A Preliminary Cost Estimate for Reducing 6PPD-Q Pollution of Salmonid Critical Habitat in the Pacific Northwest and Northern California

Spawning coho in the Quilcene River, Washington. Photo courtesy of NOAA Fisheries.

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STATEMENT OF QUALIFICATIONS

This analysis was prepared by Dr. John Talberth, who serves as President and Senior Economist for Center for Sustainable Economy (CSE). CSE is an environmental economics think tank that provides expert analysis for government, business, and non-profit clients in addition to leading strategic initiatives on forests and biodiversity, climate justice, new measures of progress, and green infrastructure.

Dr. Talberth holds a Ph.D. in Economics from the University of New Mexico and a master's degree in Planning, Public Policy, and Management from the University of Oregon. He regularly publishes peer-reviewed articles and technical reports for clients in his areas of expertise, which include benefit-cost analysis, water resources, forest management, sustainability indicators, climate change impacts and non-market valuation.

With respect to water resources, he has pioneered methods to compare green vs. grey infrastructure investments, evaluated the ecological footprint of intensive aquaculture, quantified non-market values of coastal and riverine ecosystems, led independent benefit-cost analyses of major port and mine expansions affecting fisheries and developed a "pay for performance" approach for optimizing investments in agricultural and stormwater best management practices to reduce nutrient pollution into the Chesapeake Bay. A full CV is included as Appendix F to this report.

SYNOPSIS

Coho salmon (*Oncorhynchus kisutch*) face acute toxicity from the contaminant 6PPD-Quinone (6PPD-Q) in stormwater runoff as they enter freshwater streams and rivers on their seasonal spawning migrations. Mortality events of more than 90% have been observed. 6PPD-Q has also been shown to be toxic, although to a lesser extent, to steelhead trout and Chinook salmon. 6PPD-Q is a transformation product of the ubiquitously used tire rubber antiozonant 6PPD. Scientists and federal and state agencies have identified several best management practices (BMPs) to reduce concentrations of 6PPD-Q below lethal levels.

One significant question that has yet to be researched on a large or regional scale is the overall cost of employing effective best management practices to reduce or eliminate 6PPD-Q from entering aquatic habitats. This report begins to fill that void by presenting cost estimates of plausible 6PPD-Q reduction strategies for the 24 populations of coho, Chinook, and steelhead that are listed under the Endangered Species Act in California, Oregon, Washington and Idaho. We combined spatial analysis of impervious surface areas and high traffic roadways near critical habitat reaches with cost data for three BMP categories – biofiltration, porous pavement, and media filters – to produce a range of cost estimates under different assumptions about program scale and scope. In today's (2025) dollars, we find that a strategy that treats over 353,000 acres of impervious surface within ¼ mile of critical habitat or nearly 23,000 miles of high traffic roadways is likely to cost between $25 and $123 billion to implement depending on the species targeted and the number and type of BMPs necessary for eliminating salmonid mortality.

1.0 BACKGROUND

For the past two decades, researchers in the Pacific Northwest have been studying urban runoff mortality syndrome (URMS) in coho salmon (*Oncorhynchus kisutch*). In 2020, researchers identified a specific chemical in stormwater that was directly linked to URMS. The chemical, 6PPD-Q, forms from an antiozonant, 6PPD, which has been used in tires to extend their lifespan since the 1960s.

Figure 1: *Line-up of coho for pre-spawn mortality surveys. Image courtesy of Wild Fish Conservancy.*

6PPD-Q is acutely toxic to coho and, to a lesser degree, steelhead (*Oncorhynchus mykiss*) and Chinook (*Oncorhynchus tshawytscha*) (Tian et al. 2021, 2022; Brinkmann et al. 2022; Hiki et al. 2021).[1]

In terms of lethal concentrations, the adult 24-hour lethal concentration associated with 50% mortality (LC_{50}) for juvenile coho salmon is 0.095 micrograms per liter (μg/L) (Tian et al., 2022), whereas the 3-week post-swim up stage for coho salmon has an LC_{50} of 0.041 μg/L (Lo et al., 2023). Furthermore, embryonic exposure to 6PPD-Q inhibits development and growth of alevins in the absence of mortality (Greer et al., 2023).

Rainbow trout are also sensitive but at higher concentrations with an LC_{50} ranging from 1.0 to 2.3 μg/L during 72- and 24-h exposures, respectively (Brinkmann et al., 2022; Di et al., 2022). Sensitivity has been observed in steelhead trout and Chinook salmon when exposed to undiluted stormwater runoff (French et al., 2022). Steelhead LC_{50} has been found to be about 1.0 ug/L.

[1] See also, Washington Department of Fish and Wildlife, 6PPD, available online at: https://wdfw.wa.gov/species-habitats/science/marine-toxics/6ppd.

Significant mortality events have been documented for decades and across many urban watersheds (Feist et al., 2011). Scholtz (2011) describes a 60%-100% pre-spawn mortality event in Longfellow creek, west Seattle, a range found often in the literature. In California, Oregon, and Washington, the chemical has been detected in streams and stormwater runoff at concentrations shown to kill at least half of coho in laboratory studies.[2]

Landscape modeling has shown that the severity of coho spawner mortality scales with the extent of imperviousness within a watershed (Feist et al., 2011) and, more specifically, the density of motor vehicle traffic near spawning habitats (Feist et al., 2017; Chow et al. 2019). Other factors include whether the stormwater runoff into receiving waters is mostly treated or untreated (KCWLD, 2024), traffic volume, heavier vehicles, more lanes, higher speeds, more turning and stopping, more impervious surface and absence of natural infiltration processes (Cappiella et al., 2012; WDOE, 2022a).

Taken together, these aspects of 6PPD-Q and its effects on salmonids suggest some broad design criteria for an effective regional strategy:

1. Areas of impervious surfaces where there are currently no BMPs or other treatment of stormwater should be a priority.

2. Proximity to streams matters. A rule of thumb suggested by research and other stormwater policies is ¼ mile.[3]

3. High traffic roadways matter. Concentrations of 6PPD and 6PPD-Q are greatest on arterial roads, freeways, and other congested roadways, especially those which accommodate heavier vehicles (Tian et al., 2020).

4. Hot spot mapping can help pinpoint priority BMP sites. In addition to critical habitat proximity, lack of treatment, and high traffic volume, there are a number of other factors that can help planners identify impervious surfaces in most need of treatment. This includes the pattern of stormwater conveyance. King County recently developed a screening model for 6PPD-Q export that included this factor

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[2] California Ocean Protection Council, 2025. California Proposes New Requirement for Tiremakers to Seek Chemical Alternatives to Protect Water Quality, Coho Salmon. Available online at: https://opc.ca.gov/2022/05/california-proposes-new-requirement-for-tiremakers-to-seek-chemical-alternatives-to-protect-water-quality-coho-salmon/; Herrera (2024)

[3] Mackiewicz, E., City of Bellingham, personal communication. See also KCWLD, 2024, discussion of phosphorous standards and WDOE (2012) for guidance on stormwater impact analysis.

and found primary arterial roads in urban, developed areas, especially those with higher density of freight traffic, to pose the greatest risk (Herrera, 2025).

5. Any best management practices portfolio adopted should address multiple species whenever possible. This is because critical habitat[4] designated for salmonid species overlap to a considerable degree. For example, according to spatial analysis provided by the Remote Sensing Laboratory at the University of Saint Louis (SLU, 2025) Coho critical habitat encompasses 15,343 stream miles, but 5,443 miles of this habitat is also critical habitat of one or more other species. Thus, a single BMP can be located to protect multiple at-risk fish.

2.0 WHAT WE KNOW ABOUT BMPS TO REDUCE 6PPD AND 6PPD-Q

Best management practices (BMPs) to prevent 6PPD and 6PPD-Q pollution from reaching aquatic habitats are currently under investigation by several federal and state agencies and internationally. BMPs can be grouped into two broad categories – flow and treatment BMPs and source control BMPS. Flow and treatment BMPs are "physical, structural, or mechanical devices intended to limit pollutants from entering stormwater infrastructure by providing water quality or hydrologic benefit, using specific treatment process" (WSDOT, 2019; WDOE, 2019). Examples include media filter boxes and vaults, biofiltration structures, and porous pavement. King County (Mitchell, 2024) tested untreated vs. treated stormwater runoff over three storm events and found that Coho survival was 0–5 % in untreated stormwater influent compared to 100% survival across all effluents treated by any of the 3 best management practices (BMPs) tested.

Source control BMPs are "practices meant to prevent the interaction of stormwater with pollutants through physical separation or management of activities that are sources of pollutants" (WSDOT, 2019; WDOE, 2019). Examples of source control BMPs include education and outreach programs or line cleaning.

Washington's Department of Ecology (WDOE, 2022b) evaluated 92 flow and treatment BMPs and 84 source control BMPs classifying each into high, medium, and low categories of effectiveness. The criteria applied to flow and treatment BMPs was based on reductions in the volume of runoff and thereby the contaminant load carried to surface water along with observed reductions of 6PPD-Q concentrations. The criteria for source control BMPs was developed based upon preventing tire wear particles from entering stormwater infrastructure or altering the physicochemical properties of 6PPD and 6PPD-Q, particularly the tendency to adhere to soil particles or organic matter.

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[4] For the purpose of this analysis the definition of critical habitat used herein is the habitat designated by NOAA Fisheries under the Endangered Species Act at 16 U.S.C. § 1532(5).

Overall, the analysis found that 85% of flow and treatment BMPs were capable of reducing 6PPD and 6PPD-Q at a moderate to high level while only 15% of source control BMPs fell into these categories. In fact, there is very little research supporting the idea that source control BMPs would be effective at all. For this reason, the scope of this analysis has been limited to flow and treatment BMPs except in instances when a source control BMP is required as an ancillary activity (i.e. vacuum sweeping of porous pavement). Three categories of flow and treatment BMPs considered here include biofiltration, porous pavement, and media filters.

2.1 Biofiltration and bioretention

Biofiltration is the process of improving stormwater or wastewater quality by filtering water through biologically influenced media (Hatt et al., 2009). In less technical terms, it means filtering polluted water through various facilities that rely on natural vegetation and soils to a large extent but which often include artificial filtration media as well.

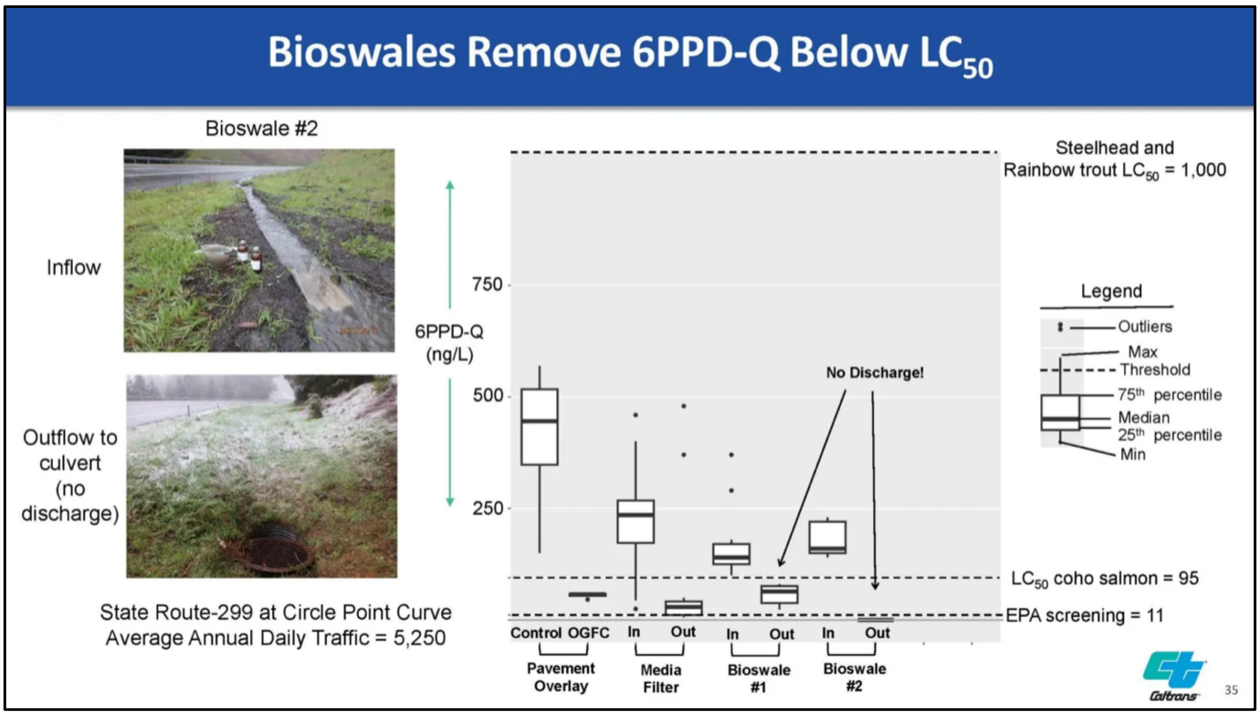
Figure 2: *A typical stormwater bioswale that combines natural filtration with an underground media filter. Image courtesy of the Klausing Group.*

Biofiltration facilities are often paired with bioretention facilities that store the treated water and percolate it underground. Biofiltration facilities can be small or large and encompass a wide range of designs including rain gardens, planters, swales, vegetated strips, artificial wetlands and stormwater ponds.

Some key considerations of using biofiltration BMPs are the amount of land needed and the necessity of using native vegetation that does not require supplemental irrigation during dry months.

Other criteria that must be considered in siting and design relate to the characteristics of underlying soils, slopes, and receiving waters and avoiding release of harmful metals and nutrients from certain soil mixes (WDOE, 2012). Biofiltration has been demonstrated to be effective at filtering 6PPD-Q. CalTrans is monitoring biofiltration facilities and has reported positive outcomes (Figure 3) at three different locations.[5] As noted above, King County found that BMPs using a high performance bioretention soil mix (HPBSM) reduced the risk of coho mortality from stormwater while also eliminating metals and nutrients of concern (Mitchell, 2024).

Figure 3: *CalTrans bioswale monitoring results along State Routes 299 and 271. Data from porous pavement and media filters are also shown for comparison purposes. Image courtesy of Maven's Notebook.*



2.2 Porous pavement

Pervious or porous pavements allow stormwater to filter through voids in the pavement surface into an underlying rock reservoir where it is temporarily stored and infiltrated into the surrounding materials. While porous pavement designs may vary, they all have a similar structure consisting of a surface pavement layer with an underlying reservoir

[5] For an overview of the CalTrans monitoring project, see NOTEBOOK FEATURE: From roads to rivers: How state agencies are tackling salmon-killing tire pollution. Maven's Notebook – California Water News Central. Available online at: ; https://mavensnotebook.com/2025/01/07/notebook-feature-from-roads-to-rivers-how-state-agencies-are-tackling-salmon-killing-tire-pollution/.

layer (CalTrans, 2023). Porous pavement can be asphalt used on road surfaces or concrete used primarily for sidewalks and driveways. For purposes of this analysis, we limit consideration to porous asphalt only since it is relevant to large impervious surface areas, including high traffic roadways.

Porous asphalt uses a standard asphalt mix with no sand or other fine materials and a polymer binder to provide strength and stability. The lack of fine materials in this mixture allows rain and snowmelt to pass through to a subbase of stone aggregate that both supports the asphalt layer and provides storage for and treatment of rainfall or snowmelt (PVPC, 2015).

Figure 4: *Porous asphalt overlay in Gresham, Oregon, 17 years after installation.*

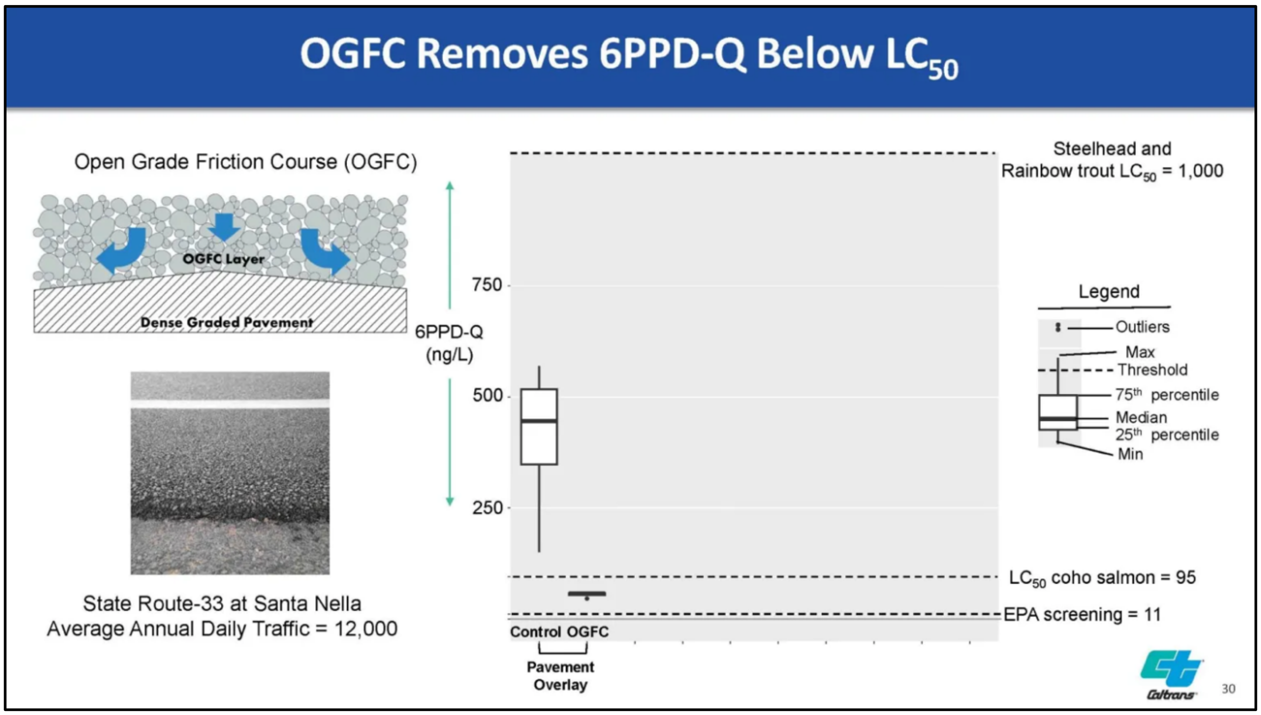
A porous asphalt layer can be installed as part of the original roadway design (i.e. for new roads) or when major reconstruction is needed or overlaid on existing asphalt. Porous overlays allow for drainage of stormwater below the overlay to a stormwater inlet, providing many of the same benefits as full-depth porous pavements but without infiltration (Holzer et al., 2022). Porous overlays are significantly less expensive since they do not require tearing up existing surfaces to install an infiltration layer beneath (Kilgore, 2023).

Porous asphalt is limited by its relatively high cost and because it is not suitable for many locations. These include places where sediment or debris drain onto the surface from surrounding lands, where there are structural foundations and utilities beneath the roadway, where vacuuming and other routine maintenance activities are not feasible, or where winter sanding is regularly used (CalTrans, 2023).

Porous asphalt, whether newly installed or installed as an overlay has been shown to be highly effective at reducing 94% - 99% of total suspended solids, 76% - 97% of metals and 42% - 43% of nutrients (EPA, 2021). It has also been shown to be an effective BMP for stormwater pollutants. Holzer and Poor (2024) sampled typical stormwater pollutants in runoff from sections of an arterial road 9–16 years after installation of three pavement types: control with conventional asphalt, porous asphalt overlay, and full-depth porous asphalt. Both types of porous pavements substantially reduced most of the stormwater pollutants measured. Total suspended solids, turbidity, total lead, total copper, and 6PPD-Q were all reduced by >75%.

CalTrans is also monitoring the effectiveness of porous asphalt for 6PPD-Q reduction. At a monitoring point in the Central Valley near Santa Nella on a high-traffic roadway the agency found that that without the porous asphalt treatment (here, an open graded friction course or OGFC, made with some concrete in the mix) the location had about 400 nanograms per liter of 6PPD-Q concentrations, about four times higher than the 95 ng/L LC_{50} for coho salmon. However, treatment by OGFC reduces 6PPD-Q concentrations in stormwater discharges to below that level (Figure 5).

Figure 5: *CalTrans monitoring results at State Road 33 in Santa Nella. Image courtesy of Maven's Notebook.*



2.3 Media filter boxes, vaults, and strips

A media filter BMP uses a bed of sand, peat, zeolite, anionic and/or cationic media, granite or other fine-grained materials or fabrics to physically separate sediment and sediment-bound pollutants and/or electro-chemically remove dissolved constituents from storm water (County of San Diego, 2018). Stormwater media filters are usually housed within a two-chambered structure including a pretreatment settling basin and a filter bed filled with sand or other absorptive filtering media.

As stormwater flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as stormwater flows through the filtering media in the second chamber (CASQA, 2003). Some specific designs include the Austin sand filter, Delaware sand filter, and multi-chambered treatment train (Figure 2).

Figure 6: *A multi-chamber treatment train designed by StormTrap, Inc.*

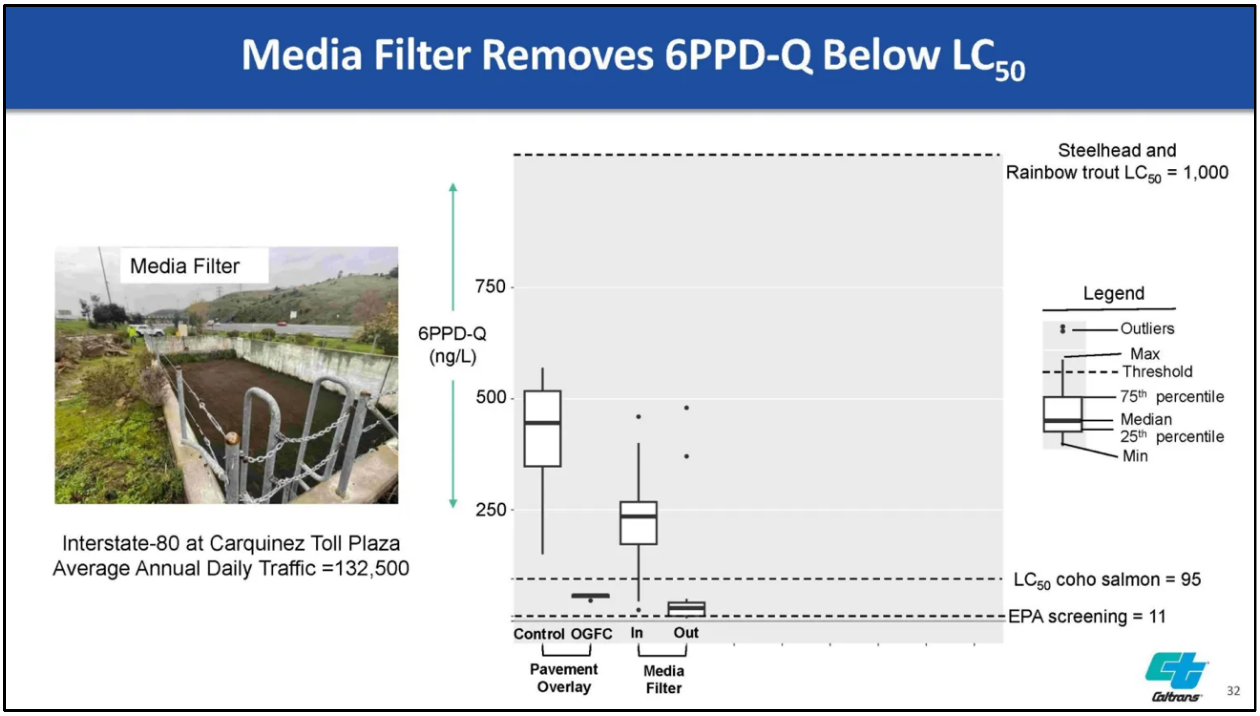
Some key considerations associated with these BMPs include high construction costs, small impervious surface areas drained, and the need for regular maintenance to unclog, clean or replace filters.

Media filters may also require a polishing layer to fully remove 6PPD and 6PPD-Q associated with smaller tire wear particles (McIntyre and Kolodziej, 2021).

With these considerations, evidence suggests that with proper maintenance and polishing, many types of media filter BMPs may be effective at reducing 6PPD-Q. Figure 7 presents results of a California Department of Transportation (CalTrans) monitoring study at the Carquinez Toll Plaza at Interstate 80 in the San Francisco Bay Area.

The media filter treats stormwater from eight freeway lanes and toll Plaza traffic. The inflowing stormwater has 200 nanograms per liter of 6PPD-Q concentrations, about double the 95 ng/L LC_{50} for coho salmon reported by Tian et al. 2022. After passing through the media filter, discharge water flowing into the San Francisco Bay was found to have 6PPD-Q concentrations below the 95 ng/L, although still higher than the Environmental Protection Agency's Aquatic Life Screening Value of 11 ng/L.

__Figure 7:__ CalTrans monitoring results at the I-80 Carquinez Toll Plaza. Image courtesy of Maven's Notebook.



3.0 METHODS, DATA SOURCES AND RESULTS

This section presents the methods, data sources and results of a preliminary cost estimate for 6PPD-Q best management practices across the Pacific Northwest and northern California. It begins with a discussion of why a large range of estimates are provided at this stage in the design of a regional best management practices strategy and then presents details of four analytical steps: (1) spatial analysis, (2) cost analysis, (3) jurisdictional analysis, and (4) extrapolation to the region. All calculation steps can be viewed on the spreadsheet accompanying this report (Appendix A).

3.1 <u>Initial costs based on assumptions about program scale</u>

For large, water-related engineering and economic studies of projects or programs that have yet to be specified in any detail the best practice is to begin with an analysis of costs associated with plausible minimum and maximum scales. This necessarily results in a large range of cost estimates which are refined once project or program alternatives are developed by the relevant agencies. Since there are no proposals on the table for a regional 6PPD-Q mitigation strategy, this report provides plausible scenarios based on assumptions about the quantity of impervious acres (IA) or high traffic roadways (HTR) treated and which practices are appropriate. In particular, and as explained in more detail in Section 3.5, the plausible maximum treatment scale considered here is treatment of roughly 60% of the IA within ¼ mile of critical habitat (353,037 IA) and the plausible minimum scale considered is 60% of high traffic roadways within critical habitat watersheds (22,639 HTR miles).

3.2 Spatial analysis

CSE contracted with the Remote Sensing Lab at Saint Louis University (SLU) and the Elastic Data Lab in Portland, OR to complete a multi-level analysis of stream miles, impervious acres (IA) and high traffic roadway miles (HTR) at the level of critical habitat units (CHUs) for each species and for four jurisdictions that were used as the basis of unit-cost estimates – Bellingham, Gresham, King County and the combined areas of Eureka, Arcata, and McKinleyville, CA.

A separate analysis for the interstate highway system was conducted, focused on the number of critical habitat stream crossings. For both the CHU and jurisdictional levels the spatial analysis team estimated impervious surface areas and high traffic roadway miles in total and within ¼ mile of critical habitat streams for any of the three species. High traffic roadway miles encompass all arterial, highway, and interstate roads.

High traffic road miles and IA within ¼ mile of critical habitat are the two metrics selected to scale cost figures up to the combined area represented by critical habitat units for these species as mapped by NOAA fisheries.[6]

Table 1 reports species-specific and combined totals across Washington, Oregon, California and Idaho CHUs. Results of the jurisdictional analyses are presented in Table 2 and the interstate crossing analysis in Table 3.

Due to overlap between critical habitat streams occupied by two or more species the totals in Table 1, Table 3 had to be adjusted with a technique to eliminate double counting. This was done by estimating the total stream miles occupied by any species in a separate GIS analysis[7] (52,241 miles) and then by multiplying per-stream mile weighted averages for each metric by this value to produce adjusted totals that eliminated double counting.[8]

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[6] NOAA Fisheries, Critical Habitat – Maps and GIS Data, West Coast Region. Available online at: https://www.fisheries.noaa.gov/resource/map/critical-habitat-maps-and-gis-data-west-coast-region.

[7] This consisted of layering each CHU one at a time and only adding stream miles where they were not previously included. This reduced the total stream miles within CHUs from 60,398 to 52,241 miles.

[8] Weighted averages for the four key metrics were based on the total stream miles occupied. So, for example, Steelhead stream miles represent about 51% of the total and so had the heaviest weight in calculating the adjusted totals in Table 2.

Key metrics associated with these spatial analyses are the following:

Total stream miles occupied by coho, Chinook or steelhead:	52,241 miles
Total impervious surface area within CHUs:	5,996,226 acres
Total impervious surface area within ¼ mile of critical habitat:	588,396 acres
Total high traffic road miles within CHUs:	37,733 miles
Total high traffic road miles within ¼ mile of critical habitat:	7,364 miles
Total interstate crossings of critical habitat streams:	709

Table 1: Spatial analysis results - CHU level

Species	IA total CHU	IA .25 CH	HTR total	HTR .25 CH	Stream miles
Coho	835,485	112,703	5,917	1,870	15,343
Chinook	2,629,880	223,540	15,892	2,384	14,401
Steelhead	3,467,095	344,023	21,815	4,260	30,653
Unadjusted total	6,932,459	680,266	43,624	8,513	60,398
Adjusted total	5,996,226	588,396	37,733	7,364	52,241

Table 2: Spatial analysis results: jurisdiction level

Jurisdiction	IA total	IA .25 CH	HTR total	HTR .25 CH
Bellingham	6,443	1,688	73	22
Gresham	6,792	805	96	12
EAM California	5,341	768	72	23
King County	142,716	15,749	1,677	277

Table 3: Spatial analysis results: interstate CH crossings

Species	CH crossings
Coho	194
Chinook	226
Steelhead	400
Unadjusted total	820
Adjusted total	709

3.3 Cost analysis

CSE conducted a thorough review of the literature and public contracting data sources to develop current ($2025) estimates of 35 BMPs that fall into the three BMP categories discussed in Section 2 – biofiltration, porous asphalt, and media filter boxes and vaults. Costs include planning, installation and maintenance over 20 years.

Key sources of information included EPA (1997), Herrera (2021), City of Bellingham (2025), CalTrans (2025), King County (2025) and scattered estimates from the scientific literature.

CalTrans data was obtained from a database accessed through a public records request. The database permits users to search all awarded contracts for a particular type of BMP and receive high, low, median and weighted average costs for BMPs expressed in user-defined terms, such as cost per square foot, square meter, or acre. A sample query for Austin sand filter vaults is attached as Appendix B.

The City of Bellingham provided detailed cost estimates for eight projects relying on advanced treatment media filter BMPs. King County provided a booklet of practice sheets for 24 BMPs with details on treatment effectiveness, typical costs, IA treated and other useful data.

Where needed, all cost estimates were converted to a per-IA drained basis by examining BMP practice sheets published by one or more of the sources listed above. These practice sheets contain a wide range of data, such as the square footage of the BMP, the impervious and pervious surface area it can drain, the volume of stormwater runoff they can handle as well as data on installation and maintenance costs. A sample BMP practice sheet from King County for a high-performance soil bioretention project is attached as Appendix C.

Results are presented in Tables 4, 5, and 6 below and depict installation costs, annual maintenance costs, total maintenance costs over 20 years, and total practice cost. Line items with identical practice names reflect cost variations across multiple locations. Since most BMPs treat less than one acre of IA, the cost estimates may represent installation of more than one physical structure.

Table 4: BMP cost estimates for media filter boxes, vaults and strips
(All costs presented as $2025 per impervoius acre treated)

Practice	Installation cost	Maintenance cost	20-yr MC	Total cost
Sand filter	$32,114	$3,854	$77,075	$109,189
Media filter swale	$5,910	$59	$1,182	$7,092
Media filter strip	$5,090	$127	$2,545	$7,635
Modular wetland vault	$76,210	$762	$15,242	$91,451
Filterra boxless media	$48,061	$481	$9,612	$57,673
Modular wetland vault	$17,487	$175	$3,497	$20,985
BioPod media filter	$222,074	$2,221	$44,415	$266,489
POST media filter	$26,691	$267	$5,338	$32,029
POST media filter	$118,475	$1,185	$23,695	$142,170
BioPod media filter	$46,028	$460	$9,206	$55,233
BiPod swales and media vaults	$32,038	$320	$6,408	$38,446
Austin sand filters	$25,291	$3,035	$60,698	$85,989
Minimum:	$5,090	$59	$1,182	$7,092
Maximum:	$222,074	$3,854	$77,075	$266,489
Average:	$54,622	$1,079	$21,576	$76,199

Table 5: BMP cost estimates for porous pavement
(All costs presented as $2025 per impervoius acre treated)

Practice	Installation cost	Maintenance cost	20-yr MC	Total cost
Porous asphalt overlay + vaccu	$217,800	$1,307	$26,136	$243,936
Porous asphalt + vacuum	$479,160	$1,307	$26,136	$505,296
Porous asphalt + vaccum	$851,162	$1,307	$26,136	$877,298
Porous asphalt + vaccum	$645,124	$1,307	$26,136	$671,260
Porous asphalt overlay + vaccu	$217,800	$1,307	$26,136	$243,936
Porous asphalt + vaccum	$500,940	$1,307	$26,136	$527,076
Open graded friction course	$72,546	$1,307	$26,136	$98,682
Open graded friction course	$226,790	$1,307	$26,136	$252,926
Minimum:	$72,546	$1,307	$26,136	$98,682
Maximum:	$851,162	$1,307	$26,136	$877,298
Average:	$401,415	$1,307	$26,136	$427,551

Table 6: BMP cost estimates for biofiltration
(All costs presented as $2025 per impervoius acre treated)

Practice	Installation cost	Maintenance cost	20-yr MC	Total cost
Biofiltration strips > 50% IA	$16,913	$1,015	$20,296	$37,209
Biofiltration strips > 50% IA	$15,158	$909	$18,190	$33,348
Biofiltration strips < 50% IA	$25,374	$1,522	$30,449	$55,823
Biofiltration swales > 50% IA	$68,819	$4,129	$82,583	$151,402
Biofiltration swales > 50% IA	$61,699	$3,702	$74,039	$135,738
Biofiltration swales < 50% IA	$103,247	$6,195	$123,896	$227,143
Stormwater park	$19,429	$11,300	$226,000	$245,429
Bioretention HPBSM planter	$489,750	$2,800	$56,000	$545,750
Bioretention HPBSM in ROW	$334,444	$11,116	$222,318	$556,762
Bioswale	$25,313	$2,600	$52,000	$77,313
Stormwater treatment wetland	$563,622	$2,500	$50,000	$613,622
Infiltration pond	$783,772	$4,800	$96,000	$879,772
Wetpond	$600,275	$2,200	$44,000	$644,275
Infiltration trench	$9,699	$582	$11,639	$21,338
Minimum:	$9,699	$582	$11,639	$21,338
Maximum:	$783,772	$11,300	$226,000	$879,772
Average:	$222,680	$3,955	$79,101	$301,780

As noted previously, practice costs vary due to important technological variations (i.e. high-performance soil media vs. conventional), variations in capital, labor, and maintenance costs across geographies, and the amount of IA that can be treated at each site given variations in soils, slope, and surrounding land uses. For example, Bellingham's priority BMP spreadsheet determined that 4 BiPod media filters would be needed to treat stormwater runoff from 32 IA at the Nome/Eldridge Street location at a total cost of $55,000 per IA. That same BMP used at the Meridian Street location would require 18 such installations to treat runoff from 9.29 IA at a total cost of $266,490 per IA.

Of the 35 BMPs listed, only a few have been monitored for 6PPD-Q reduction and even fewer for elimination of harmful bi-products such as copper and phosphorous residues from standard soil mixes in biofiltration.[9] These tend to be practices in the higher cost category. For example, the only BMP that King County considered in its cost calculation was the high-performance soil bioretention BMP shown in Table 7 (Bioretention HPBSM in ROW) which, at $556,000 per IA is among the most expensive for this category. As such, the jurisdictional analyses emphasize these higher cost practices as a safeguard but include some low-cost practices under the assumption that harmful bi-products can be limited or avoided with proper maintenance in many cases.

3.4 Jurisdictional and interstate analysis

In order to generate estimates of 6PPD-Q reduction costs per IA treated and per high traffic road mile that can be applied regionally, CSE completed detailed analyses of potential best management practices packages for the City of Bellingham, City of Gresham, King County, the combined area of Eureka-Arcata-McKinleyville and the interstate highway system. Field visits, phone and email correspondence with local stormwater experts as well as desktop reviews were the primary sources of data. The goal of these jurisdiction-level analyses was to develop four plausible scenarios of responsive BMPs and associated costs that could be extrapolated CHU-wide for coho, Chinook and steelhead. The four scenarios include:

(a) High-high (HH), which assumes a high acreage of impervious surface treated with an emphasis on higher-cost practices.

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[9] Mackiewicz, E., 2025. Personal communication via electronic mail, January 6. The City of Bellingham has determined that "we can't use the 60/40 mix because, while its great at treating 6ppdq, it's known to discharge copper (bad for all fish) and phosphorus (bad for receiving water ecology). Since 2017, we have been advised by Ecology not to use 60/40 mix within 1/4 mile of a fish bearing waterbody or any impaired water body for nutrients."

(b) High-low (HL), which assumes a high acreage of impervious surface treated with an emphasis on lower-cost practices.
(c) Low-high (LH), which assumes a low acreage of impervious surface treated with an emphasis on higher-cost practices.
(d) Low-low (LL), which assumes a low acreage of impervious surface treated with an emphasis on lower-cost practices.

Details of each analysis are provided below.

3.4.1 City of Gresham

According to spatial analysis completed by the Elastic Data Lab, there are 6,792 acres of imperious surface area within city limits. Of these, approximately 3,718 acres fall into three critical habitat watersheds of concern for 6PPD-Q – Johnson Creek, Kelly Creek, and Beaver Creek, the latter two of which drain into the Sandy River. About 747 acres are within ¼ mile of designated critical habitat streams. All three watersheds support coho, Chinook, and steelhead. The reason the remaining IA is not of concern is because stormwater here is percolated into a sandy aquifer and not critical habitat streams.

Additional data provided by the city indicates that there are 41 miles of high traffic roadways in these watersheds, which converted to impervious surface area, amounts to 188 acres.[10] Roughly 12 miles of high traffic road and 54 acres of IA associated with these roads are within ¼ miles of critical habitat streams. The City also provided an estimate of untreated IA within the three watersheds, which is approximately 83.4% based on the 2014 Wasteload Allocation Attainment report prepared to meet terms of its NPDES MS4 permit (City of Gresham, 2014).

During a site visit with fisheries and stormwater staff options for treating runoff at five problematic sites for 6PPD-Q were evaluated. This includes one site draining into Beaver Creek (Figure 7) where concentrations were observed at over 1,000 nanograms per liter (ng/L), which surpasses the 50% lethality threshold for steelhead, coho, and newly hatched rainbow trout.

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[10] High traffic roads range from 2 to 4 lanes with a standard width of 10-12 feet per lane. In this analysis, we assume that the average high traffic roadway (not including interstates) is three lanes (36 feet), plus a foot on either side for gutters.

Figure 7*: Katie Holzer, Watershed Scientist with the City of Gresham (left) surveys a Beaver Creek outfall where concentrations of 6PPD-Q were found to exceed 1,000 ng/L. Just above the outfall (right) is an ideal location for installation of a large biofiltration facility.*

Of the 35 BMPs included in Tables 4 – 6 high performance bioretention, full replacement porous asphalt, biofiltration swales and media filter swales were selected as a basis for the four cost scenarios. The first two are considered high-cost practices and the latter two lower cost practices. In terms of treatment area, for the HH and HL scenarios 3,100 acres was selected because this represents the untreated share of IA within the three priority watersheds and because the ¼ mile criteria was found less useful here due to the transport of stormwater runoff along roads via pipes into the receiving waters. In other words, contaminated runoff from well beyond the ¼ mile buffer is entering streams due to this piping system. For the LH and LL scenarios, 157 acres was selected as the treatment goal as this represents the share of high traffic roadway IA that is untreated.

Table 7 provides cost per IA treated and the share of each BMP included in each scenario. So, for example, the HH scenario would treat 30% of the total for this scenario (3,100 acres) with the high performance bioretention BMP (BMP1), 40% with porous asphalt (BMP2), 20% with biofiltration swales (BMP3) and 10% with media filter swales (BMP4). The portfolio shares were modified in the remaining scenarios to emphasize lower cost practices and to respond to observations and input during the field visit. So, for example, porous asphalt is of great interest here (Holzer and Poor, 2024) and so in one scenario (LH) this practice was elevated to a 50% share. Biofiltration and media filter swales along high traffic roads are other BMPs emphasized in Gresham and so these were elevated to a combined 80% share in the LL scenario.

Results show a range of total costs ($27 million to $1.14 billion) across the four scenarios due to the difference in assumed IA treated. Costs per IA treated ($176,260 - $369,039) and per high traffic road mile treated ($811,852 - $1,699,792) fall within a closer range, roughly 2.1x (high cost/low cost) in both cases.

Table 7: Jurisdictional analysis for Gresham, OR

Practice portfolio and costs	Cost per IA	Cost Category
(1) Bioretention HPBSM in ROW	$556,762	H
(2) Porous asphalt + vacuum	$427,551	H
(3) Biofiltration swales > 50% IA	$151,402	L
(4) Media filter swale	$7,092	L

Scenarios	IA treated	% BMP - 1	% BMP - 2	% BMP - 3	% BMP - 4
HH	3,100	0.3	0.4	0.2	0.1
HL	3,100	0.1	0.2	0.4	0.2
LH	157	0.2	0.5	0.2	0.1
LL	157	0.1	0.1	0.5	0.3

Total cost by scenario	Cost	Cost/IA	Cost/HT mile
HH	$1,144,179,487	$369,039	$1,699,792
HL	$629,813,128	$203,166	$935,780
LH	$55,951,594	$356,118	$1,640,278
LL	$27,693,136	$176,260	$811,852

3.4.2 City of Bellingham

Spatial analysis results for the City of Bellingham indicate that there are approximately 6,443 IA total, 1,668 of which fall within ¼ mile of critical habitat streams, which include Chuckanut Creek, Padden Creek, Whatcom Creek, Squalicum Creek as well as Bellingham and Chuckanut Bays. Critical habitat has been designated for Chinook and steelhead (Puget Sound distinct population segments) within the city limits, but coho are present as well in all major streams.[11] The analysis has also identified 73 miles of high traffic roadway, of which 22 fall within ¼ mile of critical habitat. This converts to 101 IA assuming the 38-foot average width discussed earlier.

The City of Bellingham has 904 mapped stormwater outfalls of which 404 (45%) have no treatment and 500 have some form of treatment, primarily for metals. Many of the untreated outfalls are within the riparian zones of Padden, Whatcom and Squalicum Creek (Figure 8). In addition, those that have treatment are not regarded as adequate

[11] See, e.g. City of Bellingham, Which fish are found in Bellingham watersheds? Fact sheet, available online at: https://cob.org/wp-content/uploads/Fish-in-Bellingham-Watersheds-Graphic.pdf.

for 6PPD-Q removal. As such, City staff have suggested treatment of all IA within ¼ mile of critical habitat as an initial estimate of scope.

Figure 8: *Natural Resources Technician Eli Mackiewicz (City of Bellingham) surveys and untreated outfall near the mouth of Squalicum Creek.*

During a site visit with Public Works Department staff, six sites where 6PPD-Q BMPs could be prioritized were assessed for specific configurations. Many of the Bellingham sites are located in two watersheds – Padden and Squalicum, where the stream corridors have little room for large treatment facilities or where there are protected riparian habitats that cannot be disturbed (Figure 8). Instead, the focus was on smaller media filter boxes or vaults or that could be constructed at untreated outfalls or larger biofiltration facilities away from stream corridors that could intercept stormwater outflows before they enter pipes that flow directly into the streams.

City staff provided a detailed spreadsheet of advanced treatment projects in various stages of implementation (Appendix D) that provides cost data incorporated into Table 4.[12] These include several types of media filter boxes and vaults as well as one modular wetland vault BMP. None of these were planned with 6PPD-Q in mind, so treatment efficacy is uncertain. However, city staff believed the higher cost BMPs that use elements like HPBSM or polishing layers are more likely to achieve 6PPD-Q removal without generating harmful by-products. Costs vary, from just under $21,000 to well over $266,000 per IA treated. The most important source of variation is the amount of IA that can be successfully treated at any one location given site specific conditions such as the room needed to build larger facilities or whether the IA being treated contain vegetated areas within their matrix.

Two media filters – Post and BiPod – as well as a porous asphalt overlay and a modular wetland vault BMP were used as a basis for the cost scenarios below. The first two are the higher cost media BMPs on the city spreadsheet provided. The wetland vault was also from the city's spreadsheet and is the lower cost item modeled along with porous asphalt. In terms of treatment area, for the HH and HL scenarios the city's suggested

[12] Entries 4 through 11 in Table 4 were extracted from Appendix D, updated to $2025, and updated to include maintenance costs over 20 years.

scope of all IA within ¼ mile of critical habitat was adopted (1,688 acres). For the LH and LL scenarios, 101 acres was selected as the treatment goal as this represents the IA on high traffic roadways, also within ¼ mile of critical habitat. Table 8 provides cost per IA treated and the share of each BMP included in each scenario.

Table 8: Jurisdictional analysis for Bellingham, WA

Practice portfolio and costs	Cost per IA	Cost Category			
(1) Post media filter	$142,170	H			
(2) BiPod media filter	$266,489	H			
(3) Porous asphalt overlay	$243,936	L			
(4) Modular wetland vault	$91,451	L			
Scenarios	**IA treated**	**% BMP - 1**	**% BMP - 2**	**% BMP - 3**	**% BMP - 4**
HH	1,688	0.4	0.4	0.1	0.1
HL	1,688	0.1	0.1	0.4	0.4
LH	101	0.4	0.4	0.1	0.1
LL	101	0.1	0.1	0.4	0.4
Total cost by scenario	**Cost**	**Cost/IA**	**Cost/HT mile**		
HH	$332,540,537	$197,003	$907,394		
HL	$295,435,359	$175,021	$806,146		
LH	$19,897,271	$197,003	$907,394		
LL	$17,677,116	$175,021	$806,146		

In both the HH and LH scenarios, the model assumes that 80% of the treatment is provided by the two higher cost BMPs (1 and 2). In the HL and LL scenarios, the emphasis is reversed, with 80% of the treatment provided by the two lower-cost BMPs (3 and 4). Results show a range of total costs ($17 million to $332 million) across the four scenarios again due to the difference in assumed IA treated. Costs per IA treated ($175,021–$197,003) and per high traffic road mile treated ($806,146–$907,394)) fall within a tight range, roughly 1.1x (high cost/low cost) in both cases.

3.4.3 Eureka-Arcata-McKinleyville

The combined urban area of Eureka, Arcata, and McKinleyville (EAM) California has numerous rivers, streams and creeks that support coho, Chinook and steelhead. Multiple federal, state, and local public agencies are investing significant funds to replenish habitat for these species in places like the Mad River and within the city limits of Eureka near the 14th street bridge.[13]

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[13] See, e.g. "City of Eureka Launches First Slough Fish Passage and Habitat Restoration Project," Redheaded Blackbelt.com, available online here.

Spatial analysis has identified 768 IA and 23 miles of high traffic roadways within ¼ mile of critical habitat. The latter converts to 106 IA. Based on discussions with local staff and review of stormwater management plans it appears that very little of the IA near critical habitat areas has any form of advanced treatment. As such, 768 IA and 106 IA were adopted as the basis for high and low treatment areas in the four cost scenarios.

Humbolt County is leading a multi-jurisdictional stormwater resource plan (SWRP) to address untreated stormwater, dry weather runoff capture, and sea level rise adaptation (GHD, 2018). Other collaborators include the City of Eureka and the Humbolt Community Services District. As part of the SWRP planning effort, the amount of land available for five priority BMPs was estimated and field verified. These BMPs include porous pavement (500 acres), bioswales (515 acres), tree planters (515 acres), rain gardens (325 acres) and infiltration facilities (325 acres).

Based on this identification and inventory of suitable sites, four BMPs were selected for analysis including full replacement porous asphalt, biofiltration swales, infiltration trenches, and Austin sand filters. These range in cost from a low of $21,338 per IA for infiltration trenches and a high of $877,298 per IA for full replacement porous asphalt. The distribution of these practices across scenarios was constrained by the available acres identified by the SWRP.

In both the HH and LH scenarios, the model assumes that 70% of the treatment is provided by the two higher cost BMPs (1 and 2). In the HL and LL scenarios, the emphasis is reversed, with 60% of the treatment provided by the two lower-cost BMPs (3 and 4).

Results are shown in Table 9 and estimate a range of total costs from $27 to $293 million across the four scenarios again due to the difference in assumed IA treated. Costs per IA treated range between $258,842 and $381,960 and between $1,192,225 and $1,759,307 per high traffic road mile treated.

Table 9: Jurisdictional analysis for Eureka-Arcata-McKinleyville

Practice portfolio and costs	Cost per IA	Cost Category
(1) Porous asphalt + vacuum	$877,298	H
(2) Biofiltration swales > 50% IA	$151,402	H
(3) Infiltration trench	$21,338	L
(4) Austin sand filters	$85,989	L

Scenarios	IA treated	% BMP - 1	% BMP - 2	% BMP - 3	% BMP - 4
HH	768	0.4	0.3	0.2	0.1
HL	768	0.2	0.2	0.4	0.2
LH	106	0.4	0.3	0.2	0.1
LL	106	0.2	0.2	0.4	0.2

Total cost by scenario	Cost	Cost/IA	Cost/HT mile
HH	$293,345,179	$381,960	$1,759,307
HL	$198,790,481	$258,842	$1,192,225
LH	$40,487,746	$381,960	$1,759,307
LL	$27,437,228	$258,842	$1,192,225

3.4.4 King County

On January 14th, 2025 King County Executive Dow Constantine sent a letter to US EPA Administrator Michael Regan noting that King County lies at the “epicenter of risk and impacts” from 6PPD-Q on salmon populations and requesting that EPA “work with tire manufacturers to ensure safe and effective replacement antiozonants are widely available and phase out the use of 6PPD in all products using all available authorities under TSCA[14] as quickly as possible” (Constantine, 2025).

The letter included information from a 6PPD-Q hot spot screening exercise and a preliminary cost assessment for treating stormwater from 1,492 IA under King County’s jurisdiction and 19,362 IA within King County’s geography with a high performance bioretention soil media (HPBSM) BMP (Appendix E). The IA figures represent about 58% of IA associated with high traffic roadways and include all IA that were assigned a score of 3 or higher on a scale of 5 by the screening study (Hererra, 2025). The cost for treating these IAs was estimated to be $981 million for IA under King County’s jurisdiction and over $13 billion for treatment of IA within King County’s geography inclusive of all capital and maintenance costs associated with this BMP over 30 years.

For this analysis, CSE adopted most of what was provided by King County but with three important modifications: (1) King County only considered one BMP that may not be suitable for many locations, so CSE expanded the list of options to include porous asphalt overlays and a BioPod filter system used in Bellingham; (2) limiting the life-cycle

[14] Toxic Substances Control Act, USC 15 U.S.C. §2601 et seq.

cost to 20 years rather than 30 to be consistent with other jurisdictions modeled and since this is the standard period for financial modeling of stormwater BMPs, and (3) limiting the extent of treatment to 58% of high traffic road IA within ¼ mile of CH for the low cost scenarios, which is estimated to be 1,913 IA. The 19,362 IA figure was retained for the high-cost scenarios.

In terms of BMP distribution, the HH and LH scenarios assume that each BMP treats an equal share (1/3) of the target IA. The HL and LL scenarios restrict use of BMP1 to just 10% of the target IA given the relatively large space requirements needed. BMP2 (porous asphalt) and BMP3 (BioPod filters) are assumed to treat 75% and 15% respectively of the target IA. Results are presented in Table 10. For the LH and LL cost scenarios, 1,913 IAs are treated at a cost of $532 to $679 million. For the HH and HL cost scenarios, 19,932 IAs are treated at a cost of $5.57 to $7.09 billion. Across all scenarios, costs per IA treated range from $278,602 – $ 354,837. Costs per high traffic road mile treated range from $1.28 – $1.63 million.

Table 10: Jurisdictional analysis for King County

Practice portfolio and costs	Cost per IA	Cost Category		
(1) Bioretention HPBSM in ROV	$556,762	H		
(2) Porous asphalt overlay	$243,936	L		
(3) BiPod media filter	$266,489	H		
Scenarios	**IA treated**	**% BMP - 1**	**% BMP - 2**	**% BMP - 3**
HH	19,992	0.33	0.33	0.34
HL	19,992	0.1	0.75	0.15
LH	1,913	0.33	0.33	0.34
LL	1,913	0.1	0.75	0.15
Total cost by scenario	**Cost**	**Cost/IA**	**Cost/HT mile**	
HH	$7,093,899,095	$354,837	$1,634,379	
HL	$5,569,804,308	$278,602	$1,283,239	
LH	$678,802,970	$354,837	$1,634,379	
LL	$532,964,968	$278,602	$1,283,239	

3.4.5 Interstate highway system

Interstate highways are major sources of 6PPD-Q pollution largely because stormwater controls in place are more about conveyance rather than treatment. Most of the stormwater runoff from these highways remains untreated (Hererra, 2024) and often contains high concentrations of 6PPD-Q. For example, across multiple storm events, three sample sites in the Seattle and Portland metropolitan areas showed minimum, median, mean and maximum 6PPD-Q concentrations well in excess of the LC_{50}

threshold for coho (95 ng/L) and above that threshold for steelhead (1,000 ng/L) at one of the three locations (Figure 9).

***Figure 9**: Results of 6PPD-Q monitoring at major interstate crossings in Seattle and Portland (Hererra, 2024).*

Location	Storm Events	6PPDQ Concentrations (ng/L)[a]			
		Minimum	Median	Mean	Maximum
SCTF-TB1 through TB4 – Test Bays and Field Protocol Influent	11	421	658	714	1,040
STTC-TB1 – Test Bay 1 Influent	3	707	765	783	878
STTC-G2 – Gravity line 2 Influent	2	1,540	1,770	1,770	2,000

[a] Concentrations were averaged within each storm event across all influent samples collected before calculating summary statistics.
ng/L = nanograms per liter

***Figure 10:** Compost amended vegetated filter strips are beginning to be deployed along the interstate highway system to treat metals and sediments. They also hold promise for 6PPD-Q reduction (WSDOT, 2023).*

State agencies are beginning to make progress installing treatment BMPs at new projects, however, these BMPs are mostly designed to address other pollutants since 6PPD-Q is still considered an "emerging contaminant."

For example, Washington State Department of Transportation (WSDOT) is deploying BMPs such as compost amended vegetated filter strips (Figure 10) and biofiltration swales as well as media filter drains when it completes resurfacing or new pavement projects. Despite being designed to filter out metals and sediments WSDOT believes these are also effective at treating 6PPD-Q (WSDOT, 2023).

As indicated in Table 3, the regional spatial analysis suggests an adjusted total of 709 unique critical habitat crossings by interstate highways across all CHUs. In terms of IA, ¼ mile each way across all lanes (in both directions) translates into roughly 3,266 IA and 709 miles of high traffic roadway.[15] Assumptions about how much of this road surface is currently treated vs. untreated are the primary factor in the cost scenarios presented below.

[15] 709 crossings with four .25 mile buffers in each direction (1 mile total) is simply 709 miles. Each two-lane road segment has 12 ft. lanes, 10 ft. outer shoulder and 4ft inner shoulder according to the Federal Highway Administration data. This is exactly the figure (38 feet) used throughout this analysis as an average width for all high traffic roadways. 709 miles x 5,280 feet x 38 feet divided by 43,560 (sq. ft./acre) yields 3,266 IA.

For the HH and HL scenarios the assumption is that 80% of the surfaces have no treatment at all. So 2,613 IA is used as the target treatment extent. This assumes that the remaining 20% has at least some stormwater treatment that may be effective in reducing 6PPD-Q concentrations. For the LH and LL scenarios, the assumption is that 60% of the surfaces have no treatment. This is equivalent to 1,959 IA. Both assumptions are consistent with the Hererra (2024) findings in Seattle and Portland.

In terms of BMPs, two higher-cost and two lower-cost BMPs were selected from Tables 4 – 6. The higher cost BMPs include full replacement porous asphalt ($877,298/IA) and and stormwater treatment wetlands ($613,622/IA).[16] The two lower cost BMPs include BiPod media filters ($266,489/IA) and biofiltration swales ($135,738/IA). Site specific analysis is needed to determine what BMPs are workable and most effective at any given site. Nonetheless, for this order of magnitude analysis it is assumed that it is feasible to treat up to 2/3 of the target IA with the higher cost BMPs and 1/3 with the lower cost BMPs in the HH and LH scenarios. This is reversed for the HL and LL scenarios. Results are reported in Table 11.

Table 11: Jurisdictional analysis for interstate highways

Practice portfolio and costs	Cost per IA	Cost Category
(1) Porous asphalt + vacuum	$877,298	H
(2) Stormwater wetlands	$613,622	H
(3) BiPod media filters	$266,489	L
(4) Biofiltration swales > 50% IA	$135,738	L

Scenarios	IA treated	% BMP - 1	% BMP - 2	% BMP - 3	% BMP - 4
HH	2,613	0.33	0.33	0.165	0.165
HL	2,613	0.165	0.165	0.33	0.33
LH	1,959	0.33	0.33	0.165	0.165
LL	1,959	0.165	0.165	0.33	0.33

Total cost by scenario	Cost	Cost/IA	Cost/HT mile
HH	$916,942,191	$350,975	$1,616,590
HL	$560,954,188	$214,715	$988,975
LH	$687,706,643	$350,975	$1,616,590
LL	$420,715,641	$214,715	$988,975

For the LH and LL cost scenarios, 1,959 IAs are treated at a cost of $421 to $688 million. For the HH and HL cost scenarios, 2,613 IAs are treated at a cost of $561 to $917 million. Across all scenarios, costs per IA treated range from $214,715 –

[16] Unlike highly urbanized areas, most of the interstate highway system is bordered by farms, forests, and other open space that can be used for larger biofiltration facilities such as constructed wetlands.

$350,975. Costs per high traffic road mile treated range from $988,975 to over $1.6 million.

3.5 Extrapolation across all critical habitat units

The final step in this preliminary analysis is the extrapolation of cost figures reported for each of the four jurisdictions and the interstate highway system in Section 3.4 across critical habitat units (CHUs) for coho, Chinook, and steelhead. This is accomplished by multiplying weighted averages of costs per impervious acre (IA) treated and per high traffic road (HTR) mile treated for each of the four cost scenarios by acres and road miles treated at the CHU level under treatment area assumptions discussed below.

Tables 12 and 13 report the weighted averages across the four scenarios from the jurisdictional and interstate analyses. For the high treatment area – high practice cost scenarios (HH), the weighted average values across the five jurisdictions are $347,321 per IA treated and $1,599,760 per HTR mile treated. For the high treatment area – low practice cost scenarios (HL), the weighted average values across the five jurisdictions are $257,622 per IA treated and $1,186,607 per HTR mile treated. For the low treatment extent – high practice cost (LH) scenario the values are $350,014/IA and $1,612,163/HTR mile. Lastly, for the low treatment extent – low practice cost (LL) scenarios the corresponding values are $242,299/IA and $1,116,029/HTR mile.

Treatment BMPs included in these scenarios emphasize full replacement porous asphalt, porous asphalt overlays, stormwater wetlands, high performance bioretention soil media facilities, BiPod media filters, POST media filters, Austin sand filters and biofiltration swales with different proportions used for each BMP depending on scenario.

Table 14 extrapolates these weighted averages to the combined area within the CHUs for coho, Chinook, and steelhead. In terms of treatment extent, the HH and HL scenarios assume that 60% of the IA within ¼ mile of critical habitat (353,037 acres) are treated by the portfolio of BMPs. This share is based on the amount of IA that is currently untreated according to the jurisdictional analyses (44 – 83%) as well as the King County screening study (Hererra, 2025) which suggests that about 58% of IA has 6PPD-Q deposition levels that warrant stormwater treatment. In the LH and LL scenarios, that same percentage is applied to high traffic roadways within the CHUs, but the ¼ mile constraint was dropped since polluted stormwater is often conveyed into pipes from a much greater distance. The treatment extent for these scenarios was set at 22,639 HTR miles.

Table 12 Weighted average treatment costs ($2025/IA) by scenario from jurisdictional analysis

Jurisdiction	HH	HL	LH	LL
Gresham	$369,039	$203,166	$356,118	$176,260
Bellingham	$197,003	$175,021	$197,003	$175,021
Eureka-Arcata-McKinleyville	$381,960	$258,842	$381,960	$258,842
King County	$354,837	$278,602	$354,837	$278,602
Interstate highway system	$350,975	$214,715	$350,975	$214,715
Average:	$330,763	$226,069	$328,178	$220,688
Weighted average:	$347,321	$257,622	$350,014	$242,299

Table 13: Weighted average treatment costs ($2025/HTR mile) by scenario from jurisdictional analysis

Jurisdiction	HH	HL	LH	LL
Gresham	$1,699,792	$935,780	$1,640,278	$811,852
Bellingham	$907,394	$806,146	$907,394	$806,146
Eureka-Arcata-McKinleyville	$1,759,307	$1,192,225	$1,759,307	$1,192,225
King County	$1,634,379	$1,283,239	$1,634,379	$1,283,239
Interstate highway system	$1,616,590	$988,975	$1,616,590	$988,975
Average:	$1,523,493	$1,041,273	$1,511,590	$1,016,488
Weighted average:	$1,599,760	$1,186,607	$1,612,163	$1,116,029

Table 14: CHU-level cost scenarios

Scenario	Treatment extent	Total cost
High extent - high cost (HH)	353,037 IA	$122,617,288,005
High extent - low cost (HL)	353,037 IA	$90,950,221,495
Low extent - high cost (LH)	22,639 HTR	$36,498,581,442
Low extent - low cost (LL)	22,639 HTR	$25,266,332,979

Across all four scenarios, the analysis suggests that a plausible 6PPD-Q best management practices strategy across the CHUs for all three species would represent a total cost of at least $25 and as much as $123 billion in 2025 dollars. Delaying implementation would cause these figures to increase roughly in line with inflation.

There are a few estimates in the published literature or from agencies that lend support for this range. For example, the 6PPD-Q mitigation cost estimate from King County ($13 billion) can be extrapolated regionally on a per-capita basis rather than on an IA or HTR mile basis as a rough corroboration using different extrapolation metrics than what appears here. Doing so generates an alternative HH estimate of $137.3 billion, relatively close to the value derived here ($123 billion).

Other support comes from a 2014 analysis of stormwater retrofit needs in the greater Puget Sound region. In that study, Simmonds and Wright (2014) concluded that a program of stormwater retrofits that included a combination of cisterns, rain gardens, and detention pond facilities needed to meet Chinook recovery plan goals would cost roughly $881 million per year over 100 years, which is about $187 on a per-capita basis.[17] Extrapolating this figure to the region implies a total investment figure of $91 billion over 20 years (the timeframe used in this study), an amount nearly identical to the HL scenario modeled here.

3.0 CONCLUSIONS

This report presents preliminary minimum and maximum estimates of what it may cost to deploy three categories of flow and treatment BMPs – biofiltration, porous asphalt, and media filters – at a West Coast regional scale throughout critical habitat units for coho, Chinook and steelhead. It is based on extrapolation of cost figures derived from detailed analyses of four jurisdictions and the interstate highway system under four cost scenarios that include both high and low estimates of treatment area extent and BMP costs. Based on the scenarios developed and variations that allow for different choices at different locations, it is likely that the cost of a regional BMP program would cost at least $25 and to up to $123 billion in 2025 dollars.

REFERENCES

Brinkmann, M., Montgomery, D., Selinger, S., Miller, J. G. P., Stock, E., Alcaraz, A. J., Challis, J. K., Weber, L., Janz, D., Hecker, M., & Wiseman, S. (2022). Acute toxicity of the tire rubber-derived chemical 6PPD-quinone to four fishes of commercial, cultural, and ecological importance. Environmental Science & Technology letters, 9(4), 333–338. https://doi.org/10.1021/acs.estlett.2c000.

California Department of Transportation (CalTrans). 2025. Contract Cost Database. Available online at: https://sv08data.dot.ca.gov/contractcost/.

California Stormwater Quality Association (CASQA). 2003. Media Filter TC-40. In California Stormwater BMP Handbook. Redondo Beach, CA: CASQA.

Cappiella, K., Stack, W.P., Fraley-McNeal, L.., Lane, C., and McMahon, G. 2012. Strategies for managing the effects of urban development on streams: U.S. Geological Survey Circular 1378, 69 p. Available online at http://pubs.usgs.gov/circ/1378.

Chow, M.I., Lundin, J.I., Mitchell, C.J., Davis, J.W., Young, G., Scholz, N.L., McIntiyre, J.K. 2019. An urban stormwater runoff mortality syndrome in juvenile coho salmon, *Aquatic Toxicology*, Volume 214, 2019, 105231, ISSN 0166-445X.

[17] Current population estimates for their study area (Puget Sound) is 4.7 million.

City of Bellingham (COB). 2025. Cost assessment of 8 priority stormwater control projects. Spreadsheet tool. Bellingham, WA: City of Bellingham Public Works.

City of Gresham. 2014. Waste load Allocation Attainment Assessment. Prepared for compliance with NPDES MS4 permit Schedule D.3.b. Gresham, OR:

Constantine, D. 2025. King County letter to EPA, Docket EPA-HQ-OPPT-2024-0403, Information to Inform Future Rulemaking. Seattle: Office of the King County Executive.

County of San Diego. 2018. Media Filter: Trash Best Management Practices Minimum Specifications. In County of San Diego LID Handbook. San Diego, CA: County of San Diego.

Di, S., Liu, Z., Zhao, H., Li, Y., Qi, P., Wang, Z., Xu, H., Jin, Y., Wang, X. 2022. Chiral perspective evaluations: enantioselective hydrolysis of 6PPD and 6PPD-quinone in water and enantioselective toxicity to *Gobiocypris rarus* and *Oncorhynchus mykiss Environ. Int*., 166 (2022), Article 107374, 10.1016/j.envint.2022.107374

Environmental Protection Agency (EPA). 2021. Permeable Pavers. Minimum Measure: Post Construction Stormwater Management in New Development and Redevelopment. Washington, DC: EPA NPDES Program.

Environmental Protection Agency (EPA). 1997. Urban Stormwater Preliminary Data Summary. Chapter 6: Costs and Benefits of Storm Water BMPs. Washington, DC: EPA Office of Water.

Feist, B.E., Buhle, E.R., Baldwin, D.H., Spromberg, J.A., Damm, S.E., Davis, J.W., Scholz, N.L. 2017. Roads to ruin: conservation threats to a sentinel species across an urban gradient. *Ecol Appl*, 27: 2382-2396. https://doi.org/10.1002/eap.1615

Feist, B.E., Buhle, Arnold,, P., Davis, J.W., Scholz, N.L. 2011. Landscape ecotoxicology of coho salmon spawner mortality in urban streams. *PLoS One*, 6 (2011), Article e23424.

French, B.F., Baldwin, D.H., Cameron, J., Prat, J., King, K., Davis, J.W., McIntyre, J.K., Scholz, N.L. 2022. Urban roadway runoff Is lethal to juvenile Coho, Steelhead, and Chinook salmonids, but not congeneric sockeye. Environ. Sci. Technol. Lett. 2022, 9, 9, 733–738.

GHD, Inc. 2018. The Eureka Area Watersheds Storm Water Resource Plan. Prepared for Humboldt County, the City of Eureka, and the Humboldt Community Services District (HCSD). Eureka, CA: GHD Inc.

Greer, J.B., Dalsky, E.M., Lane, R.F., Hansen, J.D. 2023. *Environmental Science & Technology* 2023 57 (30), 10940-10950 DOI: 10.1021/acs.est.3c01040.

Hatt, B., Morison, P., Fletcher, T.D., Deletic, A. 2009. Adoption Guidelines for Stormwater Biofiltration Systems. Melbourne: Facility for Advancing Water Biofiltration, Monash University, ISBN: 9780908583113.

Herrera Environmental Consultants, Inc. (Herrera). 2025. 6PPDQ Screening Model. Prepared for King County. Seattle, WA: King County Road Services and King County Water and Land Resources Division.

Herrera Environmental Consultants, Inc. (Herrera). 2024. 2023-2024 Summary Repot: 6PPD-Q in Highway Runoff and BMP Effectiveness – Seattle, Washington and Portland, Oregon. Olympia: Washington Department of Ecology,

Herrera Environmental Consultants, Inc. (Herrera). 2021. Johnson Creek Water Quality Retrofit Study. Appendix G. Top Concept Design Summary Sheets. Greasham, OR: City of Gresham.

Hiki, K., Asahina, K., Kato, K., Yamagishi, T., Omagari, R., Iwasaki, Y., Watanabe, H., & Yamamoto, H. 2021. Acute toxicity of a tire rubber-derived chemical, 6PPD quinone, to freshwater fish and crustacean species. Environmental Science & Technology Letters, 8(9), 779–784. https://doi.org/10.1021/acs.estlett.1c00453.

Holzer, K., Poor, C. 2024. Reduction of runoff pollutants from major arterial roads using porous pavement. *Sustainability* 16: 7506. https://doi.org/10.3390/su16177506.

Kilgore, Inc. 2023. Asphalt Overlay vs. Full Replacement. Pros, Cons, and Cost Considerations. Available online at: https://kilgorecompanies.com/blog/2023/11/23/asphalt-overlay-vs-full-replacement-pros-cons-and-cost-considerations/.

King County. 2024. Water Quality Benefits Evaluation Fact Sheets. Seattle, WA: King County, Herrera, and RKI.

King County Water and Land Resources Division (KCWLD). 2024. Testing Removal of 6PPD-Q and Coho Salmon Lethality by High-performance Bioretention Media Blends: Final Data Report. Seattle, WA: King County Department of Natural Resources and Parks.

Lewis, D.J., Dundas, S.J., Kling, D.M., Lew, D.K., Hacker, S.D. 2019. The non-market benefits of early and partial gains in managing threatened salmon. PLoS ONE 14(8): e0220260. https://doi.org/10.1371/journal.pone.0220260.

Lo, P., Marlatt, V.L., Liao, Xiangjun, Regar, Sl, Gallilee, C., Ross, Andrew R.S., Brown, T.M. 2023. Acute toxicity of 6PPD-quinone to early life stage juvenile chinook (*Oncorhynchus tshawytscha*) and coho (*Oncorhynchus kisutch*) salmon. Environmental *Toxicology* 42(4): 815-822. https://doi.org/10.1002/etc.5568.

McIntyre, J., Kolodjiez, E. 2021. Technical Q+A on Stormwater and Tire Chemical Toxicity to Aquatic Organisms. Puyallup, WA: Washington Stormwater Center.

Mitchell, C. 2024. Testing Removal of 6PPD-Q and Coho Salmon Lethality by High Performance Bioretention Media Blends: Final Data Report. Prepared by King County Water and Land Resources Division, Science and Technical Support Section. Seattle, Washington.

Papenfus, M., Weber, M.A. 2024. Valuing wild salmon and steelhead recovery in Oregon's most urbanized watershed. Ecological Economics 236, 108540. DOI: https://doi.org/10.1016/j.ecolecon.2025.108540.

Peter, K., F. Hou, F., Tian, Z., Wu, C., Goehring, M., Liu, F., Kolodziej, E. 2020. More than a first flush: urban creek storm hydrographs demonstrate broad contaminant pollutographs. *Environmental Science and Technology*. 2020; 54: 10(6152–6165). https://doi.org/10.1021/acs.est.0c00872.

Pioneer Valley Planning Commission. 2015. Fact Sheet: Understanding Porous Asphalt. PVPC Sustainability Toolkit. Springfield, MA: PVPC.

Saint Louis University (SLU) Remote Sensing Lab. 2025. Spatial Analysis to Support 6PPD-Q mitigation. Prepared for Center for Sustainable Economy. Saint Louis, MO: Remote Sensing Lab at West Pine Mall.

Scholz, N.L., Myers, M.S., McCarthy, S.G., Labenia, J.S., McIntyre, J.K., Ylitalo, G.M., Rhodes, L.D., Laetz, C.A., Stehr, C.M., French, B.L. and McMillan, B., 2011. *Recurrent* *die-offs of adult coho salmon returning to spawn in Puget Sound lowland urban streams*. *PloS one*, 6(12), p.e28013.

Shanshan Di, Zhenzhen Liu, Huiyu Zhao, Ying Li, Peipei Qi, Zhiwei Wang, Hao Xu, Yuanxiang Jin, Xinquan Wang. 2022. Chiral perspective evaluations: Enantioselective hydrolysis of 6PPD and 6PPD-quinone in water and enantioselective toxicity to Gobiocypris rarus and Oncorhynchus mykiss, Environment International, Volume 166, 2022, 107374, ISSN 0160-4120.

Simmonds, J., Wright, O. 2014. Development of a Stormwater Retrofit Plan for Water Resources Inventory Area (WRIA) 9: Comprehensive Needs and Cost Assessment and Extrapolation to Puget Sound. Seattle, WA: King County Water and Land Resources Division.

Tian, Z., Gonzalez, M., Rideout, C. A., Zhao, H., Hu, X., Wetzel, J., Mudrock, E., James, C., McIntyre, J., & Kolodziej, E. P. 2022. 6PPD-quinone: Revised toxicity assessment and quantification with a commercial standard. Environmental Science & Technology Letters, 9(2), 140–146. https://doi.org/10.1021/acs.estlett.1c00910.

Tian, Z., Zhao, H., Peter, K. T., Gonzalez, M., Wetzel, J., Wu, C., Hu, X., Prat, J., Mudrock, E., Hettinger, R., Cortina, A. E., Biswas, R. G., Kock, F. V. C., Soong, R., Jenne, A., Du, B., Hou, F., He, H., Lundeen, R., & Kolodziej, E. P. 2021. A ubiquitous tire rubber–derived chemical induces acute mortality in coho salmon. Science, 371(6525), 185–189. https://doi.org/10.1126/science.abd6951.

Washington Department of Ecology (WDOE). 2022a. 6PPD in Road Runoff. Assessment and Mitigation Strategies. Olympia, WA: WDOE.

Washington Department of Ecology (WDOE). 2022b. Stormwater Treatment of Tire Contaminants Best Management Practices Effectiveness. Olympia, WA; WDOE.

Washington Department of Ecology (WDOE). 2019. Ecology. Stormwater Management Manual for Western Washington. Olympia, WA: Washington State Department of Ecology.

Washington Department of Ecology (WDOE). 2012. Stormwater Management Manual for Western Washington. Volume 1: Minimum Technical Requirements and Site Planning. Olympia, WA: WDOE Water Quality Program.

Washington State Department of Transportation (WSDOT). 2023. WSDOT Stormwater Retrofit. Protecting species, habitat, and human health from stormwater impacts by improving water quality and reducing effects of stormwater runoff including 6PPD-quinone. Olympia, WA: WSDOT.