are by definition effective when they infiltrate all stormwater. Many bioswales and biostrips convey water to discharge points with only partial infiltration and, as shown in Section 3.4.3 Example 2, some reduction of 6PPD-Q during conveyance. The latter scenario may be more common in many California roadways where space for infiltration TBMPs is limited.
    b. Large-scale bioretention systems are uncommon because siting, constructing, and maintaining them is challenging. Bioswales and biostrips provide treatment and infiltration while conveying stormwater, are easier to maintain, and are more common.
    c. Monitoring bioswale TMBPs and NEAT areas that can provide mitigation via limited infiltration combined with 6PPD-Q attenuation will address this data gap.
4. What is the prioritization approach for 6PPD-Q TBMPs?
    a. The scientific findings of this report show that 6PPD-Q concentrations appear to be below levels of concern in many aquatic ecosystems.
    b. Caltrans, NMFS, the SWRCB, and the public need a systematic approach to prioritize the need for TBMPs to appropriately address risks where they exist.

Section 7

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Appendix A: 6PPD-Q Monitoring Site Information

Table A-1. Site Information

Station Code	Figure 4-1 Map Key	Station Name	Station Description	Position	Receives Flow From	Caltrans District	RWQCB	County	Roadway	Postmile	Latitude	Longitude	AADT Total	AADT% Trucks
1-321	1	Wilson Creek	A series of three storm drain drop inlets collects stormwater runoff from the north and southbound lanes and shoulders and discharges it via a 24" CMP into a gully that flows into Wilson Creek.	CMP outfall	Highway & shoulder	1	1	Del Norte	US-101	DN-101-12.88-NB	41.6053	-124.1020	3100	12%
1-341	5	North Weott	Characterization site off Highway 101 in Humboldt Redwoods State Park.	Shoulder	Highway and shoulders	1	1	Humboldt	US-101	HUM-101-37.33	40.3726	-123.9268	8350	9%
1-343	4	Carlotta	Rolling forested hills	EOP	Highway & Shoulder	1	1	Humboldt	SR-36	HUM-36-4.23	40.5399	-124.0726	3600	13%
1-344	3	Circle point curve influent	influent (edge-of-pavement) location for a Stormwater Biofiltration Swale BMP	Swale Beginning	Highway & Shoulder	1	1	Humboldt	SR-299	HUM-299-25.34-EB	40.9237	-123.8109	5250	13%
1-345	3	Circle point curve effluent	Effluent for bioswale TBMP	Swale end	Swale Beginning	1	1	Humboldt	SR-299	HUM-299-25.34-EB	40.9232	-123.8106	5250	13%
1-346	7	Richardson Grove	End of ditch where land drops off steeply at top of creek bank	Ditch	Highway	1	1	Humboldt	US-101	HUM-101-0.88-NB	40.0113	-123.7910	3670	11%
1-347	6	Founders Gove	PCC inlet to downdrain	PCC inlet	Highway	1	1	Humboldt	US-101	HUM-101-35.7-SB	40.3529	-123.9280	8350	9%
1-348	8	Mcoy Creek influent	Bioswale off of SR 271	Swale Beginning	Highway	1	1	Mendocino	SR-271	MEN-271-17.92 NB	39.9544	-123.7759	125	13%
1-349	8	Mcoy Creek effluent	Bioswale off of SR 271	Swale end	Swale Beginning	1	1	Mendocino	SR-271	MEN-271-17.92 NB	39.9544	-123.7760	125	13%
1-351	2	Lord Ellis Summit influent	Influent for bioswale TBMP	Influent	Highway	1	1	Humboldt	SR-299	HUM-299-18.42	40.9303	-123.8550	5250	13%
1-352	3	Lord Ellis Summit effluent	Effluent for bioswale TBMP	Effluent	Highway	1	1	Humboldt	SR-299	HUM-299-18.42	40.9305	-123.8550	5250	13%
1-353	18	Fish Rock Gulch - Runoff	Hairpin turn at bottom of steep hill in both directions	Culvert	Highway	1	1	Mendocino	SR-1	MEN-1-4.64	38.8056	-123.5791	3100	6%
1-354	18	Fish Rock Gulch - Upstream	Receiving waters upstream of SW discharge	From bank	Upstream	1	1	Mendocino	SR-1	MEN-1-4.64	38.8058	-123.5792	3100	6%
1-355	18	Fish Rock Gulch - Upstream	Receiving waters downstream of SW discharge	From bank	Upstream + Discharge	1	1	Mendocino	SR-1	MEN-1-4.64	38.8054	-123.5790	3100	6%
3-412	9	Karbet South	I-5 SB, on Karbet Way, N of Seamus Ave, downstream	EOP	Freeway	3	5	Sacramento	I-5	SAC-5-19.73	38.5308	-121.51748	106000	11%
4-434	11	Carquinez influent	Austin Vault Sand Filter Influent Pipe	Influent	Highway and slopes	4	2	Solano	I-80	SOL-80-27	38.0680	-122.2266	132500	5%
4-435	11	Carquinez effluent	Austin Vault Sand Filter Effluent Pipe	BMP Effluent	BMP	4	2	Solano	I-80	SOL-80-27	38.0678	-122.2266	132500	5%
4-445	10	Napa	Roadway edge before earthen swale	Edge of Pavement	Highway	4	2	Napa	SR-29	NAP-29-6.04-NB	38.2398	-122.2671	33200	7%
4-446	14	Whitehouse Creek	Curb and gutter discharge to drop inlet	Edge of Pavement	Highway	4	2	San Mateo	SR-1	SM-1-4.32-NB	37.1495	-122.3477	5550	6%

Station Code	Figure 4-1 Map Key	Station Name	Station Description	Position	Receives Flow From	Caltrans District	RWQCB	County	Roadway	Postmile	Latitude	Longitude	AADT Total	AADT% Trucks
5-312	16	Rincon Creek	Entrance point into a Portland cement concrete channel that runs into a ditch	Runoff	Highway	5	3	Santa Barbara	US-101	SB-101-0.119-NB	34.3776	-119.4790	67500	5%
5-313	13	San Lorenzo Park	Curb and gutter discharge to CMP inlet	Edge of Pavement	Highway	5	3	Santa Cruz	SR-9	SCR-9-19.2-EB	37.2060	-122.1450	4925	3%
5-314	12	Big Basin Way	AC inlet to downdrain	AC inlet	Highway	5	3	Santa Cruz	SR-236	SCR-236-4.27-WB	37.1663	-122.1649	<1000*	Not available
7-426	17	Malibu Lagoon	Malibu Creek TMDL WS #40, SR-1 North Bound and Malibu Lagoon	EOP	Highway	7	4	Los Angeles	SR-1	LA-1-46.86	34.0349	-118.6814	46000	3%
10-306	15	Santa Nella HMA Control	Curb and gutter conveyance along AC Dike Type E on SR 33, postmile 13.45 NB	Edge of Pavement	Highway	10	5	Merced	SR-33	MER-33-13.45-NB	37.0598	-121.0163	12350	26%
10-307	15	Santa Nella HMA-O Treatment	Earthen overside drain at end of AC Dike Type E on SR 33, Postmile 14.33 NB	Edge of Pavement	Highway	10	5	Merced	SR-33	MER-33-14.33-NB	37.0725	-121.0162	12350	26%

Appendix B: Caltrans 6PPD-Q Monitoring Data

Station Code	Sample Date	Collection Time	Storm # for Site	Grab # for Storm	6PPD-Q (ng/L)	SSC (mg/L)	TOC (mg/L)	DOC (mg/L)	Station ID	Storm Date Ending	# 6PPD-Q grabs	Median 6PPD-Q	Max 6PPD-Q	Min 6PPD-Q	Mean 6PPD-Q	Stdev 6PPD-Q	Pearson R v SSC	Pearson R v TOC	Pearson R v DOC	Last < avg of first?	First > Avg of last?	Pearson R v Flow	Flow rate at time of grab (L/sec)
1-321	03-19-2023	4:05	1	1	20	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.800
1-321	03-19-2023	5:51	1	2	11	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.556
1-321	03-19-2023	7:51	1	3	12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.952
1-321	03-19-2023	9:04	1	4	5.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.769
1-321	03-19-2023	9:55	1	5	5	--	--	--	1-321	03-19-2023	5	11	20	5	11	6	No data	No data	No data	Yes	Yes	0.46	0.444
1-341	03-19-2023	1:20	1	1	86	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.217
1-341	03-19-2023	2:25	1	2	75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.526
1-341	03-19-2023	11:12	1	3	61	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.179
1-341	03-19-2023	11:35	1	4	75	--	--	--	1-341	03-19-2023	4	75	86	61	74	10	No data	No data	No data	No	Yes	0.10	0.035
1-343	03-19-2023	1:45	1	1	100	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.075
1-343	03-19-2023	2:45	1	2	57	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.609
1-343	03-19-2023	9:50	1	3	58	--	--	--	1-343	03-19-2023	3	58	100	57	72	25	No data	No data	No data	No	Yes	-0.89	0.356
1-343	01-31-2024	3:44	2	1	99	209	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.750
1-343	01-31-2024	4:50	2	2	55	37	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.820
1-343	01-31-2024	10:10	2	3	97	215	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4.000
1-343	01-31-2024	12:40	2	4	77	25.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.380
1-343	01-31-2024	15:38	2	5	95	36.5	--	--	1-343	01-31-2024	5	95	99	55	85	19	0.65	No data	No data	No	No	0.09	0.630
1-343	03-09-2024	4:28	3	1	88	1060	16	15	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.450
1-343	03-09-2024	5:12	3	2	59	20.4	3.8	3.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.060
1-343	03-10-2024	10:50	3	3	62	191	9	5.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.250
1-343	03-10-2024	11:50	3	4	65	153	1.3	1.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.080
1-343	03-10-2024	12:50	3	5	69	79.2	1.2	0.73	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.000
1-343	03-10-2024	13:50	3	6	71	27.8	1.1	0.79	1-343	03-10-2024	6	67	88	59	69	10	0.88	0.65	0.73	No	Yes	-0.20	0.830
1-344	04-16-2023	16:21	1	1	220	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	12.326
1-344	04-17-2023	11:20	1	2	150	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	11.731
1-344	04-17-2023	14:45	1	3	230	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	13.110
1-344	04-17-2023	16:25	1	4	140	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.941
1-344	04-17-2023	16:50	1	5	160	--	--	--	1-344	04-17-2023	5	160	230	140	180	42	No data	No data	No data	No	Yes	0.58	2.212
1-346	02-29-2024	5:35	1	1	76	735	7.7	4.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.075
1-346	02-29-2024	7:45	1	2	120	327	11	2.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.270
1-346	02-29-2024	10:00	1	3	96	114	3.6	2.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.074
1-346	02-29-2024	11:05	1	4	90	226	3.4	2.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.109
1-346	02-29-2024	12:15	1	5	80	2110	3.5	2.6	1-346	02-29-2024	5	90	120	76	92	17	-0.51	0.59	-0.51	No	No	0.91	0.026
1-346	03-09-2024	5:45	2	1	75	1140	5.8	4.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.060
1-346	03-09-2024	7:15	2	2	77	372	5.2	4.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.100
1-346	03-10-2024	12:40	2	3	46	76.2	7.5	7.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.030
1-346	03-10-2024	13:50	2	4	86	754	5.8	3.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.270
1-346	03-10-2024	14:20	2	5	87	327	3.7	2.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.170
1-346	03-10-2024	15:50	2	6	120	431	2.6	1.9	1-346	03-10-2024	6	81.5	120	46	82	24	0.20	-0.92	-0.94	No	No	0.62	0.170
1-346	03-27-2024	8:20	3	1	99	634	8.6	6.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.068
1-346	03-27-2024	9:30	3	2	120	267	4.8	3.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.074
1-346	03-27-2024	12:00	3	3	100	225	5.8	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.068
1-346	03-27-2024	12:50	3	4	150	261	3.6	2.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.085
1-346	03-27-2024	13:55	3	5	120	612	5.4	2.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.125
1-346	03-27-2024	14:50	3	6	110	92.3	3.6	2.9	1-346	03-27-2024	6	115	150	99	117	19	-0.17	-0.65	-0.66	No	No	-0.09	0.313
1-347	02-29-2024	3:05	1	1	180	32.8	4.6	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	No data
1-347	02-29-2024	4:20	1	2	150	9.7	4.1	3.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	No data
1-347	02-29-2024	8:05	1	3	95	20.6	1	0.91	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.311
1-347	02-29-2024	9:15	1	4	140	6.5	1.5	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	No data
1-347	02-29-2024	11:00	1	5	170	3.9	2.7	2.3	1-347	02-29-2024	5	150	180	95	147	33	0.05	0.79	0.72	No	Yes	No data	No data

Station Code	Sample Date	Collection Time	Storm # for Site	Grab # for Storm	6PPD-Q (ng/L)	SSC (mg/L)	TOC (mg/L)	DOC (mg/L)	Station ID	Storm Date Ending	# 6PPD-Q grabs	Median 6PPD-Q	Max 6PPD-Q	Min 6PPD-Q	Mean 6PPD-Q	Stdev 6PPD-Q	Pearson R v SSC	Pearson R v TOC	Pearson R v DOC	Last < avg of first?	First > Avg of last?	Pearson R v Flow	Flow rate at time of grab (L/sec)
1-347	03-22-2024	5:50	2	1	300	71.1	8.7	8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.492
1-347	03-22-2024	6:50	2	2	140	16.9	2.1	1.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.966
1-347	03-22-2024	9:25	2	3	150	6.2	2.6	2.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.574
1-347	03-22-2024	10:25	2	4	200	10.6	3.2	3.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	No data
1-347	03-22-2024	12:00	2	5	170	4.8	2.7	2.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	No data
1-347	03-22-2024	13:00	2	6	170	2.5	2.6	2.7	1-347	03-22-2024	6	170	300	140	188	58	0.90	0.97	0.98	No	Yes	-0.59	No data
1-347	05-04-2024	0:35	3	1	160	15	15	14	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.160
1-347	05-04-2024	2:05	3	2	150	2.8	9.4	9.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.368
1-347	05-04-2024	4:05	3	3	110	2	3.5	3.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.165
1-347	05-04-2024	7:15	3	4	110	2.9	2.2	2.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.430
1-347	05-04-2024	8:30	3	5	120	2.6	2.7	2.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.259
1-347	05-04-2024	10:00	3	6	160	3.8	3.8	3.6	1-347	05-04-2024	6	135	160	110	135	24	0.58	0.69	0.68	No	Yes	-0.73	0.512
1-348	02-29-2024	7:35	1	1	<0.34	407	3.8	9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.142
1-348	02-29-2024	9:30	1	2	<0.34	73.3	11	9.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.313
1-348	02-29-2024	10:30	1	3	<0.34	230	8.6	7.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.973
1-348	02-29-2024	11:30	1	4	<0.34	80.4	8	7.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.209
1-348	02-29-2024	12:30	1	5	<0.34	82.7	8.3	7.3	1-348	02-29-2024	5	0.335	0.335	0.335	0	0	No data	No data	No data	No data	No data	No data	0.311
1-348	03-09-2024	6:00	2	1	<0.34	53.3	10	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.595
1-348	03-09-2024	7:30	2	2	<0.34	57.5	8.6	7.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.878
1-348	03-10-2024	12:10	2	3	<3.45	19.5	8.6	7.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.793
1-348	03-10-2024	13:10	2	4	<3.45	29.1	8.9	8.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.793
1-348	03-10-2024	14:30	2	5	<0.34	58.7	3.3	3.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.359
1-348	03-10-2024	15:30	2	6	<0.34	30.2	4.6	4.2	1-348	03-10-2024	6	0.335	3.45	0.335	1	2	No data	No data	No data	No data	No data	No data	2.124
1-348	03-22-2024	7:30	3	1	8.6	784	10	3.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.832
1-348	03-22-2024	8:20	3	2	<3.15	104	2.3	1.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.398
1-348	03-22-2024	9:15	3	3	1.4	233	1.8	1.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.964
1-348	03-22-2024	10:30	3	4	1.8	211	1.6	1.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.520
1-348	03-22-2024	11:45	3	5	2	47.1	2.5	2.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.113
1-348	3/22/2024	13:10	3	6	2.2	51.1	2	1.9	1-348	3/22/24	6	2.1	8.6	1.4	3	3	0.90	0.98	0.90	No	Yes	0.19	0.113
1-351	03-27-2024	6:45	1	1	140	128	1.3	0.95	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.229
1-351	03-27-2024	7:55	1	2	130	301	2.6	1.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.585
1-351	03-27-2024	10:20	1	3	160	57	1.6	1.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.536
1-351	03-27-2024	12:00	1	4	100	113	0.73	0.69	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5.899
1-351	03-27-2024	13:00	1	5	120	486	0.62	0.45	--	--	--	--	--	--	--	--	--	--	--	--	--	--	11.799
1-351	03-27-2024	14:10	1	6	140	66.7	1.1	0.84	1-351	03-27-2024	6	135	160	100	132	20	-0.38	0.42	0.31	No	No	-0.63	1.195
1-351	04-25-2024	18:30	2	1	370	292	25	21	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.053
1-351	04-25-2024	21:15	2	2	290	78.5	5.5	5.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.599
1-351	04-25-2024	22:30	2	3	180	92.6	3.5	3.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.492
1-351	04-26-2024	6:30	2	4	150	54.9	1.7	1.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.212
1-351	04-26-2024	7:30	2	5	120	17.5	1.6	1.6	1-351	04-26-2024	5	180	370	120	222	105	0.87	0.87	0.88	Yes	Yes	0.09	0.577
1-352	03-27-2024	7:50	1	1	76	59.9	2.4	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	No data
1-352	03-27-2024	10:25	1	2	66	15.4	3.2	2.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	No data
1-352	03-27-2024	12:05	1	3	76	61.3	1.5	1.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	No data
1-352	03-27-2024	13:05	1	4	81	120	1.4	1.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	No data
1-352	03-27-2024	14:15	1	5	62	22.9	2.2	2	1-352	03-27-2024	5	76	81	62	72	8	0.91	-0.65	-0.72	Yes	No	No data	No data
1-352	04-26-2024	6:00	2	1	30	18.9	7.6	7.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	No data
1-352	04-26-2024	7:00	2	2	41	18.2	6	5.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	No data
1-352	04-26-2024	8:00	2	3	23	12.6	10	9.6	1-352	04-26-2024	3	30	41	23	31	9	0.73	-0.97	-0.99	Yes	No	No data	No data

Station Code	Sample Date	Collection Time	Storm # for Site	Grab # for Storm	6PPD-Q (ng/L)	SSC (mg/L)	TOC (mg/L)	DOC (mg/L)	Station ID	Storm Date Ending	# 6PPD-Q grabs	Median 6PPD-Q	Max 6PPD-Q	Min 6PPD-Q	Mean 6PPD-Q	Stdev 6PPD-Q	Pearson R v SSC	Pearson R v TOC	Pearson R v DOC	Last < avg of first?	First > Avg of last?	Pearson R v Flow	Flow rate at time of grab (L/sec)
1-353	10/12/2024	4:55	1	1	240	15.6	103	102	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-353	10/12/2024	7:00	1	2	180	9.5	56	49	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-354	10/12/2024	5:05	1	1	2.5	0.7	1.8	1.8	--	s - only two sa	--	--	--	--	--	--	--	--	--	--	--	--	--
1-354	10/12/2024	7:10	1	2	3.6	1.3	4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-355	10/12/2024	5:15	1	1	2.0	2.6	4.1	3.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1-355	10/12/2024	7:20	1	2	4.8	3.5	6.8	6.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	01-13-2023	10:30	1	1	210	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	01-13-2023	12:30	1	2	180	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	01-13-2023	13:40	1	3	360	--	--	--	3-412	01-13-2023	3	210	360	180	250	96	No data	No data	No data	No	No	No data	--
3-412	04-13-2024	9:20	2	1	390	27.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	04-13-2024	9:50	2	2	530	22	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	04-13-2024	10:16	2	3	490	72.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	04-13-2024	10:37	2	4	630	74.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	04-13-2024	11:06	2	5	480	89.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	04-13-2024	12:02	2	6	500	20.2	--	--	3-412	04-13-2024	6	495	630	390	503	78	0.31	No data	No data	No	No	No data	--
3-412	05-04-2024	9:15	3	1	240	41.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	05-04-2024	10:00	3	2	550	19	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	05-04-2024	10:45	3	3	560	75.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	05-04-2024	12:30	3	4	520	44.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	05-04-2024	13:55	3	5	460	14.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-412	05-04-2024	14:15	3	6	510	11.7	--	--	3-412	05-04-2024	6	515	560	240	473	120	0.04	No data	No data	No	No	No data	--
4-434	01-13-2023	10:11	1	1	92	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.735
4-434	01-13-2023	11:02	1	2	255	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.280
4-434	01-13-2023	12:13	1	3	240	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.880
4-434	01-14-2023	7:05	1	4	150	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	15.450
4-434	01-14-2023	19:01	1	5	400	--	--	--	4-434	01-14-2023	5	240	400	92	227	117	No data	No data	No data	No	No	-0.07	4.910
4-434	03-21-2023	7:50	2	1	110	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.002
4-434	03-21-2023	8:55	2	2	230	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.380
4-434	03-21-2023	10:15	2	3	190	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.150
4-434	03-21-2023	10:35	2	4	180	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.530
4-434	03-21-2023	19:30	2	5	240	--	--	--	4-434	03-21-2023	5	190	240	110	190	51	No data	No data	No data	No	No	0.76	2.850
4-434	01-13-2024	18:50	3	1	25	8.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.016
4-434	01-13-2024	19:30	3	2	460	65.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	11.570
4-434	01-13-2024	20:30	3	3	290	22.75	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4.380
4-434	01-13-2024	21:30	3	4	240	13.4	--	--	4-434	01-13-2024	4	265	460	25	254	179	0.87	No data	No data	No	No	0.90	0.888
4-434	01-31-2024	15:25	4	1	44	3.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.390
4-434	01-31-2024	17:25	4	2	320	25.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.220
4-434	01-31-2024	19:25	4	3	370	17.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4.300
4-434	01-31-2024	20:25	4	4	260	55.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	27.580
4-434	01-31-2024	21:25	4	5	220	18.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.300
4-434	01-31-2024	23:25	4	6	190	8.9	--	--	4-434	01-31-2024	6	240	370	44	234	114	0.45	No data	No data	No	No	0.19	4.190

Station Code	Sample Date	Collection Time	Storm # for Site	Grab # for Storm	6PPD-Q (ng/L)	SSC (mg/L)	TOC (mg/L)	DOC (mg/L)	Station ID	Storm Date Ending	# 6PPD-Q grabs	Median 6PPD-Q	Max 6PPD-Q	Min 6PPD-Q	Mean 6PPD-Q	Stdev 6PPD-Q	Pearson R v SSC	Pearson R v TOC	Pearson R v DOC	Last < avg of first?	First > Avg of last?	Pearson R v Flow	Flow rate at time of grab (L/sec)
4-435	01-13-2023	10:35	1	1	370	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.108
4-435	01-13-2023	11:18	1	2	480	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.070
4-435	01-13-2023	12:34	1	3	31	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.456
4-435	01-14-2023	7:15	1	4	27	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.300
4-435	01-14-2023	19:11	1	5	32	--	--	--	4-435	01-14-2023	5	32	480	27	188	220	No data	No data	No data	No	Yes	-0.39	2.510
4-435	03-21-2023	8:50	2	1	7.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.004
4-435	03-21-2023	9:30	2	2	5.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4.340
4-435	03-21-2023	10:25	2	3	9.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.530
4-435	03-21-2023	10:55	2	4	12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4.040
4-435	03-21-2023	19:50	2	5	31	--	--	--	4-435	03-21-2023	5	9.4	31	5.9	13	10	No data	No data	No data	No	No	-0.11	2.140
4-435	01-13-2024	19:46	3	1	34	10.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.150
4-435	01-13-2024	20:10	3	2	14	3.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4.860
4-435	01-13-2024	20:45	3	3	10	2.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4.050
4-435	01-13-2024	21:40	3	4	14	1.7	--	--	4-435	01-13-2024	4	14	34	10	18	11	0.97	No data	No data	No	Yes	0.85	3.330
4-435	01-31-2024	16:50	4	1	9.5	4.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.770
4-435	01-31-2024	18:50	4	2	20	3.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.120
4-435	01-31-2024	20:50	4	3	48	11.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4.260
4-435	01-31-2024	21:50	4	4	40	12.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.840
4-435	01-31-2024	22:50	4	5	46	2.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	10.480
4-435	01-31-2024	23:50	4	6	50	1.7	--	--	4-435	01-31-2024	6	43	50	9.5	36	17	0.21	No data	No data	No	No	0.78	7.630
4-445	01-31-2024	10:40	1	1	320	50.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.010
4-445	01-31-2024	13:50	1	2	600	44.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.040
4-445	01-31-2024	14:45	1	3	730	54.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.050
4-445	01-31-2024	18:10	1	4	650	47.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.080
4-445	01-31-2024	19:10	1	5	410	27	--	--	4-445	01-31-2024	5	600	730	320	542	171	0.45	No data	No data	No	No	-0.40	1.400
4-445	02-29-2024	15:20	2	1	230	134	6	6.2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.110
4-445	03-01-2024	14:10	2	2	310	165	7.5	6.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.030
4-445	03-01-2024	16:35	2	3	330	624	13	5.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.090
4-445	03-01-2024	17:05	2	4	440	51.9	2.7	2.3	4-445	03-01-2024	4	320	440	230	328	87	-0.13	-0.34	-0.88	No	No	0.22	0.760
4-445	04-13-2024	3:48	3	1	660	598	34	32	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.819
4-445	04-13-2024	4:25	3	2	230	33.3	13	13	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.416
4-445	04-13-2024	5:10	3	3	190	163	11	11	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.229
4-445	04-13-2024	6:00	3	4	240	22.6	9.3	9.3	4-445	04-13-2024	4	235	660	190	330	221	0.94	0.98	0.98	No	Yes	0.93	0.172
4-446	01-31-2024	12:20	1	1	52	65.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.060
4-446	01-31-2024	14:25	1	2	100	69	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.500
4-446	01-31-2024	15:10	1	3	99	69.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.500
4-446	01-31-2024	18:40	1	4	53	10.3	--	--	4-446	01-31-2024	4	76	100	52	76	27	0.62	No data	No data	No	No	0.64	0.600
4-446	03-22-2024	19:15	2	1	77	61	42	41	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.460
4-446	03-22-2024	20:10	2	2	48	49.6	4.5	4.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.079
4-446	03-22-2024	21:15	2	3	56	8.5	5.6	5.5	4-446	03-22-2024	3	56	77	48	60	15	0.44	0.97	0.97	No	Yes	-0.88	2.318
4-446	03-27-2024	17:00	3	1	110	296	28	28	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.229
4-446	03-27-2024	17:30	3	2	100	10.6	4.8	4.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.430
4-446	03-27-2024	21:20	3	3	93	28.7	13	13	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.574
4-446	03-27-2024	22:20	3	4	64	6.3	4.6	4.4	4-446	03-27-2024	4	96.5	110	64	92	20	0.64	0.67	0.67	Yes	Yes	0.27	0.205

Station Code	Sample Date	Collection Time	Storm # for Site	Grab # for Storm	6PPD-Q (ng/L)	SSC (mg/L)	TOC (mg/L)	DOC (mg/L)	Station ID	Storm Date Ending	# 6PPD-Q grabs	Median 6PPD-Q	Max 6PPD-Q	Min 6PPD-Q	Mean 6PPD-Q	Stdev 6PPD-Q	Pearson R v SSC	Pearson R v TOC	Pearson R v DOC	Last < avg of first?	First > Avg of last?	Pearson R v Flow	Flow rate at time of grab (L/sec)
5-312	01-31-2024	22:12	1	1	480	915	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.283
5-312	01-31-2024	22:50	1	2	370	207	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.133
5-312	01-31-2024	23:43	1	3	240	220	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.115
5-312	02-01-2024	0:15	1	4	250	273	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	12.176
5-312	02-01-2024	5:55	1	5	220	49.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.398
5-312	02-01-2024	7:01	1	6	420	44.7	--	--	5-312	02-01-2024	6	310	480	220	330	108	0.59	No data	No data	No	Yes	-0.60	1.416
5-312	04-13-2024	13:00	2	1	400	63.8	12	12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.114
5-312	04-13-2024	13:40	2	2	340	186	12	12	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.329
5-312	04-13-2024	14:20	2	3	410	69.7	5.7	5.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.320
5-312	04-13-2024	15:05	2	4	580	466	3	3.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	11.947
5-312	04-13-2024	15:45	2	5	340	43.5	2.6	2.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5.099
5-312	04-13-2024	16:35	2	6	300	32.8	2.8	2.7	5-312	04-13-2024	6	370	580	300	395	100	0.86	-0.16	-0.13	Yes	No	0.74	1.678
5-313	05-04-2024	8:30	1	1	220	62.1	43	29	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.012
5-313	05-04-2024	9:30	1	2	190	40	16	15	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.750
5-313	05-04-2024	10:30	1	3	120	24.4	7.2	6.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.613
5-313	05-04-2024	11:00	1	4	120	44.7	3.4	2.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.000
5-313	05-04-2024	12:15	1	5	87	7.2	5.5	4.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.300
5-313	05-04-2024	13:00	1	6	65	6.6	6.2	5.7	5-313	05-04-2024	6	120	220	65	134	60	0.89	0.84	0.88	Yes	Yes	-0.11	0.200
5-314	02-29-2024	10:00	1	1	39	19.2	16	15	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.030
5-314	02-29-2024	12:10	1	2	24	28.5	11	10	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.200
5-314	02-29-2024	18:45	1	3	4.35	36	2.7	2.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.380
5-314	03-01-2024	14:30	1	4	<3.5	2.8	5.5	5.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.090
5-314	03-01-2024	18:20	1	5	<3.5	8.5	4.3	4.5	5-314	03-01-2024	5	4.35	39	3.45	15	16	0.25	0.98	0.97	No	Yes	-0.38	0.110
5-314	03-27-2024	21:45	2	1	14	13	5.4	4.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.043
5-314	03-27-2024	22:15	2	2	16	264	4.8	4.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.100
5-314	03-27-2024	22:45	2	3	14	28.6	3.5	2.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.250
5-314	03-27-2024	23:45	2	4	16	115	3.7	2.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.750
5-314	03-28-2024	0:45	2	5	6.8	59.6	2.7	2.1	5-314	03-28-2024	5	14	16	6.8	13	4	0.41	0.64	0.48	Yes	No	-0.72	1.200
5-314	04-13-2024	1:10	3	1	8.6	287	5.9	4.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.043
5-314	04-13-2024	2:30	3	2	16	136	5.3	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.111
5-314	04-13-2024	4:45	3	3	<3.6	8	5.1	4.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.286
5-314	04-13-2024	6:15	3	4	<3.3	11.1	4.9	4.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.200
5-314	04-13-2024	9:00	3	5	<3.5	13.4	5.4	5.1	5-314	04-13-2024	5	3.55	16	3.25	7	6	0.58	0.34	0.23	No	No	-0.39	0.063
7-426	01-14-2023	9:45	1	1	330	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7-426	01-14-2023	10:35	1	2	370	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7-426	01-14-2023	13:16	1	3	280	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7-426	01-14-2023	15:06	1	4	310	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7-426	01-14-2023	18:10	1	5	290	--	--	--	7-426	01-14-2023	5	310	370	280	316	36	No data	No data	No data	No	No	No Data	--

Station Code	Sample Date	Collection Time	Storm # for Site	Grab # for Storm	6PPD-Q (ng/L)	SSC (mg/L)	TOC (mg/L)	DOC (mg/L)	Station ID	Storm Date Ending	# 6PPD-Q grabs	Median 6PPD-Q	Max 6PPD-Q	Min 6PPD-Q	Mean 6PPD-Q	Stdev 6PPD-Q	Pearson R v SSC	Pearson R v TOC	Pearson R v DOC	Last < avg of first?	First > Avg of last?	Pearson R v Flow	Flow rate at time of grab (L/sec)
10-306	01-19-2024	22:10	1	1	560	73.9	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.200
10-306	01-19-2024	23:10	1	2	520	55.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.160
10-306	01-19-2024	23:50	1	3	460	46.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.270
10-306	01-20-2024	0:30	1	4	510	52.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.030
10-306	01-20-2024	16:30	1	5	570	117	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.020
10-306	01-20-2024	21:50	1	6	330	34	--	--	10-306	01-20-2024	6	515	570	330	492	88	0.75	No data	No data	Yes	Yes	0.178	0.020
10-306	01-31-2024	22:37	2	1	430	103	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.067
10-306	01-31-2024	23:55	2	2	400	83.3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.281
10-306	02-01-2024	0:50	2	3	250	49.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.183
10-306	02-01-2024	2:10	2	4	150	29.2	--	--	10-306	02-01-2024	4	325	430	150	308	131	0.99	No data	No data	Yes	Yes	0.21	0.100
10-307	01-31-2024	23:45	1	1	59	58.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.039
10-307	02-01-2024	0:15	1	2	58	61.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.044
10-307	02-01-2024	0:55	1	3	57	51	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.037
10-307	02-01-2024	2:00	1	4	46	25.7	--	--	10-307	02-01-2024	4	57.5	59	46	55	6	0.98	No data	No data	Yes	No	0.97	0.012

Notes: No data indicates correlation not analyzed for lack of SSC, TOC or DOC data, or because of excessive non-detects in 6PPD-Q data
Data below detection limit are treated as the detection limit and indicated as "< MDL" in the results (where MDL is the actual balue of the MDL)
Yellow highlights indicate statistically significant ($p < 0.05$) correlation
Horizontal lines demarcate groups of data for statistical summary
Blank entries indicate no data available