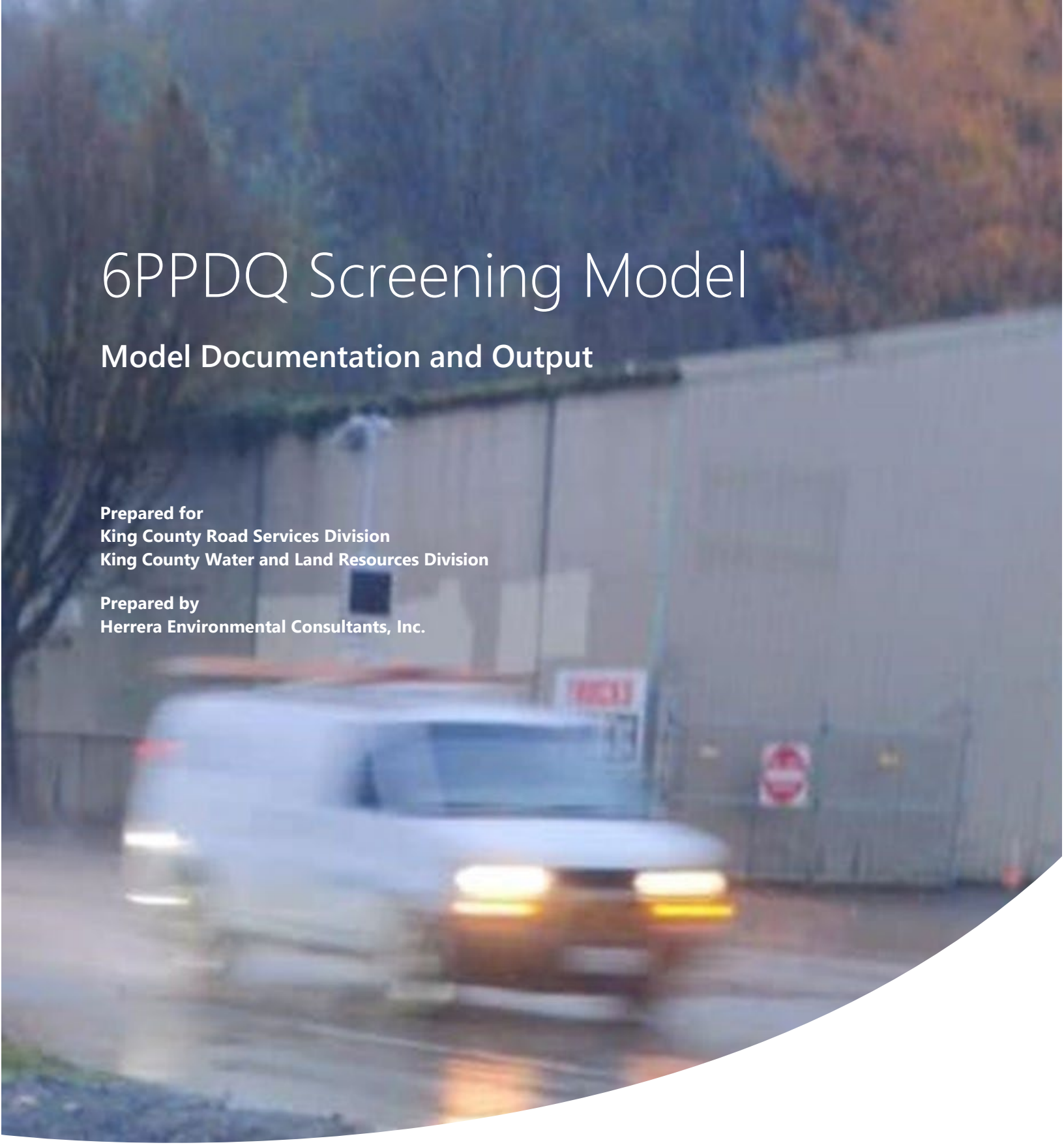


6PPDQ Screening Model

Model Documentation and Output

Prepared for
King County Road Services Division
King County Water and Land Resources Division

Prepared by
Herrera Environmental Consultants, Inc.

HERRERA
Science + Planning + Design

6PPDQ Screening Model

Model Documentation and Output
King County, Washington

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Executive Summary

Tire-derived pollutants, such as 6PPD(N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine) and its oxidation product 6PPD-quinone (6PPDQ), are conveyed through roadway runoff to streams, causing urban runoff mortality syndrome (URMS) in coho salmon and adverse effects to other salmonids and aquatic organisms. There are hundreds of stormwater outfalls within 100 feet of coho bearing streams in King County, Washington. King County roads vary in their potential to generate tire-derived toxic chemicals, and King County is looking to develop a method to prioritize the placement of stormwater treatment facilities.

This report documents the development and application of the 6PPDQ Screening Model (Screening Model). The Screening Model is an expert-knowledge-based spatial model that classifies roadways by the relative expected amount of 6PPDQ delivery to the stormwater drainage network, using available spatial data for model inputs. To support development of a Screening Model that meets the specific needs of King County roads and stormwater planners, the project team identified the following model specifications that served as guiding principles throughout its development.

Model Purpose	(1) To inform the selection of monitoring sites by defining the key influential landscape factors to evaluate across, and (2) to provide a relative scoring/ranking of public roadways in terms of the export of 6PPDQ
Model Endpoint	"Delivery of 6PPD/6PPDQ to Stormwater Conveyance Network" expressed as the relative amount of 6PPDQ or its parent material expected at the point of input to the conveyance network
Model Scope	Public roadways in the King County geographic area
Model User	Technical staff within stormwater management agencies with GIS experience
Model Output User	Project managers and technical staff who are selecting monitoring sites to characterize 6PPDQ and/or prioritizing drainage areas/roadways for stormwater retrofits

The model was developed with local and regional subject matter experts in stormwater pollution, road runoff, tire wear, and spatial data analysis and modeling. The primary factors influencing the export of 6PPDQ from roadways and the datasets used are described below.

Number and Composition of Vehicles

Motor vehicle tires emit rubber pieces when vehicles drive, turn, brake, and accelerate on the road. These rubber pieces range from large, visible chunks found along the roadway to microscopic particles. Experts understand that the primary factor leading to tire wear generation is the number of vehicles on the road per unit distance, followed by the vehicle weight, tire width, and number of tires/axles per vehicle.

The Screening Model relied on the Puget Sound Regional Council (PSRC)'s SoundCast model—an activity-based travel model—that provided contemporary estimates of vehicular traffic, including the number of medium-weight and heavy-weight vehicles (i.e., single-unit and double-unit or larger trucks, respectively).

Imperviousness of the Roadway Skirt

Tire wear particles accumulate in the roadway skirt (the area within 6 meters of the active roadway). Tire wear particles deposited on pervious surfaces will run off at a slower rate than those deposited on impervious surfaces. Further, 6PPD has a strong tendency to adsorb on organic matter in soils and sediments, and 6PPDQ degradation occurs more rapidly in biologically active and aerobic soils.

The Screening Model relied on the 2019 ECOPIA high-definition land cover vector dataset for King County to (1) identify the extent of the roadway surface and (2) determine the imperviousness of the roadway skirt.

Connectedness of the Roadway and Skirt

The presence of a conveyance network is critical for determining how much runoff will ultimately be conveyed from the roadway and its skirt. Conveyance network includes catch basins, pipes, ditches, and swales.

The Screening Model relied on the mapped stormwater conveyance data from King County, Washington State Department of Transportation (WSDOT), and Seattle Public Utilities. Compiling all stormwater conveyance within the King County geographic area was beyond the scope of this project. A simple model was used to impute predicted conveyance percentages where gaps existed.

The Screening Model provides a score between 0 and 5 for the predicted export of 6PPDQ to the stormwater network from a roadway segment. Importantly, the score is on a log-10 scale, such that a road segment with a score of 5 is expected to deliver 10 times that of a score of 4, 100 times that of a score of 3, 1,000 times that of a score of 2, etc. This Screening Model does not propose a specific threshold for environmental concern, and Herrera cautions against the interpretations of a "low score" as unimportant or of a "high score" as most important. Environmental factors, such as proximity and connectedness of a roadway to waterways with sensitive species, and human factors, such as traffic safety and historically underserved areas, may be considered in the application of the Screening Model scores in the prioritization of road retrofits, as described in the prioritization tool below.

The Screening Model has identified that the roads with the most 6PPDQ export are primary arterial roads in urban, developed areas, especially those with higher density of freight traffic. Freeways boast the highest amount of traffic. However, outside of urban cores, freeway skirts are typically grass and may provide opportunity for the capture and degradation of 6PPDQ. Further, many highways and freeways in rural areas lack formal stormwater conveyance infrastructure, which is expected to reduce the overall export of 6PPDQ. Informal conveyance (e.g., runoff carved channels) along roadways were not captured in this model.

Figure ES-1. Screening Model Scores for King County and White Center, Washington.



King County **White Center**

The Screening Model was developed as part of the *Multi-Criterion Decision Tool to Address 6PPDQ Tire Wear Particles project (Multi-Criterion Decision Tool* project hereafter*)*. Under the *Multi-Criterion Decision Tool* project, the output from the Screening Model will be integrated into a King County stormwater retrofit prioritization tool (prioritization tool), which is a decision guidance tool being separately developed to support retrofit planning efforts. The prioritization tool will identify and prioritize drainage subbasins and roadway segments where improvements to existing stormwater management infrastructure would yield multi-benefit outcomes. The prioritization tool will compare subbasins and/or roadway segments. This allows the user to consider multiple decision criteria, such as presence of fish-bearing streams, hotspots for other stormwater pollutants, and metrics for human health equity, among others, when evaluating the selection and siting of stormwater retrofits. This project is funded mainly through a Puget Sound National Estuary Program (NEP) grant and an Interagency Agreement (IAA) with the Washington State Department of Ecology (Ecology), as well as through in-kind support from the Washington State Department of Transportation (WSDOT) and King County.

1. Background

Tire-derived pollutants, such as 6PPD(N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine) and its oxidation product 6PPD-quinone (6PPDQ), are conveyed through roadway runoff to streams, causing urban runoff mortality syndrome (URMS) in coho salmon and adverse effects to other salmonids and aquatic organisms. There are hundreds of stormwater outfalls within 100 feet of coho bearing streams in King County, Washington. King County roads vary in their potential to generate tire-derived toxic chemicals, and King County is looking to develop a method to prioritize the placement of stormwater treatment facilities. To do so, King County is developing the *Multi-Criterion Decision Tool to Address 6PPD-q Tire Wear Particles project (Multi-Criterion Decision Tool* project hereafter*).* The *Multi-Criterion Decision Tool* project is supported in part by a grant that was issued by U.S. Environmental Protection Agency (EPA), using funding from the Puget Sound National Estuary Program (NEP) Stormwater Initiative Lead (SWSIL) (WQNEPSW-2023-KiCoRD-00003). A component of the *Multi-Criterion Decision Tool* is a 6PPDQ Screening Model that predicts the amount of 6PPDQ exported from public roadways in the King County geographic area.

This report documents the Screening Model developed in accordance with the Quality Assurance Project Plan (QAPP) (Herrera 2024) that was approved by King County and the Washington State Department of Ecology.

1.1. Problem Statement

For the past two decades, researchers in the Pacific Northwest of the United States (U.S.) have been studying urban runoff mortality syndrome (URMS) in coho salmon. Decades of investigations have sought to identify the chemical(s) causing the mortality in coho salmon (Tian et al. 2021, Tian et al. 2022). In 2020, researchers identified a specific chemical in stormwater that was directly linked to URMS. The chemical, 6PPDQ, forms from an antioxidant, 6PPD, which is used in tires to extend their lifespan. This chemical is acutely toxic to coho and, to a lesser degree, toxic to several other aquatic species (Tian et al. 2021, 2022; Brinkmann et al. 2022; Hiki et al. 2021).

6PPD is a rubber antioxidant/antiozonant that is used in automobile tires to extend their lifespan (Tian et al. 2021, 2022; Brinkmann et al. 2022; Hiki et al. 2021). When 6PPD is exposed to air, it reacts with ozone or oxygen to create a degradation product called 6PPDQ. It is still unclear how long it takes for all the 6PPD to fully migrate out of a tire or its wear particles, but, eventually, the 6PPD will react with oxygen gas or ozone and will be released to the environment in various forms, called transformation products. Recent studies suggest that, upon exposure to the atmosphere and oxidation, about 10 percent of 6PPD in tires transforms to 6PPDQ and that the remaining 90 percent is transformed into other chemical byproducts with unknown fates and toxicity (Hu et al. 2022, Seiwert 2022). Several studies have been conducted related to the transformation of 6PPD to 6PPDQ in the presence of ozone under various conditions (Hu et al. 2022, Zhao et al. 2023, Seiwert et al. 2022); however, more research is needed to understand whether ozone concentrations as an environmental variable impacts the transformation of 6PPD to 6PPDQ.

6PPDQ has been found to be highly toxic to juvenile coho salmon and other aquatic organisms. Estimates of 6PPDQ toxicity closely matched estimates derived from bulk roadway runoff and tire wear particle (TWP) leachate exposures, indicating that 6PPDQ was contributing most of the observed mixture toxicity (Zhenyu et al. 2021).

In tire leachate, 6PPDQ is likely not the only contaminant that is hazardous to aquatic life (Challis et al. 2021; Rauert et al. 2022). However, it appears that, in TWP leachate, 6PPDQ is the most toxic chemical to coho salmon adults (McIntyre and Kolodziej 2021) and juveniles (Tian et al., 2021). Brinkmann et al. (2022) investigated the acute toxicity of 6PPDQ to rainbow trout, brook trout, arctic char, and white sturgeon and reported 96-hour acute toxicity thresholds (LC_{50}) of 1.0 ug/L or less for the two trout species. Tian et al. (2022) reported a revised juvenile coho salmon LC_{50} of 0.095 ug/L, indicating substantial sensitivity to 6PPDQ (Ecology 2022), and Lo et al. (2023) found even lower toxicity thresholds for newly feeding juvenile coho (~3 weeks post swim-up) at an LC_{50} of 0.041 ug/L.

1.2. Project Overview

This section provides an overview of the modeling project deliverables within the greater context of King County's Statement of Work for the *Multi-Criterion Decision Tool* project. The *Multi-Criterion Decision Tool* project includes development of a model to qualitatively estimate 6PPDQ export from roadways (Screening Model), field sampling to characterize 6PPDQ in roadway runoff, validation of the Screening Model based on the results from the roadway runoff study, and the integration of model outputs into a decision-support tool for prioritizing roadway retrofit planning efforts. This report focuses on the development of the Screening Model as part of the *Multi-Criterion Decision Tool* project.

1.2.1. Modeling

The Modeling QAPP (Herrera 2024) describes the work needed to develop the Screening Model. Table 1 summarizes the project deliverables. The development of the Screening Model is documented in this report. Broadly, a conceptual model was developed based on literature review and elicitation from subject matter experts (SMEs). Under advisement from the SMEs, the conceptual model was further refined and specified into an initial draft Screening Model based on the most influential factors affecting 6PPDQ export and availability of suitable spatial proxies for those factors. The initial draft Screening Model was further reviewed by the SMEs. This review informed further refinement of the Screening Model and its underlying geospatial analysis.

Table 1. Modeling Deliverables Summary.

Deliverable	Purpose	Timeline
Quality Assurance Project Plan: Screening Model for 6PPDQ Delivery to the Stormwater Network ("Modeling QAPP")	The Modeling QAPP will describe how traffic and road data will be used to create a GIS 6PPDQ spatial data layer linking relative amounts of 6PPDQ in roadway runoff with road segment attributes	Q2–Q3 2024
Screening Model Report (this document)	Document how the 6PPDQ spatial data layer was developed and identify data gaps that could be filled to further refine the map	Q4 2024

1.2.2. Sampling

The next phase of this project will include field sampling for 6PPDQ. The purpose of the field sampling will be to characterize 6PPDQ export from roadways across a gradient of road use and road drainage characteristics to ground truth and validate the 6PPDQ Screening Model. This work will be funded mainly through a Puget Sound National Estuary Program (NEP) grant and an Interagency Agreement (IAA) with the Washington State Department of Ecology (Ecology), as well as through in-kind support from the Washington State Department of Transportation (WSDOT).

Ten to twenty candidate sites will be selected based on the feasibility and safety of collecting samples of roadway runoff, while ensuring a gradient of Screening Model outputs are represented across the sites. After conducting field reconnaissance, up to 12 sites will be selected for the monitoring study. Site selection will be documented in a Site Screening Technical Memorandum (see Table 2). Monitoring data will include rainfall, discharge, total suspended solids, 6PPDQ, and particle size distribution. The final report from that study may include recommendations for adjustments of the Screening Model to improve performance.

Separate from the Modeling QAPP, a Sampling QAPP describing the sampling methods to be used (see Table 2) will be developed. The Sampling QAPP will describe methods used to collect stormwater samples from King County roads, including goals and objectives of sampling, types of data to be collected, sampling locations, data collection procedures, data collection frequency, duration of sampling period, data quality objectives, and data quality assurance review procedures.

Table 2. 6PPDQ Field Sampling Project Deliverables Summary.

Deliverable	Purpose	Timeline
Site Screening Technical Memorandum	This memorandum will summarize observations at each candidate site and provide a list of recommended sites for stormwater sampling to be conducted. It will also include a summary of sampling methods expected to be potentially feasible at each stormwater sampling site and the pros and cons of each method. Some sampling methods will likely only be possible at sites with certain characteristics. Examples of sampling methods that may be considered include flow-weighted sampling of sheet flow with installation of curbs or weirs, flow-weighted sampling from stormwater pipes or ditches, manual time-weighted sampling with grabs, passive sampling technologies, and more.	Early 2025
QAPP: 6PPDQ Road Runoff Characterization Study (*Sampling QAPP*)	The *Sampling QAPP* will describe methods used to collect stormwater samples from King County roads, including goals and objectives of sampling, types of data to be collected, sampling locations, data collection procedures, data collection frequency, duration of sampling period, data quality objectives, and data quality assurance review procedures.	Early 2025
Stormwater Sampling Data Report	This report will include tabular and graphical summaries of the data collected under the *Sampling QAPP* and an evaluation of differences in field-collected 6PPDQ concentrations and those estimated by the 6PPDQ spatial data layer (i.e., field validation of the Screening Model). Recommendations for model improvements will be included.	Late 2026

1.2.3. Roadway Prioritization

Under the *Multi-Criterion Decision Tool* project, the output from the Screening Model will be integrated into a King County stormwater prioritization tool (prioritization tool), which is a decision guidance tool being separately developed to support retrofit planning efforts. The prioritization tool will identify and prioritize drainage subbasins and roadway segments where improvements to existing stormwater management infrastructure would yield multi-benefit outcomes. The prioritization tool will compare subbasins and/or roadway segments. This allows the user to consider multiple decision criteria, such as presence of fish-bearing streams, hotspots of other stormwater pollutants, metrics for human health equity, and principles of social justice, among others, when evaluating the selection and siting of stormwater retrofits.

King County will develop a final Road Segment Prioritization report that will summarize methods, results, lessons learned, and recommendations for future work.

2. Model Development

This section describes the development process for the Screening Model including identification of the purpose, goals and objectives; development steps; identification of SMEs; and conceptual model development.

2.1. Model Purpose, Goals, and Objectives

During Step 1 of model development (accomplished under the QAPP), the specific use and users of the model were identified. They are presented again here due to their influence on decisions made during Screening Model development by the SMEs and the project team in consideration of the necessary granularity of model inputs and outputs.

For the Screening Model, Herrera has identified the following:

- Model Purpose: (1) To inform the selection of monitoring sites by defining the key influential landscape factors across which to evaluate, and (2) to provide a relative scoring/ranking of public roadways in terms of the export of 6PPDQ
- Model Endpoint: "Delivery of 6PPD/6PPDQ to Stormwater Conveyance Network" expressed as the relative amount of 6PPDQ or its parent material expected at the point of input to the conveyance network[1]
- Model Scope: Public roadways in the King County geographic area
- Model User: Technical staff within stormwater management agencies with GIS experience
- Model Output User: Project managers and technical staff who are selecting monitoring sites to characterize 6PPDQ and/or prioritizing drainage areas/roadways for stormwater retrofit

The Screening Model estimates the relative magnitude of 6PPDQ export from individual roadway segments. A roadway segment is defined as a distinct unit of roadway, represented spatially as a line segment between intersections or at other common breakpoints.

Initially, the Screening Model was planned to primarily focus on public roadways managed by King County and Washington State Department of Transportation (WSDOT) and to use readily available datasets for other jurisdictions. This decision was driven by the numerous locations and varying data quality of mapped stormwater conveyance by jurisdictions in King County. After the QAPP was finished, the project team determined that the Screen Model could evaluate all public roadways in the King County geographic area, due to the structure of the Screening Model and the availability of stormwater

[1] *Note: The conceptual model developed within the QAPP and displayed in the next chapter extends to "Delivery to Surface Waters" and considers transport and treatment, but this is outside of the scope of the 6PPDQ Screening Model.*

conveyance data compiled under a separate King County effort. That data compilation effort is detailed in Section 2.5.2.

2.2. Summary of Model Development Methodology

This section provides a high-level summary of the development of the Screening Model. Table 3 summarizes the overall approach for developing the Screening Model. Steps 1 through 3 were completed and are documented in the QAPP (Herrera 2024) and are summarized in this report. The remaining steps are documented in this report.

Table 3. Summary of Screening Model Development Approach.		
Step	**Description**	**Activity**
1. Clear definition of endpoint and model purpose	To ensure proper detail and specificity, it is critical to clearly define the scope, endpoint, purpose, and user of the model.	Accomplished as part of Modeling QAPP development.
2. SME Identification and Recruitment	Subject matter experts (SMEs) are selected based on their knowledge of the issue, capability to communicate their knowledge, awareness of their own knowledge and problem-solving ability, reliability, and freedom from conflicts of interest.	Herrera and the IRT collaboratively identified and recruited SMEs who are experts in 6PPDQ, roadway and parking lot runoff, and tire wear.
3. Conceptual Model Development	A conceptual model for the defined endpoint is developed according to the boundaries and scale relevant to model use. The conceptual model maps influential factors and their relationships leading to the endpoint. The team of SMEs reviews the draft model independently and then discusses their feedback as a group before refining the final model, a process intended to reduce bias by any individual expert.	Herrera and the IRT developed a draft conceptual model for SME review and feedback based on a literature review. This is documented in the Modeling QAPP for Ecology approval. Workshop (August 2023)
MILESTONE: CONCEPTUAL MODEL		
4. Identification of Primary Factors and Spatial Proxies	The conceptual model is used to identify appropriate spatial proxies for use in the Screening Model (e.g., modeled vehicle traffic by vehicle weight class; drainage features; adjacent imperviousness). The overall structure of the conceptual model is retained (Figure 1), but the constituent model inputs are generalized for suitability over a large geographic extent (e.g., the presence and length of drainage infrastructure associated with a target roadway is applied as a model input, but the connectivity of the broader stormwater drainage network is not).	SpET Workshop (Fall 2023) SME Workshop (Fall 2023)
5. Compilation and Harmonization of Spatial Data	During the development of the modeling QAPP, an initial evaluation of the input spatial features for the Screening Model identified instances of misalignment between features. This included misalignment of roadway spatial features (between the st_address roads and the Puget Sound Regional Council (PSRC) SoundCast traffic model links), as well as misalignment between the st_address layer and other non-road model inputs (including stormwater infrastructure and the road skirt). At this stage, the project team seeks to develop a programmatic process to unify the disparate layers. This improves the confidence of assigning appropriate attributes to each target road segment.	Q1–Q2 2024
6. Scoring of Roadway Using the Screening Model	Individual roadway segments are scored through the Screening Model. The SME team reviews and provides comments on the initial generalized roadway types and scoring.	Q2–Q4 2024
MILESTONE: SCREENING MODEL		

IRT: King County Internal Review Team; SME: Subject Matter Expert; SpET: Spatial Expert Team

2.3. Subject Matter Expert Teams

The development of the Screening Model has been supported by two groups: (1) SMEs, who have provided guidance on the conceptual model for 6PPDQ and have reviewed the draft Screening Model, and (2) the Spatial Expert Team (SpET), which has helped identify suitable proxies and methods for translating the conceptual model to a robust spatial model. See Table 4 and Table 5.

Table 4. Subject Matter Experts (SMEs) for Conceptual Model and Screening Model Development.

Expert	Title	Association
Kathy Peter, Ph.D.	Aquatic Chemist, Research Scientist	University of Washington Center for Urban Waters
Jenifer McIntyre, Ph.D.	Aquatic Toxicologist, Assistant Professor	Washington State University
Rhea Smith	Aquatic Toxicologist	Washington State Department of Ecology
Stephen Conroy, Ph.D.	Environmental Scientist	King County Road Services Division
Jennifer Lanksbury	Ecotoxicologist	King County Water and Land Resources Division
Jeneé Colton	Supervisor, Toxicology and Contaminant Assessment Unit	King County Water and Land Resources Division
Kelly Moran, Ph.D.	Senior Scientist	Clean Water Program San Francisco Estuary Institute

Table 5. Spatial Expert Team (SpET).

Expert	Title	Association
James (JJ) Bach	Roads Spatial Data Specialist	King County Road Services Division
Jeff Burkey	Hydrologist	King County Water and Land Resources Divisions
Jennifer Schmidt, GISP	Geospatial Science Associate Practice Director	Herrera Environmental Consultants
Stephen Conroy, Ph.D.	Environmental Scientist	King County Road Services Division

2.4. Conceptual Model Development

The project team developed a conceptual model for the delivery of 6PPDQ to surface waters and to summarize our current understanding and uncertainty. The conceptual model serves as the foundation for the Screening Model for this project by identifying the key factors that influence the delivery of 6PPDQ to surface water. The conceptual model was developed by the project team based on the literature review, with assistance from the SMEs. A SME workshop was convened on August 23, 2023, to provide input on development of a conceptual model.

The QAPP (Herrera 2024) includes a thorough description of the literature review that supports the conceptual model and a narrative to accompany the conceptual model. An updated conceptual model graphic from the QAPP is presented in Figure 1. The updates to the graphic are to enhance understanding and there is no change in content or meaning. The conceptual model focuses on automobile tires as the primary contributing source of 6PPDQ, specifically, TWPs.

The conceptual model is broken into four components: (1) Generation of TWPs; (2) Deposition and Buildup of TWPs; (3) Transformation of 6PPD to 6PPDQ; and (4) Wash-off and Transport of TWPs/6PPDQ. The reader is referred to the QAPP for additional information.

Under advisement of SMEs, the conceptual model was further refined and specified into the Screening Model based on the most influential factors affecting 6PPDQ export and availability of suitable spatial proxies for those factors. The endpoint for the Screening Model is the 6PPDQ delivery from roadways to the stormwater conveyance network. The conceptual model extends to 6PPDQ delivery from deposition areas other than roadway surfaces (specifically areas near roadways) and delivery to surface waters.

6PPDQ on Roadways

Conceptual Model

Generation of Tire Wear Particles (TWPs) on Roadways and Parking Lots.
Tires contain various levels of 6PPD, an antiozonant. When exposed to ozone and oxygen, 6PPD transforms to 6PPDQ and other products. Transformation occurs at the surface of tires and tire wear particles (TWPs). Most transformation and mobilization of 6PPDQ is expected to occur on TWPs, due to their surface area, compared to whole tires.



Braking/Acclerating

Cornering

Speed

VEHICLE BEHAVIOR

Activities like cornering, braking, and acceleration have been shown to increase the tire wear rate.
However, there is little in-situ data to describe the magnitude of infuence.

Vehicle Composition
Vehicle composition captures the relative make-up of the vehicle population, which includes the vehicle weight, tire width, and number of axles/tires per vehicle

Road Roughness

Road Temperature

Road Friction

Roadway Conditions
Road temperature, roughness, and presence of road salts may all theoretically influence the rate of tire wear, but there are no field studies to describe the relative importance.

TIRE WEAR RATE
(Mass or # Particles/Vehicle/Time)

Number of Vehicles
(#Vehicle/Time)

TWP GENERATION
TWP/Distance/Time

Deposition Outside of Generation Area Buffer
Fine and ultrafine TWPs can transport long distances beyond the immediate proximity of roadways and parking lots. Little is known on the 6PPDQ transport and delivery related to these smaller TWPs.



Deposition/Build-up on Roadways and Nearby Areas
Most of the mass of TWPs typically deposits relatively near the generation area, which include the roadway itself, directly connected impervious area (DCIA), unconnected imperious area (UIA), and pervious area (PA). TWP may be resuspended and blown away from active roadway surfaces. Smaller particles may travel further afield.

Imperviousness and Connectedness of 6-meter Buffer on Roadway
- Roadway Buffer Imperviousness
- Roadway Curb/Gutter
- Roadway Embankment
- Area Directly Conveyed to Stormwater System

TWP DEPOSITION ON ROADWAY
(TWP/Area/Time)

TWP DEPOSITION ON DCIA
(TWP/Area/Time)

TWP DEPOSITION ON PA OR UIA
(TWP/Area/Time)

Deposition Area Removal (Street, Parking Lot, Sidewalk Sweeping)

Antecedent Dry Period

TWP BUILD-UP ON ROADWAY
(TWP/Area)

TWP BUILD-UP ON DCIA
(TWP/Area)

TWP BUILD-UP ON PA OR UIA
(TWP/Area)



Degradation
Sequestration/Degradation
6PPD and 6PPDQ degrade by biotic and abiotic processes. Additionally, Studies have found that 6PPD and 6PPDQ are show a strong affinity for soils and organic matter and may be sequestered in soils. There are not sufficient data to differentiate degradation rates among pervious areas within King County. However, vegetation type, soil type, temperature, and other factors may influence this rate. Biological activity is expected to be greater on vegetated areas than impervious surfaces.

Transformation of 6PPD to 6PPDQ and Degradation
Transformation
6PPDQ forms on the surface of tires and TWPs when 6PPD is exposed to ozone and, to a lesser degree, oxygen. This includes on the tire, on deposited TWPs, and TWPs accumulated in transport (such as within stormwater pipes or BMPs).

The transformation of 6PPD to 6PPDQ is a function of TWP Surface Area, 6PPD levels in tires, and ozone availability. There is inadequate supporting information to suitably geographically differentiate transformation process rates within King County.

6PPDQ BUILDUP ON ROADWAY
(Mass/Area)

6PPDQ BUILDUP ON DCIA
(Mass/Area)

6PPDQ BUILDUP ON PA OR UIA
(Mass/Area)

Storm Intensity and Duration

Wash-off & Transport of 6PPDQ from Roadways and Nearby Areas
Depending on the intensity and duration, rain events can mobilize TWPs and other particles with bound 6PPDQ, transporting from surfaces to the stormwater conveyance network, if present. During conveyance, the particles may settle or be adsorbed, removing 6PPDq from runoff. Stormwater treatment BMPs offer filtering/adsorption sites for 6PPDQ and particles with bound 6PPDQ.

6PPDQ EXPORT FROM ROADWAY RUNOFF - EDGE OF PAVEMENT
(Mass/Area)

6PPDQ EXPORT FROM DCIA RUNOFF
(Mass/Area)

6PPDQ EXPORT FROM PA OR UIA
(Mass/Area)

6PPDQ REACHING STORMWATER NETWORK
(Mass)

Roadway Connectedness and/or Treatment



Pathway
(Pipe, Ditch, Gutter, Swale)

6PPDQ DELIVERY TO SURFACE WATER
(Mass)



In-line or Regional Stormwater Treatment

TWP: Tire Wear Particles
DCIA: Directly Connected Impervious Area
PA: Pervious Area
UIA: Unconnected Impervious Area (drains to pervious area)

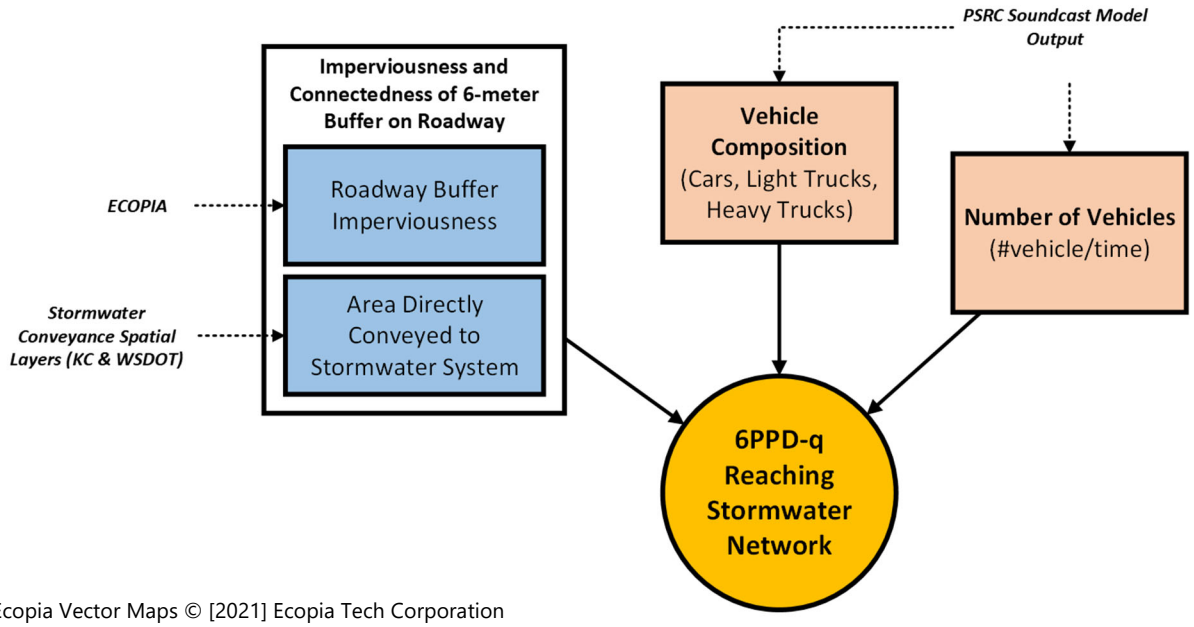
2.5. Identification of Primary Factors and Spatial Proxies

The conceptual model was simplified based on input from the SMEs on the most important primary factors driving delivery of TWPs and 6PPDQ, and on available spatial data (Figure 2). Based on SME input and literature review, the foremost factors in determining the total amount of tire wear occurring on a roadway segment are the total number of vehicles using the roadway and the composition of those vehicles (i.e., the weight and number of tires per vehicle). The meeting notes and communications are documented in Appendix B.

After tire wear occurs, the total export to the stormwater conveyance network is determined by where those TWPs are ultimately deposited and the connectedness of that roadway segment and its adjacent buffer. TWPs deposited on pervious surfaces will run off at a slower rate than those deposited on impervious surfaces. Further, 6PPD has a strong tendency to adsorb on organic matter in soils and sediments, and 6PPDQ degradation occurs more rapidly in biologically active and aerobic soils. The presence of a conveyance network is critical for determining how much runoff will ultimately be conveyed from the roadway and its skirt (where "skirt" is the area within a 6-meter buffer of the active roadway surface). Runoff from roadways without stormwater conveyance is generally expected to have minor export and higher rates of TWPs/6PPD retention and 6PPD/6PPDQ degradation. Deposition of tire wear particles beyond the roadway skirt occurs at an unknown rate but is expected to be much less compared to the skirt itself (i.e., 1 or more orders of magnitude less). This Screening Model does not consider deposition occurring beyond the skirt.

Under guidance from the SpET, spatial layers were identified to serve as direct or proxy variables for the simplified conceptual model. The spatial layers are detailed in Table 6. Specific rationale for their selection is provided in the following text and is further described in Appendix B.

Figure 2. Simplified Conceptual Model for Screening Model.



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Table 6. Spatial Datasets Used in Screening Model.					
Model Dataset (Source)	**Dataset Recency**	**Screening Model Attribute**	**Screening Model Variable**	**Data Type**	**Notes**
st_address (King County)	November 2022	Primary layer for scoring attributes	Roadway deposition area	Polylines	Unique road ID numbers generated for each distinct line section in the source dataset (at intersections, where road names change, and where breaks otherwise present in the st_address source layer)
Metro Transportation Network in King County for car mode (TNET)	January 2024	Source of jurisdiction attribute	Jurisdiction	Polylines	Jurisdictions applied to WSDOT state route and interstate road lines. Remaining road jurisdictions were attributed from the City_L attribute from the TNET automotive model.
SoundCast Travel Model (PSRC)	Baseline modeled 2018; version 3.0.1 modeled 2022	Average Daily Traffic (ADT)	Vehicle counts	Numeric	The PSRC SoundCast links do not directly overlap with st_address lines for roadways in all cases. The approach for reconciling is discussed in the next section.
SoundCast Travel Model (PSRC)	Baseline modeled 2018; version 3.0.1 modeled 2022	Medium Truck Traffic, Heavy Truck Traffic	Vehicle composition	Numeric	The PSRC SoundCast links do not directly overlap with st_address lines for roadways in all cases. The approach for reconciling is discussed in the next section.
Stormwater conveyance data (multiple sources; see Appendix C)	2021-2024 (multiple years)	Road drainage – presence of stormwater conveyance features	Roadway connectedness	Categorical; Numeric	Categorical values for stormwater feature type (ditch, swale, stream, pipe, culvert) for King County, WSDOT, and Seattle stormwater records. Length of conveyance along road for all features, based on intersection with the buffer around each derived road surface extent polygon
Land Cover (Ecopia[a] via King County)	2019	Impervious percent cover; Spatial extent of road surface extent polygons	Roadway connectedness	Numeric	Road surface extent polygon derived from Ecopia land cover classifications and associated with st_address lines for roadways using the approach described in the next section. Road surface extent used to generate the road skirt (buffered road surface polygon; non-inclusive of road surface extent polygon). Road skirt imperviousness calculated based on the percent cover by area of impervious and water land cover types (from Ecopia classifications) within the generated road skirt.

[a] "Ecopia Vector Maps © [2021] Ecopia Tech Corporation"

Roadways are categorized based on their functional classification (FCC): Local, Collector, Minor Arterial, Primary Arterial, and Freeway. These classifications were provided in the st_address spatial layer from King County and defined below.

- Freeways are the highest classification of roadways. These arterial roads provide the highest level of mobility and the highest speeds over the longest uninterrupted distance. Interstates nationwide usually have posted speeds between 55 and 75 miles per hour (mph).
- Arterials connect major activity centers within metropolitan areas as well as large cities in rural areas. Unlike interstates and freeways, other arterials have lower traffic demands and access is not always restricted to ramps. Posted speed limits on arterials usually range between 50 and 70 mph. Minor arterials are used for trips of moderate distance and slower speeds than primary arterials.
- Collectors are major and minor roads that connect local roads and streets with arterials. Collectors provide less mobility than arterials at lower speeds and for shorter distances. They balance mobility with land access. The posted speed limit on collectors is usually between 35 and 55 mph.
- Local roads provide limited mobility and are the primary access to residential areas, businesses, farms, and other local areas. Local roads, with posted speed limits usually between 20 and 45 mph, are the majority of roads in the U.S.

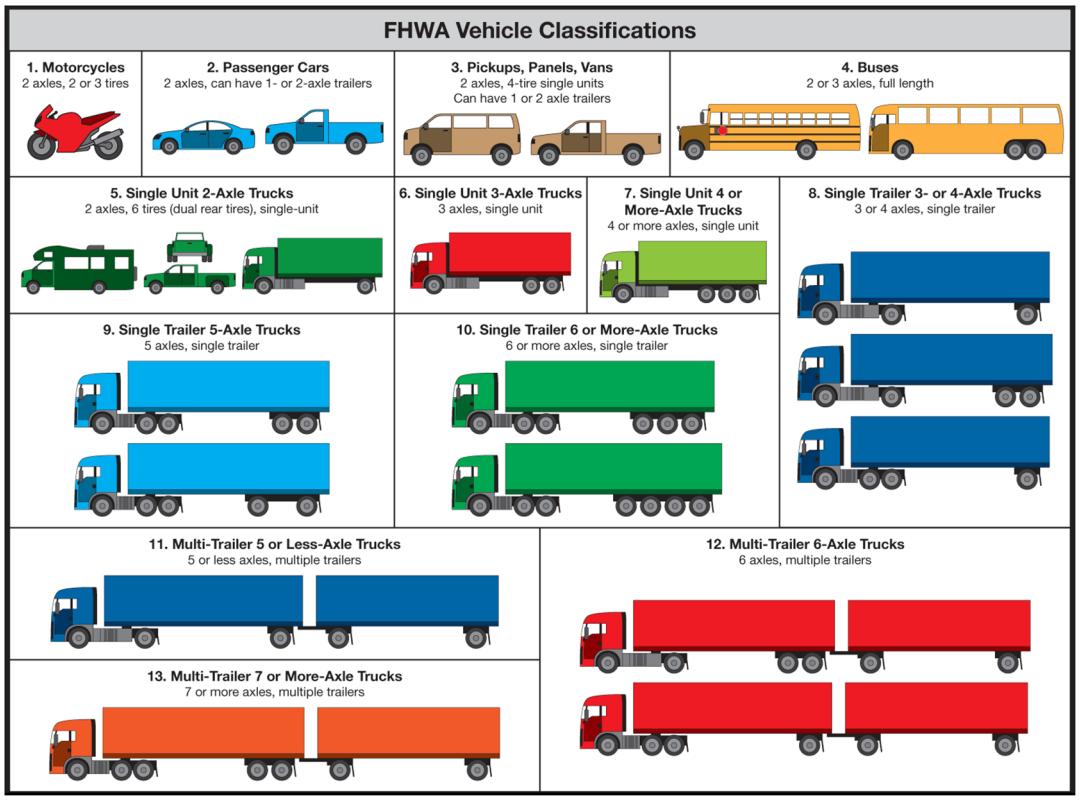
2.5.1. Deposition (Traffic Intensity and Composition)

The PSRC SoundCast model is an activity-based model system that represents the travel behavior of each individual and household throughout King, Kitsap, Pierce, and Snohomish counties. The SoundCast model depicts travel behaviors that depend on the built environment and demand from other transportation users. SoundCast outputs transportation network measures, such as highway volumes in 1-hour periods in a future year, or number of boardings on a transit line. It also outputs measures related to people, like average distance to work by home county or the number of transit trips different types of people will take. The truck model defines a truck based on relative weight classes and separates medium and heavy trucks for analysis purposes. Trucks are defined to match the definitions WSDOT uses to collect truck counts. These definitions rely primarily on weight, but for other purposes, these categories are also loosely correlated to other defining characteristics of trucks. The following general categories of trucks are used:

- Medium trucks are defined as single unit, 6 or more tires, 2 to 4 axles and 16,000 to 52,000 pounds. gross vehicle weight (examples are shown in boxes 5, 6, and 7 in Figure 3)
- Heavy trucks are defined as double or triple unit, combinations,5 or more axles, and greater than 52,000 pounds. gross vehicle weight (examples are shown in boxes 8 to 12 in Figure 3).

In these definitions, the medium trucks are directly correlated to single-unit trucks collected in the WSDOT truck counts and heavy trucks are directly correlated to double- and triple-unit trucks in the counts. Commercial vehicle trips (Light Trucks) are not included in the truck model, because they are captured, at least in part, by Daysim (the Activity Based Model engine in SoundCast).

Figure 3. Federal Highway Administration (FHWA) Vehicle Classifications.



Source: Texas Department of Transportation

2.5.2. Connectedness (Imperviousness and Conveyance)

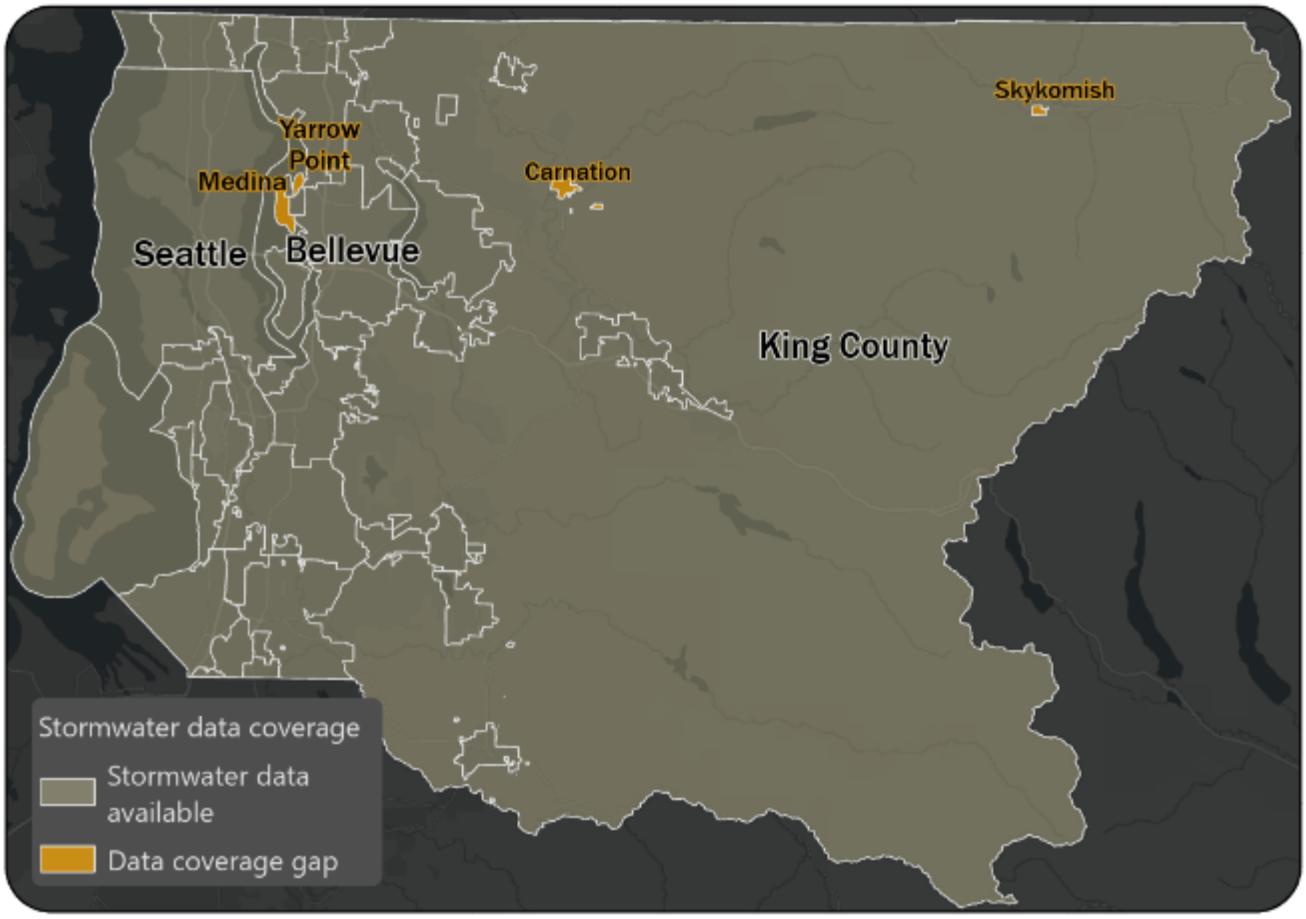
The Ecopia layer was selected to represent imperviousness, because it had high-definition spatial coverage and provided identification of specific types of impervious surfaces (e.g., roads, sidewalks, bridges). This allowed for extraction of spatially explicit road surface extent polygons, as well as other impervious feature classes. Alternative impervious land cover datasets that were considered include the 2021–2022 Statewide Ecopia dataset for Washington and the 2015 Impervious and Impacted Surface dataset for Western King County, Washington.

After publishing the QAPP, the project team became aware that King County staff, under a separate effort, had compiled available stormwater features from nearly all jurisdictions in King County as of 2023 into a single dataset. This dataset was then integrated in the Screening Model, such that nearly all the public roadways in the King County geographic area were evaluated. This is a change from the QAPP (Herrera 2024).

Stormwater conveyance spatial data was readily available from King County Stormwater Services, Seattle Public Utilities, and WSDOT. King County GIS produced a preliminary, aggregated spatial inventory of stormwater records across all jurisdictions within the county, sourcing stormwater spatial files from King County, cities, and WSDOT where available. The spatial layers included in the aggregated stormwater inventory from each jurisdiction are summarized in Appendix C. This aggregated inventory has not been subject to standard quality control processes by County staff and includes both open and closed

stormwater conveyance network features, as well as retention ponds, bioswales, and other stormwater treatment devices within some jurisdictions (Appendix C). It is assumed that there may be inaccuracies in the types of features present; however, the Screening Model is relying on the dataset to determine whether any physical stormwater conveyance network features are present and does not distinguish between types. Therefore, the team determined that the dataset was of adequate quality for use in the Screening Model. The Screening Model computes the length of a road segment that has associated stormwater conveyance network features if they are present. Data from the City of Issaquah were not included in the original aggregated stormwater conveyance inventory but were added to this aggregated layer by Herrera. The jurisdictions of Carnation, Skykomish, Medina, and Yarrow Point are without stormwater coverage (aside from coverage provided by WSDOT and/or King County stormwater layers; Figure 4).

Figure 4. Jurisdictions Without Stormwater Infrastructure Mapping in the Screening Model.



This model does not include targeted scoring of stormwater treatment devices, such as retention ponds and bioswales, that are located along roadways. Those devices may provide enhanced treatment, but their presence does not have an additional influence on roadway score in this model. Larger treatment facilities may be represented in part by influencing the "road buffer imperviousness" of a road segment, but in-line treatment devices are not represented. Those devices, in a sense, are the endpoint of the simplified model because they are the entry-point of the stormwater network.

2.5.3. Factors Dropped Due to Limited Data

Some potentially important factors identified in the conceptual model were dropped due to uncertainty in the factors' influence on 6PPDQ export from roadway, due to limited or no spatial data, or both. These factors and their relative importance to the model output are summarized in Table 7.

Table 7. Factors Dropped from Screening Model.

Factor	Description	Spatial Data Availability	Qualitative Importance to 6PPDQ Export
Vehicle Behavior	Vehicle behaviors, like turning, braking, and accelerating, have been shown to increase the TWP generation rate in laboratory settings and in a handful of field studies. However, the magnitude of impact of vehicle behavior on the Tire Wear Rate is not well understood at this time.	No direct measure. Braking/accelerating may be assumed based on intersection, stop signs/lights, traffic congestion data. Turning may be calculated based on intersections, driveways, and road sinuosity.	Potentially important but expected to be minor compared to the total number of vehicles.
Roadway Conditions	Roadway conditions, like roughness, temperature, and friction (as influenced by road and tire material), may impact the Tire Wear Rate.	Some data availability for roadway material, but there is limited to no data linking roadway material to tire wear rate. Road temperature may be assumed using interpolated air temperature monitoring data.	Potentially important but expected to be minor compared to the total number of vehicles.
Street Sweeping	Street sweeping may remove a portion of accumulated TWPs. However, street sweepers are only moderately efficient in collecting particles in the size range of tire wear, particularly when considering realistic sweeping frequencies and equipment types—and that only a portion of the area where TWPs accumulate may be reached by street sweepers.	Street sweeping route and frequency data may be gathered from jurisdictions.	Potentially important but further research is needed.
Curbs and Gutters	Gutters and curbs may serve as a trap for TWP as they are pushed away from the road surface due to turbulence. This may prevent TWP from reaching pervious, vegetated areas where TWP may be sequestered, and 6PPDQ may degrade.	Curb and gutter line data are available for King County and City of Seattle.	The relative capture of TWP by curbs and gutters has not been studied.
Stormwater treatment facilities	Stormwater treatment devices (e.g., in-line filters, rain gardens, bioswales, ponds) may be able to remove TWP and offer sequestration sites for 6PPDQ.	King County and other jurisdictions have mapped locations of their facilities. There is not yet a combined data layer with consistent and quality-checked categorization of facilities.	The removal effectiveness for 6PPDQ and TWP of varying stormwater treatment devices are active research questions. Treatment extends beyond the scope of the Screening Model.

2.6. Compilation and Harmonization of Spatial Data

2.6.1. Harmonization of Spatial Layers

The selected data layers for analysis did not exhibit consistent spatial alignment, which makes it challenging to assign attributes from a source dataset to a target dataset. Pre-processing and additional data handling was necessary to create spatial agreement between the lines representing roadways (e.g., Metro Transportation Network (TNET), the PSRC SoundCast model links, and the st_address lines) and real-world features (e.g., the road surface extent polygons and stormwater conveyance network).

The modeling team developed methods to represent relationships between these disparate sources of spatial data. The primary method involved breaking apart a high-resolution representation of road surfaces into units that could be associated with attributable line segments (Figure 5). This is described in the following subsections.

Figure 5. Example of st_address and Generated Road Surface Extents and Skirts.



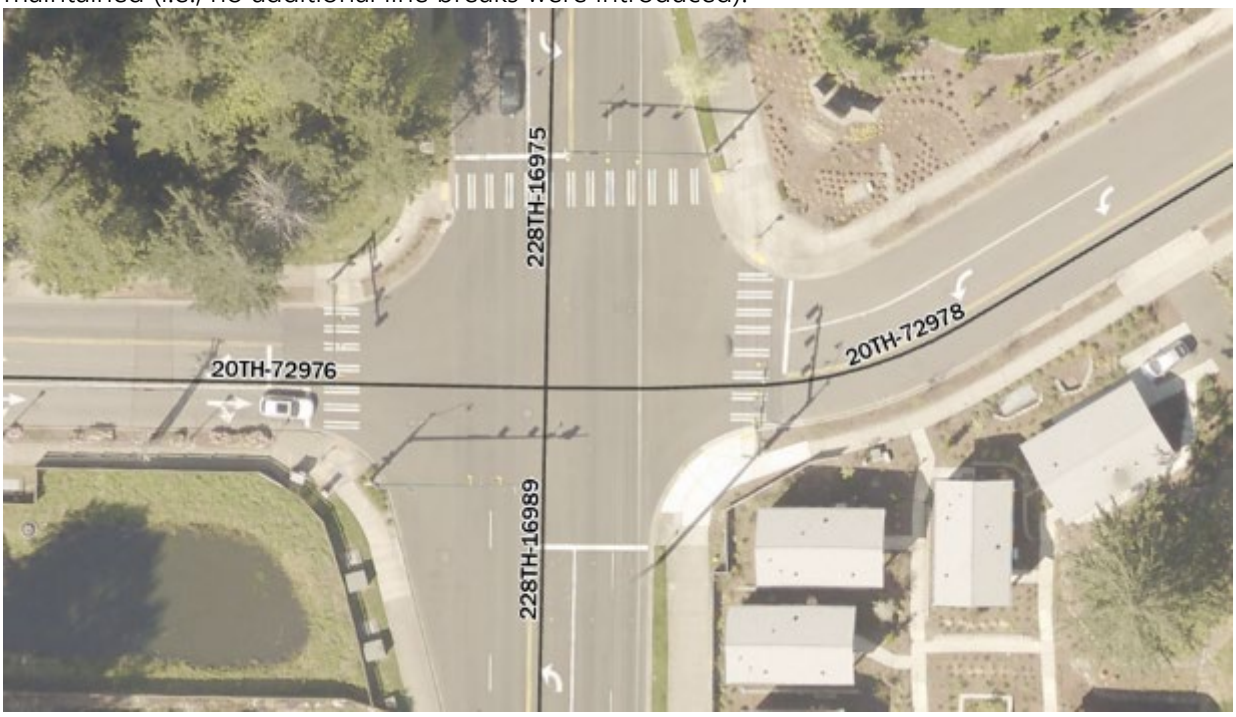
Note: In the figure above, the st_address lines (black lines) did not consistently follow the real-world road centerlines. The Ecopia "road" land cover designation (yellow polygon) was used to generate roadway surface extent polygons attributed with the st_address RoadSegmentID. A road "skirt" (orange polygon) was generated as a 6-meter buffer on either side of the road surface extent polygon.

2.6.1.1. Road Surface Extent Polygons

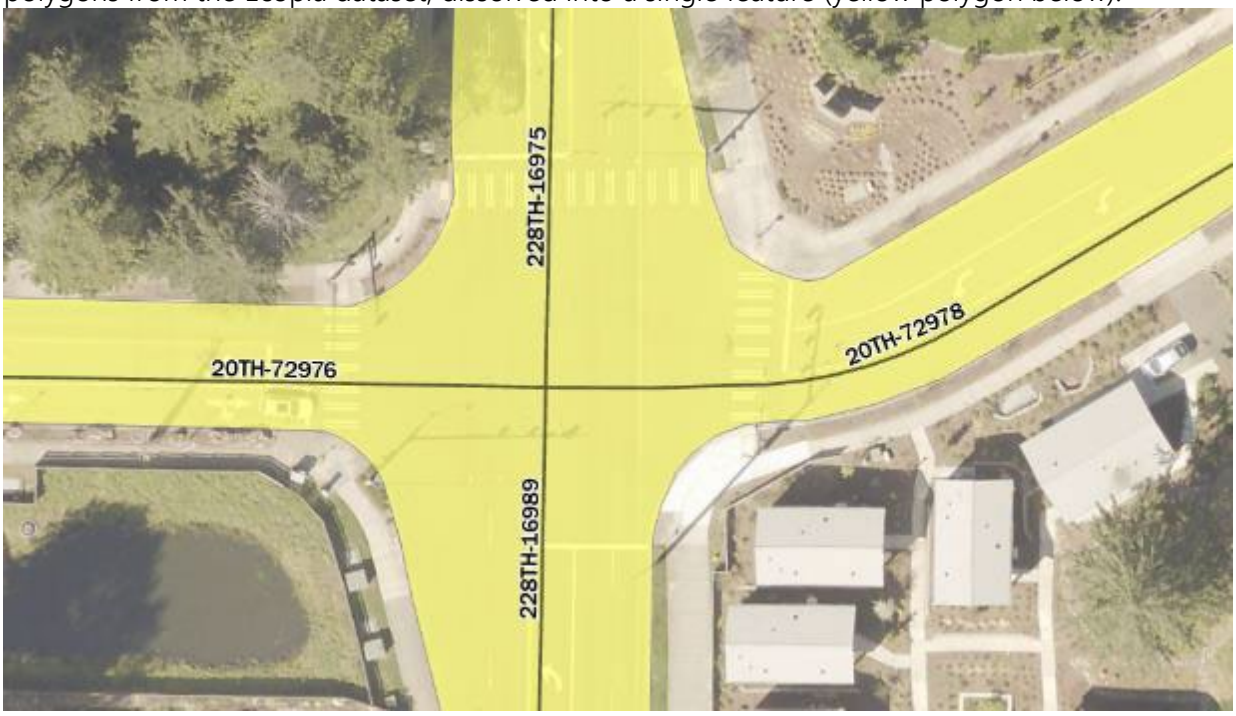
The st_address layer was used as the target road layer for appending all other spatial attributes (e.g., traffic, stormwater infrastructure). The st_address road layer is represented by two-dimensional lines (i.e., does not include an elevation dimension) that are broken at intersections. This layer was developed by King County to represent the mid-line of the rights-of-way between parcels. Consequently, the st_address road layer is often not spatially consistent with the centerlines of roadways as they exist in the physical world. This makes it challenging to spatially represent relationships between the st_address road segments and other spatial datasets. To make it possible to associate other spatial data with the st_address lines, the "road"-type land cover from the Ecopia dataset was extracted to create a representative road surface. Then, the road surface was subdivided and associated with unique road segment IDs from the st_address layer. This process is explained stepwise below.

Step-wise process:

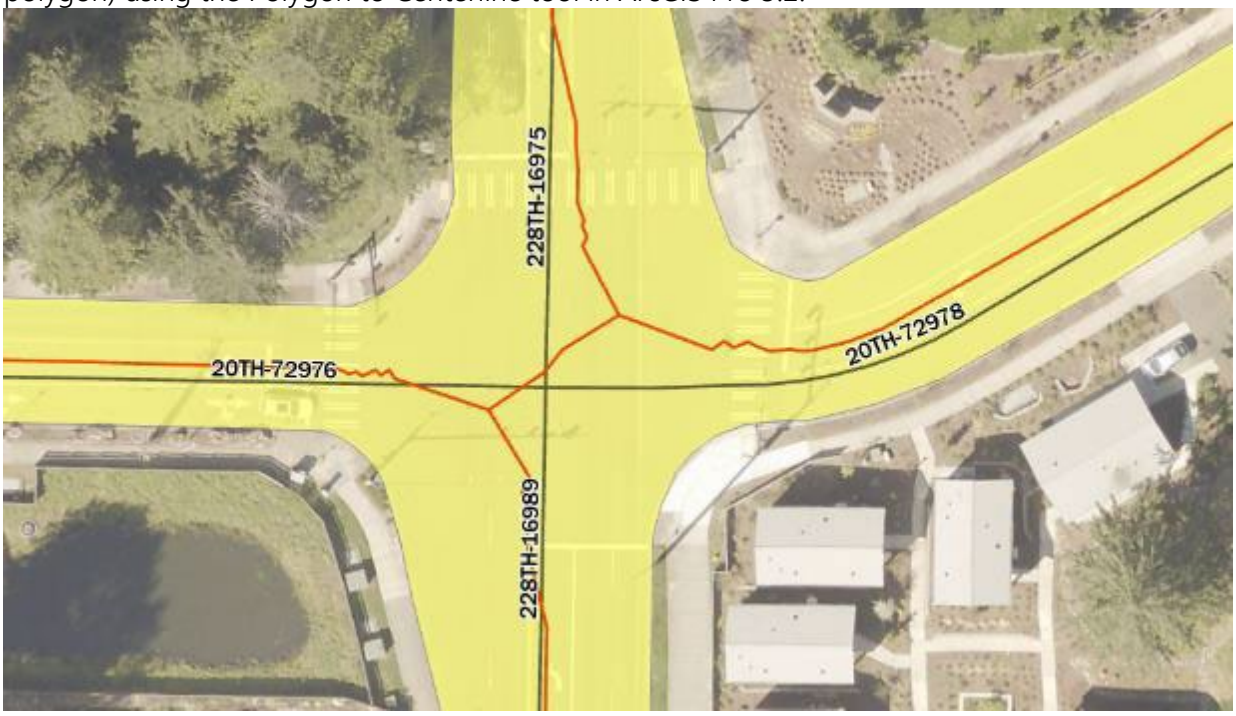
1. Herrera assigned a unique RoadSegmentID to each st_address feature based on the road name and a unique identifying number. This was done to distinguish between roads that shared the same name but occupied a different spatial extent (e.g., Main St-0038 and Main St-0039 are different subunits of the same named road). The original line breaks from the st_address feature class were maintained (i.e., no additional line breaks were introduced).



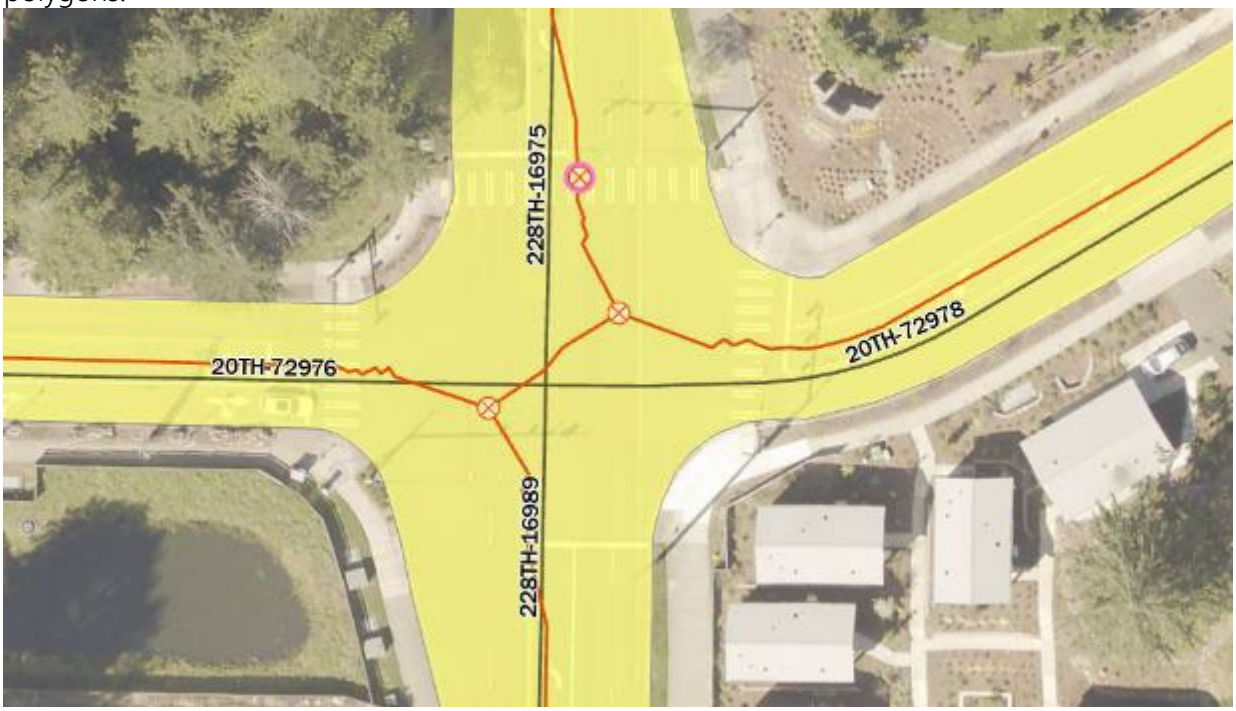
2. Herrera generated a new polygon feature representing all road and bridge-type land cover polygons from the Ecopia dataset, dissolved into a single feature (yellow polygon below).



3. Herrera created a new centerline feature (orange lines) based on the new road area polygon (yellow polygon) using the Polygon to Centerline tool in ArcGIS Pro 3.2.



4. Herrera generated points at the origin and terminus of road centerline segments (circled orange x-marks). This included points at all centerline intersections, as well as the starts and ends of short centerline segments that were created near complex intersections and curves (highlighted in pink). These smaller segments that are not directly associated with line intersections are processing relics of the Polygon to Centerline geospatial tool, and do not strongly influence the final shape of road polygons.



5. Herrera generated a series of lines (shown in brown) that radiated outward from centerline points (circled orange x-marks) and intersected the edges of the road area (yellow). These lines were generated using the following steps:

   a. Create a small buffer around each road centerline point (generated in the previous step). Convert the buffer perimeter to a line.

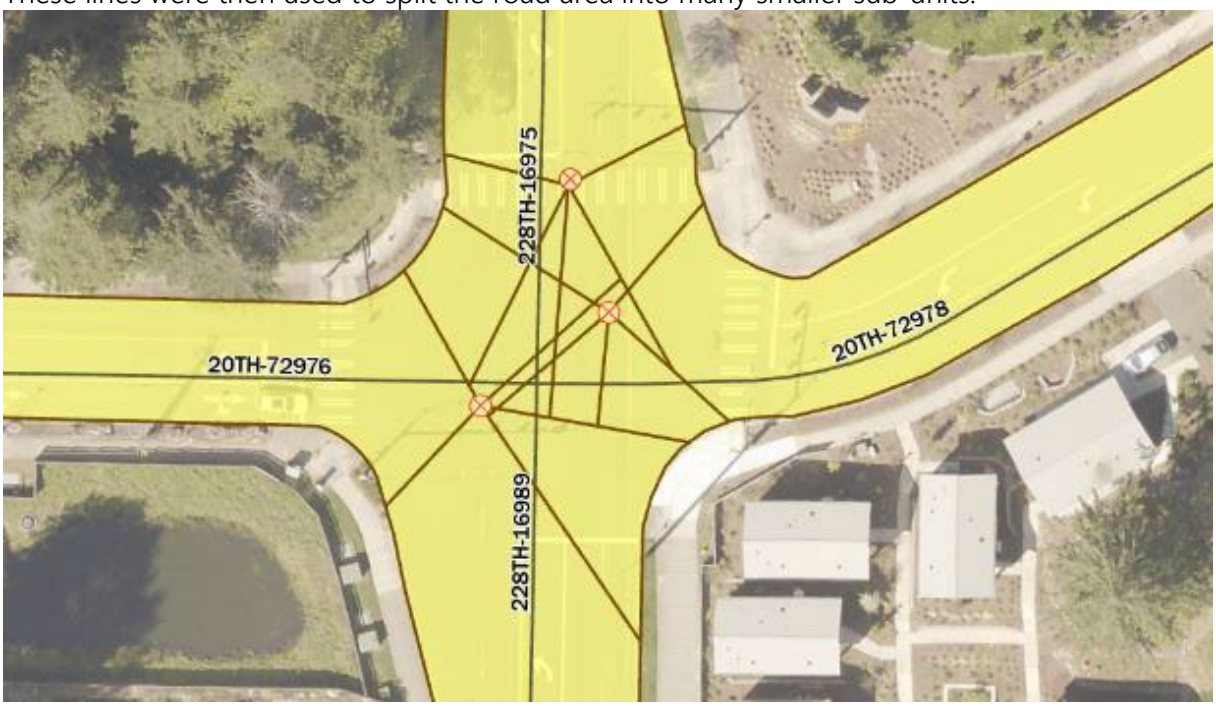
   b. Split the buffer outline where it intersects road centerlines. This will produce a series of split arcs centered around each intersection point.

   c. Use the Feature Vertices to Points geoprocessing tool to create a point in the middle of each split arc (and not the ends). In addition to the mid-arc points, additional points are created as a relic of this geoprocessing, such that the number of points is the number of intersecting road centerlines plus one or two additional points.

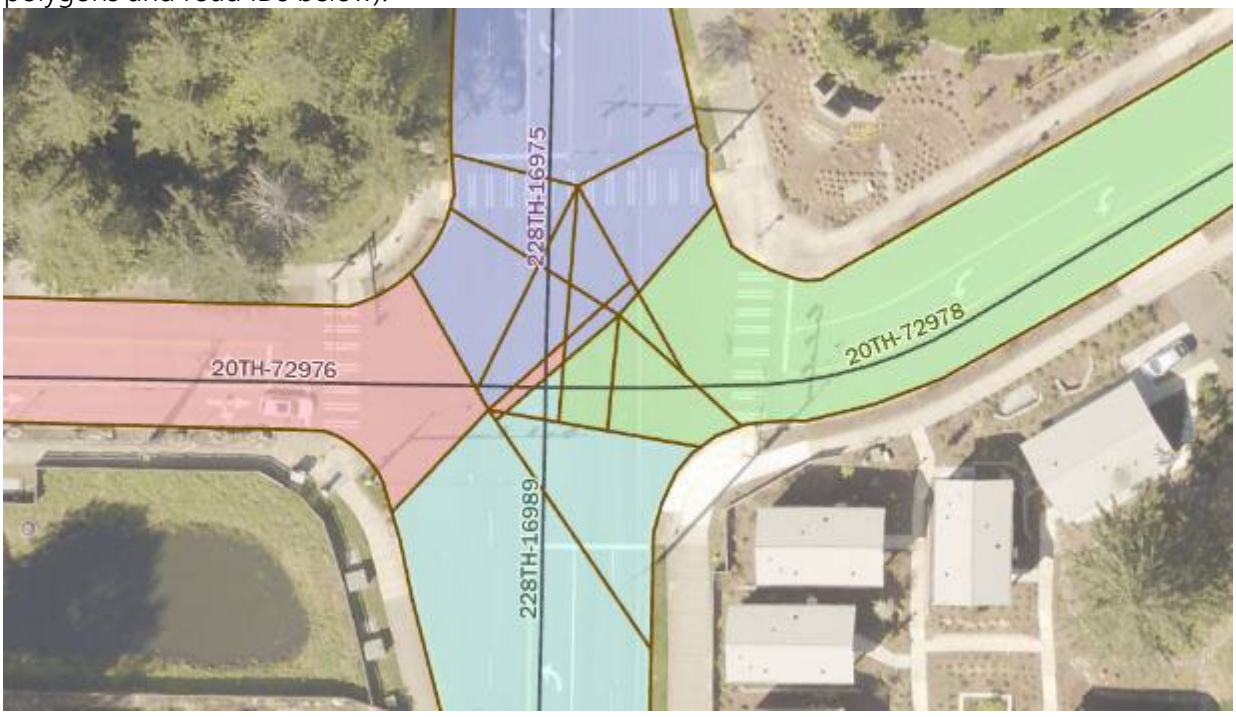
   d. Use the XY to Line tool to draw a line between each intersection point and each of the arc midpoints, from sub-step above) based on shared identification fields. This will appear like irregular spokes around a tire hub.

   e. Use the Extend tool to lengthen each linear spoke sequentially until it intersects another spoke or extends beyond the road area (yellow).

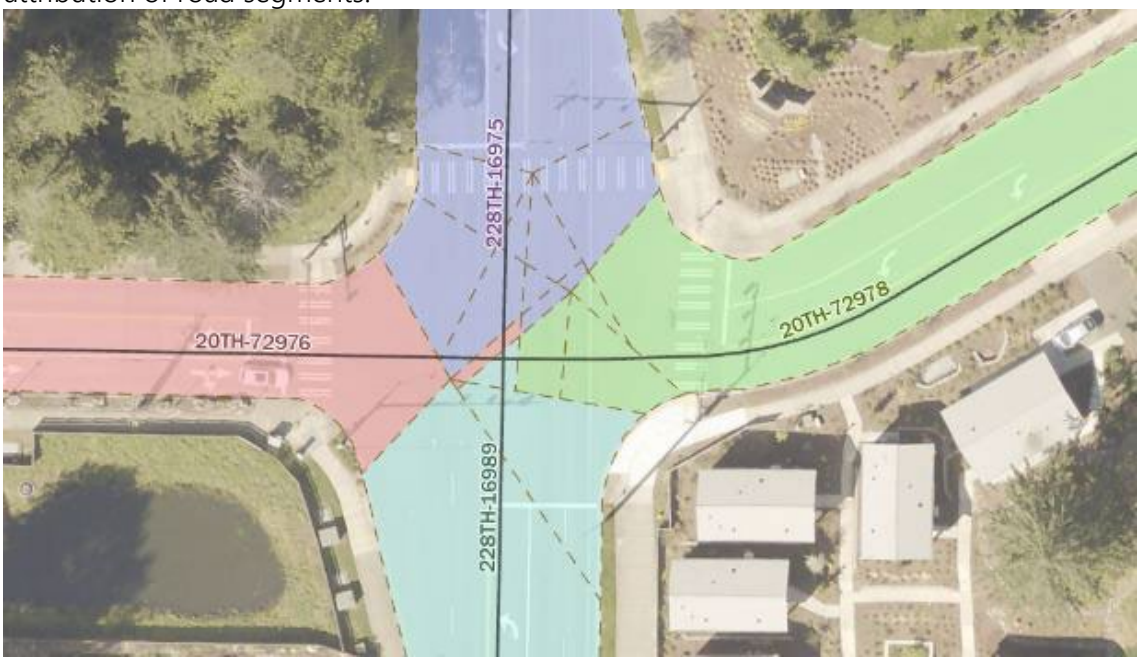
These lines were then used to split the road area into many smaller sub-units.



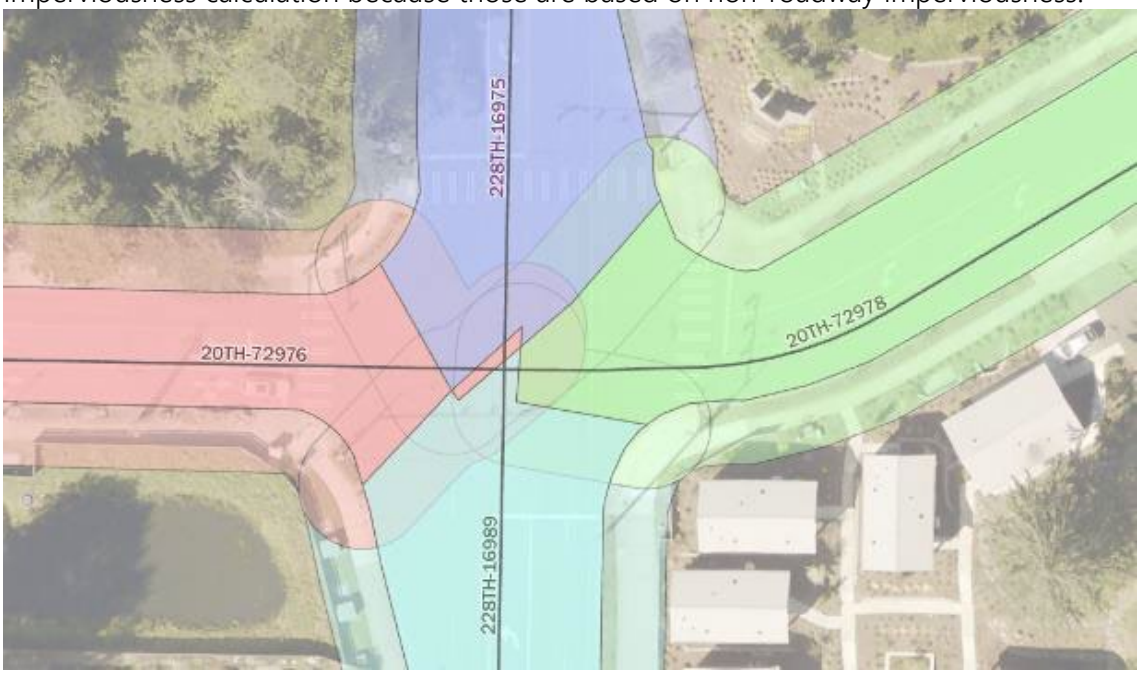
6. Herrera used the Spatial Join function in ArcGIS Pro 3.2 to pair each split road area fragment with the st_address segment that shared the greatest overlap. Each road area could only be joined to one road segment, but one road segment could be joined to many road areas (multicolored polygons and road IDs below).



7. Road area polygons sharing the same RoadSegmentID were dissolved into a single feature in order to create new, spatially explicit road area polygons that better align with real-world road features than the st_address lines. In some cases, this resulted in the creation of multi-part road areas (small pink area below). These small, disconnected areas did not substantially affect the final scoring and attribution of road segments.

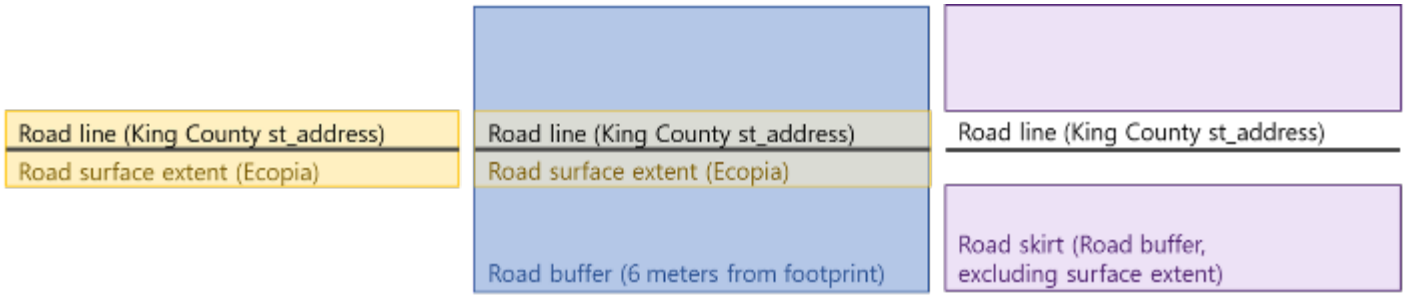


8. The new derived road surface extent layer was used to generate a 6-meter buffer of the roadway (semi-transparent polygons below), as well as the road skirt (the area within a 6-meter buffer of the active roadway surface, exclusive of the road surface extent). Note that while the buffer polygons for each roadway segment overlap at intersections, there is no impact on the road skirt imperviousness calculation because those are based on non-roadway imperviousness.



The road surface extent, buffer, and skirt all have a shared RoadSegmentID. When the road surface extent, buffer, and/or skirt are spatially intersected with another data layer, the resultant output can be assigned to the st_address layer using the shared RoadSegmentID attribute. Figure 6 shows a simplified schematic of the roadway surface extent, buffer, and skirt.

Figure 6. Roadway Skirt Development Demonstration



2.6.1.2. PSRC SoundCast

The SoundCast traffic model produces a series of related points, lines, and polygons that describe traffic volumes across the study area. Traffic volumes are modeled and reported for large roadways on SoundCast road lines. For smaller, local roadways, traffic volumes are modeled and reported on a mix of road lines and SoundCast polygons (Traffic Analysis Zones (TAZ)). Traffic along a SoundCast road line represents modeled traffic for only that road section. Traffic within a SoundCast polygon represents all traffic on other roads falling within that polygon that are not otherwise attributed with traffic by a SoundCast road line.

The process used to prepare the SoundCast dataset and attribute the traffic data to the appropriate RoadSegmentID is described below. An example of the SoundCast data structure is provided in Figure 7.

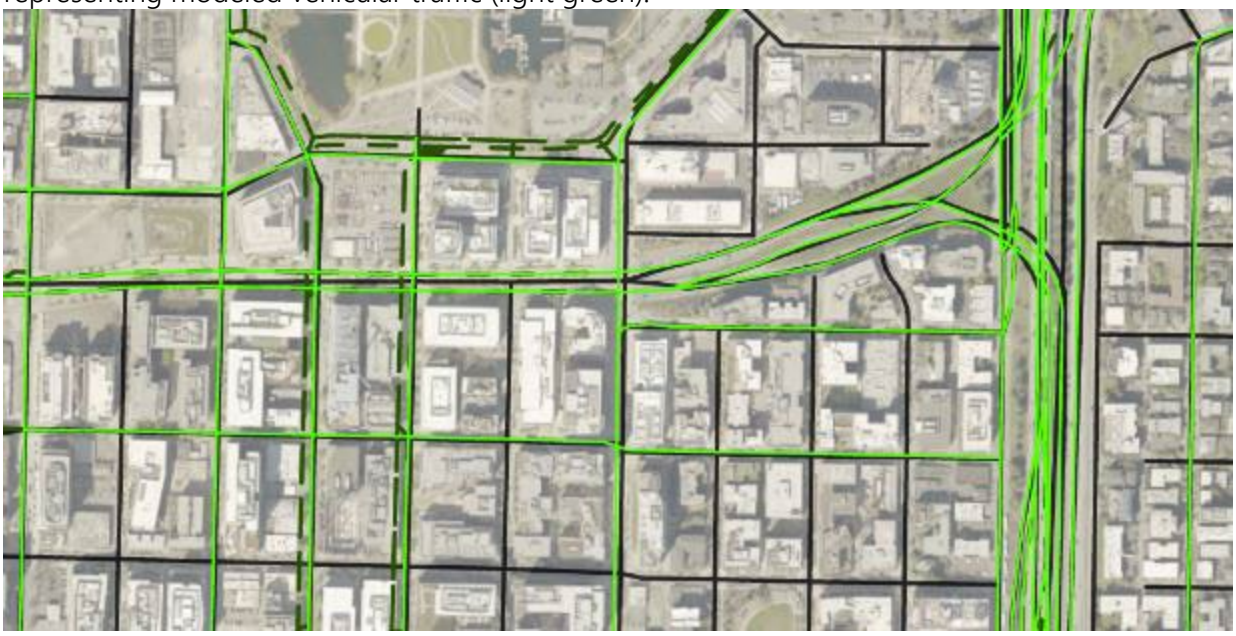
Figure 7. Example of PSRC SoundCast Data Alignment with st_address.



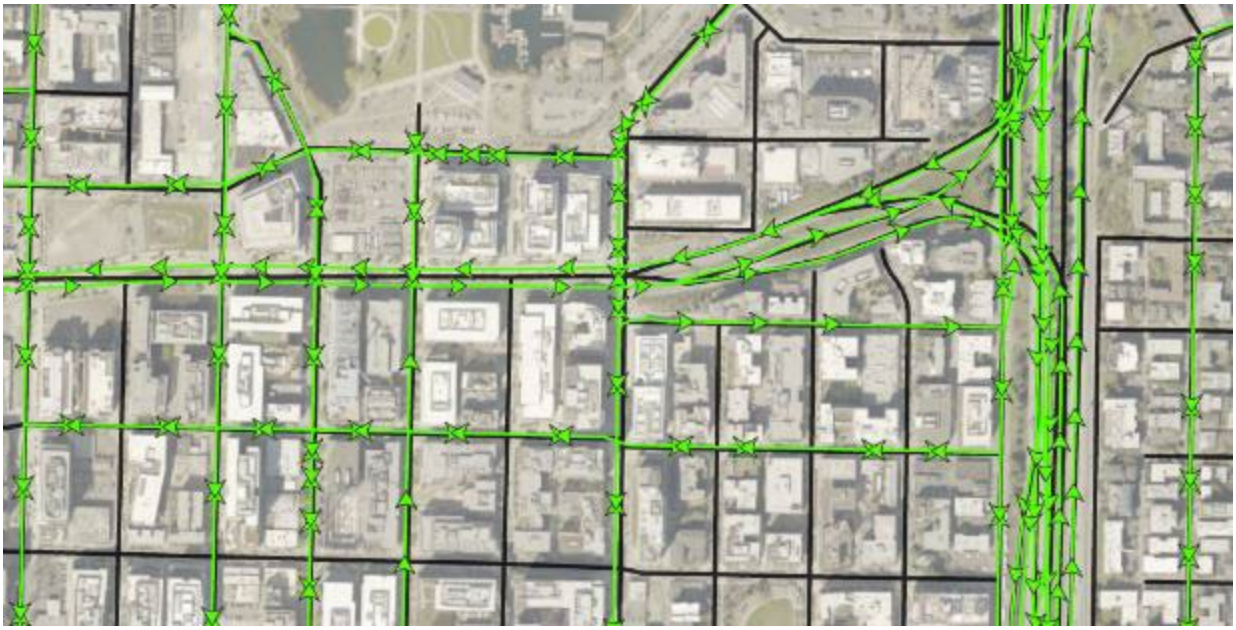
Note: (Left) Lines representing PSRC SoundCast traffic estimates along busy roadways (red) were assigned to st_address roadways (black) where they substantially overlapped with the road buffer (yellow; road surface with a 6-meter buffer). (Right) Estimated traffic with each PSRC TAZ polygon (blue areas) was distributed onto the less-busy roads contained within them (yellow lines) following the process described in Step 4 below.

Step-wise process:

1. Herrera omitted modeled traffic associated with non-vehicular (pedestrian, cycling, ferry, etc.) travel from the PSRC SoundCast lines (dashed dark green lines, below). Herrera maintained lines representing modeled vehicular traffic (light green).



2. Traffic was modeled in two directions along many sections of SoundCast lines (green arrows). Where traffic was modeled in two directions in the SoundCast model, Herrera computed the sum of traffic volumes in each direction and created a single representational line. Where traffic was modeled in only one direction, a single line was present in the SoundCast lines. These single-direction traffic lines were maintained without modification.



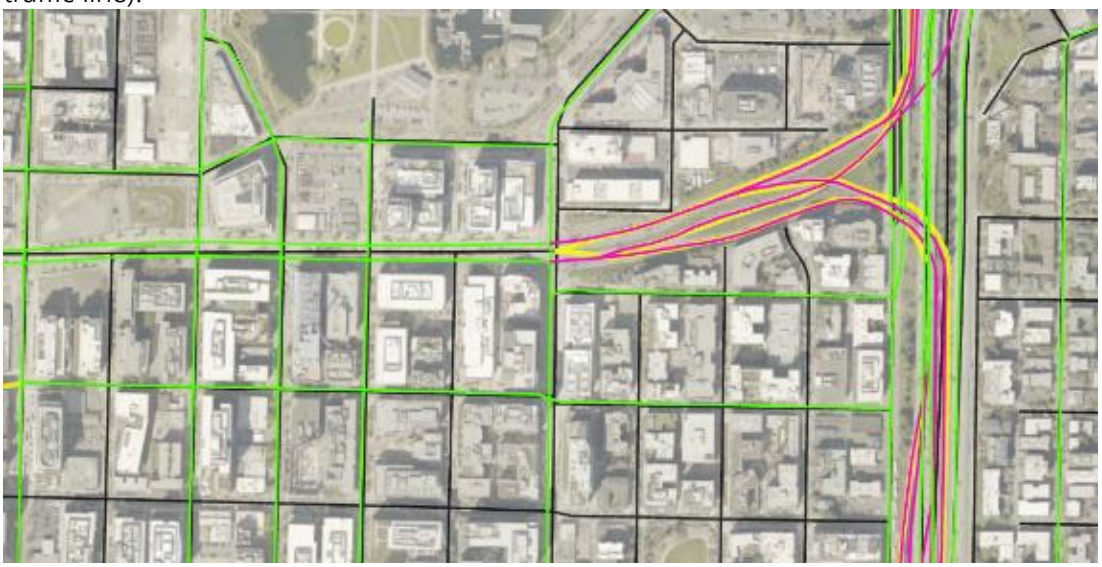
3. Traffic from the SoundCast dataset was attributed with general road classes (Table 8) that were similar, but not identical, to road categories in the st_address dataset. These classes were used to apply a rough stepwise approach to assigning traffic data, which limited the incidence of traffic from the SoundCast lines being attributed to the incorrect st_address roadway.

Table 8. Summary of Similar Attributes Between the King County st_address Roadway Layer and PSRC SoundCast Lines.

Description	PSRC SoundCast Category	King County st_address Road Class
Freeway on/off ramps	2: Expressway	F: Freeway (selected subset; road name is 'RAMP')
Freeways	1: Freeway	F: Freeway (excluding ramps)
Busy urban roadways	3, 4: Urban arterial	(F: Freeway, if not attributed in previous steps) P: Primary Arterials M: Minor Arterials C: Collectors L: Local Streets
Rural roadways	6: Rural arterial	(F: Freeway, if not attributed in previous steps) P: Primary Arterials M: Minor Arterials C: Collectors L: Local Streets
Other roadways	5: Central connectors (assigned by TAZ association; see step 4, Figure 8)	C: Collectors L: Local Streets

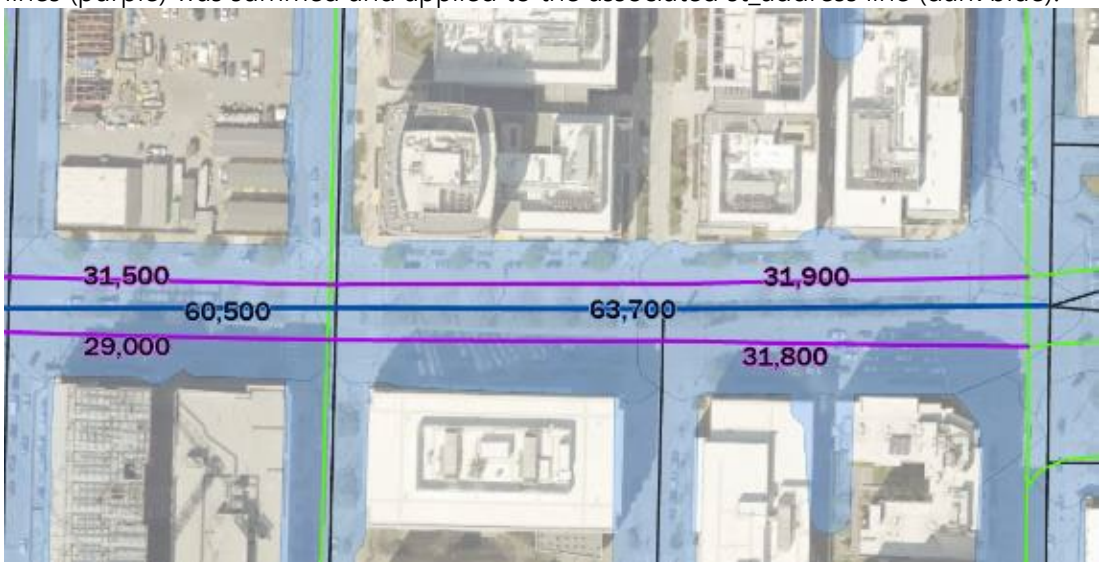
Traffic volumes were applied in the order listed above. St_address roadway lines that were not assigned traffic volumes in previous steps were included in subsequent steps until traffic was assigned. No freeway-class roads were assigned traffic using the TAZ allocation method described in steps 4a-d below.

a. Traffic was applied to ramp-type roads (SoundCast category 2 (pink lines); st_address road class F subset where road name is "RAMP" (yellow lines)) before assigning traffic to other road types. This helped reduce complexity and overlap between ramps and other freeway-type roads in areas with complex geometry. Roads in the st_address road dataset that had been assigned traffic were excluded in all subsequent traffic attribution steps (i.e., no road segments could have their attributed traffic volumes overwritten or modified once applied in relation to a SoundCast traffic line).

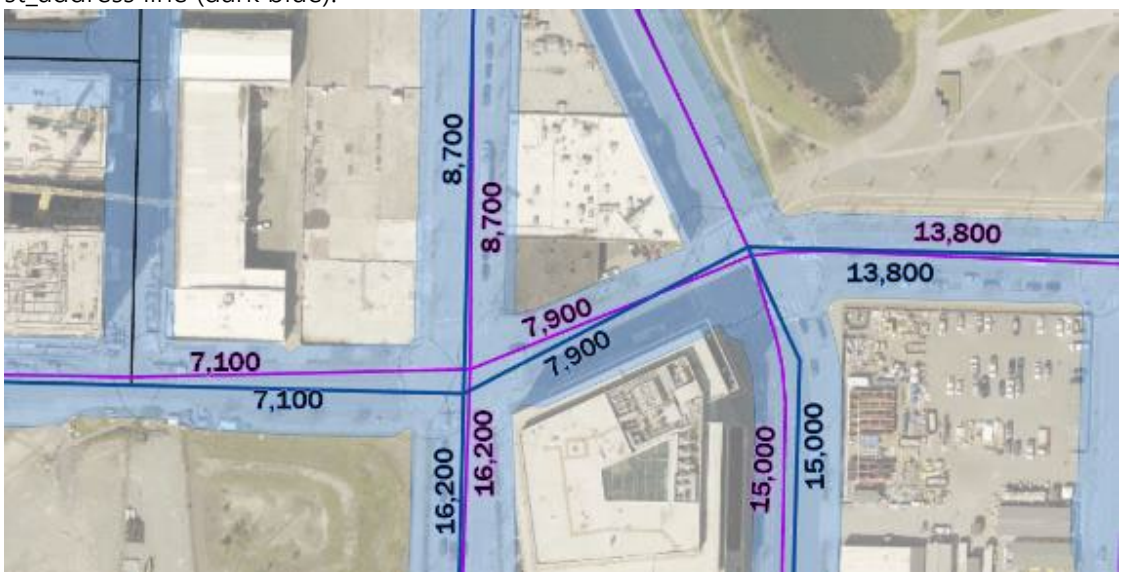


b. Some busy roadways were represented by a single line in the st_address road lines and by multiple lines in the SoundCast lines. To accurately assign traffic to roads in the st_address line that should be represented by multiple SoundCast lines, Herrera spatially intersected the SoundCast lines with the 6-m road buffer (blue polygons) and computed the ratio of the length of the intersecting SoundCast line with the length of the associated st_address line.

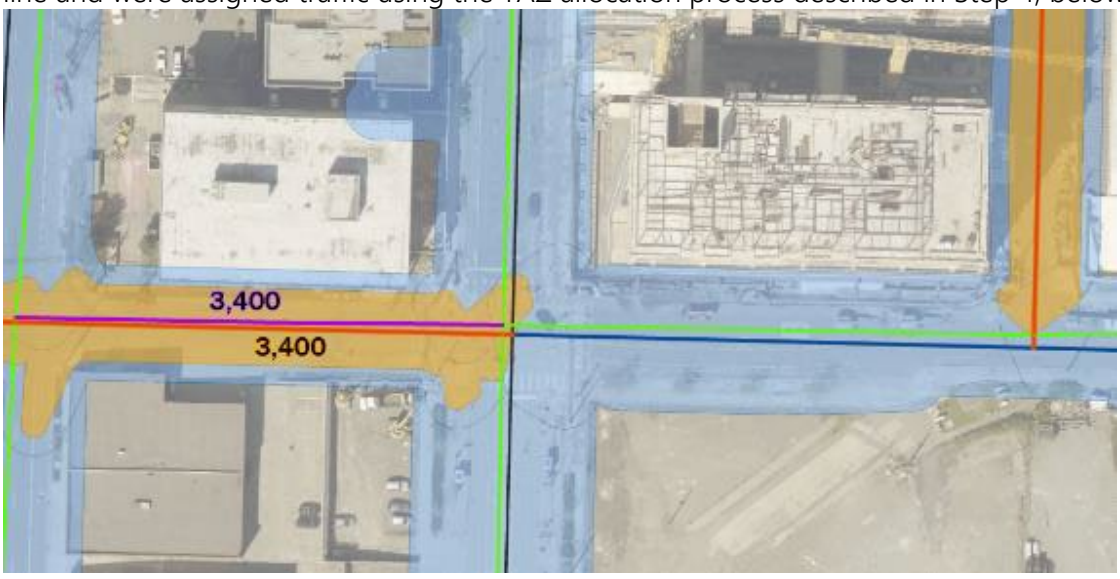
   i. Where the ratio of the intersected length of the SoundCast line divided by the associated length of the st_address line was greater than 0.75, traffic from any contributing SoundCast lines (purple) was summed and applied to the associated st_address line (dark blue).



ii. Where the ratio of the intersected length was between 0.5 and 0.75, traffic from the SoundCast line segment with the largest overlap ratio (purple) was applied to the associated st_address line (dark blue).



c. A smaller road buffer (2.4 meters; orange polygon) was applied to road footprints associated with local-type roads (Table 9). This smaller road buffer was used to reduce misattribution of relatively short and/or narrow local roads with traffic from busier nearby roads. As in previous steps, the ratio of the intersected length of the SoundCast line (purple line) divided by the associated length of the st_address line (orange line) was computed for local-type roads. Where the ratio between the intersected length of the SoundCast line and the st_address line was >0.4, traffic values from the SoundCast line segment with the greatest overlap ratio were applied to the st_address segment. (Note: most local-type roads did not have a corresponding SoundCast line and were assigned traffic using the TAZ allocation process described in Step 4, below).



d. Results of this automated road attribution approach were reviewed by a spatial analyst after each step, identifying very high-value road segments within each road class and visually

comparing to nearby road types, traffic volumes, and PSRC-modeled traffic lines. Collector- and Local-type roads that had been correctly attributed with high traffic volumes were validated and maintained. For example, Edgar Martinez Drive near the stadiums in Seattle is classified as "Local," but in practice this is a high-volume roadway used as an entry/exit to south downtown from Interstate 90 (I-90), Interstate 5 (I-5), and State Route 99 (SR 99), and it was determined that the assigned traffic was appropriate. Erroneous or misattributed road values were cleared from Collector- and Local-type roads. These roads were re-attributed with traffic values using the TAZ allocation approach (see below).

4. Herrera modeled traffic volumes for smaller roads within TAZ polygons, as these smaller roads did not have 1:1 associations with SoundCast road lines. To assign modeled traffic volumes to st_address road segments falling within TAZ polygons, Herrera employed a multi-part process to allocate traffic (see Figure 8 for a simplified schematic of this approach):

   a. Modeled SoundCast traffic volumes for small roads (green lines) were summed within each TAZ area (yellow polygon). Roads that had not yet received modeled traffic data in previous steps (black lines) were intersected with the TAZ polygon.



   b. Herrera calculated the total number of unique road segments (by unique RoadSegmentID) within each TAZ area. Herrera then divided the total traffic volume within the TAZ by the number of unique road segments, yielding an average traffic per segment.

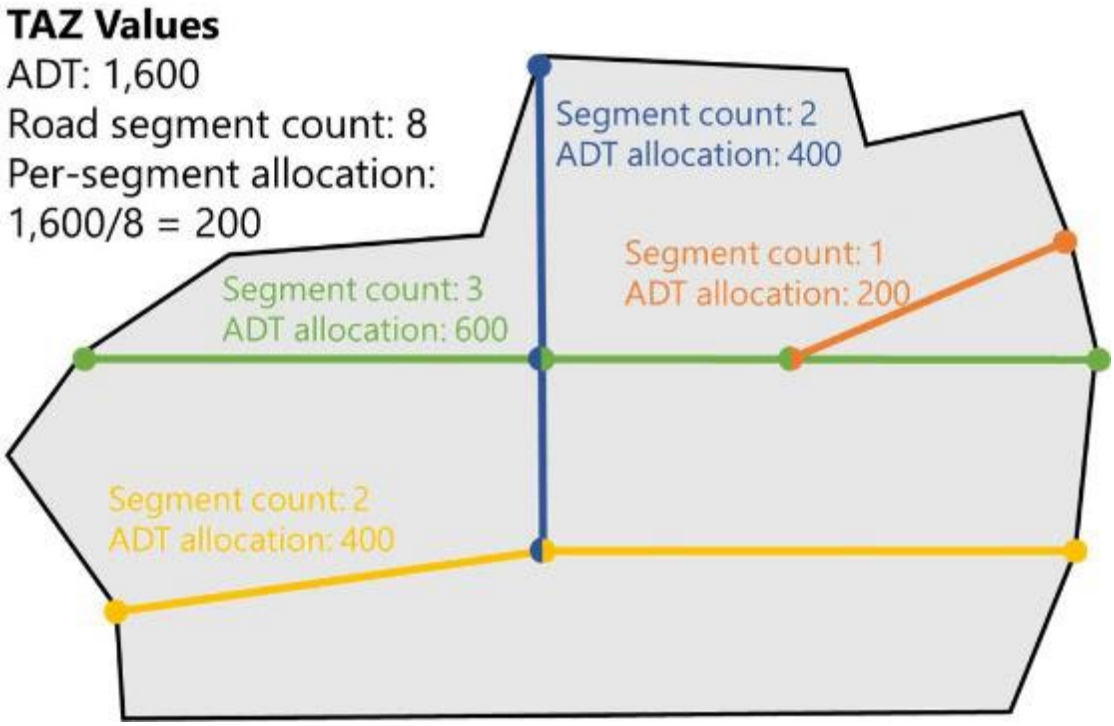
   c. Herrera calculated the number of unique road segments within each TAZ belonging to the same named road (e.g., roads with unique RoadSegmentIDs of Main St-1001 and Main St-1005 both belong to the named road "Main St"). Herrera then multiplied the number of road segments sharing a name by the average traffic per road segment within the TAZ.

   d. The result of this calculation was applied to each segment in the TAZ. For example, if a TAZ contained two named roads (e.g., Front Street and 2nd Ave), with seven segments belonging to

the first named road and three segments belonging to the other road, then each unique segment belonging to the first road (Front Street) would be attributed with 70 percent of the total modeled traffic value for the TAZ. This assumes that a driver who traverses one unique segment of a road within a TAZ will also traverse the adjacent unique segment.

The above-described approach of casting is expected to overestimate traffic on some roadways and underestimate on others. This is assumed to primarily affect local roadways with lower levels of traffic by potentially overestimating traffic volumes.

Figure 8. Example of PSRC SoundCast Traffic Assignment within a TAZ.



The area of each TAZ is related to the geographic density of parcels across the study area. This results in a wide range of TAZ sizes, from the smallest urban TAZ containing several multi-story apartment buildings in Seattle (2.8 acres) to the largest TAZ in northeast King County (240,300 acres). The median TAZ acreage was 185 acres. The interquartile range for TAZ area is 54 to 276 acres. As interquartile ranges, the number of segments per acre in TAZ ranged from 0.2 to 0.6, and the road length per acre ranged from 120 to 290 feet, with the highest densities in the downtown core of Seattle.

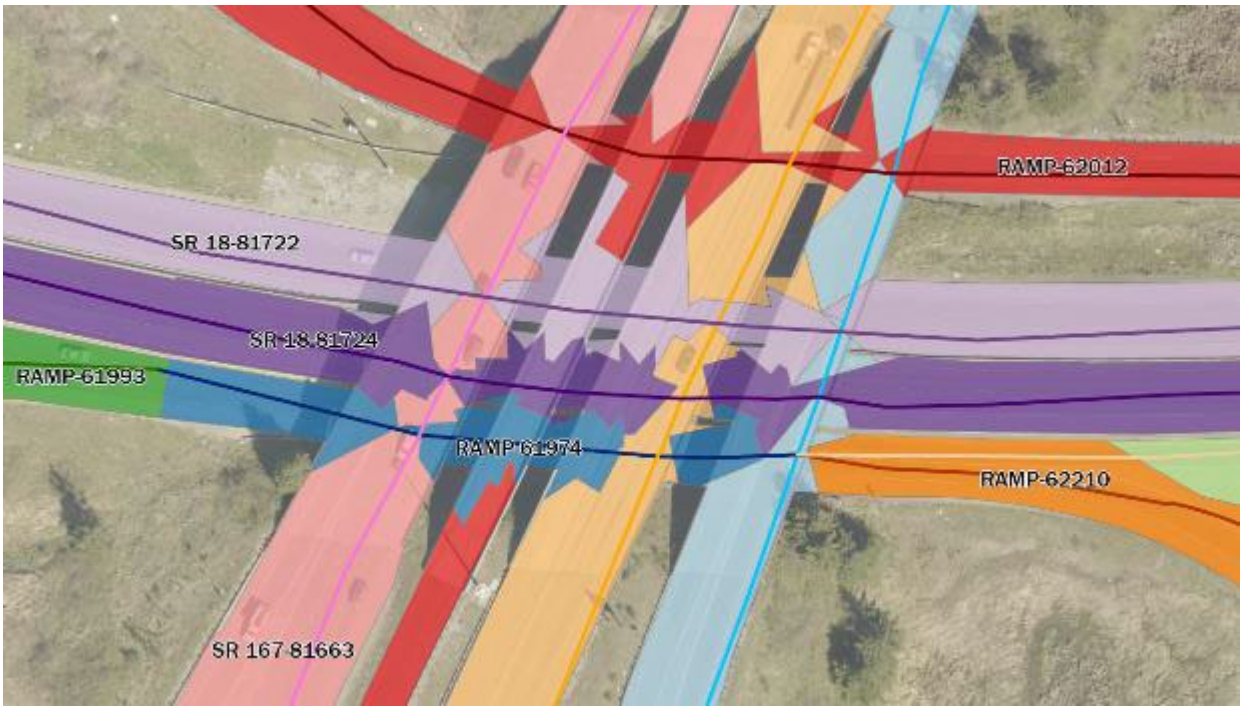
2.6.1.3. Complexities with Traffic Attribution

Accurately attributing roads with associated characteristics (drainage connectivity, traffic, etc.) was complicated at major interchanges and at over/underpasses. Where overpasses and underpasses were present, road surface extent polygons were split and attributed to road lines using the same method as applied at intersections. Complex overpass geometry and the presence of onramps and offramps resulted in greater fragmentation of road surface extent polygons than occurred at most standard

intersections (Figure 9). This fragmentation, coupled with mismatched alignment of road lines and road polygons, made it more likely that road surface extent polygon fragments would be assigned to the incorrect road line (Figure 10). In future iterations of this model, applying elevation attributes, such as from LiDAR bare earth and surface return, to road lines and/or road polygons could help distinguish between overlapping road features and associated real-world drainage and other features. Neither the Ecopia-derived road surface extent polygons nor the road lines from King County had vertical attributes.

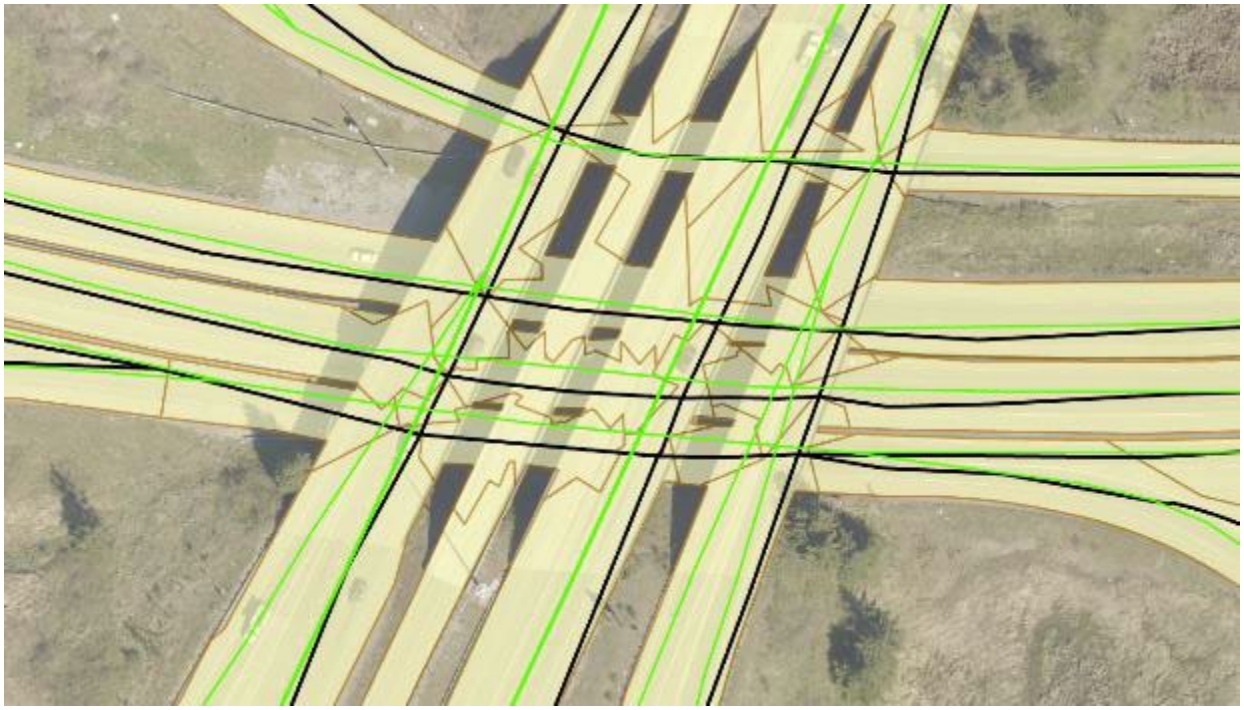
Additionally, some multi-lane and bi-directional roads were represented with different numbers of lines in the st_address and SoundCast modeled. This complexity was addressed by using the stepwise approach to assigning traffic volumes described in Section 2.6.1.2 (i.e., first applying traffic to ramp-type roads, then to freeways and major roadways, and finally to local roads). However, some incorrect attribution of higher traffic volumes to local roads at overpasses may have occurred in the model.

Figure 9. Example of Road Fragmentation at Overpass/Underpass Roadway Configuration.



The Ecopia road surface extent (multicolor polygons) corresponds to unique road segments from the st_address line layer (multicolored lines).

Figure 10. Example of Modeled SoundCast Traffic (Green Lines) Overlapping Multiple Fragmented Road Surface Extent Polygons.



2.6.1.4. Imperviousness and Conveyance Attribution

The impervious land cover from the Ecopia dataset (i.e., road, sidewalk, driveway, parking, building, and other pavement) was intersected with the road skirt layer for each roadway segment (see Figure 11). The percent impervious was calculated by dividing the impervious area coverage by the total skirt area.

The length and type of stormwater conveyance were attributed to each roadway segment by intersecting the King County, WSDOT, and City of Seattle conveyance lines with the roadway surface extent polygon and its respective skirt.

It is possible these datasets are incomplete and the extent of that is unknown. Where no stormwater conveyance data were available, the percent conveyance for a specific roadway segment were imputed based on a locally weighted regressions on roadway skirt imperviousness and roadway classification (see next section).

Figure 11. Example of the Impervious Land Cover (grey polygons) and Stormwater Conveyance Networks (black arrows) for WSDOT and King County.



"Ecopia Vector Maps © [2021] Ecopia Tech Corporation"

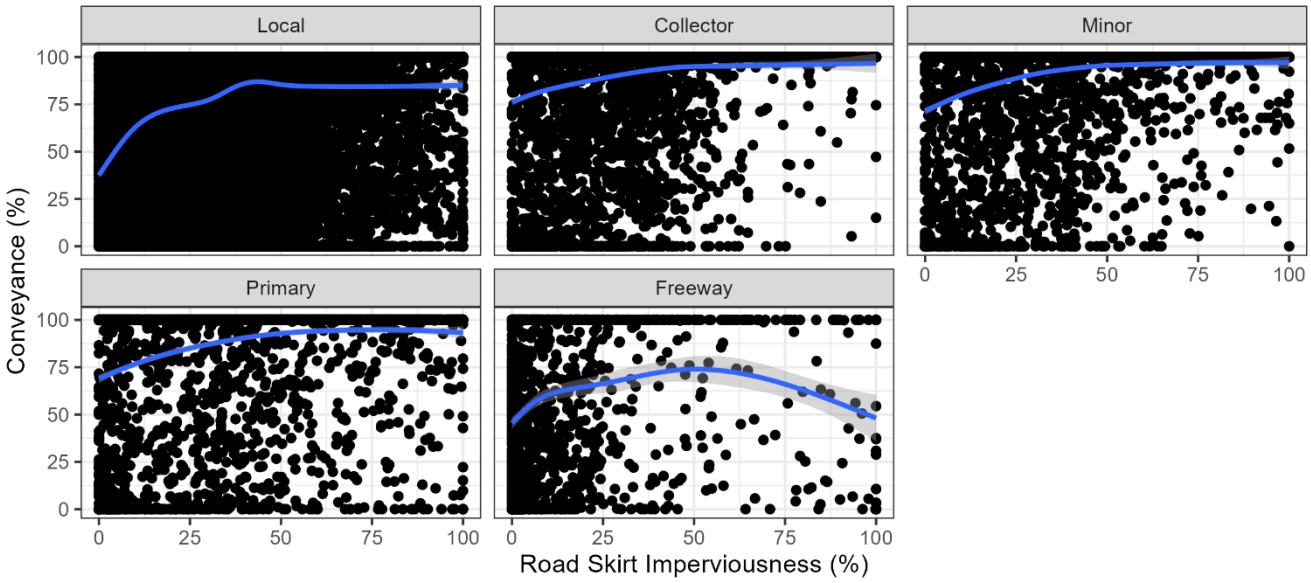
2.6.1.5. Imputation of Conveyance Based on Land Cover and Roadway Classification

There are four jurisdictions that did not have stormwater conveyance data in the compiled database (the cities of Carnation and Medina and towns of Skykomish and Yarrow Point). Rather than omit the roadways within those jurisdictions or assume a single conveyance percentage, Herrera developed a predictive model. A LOESS (Locally Estimated Scatterplot Smoothing) model is a non-parametric regression technique used to fit a smooth curve to data. Predicting the stormwater conveyance percentage of a roadway segment was based on two predictors: roadway classification and the imperviousness of the roadway's skirt. The LOESS model fit separate smooth curves for each classification. The model treated each class (e.g., freeway, primary arterial, etc.) independently, estimating the relationship between imperviousness and stormwater conveyance for each category. For each roadway classification, LOESS performed localized weighted regressions over the imperviousness data, creating smooth curves that adapt to the local trends of the data.

The resulting model captures complex, non-linear relationships between imperviousness and stormwater conveyance, accounting for differences between roadway classifications (Figure 12). LOESS does not impose a rigid functional form, making it flexible for scenarios where the relationship between variables is not well defined. The Freeway category had an unexpected function where conveyance percentage

peaked at approximately 50 percent imperviousness and then decreased. Herrera conducted desktop analysis to assess this and found that this function appears to be due to unmapped highway drainage conveyances in urban areas. That is, the WSDOT stormwater conveyance layer does not (or does not consistently) include local jurisdictions' conveyance infrastructure. A reasonable assumption is that the amount of conveyance in urban areas (higher imperviousness) would be similar to that expected for primary arterials. For the purposes of imputing percent conveyed for freeways in jurisdictions with missing data, the primary arterial function was used.

Figure 12. Relationship between Road Skirt Imperviousness and Percent Conveyed by FCC.



2.7. Scoring of Roadways Using Screening Model

2.7.1. Scoring System

Herrera developed a simple process-based equation to score individual roadway segments. First, Herrera assumed that the export of 6PPDQ from a roadway to the stormwater conveyance network (*Export*) is proportional to both (1) the amount of tire wear particles deposited on the roadway and its skirt (*Deposition*) and (2) the capacity for stormwater-mediated transport from the roadways and its skirt to reach the conveyance network (*Connectedness)*. Export is the relative measure of the mass of TWP and 6PPDQ export per distance of a roadway segment.

Equation 1:

$$Export \sim Deposition * Connectedness$$

Deposition (mass per distance) is driven by the number and type of vehicles on the roadway. *Connectedness* (percent mass exported) is primarily driven by the expected amount of stormwater runoff from the roadway and its skirt and whether there is a conveyance network present at the roadway.

Equation 2:

$$Deposition \sim PassengerVehicleCount + x * MediumVehicleCount + y * HeavyVehicleCount$$

To consider the varying tire wear emission factors for different vehicles, Herrera used scaling factors, *x* and *y*, for medium-weight and heavy-weight vehicles relative to passenger vehicles (Equations 3 and 4). For detail on the development of these scaling factors, see the *Tire Wear Rate* section below.

Equation 3:

$$x = \frac{TWR_{MediumVehicle}}{TWR_{PassengerCar}}$$

Equation 4:

$$y = \frac{TWR_{HeavyVehicle}}{TWR_{PassengerCar}}$$

Connectedness is assumed to be proportional to the amount of stormwater runoff leaving the road and its skirt and the fraction of the roadway served by a stormwater conveyance system (e.g., pipe or ditch) (Equation 5). *RoadSkirtImperviousness* is a suitable proxy for the relative expected volume of stormwater runoff leaving the roadway skirt (along with runoff from the roadway). For *PctConveyance*, the value is set as the percent of the roadway length, with a conveyance set to a minimum of 1 percent and a maximum of 100 percent. This value was not set to zero because there is likely to be some stormwater runoff that reaches surface waters or stormwater networks outside of the roadway buffer, albeit at a lower rate. The *PctConveyance* was modified to 100 percent if the roadway segment intersected a waterbody (e.g., a bridge), as described below in *Weighting for Surface Water Proximity and Crossing*. Both *RoadSkirtImperviousness* and *PctConveyance* are input as values between 0.01 and 1.0 (e.g., 50 percent is 0.5). As an example, an urban roadway with a 100 percent impervious skirt and 100 percent conveyance would have a *Connectedness* score of 1.0 (1.0 * 1.0), where 100 percent of the deposited tire wear particles and 6PPDQ is expected to reach the stormwater conveyance network., and a suburban roadway with 50 percent imperviousness and 50 percent conveyance (i.e., half of the length of the road has drainage infrastructure) would have a *Connectedness* score of 0.25 (0.5 * 0.5), where 25 percent of the deposited tire wear particles and 6PPDQ is expected to reach the stormwater conveyance network.

Equation 5:

$$Connectedness \sim RoadSkirtImperviousness * PctConveyance$$

Then Herrera combined Equations 2 and 5 into Equation 6.

Equation 6:

$$Export \sim (PassengerVehicleCount + x * MediumVehicleCount + y * HeavyVehicleCount) * RoadSkirtImperviousness * PctConveyance$$

Equation 6 was log-transformed to set a more relative, relatable scale, where the difference in the score by 1 point is interpreted as an order of magnitude difference in the amount of export (Equation 7). To constrain the lower end of roadway scores and maintain an approachable scale, Herrera set the minimum score to zero. This approach provides a score that is readily interpretable by users with an approximate range of 0 to 5. However, as with all log-transformed data, there is a risk of misinterpretation where a user implicitly groups high-scoring road segments (e.g., 4s and 5s, despite underlying magnitude(s) of difference between the predicted export of TWP and 6PPDQ).

Equation 7:

$$Score_i = \log_{10}(PassengerVehicleCount + x * MediumVehicleCount + y * HeavyVehicleCount) + \log_{10}(RoadSkirtImperviousness) + \log_{10}(PctConveyance)$$

The *Connectedness* score components, *RoadSkirtImperviousness* and *PctConveyance,* are both constrained from 0.01 and 1.0; therefore, their log-10 transformations range from -2 to 0. That is, a roadway segment with 100 percent conveyance and 100 percent imperviousness would have no subtraction of the *Deposition* score component. For example, a roadway segment with daily traffic of 10,000 passenger vehicles only would have a *Deposition* score of 4. If that roadway segment was 100 percent ditched with no roadway skirt imperviousness, the final score would be 2 (i.e., 4 – 0 – 2), where *PctConveyance* = 1.0 *and RoadSkirtImperviousness* = 0.01. However, if the roadway was in a dense urban area that was 100 percent impervious and 100 percent piped, the final score would be 4 (i.e., 4 – 0 – 0).

2.7.2. Weighting Factors for Vehicle Type, Water Crossing, and Conveyance Type

2.7.2.1. Tire Wear Rate

As described above, scaling factors for the composition of traffic were developed. Moran et al. (2023) provided an estimated tire wear rate (TWR) for passenger vehicles of 130 mg/km, which is based on recent tire wear data documented in Europe for tires considered similar in size to tires sold in the U.S. The passenger vehicle TWR provided by Moran et al. (2023) is comparable to the 100 to 120 mg/km per vehicle estimated TWR provided by Mennekes and Nowack (2022) for passenger vehicles in western Europe. Due to the lack of TWR data for larger vehicles, Moran et al. (2023) developed TWR estimates for light truck/SUV, medium truck, and heavy-duty vehicle tires assuming a linear function with number of tires and tire tread width (TTW), which accounts for the additional wear surface on larger vehicle tires. Herrera expanded on this to include vehicle weight because TWR generally increases with increasing vehicle weight (Baensch-Baltruschat et al. 2020). To account for an increase in vehicle weight per vehicle class, a logarithmic transformation was applied to the vehicle weight to help linearize the relationship between weight ratios and the other variables in Equation 8. A non-transformed ratio was also evaluated and resulted in values well beyond the range (i.e., more than a factor of ten) presented in the literature for heavy vehicles (e.g., Kole et al. 2017). The tire wear rate of medium to heavy vehicles is a data gap and is presented here using modeled data. Herrera strongly recommends further research to support the tire wear rate estimates (see Moran et al. 2023.).

Equation 8 estimates TWR per vehicle for a specified vehicle class, assuming an increase in TWP emissions with an increase in tire tread width, number of tires, and vehicle weight.

Equation 8: $$TWR_x = TWR_{pv} * \frac{ATTW_x}{ATTW_{pv}} * \frac{nTires_x}{nTires_{pv}} * \frac{\log(Weight_x)}{\log(Weight_{pv})}$$

Where,

TWR_x = tire wear rate per vehicle kilometers traveled (mg/km) for vehicle class x
TWR_{pv} = tire wear rate per vehicle kilometers traveled (mg/km) for passenger vehicle
$ATTW_x$ = average tire tread width (mm) for vehicle class x
ATT_{pv} = average tire tread width (mm) for passenger vehicle
$nTires_x$ = average number of tires (n) per vehicle class x
$nTires_{pv}$ =average number of tires (n) per passenger vehicle
$Weight_x$ =average weight of vehicle (lb) for vehicle class x
$Weight_{pv}$ = average weight of vehicle (lb) for passenger vehicle
Table 9 summarizes the estimated TWR per vehicle for various vehicle classes.

Table 9. Calculated TWR Factors.

Vehicle Class	Axles[a]	Average Tire Tread Width (mm)[b]	Estimated Average Number of Tires[b]	Assumed Curb Weight + Payload (lb)	TWR (mg/km)	Relative Emission Factor (Divided by Passenger Vehicle TWR)
Passenger Vehicle	2	221	4	3,500	130[b]	1.00
Light Truck/SUV	2	255	4	7,000[c]	163	1.25
Medium Weight Truck	2–4	278	6	34,000[d]	314	2.42
Heavy Truck	5+	278	18	80,000[e]	1,018	7.83
Average TWR of Passenger Vehicle & Light Truck/SUV (assuming equal representation on roadways)					146	1.12

[a] Source: SoundCast

[b] Source: Moran et al. 2023

[c] Light duty trucks are between 6,000 and 8,000 lb (Kennedy and Gadd 2002). Average is 7,000 lb.

[d] Assumes medium weight truck six or more tires and two to four axles is between 16,000 to 52,000 lb gross vehicle weight (SoundCast). Average is 34,000 lb.

[e] Source: https://dot.ca.gov/programs/traffic-operations/legal-truck-access/weight-limitation

2.7.2.2. Weighting for Surface Water Proximity and Crossing

The scoring system was modified to give greater weight to roadways crossing surface waters in two ways: (1) by treating the water surface in the skirt of the roadway as an impervious land cover (e.g., a bridge roadway segment's skirt would be 100 percent "imperviousness") and (2) by setting the conveyance of roadway segments crossing a stream or water body to 100 percent.

From a mass loading perspective, 6PPDQ export from bridges may be less acute during storm events and have a more chronic loading compared to a similar road with a 100 percent paved skirt. This is because there is less surface area for tire wear particles to build up on that would be washed off during a storm. Due to the minimal or nonexistent skirt, the waterway would be subject to a direct continual, lower-level load of TWPs as particles are blown off the road by wind and vehicular turbulence.

In some cases, the increased conveyance score due to water crossings may overestimate the amount of TWP/6PPDQ reaching the waterway, especially in cases with rural roadways with little stormwater infrastructure to convey runoff to the waterway. However, SMEs and King County staff deemed that this weighting was appropriate given the concern for contamination of surface waters.

2.7.2.3. Transport within the Stormwater Conveyance Network

Since the endpoint of this model is export to the stormwater conveyance network, the current version of the model does not differentiate between the *Connectedness* of different types of conveyance networks. In other words, ditches and piped networks are weighed the same in the model, even though it is possible that ditches may account for a reduction and/or degradation of 6PPDQ that differs from piped conveyance. A brief literature review was performed to investigate to what extent 6PPDQ reduction may be achievable by ditches. Due to a lack of data specific to TWP and 6PPDQ, it was assumed that total suspended solids (TSS) reduction may be representative of TWP removal and that swales were representative of ditches.

A study performed by Backstrom et al. (2006) found that particles between 9 and 15 µm are most easily transported out of grassed swales. For reference, Kreider et al. (2010) found that TWP size ranges from 4 to 350 µm, with a bimodal distribution peaking at approximately 5 µm and 25 µm (in terms of number of particles). Backstrom et al. (2006) also found that roadside swales may attenuate peaks of pollutant loads without being capable of producing consistently high removal rates. Li et al. (2016) summarized the performance of grassed swales with data available in the Best Management Practice (BMP) Database and found they have a median TSS removal rate of 13 percent.

With the variability in removal rates for smaller fractions of TWP and low TSS reduction rates reported for swales, it was assumed that ditches achieve a similarly low percent reduction of TWP. For the purpose of this Screening Model, it is therefore assumed that ditches have the same conveyance as pipes and any ability of ditches to achieve runoff reduction and biological degradation of stormwater is assumed to be represented in the modeled pervious surfaces. In the next phase of this project, King County is partnering with WSDOT to collect and analyze 6PPDQ samples upstream and downstream of grass swales along highways. The data from this study may support adjustments to the Screening Model for vegetated ditches.

The soils, vegetation type and density, slope, and other factors are expected to influence the capture, removal and degradation, and wash off rate of TWPs and 6PPDQ. However, due to a lack of available data and knowledge of the magnitude of those factors' influence, they were excluded from the Screening Model. Evaluating the export of 6PPDQ via the stormwater conveyance network is an area for future research and in-field monitoring.

3. Screening Model Results

This chapter provides numerical and graphical summaries of the spatial inputs and outputs of the 6PPDQ Screening Model. These results also provide a quality assurance step by ensuring that the attributes being used in the model are reasonable and have been appropriately assigned to roadways.

3.1. Distribution of Input Layers

3.1.1. Distribution of Spatial Layer Values

Table 10 and Figures 13 through 18 in this section summarize the distribution of the model input variables. The vast majority of the total number of roadways in King County are local roads with low levels of daily traffic, in terms of both number of segments (78 percent) and total length of roadway (70 percent) (Table 10). While there were fewer freeway segments, those segments tended to be longer than the other classifications. There are similar counts and lengths of collector, minor arterial, and primary arterial roadways in the study area.

Table 10. Summary of Spatial Attributes by Roadway Function Classification.

	Local	Collector	Minor Arterial	Primary Arterial	Freeways
Number Segments	69,910	7,269	5,780	4,925	1,425
Mean Road Length (mi)	0.09	0.10	0.11	0.13	0.43
Total Length (mi)	6,086	761	615	648	618
Mean Skirt Imperviousness (%)	33.5	31.4	40.1	44.7	14.9
Mean ADT	479	3,244	8,258	18,818	29,994
Mean Daily Medium Trucks	11	74	219	633	1,932
Mean Daily Heavy Trucks	3	11	39	135	1,382
Number Segments with Conveyance Data	69,584	7,218	5,778	4,914	1,424
Number Segments with Conveyance Type	29,491	3,042	3,002	2,996	1,115
Mean Conveyed (%)	76.5	89.3	90.4	87.8	55.9

ADT: Average Daily Traffic

In terms of average daily traffic (ADT), the distributions followed expectations from the FCC (Figure 13).[2] Freeways had the highest amount of traffic. Primary arterials had the second highest traffic volume. Some primary arterial segments had higher ADT than freeways and occasionally less than the designated minor arterials. In many cases, the two directions of traffic on freeways are designated with two separate lines due to separation by the median. The traffic numbers for the other roadway designations are typically bidirectional (i.e., the traffic total includes both directions of vehicle travel). This partially explains why some primary arterial roadway segments have more traffic than freeway segments.

There are a few minor arterials where traffic counts are nearly as high as 50,000 vehicles per day. These appear to be appropriately assigned. Examples of high-traffic minor arterials are NE Novelty Hill Road, East Valley Highway, Factoria Boulevard, Woodinville-Redmond Road NE, and several discrete roadway segments near freeway/highway exits. It is also possible that some segments may be misspecified due to proximity of the roadway st_address segment to the PSRC model link for a roadway with greater traffic. This may result in an overestimate of the 6PPDQ export from those few roadway segments. However, those misspecifications are easily identifiable by users through desktop review to evaluate if the values appear reasonable given the roadway size, nearby land use, and nearby/intersecting roadways that may cause misspecification. For example, a local road that over- or underpasses a freeway would not reasonably have 88,000 vehicles per day, nor would a freeway segment have less than 1,000 vehicles. These errors may be overwritten in the project spatial database by inputting traffic estimates based on the values for roadways up and down street of the misspecified segment. At this time, no overwriting corrections have been made to the Screening Model output dataset.

Collectors had the widest distribution of traffic volumes, ranging from less than 100 vehicles per day to over 10,000 vehicles per day. Similar to minor arterials described above, some collectors are likely to be misattributed with higher traffic volumes from nearby busier roads at intersections or overpasses. Local roads had the lowest amount of traffic. Some collector and local roads had high traffic level (>10,000); manual inspection of these segments found that these traffic levels appeared to be appropriate (e.g., Logan Avenue in Renton, 16th Avenue Southwest on Harbor Island, Southwest Oregon Street in West Seattle, Lakeland Hills Way in Auburn, and Air Cargo Road in SeaTac, and South Atlantic Street in Seattle).

Medium and heavy trucks follow the FCC trend but with more variability (Figure 14 and Figure 15, respectively). The relatively lower counts of medium and heavy trucks on some freeway designated segments result from on- and off-ramps, where there is typically still elevated passenger vehicle use but lower freight use. Exceptions are found at ramps near industrial and commercial cores. On most roadways, the number of medium trucks is greater than the number of heavy trucks. State Route 18

[2] Figures 13 to 20 are violin plots from the geom_violin function in ggplot (version 3.4.4). These plots display the distribution of the numbers of road segments across the target variable (e.g., average daily traffic, imperviousness). In these plots, the density distributions are for individual FCC classes based on number of road segments (i.e., not length of road segments). In each plot, the median is shown as a solid horizontal and the 25th and 75th percentiles are shown as dashed lines. The width of the violin plots is a smoothed kernel density estimation to visualize the data distribution. Each point is an individual road segment. The horizontal spread within each classification is for ease of viewing purposes only.

(SR 18) and I-90 east of Issaquah are exceptions, where there are more heavy trucks (~2,000 and 3,000 per day, respectively) than medium trucks (~500 and ~1,000 per day, respectively).

There are a number of road segments with traffic counts equal to zero. These are 178 local road segments (0.3 percent of all local roads), 63 collectors (0.9 percent of all collectors), 18 minor arterials (0.3 percent of all minor arterials), 2 primary arterials (<0.1 percent of all primary arterials), and 2 freeways (0.1 percent of all freeways). These were evaluated and these values match the estimate from the PSRC SoundCast model output. These segments are isolated and are immediately adjacent to connecting road segments with non-zero traffic counts that appear more realistic. A greater number of road segments had medium- or heavy-trucks counts equal to zero. These were primarily locals, collectors, and minor arterials, and values of 0 trucks were not unexpected. Nearly all freeway segments with 0 trucks were associated with on- and off-ramps into residential neighborhoods where truck traffic would not be expected.

Figure 13. Average Daily Traffic Distribution for Roadways in King County by Count of Roadway Segments.

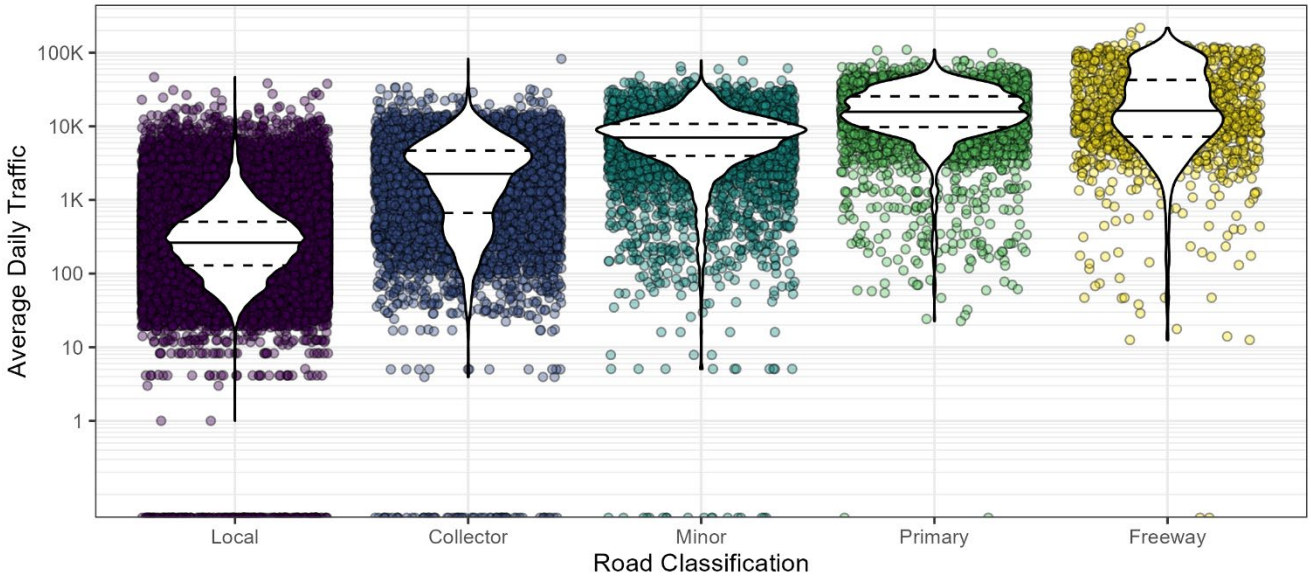


Figure 14. Average Daily Medium-weight Truck Traffic Distribution for Roadways in King County by Count of Roadway Segments.

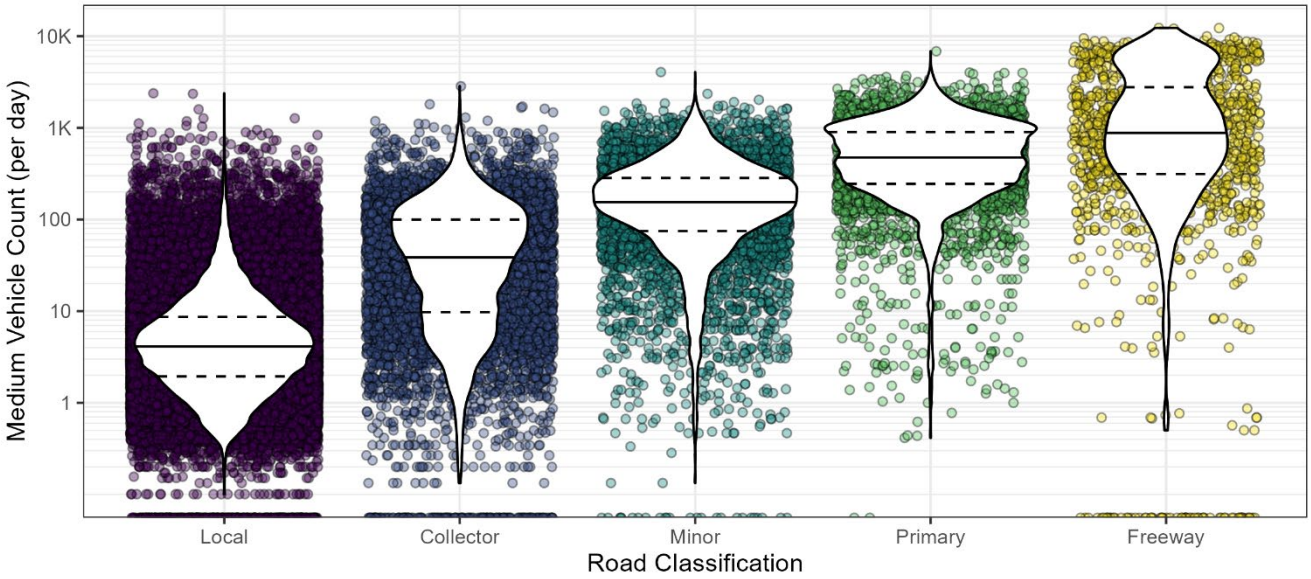
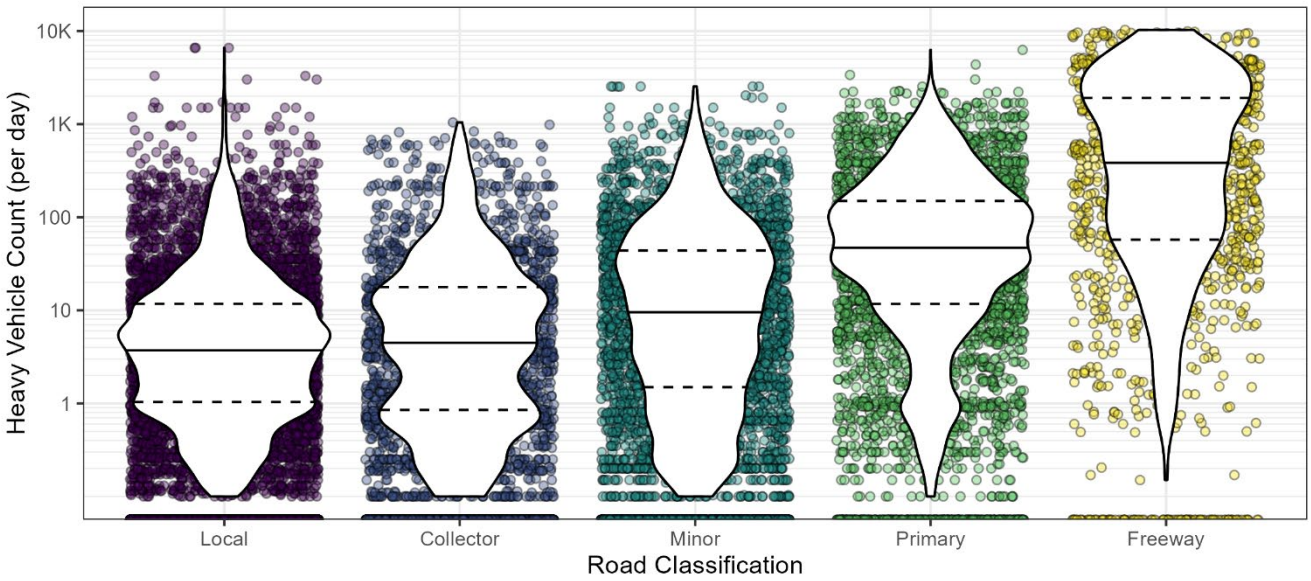
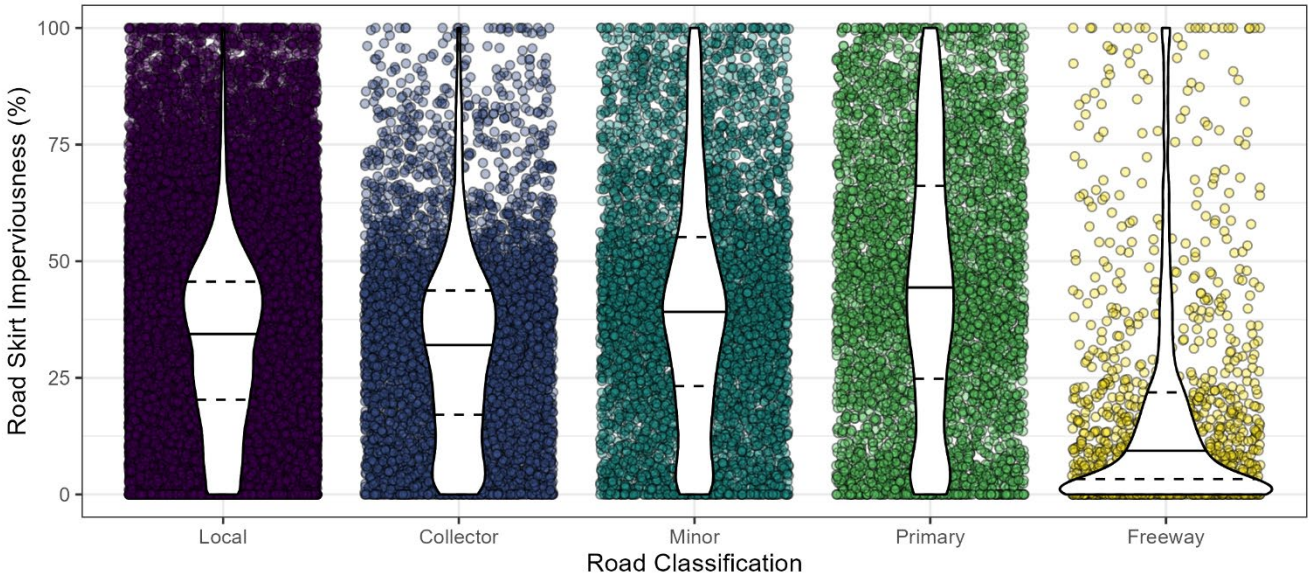


Figure 15. Average Daily Heavy-weight Truck Traffic Distribution for Roadways in King County by Count of Roadway Segments.



Freeways had low levels of imperviousness in the roadway skirt (Figure 16). Except for in the most densely urban of areas, freeways typically have large setbacks away from the roadway and a lack of sidewalks, driveways, and buildings. The other roadway classifications followed a relatively similar distribution, with the most frequent imperviousness at approximately 40 percent. Minor and primary arterial roads had flatter distributions with a greater frequency of roads with high imperviousness in the skirt.

Figure 16. Road Skirt Imperviousness (%) Distribution for King County and WSDOT Roadways by Count of Roadway Segments.



Conveyance presence followed a bimodal pattern, with a lower peak near zero and greater peak near 100 percent (Figure 17). Freeways and local roadways had the highest relative proportion of no conveyance network, particularly for roads with low skirt imperviousness (Figure 18). Stormwater conveyance type data were evaluated for only unincorporated King County, WSDOT, and Seattle roadway segments because these segments had consistent labeling and the other jurisdictions' data were not reviewed for quality. Piped networks were more common, with increasing roadway skirt imperviousness across all classifications, and ditches were primarily found along roadways with low skirt imperviousness. Roadways within urban areas had greater levels of skirt imperviousness and piped conveyance.

Figure 17. Roadway Conveyance (%) Distribution for Roadway Segments in King County.

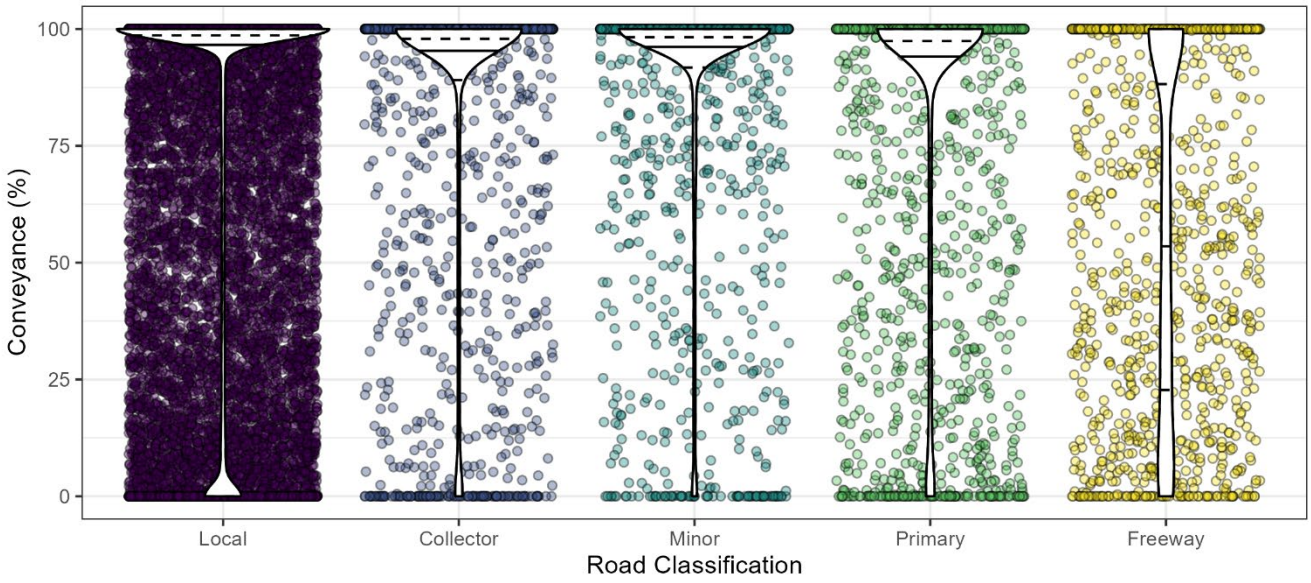
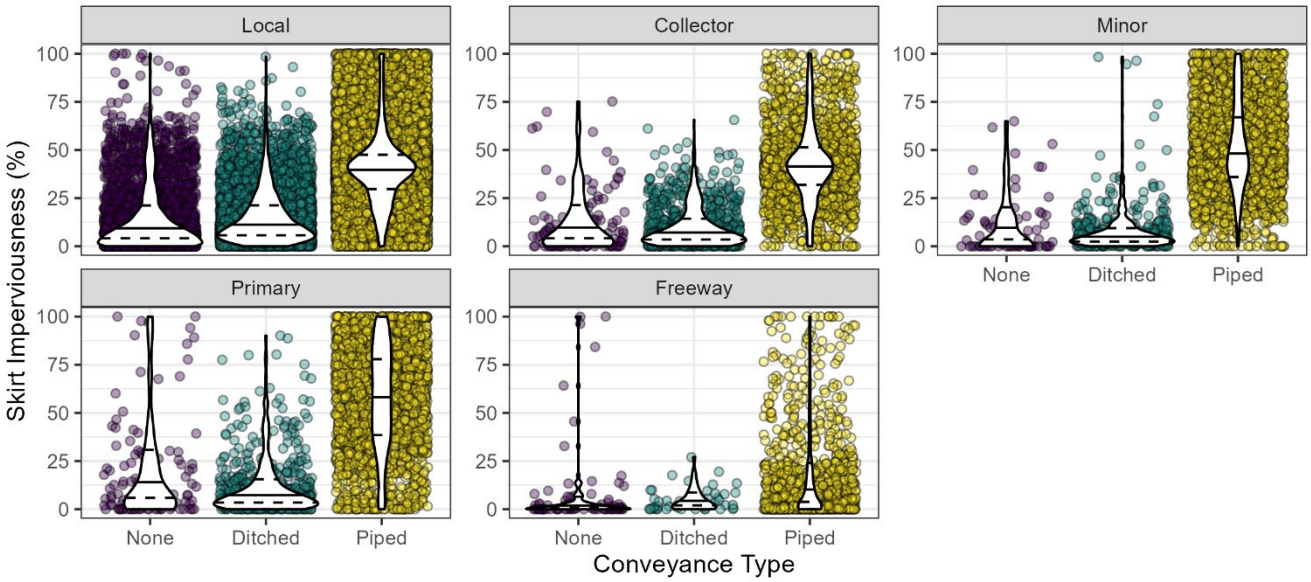


Figure 18. Conveyance Type and Roadway Skirt Imperviousness by FCC for unincorporated King County, Seattle, and WSDOT roads.



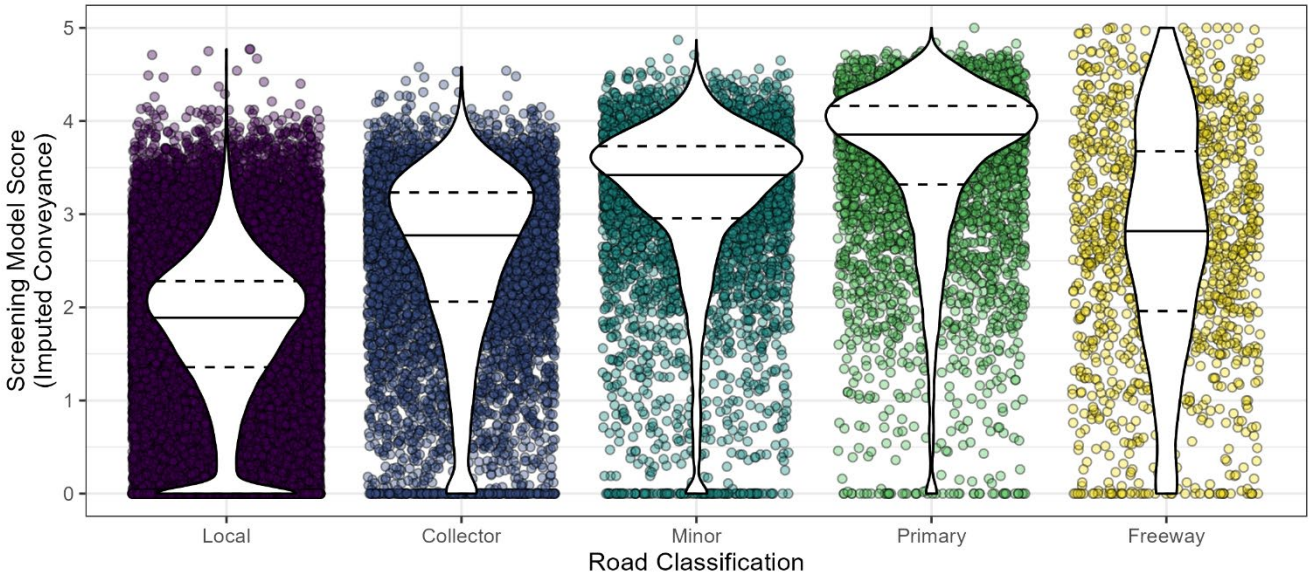
3.2. Screening Model Scores

In agreement with the spread in the distribution of the input spatial layers, there was ample spread in the scores across the various road classifications. Primary arterials tended to have the greatest export, followed by minor arterials, then collectors, then freeways, and local roadways with the lowest export (Figure 19). It appears that that lower scores for freeways are primarily due to the lower rate of

conveyance presence and lower imperviousness. These scores are sensitive to data gaps in stormwater conveyance mapping and traffic model accuracy, both of which are assumed to be adequate for this planning-level analysis (see Chapter 4).

The top 10 list for all the analyzed segments is provided in Table 11 and for designated county-owned road segments in Table 12. Figure 21 provides an example of Screening Model scores in White Center, Washington, and Appendix A provides further examples using Google Street View.

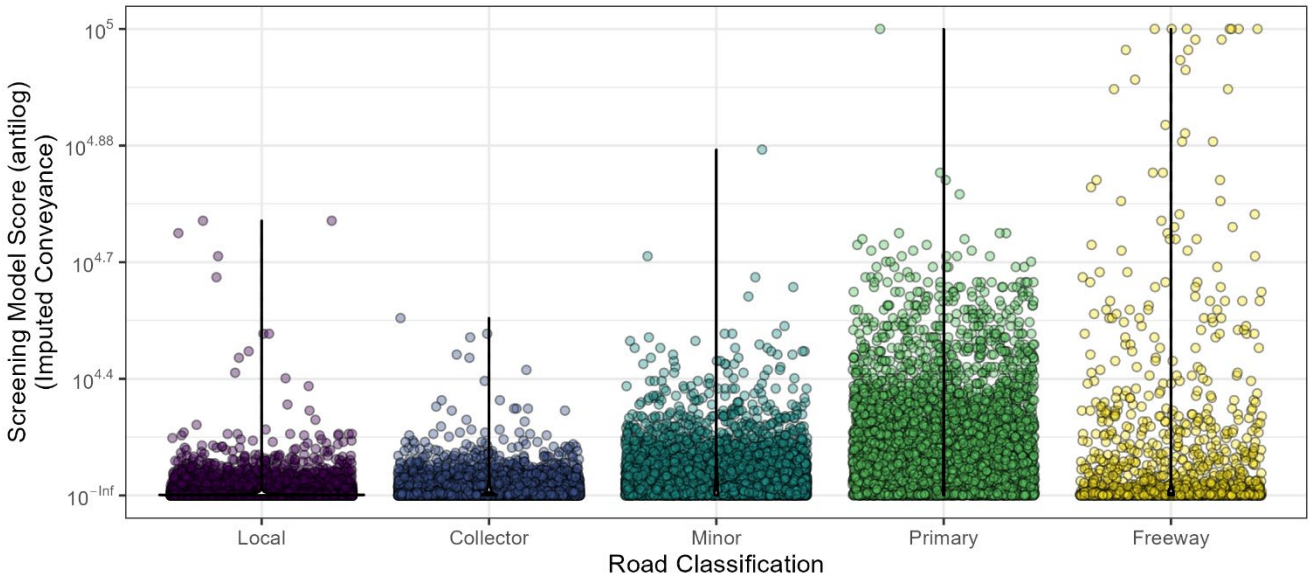
Figure 19. Distribution of Screening Model Scores.



Note: Conveyance is imputed for Carnation, Medina, Skykomish, and Yarrow Point.

When reviewing these scores, it is important to recall that the scores are on a log-scale basis. For example, a difference between a score of 3 and a score of 5 is a 100-fold increase in the expected export of 6PPDQ to the stormwater conveyance network. To illustrate this, Figure 20 displays the scores as an antilog. From this plot, it is clearer that there are some outstanding segments, in terms of the expected 6PPDQ export to the stormwater conveyance network.

Figure 20. Distribution of Screening Model Scores (antilog).



Note: Conveyance is imputed for Carnation, Medina, Skykomish, and Yarrow Point.

A high-level review of model output was conducted to look for gross misspecification. To conduct this, Herrera looked for examples where "Local" roads had very high traffic (greater than 10,000) and when Freeways had lower-than-expected traffic. This review found one questionable value: the road segment south-bound SR 99 just north of the Duwamish River bridge in South Seattle (SR 99-81899) as allocated a traffic value of 0. This occurred due to a PSRC model link with traffic values of zero that was closer to the st_address segment than the appropriate model link. This misspecification does not extend into the down-road segment (SR 99-81907), which has an assigned ADT of 54,285 and model score of 4.59.

At this stage in the model development, the identified issues have been left uncorrected. Users of the model should critically review project-specific areas of interest to correct any gross misspecifications.

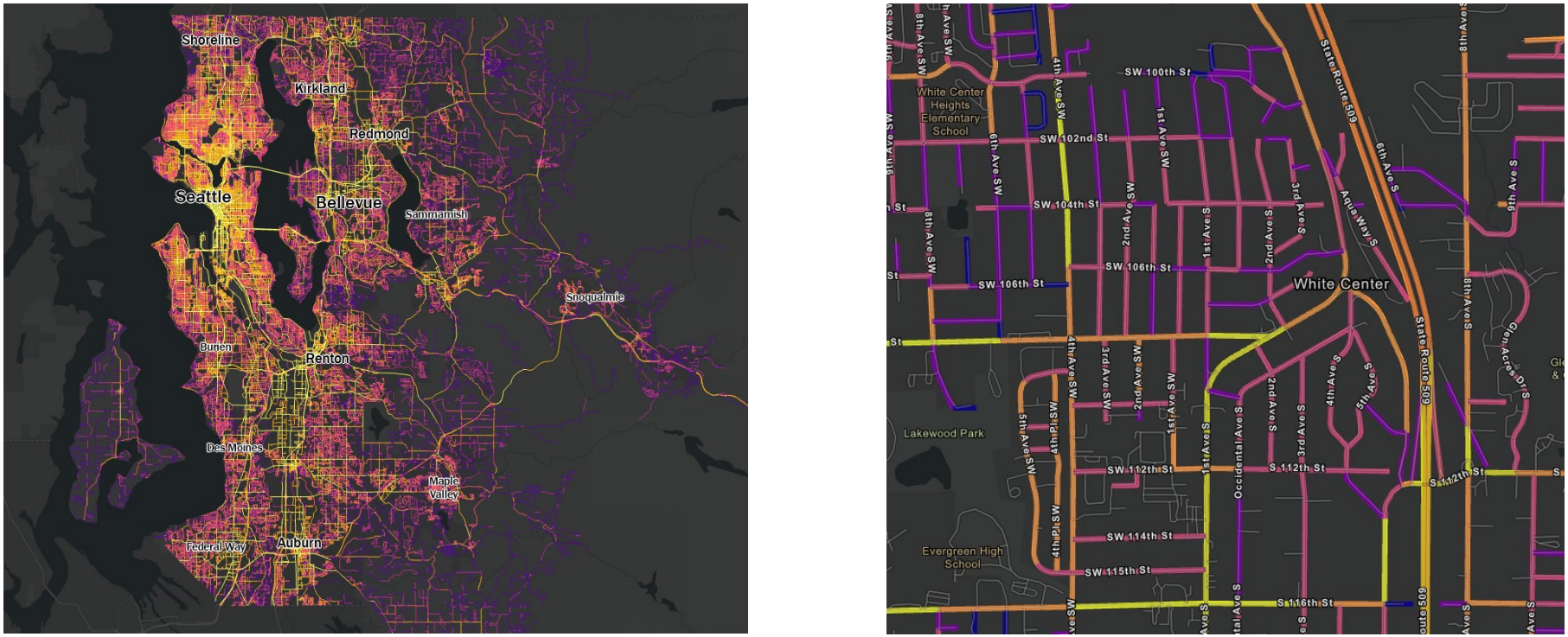
Table 11. Top 10 Screening Model Scores.

Juris	Name	Road Segment ID	FCC	Road Miles	ADT	Heavy Trucks Per Day	Medium Trucks Per Day	Gen. Score	Roadway Skirt Imperviousness (%)	Roadway Drainage	Conveyance (%)	Stream Crossing?	Connectedness Score	Total Score
WSDOT	I-5 FWY	I-5-41892	Freeway	0.4	113,681	3265	7722	5.2	65	Piped	100	0	-0.19	5
WSDOT	I-5 FWY	I-5-41897	Freeway	0.7	100,859	3818	6274	5.17	95	Piped	100	0	-0.02	5
WSDOT	I-5 FWY	I-5-41916	Freeway	0.1	112,034	4385	8043	5.22	77	Piped	100	0	-0.12	5
WSDOT	I-5 FWY	I-5-41925	Freeway	0.2	86,725	4954	5982	5.14	100	Piped	100	0	0	5
WSDOT	I-5 FWY	I-5-41960	Freeway	0.4	92,253	4970	7060	5.16	78	Piped	100	0	-0.11	5
WSDOT	I-5 FWY	I-5-41998	Freeway	0.1	89,823	9499	6121	5.24	100	Piped	100	0	0	5
WSDOT	LAKE CITY WAY NE	LAKE CITY-42971	Primary	<0.1	107,456	205	4008	5.1	82	Piped	100	0	-0.09	5
WSDOT	I-90 FWY	I-90-42053	Freeway	0.3	86,091	1356	5292	5.05	87	NA	14	1	-0.06	4.99
WSDOT	I-90 FWY	I-90-42021	Freeway	2.2	81,212	1387	5479	5.03	90	Piped	5	1	-0.05	4.98
WSDOT	I-5 FWY	I-5-41964	Freeway	0.1	107,212	5039	6555	5.21	58	Piped	100	0	-0.23	4.98

Table 12. Top 10 Screening Model Scores (King County Managed Roadways Only).

Juris.	Name	Road Segment ID	FCC	Road Miles	ADT	Heavy Trucks Per Day	Medium Trucks Per Day	Gen. Score	Roadway Skirt Imperviousness (%)	Roadway Drainage	Conveyance (%)	Stream Crossing?	Connectedness Score	Total Score
King County	SW ROXBURY ST	ROXBURY-85998	Primary	<0.1	39,122	261	933	4.67	49	Piped	100	0	-0.31	4.36
King County	SE PETROVITSKY RD	PETROVITSKY-80926	Primary	0.2	27,306	396	609	4.53	57	Ditched	100	0	-0.24	4.29
King County	16TH AVE SW	16TH-11070	Primary	0.1	23,715	85	470	4.44	68	NA	100	0	-0.17	4.27
King County	16TH AVE S	16TH-11032	Primary	0.5	18,621	148	1113	4.37	78	Ditched	100	1	-0.11	4.26
King County	SW ROXBURY ST	ROXBURY-85975	Primary	0.1	15,821	175	463	4.29	94	Piped	100	0	-0.03	4.26
King County	SW ROXBURY ST	ROXBURY-85965	Primary	0.1	20,550	199	509	4.4	71	Piped	100	0	-0.15	4.25
King County	16TH AVE SW	16TH-11084	Primary	0.1	16,880	29	226	4.29	89	Ditched	100	0	-0.05	4.24
King County	SW ROXBURY ST	ROXBURY-85969	Primary	0.1	30,785	175	865	4.57	46	Ditched	100	0	-0.34	4.23
King County	AUBURN WAY S	AUBURN-35076	Primary	0.1	25,492	25	577	4.47	55	NA	100	0	-0.26	4.21
King County	S 132ND ST	132ND-63981	Collector	<0.1	24,791	269	1806	4.5	51	Piped	100	0	-0.29	4.21

Figure 21. Screening Model Scores for King County (left) and White Center, Washington.



4. Model Quality Assessment

Quality objectives for the model inputs and outputs were identified in the Modeling QAPP (Herrera 2024). Table 13 summarizes those objectives and how they were met, which is further detailed in the following subsections.

Table 13. Summary of Quality Assessment per Modeling QAPP (Herrera 2024).

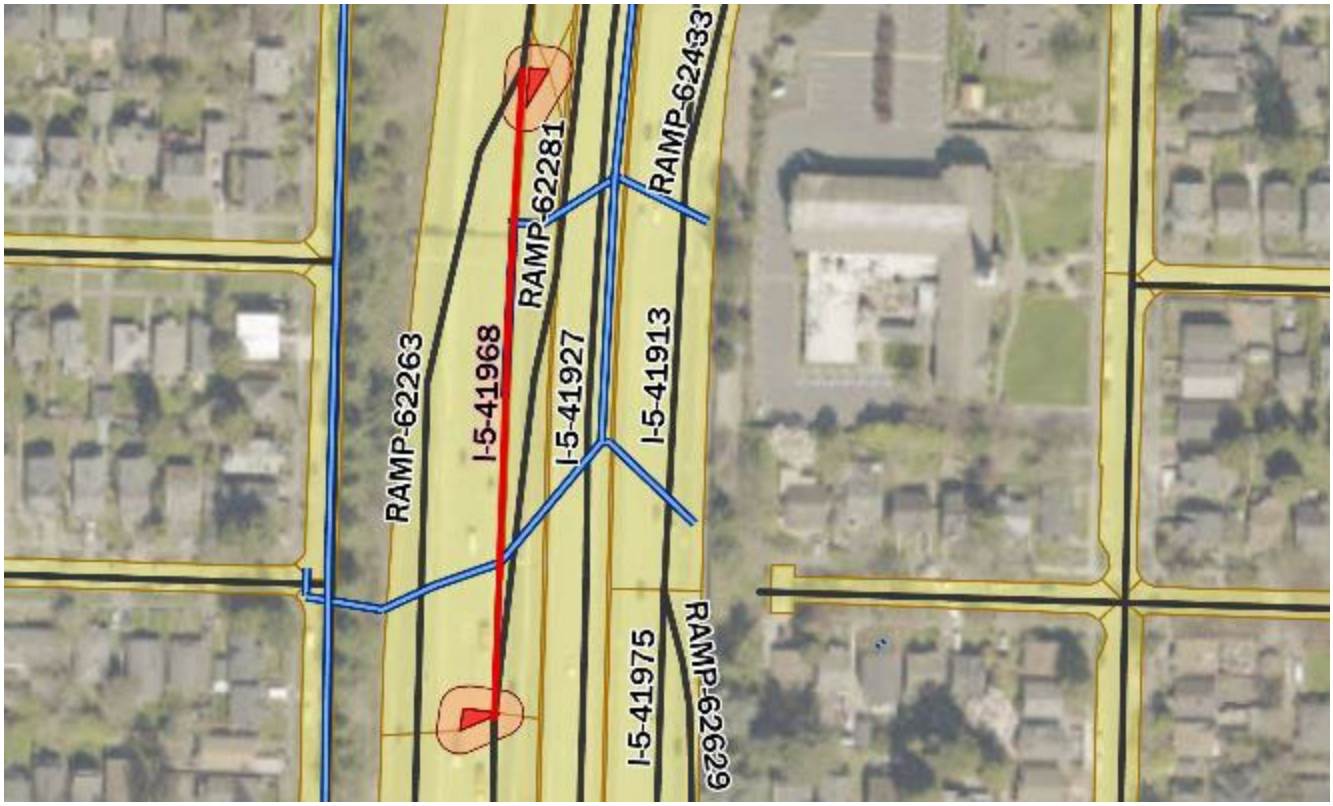
Objective	QAPP Reference Section	Objective Met?	Rationale
Quality of Model Input Data			
Input data reasonable	5.2	Yes	Spatial datasets were developed with rigorous quality control procedures and documentation. Anomalous or questionable results were removed. All spatial datasets meet the Washington State Geographic Information Council Geospatial Data Guidelines or Federal Geographic Data Committee (FGDC) Content Standards for Digital Geospatial Metadata and National Map Accuracy standards. Potential inaccuracies, imprecision, bias, and other sources of uncertainty are summarized in the Screening Model documentation.
Input data representative	5.2	Yes	Spatial datasets have sufficient resolution and recency to represent roadway and drainage network conditions. Spatial layers were aligned to improve accuracy. Methods to align spatial layers and discussion of any data quality concerns are documented herein. The spatial coverage, completeness, and accuracy of spatial layers were compared against the Ecopia-derived road surface extent polygons, rather than against the st_address layer, to ensure accurate spatial comparisons.
Quality of Model Outputs			
Model free of critical flaws	5.3	Yes	Model quality reviewed by SMEs and Internal Review Team (IRT). Feedback from SME's and IRT were used to revise the Model as appropriate.
Model provides results that are meaningful for selecting monitoring sites across a gradient of input parameters and expected delivery of 6PPDQ to stormwater conveyance network	5.3, 6.2.1.6	Yes	Spatial fidelity of inputs and synthesized outputs were managed. Known spatial data gaps and sources of uncertainty are documented. Quality of the input spatial dataset and literature values for vehicle tire wear rates were considered during roadway scoring. Due to a low confidence in some literature values for tire wear rates (see Mennekes and Nowack 2022), the methodology in Moran et al. (2023) was extended to consider vehicle weight. Processing steps applied in the assembly of spatial data inputs are repeatable and clearly documented; quantification of data source certainty and spatial alignment are calculated for each feature, where relevant.

4.1. Input and Data Processing Quality Assessment

The acceptance criteria of data reasonableness and data representativeness as defined in the QAPP were applied to all existing data used for model development. Potential inaccuracies, imprecision, bias, and other sources of uncertainty are summarized in the Screening Model documentation. Metadata associated with the input layers is also carried over in the Screening Model documentation. Generally, existing data were evaluated for (1) spatial alignment between layers, (2) the plausibility of reported values compared to expected values (e.g., tens-of-thousands of vehicles per day on a suburban street is not plausible), and (3) gaps in the spatial coverage (e.g., areas where stormwater infrastructure is not mapped).

The approach for splitting the Ecopia land classification layer to create road surface extent polygons generally produced representative spatial relationships between st_address road segments and associated road surface polygons. However, in some cases where complicated roadway lines were poorly-matched with actual road surfaces, the automated process for apportioning road polygons resulted in highly fragmented or undersized road footprints (Figure 22). This resulted in some road segments receiving disproportionately low scores for drainage connectivity relative to their imperviousness, as the road skirt and buffer generated from the associated road surface extent polygon were undersized; an issue that was exacerbated by incomplete mapping of stormwater infrastructure along WSDOT-managed roads in some jurisdictions. This issue appears to be most pronounced at sites with complex freeway geometry (ex: a ramp joining a freeway along an overpass, with another roadway below). The extent of this issue may be roughly estimated by calculating the number of road surface extent polygons falling below a reasonable size threshold, and by associating those small polygons with road segments that have very low connectivity scores. Additional manual review of road surface polygon splitting at complicated roadway interactions would help resolve this issue.

Figure 22. Example of an Undersized Road Surface Extent Polygon Resulting from Complicated Road Geometry.



Note: This image shows road segments (from the st_address layer), associated road surface extent polygons (yellow), and nearby drainage infrastructure (blue lines). There are several ramps and freeway line segments converging across a relatively short distance. This resulted in some very small portions of the road surface extent polygons being attributed to road segment I-5-41968 (highlighted in red). The two triangular portions of road surface polygon assigned to road segment I-5-41968 were used to develop the road skirt and buffer, which were then used to attribute the length of nearby drainage infrastructure back to the road segment in the st_address layer. Since the road surface extent polygon was undersized, the road buffer was also undersized, and failed to capture drainage infrastructure that would receive roadway export from this road segment.

There was a nominal amount of misspecification of the model where SoundCast traffic numbers were inappropriately assigned to roadways. Herrera applied a stepwise approach to assigning traffic volumes to st_address lines, moving from most-confident spatial matches between SoundCast lines and st_address lines (ramps, freeways) to less-confident direct matches (primary/main streets, collectors, local roads, remaining unassigned roads based on aggregated TAZ polygon projections). Based on internal review, misspecifications are very rare, and upon manual inspection, these errors are easy to identify. For hot spot evaluation, this error is manageable because the misidentified "hot spot" road segment will be proximate to an actual road segment "hot spot." If working within a small number of catchment areas, manual correction may be appropriate.

4.2. Model Output Quality Assessment

The Model Quality Objectives for the Screening Model are qualitative, due to the planned purpose of the model's use (to develop categorizations rather than quantitative results). As described in Section 6.2.1 of the QAPP, quality of the model was assessed by both the surveyed expert team (SME team) and by an additional review team (Internal Review Team [IRT]). Specifically:

- The Screening Model should be free of critical flaws, as assessed by the SME team and the IRT. Critical flaws will be defined at the discretion of the individual SMEs, in consideration of the model objectives and intended use. For example, a critical flaw would be the exclusion of a highly influential factor (e.g., number of vehicles) or relying on a gross misrepresentation of that factor (i.e., it is inaccurate by over an order of magnitude). As another example, a critical flaw would be that the model output is not the right format for input into the *Multi-Criterion Decision Tool*.
- The Screening Model should provide results that are meaningful for selecting monitoring sites across a gradient of input parameters and expected delivery of 6PPDQ to surface waters.

The SME team and IRT reviewed a draft version of the Screening Model and this technical memorandum in March 2024. Their comments were used to improve the model by (1) decreasing the weighting of road skirt imperviousness, (2) adjusting the tire wear rate scaling factors, and (3) integrating the presence of a waterbody into the *Connectedness*. During their review, the teams also discussed the uncertainty of the varied tire wear rate associated with vehicle behavior (e.g., braking, accelerating, turning). This topic was discussed at length during the development of the conceptual model as part of the QAPP. At this time, the magnitude of impact of vehicle behavior on the Tire Wear Rate is not well understood. Given the paucity of field-verified information, one expert in the SME workshop cautioned against inferring changes in tire wear rate based on vehicle behavior until additional studies are completed.

4.3. Recommended Future Studies to Fill Data Gaps

During the development of the conceptual model and Screening Model, several knowledge and data gaps were identified. These are described in Table 14 and potential data sources or studies that could be used to fill those gaps are identified.

Table 14. Tire Wear Particle and 6PPDQ Export Knowledge and Data Gaps.		
Knowledge/Data Gap	**Description**	**Data Source/ Existing or Planned Studies**
Unified and Complete Stormwater Infrastructure Dataset	The Screening Model used a compiled dataset of stormwater conveyance layers from nearly all jurisdictions in the King County geographic area. The completeness, accuracy, and recency of the datasets were not evaluated as part of this study. Except for King County, Seattle, and WSDOT stormwater layers, the type of conveyance (e.g., ditch, pipe) was not maintained due to challenges in the alignment of disparate value names and definitions.	There is considerable regional interest to complete this effort. However, no efforts are underway or planned.
Tire Wear Generation and Deposition on Private Roads, Parking Lots, and Other Areas	The scope of the Screening Model targeting public roadways in the King County geographic area. By design, this excludes many locations where tire wear occurs, including, but not limited to, private roads, public and private parking lots, loading docks.	No planned studies are known. Some existing datasets may be used to develop tools to identify generation/deposition areas and determine usage based on satellite imagery over multiple dates or other vehicle count data sources.
Vehicle Behavior Influence on Tire Wear Rate and Export	Vehicle behavior (e.g., slow cornering, starting/stopping, turning) were identified as factors influencing the tire wear rate during conceptual model development, but there was not suitable confidence to assign specific weighting.	There are no known studies currently that are evaluating vehicle behavior impacts at a landscape scale. Several studies have focused on individual driving behavior (e.g., rapid acceleration and sharp turning), but those are not readily translated to specific roadways (e.g., Liu et al. 2022, Pohrt 2019). The next phase of this project includes field sampling for 6PPDQ in highway runoff. The study could select sites along the same roadway segment with a site near a turn in the road and another during a straightaway to compare tire wear rates.
Conveyance Type Influence on Tire Wear/ 6PPDQ Transport	The type of conveyance network (e.g., pipe, vegetated ditch, dirt ditch, etc.) are expected to influence the export of tire wear particles and 6PPDQ due to physical, chemical, and biological conditions. The conveyance network may also act as temporary storage for tire wear particles, which are later exported during intense storm events. At this time, there is insufficient data to differentiate export based on the conveyance type.	Several studies are investigating 6PPDQ transport through various treatment devices, but, to our knowledge, there are none planned that are specifically comparing transport between conveyance types. In the next phase of this project, King County is partnering with WSDOT to collect and analyze 6PPDQ samples upstream and downstream of grass swales along highways. The data from this study may support adjustments to the Screening Model for vegetated ditches. However the existing spatial conveyance data infrequently provide designation for whether ditches are vegetated or grassy.

Table 14 (continued). Tire Wear Particle and 6PPDQ Export Knowledge and Data Gaps.		
Knowledge/Data Gap	**Description**	**Data Source/ Existing or Planned Studies**
Increased Tire Wear Associated with Public Bus Routes	The PSRC SoundCast model did not capture mass transit busses, which are expected to have a higher tire wear rate than passenger vehicles, similar to the medium-weight freight vehicles.	Spatial data for the bus routes for SoundTransit and Metro are available, but these do not contain the frequency of those bus trips, which would be used to develop a daily traffic estimate. Those daily trip data are available in other data formats.
Street Sweeping Effectiveness for Tire Wear Particles	The effectiveness of street sweepers to remove TWPs and 6PPDQ is not quantified, yet. Street sweepers are effective at removing large particles but may not effectively remove deposited fine TWPs, especially those blown away from active roadway area.	Street sweeping studies by Seattle Public Utilities (SPU) and City of Redmond are currently underway. The SPU study will quantify the mass of 6PPDQ removed from roadways by street sweeping (SPU 2023). The Redmond study includes paired watershed monitoring for Tosh Creek (application) and Country Creek (control) (Herrera 2022). City staff will sweep all public roads (3.54 miles) in the Tosh Creek watershed within Redmond city limits one time per month from October 2022 through September 2023, and two times per month from October 2023 through September 2024. This will be in addition to the regularly scheduled quarterly street sweeping.
Deposition of Tire Wear Particles/6PPD Transformation Outside of Highway Skirt	The Screening Model specifically focused on the roadway skirt—a 6-meter buffer on either side of the active roadway, where the majority of tire wear particle deposition, by mass, is expected to occur. However, finer particles may travel beyond the skirt to be deposited with greater distance. The geographic dispersion of tire wear particles and resultant 6PPDQ is a data gap.	Some studies have looked at the distribution of TWPs from the roadway surface (e.g., Jarlskog et al. 2022). However, the measures of TWP mass and concentration are variable based on multiple meteorologic and topographic features. No known studies are planned that explicitly investigate 6PPDQ export from surfaces beyond the active roadway and its skirt.

5. Conclusions and Next Steps

This report documents the development and initial implementation of the 6PPDQ Screening Model for the King County geographic area. The Screening Model estimates the relative expected amount of 6PPDQ delivery to the stormwater drainage network based on four primary factors: the number of vehicles, the size and weight of vehicles, the imperviousness of the roadway skirt, and the presence of a conveyance network.

By design, the model is simple and adaptable. It may be expanded to include additional factors, such as adjusting export based on conveyance type (pipe versus ditch) and adjusting tire wear generation rates based on road geometry (grade and curvature), as more data become available that support those adjustments.

At this stage, the Screening Model output should not be used while unsupervised. Although the input data are generally accurate, Herrera knows there are numerous misspecifications for traffic and, to a far lesser degree, for road skirt imperviousness and conveyance networks in the model. When evaluating model impact, the user should critically consider if the specific results for a roadway are reasonable: Does the number of cars on this roadway make sense? Is the estimated number identical to a nearby, far-busier road? A user can manually rescore individual roads by inputting corrected traffic estimates (using up- or downstreet segments or other best estimates) and using the Screening Model scoring equation. Misspecifications can greatly inflate or deflate the final score. For example, if an existing conveyance structure is not mapped for a roadway segment in a jurisdiction where data were available or captured in the spatial model, then the final score could be depressed by up to 2 points. To evaluate the frequency of these misspecifications, an analysis could be conducted where (1) a set number of random roadway segments are selected and stratified across each jurisdiction and each roadway classification, and (2) the presence/extent of imperviousness and conveyance are inspected via desktop or dashboard research.

The next phase of this project will include field sampling for 6PPDQ. The purpose of the field sampling will be to characterize 6PPDQ export from roadways across a gradient of road use and road drainage characteristics. The collected 6PPDQ data will be used to ground truth and validate the 6PPDQ Screening Model. The 6PPDQ Screening Model, developed under this QAPP, will be used to inform site selection across a gradient of road use and road drainage characteristics. Based on the feasibility and safety of collecting samples of roadway runoff, 10 to 20 candidate sites that represent a gradient of Screening Model outputs will be selected. After conducting field reconnaissance, up to 12 sites will be selected for the monitoring study.

Under the *Multi-Criterion Decision Tool* project, the output from the Screening Model will be integrated into a King County stormwater prioritization tool, which is described in the Background chapter. King County will develop a final Road Segment Prioritization report that will summarize methods, results, lessons learned, and recommendations for future work.

5.1. Expanded Implementation

There is interest in expanding this Screening Model to areas elsewhere in the Puget Sound lowlands. Outside of King County, four additional datasets are needed: (1) high-resolution impervious land cover, (2) stormwater conveyance infrastructure, (3) road lines, and (4) traffic volumes. This Screening Model approach may need to be adapted for use in other areas depending on available spatial data attributes. For example, the stepwise approach of allocating modeled traffic volumes depends on being able to distinguish between road classes (applying traffic to ramps, then major roadways, then local roads). If ramps and other road classes cannot be readily distinguished from one another, a different approach for subsetting and allocating traffic along roads may need to be developed based on the available data sources.

5.1.1. Land Cover

The Ecopia high-definition land cover dataset has not been publicly purchased outside of the King County geographic area. Instead, there is a statewide 3-foot raster available for Washington, using 2021–2022 imagery.[3] Ecopia used proprietary extraction and modeling software to process raw images into seven high-resolution land cover classifications. The classifications are impervious, impervious (covered by trees), shrub/low vegetation, tree/forest/high vegetation, open water, railroad, and unclassified. This dataset differs from the Ecopia dataset used for the King County Screening Model, because that dataset includes land cover designations that differentiate impervious cover to road, sidewalk, driveway, parking, building, and other pavement. Herrera leveraged that dataset to precisely define the roadway surfaces and then define the 6-meter buffer from the edge of the roadway.

5.1.2. Stormwater Conveyance Infrastructure

The Screening Model framework will accept spatial data for the location and type of stormwater infrastructure. The spatial dataset should include all stormwater conveyances (e.g., pipes, ditches, swales). At this time, the model does not differentiate between the type of stormwater conveyance, but that information may be incorporated into future versions of the model as further research in 6PPDQ and TWP retention is completed.

5.1.3. Road Lines

The location of roadways is critical for the Screening Model. There were many cases where the st_address line did not follow the roadway centerline, even occurring entirely off the roadway in some cases. This potential misalignment of the roadway spatial layer should be considered when selecting the principal roadway data source. Additionally, the model builder should consider the length of individual roadway segments. Some roadway data sources will be at the block-level of resolution, like st_address, and other sources may define a roadway as a single continuous line spanning multiple blocks. This decision may be informed by the desired level of resolution in the model output.

[3] https://geo.wa.gov/datasets/land-cover-statewide-ecopia-data-2021-2022-3ft-raster/about

To address challenges with misattribution of modeled traffic and conveyance networks at over/underpasses and in tunnels, future refinement of the study road lines, surface extent polygons, skirts, and buffers to include elevation attributes is advisable. This would allow for meaningful distinction between road features that share the same horizontal extent and occupy different vertical space. This could result in reduced misattribution of modeled traffic volumes (particularly at freeway overpasses with lower-traffic local roads below) and could help avoid assigning drainage features where they do not make sense (e.g., no swales falling within the skirt of a raised freeway).

5.1.4. Traffic Volume

Modeled traffic volumes in the Puget Sound area are available. The PSRC SoundCast model includes geographic areas of King, Snohomish, Kitsap, and Pierce counties. The Thurston Regional Planning Council's Greater Thurston Regional Travel Demand Model includes the geographic areas of Thurston County, Lewis County, Greys Harbor County, and portions of Mason and Pierce counties. The Whatcom County Travel Demand Model includes the Whatcom County geographic area. Within the Puget Sound region, there are no modeled traffic volumes for Jefferson County, Clallam County, Island County, Skagit County, and the majority of Mason County.

6. References

Bäckström, M., et al. (2006). "Transport of stormwater pollutants through a roadside grassed swale." Urban Water Journal 3: 55-67.

Baensch-Baltruschat, B., Kocher, B., Stock, F., and Reifferscheid, G. 2020. Tire and road wear particles (TRWP) – A review of generation, properties, emissions, human health risk, ecotoxicity, and fate in the environment. *Science of The Total Environment*, 137823.

Brinkmann, M., D. Montgomery, S. Selinger, J. G. P. Miller, E. Stock, A. J. Alcaraz, J. K. Challis, L. Weber, D. Janz, M. Hecker & S. Wiseman. 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.

Herrera Environmental Consultants. 2022. Addendum 1 to the Quality Assurance Project Plan for the Redmond Paired Watershed Study. Prepared for the City of Redmond. Seattle, WA.

Herrera Environmental Consultants. 2024. Quality Assurance Project Plan: Screening and Predictive Models of 6PPD q Delivery to the Stormwater Network. Prepared for King County Water and Land Resources Division. Seattle, Washington.

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 and Technology Letters, 8(9), 779–784

Järlskog, I., D. Jaramillo-Vogel, J. Rausch, M. Gustafsson, A. Strömvall, and Y. Andersson-Sköld. 2022. Concentrations of tire wear microplastics and other traffic-derived non-exhaust particles in the road environment. Environment International 170: 107618.

Kole, P. J., Löhr, A. J., Van Belleghem, F., & Ragas, A. 2017. Wear and Tear of Tyres: A Stealthy Source of Microplastics in the Environment. International Journal of Environmental Research and Public Health, 14(10), 1265. https://doi.org/10.3390/ijerph14101265

Mennekes, D. and B. Nowack (2022). "Tire wear particle emissions: Measurement data where are you?" Science of the Total Environment 830: 154655.

Moran, K., Gilbreath, A., Méndez, M., Lin, D., Sutton, R. 2023. Tire Wear: Emissions Estimates and Market Insights to Inform Monitoring Design. SFEI Contribution #1109. San Francisco Estuary Institute, Richmond, CA.

Seattle Public Utilities. 2023. Stormwater Action Monitoring (SAM) Round 4 Effectiveness Study and Source Identification. Seattle, WA.

Tian, Z. Y., H. Zhao, K. T. Peter, M. Gonzalez, J. Wetzel, C. Wu, X. Hu, J. Prat, E. Mudrock, R. Hettinger, A. E. Cortina, R. G. Biswas, F. V. C. Kock, R. Soong, A. Jenee, B. Du, F. Hou, H. He, R. Lundeen, A. Gilbreath, R. Sutton, N. L. Scholz, J. W. David, M. C. Dodd, A. Simpson, J. K. McIntyre & E. P. Kolodziej. 2021. Ubiquitous Tire Rubber-Derived Chemical Induces Acute Mortality in Coho Salmon. Science, 371 (6525): 185

Tian, Z. Y., M. Gonzalez, C. A. Rideout, H. N. Zhao, X. M. Hu, J. Wetzel, E. Mudrock, C. A. James, J. K. McIntyre & E. P. Kolodziej. 2022. 6PPD-quinone: Revised Toxicity Assessment and Quantification with a Commercial Standard. Environmental Science & Technology Letters, 9(2): 140.

Appendix A

Example Screening Model Scores and Google Street View Images

Figure A1. Screening Model Example: 16th Ave SW (16TH-11076) in White Center.



(Map data ©2023 Google)

This roadway segment receives 6,561 total vehicles per day, of which 5 are heavy trucks and 107 are medium trucks. The roadway skirt is 98 percent impervious and runoff is collected in catch basins into a piped conveyance network (100 percent conveyed). This segment had a model score of 3.88 (95.9th percentile).

Figure A2. Screening Model Example: Edgar Martinez Ramp (RAMP-62710) onto I-90 in Seattle.



(Map data ©2023 Google)

This roadway segment receives 28,676 total vehicles per day, of which 667 are heavy trucks and 1,750 are medium trucks. The roadway skirt is 88 percent impervious (there is vegetation underneath the overpass) and runoff is collected in catch basins into a piped conveyance network (100 percent conveyed). This segment has a model score of 4.54 (99.7th percentile).

Figure A3. Screening Model Example: 24000 Block of 208th Ave SE (208TH-15051) in unincorporated King County.



(Map data ©2018 Google)

This roadway segment receives 146 total vehicles per day, of which 0 are heavy trucks and 1 are medium trucks. The roadway skirt is 13 percent impervious and there is no conveyance present. This segment (among many others) had the lowest model score of 0 (7.9th percentile).

Figure A4. Screening Model Example: SR-18 (SR 18-81753) near Auburn, WA.



(Map data ©2022 Google)

This roadway segment receives 20,298 total vehicles per day, of which 1784 are heavy trucks and 834 are medium trucks. The roadway skirt is 14 percent impervious and there is no mapped conveyance present. This segment had a model score of 3.69 (93.8th percentile).

Figure A5. Screening Model Example: Fall City Carnation Rd (SR-203) (FALL CITY-CARNATION-40224).



(Map data ©2021 Google)

This roadway segment receives 7,198 total vehicles per day, of which 746 are heavy trucks and 254 are medium trucks. The roadway skirt is 1 percent impervious and there is 22 percent ditched conveyance. This segment had a model score of 0.26 (9.5th percentile).

Figure A6. Screening Model Example: Preston-Fall City Rd (near SR-203) (PRESTON-FALL CITY-61575).



(Map data ©2023 Google)

This roadway segment receives 5,865 total vehicles per day, of which 399 are heavy trucks and 200 are medium trucks. The roadway skirt is 87 percent impervious and runoff is collected in catch basins into a piped conveyance network (100 percent conveyed). This segment had a model score of 3.93 (96.4th percentile).

Figure A7. Screening Model Example: Interstate 5 (I-5-41872).



(Map data ©2023 Google)

This roadway segment receives 92,252 total vehicles per day, of which 4,970 are heavy trucks and 7,060 are medium trucks. The roadway skirt is 52 percent impervious and runoff is collected in catch basins into a piped conveyance network (100 percent conveyed). This segment had a model score of 4.88 (100th percentile).

Appendix B

Model Development Documentation

This appendix details the development of the screening model structure from conceptual model to the version presented in this technical memorandum. The stages of model development were conceptual model, preliminary Screening Model, and the working Screening Model. The descriptor "working" is intentionally used here to signify that it is a functional model but there are specific areas for further improvement and refinement.

Identification of Spatial Proxies and Model Simplification

Spatial Proxy Identification

Participants and Dates

Spatial Expert Team (SpET):

- James (JJ) Bach, Roads Spatial Data Expert, King County Road Services Division
- Jeff Burkey, Hydrologist, King County Science and Technical Support
- Jennifer Schmidt, Geospatial Science Associate Practice Director, Herrera Environmental Consultants
- Stephen Conroy, Environmental Scientist, King County Road Services Division

Facilitator:

- Timothy Clark, Senior Scientist, Herrera Environmental Consultants
- Lauren Ode-Giles, GIS Specialist, Herrera Environmental Consultants

Meeting Dates:

- October 12, 2023
- December 5, 2023

Elicitation Summary

Prior to the first SpET meeting on October 12, 2023, Herrera distributed a draft version of the conceptual model (developed with the SME group) along with definitions of the model factors. The distribution included a prompt for the SpET members to individually identify potential spatial layer datasets that directly represent the factors in the conceptual model or may serve as proxies.

During the meeting, the facilitators went through each of the model factors and the SpET member responses (if any) and led discussion of the appropriateness of the identified spatial layers. If no spatial layer was identified, a short discussion was held to brainstorm potential layers or analytical approaches to generate the information. During this process, there was no disagreement between SpET members on the appropriate layers. A summary of the identified layers/analytical approaches is provided in Table B-2.

Following the first SpET meeting, the project team evaluated the identified spatial layers, the analytical requirements for each, and the level of importance and reliability for the factor to predicting the export of 6PPDQ from roadways. The latter was informed by input from the SME team during conceptual model development and high-level evaluation of the data completeness and accuracy of the existing datasets. For each factor/spatial layer, rationale for inclusion/exclusion is provided in Table B-2. For example, vehicle speed was identified as a factor that likely contributed to tire wear rate, but SMEs expressed uncertainty on its relative importance compared to major factors (e.g., number of vehicles, number of heavy vehicles, roadway skirt imperviousness). The SpET identified that the Speed Limit from the Metro Transportation Network (TNET) was not a trustworthy estimate, and identified that Traffic Signs layer could be used, filtering to Speed Limit signs. The project team determined that the level of effort to ensure correct attribution of speed limits, as a proxy for vehicle speed, using points along roadways was not a worthwhile investment of time considering the SME team's assessment.

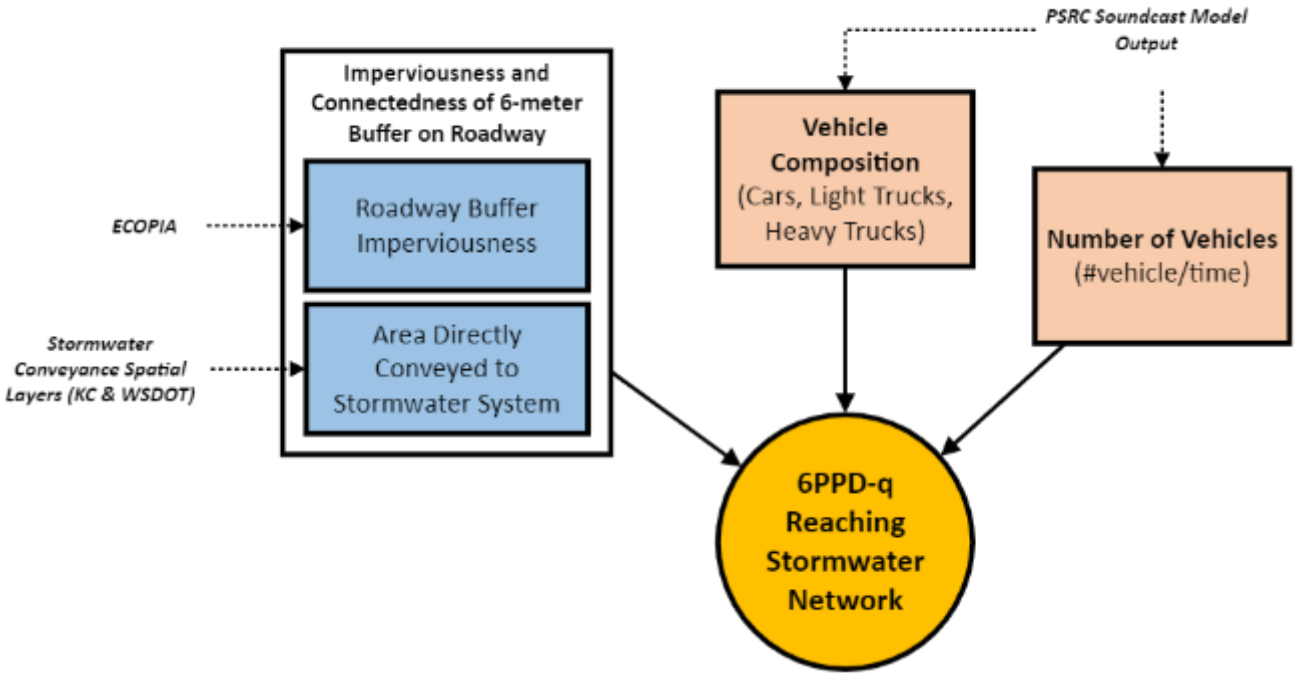
Table B-1. Spatial Sources, Attributes, and Evaluation Summary						
6PPDQ Conceptual Model Element	**Layer Attribute**	**Importance for Screening Model**	**Data Type**	**Data Source**	**Data Processing Approach**	**Notes**
--	**Segment ID**	**Required**	ID	KCGIS st_address	Generated unique ID	
--	**TNET Road ID**	**Required**	ID	TNET	Spatial Join with TNET	
--	**Jurisdiction**	**Required**	Categorical	TNET	None (or may need to spatially join if not in TNET)	TNET file only indicates the jurisdiction it is within, not who is the owner. The owner is the same nearly of the time as jurisdiction, except for WSDOT. There is a very, very small population of road segments jointly owned by KC and various Cities.
Number of vehicles	**Average Daily Traffic**	**HIGH**	Numeric	PSRC SoundCast Model	Has modeled data for most roadways, but no minor residential roads. Could assume these are all minor inputs but highlight stream proximity (which would be a separate effort). Or extrapolate to TAZ (transportation analysis zone) and apply to unmatched roadways.	These are modeled data and expected to provide appropriate traffic orders of magnitude estimates for total traffic and freight traffic.
				King County Counts	Merge count and location by ID extrapolate from point to segment between major intersections	Count data is broken up by direction of traffic: https://gismaps.kingcounty.gov/trafficcounts/counts.aspx This would require development of a spatial model to assign traffic to individual roadways. The traffic counts are biased toward busier roads. The SpET recommended using the PSRC SoundCast model since the developers had already puzzled through the intricacies of developing a traffic model that will be more robust than could be built under the Screening Model's scope and budget.
				WSDOT Counts	As above	As above
Road Drainage	**Curbed**	**Moderate**	Numeric (length of curb along road segment)	KCGIS Curb_line	Intersection of buffer (from edge of road area buffer) and curb_line	
	Guttered	**Moderate**	Numeric (length of gutter along road segment)	KCGIS Gutter_line	Intersection of buffer (from edge of road area buffer) and gutter_line	
	Roadway skirt Imperviousness	**Required**	Numeric (0 to 100%)	KCGIS Ecopia	6-m buffer from edge of road area buffer to produce road skirt; extract impervious-type road classes and calculate percent cover within road skirt.	Determining road edge: Could use "sidewalk" and/or "shoulder" polylines for King County roadways; would need to assume a width. Rely on Ecopia "street" landcover classification
	Roadway Conveyance System	**High**	Categorical (Piped, Ditched, None, Swale)	King County Stormwater Services Conveyances	Generate combo layer from 2 King County sources (open, closed)	
				WSDOT Conveyances	Generate combo layer from 2 WSDOT sources (pipes, culverts)	
				Other Jurisdiction Conveyances	Evaluate feasibility of compiling stormwater conveyance data from municipal jurisdictions in the King County geographic area.	Herrera has quality datasets for City of Seattle on hand.
Vehicle Composition	**# Buses Per Day**	**Moderate**	Numeric	King County Metro Routes	Join with st_address or road surface extent polygon	
				Route Frequency	Join by Bus Route ID	Not found on GIS, likely could grab from a bus schedule but would require time to digitize and/or develop lookup tables
	Freight Use	**High**	Numeric	PSRC SoundCast Model	See PSRC row above	See PSRC row above

Table B-1 (continued). Spatial Sources, Attributes, and Evaluation Summary						
6PPDQ Conceptual Model Element	**Layer Attribute**	**Importance for Screening Model**	**Data Type**	**Data Source**	**Data Processing Approach**	**Notes**
Vehicle Behavior (congestion, starting/stopping, speed, cornering)	**StopSign**	**Low**	Binary	KCGIS Traffic Signs/sign point	Within ***100 ft*** up-street of stop sign	
	StopLight	**Low**	Binary	KCGIS Signal point	Within ***100 ft*** up-street of stop light	
	Yield (merging/ traffic circles)	**Low**	Binary	KCGIS Traffic Signs/sign point	Within ***100 ft*** up-street of yield	
	Sinuousity	**Low**	Numeric	from TNET roadway	https://gis.stackexchange.com/questions/202439/calculating-sinuosity-of-each-road-segment	
	Grade	**Low**	Numeric	Road_gradient_line (KC)	Intersection/Spatial Join—or join by ID from TNET	
				WSDOT		Not known if WSDOT roads contain slope/grade attribute
	Speed Limit	**Low**	Numeric	KCGIS Traffic Signs/sign point	Intersect with road buffer apply between stop signs.	
			Numeric	TNET/Speed Limit		Roads staff cautioned that the TNET speed limit valuers are often inaccurate.
Roadway Material	**Material**	**Low**	Categorical	Roadlog_SurfaceType_line (KC)	Intersection/Spatial Join - or join by ID from TNET	
Proximity to water body within drainage catchment	**Dist_Water**	**NA**	Numeric	KCGIS Wtrbdy and wtrcrs	Near	Developed tool to automate; had to export lines for each catchment and merge/append all back to same dataset after running "near" (otherwise, "near" tool overwrites other outputs)

Model Simplification

Herrera simplified the conceptual model (Figure B-1) based on input from the SMEs on the most important primary factors driving delivery of TWPs and 6PPDQ, and available spatial data (Table B-2). Based on SME input and literature review, the foremost factors in determining the total amount of tire wear occurring on a roadway segment (a distinct unit of roadway, represented spatially as a line segment between intersections or at other common breakpoints) are the total number of vehicles using the roadway and the composition of those vehicles (i.e., the weight and number of tires per vehicle). After tire wear occurs, the total export to the stormwater conveyance network is determined by where those TWPs are ultimately deposited and the connectedness of that roadway segment and its adjacent buffer. TWPs deposited on pervious surfaces will run off at a lower rate than those deposited on impervious surfaces. Further, 6PPD has a strong tendency to adsorb on organic matter in soils and sediments, and 6PPDQ degradation occurs more rapidly in biologically active and aerobic soils. The presence of a conveyance network is critical for determining how much roadway and skirt runoff will ultimately be conveyed from the roadway. Runoff from roadways without stormwater conveyance is generally expected to have minor export and higher rates of TWP/6PPD retention and 6PPD/6PPDQ degradation.

Figure B-2. Simplified Conceptual Model for Screening Model.



This model does not include stormwater treatment devices, such as retention ponds and bioswales, that are located along roadways. Those devices may provide enhanced treatment. Those larger facilities may be represented by "road buffer imperviousness," but in-line treatment devices are not represented. Those devices, in a sense, are the endpoint of the simplified model because they are the entry-point of the stormwater network.

Herrera chose to use the Ecopia layer as the spatial layer to represent imperviousness because it had high-definition imperviousness coverage and provided identification of specific types of impervious surfaces (e.g., roads, sidewalks, bridges), which allowed us to spatially define the roadway surface extent as a 2-dimensional polygon. Alternative impervious land cover datasets that were considered include the 2021–2022 Washington statewide Ecopia dataset and the 2015 Impervious and Impacted Surface for Western King County Washington dataset.

The PSRC SoundCast model is an activity-based model system that represents the travel behavior of each individual and household throughout King, Kitsap, Pierce, and Snohomish counties. The SoundCast model depicts travel behaviors that depend on the built environment and demand from other users. SoundCast outputs transportation network measures, such as highway volumes in one-hour periods in a future year or number of boardings on a transit line. It also outputs measures related to people, like average distance to work by home county or the number of transit trips different types of people will take. The truck model defines a truck based on relative weight classes and separates medium and heavy trucks for analysis purposes. Trucks are defined to match the definitions WSDOT uses to collect truck counts. These definitions rely primarily on weight, but for other purposes these categories are also loosely correlated to other defining characteristics of trucks. The following general categories of trucks are used:

- Medium trucks are defined as single unit, six or more tires, two to four axles and 16,000 to 52,000 pounds. gross vehicle weight.
- Heavy trucks are defined as double or triple unit, combinations, five or more axles, and greater than 52,000 pounds. gross vehicle weight.

In these definitions, the medium trucks are directly correlated to single-unit trucks collected in the WSDOT truck counts, and heavy trucks are directly correlated to double- and triple-unit trucks in the counts. Commercial vehicle trips (Light Trucks) are not included in the truck model, because they are captured, at least in part, by Daysim (the Activity Based Model engine in SoundCast).

Review of Initial Screening Model

Participants and Dates

Subject Matter Experts (SMEs):

- Kathy Peter, Ph.D., Aquatic Chemist, Research Scientist, University of Washington
- Jenifer McIntyre, Ph.D., Aquatic Toxicologist, Washington State University
- Rhea Smith, Aquatic Toxicologist, Washington State Department of Ecology
- Stephen Conroy, Ph.D., Environmental, King County Road Services Division
- Jennifer Lanksbury, Ecotoxicologist, King County Water and Land Resources Division
- Jenée Colton, Supervisor, King County Water and Land Resources Division
- Kelly Moran, Ph.D., Senior Scientist, San Francisco Estuary Institute

Spatial Expert Team (SpET):

- James (JJ) Bach, Roads Spatial Data Expert, King County Road Services Division
- Jeff Burkey, Hydrologist, King County Science and Technical Support
- Jennifer Schmidt, Geospatial Science Associate Practice Director, Herrera Environmental Consultants
- Stephen Conroy, Ph.D., Environmental Scientist, King County Road Services Division

King County Internal Review Team (IRT):

- Carly Greyell, Project Manager, King County Water and Land Resources Division
- Todd Hunsdorfer, Stormwater Program Manager, King County Water and Land Resources Division
- Jennifer Lanksbury, Ecotoxicologist, King County Water and Land Resources Division (also SME)
- Jenée Colton, Supervisor, King County Water and Land Resources Division (also SME)
- Jeff Burkey, Hydrologist, King County Science and Technical Support (also on SpET)

Facilitator:

- Timothy Clark, Senior Scientist, Herrera Environmental Consultants

Meeting Dates:

- March 18, 2024 (SMEs only)

Elicitation Summary

Prior to the March 18 meeting, Timothy Clark sent an email to the SMEs, SpET, and IRT with the draft QAPP, draft technical memorandum, and the following instructions on March 1, 2024.

Hello everyone!
I'm excited to share our drafts of the 6PPD-q Screening Model and the Quality Assurance Project Plan (QAPP) with you. As you can see from the email TO list, this is a large group of reviewers, but each of you has a separate role which I will describe below.

What are these *draft* documents?

- Quality Assurance Project Plan | Screening Model for 6PPD q Delivery to the Stormwater Network
  - This QAPP provides the background on the project and what it's trying to achieve, measures of quality/success, and the methods for Screening Model development.
  - The QAPP includes a literature review of 6PPD-q fate and transport in the environment (at it relates to roadway runoff) and the Conceptual Model developed with subject matter experts. The process for developing the conceptual model is also described.
  - In the near future, the QAPP will include documentation on how the Screening Model will be integrated with a stormwater retrofit prioritization tool, which provides users the ability to consider multiple variables (cost, location, co-benefits, stream fish use) when making planning/retrofit-siting decisions. You will notice highlighted text or comments where sections are TBD. The team who will be leading that part of the project just got under contract with King County and have not yet had time to contribute to those sections.
  - Link: REMOVED
- Technical Memo | Pilot 6PPD-q Screening Model Documentation and Output
  - This memo presents the pared down Screening Model (simplified from the Conceptual Model), the spatial data inputs, and the scoring system used to assign roadway segments a point-value score for "delivery of 6PPD-q to the stormwater network."
  - The memo does not rehash the background content found in the QAPP. Its goal is to present the Screening Model.
  - Link: REMOVED

What am I supposed to do with them?

Great question! I will break down the role/expectation/guidelines for each team below. You may be on multiple teams!

- *Subject Matter Expert Team* (Kathy Peter, Jen McIntyre, Rhea Smith, Stephen Conroy, Jen Lanksbury, Jenee Colton, Kelly Moran)
  - To date, you have provided input at virtual meetings and via email and have been pivotal in the development of this working model.
  - *Your primary role is to review the Technical Memo, specifically the scoring approach.* You do not need to track changes or make comments in the document, rather you are asked to respond to the questions below in preparation for our meeting on March 18:
    - What is your evaluation of the Screening Model scoring system? Do you believe it appropriately characterizes the generation, deposition, and transport of tire wear particles and 6PPD-q from roadways to the stormwater network (as a planning-level tool)?

        - Keeping in mind that the model endpoint is the stormwater conveyance network (not downstream surface waters), are there any critical missing variables in the model? (e.g., congestions, cornering, curbs)
    - **Schedule**: We have a meeting scheduled on **March 18 t**o discuss the Screening Model. Please review the Screening Model and prepare responses to the above questions before that meeting (along with any other comments, questions, concerns you may have). At the March 18 meeting, I will briefly review the screening model and then facilitate a discussion. If you are able to provide your comments/responses to me prior to that meeting, it would be appreciated but not expected.
    - The QAPP is available to you as a reference because it provides more background to the project and process, but if there are specific questions that come up for you that are not covered in the TM, please make note of that and you can contact me directly. I want to value your time and not send you digging through a maze of documents.
- *Spatial Expert Team* **(JJ Bach, Jeff Burkey, Jenn Schmidt, Stephen Conroy)**
    - Please review the Tech Memo, specifically the descriptions/characterization of the input spatial layers and the described spatial analysis process. Please consider the following questions:
        - The harmonization of the disparate datasets was challenging. Do you believe our approach adequately reconciled the misalignment of features? And that the uncertainty and need for desktop verification for scores is clear. Do you have suggestions for how to clean up misalignment? (primarily found at intersections/overpasses/tunnels).
    - The QAPP is available to you as a reference because it provides more background to the project and process, but if there are specific questions that come up for you that are not covered in the TM, please make note of that and you can contact me directly. I want to value your time and not send you digging through a maze of documents.
    - *You are requested to review the Tech Memo and track edits/comments.*
    - **Schedule**: Your comments/tracked edits in the Tech Memo are expected by **March 22**.
- *King County Internal Review Team (***Todd Hunsdorfer, Jeff Burkey, Carly Greyell, Jenee Colton, Jen Lanksbury)**
    - You have previously reviewed the QAPP and we have addressed those comments. However, there have been substantive changes to modeling approach sections of the document. This reflects the decision to switch from a Bayesian network to a more approachable single equation. This change reflects the subject matter experts' input that only a few input variables may appropriately be used for this high-level screening process: traffic intensity, traffic composition/weight, roadway skirt imperviousness, and conveyance network. Given the short list of variables and available datasets, development of Bayesian network was determined to be unnecessary. These major edits occurred within Chapter 6.
    - *You are responsible for reviewing both documents and tracking edits/comments.*
    - **Schedule**: Your comments/tracked edits are expected by **March 22**.

Thank you for your time and consideration. Please let me know if you have any questions/issues accessing the document links above.

The March 18 SME meeting was attended by Stephen Conroy, Carly Greyell, Jennifer Lanksbury, and Rhea Smith. Additionally, Chelsea Mitchell and Carly Greyell (King County) and Tatiana Dreisbach and Chris Gustafson (WSDOT) attended to listen in on the discussion. Kathy Peter, Jenifer McIntyre, and Jenee

Colton were not able to attend. Jenee Colton provided feedback via written comment on the draft technical memorandum and email.

The following changes to the Screening Model were recommended:

- Do not use the Kole et al. (2017) estimates for tire wear. Most tire wear rate literature values are not reliable. Mennekes and Nowack (2022) provide thorough documentation of this, as does Moran et al. (2023). The project team was recommended to use the Moran et al. (2023) data, and to extend the method to consider vehicle weight.
- Do not double-count imperviousness. The original *Deposition* equation included imperviousness as a location of deposition. The SMEs recommended dropping it there and retaining it only in the *connectedness* equation. This was to avoid overly weighting the imperviousness.
- Evaluate if the *connectedness* associated with ditches is equivalent to pipes or if a correction factor should be employed.
- Reconsider inclusion of vehicle behavior. Some SMEs suggested that vehicle behaviors (e.g., stopping, slowing, accelerating, turning) would impact the tire wear rate. However, other SMEs suggested field data is currently too limited to vary the magnitude of that influence, and so it should not be included at this time.
- Consider including type of pavement. Pavement type may impact tire wear rate, and some pavement types (rubberized asphalts) may be a source of 6PPD/6PPD-q. SMEs acknowledged this this may be a factor but did not think it was a primary driver/source of tire wear/6PPD-q.
- Consider adding parking lots as a source. While likely an important contributor of tire wear, parking lots were beyond the scope of the roadway-focused model.
- Consider including roadway elevation. Overpasses and bridges may dust the roads beneath them, and uphill roads may contribute to downstream locations due to partial wash off. While this is not captured in the model, this may be considered when siting and designing roadside treatment systems.

Generally, the SMEs were supportive of the Screening Model and scoring approach and appreciated its simplicity and adaptability.

Appendix C

Stormwater Conveyance Layer Inventory

Table C-1. Stormwater Conveyance Data Sources.		
Stormwater Jurisdiction	**Stormwater Conveyance Layers Used**	**Recency**
King County	Conv_Closed Ctrl_Filter_Strip Open_Ditch Open_Trench_Drain_and_Interceptor_Trench_Gutter Ctrl_Other_Line Ctrl_Tank Water_Quality_Swale Ctrl_Pond_and_Vault Ctrl_ProprietaryDevice_Vault_InfiltrationSys Proxy_Flow	2022–2024
WSDOT	Ditch LinearDrain ArtificialPath Pipes StormwaterPondPoly	2023–2024
Algona	DITCH STORMLINES DETENTION	2023
Auburn	StormChannels StormCulverts StormPipes StormDetentionSites	2023
Beaux Arts Village	StormMains	2023
Bellevue	Storm_Casings Storm_Culverts Storm_Gravity_Mains Storm_Gravity_Mains_Abandoned Storm_Lateral_Line Storm_Lateral_Repair Storm_Open_Drains	2020
Black Diamond	Storm_Pressure_Mains StormPipes RainGarden	2023
Bothell	dCulverts dPipes dBioSwales dDitches dTrenches dPhantomLines dBioretention dDetentionPonds dVaults	2023

Table C-1 (continued). Stormwater Conveyance Data Sources.		
Stormwater Jurisdiction	**Stormwater Conveyance Layers Used**	**Recency**
Burien	SWM_Conveyance	2023
Carnation	--	--
Clyde Hill	Storm_Pipes_2014_CH	2023
Covington	SWM_StrmLine	2023
Des Moines	swOpenDrainline swGravityMain swDetention	2023
Duvall	CoD_Storm_Pipe_Editing	2023
Enumclaw	coe_stormPipeLim coe_stormCulvertLim	2023
Federal Way	STRMPIPE STRMLINE STRMPOLY	2023
Hunts Point	Conveyance_full	2023
Issaquah	Stormwater Pipes sdOpen Drain (Ditch)	2021
Kenmore	StreamCulvert OpenConveyance EnclosedConveyance Vaults Tanks PreTreatment Ponds Infiltration Drywell Filtration DispersionBMP Biofiltration	2023
Kent	stmTrenches stmPipes stmTanks stmOpenConvey stmBioswales stmCulverts stmVaults stmPonds stmMultiPipeSystems stmPermeablePvmt	2023
Kirkland	SW_Channel SW_Main	2023

Table C-1 (continued). Stormwater Conveyance Data Sources.		
Stormwater Jurisdiction	**Stormwater Conveyance Layers Used**	**Recency**
Lake Forest Park	Ditches Pipes	2023
Maple Valley	SWM_Open_Channel SWM_Force_Main SWM_Pipes Infiltration_Area Infiltration_Gallery Pond SWM_Detention_Vault SWM_Filtration_Vault SWM_Infiltration_Vault	2023
Medina	--	--
Mercer Island	sdGravityMain sdLateralLine sdVirtualLines	2023
Milton	StormChannel StormCulvert StormPipe	2023
Newcastle	swGravityMain WQ_Detention Open_Drains GSI	2023
Normandy Park	bioswale culverts detention ditches pipes retention vaults	2023
North Bend	SD_Flowline SD_Infiltration SD_Pond SD_Masterpipe_1	2023
Pacific	Storm	2023
Redmond	Pond swBioswale swCulvert swInfiltrationTrench swPipe swVault	2023

Table C-1 (continued). Stormwater Conveyance Data Sources.		
Stormwater Jurisdiction	**Stormwater Conveyance Layers Used**	**Recency**
Renton	Culvert GravityMains Pipe OpenDrain PressurizedMains PrivateCulvert PrivateOpenDrain PrivatePipe StormwaterPonds VirtualDrainline LateralLine LateralLines	2023
Sammamish	Channels Pipes Ponds Vaults	2023
SeaTac	StormwaterLines	2023
Seattle	StormwaterDrainageOpenChannels (Port of Seattle) StormwaterDrainageLines (Port of Seattle) StormwaterStormwaterPolygons (Port of Seattle) SPU_DWW_Mainlines (Seattle Public Utilities; SPU) SPU_Owned_nonMainlines (SPU) SPU_DWW_Swales (SPU) DWW_Ditches_and_Culverts (SPU) DWW_Surface_Drainage_Curb_and_Gutter (SPU)	2023–2024
Shoreline	swCulvert swDitch swDrain swFilterStrip swInfiltration swMediaFilterDrain swPermeablePavement swPipe swPond swRainGarden swSwale swVault	2023
Skykomish	--	--

Table C-1 (continued). Stormwater Conveyance Data Sources.		
Stormwater Jurisdiction	**Stormwater Conveyance Layers Used**	**Recency**
Snoqualmie	swGravityMain swLateralLine swDitchesSwales swBioswales swStormPonds	2023
Tukwila	Storm_Pipe Storm_Ditch Storm_Detention_Water_Quality_Structure	2023
Woodinville	sw_pipe sw_open_channel sw_facility	2023
Yarrow Point	--	--