Prioritizing stormwater pollutant risks: an annotated bibliography

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1 Introduction

In three steps, one can understand the entire 'theory of change[1]' for education and outreach (E&O) programs to protect receiving water quality. First, an E&O/behavior change program leads to an observable change in behavior of households or firms. Second, those household and business behavior changes reduce pollutant loading to streams, rivers, and estuaries. Third, those reduced pollutant loads improve water quality in the environment. These three steps are predicated on a methodology to infer where and what in a watershed to focus. The implementation of the Clean Water Act (1972) and its regulatory framework, the NPDES[2] program, included 303d listings of impaired water bodies and meeting the requirements of subsequent TMDL[3] formulations. Within Washington State, the NPDES Municipal Storwmater Permit applies to a jurisdiction's MS4[4] that discharge to state and federal water bodies. The requirement to meet the E&O portion of the Permit applies regardless of whether a water body has a 303d listing or an assigned TMDL.

An ACWA[5] report from 2018 (Berckes et al., 2019) on responses from state representatives implementing 303(d) / TMDL programs suggested that many states focused primarily on bacteria and nutrients - with bacteria considered as 'relatively *easy* work to accomplish based on established methods of calculation.' Another key finding from that report was that in some states, economic value was used to prioritize 303(d) programs, while human health was used as a priority metric in other states. The report notes that efforts to value clean water from the perspective of biota or an environmental justice lens were universally lacking.

This annotated bibliography provides an overview of stormwater pollutant prioritization by summarizing several critical studies from the last 15 years. The annotated bibliography is based on peer-reviewed studies that focus on the issues at a national level. However, we believe those studies' outcomes are relevant to Washington state jurisdictions. This document is not intended as a substitute for reading the studies summarised here or others. Instead, the intention is to create a road map of significant works that

[1] A theory of change is a methodology that informs the understanding and explaining of how change takes place and how specific interventions can lead to desired outcomes and goals.

[2] National Pollutant Discharge Elimination System

[3] Total Maximum Daily Load

[4] municipal separate stormwater systems or public stormwater system

[5] Association of Clean Water Administrators

have emerged in the last few decades. In addition, a short review section of some studies that outline the connection between environmental justice and prioritizing pollutants is presented as a second part of the annotated bibliography. This additional review section illustrates the need to ensure that under-resourced communities that have long borne the brunt of stormwater pollution must factor into any pollutant mitigation plan.

2 Prioritizing Pollutants

2.1 2007 - Prioritizing pollutant risk - a European framework

Eriksson, E., Baun, A., Scholes, L., Ledin, A., Ahlman, S., Revitt, M., Noutsopoulos, C., and Mikkelsen, P. S. (2007). Selected stormwater priority pollutants—a European perspective. *Science of the Total Environment*, 383(1-3):41–51

Eriksson et al. (2007) developed a framework to prioritize stormwater pollutants for a European 5^{th} Framework Project named DayWater. The goal of this framework was to inform a decision support system for developing stormwater source control measures to effect sustainable stormwater management. They used a version of the Chemical Hazard Identification and Assessment Tool (CHIAT), which outlines five steps to identify relevant priority pollutants. The five steps are:

1. Source characterization - over 650 organic compounds, 30 metals, and inorganic trace elements were identified

2. Recipient exposure targets and criteria identification - surface water was designated as the recipient, and aquatic organisms and humans (secondary) were identified as exposure targets.

3. Hazard identification - physicochemical properties of the identified pollutants and their environmental fate were categorized. A focus was placed on PAHs[6], pesticides, and XOCs[7].

4. Hazard assessment - this step was excluded per the authors' explanation that hazard assessment was not the focus of this work, but pollutant identification was.

[6] Polycyclic Aromatic Hydrocarbons
[7] Xenobiotic Organic Compounds

5. Stakeholder involvement - three stakeholder meetings were held, each building on outcomes of the previous meeting. The meetings identified specific pollutants, grouped and selected representative pollutants, and finally selected water quality analytes, including metals and organic compounds.

Ultimately, 25 priority pollutants were selected, including 6 water quality parameters (BOD[8], COD[9], SS[10], N[11], P[12], pH), 7 metals, 3 PAHs, 4 herbicides, and 5 miscellaneous organic compounds. Eriksson et al. (2007) state that their list of priority pollutants was intended for use as a framework for risk and hazard assessments, a basis for comparing stormwater BMPs[13], and to inform stormwater monitoring programs.

2.2 2012 - Prioritizing the risk posed by stormwater pollutant sources

Lundy, L., Ellis, J. B., and Revitt, D. M. (2012). Risk prioritisation of stormwater pollutant sources. *Water Research*, 46(20):6589–6600

The study by Lundy et al. (2012) sets up another framework for prioritizing pollutant risk - grouped by land use and land cover. They propose evaluating pollutant risk in terms of estimates of the likelihood of occurrence and the severity of its impact. They analyzed data from other studies on loading rates and sources of various pollutants, combined with matrices that assessed the degrees of likelihood of: A) occurrence in stormwater, and B) levels of consequence posed by that pollutant. This work from a decade ago identified road surfaces as the primary source of pollutants and likely a critical space for intervention in the urban ecosystem. They recognized the need for mitigation practices before road runoff enters roadside ditches or piped drainage networks. Of the four pollutants considered by Lundy et al. (2012) - TSS[14], BOD, cadmium, and lead - TSS was considered the pollutant that posed the most significant risk, followed by cadmium. BOD posed the lowest risk to downstream receiving waters. The paper concludes by recognizing the difficulties posed with removing TSS from roadway surfaces, suggesting

[8]biological oxygen demand
[9]chemical oxygen demand
[10]suspended sediments
[11]nitrogen
[12]phosphorous
[13]Best Management Practices
[14]total suspended sediments

the use of structural stormwater BMPs - such as infiltration trenches, infiltration basins, and sub-surface flow constructed wetlands - between the road surface and before discharge into receiving waters.

2.3 2016 - Prioritizing heavy metals risk

Ma, Y., Egodawatta, P., McGree, J., Liu, A., and Goonetilleke, A. (2016). Human health risk assessment of heavy metals in urban stormwater. *Science of the Total Environment*, 557:764–772

Ma et al. (2016) looked specifically at the risk that heavy metals in urban stormwater posed to human health. They developed a Hazard Index (HI) derived from traffic and land use metrics because traffic and land use were presumed to be the greatest sources of heavy metals in an urban landscape. The authors state that in 2016, there was no reliable methodology available to quantify the risk posed by heavy metals emanating from these two sources. The study involved vacuuming street and roof dust samples, conducting laboratory analyses of those samples, and assessing the risk to humans through three pathways (stormwater ingestion as drinking water, ingestion of stormwater while swimming, and dermal contact.) Using these methods, they developed a model for heavy metal build-up based on daily traffic volume and land use (as covariates), and a human health risk model based on a hazard index related to total heavy metals and fine solids heavy metals. In order of decreasing risk, they showed the following heavy metals posed risk to human health: $chromium > manganese > lead > aluminum > iron > cadmium > zinc > copper > nickel$. The authors showed that individual heavy metals do not pose as much risk as a mixture of multiple heavy metals, noting that even low concentrations of chromium, manganese, and lead[15] are extremely toxic so more importance should be paid to a hazard index as opposed to actual concentration values. They also showed that traffic volume was the most significant driver of health risks associated with heavy metals in stormwater.

2.4 2017 - Prioritizing toxic metals and PAH risk

Ma, Y., Liu, A., Egodawatta, P., McGree, J., and Goonetilleke, A. (2017). Assessment and management of human health risk from toxic metals and polycyclic aromatic hydrocarbons in urban stormwater arising from anthro-

[15] USEPA state that there is no safe level for lead exposure

pogenic activities and traffic congestion. *Science of the Total Environment*, 579:202–211

In another study by Ma et al. (2017), the build-up of 9 toxic metals (aluminum, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc) and 15 PAHs on road surfaces was evaluated similarly to their previous work (Ma et al., 2016). Once again, a risk model was developed using daily traffic volume statistics and land use covariates. They found that traffic volume and land use were not significant enough to explain hazard indices. Therefore, they developed another model that included traffic congestion and additional metrics of anthropogenic activity, such as motor vehicle-related businesses, retail, education, hospitality, catering, and commercial offices. It should be noted that high congestion leaves more time for cars to deposit pollutants. Their results showed that the highest risk levels to human health in terms of metals and PAHs were dependent on anthropogenic activities on residential and commercial areas - with motor vehicle related businesses from commercial and mixed commercial/residential areas posing the highest risk.

2.5 2018/2020 - Oregon pollutant toxicity ranking database

Danielsen, A. (2018). Oregon Pollutant Toxicity Ranking DatabaseA Tool for Supporting Risk Assessment of Oregon's Water Quality. mathesis, Portland State University, Portland, OR

As part of a master's thesis project, a toxics ranking database was developed by (Danielsen, 2018) to inform public education and outreach efforts in Oregon. The database was designed to help target specific behaviors that would lead to 'quantifiable change', specifically with regard to metals, pesticides, and consumer product chemicals. The database characterizes pollutant distribution, source, uses, transport, and fate. The ranking was based on toxicity to humans, fish, invertebrates, and amphibians. The primary objective of the database was to develop a toxicology scale that assigned a numerical value to risk level. It should be noted that this database saw further development beyond what is described in the 2018 thesis. In the thesis document, an actual ranking of pollutants is not presented - instead, the methodology and possible future uses of the database are presented. For example, the determination of which chemicals and pollutants to include was based on a November 2017 forum where a group of scientists and stakeholders reviewed survey data to determine which pollutants were of most concern across the state. The scientists were also asked a series of questions that were used to inform pollutant ranking. I reached out to the author and collaborator to obtain a copy of the latest version of the database in 2021 (Danielsen and Handaly, 2020). The authors of the database acknowledge that more work is needed, but their work is an excellent framework for developing future education and outreach programs. Based on the database's risk ratings for stormwater - heavy metals pose the highest risk, with zinc in metal roofs and car tires with the highest risk score. A suite of pesticides follows zinc in priority, followed by various plastic ingredients and breakdown products - Phthalates, PVC, Bisphenol, and microplastics.

2.6 2019 - The need to consider exposure and toxicity when assessing pollutant mixtures

Altenburger, R., Brack, W., Burgess, R. M., Busch, W., Escher, B. I., Focks, A., Hewitt, L. M., Jacobsen, B. N., de Alda, M. L., Ait-Aissa, S., et al. (2019). Future water quality monitoring: improving the balance between exposure and toxicity assessments of real-world pollutant mixtures. *Environmental Sciences Europe*, 31(1):1–17

Altenburger et al. (2019) speak to the need for determining causal relationships between pollutant mixtures and toxic biological endpoints. They also make the case that while monitoring chemicals in aqueous environments is important, biological responses measured through the development of bioassays provide a holistic picture of chemical burden. They propose developing a metric called Toxic Units (TU), where TU is calculated as the ratio of environmental concentrations to the concentration toxic to a specific aquatic species. In place of disconnected environmental assessments of specific pollutants, they proposed more comprehensive assessments using a line of evidence approach that accounts for chemical occurrence, bioanalytical data to establish concentration-effect relationships, in situ functional responses, and field surveys that characterize the population and community structure. In conclusion, they hypothesize that such an approach will yield better water quality assessments leading to better allocations of resources to tackle the sources of the water quality impairments.

2.7 2019 - Stormwater as a source of mixed contaminants

Masoner, J. R., Kolpin, D. W., Cozzarelli, I. M., Barber, L. B., Burden, D. S., Foreman, W. T., Forshay, K. J., Furlong, E. T., Groves, J. F., Hladik,

M. L., et al. (2019). Urban stormwater: An overlooked pathway of extensive mixed contaminants to surface and groundwaters in the United States. *Environmental Science & Technology*, 53(17):10070–10081

A study by Masoner et al. (2019) evaluated stormwater runoff for 50 events from 21 urban locations across the United States, analyzing stormwater samples for 438 organic chemicals and 62 inorganic ones. Samples were collected in constructed conveyance infrastructure comprising concrete culverts, canals, and open dirt ditches. They also collected and evaluated catchment and stormwater distribution characteristics as additional dependent factors, with runoff from roofs to road surfaces. They found that 215 of the 438 organic chemicals analyzed were detected in their stormwater samples, with 69 of those organic samples detected in over half the samples. Pesticides were the most frequently measured group of organic contaminants. They showed that many of the same chemicals detected in their stormwater samples were also seen in another study (Bradley et al., 2017) that assessed streams impacted by agriculture and development. In fact, there was a greater detection frequency and concentration of neonicotinoid insecticide in urban stormwater compared to another study (Hladik et al., 2014) on agricultural streams in the Midwestern U.S. The authors showed that organic chemical loads from some runoff events were similar to daily treated effluent loads from wastewater treatment plants (WWTP). They conclude that when compared to WWTP effluent, untreated urban stormwater contributes higher loads of PAHs, pesticides, and PCBs; similar loads of household and industrial chemicals and non-prescription pharmaceuticals; and smaller loads of prescription pharmaceuticals, biogenic hormones, and plant/animal sterols.

2.8 2020 - Need for re-examining pollutant sources in stormwater

Müller, A., Österlund, H., Marsalek, J., and Viklander, M. (2020). The pollution conveyed by urban runoff: A review of sources. *Science of the Total Environment*, 709:136125

Müller et al. (2020) focus their work on the sources of pollutants in stormwater as an organizing framework, eschewing the traditional classification of pollutants by their physicochemical properties. Instead, they synthesized existing studies examining emerging and well-established sources of stormwater pollutants. Sources of pollutants that were examined were:

1. Atmospheric deposition.
2. Drainage surfaces - roads and paved surfaces; building materials and surfaces; green areas like parks, lawns, urban forests, and sports facilities.
3. Anthropogenic activities - vehicular sources, road and construction activities, littering, illicit dumping, gardening, and pets/wildlife.
4. Urban drainage - GSI[16], materials used to make pipes, and cross-connections between wastewater and stormwater networks.

They identify atmospheric deposition, vehicles and roadways, and metal cladding around buildings as the primary sources of pollution. They also note that with improvements in manufacturing and processing of materials, a lot of the historical data on pollutant loading rates are obsolete and should be considered 'historical data'; they caution against reliance upon these data. They conclude by stating that with further development of new consumer materials, new unsampled pollutants are likely to emerge.

2.9 2021 - Tire wear breakdown products in stormwater

Tian, Z., Zhao, H., Peter, K. T., Gonzalez, M., Wetzel, J., Wu, C., Hu, X., Prat, J., Mudrock, E., Hettinger, R., et al. (2021). A ubiquitous tire rubber–derived chemical induces acute mortality in coho salmon. *Science*, 371(6525):185–189

In this critical study by Tian et al. (2021), a toxicant from the breakdown of vehicle tires was identified as the chief agent of Urban Mortality Runoff Syndrome - the syndrome describing pre-spawn mortality of Pacific Northwest coho salmon in urban creeks of the Puget Sound region. The toxicant identified by Tian et al. (2021) is a toxic quinone transformation product of N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine (6PPD) called 6PPD-quinone (6PPD-q). 6PPD-q is formed by the breakdown of 6PPD, where 6PPD is a widely used compound incorporated into tire rubber to prevent tire rubber from oxidizing and breaking down when exposed to the elements - particularly ozone. Tian et al. (2021) estimated that 6PPD-q loadings to streams near multilane highways range from 0.2 to 3.5 μg/L per storm event, with LC50[17] for coho salmon estimated to be 0.095 μg/L. With the

[16] green stormwater infrastructure

[17] LC50 - a measure of toxicity. In this case, the concentration of 6PPD-q in water needed to kill 50% of group of coho salmon after a single exposure.

publication of the Tian et al. (2021) paper, it appears the most toxic pollutants in stormwater, in terms of prevalence and exposure, emanate from vehicles and transportation networks.

An important outcome of this work is that the characterization of stormwater pollution for known priority pollutants is insufficient to explain even the most acute stormwater problems. With the inherent complexity of stormwater, what other problems could we be missing by focusing on monitoring a small group of known contaminants (PAHs, metals, nutrients, conventionals, bacteria)?

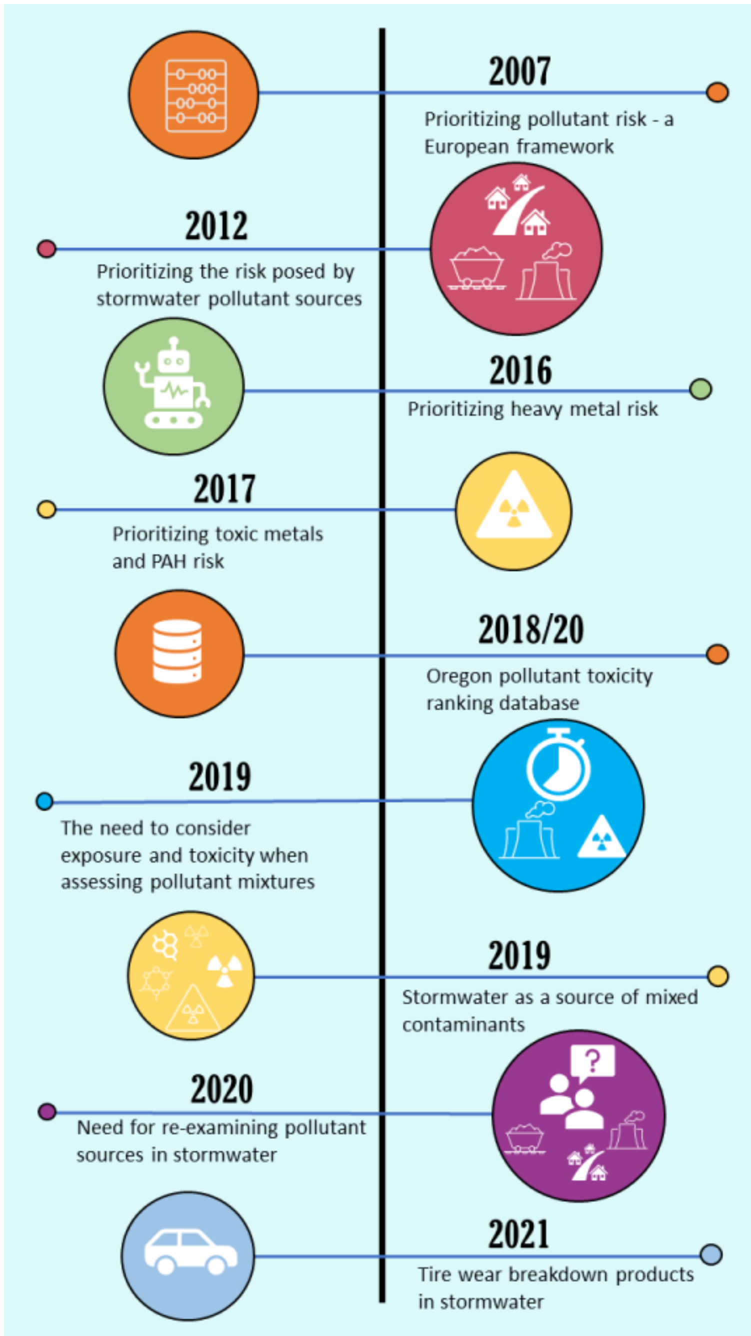

Figure 1: A timeline of recent pollutant prioritization based on nine studies summarized in this document.

3 Prioritizing Environmental Justice

The roots of the environmental justice movement in the US can be traced to the Civil Rights movement but are directly associated with protests in 1982 related to the dumping of PCB[18]-contaminated soils in a Black farming community in rural North Carolina (Lehtinen, 2009). The Office of Environmental Justice, established in 1992, operates within the US EPA with the mandate to examine every federal regulation regarding its implications for environmental justice issues.

The HEAL[19] Act passed by the Washington state legislature in 2021 defines environmental justice as "*the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, rules, and policies. Environmental justice includes addressing disproportionate environmental and health impacts in all laws, rules, and policies with environmental impacts by prioritizing vulnerable populations and overburdened communities, the equitable distribution of resources and benefits, and eliminating harm.*" All seven state government agencies covered by the HEAL Act are required to carry out environmental justice assessments "*when making decisions and to assist the agency with the equitable distribution of environmental benefits, the reduction of environmental harms, and the identification and reduction of environmental and health disparities*" - see RCW:70A.02.060.

Waller et al. (1997) break down environmental justice studies to three basic questions:

- Are members of a particular subpopulation subject to disproportionately high exposure?
- Are they experiencing a disproportionate number of adverse outcomes?
- Is their risk of particular outcomes unduly increased by the exposure?

Evaluating the equitable distribution of the burdens associated with environmental pollution across socioeconomic demographics is a complex and evolving area of work. Waller et al. (1997) proposed a risk-exposure model that evaluates the preponderance of a pollutant in an area and the dose a human will receive of that pollutant, describing those phenomena as ex-

[18]polychlorinated biphenyls

[19]Healthy Environment for All (SB 5141)

posure inequity[20] and risk injustice[21], respectively. They used a Bayesian framework to quantify the uncertainty in both exposure and response variables.

Spatial models to map toxic exposure and environmental justice were used within an early geographic information system (GIS) by Bevc et al. (2007). They sought to move past the standard proximity-exposure model where proximity to polluted sites was equivalent to exposure to a specific pollutant. Instead, Bevc et al. (2007) expanded their focus to include health, demographic, and biophysical[22] data to develop models of potential mental and physical health. They also point out the strong connection between environmental pollution and human health, an issue many environmental justice scholars of that time overlooked.

Zartarian et al. (2011) developed the Community-Focused Exposure and Risk Screening Tool (C-FERST), a GIS tool to assess community-level exposure and risk to environmental pollutants. In Washington State, the best mapping tool that shows the cumulative risk of environmental pollution at a neighborhood level is described by Min et al. (2019) and is called the Washington Environmental Health Disparities Map. The tool is available at https://fortress.wa.gov/doh/wtn/WTNIBL/ and combines 19 community health indicators, demographic data, diesel emissions exposure, and hazardous waste proximity.

The Western Washington Municipal Stormwater Permits requires watershed-scale stormwater planning to determine where stormwater facilities might be needed, or additional land use development strategies that will provide water quality benefits. Phase I Permittees were required to develop a watershed-scale stormwater plan in the 2013-2019 Permit and to build on that plan in the 2019-2024 Permit. The Western WA Phase II Permittees are required to develop a Stormwater Management Action Plan in the 2019-2024 Permit cycle. Guidance provided on these plans includes consideration of overburdened communities in the development and prioritization of projects.

The Permit's requirement to *include* under-resourced communities is in itself a large area of work and study. A study by Hoover et al. (2021) of 119 GSI projects in several large cities in the US found that community engagement tended to be mostly passive, driven by complaints or individual relationships. They suggest a more active engagement strategy with the community is achievable by prioritizing needs identified by a community and

[20] refers to differences in exposure distributions

[21] refers to differences in adverse outcomes due to exposure inequity

[22] geological, hydrological, and meteorological characteristics

creating frameworks for conflict resolution between jurisdiction and community. So that community engagement is a central focus of any environmental mitigation strategy or effort, a community must be engaged early Hoover et al. (2021) and authentically and provided compensation or resources to facilitate engagement Black et al. (2013). We should also remember that every community is heterogeneous and should not be treated as a monolith.

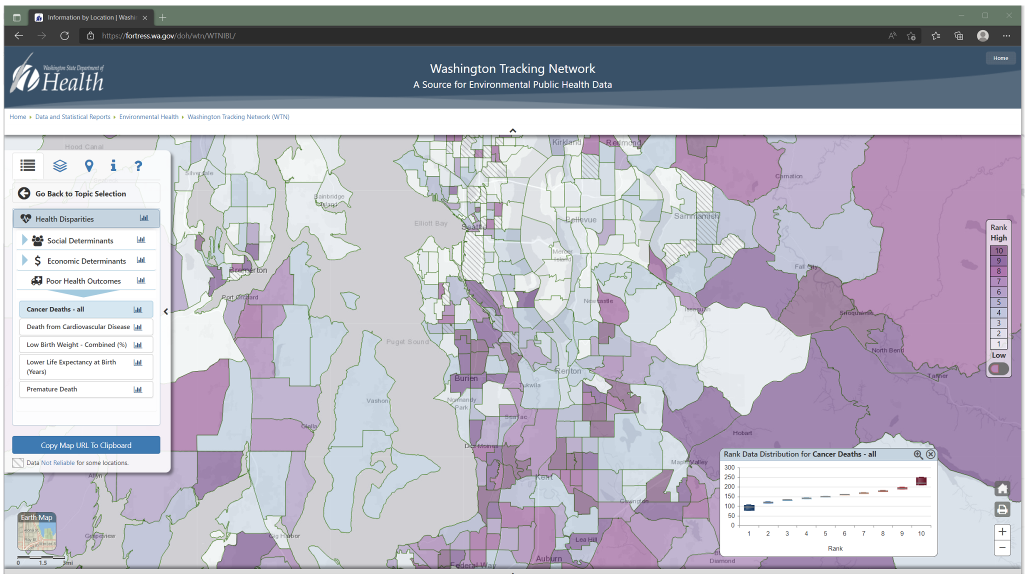

Figure 2: An interactive mapping tool that ranks the cumulative risk from environmental factors faced by Washington neighborhoods - https://fortress.wa.gov/doh/wtn/WTNIBL/

4 Conclusions

The HEAL Act requires multiple state agencies in Washington to address environmental justice in the state intentionally. The recent Municipal Stormwater Permit in Washington requires jurisdictions to conduct basin-level planning and include under-resourced communities. State-of-the-art mapping tools offer insight into cumulative exposure risk at the neighborhood scale and help inform environmental policy at multiple scales. Based on the studies summarized here, it is evident that perceptions of pollutant risk have evolved over the last several decades. In recent years, stormwater runoff from roadways and the pollutant mixtures they transport are of particular worry. Using the Health Disparities map in conjunction with basin level maps to identify roadway sources of stormwater that impact under-resourced communities and targeting those communities for intervention, outreach, education, and incentives could be highly impactful.

From a pollutant risk perspective, engaging health professionals (Venkataramanan et al., 2019; Kondo et al., 2015) and community (Jayakaran et al., 2021) are potent avenues for determining what pollutants might be posing the most significant risk. From just the nine studies outlined here, it is clear that pollutants must be viewed as mixtures, and vehicles and roadways are among the most potent contributors of pollutants to stormwater.

References

Altenburger, R., Brack, W., Burgess, R. M., Busch, W., Escher, B. I., Focks, A., Hewitt, L. M., Jacobsen, B. N., de Alda, M. L., Ait-Aissa, S., et al. (2019). Future water quality monitoring: improving the balance between exposure and toxicity assessments of real-world pollutant mixtures. *Environmental Sciences Europe*, 31(1):1–17.

Berckes, J., Iott, T., and Gonzalez, J. (2019). 303(d) and TMDLs: State of the States. Summary report, Association of Clean Water Administrators, Washington DC.

Bevc, C. A., Marshall, B. K., and Picou, J. S. (2007). Environmental justice and toxic exposure: Toward a spatial model of physical health and psychological well-being. *Social Science Research*, 36(1):48–67.

Black, K. Z., Hardy, C. Y., De Marco, M., Ammerman, A. S., Corbie-Smith, G., Council, B., Ellis, D., Eng, E., Harris, B., Jackson, M., et al. (2013). Beyond incentives for involvement to compensation for consultants: increasing equity in cbpr approaches. *Progress in Community Health Partnerships*, 7(3):263.

Bradley, P. M., Journey, C. A., Romanok, K. M., Barber, L. B., Buxton, H. T., Foreman, W. T., Furlong, E. T., Glassmeyer, S. T., Hladik, M. L., Iwanowicz, L. R., et al. (2017). Expanded target-chemical analysis reveals extensive mixed-organic-contaminant exposure in US streams. *Environmental Science & Technology*, 51(9):4792–4802.

Danielsen, A. (2018). Oregon Pollutant Toxicity Ranking DatabaseA Tool for Supporting Risk Assessment of Oregon's Water Quality. mathesis, Portland State University, Portland, OR.

Danielsen, A. and Handaly, K. (2020). Oregon Pollutant Ranking List - Database File. UnPublished Database.

Eriksson, E., Baun, A., Scholes, L., Ledin, A., Ahlman, S., Revitt, M., Noutsopoulos, C., and Mikkelsen, P. S. (2007). Selected stormwater priority pollutants—a European perspective. *Science of the Total Environment*, 383(1-3):41–51.

Hladik, M. L., Kolpin, D. W., and Kuivila, K. M. (2014). Widespread occurrence of neonicotinoid insecticides in streams in a high corn and soybean producing region, USA. *Environmental Pollution*, 193:189–196.

Hoover, F.-A., Meerow, S., Grabowski, Z. J., and McPhearson, T. (2021). Environmental justice implications of siting criteria in urban green infrastructure planning. *Journal of Environmental Policy & Planning*, 23(5):665–682.

Jayakaran, A. D., Rhodes, E., and Vogel, J. (2021). Stormwater management at the lot level: engaging homeowners and business owners to adopt green stormwater infrastructure. In *Oxford Research Encyclopedia of Environmental Science*.

Kondo, M. C., Low, S. C., Henning, J., and Branas, C. C. (2015). The impact of green stormwater infrastructure installation on surrounding health and safety. *American Journal of Public Health*, 105(3):e114–e121. PMID: 25602887.

Lehtinen, A. A. (2009). Environmental Justice. In Kitchin, R. and Thrift, N., editors, *International Encyclopedia of Human Geography*, pages 535–539. Elsevier, Oxford.

Lundy, L., Ellis, J. B., and Revitt, D. M. (2012). Risk prioritisation of stormwater pollutant sources. *Water Research*, 46(20):6589–6600.

Ma, Y., Egodawatta, P., McGree, J., Liu, A., and Goonetilleke, A. (2016). Human health risk assessment of heavy metals in urban stormwater. *Science of the Total Environment*, 557:764–772.

Ma, Y., Liu, A., Egodawatta, P., McGree, J., and Goonetilleke, A. (2017). Assessment and management of human health risk from toxic metals and polycyclic aromatic hydrocarbons in urban stormwater arising from anthropogenic activities and traffic congestion. *Science of the Total Environment*, 579:202–211.

Masoner, J. R., Kolpin, D. W., Cozzarelli, I. M., Barber, L. B., Burden, D. S., Foreman, W. T., Forshay, K. J., Furlong, E. T., Groves, J. F., Hladik, M. L., et al. (2019). Urban stormwater: An overlooked pathway of extensive mixed contaminants to surface and groundwaters in the United States. *Environmental Science & Technology*, 53(17):10070–10081.

Min, E., Gruen, D., Banerjee, D., Echeverria, T., Freelander, L., Schmeltz, M., Saganić, E., Piazza, M., Galaviz, V. E., Yost, M., et al. (2019). The Washington State Environmental Health Disparities Map: Development of a community-responsive cumulative impacts assessment tool. *International Journal of Environmental Research and Public Health*, 16(22):4470.

Müller, A., Österlund, H., Marsalek, J., and Viklander, M. (2020). The pollution conveyed by urban runoff: A review of sources. *Science of the Total Environment*, 709:136125.

Tian, Z., Zhao, H., Peter, K. T., Gonzalez, M., Wetzel, J., Wu, C., Hu, X., Prat, J., Mudrock, E., Hettinger, R., et al. (2021). A ubiquitous tire rubber–derived chemical induces acute mortality in coho salmon. *Science*, 371(6525):185–189.

Venkataramanan, V., Packman, A. I., Peters, D. R., Lopez, D., McCuskey, D. J., McDonald, R. I., Miller, W. M., and Young, S. L. (2019). A systematic review of the human health and social well-being outcomes of green infrastructure for stormwater and flood management. *Journal of environmental management*, 246:868–880.

Waller, L. A., Louis, T. A., and Carlin, B. P. (1997). Bayes methods for combining disease and exposure data in assessing environmental justice. *Environmental and Ecological Statistics*, 4(4):267–281.

Zartarian, V. G., Schultz, B. D., Barzyk, T. M., Smuts, M., Hammond, D. M., Medina-Vera, M., and Geller, A. M. (2011). The Environmental Protection Agency's Community-Focused Exposure and Risk Screening Tool (C-FERST) and its potential use for environmental justice efforts. *American journal of public health*, 101(S1):S286–S294.