VELMA model green infrastructure applications for reducing 6PPD-quinone concentrations in Puget Sound urban streams

Jonathan Halama[2], Robert McKane[1], Sonali Chokshi[1], Allen Brookes[1], Kevin Djang[3]

[1] U.S. Environmental Protection Agency, Center for Public Health and Environmental Assessment, Pacific Ecological Systems Division, Corvallis, OR, USA
[2] Spatial Synergy Solutions, Independence, OR, USA
[3] Inoventures LLC, c/o U.S. Environmental Protection Agency, Corvallis, OR, USA
[4] University of Washington Tacoma, Center for Urban Waters, WA, USA
[5] Northeastern University College of Science, Boston, MA, USA

Presentation: Stormwater Work Group - 6PPD Subgroup Meeting, June 12, 2024

We gratefully acknowledge financial support provided by U.S. EPA Region 10 and EPA-ORD's Safe and Sustainable Water Resources Research Program.

Disclaimer: The views expressed here are those of the author[s] and do not necessarily represent the views or policies of the U.S. EPA.

US EPA Office of Research and Development
Center for Public Health and Environmental Assessment, Pacific Ecological Systems Division, Corvallis, OR

What's killing the coho?

A decades-long mystery solved

The Seattle Times

Stormwater pollution in Puget Sound streams killing coho before they can spawn

October 18, 2017

1 of 2 | *Coho salmon, including females full of eggs, are dying before they can spawn in Puget Sound streams polluted with stormwater runoff. (NOAA Fisheries)*

Science Tian et al. 2021 REPORTS

Cite as: Z. Tian *et al.*, *Science* 10.1126/science.abd6951 (2020).

6PPD-quinone

A ubiquitous tire rubber–derived chemical induces acute mortality in coho salmon

Zhenyu Tian[1,2], Haoqi Zhao[3], Katherine T. Peter[1,2], Melissa Gonzalez[1,2], Jill Wetzel[4], Christopher Wu[1,2], Ximin Hu[3], Jasmine Prat[4], Emma Mudrock[4], Rachel Hettinger[1,2], Allan E. Cortina[1,2], Rajshree Ghosh Biswas[5], Flávio Vinicius Crizóstomo Kock[5], Ronald Soong[6], Amy Jenne[5], Bowen Du[6], Fan Hou[3], Huan He[3], Rachel Lundeen[1,2], Alicia Gilbreath[7], Rebecca Sutton[7], Nathaniel L. Scholz[8], Jay W. Davis[9], Michael C. Dodd[3], Andre Simpson[5], Jenifer K. McIntyre[4], Edward P. Kolodziej[1,2,3*]

PLOS WATER

RESEARCH ARTICLE

Improved urban runoff prediction using high-resolution land-use, imperviousness, and stormwater infrastructure data applied to a process-based ecohydrological model

Jonathan Halama[1]*, Robert McKane[1], Bradley Barnhart[2], Paul Pettus[1], Allen Brookes[1], Kevin Djang[3], Vivian Phan[1], Sonali Chokshi[1], James Graham[4]

1 U.S. Environmental Protection Agency, Corvallis, OR, United States of America, **2** NCASI, Corvallis, OR, United States of America, **3** Inoventures Inc., Corvallis, OR, United States of America, **4** Cal Poly Humboldt, Arcata, CA, United States of America

* Halama.Jonathan@EPA.gov

OPEN ACCESS

Citation: Halama J, McKane R, Barnhart B, Pettus P, Brookes A, Djang K, et al. (2023) Improved urban runoff prediction using high-resolution land-use, imperviousness, and stormwater infrastructure data applied to a process-based ecohydrological model. PLOS Water 2(11): e0000155. https://doi.org/10.1371/journal.pwat.0000155

Editor: Abolghasem Akbari, Khavaran Institute of Higher Education, IRAN, ISLAMIC REPUBLIC OF

Received: February 16, 2023

Accepted: October 12, 2023

Published: November 20, 2023

Abstract

Modeling large-scale hydrological impacts brought about by site-level green and gray stormwater remediation actions is difficult because urbanized areas are extremely complex dynamic landscapes that include engineered features that, by design, expedite urban runoff to streams, creeks, and other water bodies to reduce urban flooding during storm events. Many urban communities use heavily engineered gray infrastructure to achieve that goal, along with more recent additions of green infrastructure such as rain gardens, bioswales, and riparian corridors. Therefore, successfully characterizing those design details and associated management practices, interactions, and impacts requires a detailed understanding of how fine and course-scale hydrologic processes and routing are altered and managed in urban watersheds. To enhance hydrologic modeling capabilities of urban watersheds, we implemented a number of improvements to an existing ecohydrology model called VELMA—Visualizing Ecosystem Land Management Assessments—including the addition of spatially explicit engineered features that impact urban hydrology (e.g., impervious surfaces, curbed roadways, stormwater routing) and refinement to the computational representations

frontiers | Frontiers in Environmental Science

TYPE Methods
PUBLISHED 06 March 2024
DOI 10.3389/fenvs.2024.1364673

OPEN ACCESS

EDITED BY
Rui Zhang,
University of Jinan, China

REVIEWED BY
Kathryn Hassell,
RMIT University, Australia
Qinghui Huang,
Tongji University, China

*CORRESPONDENCE
Jonathan J. Halama,
Halama.Jonathan@epa.gov

RECEIVED 02 January 2024
ACCEPTED 21 February 2024
PUBLISHED 06 March 2024

CITATION
Halama JJ, McKane RB, Barnhart BL, Pettus PP, Brookes AF, Adams AK, Gockel CK, Djang KS, Phan V, Chokshi SM, Graham JJ, Tian Z, Peter KT and Kolodziej EP (2024), Watershed analysis of urban stormwater contaminant 6PPD-Quinone hotspots and stream concentrations using a process-based ecohydrological model.
Front. Environ. Sci. 12:1364673.
doi: 10.3389/fenvs.2024.1364673

Watershed analysis of urban stormwater contaminant 6PPD-Quinone hotspots and stream concentrations using a process-based ecohydrological model

Jonathan J. Halama[1]*, Robert B. McKane[1], Bradley L. Barnhart[2], Paul P. Pettus[1], Allen F. Brookes[1], Angela K. Adams[3], Catherine K. Gockel[3], Kevin S. Djang[4], Vivian Phan[1], Sonali M. Chokshi[1], James J. Graham[5], Zhenyu Tian[6,7], Katherine T. Peter[7,8] and Edward P. Kolodziej[7,8,9]

[1]U.S. Environmental Protection Agency, Corvallis, OR, United States, [2]Independent Researcher, Middleton, WI, United States, [3]U.S. Environmental Protection Agency, Seattle, WA, United States, [4]Inoventures Inc, Corvallis, OR, United States, [5]Cal Poly Humboldt, Arcata, CA, United States, [6]Northeastern University, Boston, MA, United States, [7]Center for Urban Waters, Tacoma, WA, United States, [8]University of Washington Tacoma, Tacoma, WA, United States, [9]University of Washington, Seattle, WA, United States

EPA announces $12M to protect salmon by reducing toxic tire dust, other pollutants in stormwater

March 27, 2024

Contact Information
EPA Region 10 Public Affairs (r10_press_team@epa.gov)

SEATTLE - Today at an event in Tacoma with U.S. Representative Derek Kilmer, Regional Administrator Casey Sixkiller and other officials, U.S. Environmental Protection Agency Acting Assistant Administrator for Water Bruno Pigott announced $12 million in new Puget Sound stormwater funding to address pollution entering Puget Sound through the Stormwater Strategic Initiative.

The initiative, which is a partnership of Washington departments of Ecology and Commerce and the Washington Stormwater Center, will invest in efforts to reduce untreated stormwater runoff entering Puget Sound and impacting aquatic life including salmon, freshwater streams, and exacerbating nutrient pollution that can cause harmful algal blooms.

“The Biden-Harris Administration recognizes the unique significance of the Puget Sound and is committed to protecting treasured waters and vital species as part of our unprecedented investing in America agenda,” said Pigott. “Today’s $12 million announcement is a perfect example of how federal dollars, interdisciplinary partnerships, and innovation can ensure clean and fishable waters for generations to come.”

With today’s announcement, EPA has invested a total of $35 million to address toxics through the Stormwater Strategic Initiative. Previously, EPA funded the Puget Sound Regional Council’s stormwater parks planning project, which is laying the groundwork for new stormwater parks across the Puget Sound region. Kitsap County, King County, City of Bellevue and Futurewise GreenLink Port Angeles are also each receiving a $100,000 EPA stormwater park planning grant.

https://www.epa.gov/newsreleases/epa-announces-12m-protect-salmon-reducing-toxic-tire-dust-other-pollutants-stormwater

VELMA Ecohydrology Model

- **Estimate**: Contaminant Fate and Transport in Urban and Rural Watersheds: Organics, Nutrients, Metals
- **Inform**: Green Infrastructure Options for Reducing Toxic Chemicals in Stormwater
- **Support**: Clean Water Act, Endangered Species Act, National Pollutant Discharge Elimination System, H.R.4266-Clean Water Through Green Infrastructure Act

US EPA Office of Research and Development
Center for Public Health and Environmental Assessment, Pacific Ecological Systems Division

Bioswale
Longfellow Creek Watershed
West Seattle, WA

VELMA: Grid-based Urban Fate and Transport

Water & Chemical Transport

- Daily precipitation and runoff
- Surface layer perviousness (0-1)
- Stormwater System
  - Spatially-explicit roads, curbs, drains, pipes
  - Transfers: curb to drain to pipe to stream…
- Soil matrix (5-meter grid)
  - Vertical and lateral flow (see figure)
  - Contaminant & nutrient transport, decomposition, sorption, desorption, aqueous/solid phase mass balance

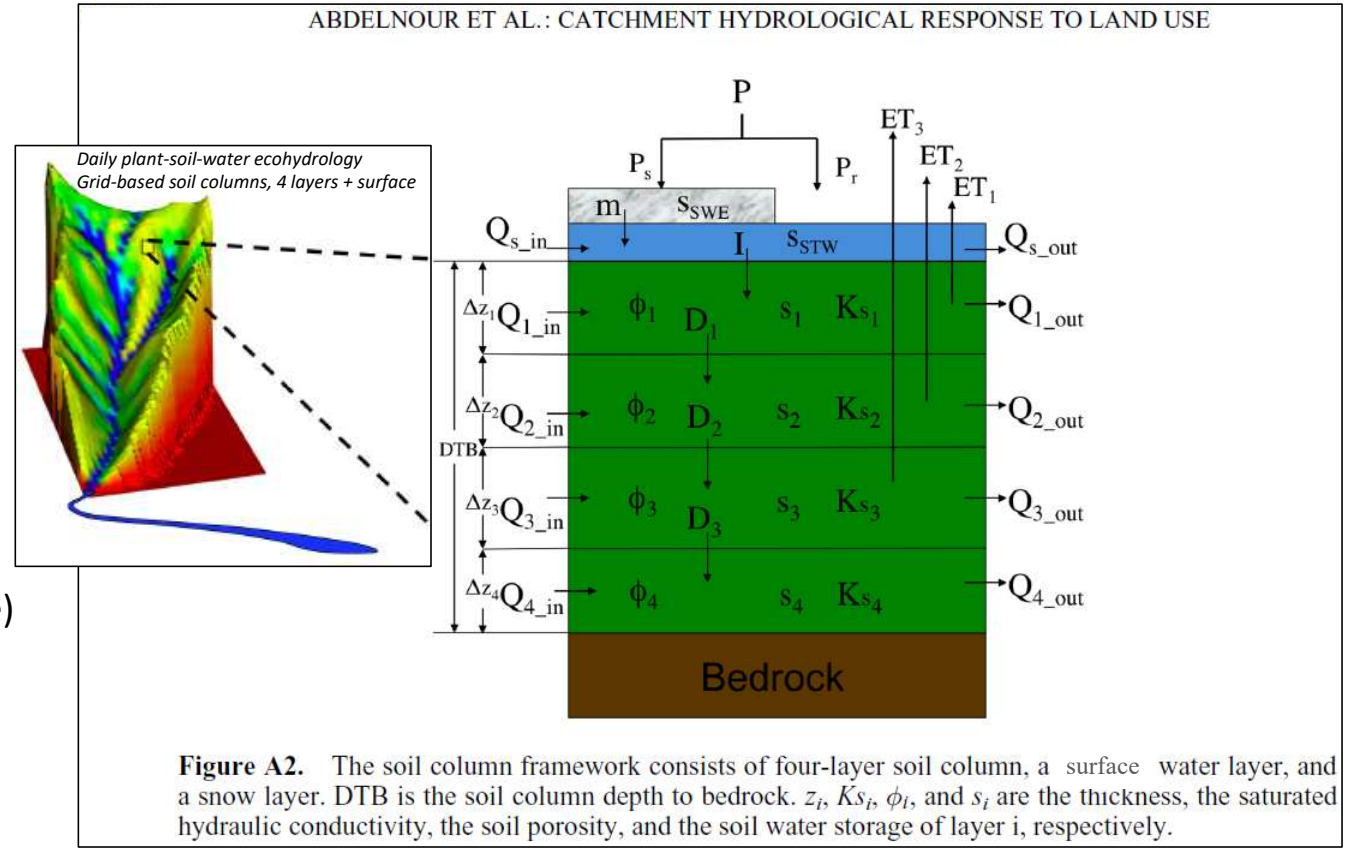
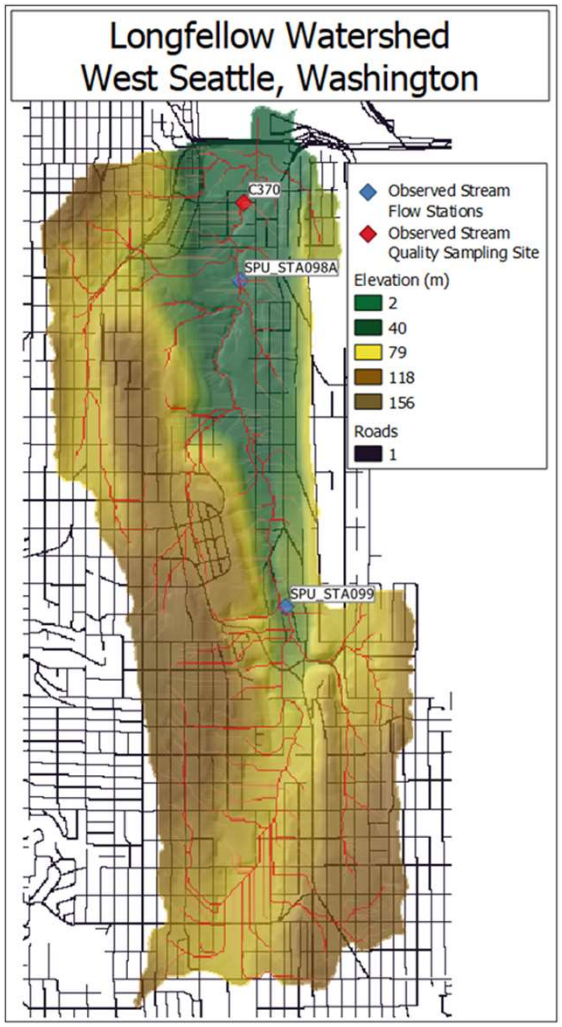
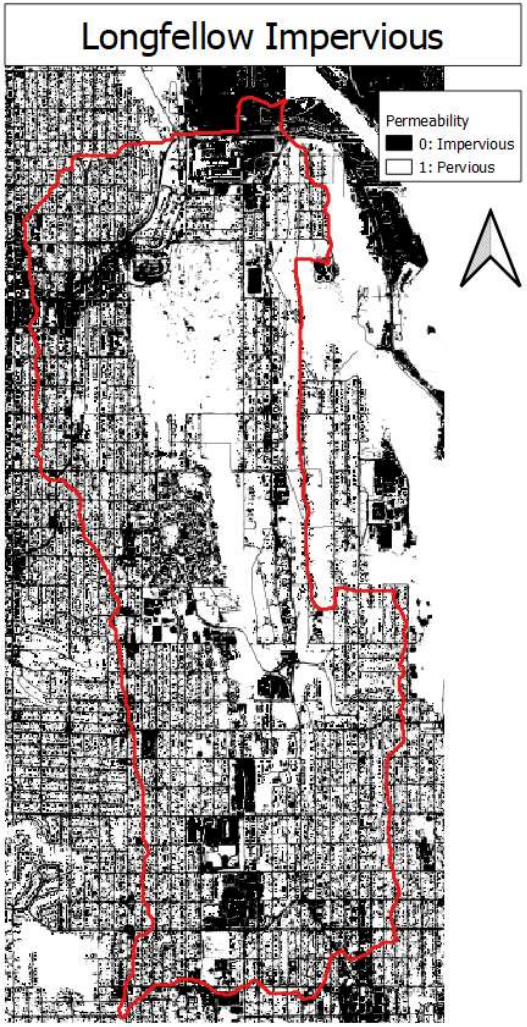
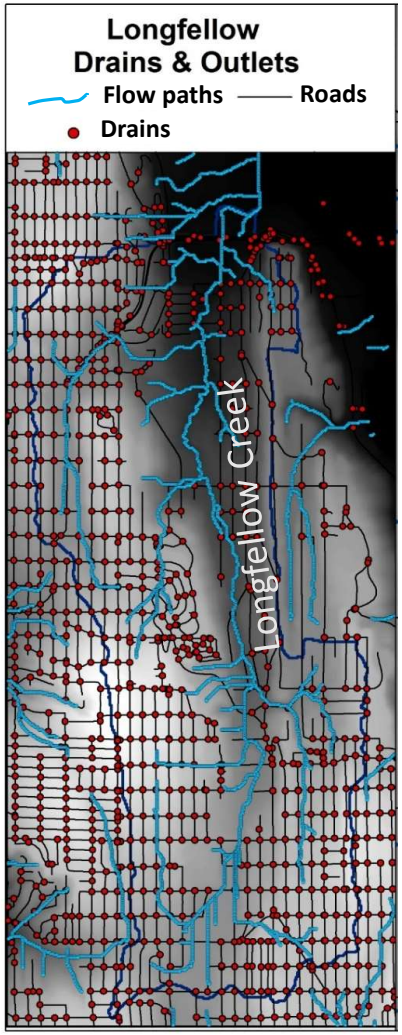


Figure A2. The soil column framework consists of four-layer soil column, a surface water layer, and a snow layer. DTB is the soil column depth to bedrock. z_i, Ks_i, ϕ_i, and s_i are the thickness, the saturated hydraulic conductivity, the soil porosity, and the soil water storage of layer i, respectively.

VELMA Urban Setup: Major Spatial Components







VELMA urban stormwater runoff performance tests

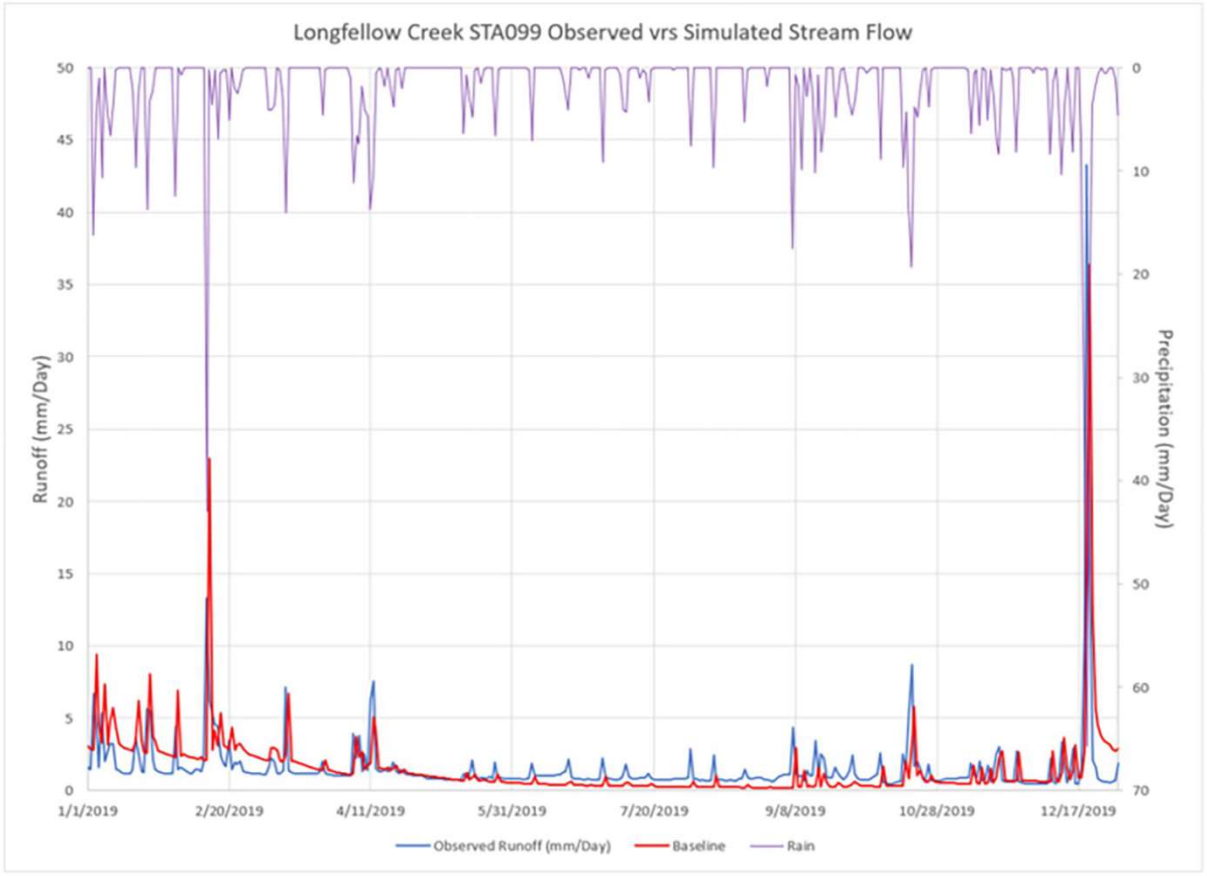
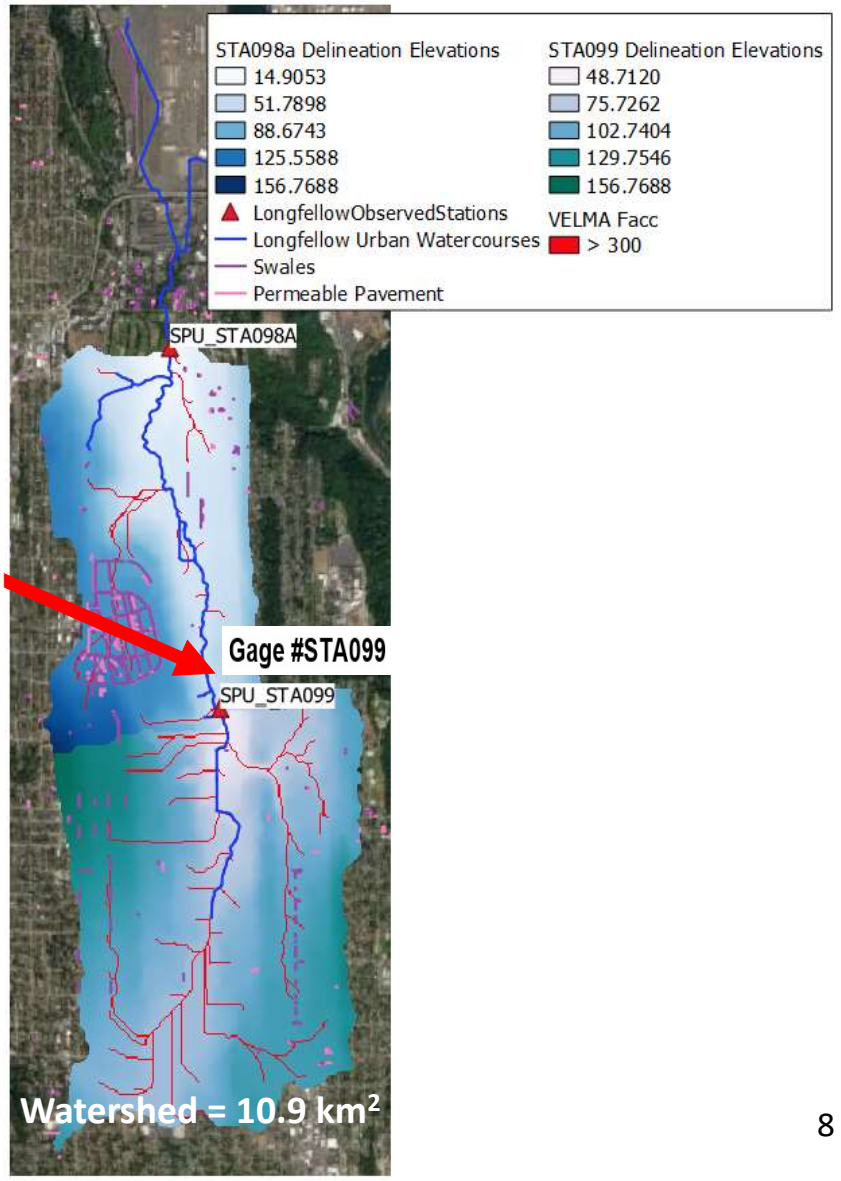


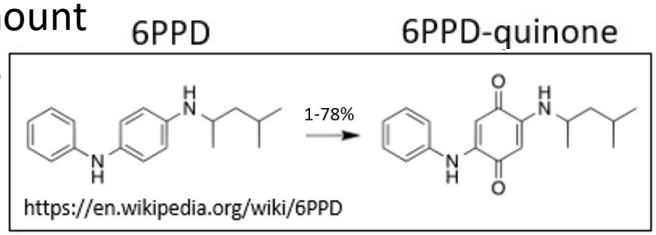
Fig 9. 2020 observed versus simulated stream runoff (mm/day, left y axis) at Longfellow Creek gauge station STA099. Precipitation events are displayed upside down (right y axis).



Halama et al., 2023.
Improved urban runoff prediction using high-resolution land-use, imperviousness, and stormwater infrastructure data applied to a process-based ecohydrological model.
PLOS Water, 2(11), p.e0000155.

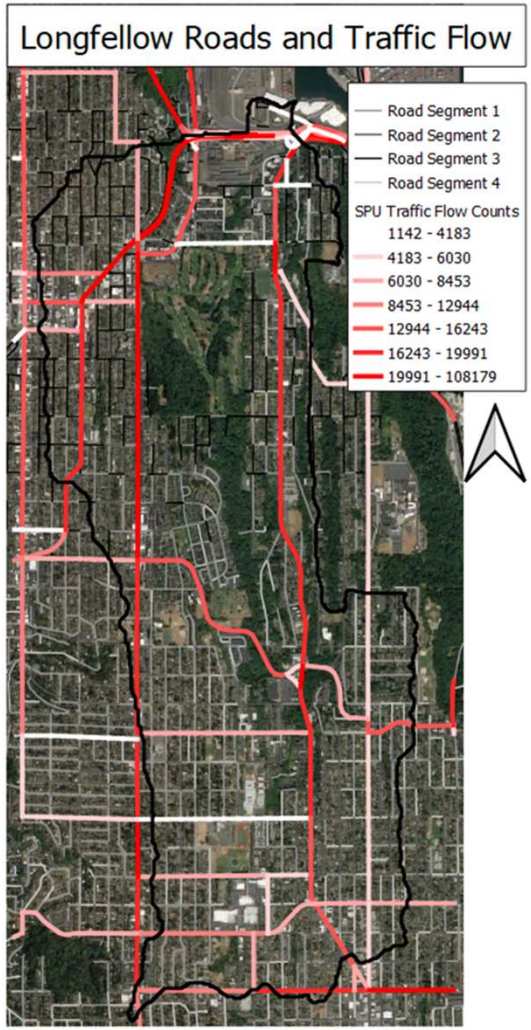
VELMA 6PPD calibration setup

- 6PPD deposition, degradation to 6PPD-quinone
  - 6PPD location, timing, amount
  - Fraction to 6PPD-quinone



- Parameters: 6PPD fate and transport

Group	Item	Parameter		
contaminant	RoadDepo_6PPD	setMolarSolubilityCoefficient	*	0.000158
contaminant	RoadDepo_6PPD	setChemMaxDecay	*	0.2207475
contaminant	RoadDepo_6PPD	logKocSlope		NA
contaminant	RoadDepo_6PPD	uniqueSequenceId		1
contaminant	RoadDepo_6PPD	uniqueId		1
contaminant	RoadDepo_6PPD	Koc	*	11000
contaminant	RoadDepo_6PPD	logKocIntercept		NA
contaminant	RoadDepo_6PPD	setMolarMass	*	268.404
contaminant	RoadDepo_6PPD	logKow	*	3.6
contaminant	RoadDepo_6PPD	setDecompositionFactorMode		NONE
contaminant	RoadDepo_6PPD	modelClass		OrganicContaminantModel
contaminant	RoadDepo_6PPD	uniqueName		RoadDepo_6PPD
contaminant	RoadDepo_6PPD	directKocSpecification		true



***From EPA CompTox Database https://comptox.epa.gov/dashboard**

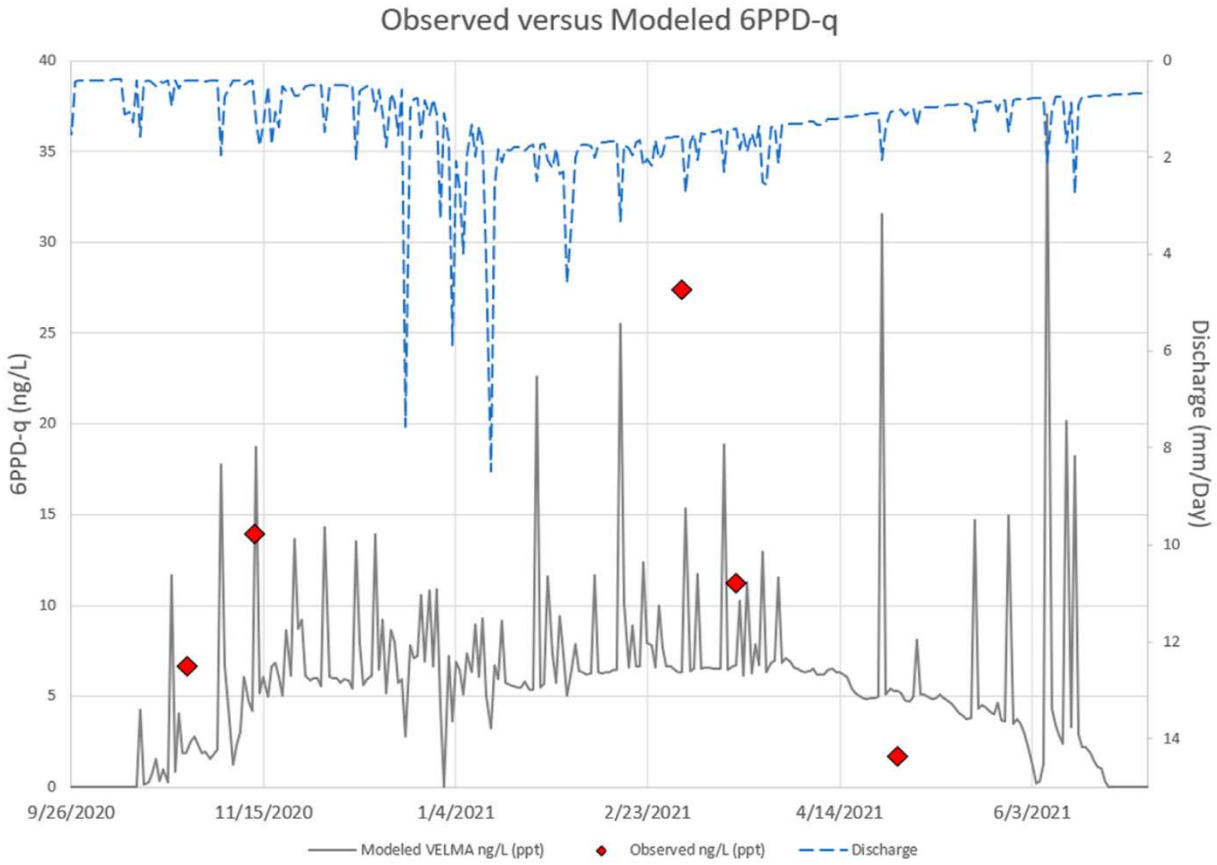
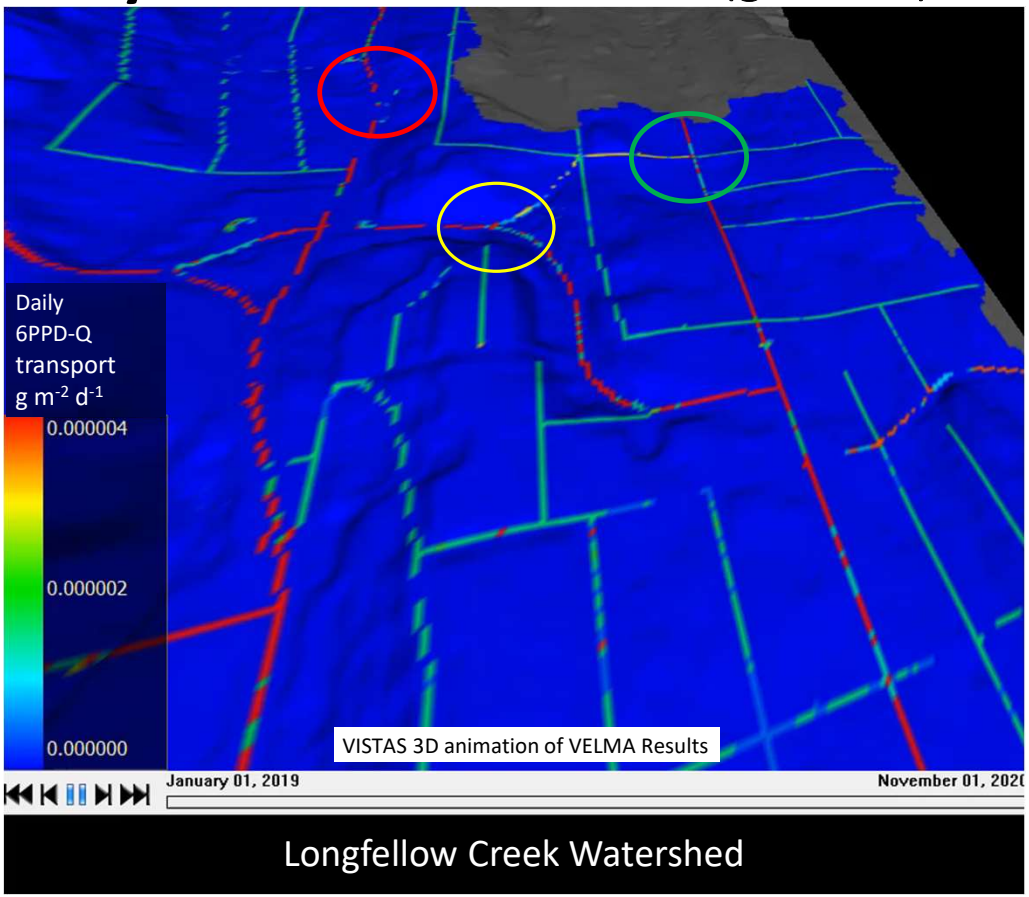


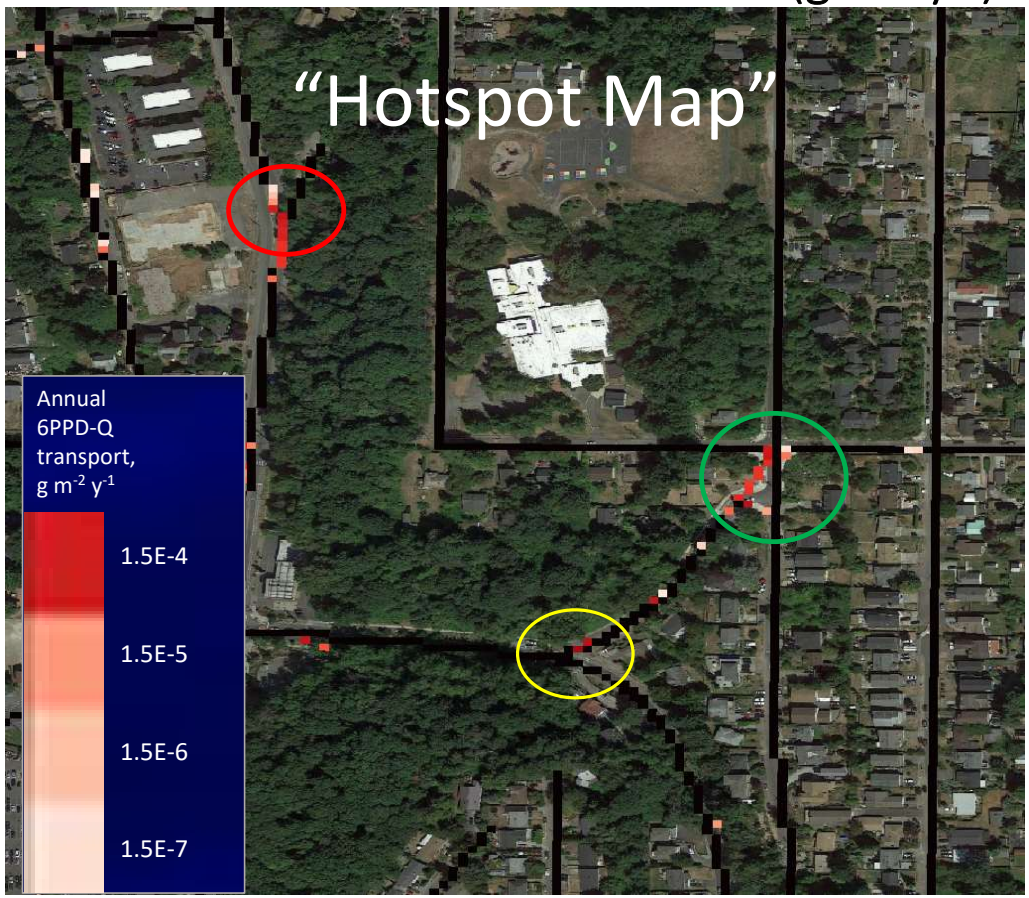
FIGURE 4
Observed grab samples *versus* simulated daily VELMA 6PPD-Q ng/L during 2020 and 2021 at the Longfellow Creek upper watershed pour point location in Figures 1, 3, plus observed 6PPD-Q values listed in Table 1.

Halama, J.J., et al. 2024.
Watershed analysis of urban stormwater contaminant 6PPD-Quinone hotspots and stream concentrations using a process-based ecohydrological model.
Frontiers in Environmental Science, *12*, p.1364673. https://doi.org/10.3389/fenvs.2024.1364673

Daily 6PPD-Q Surface Transfers (g m^{-2} d^{-1})

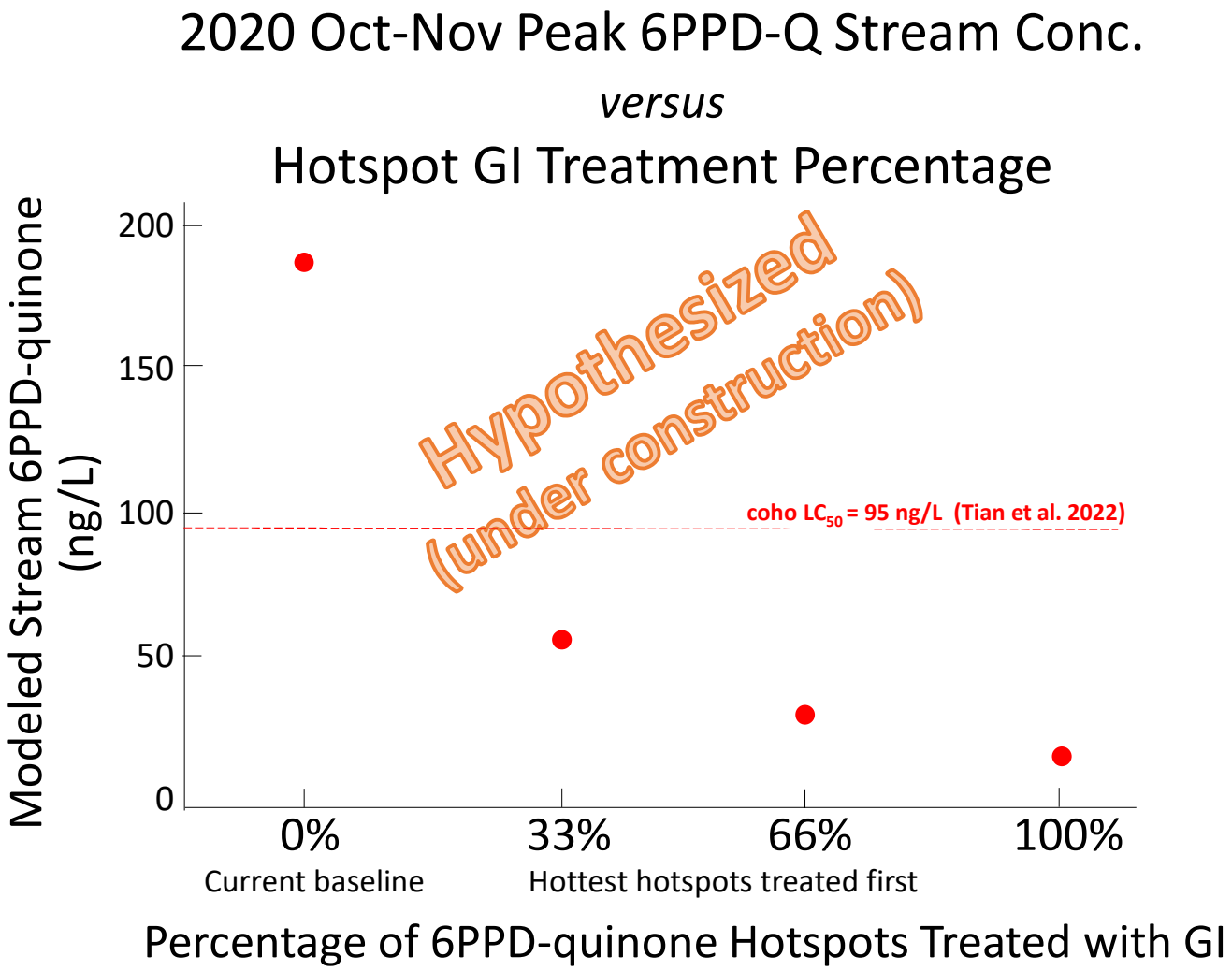


2020 Annual 6PPD-Q Surface Transfers (g m^{-2} y^{-1})



NOTE: 6PPD-Q Annual sums are ~100x larger than daily values

Simulated effects of hotspot GI treatments on stream 6PPD-quinone ng/L



Summary

- **Model performance:** Though modeled stream 6PPD-Q concentrations are consistent with limited available stream data, confident use of VELMA for informing GI best practices awaits more extensive performance tests.
- **New findings:** VELMA can identify 6PPD-Q hotspots at fine scales (5m) for prioritizing watershed-scale GI treatment placement, type, and amounts required to lower coho mortality.
- **Next steps:**
  - More testing in more urban watersheds: Miller, Thornton, Pipers, Taylor (high coho prespawn mortality in all).
  - Coordination & integration of data and modeling across multiple scales (plots → whole watershed).
  - Progress on these steps will continue to depend on collaboration of modelers with empirical researchers, community and tribal watershed mangers, and state and federal decision makers.
- **Important unanswered modeling questions/uncertainties:**
  - Spatial and temporal 6PPD deposition patterns?
  - 6PPD rates of conversion to 6PPD-Q?
  - 6PPD-Q half-life?
  - Optimal GI soil treatments to maximize contaminant retention and decay?

Project Collaborators – Thank you!

- EPA-ORD VELMA Team: Jonathan Halama (Spatial Synergy Solutions), Bob McKane, Vivian Phan, Allen Brookes, Kevin Djang (Inoventures)
- Other EPA-ORD: Paul Mayer, Brenda Rashleigh, Jim Markwiese, Matt Hopton, many others
- EPA Region 10: Angela Adams, Rob Elleman, Catherine Gockel, Mark Jankowski, Lisa Chang, Michael Rylko, Rochelle Labiosa, Peter Murchie
- University of WA Tacoma Center for Urban Waters: Ed Kolodziej, Kathy Peter, Zhenyu Tian (Northeastern University), Joel Baker, Tessa Francis, Tarang Khangaonkar (PNNL)
- State of WA: Karen Dinicola, Rhea Smith, Brandi Lubliner (Ecology), Scott Redman (PSP)
- King County: Matt Goehring et al.
- City of Seattle: Catherine Wendland et al.
- City of Burien: Dan O'Brien, Paige Morris
- SeaTac International Airport: Dan Smith
- Port of Seattle: Josh Feigin, Sarah Cox
- City of Normandy Park: Amanda Leon