

**Who is Most Impacted?**  
**A GIS Cumulative Impacts Analysis on Chemical Waste Hazards, Floodplains, and Sea  
Level Rise in King County, WA**

Carly Bednarski

A thesis

submitted in partial fulfillment of the  
requirements for the degree of

Master of Science

University of Washington

2022

Committee:

Tania Busch Isaksen

Matthew Kelley

Program Authorized to Offer Degree:

Environmental and Occupational Health Sciences

School of Public Health

© Copyright 2022

Carly Bednarski

University of Washington

**Abstract**

Who is Most Impacted?

A GIS Cumulative Impacts Analysis on Chemical Waste Hazards, Floodplains, and Sea Level  
Rise in King County, WA

Carly Bednarski

Chair of the Supervisory Committee:

Tania Busch Isaksen

Department of Environmental and Occupational Health Sciences

Despite the Washington State Environmental Health Disparities Map and the Duwamish Valley Cumulative Health Impacts Analysis assessments being resources for communities to access environmental threats and social vulnerabilities, there is no single map that includes all factors associated with potential chemical mobilization and flood risks. These factors include sites of possible chemical mobilization, floodplain zones, sea level rise, and incorporating community demographics, that when combined, illustrate a more complete picture of communities' potential cumulative impacts. This study produced three cumulative impact maps using the California Environmental Protection Agency (Cal/EPA) Environmental Justice Action Plan screening methodology in the Environmental Systems Research Institute (ESRI) Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) Pro application software.

The first cumulative impacts map ranked communities' potential impacts by considering chemical waste hazards along with socioeconomic and sensitive population factors, by census tract. The second map factored in the 100-year floodplain, while the third map included sea level rise. The comparison of the three cumulative impacts maps showed how impacts changed for communities based on incorporating different environmental threats, demonstrating the effects these environmental changes would have on present-day communities. Current demographic data was used in all three calculations to apply future scenario events to present-day communities, invoking the need for policy changes or mitigation strategies present-day rather than in the future when it may be too late. Secondary data from the Department of Ecology, the Washington State Department of Health Washington Tracking Network, the Washington State Department of Health Environmental Health Disparities Index, and the National Oceanic and Atmospheric Association (NOAA) were used to perform all analyses and create all maps. Communities may be unaware of their current or future flood potential as well as chemical waste hazards that are within close proximity to them. Understanding the impact climate change will have on sea level rise and incorporating that information into the cumulative impacts maps is vital as it changes communities' environmental threats. Policy decisions can then be based on these cumulative impacts maps, such as developing more targeted mitigation strategies to diminish consequences from future flood risk or chemical mobilization.

# TABLE OF CONTENTS

1. Specific Aims.....	1
2. Background Literature.....	2
A. Introduction.....	2
B. Climate Change and Floods.....	2
C. Chemical Waste Hazards.....	5
D. Environmental Justice.....	8
E. Map Properties: Importance of Resolution and Scale.....	9
F. Current Study.....	10
3. Methods and Initial Results.....	10
A. Methods Overview.....	10
B. Initial Results.....	18
i. Indicators in Environmental Threat.....	18
ii. Indicators in Social Vulnerability.....	28
C. Socioeconomic Factors and Chemical Waste Hazards.....	34
i. Proximity Analysis.....	34
ii. Site Hazard Assessment Evaluation.....	35
4. Cumulative Impact Analyses.....	39
A. Aim 1) Chemical Waste Hazards Cumulative Impacts.....	39
B. Aim 2) Floodplains and Chemical Waste Hazards Cumulative Impacts.....	42
C. Aim 3) Sea Level Rise, Floodplains, and Chemical Waste Hazards Cumulative Impacts.....	44
5. Discussion.....	47
A. Potential Uses in Policy and Practice.....	49
B. Limitations and Recommendations for Future Research.....	49
C. Conclusions.....	50
List of References.....	52

## LIST OF FIGURES

Figure 1 <i>Steps in the MCTA Cleanup Process [2]</i> .....	6
Figure 2 <i>The Cumulative Impact’s Formula</i> .....	11
Figure 3 <i>Analysis Indicators and Formulas</i> .....	14
Figure 4 <i>Toxic Releases from Facilities Indicator</i> .....	19
Figure 5 <i>Population in the 100-Year Floodplain Indicator</i> .....	20
Figure 6 <i>Population in Sea Level Rise Impacted Area Indicator</i> .....	21
Figure 7 <i>Environmental Exposures Component</i> .....	21
Figure 8 <i>Proximity to Hazardous Waste Generators and Facilities Indicator</i> .....	22
Figure 9 <i>Proximity to Superfund Sites Indicator</i> .....	23
Figure 10 <i>Proximity to Facilities with Highly Toxic Substances Indicator</i> .....	24
Figure 11 <i>Wastewater Discharge Indicator</i> .....	25
Figure 12 <i>Land Area in 100-Year Floodplain Indicator</i> .....	26
Figure 13 <i>Sea Level Rise Impacted Area Indicator</i> .....	27
Figure 14 <i>Environmental Effects Component</i> .....	27
Figure 15 <i>People of Color Indicator</i> .....	29
Figure 16 <i>Population Living in Poverty Indicator</i> .....	30
Figure 17 <i>Limited English Proficiency Indicator</i> .....	31
Figure 18 <i>Socioeconomic Factors Component</i> .....	31
Figure 19 <i>Persons Over the Age 65 Indicator</i> .....	32
Figure 20 <i>Population with a Disability Indicator</i> .....	33
Figure 21 <i>Sensitive Population Component</i> .....	33
Figure 22 <i>Department of Ecology’s Site Cleanup Definitions</i> .....	36
Figure 23 <i>Chemical Waste Hazards Cumulative Impact Indicators</i> .....	39
Figure 24 <i>Chemical Waste Hazards Cumulative Impact King County</i> .....	40
Figure 25 <i>Chemical Waste Hazards Cumulative Impact Area of Interest</i> .....	41
Figure 26 <i>Floodplains and Chemical Waste Hazards Cumulative Impact Indicators</i> .....	42
Figure 27 <i>Floodplains and Chemical Waste Hazards Cumulative Impact King County</i> .....	43
Figure 28 <i>Floodplains and Chemical Waste Hazards Cumulative Impact Area of Interest</i> .....	44
Figure 29 <i>Sea Level Rise, Floodplains, and Chemical Waste Hazards Cumulative Impact Indicators</i> .....	45

Figure 30 *Sea Level Rise, Floodplains, and Chemical Waste Hazards Cumulative Impact King County*.....46

Figure 31 *Sea Level Rise, Floodplains, and Chemical Waste Hazards Cumulative Impact Area of Interest*.....47

## LIST OF TABLES

Table 1 <i>Areas of Washington State Relative Sea Level Rise Projections [10]</i> .....	4
Table 2 <i>Indicators and Established Impact Rank Ranges</i> .....	13
Table 3 <i>Indicator Summary Statistics</i> .....	16
Table 4 <i>Color Coded Component and Indicators</i> .....	17
Table 5 <i>Average Chemical Waste Hazards Proximity Ranks Within Socioeconomic Impact Ranks</i> .....	35
Table 6 <i>Average Percent of Unvisited Sites Within Socioeconomic Impact Ranks</i> .....	37
Table 7 <i>Socioeconomic Impact Ranks, Site Hazard Assessment Ranks, and Percent Visited Sites</i> .....	38

## ACKNOWLEDGEMENTS

I am deeply grateful to so many individuals' love and support during this process. A sincerest thank you:

To my advisor and committee chair, Dr. Tania Busch Isaksen, your guidance and unwavering support in this journey during a global pandemic encouraged me at every step. I could not have asked for a better mentor (or a funnier one).

To my committee member, Dr. Matthew Kelley, for guiding me through the field of Geographic Information Systems. Without your vast knowledge and support, this project would not have come together. I am grateful for everything I have learned along the way.

To Gregory Lund, for his dedication and passion for teaching at the University of Tacoma's Geographic Information System's certificate program.

To my cohort and peers, for making classes and discussions so engaging, even virtually. I have learned so much from everyone. A special thank you to Joanne Medina and Anna Mounsey, who have supported and encouraged this project at every step, offering feedback and plenty of jokes. I am deeply grateful to Daaniya Iyaz and Claudia Nguyen; your friendship, laughter, and support truly kept me going throughout the program and I am so proud of what you both have accomplished at the University.

To all that provided feedback, specifically Ron, for dedicating so much of your own time to help me.

To my best friends, Kimberly, Meghan, and Bronwen, for always being my support system and hype women. Your texts, Snapchats, and visits never fail to make me smile, even when it feels impossible.

To my mom and sister, you both inspire me every day and there is nothing I cannot accomplish with you both by my side; and to my chosen family, Venkat, Murugu, and Uji, your love and support is always felt.

To my partner Stuart, I cannot describe what your support and comfort have meant to me. You push me to be stronger and achieve things I never thought I could. I love you.

## 1. SPECIFIC AIMS

The cost of flooding exceeds all other natural hazards in Washington State with over an 80% chance of 10 or more flooding events occurring within a given year. As climate change worsens, increases in flood frequency and severity [1] makes it critical to have cumulative impacts maps of environmental hazards. The Washington State Environmental Health Disparities Map and the Duwamish Valley Cumulative Health Impacts Analysis assessments help inform policymakers and prepare communities for environmental hazards by informing them of their susceptibility and risks. However, both do not have a single map that illustrates the cumulative impacts based on a calculation of chemical waste hazards, which can lead to chemical mobilization, floodplain zones, and combined demographic factors that affect communities' unequal impacts, while also incorporating the effects of sea level rise.

### **Aim 1) Describe cumulative impacts associated with chemical waste hazard locational data and demographic data, by census tract.**

This aim creates a map that illustrates cumulative impacts from chemical waste hazards, which includes toxic releases from facilities, proximity to hazardous waste generators and facilities, proximity to Superfund sites, proximity to facilities with highly toxic substances, and wastewater discharge, and demographic data, which includes people of color, population living in poverty, limited English proficiency, persons over the age 65, and population with a disability, to establish the base map for Aim 2.

### **Aim 2) Describe cumulative impacts associated with floodplain zonal data, chemical waste hazard locational data, and demographic data, by census tract.**

This aim creates a map that illustrates cumulative impacts from floodplain zonal data, which includes population in the 100-year floodplain and land area in the 100-year floodplain, chemical waste hazards, and demographic data, to establish the base map for Aim 3.

### **Aim 3) Describe cumulative impacts associated with sea level rise data, floodplain zonal data, chemical waste hazard locational data, and demographic data, by census tract.**

This aim creates a map that illustrates cumulative impacts from sea level rise data, which includes population in the sea level rise impacted area and sea level rise impacted area, floodplain zonal data, chemical waste hazards, and demographic data.

This project created three cumulative impacts maps that considered demographic data, chemical waste hazards, the 100-year floodplain, and sea level rise data of census tracts in King County, WA. These maps provide greater insight into the potential impacts of chemical waste hazards, floods, and sea level rise for communities that not only policymakers but also the affected communities can use for adaptation planning. The three maps demonstrate the effects that a number of environmental changes can contribute to a community's overall environmental risk. Current demographic data was utilized in all three calculations to visualize potential future impacts on present-day communities to make the hazards more apparent and pertinent. Ultimately, the maps provide a valuable resource for new policies and better mitigation strategies for impacted communities.

## **2. BACKGROUND LITERATURE**

### **A. Introduction**

Of all the natural disasters that occur worldwide, flooding accounts for 40% and is of particular concern due to its multiple environmental consequences [2]. This includes direct contamination of residential areas, contamination of drinking water sources, disruption of residential and industrial sewage systems, and increase in the amount of runoff from farms and industrial sites [2]. It has been estimated that between 1988 and 2017, approximately 73 billion dollars of flood damage could be attributed to increases in extreme precipitation events from climate change [3]. According to epidemiological evidence, chemical material can lead to contamination of multiple areas and affect human health in flooding events due to chemical mobilization from storage or chemical remobilization within the environment [2, 3]. Thus, having the public understand if their home is at risk of not only flooding, but also how flood transported chemicals pose a risk is vital. Flooding events are also predicted to increase in frequency and intensity due to climate change, adding further potential risk to communities. There are currently no maps that take into account the combination of demographic data, the 100-year floodplain, the risk of flood-transported chemicals from chemical waste hazards, and sea level rise data that quantify communities' potential cumulative impacts in King County, WA.

The purpose of this research was to create and compare three cumulative impact maps for King County, WA that considered demographic data, chemical waste hazards, the 100-year floodplain, and sea level rise. Additional questions of interest included: 1) Are higher socioeconomic vulnerable communities within closer proximity to chemical waste hazards compared to lower socioeconomic vulnerable communities in Southwestern King County? 2) Are there disparities in decision-making when it comes to evaluating chemical waste hazards in Southwestern King County?

### **B. Climate Change and Floods**

Floods in Washington State arise from several sources. In Western Washington, fall and winter rainstorms lead to flooding events [4]. Warm air temperatures and the pre-existing snowpack can augment rain-on-snow melt flooding in spring or summer as the snow rapidly melts [4]. Eastern Washington experiences intense thunderstorms in the summer that produce extremely heavy localized precipitation, generating large flooding events [4]. While floods can occur any time of year, rainfall-generated river, stormwater, and terrestrial flow peaks in the winter lead flooding events in the western half of the state while snowmelt-generated peak river flows in the summer lead flooding events in the eastern half of the state [4]. Atmospheric rivers (ARs) play an important role in large flooding events in western Washington [4]. ARs are characterized by long, narrow plumes of warm, moist air that originate from the tropical regions of the Pacific, bringing heavy precipitation events [4]. Climatological studies performed concluded that landfalling winter storms with AR attributes along the West Coast produced twice as much precipitation as non-AR storms and yield a daily increase in streamflow much larger than non-AR storms [5].

Due to heavy precipitation events, the flood season occurs from late October to mid-March [5]. Precipitation in western Washington varies annually from approximately 950 mm in Seattle to approximately 375 mm in the town of Sequim to 2000–5000 mm in the Olympic and Cascade Mountains [5]. River basins in Washington state are prone to quick runoff, varying from a few hours to a few days, due to the topography and heavy winter-season rains [5]. Spring-melt flooding from an abundant snowpack does occur in western Washington due to climate change affecting the river basin channels' capacities to accommodate heavy runoff volume [5].

Multiple climate scenario projections predict future warming conditions that will lead to transitional basins, meaning a small temperature change will have significant effects on the amount of snow and rainfall a basin area could receive [4]. Global Circulation Models also predict that future atmospheric rivers will have higher integrated water vapor, increasing the number of days of extreme precipitation along the West Coast, causing more extreme flooding events in western Washington [4]. Subsequently, Seattle will continue to experience changes in flooding frequency and intensity from projected increases in sea level rise and heavy rain events frequencies [6]. The amount of rainfall collected between 1978-2007 in Seattle Public Utilities' gauges found a small, statistically significant increasing trend of short-duration but high-intensity precipitation events, with heavy rainfall intensity events having a 1-2% chance of occurring each year [6]. These findings were in alignment with the University of Washington's Climate Impacts Group, which projects that by the 2050s there will be an increase from 6-20% in the number of days with more than 1 inch of rain, with sea level rise also causing the reach of waves in a storm surge event to extend [6]. Projections of future climate made by general circulation models performed in the North Cascade Mountains were consistent with previous regional studies. Simulation results projected increased winter flows, decreased summer flows and snowpack, and a shift in spring melt peak timing [7]. Temperature and precipitation are the leading factors that control the timing and magnitude of streamflow in Washington. Increasing temperatures contribute to snowpack declines and cause changes to spring and summer streamflow. Increases in temperature and precipitation determine winter streamflow [7]. Flash floods from extreme precipitation events continue to claim human lives and contribute to property damage [8]. Thus, the need to develop improved disaster preparedness and climate change adaptation strategies to reduce communities' vulnerability to weather extremes is significant [8].

The National Oceanic and Atmospheric Association (NOAA) has been measuring water levels through water level tide gauges for over a century [9]. Global sea levels have risen approximately 1.7 mm/yr over the last century and approximately 3.2 mm/yr over the last several decades [9]. In Washington state, Puget Sound will experience the greatest sea level rise compared to the Northwest Olympic Peninsula and the Central and Southern Coast, ranging from 3-22 inches by the year 2050 and 6-50 inches by the 2100, displayed in Table 1 [10]. The south Puget Sound will experience the greatest relative sea level rise because it has been subsiding at a rate of 2 mm/yr along with increased precipitation events and frequency and intensity of floods [10]. Sea level rise relative to land has been increasing the tidal datum elevations, the standard elevation defined by a certain phase of the tide [9]. These tidal datums are references used to measure local water levels; an increasing tidal datum elevation indicates rising sea levels [9]. Thus, extreme flooding events have been reaching higher grounds and covering larger areas, increasing event frequency and duration [9]. There is also the issue of sea level rise relative to land increasing lesser extreme events (occasional minor coastal flooding) that are becoming

more noticeable and widespread [9]. Minor coastal flooding elevation thresholds, established by the National Weather Service, has recorded increasing water level exceedances over time [9]. Recurrent coastal flooding impacts include frequent road closures, overwhelmed stormwater drainage capacities, and deterioration and corrosion of infrastructure not designed to withstand frequent inundation or salt-water exposure [9]. The impacts have created a time pressure dependent on the local sea level rise relative to land rate when critical elevation thresholds of systems are increasingly compromised by tidal flooding [9]. This time pressure makes it critical for coastal planning to start preventing the degradation of systems and start encouraging resiliency efforts [9].

Coastal land use and development alter the regional impacts of climate change [10]. Thus, the projected trends represented in Table 1 have a wide range based on “significant physical and chemical stressors: (a) inundation of low-lying areas by high tides as sea level rises; (b) flooding of coasts during major storm events, especially near river mouths; (c) accelerated erosion of coastal bluffs; (d) shifting of beach profiles, moving the position of the Mean High Water line landward; (e) saltwater intrusion into coastal freshwater aquifers; and (f) increased ocean temperature and acidity” [10]. Overall, erosion rates and coastal flooding will increase due to sea level rise, threatening coastal development and a multitude of homes and infrastructure [10]. However, not all persons will experience the same adverse impacts from natural hazard events.

<i>SLR Estimate</i>	<i>By the Year 2050</i>			<i>By the Year 2100</i>		
	NW Olympic Peninsula	Central and Southern Coast	Puget Sound	NW Olympic Peninsula	Central and Southern Coast	Puget Sound
<i>Very Low</i>	-5” (-12 cm)	1” (3 cm)	3” (8 cm)	-9” (-24 cm)	2” (6 cm)	6” (16 cm)
<i>Medium</i>	0” (0 cm)	5” (12.5 cm)	6” (15 cm)	2” (4 cm)	11” (29 cm)	13” (34 cm)
<i>Very High</i>	14” (35 cm)	18” (45 cm)	22” (55 cm)	35” (88 cm)	43” (108 cm)	50” (128 cm)

**Table 1.** Areas of Washington State relative sea level rise projections [10].

Age, spoken language, and disabilities have been identified as indicators of social vulnerability to environmental hazards, decreasing a community’s resiliency [11, 12, 13, 14, 15]. Persons over the age of 65 are more likely to have pre-existing medical conditions and compromised mobility, making it more difficult to tolerate and respond to environmental hazards. They also have more difficulty evacuating in a flooding event, possibly increasing the burden of care to others [12, 13, 14]. Language barriers make it difficult to understand warning announcements and interact with flood preparation and evacuation procedures, affecting a person’s ability to act during a natural hazards event [11, 12, 13, 14, 15]. Persons with disabilities are at a greater risk of injury, mortality, destitution, and displacement, and social and environmental barriers put disabled persons at greater adverse risk during a natural hazards event [16, 17]. Barriers include inaccessible warning information, the absence of specific evacuation plans, and lack of accessible evacuation transport [16, 17]. Lower-income and communities of color also have limited access to risk management instruments and are less able to cope with natural hazards events compared to white, higher-income communities [16, 17, 18]. These communities are more likely to reside in hazardous locations more prone to natural hazards events [16, 17, 18]. When a natural hazards event occurs, communities that are more at risk but lack resources to respond to

such events have more difficulty coping, making them more severely affected as well as accentuating the disparities that exist, creating a positive feedback loop [16, 17, 18]. Climate change is predicted to continue exacerbating these indicators [5, 6, 8, 9].

### **C. Chemical Waste Hazards**

Having communities understand if their homes are at risk of not only flooding but contamination from transported chemicals is vital as it changes communities' potential risk and exposure to hazards [2]. Chemicals can biotransform when they come into contact with different environmental mediums (e.g., water), be transported to new locations, and can be re-suspended into the water column during flooding events.

The Department of Ecology has identified over 13,000 chemical waste hazards in need of cleanup in Washington state [2]. In this paper, all sites will be referred to as chemical waste hazards as an umbrella term and specifically includes toxic releases from facilities, hazardous waste generators and facilities, Superfund sites, facilities with highly toxic substances, and wastewater discharge [2]. A chemical waste hazard means any site where there has been confirmation of a release or threatened release of a hazardous substance dangerous to humans that requires remedial action. Toxic substances can include petroleum, heavy metals, chemicals and pesticides, and persistent organic pollutants [2]. These substances can contaminate multiple types of media such as soil, sediment, water, and air.

“The primary media for transport of contaminants and exposure to organisms are surface water, groundwater, sediment, and tissue (i.e., from consumption of contaminated prey items or food chain transfer). Surface water flow over upland areas erodes soil or collects material from impermeable surfaces and transports contaminants from urban or industrial areas in the dissolved or particulate phase. Precipitation infiltrates upland soils and can leach contaminants from soils as it percolates to the water table and flows along the top of impermeable layers or alongside discharge pipes before entering the river as seeps above the waterline or as transition zone water below the waterline” [20].

The clean-up of sites in Washington state are handled mostly by the Department of Ecology's Toxics Cleanup Program (TCP) and are cleaned up under the Model Toxics Control Act (MTCA), which funds and directs the investigation, cleanup, and prevention of chemical waste hazards [2]. Figure 1 outlines generalized steps in the MTCA cleanup process. The TCP receives funding from the MTCA and implements and enforces the MTCA [2]. Some sites fall under different program or agencies responsibilities due to the type of facility or contamination. The main exception are Superfund sites, which are managed by the Environmental Protection Agency (EPA) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), known as the Superfund [2]. Other exceptions include active spills, Dangerous Waste Facilities, nuclear cleanup, former landfills, and large industrial sites [2].

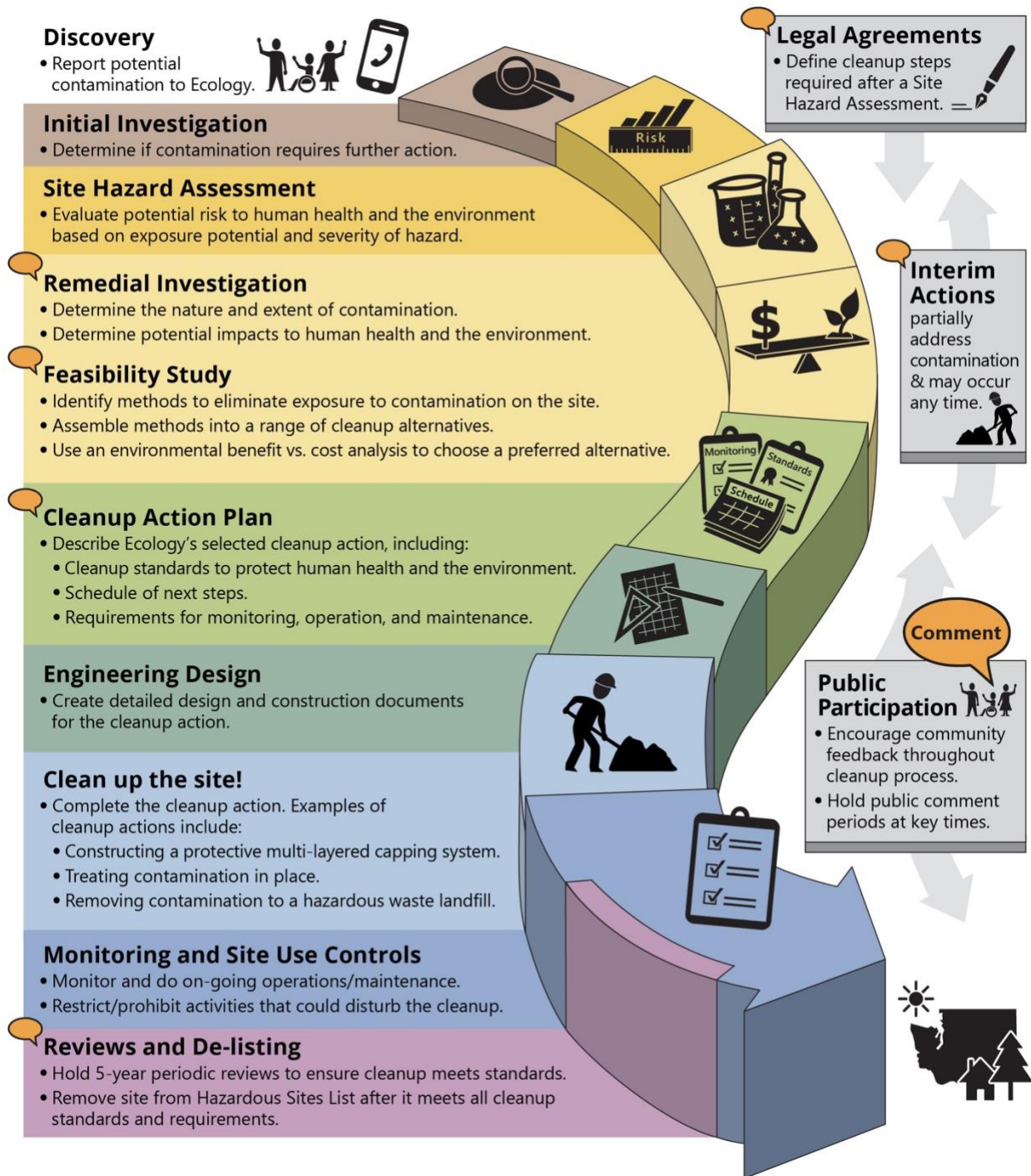


Figure 1. Steps in the MTCA cleanup process [2].

Adapting chemical waste hazards to climate change is a critical challenge in Washington state [19], especially when addressing flood and sea level rise impacts. The TCP including regionally-specific climate change impacts can help assess the risks associated with such hazards and gives the opportunity to include climate-resilient adaptation measures in the different cleanup process steps, referenced in Figure 1 [19]. The Department of Ecology conducted a vulnerability assessment for the state's cleanup sites. This report identified what type of sites were most

vulnerable to climate change impacts, specifically sea level rise and flooding events [19]. Sites identified to have the greatest vulnerability to sea level rise included those located in low-lying coastal shorelines, marshy shorelines and estuaries, beaches and tidal flats, and coastal bluffs [19]. Sites identified to have the greatest vulnerability to flooding included those located along developed shorelines in low-lying areas, beaches and tide flats, along marshy shorelines and river deltas, downstream from a dam, and in the 100 and 500-year floodplains [19]. These vulnerable sites may have contamination left in place intended for permanent isolation (e.g., sediment), closed or abandoned landfills, upland and aquatic confined disposal facilities, and no to limited protection along the shoreline to diminish contaminant transport from eroding contaminated soil to surface water or sediment [19]. Current floodplains and floodways are projected to be more extensive in the future [19]. Sites located in or near floodplains are subject to more frequent and severe flooding [19]. There will also be an increase in the percentage of area flooded and the magnitude of flooding [19]. Sea level rise is predicted to affect sites through changes in the water table, saltwater intrusion, and inundation as well as will exacerbate the impacts from flooding events [19].

The degree of human exposure to hazardous pollutants is likely to be altered by global climate change, thus changing communities' future risks to pollutants [20]. The level of exposure to pollutants is predicted to increase since chemicals' persistence and mobility in the environment is dependent on environmental conditions [20]. Pollutants that do not easily degrade will persist in the environment for longer periods of time with the potential of more frequent mobilization and resuspension activity due to flooding events and sea level rise [20]. This increases possible exposure to communities. Environmental changes will have negative implications for human exposure to hazardous chemicals [20]. Increased volatilization of persistent chemicals is an expected consequence of temperature increases, increasing the risk of long-range transport [20]. Changes in moisture content combined with increases in temperatures will affect soil characteristics and hydrology, changing the transportation, dilution, and persistence of contaminants [20]. Increases in frequency and intensity of extreme weather events will significantly alter the mobility of contaminants, such as flooding events transporting contaminants from already contaminated areas to non-contaminated areas [20]. Legacy pollutants pose the greatest long-term risk to humans and the environment due to their long half-lives, low environmental degradability, and high toxicity concerning flooding events. Large-scale environmental processes (e.g., climate change) are predicted to influence legacy pollutants' fate and transport since they persist and bioaccumulate in the environment, altering human and environmental exposures [20]. Legacy pollutants' relative abundance in the environment is dictated by the transfer among environmental media compartments (water or air) versus reservoir compartments (soil and sediments) and climate-dependent chemical transformation processes [20].

In urban coastlines specifically, sediments have become contaminant repositories for potential sources of pollution released during flooding events. Sea level rise induced flooding affects both the biogeochemistry and physics of these sediments and water [21]. With nearly 40% of the global population living within 100 km of a coastline [21], the impacts of sea level rise on coastal pollutants have significant environmental, economic, and ecological importance. This is especially true with the increasing intensity and frequency of extreme weather events and sea level rise, increasing overall flood risks [21]. Flooding events cause an increase in the diffusive

flux of contaminants, mobilize sediments into the water column, and transport resuspended contaminants from their original deposition site [21, 22]. Disturbances throughout flooding and resuspension activity further change the chemical and physical environment, causing potential significant environmental and public health risks [21, 22]. Thus, understanding the fate and behavior of pollutants within flood-prone chemical waste hazards is crucial for future mitigation planning.

## **D. Environmental Justice**

Marginalized and lower socioeconomic communities experience more extensive environmental risk exposure and unequal impacts [11, 12, 13, 14, 15, 23, 24, 25]. A growing body of quantitative research on racial and socioeconomic disparities in environmental hazard exposures has found a significant correlation between socioeconomic status and the proximity to a polluting facility [12, 13, 14, 23, 24, 25]. Communities of color have historically been in closer proximity to Hazardous Waste Generators and Facilities, Superfund sites, and Facilities with Highly Toxic Substances when compared to predominantly white communities [11, 12, 13, 14, 15, 23, 24, 25]. Superfund sites are polluted locations designated by the Environmental Protection Agency under the Comprehensive Environmental Response, Compensation, and Liability Act that require a long-term response for management and clean up [26]. These sites are prioritized in the National Priorities List, which is a list of hazardous sites of national priority eligible for long-term remedial investigation and action financed by the federal Superfund program [26]. These communities are at a greater exposure risk and thus are more likely to experience greater adverse health outcomes. Low-income communities have a lower resiliency when responding to environmental risk [11, 12, 13, 14, 15, 23, 24, 25]. Persons living in poverty experience chronic stress, lack of resources, lack of education, poor physical and mental health, etc., that already negatively impact their biological susceptibility or extrinsic vulnerabilities when coupled with environmental risk factors [11, 12, 13, 14, 15, 23, 24, 25]. Communities with a high level of linguistic isolation also live in closer proximity to Hazardous Waste Generators and Facilities, Superfund sites, and Facilities with Highly Toxic Substances than communities with lower levels of linguistic isolation [11, 12, 13, 14, 15]. These communities experience greater civil engagement barriers that affect environmental policies, leading to environmental disparities that the community cannot effectively respond to [11, 12, 13, 14, 15]. These inequities influence social disparities in exposure and impact needs and coupled with the frequency and magnitude of floods expected to increase due to climate change, these disparities are likely to increase unless policy changes are made [23, 24, 25].

Achieving environmental justice is a difficult issue to address due to the United States' racialized history which has shaped the socio-ecological formations of communities (how individuals interact and respond to the environment, and how those interactions subsequently affect society and the environment) [25]. Colorblind adaptation planning is defined as "vulnerability mitigation and adaptation planning projects that overlook racial inequality or dismiss the systematic causes of racial inequality by attributing racial disparities to non-racial causes" [25]. It fails to take racial differences and the structure of racial inequality into account and ends up benefiting some populations while ignoring or hurting others [25]. Rather than using top-down managerial approaches, more collaborative and inclusive forms of governance should be used to form and implement more racially equitable outcomes [25]. To achieve this, the racial formation should be

combined with the geographical study of analysis to illustrate how racial formations are also environmental [23, 25]. Thus, racial categories are not the only issue produced over time and through racial policies and decisions, but socio-ecological relations of racialized spaces (process by which residential locations and communities are defined by racial identity) are also produced [23, 25]. Systematic racism has led to the formation of vulnerability concerning the effects of climate change, such as toxic substance releases, poor water quality, and extreme weather events [25]. Structural and colorblind racism create barriers for community co-engagement opportunities needed to address effective and equitable adaptation planning [25]. If marginalized communities are left out of the discourse on climate change science and policy decisions, that exclusion further reinforces marginalization and institutional racism around adaptation planning [23, 25].

For example, flood studies conducted on Hurricane Harvey in the Greater Houston area found that when looking at the areal extent of flooding, frequency and intensity were significantly greater in communities with high proportions of socioeconomically deprived, disabled, minority residents [24], while another study done at household-level on flood exposure found that residences within the 100-year flood zones in Greater Houston were more likely marginalized racial/ethnic groups with less property-level flood hazard mitigation and lower perceptions of flood risk [24]. Ultimately, prior studies done in greater Houston indicate that markers of social disadvantage correlate with heightened flood hazard exposure [24].

Flood hazard, flood exposure, and population vulnerability are the three components to flood risk [20, 25, 27]. The magnitude of a flood's impact is dependent on the level of vulnerability and exposure of human communities to the hazard, which varies across economic, social, geographic, demographic, cultural, institutional, governance, and environmental conditions [27]. Flood exposure is driven by a lack of awareness of potential hazards, the ability to cope with and adapt to adverse impacts, the trade-off between flood risk and amenities in flood zones, and governmental and institutional factors [27]. Due to these complex relationships, adaptation and mitigation practices should take the dynamic nature of vulnerability and exposure into account to effectively address flooding hazards [27]. High vulnerability and exposure are products of socio-economic disparities, environmental mismanagement, inappropriate urban planning, and failed governance that led to unsustainable developments [27]. Since environmental justice is a form of distributive justice, this project addressed the distribution of burdens about flood hazards based on the assessment of the geographical distribution of environmental hazards among census tracts. The ability of communities to respond to and cope with environmental hazards is significantly affected by demographic characteristics [8, 23, 24, 25].

## **E. Map Properties: Importance of Resolution and Scale**

Map scales and properties are important factors to consider when visualizing data, as they can create misleading conclusions within the visualization. There are three units of measurement commonly used when displaying data: map units, display units, and location units [28]. Map units are the units that the spatial data in the map is drawn after [28]. They are determined by the linear coordinate system of the map and are read-only, meaning they can only be changed if the coordinate system is changed [28]. Display units are used by the coordinate system and display the real-world coordinate values corresponding with the current location on the map [28].

Location units are the coordinate units available to the project and can be removed, formatted, or assigned [28].

Scale refers to two factors: resolution and extent [29]. With spatial analysis, not all levels of details can be sensed, captured, and handled due to the massive amount of data it would create. Thus, it is essential to reduce detail and capture only the significant features in spatial analysis, known as cartographic generalization, aggregation, and approximation [29, 30]. Both the spatial resolution of data and the spatial resolution of processes must be considered in spatial analysis. As all geographic data is specific to resolution, all transformations, analyses, and manipulations must be scale-specific [29, 30]. Information is either lost or gained when these factors change. These factors are important to consider especially when data is being interpolated since both data and process resolution and extent can significantly affect the quality and usefulness of the output. For example, inverse distance weighted (IDW) interpolation estimates cell values by averaging the sample data point values of neighboring processing cells. The closer a neighboring cell is to the cell center being estimated, the more influence it has in the averaging process [30]. Increasing the extent and including more points that are farther from the cell location where the averaging process is based on can result in an inaccurate interpolation and subsequent inaccurate statistical analysis since those points have no spatial correlation [30].

## **F. Current Study**

According to the background literature, it is clear chemical waste hazards, floodplain zones, and sea level rise are all interconnected and amplify the effects of each other. Certain demographic factors put communities at a greater risk of enduring unequal burdens of environmental hazards and make it more difficult to respond and cope with such hazards, decreasing the community's resiliency and increasing social disparities. This cycle perpetuates inequity of environmental threats and social vulnerabilities. However, there is no impact assessment that considers all previously stated factors in community cumulative risk to environmental hazards and social vulnerabilities, and specifically how that risk changes. Therefore, the purpose of this research was to create and compare three cumulative impact maps for King County, WA that considered demographic data, chemical waste hazards, the 100-year flood zone, and sea level rise to address the research gap. Additional questions of interest concerning the relationship between social disparities and chemical waste hazards were also explored to determine if King County emulates findings in the background literature. These research questions included: 1) Are high socioeconomic vulnerable communities within closer proximity to chemical waste hazards compared to lower socioeconomic vulnerable communities in Southwestern King County? 2) Are there disparities in decision-making when it comes to evaluating chemical waste hazards in Southwestern King County?

## **3. METHODS AND INITIAL RESULTS**

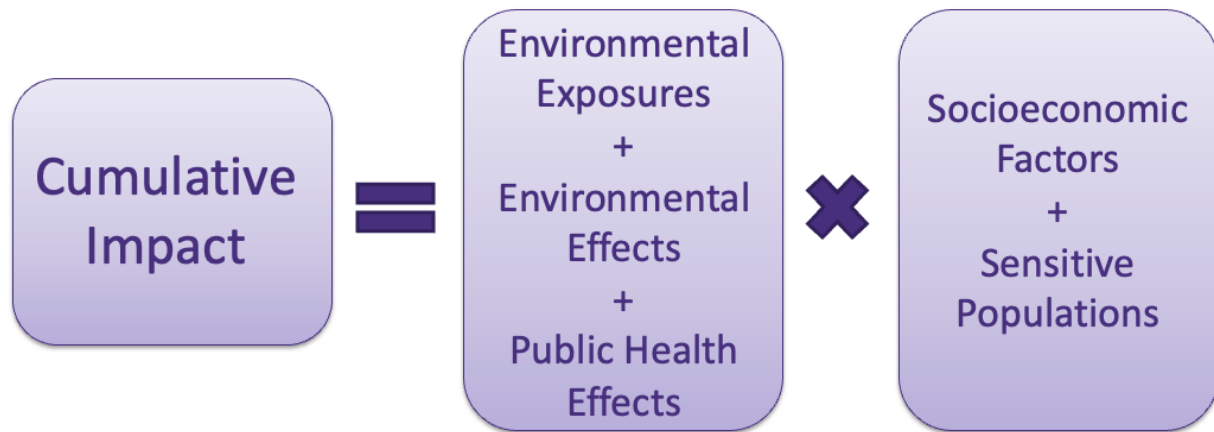
### **A. Methods Overview**

To characterize disparities in the distribution of the aforementioned environmental hazards and adverse impacts, the California Environmental Protection Agency (Cal/EPA) Environmental Justice Action Plan screening methodology is used to evaluating cumulative impacts, defined as

"the exposures, public health or environmental effects from the combined emissions and discharges, in a geographic area, including environmental pollution from all sources, whether single or multi-media, routinely, accidentally, or otherwise released. Impacts will take into account sensitive populations and socio-economic factors, where applicable and to the extent data are available" [31].

The screening methodology is based on the current scientific understanding of adverse impacts on health from environmental pollution and the non-intrinsic socioeconomic factors that mediates those impacts [11, 31]. Figure 2 illustrates the cumulative impact formula, which is separated into two distinct factors: *environmental threat* and *social vulnerability* [11, 31]. *Environmental threat* indicators can include exposures (concentration level of airborne contaminants), public health effects (asthma rates), and environmental effects (presence of hazardous waste cleanup sites) while *social vulnerability* indicators include sensitive populations (children, elderly, people with pre-existing conditions, and pregnant women) and socioeconomic factors (income, percent minority, education attainment, etc.).

It is important to remember that this ranking methodology is relative [11, 31]. From a cumulative health impacts perspective, the ranks indicate that communities in certain census tracts are potentially disproportionately affected by multiple hazards compared to other census tracts, and thus will potentially have greater difficulty responding and adapting to such stressors [15]. Risk is defined as how likely a community's exposure to an environmental hazard will result in negative impacts, such as an increased likelihood of experiencing adverse health outcomes [15]. Vulnerability is defined as a community's non-biological situation that affects their ability to cope with risk factors, or the community's resiliency [15].



**Figure 2.** The cumulative impact's formula. The sum of environmental threat is multiplied by the sum of social vulnerability.

Based on existing risk assessment guidance, which indicates that population characteristics modify and amplify pollution exposure impacts and response to burdens, *environmental threat* is multiplied by *social vulnerability* [11, 31]. The ranking of factors helps compare the environmental hazards and social factors but should not be taken as absolute values [11, 31]. Impact ranks assigned are calculated for a geographical area, meaning spatial boundaries must be delineated [11]. This research utilized census tracts in King County, specifically analyzing Southwestern King County as the area of interest. This was defined as the area of interest because it had the greatest *environmental threat* and *social vulnerability* data variation.

The cumulative impact analysis examines hazard sources, public and environmental exposure and effects, and population characteristics that influence a community's risk and vulnerability [11, 31]. Indicators are divided five components, or categories, each with an established range of impact ranks [11, 23, 31]. The range of impacts developed by the Cal/EPA screening methodology is dependent upon the quality and quantity of current data and the agency's ability to address subsequent impacts [11, 31]. Exposure data is most closely associated with pollution impact and typically has a vast amount of information on the types and extent of potential exposures based on extensive monitoring and reporting systems, and thus was assigned an impact range of 1-10 [11, 31]. In contrast, environmental and public health effects associated data has less certainty and available information, and thus have a range of 1-5 [11, 31]. Social vulnerability characteristics have a range of 1-3 determined by scientific evidence for a several-fold difference in pollution burden response from populations, dependent on intrinsic (i.e., biological traits) or extrinsic factors (i.e., socioeconomic status) [11, 31]. Refer to the Cal/EPA's *Cumulative Impacts: Building a Scientific Foundation* report for information about the development of impact rank ranges.

This research utilized Environmental Systems Research Institute (ESRI) Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) Pro application software to perform all analyses and create all the maps. Secondary data was used from the Department of Ecology [32], the Washington State Department of Health Washington Tracking Network [33, 34, 35, 36, 37, 38, 39], the Washington State Department of Health Environmental Health Disparities Index [40], and the National Oceanic and Atmospheric Association (NOAA) [41]. A mixed methodology was incorporated based on the Cal/EPA Environmental Justice Action Plan screening methodology [11], the Washington State Environmental Health Disparities Map [15], and the Duwamish Valley Cumulative Health Impacts Analysis assessments [23]. Both the Washington State Environmental Health Disparities Map and the Duwamish Valley Cumulative Health Impacts Analysis use the basis of the Cal/EPA screening methodology discussed previously; however, components and calculations differ slightly. In this analysis, components included followed the Washington State Environmental Health Disparities Map, represented in Table 2. Since this analysis focused on ranking environmental health hazards and identifying communities' unequal impacts from environmental hazards, public health effects were not included in this analysis, adhering to the Washington State Environmental Health Disparities Map framework [15]. It is acknowledged that environmental and public health effects can overlap. However, contaminants in water and their subsequent public health effects are difficult to model and measure specifically in relation to flooding events and sea level rise. The magnitude of public health effects as a consequence of environmental hazards is a complex relationship that is dependent on the consideration of genetic, behavioral, and other risks [15]. This analysis is considering health outcomes as a part of a community's overall vulnerability, meaning a higher vulnerability impact is associated with a greater probability of adverse health outcomes [15].

<i>Calculation</i>	<i>Component</i>	<i>Definition</i>	<i>Impact Rank Range</i>
<i>Environmental Threat</i>	Environmental Exposures	Contact with pollution	1-10
	Environmental Effects	Adverse built environment conditions	1-5
<i>Social Vulnerability Characteristics</i>	Socioeconomic Factors	Community characteristics that result in increased vulnerability to pollutants	1-3
	Sensitive Populations	Populations with traits that may magnify the effects of pollutant exposures	1-3

**Table 2.** Indicators with the established impact rank ranges. Public health effects were not included in this analysis [15].

The mixed methodological component calculations can be split into two relative “sections” for explanation purposes. In the first section, calculations followed the Duwamish Valley Cumulative Health Impacts Analysis, which averages indicators in each component then sums the components to calculate the *environmental threat* and *social vulnerability*, represented in Figure 3. This figure also includes the specific indicators used in this analysis. In comparison, the Washington State Environmental Health Disparities Map framework calculated the *environmental threat* and *social vulnerability* by assigning each indicator a decile score based on the rank-order of raw data values and half weighting the percentile scores due to uncertainties in exposures to communities [15].

Cumulative Impact Score			
<i>Cumulative Impacts = Environmental Threat X Social Vulnerability</i>			
Environmental Threat		Social Vulnerability	
Environmental Threat Score = Average Environmental Exposure Indicators + Average Environmental Effect Indicators		Social Vulnerability Score = Average Socioeconomic Indicators + Average Sensitive Population Indicators	
Environmental Exposures (1-10)	Environmental Effects (1-5)	Socioeconomic Factors (1-3)	Sensitive Populations (1-3)
Toxic Releases from Facilities [40] Population in the 100-Year Floodplain [37] Population in Sea Level Rise Impacted Area [37, 41]	Proximity to Hazardous Waste Generators and Facilities [40] Proximity to Superfund Sites [40] Proximity to Facilities with Highly Toxic Substances [40] Wastewater Discharge [40] Land Area in the 100-Year Floodplain [33] Sea Level Rise Impacted Area [41]	People of Color [34] Population Living in Poverty (<= 185% of Federal Poverty Level) [35] Limited English Proficiency [36]	Persons Over the Age 65 [39] Population with a Disability [38]

**Figure 3.** Analysis indicators and formulas.

Secondary datasets used in this analysis’s cumulative impact assessments had varying data collection and calculation methods. Therefore, raw data values were not utilized. Instead, the various datasets were standardized by calculating the Z-score to allow for comparisons between different samples on the same relative scale [42]. Z-scores were calculated for each component indicator [42], illustrated in Equation 1, and then reclassified using equal intervals for the given impact rank ranges developed by the Cal/EPA [11, 23, 31], assigning each census tract an impact rank for each indicator. Table 3 reports the indicator summary statistics before data standardization.

$$Z_{ij} = \frac{X_{ij} - \mu_i}{\sigma_i}$$

Where,

$X_{ij}$  = value for indicator i for census tract j

$\mu_i$  = average for indicator i

$\sigma_i$  = standard deviation for indicator i

**Equation 1.** Z-score formula [42].

<i>Component</i>	<i>Indicator</i>	<i>Units</i>	<i>Data Source</i>	<i>Average</i>	<i>Standard Deviation</i>	<i>Minimum</i>	<i>Maximum</i>
<i>Environmental Exposures</i>	Toxic Releases from Facilities	Average Toxicity-Weighted Concentrations (RSEI)	WA State Department of Health Environmental Health Disparities Index	19,349.58	27,811.06	0	186,434.59
	Population in the 100-Year Floodplain	Count	WA State Department of Health WA Tracking Network	40	117	0	1,066
	Population in Sea Level Rise Impacted Area	Count	NOAA, WA State Department of Health WA Tracking Network	252	725	0	6,262
<i>Environmental Effects</i>	Proximity to Hazardous Waste Generators and Facilities	Proximity (km)	WA State Department of Health Environmental Health Disparities Index	0.08	0.07	0	0.64
	Proximity to Superfund Sites	Proximity (km)	WA State Department of Health Environmental Health Disparities Index	0.25	0.28	0	1.47
	Proximity to Facilities with Highly Toxic Substances	Proximity (km)	WA State Department of Health Environmental Health Disparities Index	0.6	0.59	0	3.37
	Wastewater Discharge	Proximity (km)	WA State Department of Health Environmental Health Disparities Index	0.03	0.08	0	0.64
	Land Area in 100-Year Floodplain	Percent	WA State Department of Health WA Tracking Network	0.28	1.13	0	12.13
	Sea Level Rise Impacted Area	Percent	NOAA	4.51	12.58	0	94.66
<i>Socioeconomic Factors</i>	People of Color	Percent	WA State Department of Health WA Tracking Network	41.78	18.46	8.27	93.79

	Population Living in Poverty (<= 185% of Federal Poverty Level)	Percent	WA State Department of Health WA Tracking Network	17.91	11.76	1.42	70.71
	Limited English Proficiency	Percent	WA State Department of Health WA Tracking Network	10.66	8.22	0	40.79
<i>Sensitive Populations</i>	Persons Over the Age 65	Percent	WA State Department of Health WA Tracking Network	13.41	5.16	0	51.7
	Population with a Disability	Percent	WA State Department of Health WA Tracking Network	9.68	4.09	0	29.3
<i>Confirmed and Suspected Hazardous/Dangerous Waste Sites</i>	Total Number of Sites	Count	Department of Ecology	2,068	13.2	0	2,068
	Unvisited Sites	Percent	Department of Ecology	70	36.1	0	100
	Visited Sites	Percent	Department of Ecology	30	24.57	0	100

**Table 3.** Indicator summary statistics for census tracts in King County.

Referring to Table 4 to further help visualize the components, indicators, and calculations framework, the socioeconomic factors' component will be used as an example. This component has an established impact rank of 1-3. For a particular census tract, the minority percentage, poverty percentage, and limited English proficiency percentage standardized indicator layers all received an impact rank of 3. The three indicators were summed then averaged ( $3+3+3=9/3$ ), giving the census tract a socioeconomic factors component impact rank of 3.

<i>Component</i>	<i>Indicator</i>
<i>Environmental Exposures (Rank 1-10)</i>	Toxic releases from facilities Population in the 100-year floodplain Population in sea level rise impacted area
	Average
<i>Environmental Effects (Rank 1-5)</i>	Proximity to hazardous waste generators and facilities Proximity to Superfund sites Proximity to facilities with highly toxic substances Wastewater discharge Land area in 100-year floodplain Sea level rise impacted area
	Average
<i>Environmental Threat</i>	SUM (Environmental Exposures + Environmental Effects)
<i>Socioeconomic Factors (Rank 1-3)</i>	People of color Population living in poverty Limited English proficiency
	Average
<i>Sensitive Populations (Rank 1-3)</i>	Persons over the age 65 Population with a disability
	Average
<i>Social Vulnerability</i>	SUM (Socioeconomic + Sensitive Populations)
<i>Final Impact Rank</i>	(Environmental Threat X Social Vulnerability)

**Table 4.** Color coded component and indicators with data calculations.

In the second calculation section, after the Z-score standardization was complete, the *environmental threat* and *social vulnerability* were calculated (Table 4). *Environmental threat* is the sum of the environmental exposure factors' component impact rank plus the environmental effect factors' component impact rank [23, 31]. These indicators account for the pollution burden. *Social vulnerability* is the sum of the socioeconomic factors' component impact rank plus the sensitive population factors' component impact rank [23, 31]. These indicators affect a community's vulnerability to pollution burden. *Cumulative impact* ranks were then calculated by multiplying the *environmental threat* and *social vulnerability* for each census tract [23, 31]. Adhering to the Washington State Environmental Health Disparities Map framework, the final *cumulative impact* rankings were ordered from high to low impact ranks, reclassified using equal intervals and assigned a corresponding impact rank from a 1-10 scale to better compare impact differences among census tracts [23]. In comparison, the Duwamish Valley Cumulative Health Impacts Analysis left the final cumulative impact rankings as raw impact ranks rather than

reclassifying them on the same relative scale, making cumulative impact comparison among all census tracts in King County difficult.

## **B. Initial Results**

### *i. Indicators in Environmental Threat*

The data were standardized by calculating the Z-score for all *environmental exposure* and *environmental effect* indicators. Each Z-score indicator was converted to a separate raster layer and reclassified into equal interval classifications based on the appointed ranges. Once all indicators were reclassified, the environmental threat was calculated.

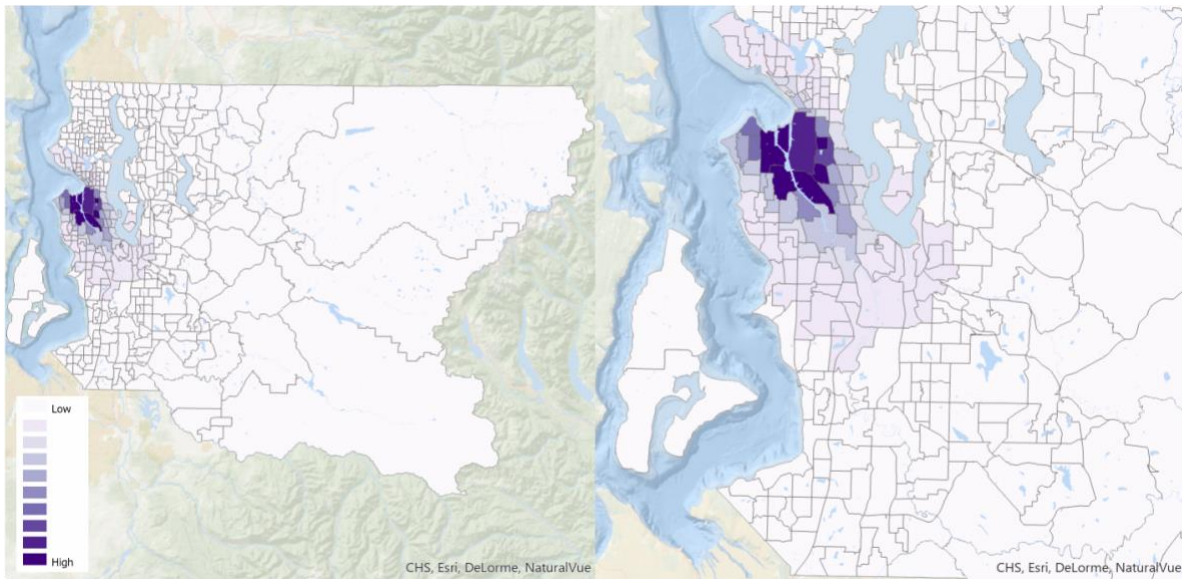
Data collection and original calculations for environmental threat indicators were calculated by the agencies listed under the data source column in Table 4 unless otherwise noted.

#### *Environmental Exposures 1-10*

Environmental exposure refers to how a person comes into contact with an environmental hazard. Each Z-score indicator was converted to a separate raster layer. The cell assignment types were set to “cell center” meaning the polygon attribute that overlaps the center of the cell yields the cell attribute and cell size was set to 10. The Reclassify tool was used to reclassify the raster layers into equal interval classifications on a 1-10 impact rank range, with an impact rank of “10” considered the greatest potential impact for environmental exposure indicators compared to an impact rank of “1”. The darker the purple, the greater environmental exposure, or the more harmful the exposure.

#### *Toxic Releases from Facilities*

This indicator represents the average toxicity-weighted concentrations of chemical releases to air from facility emissions and off-site incineration from the Risk Screening Environmental Indicators (RSEI) model [15, 40]. It accounts for the size of the chemical release, the fate and transport in the environment, the size and location of the exposed population, and the chemical's toxicity to derive a toxicity-weighted concentration [15, 40]. It assumes people are exposed continuously at their place of residence [15, 40]. Since there is the potential for atmospheric deposition into the terrestrial and aquatic environment in combination with air exposure, this is a concern with respect to flooding events and sea level rise as discussed in the background literature, and is considered an exposure in this analysis. Figure 4 visualizes toxic releases from facilities in King County and the area of interest.

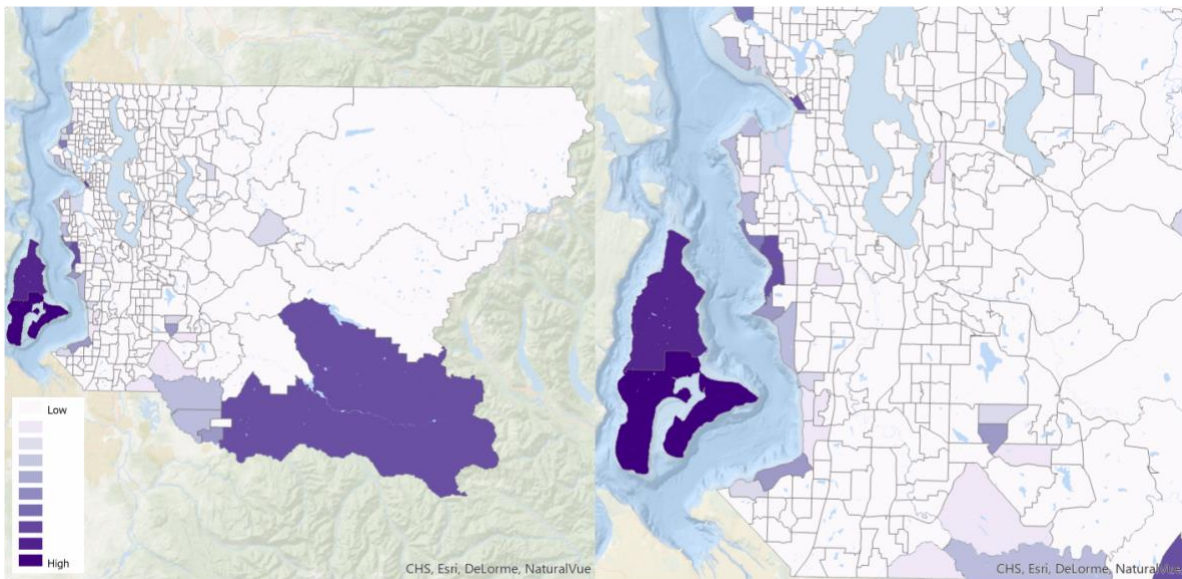


**Figure 4.** Toxic releases from facilities indicator, King County (left) and area of interest (right).

#### *Population in the 100-Year Floodplain*

The magnitude of a flood’s impact is dependent on the level of vulnerability and exposure of human communities to the hazard [27]. The ability of communities to respond to and cope with environmental hazards is significantly affected by demographic characteristics [8]. Thus, identifying which communities may be impacted by a 100-year flood can help address and improve existing adaptive capacities. Population living within the 100-year flood zone was considered an exposure as it puts persons in contact with floodwaters and potential flood-transported chemicals. Figure 5 visualizes the population in the 100-year floodplain in King County and the area of interest.

The area of land in each census tract at risk from a 100-year flood was calculated according to the Federal Emergency Management Agency’s (FEMA) coding scheme, which includes moderate to low-risk areas, high-risk areas, high-risk coastal areas, and undetermined risk areas [37]. The Q3 flood data was used for the calculation, which is derived from the Flood Insurance Rate Maps (FIRMs) published by FEMA. The 100-year floodplain feature layer represents areas that will be inundated by a flood event having a 1% chance (1 in 100) of being equaled or exceeded in any given year [43]. Flood exposure is quantified as the count and ratio of population located in the 100-year-flood zone for each county with the population distribution downscaled from census data to the block group level onto a 30 m-resolution land cover [37, 43]. The flood risk was multiplied by the number of people living in the census block and then summed with the number of people at risk across the census tract to estimate the population living in the 100-year flood zone [37].



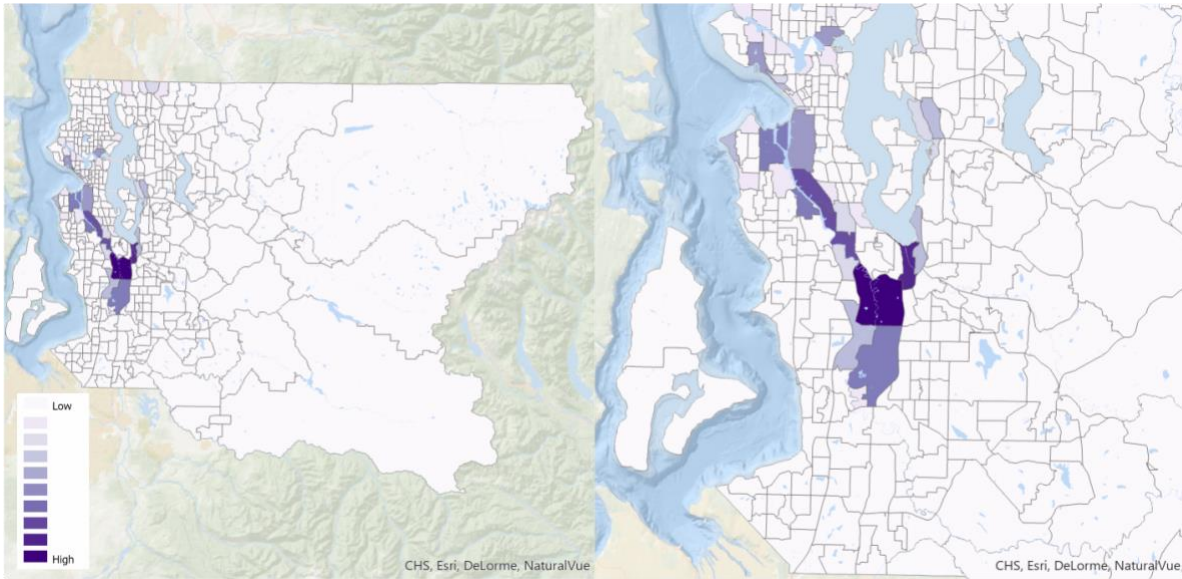
**Figure 5.** Population in the 100-year floodplain indicator, King County (left) and area of interest (right).

#### *Population in Sea Level Rise Impacted Area*

Large-scale environmental processes (e.g., sea level rise) are predicted to influence pollutants' fate and transport since they persist and bioaccumulate in the environment, altering human and environmental exposures [20]. Overall, sea level rise will increase erosion rates and exacerbate flooding events, threatening coastal development and a multitude of homes and infrastructure [10]. Population living within potential sea level rise area was considered an exposure as it puts persons in contact with rising water levels and potential mobilized chemicals. Figure 6 visualizes the population in potential sea level rise impacted area in King County and the area of interest.

Secondary Southwest Puget Sound digital elevation model (DEM) data was utilized from the National Oceanic and Atmospheric Association's (NOAA) Sea Level Rise Data. A DEM is a raster representation of a continuous surface with an accuracy determined by the resolution [44]. Every grid cell represents the elevation of that location, or grid cells contain elevation data in units of the DEM layer [44]. The DEM was produced from the 2016 King County, WA LiDAR, 2016 West Washington LiDAR, and 2010-2011 USGS ARRA LiDAR Pierce County datasets [41]. It includes coverage for King, Pierce, and Thurston Counties. Its vertical units are meters with a resolution of 3 meters [41]. The Reclassify tool was used to reclassify the DEM layer into a classification that only considered 0–10-foot bands for sea level rise. This created new grids but instead of cells containing elevation data, they contained the classified data. This classification range was chosen based on current sea level rise predictions for Washington State developed for low and high trajectories of future greenhouse gas emissions [45]. It's predicted that the sea level will rise by at least 1.6-3 feet for a low to high greenhouse gas scenario (RCP 4.5 [low] and RCP 8.5 [high] respectively), with a projected upper limit of 8.3-10 feet for a low to high greenhouse gas scenario [45]. This reclassified raster layer was converted to a polygon layer and spatially joined to the census tract vector layer. The area of land in each census tract within potential sea level rise, referred to as sea level rise risk, was calculated by dividing a census tract's total area by the total area of sea level rise in acres within the census tract [42].

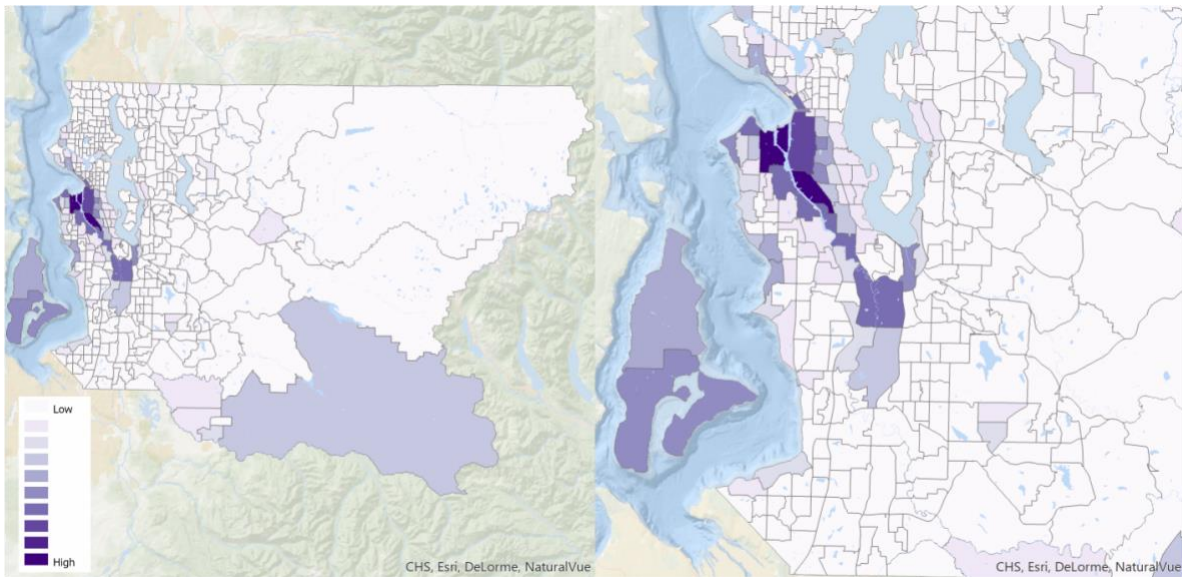
Sea level rise risk was multiplied by the number of people living in the census tract [37] to estimate the population living in a potential sea level rise area. The calculation was based on the Washington State Department of Health Washington Tracking Network *population in the 100-year flood zone* calculation.



**Figure 6.** Population in sea level rise impacted area indicator, King County (left) and area of interest (right).

#### *Environmental Exposures Component*

All indicators defined as an environmental exposure were summed, averaged, then reclassified on a 1-10 impact rank range to create an environmental exposures component impact. Figure 7 visualizes the environmental exposures component in King County and the area of interest.



**Figure 7.** Environmental exposures component, King County (left) and area of interest (right)

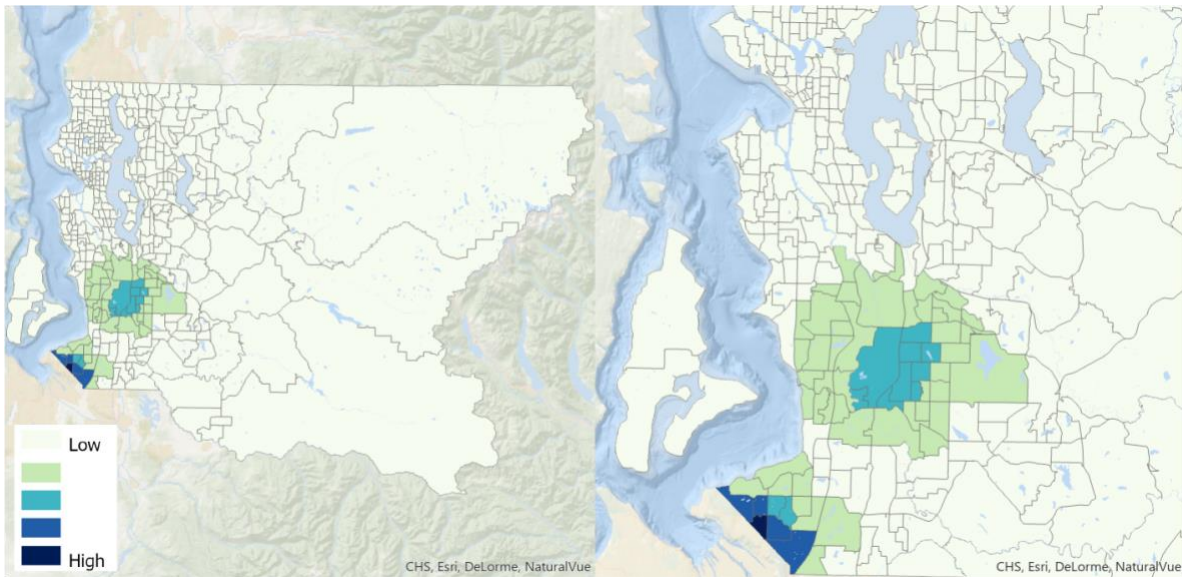
### ***Environmental Effects 1-5***

Environmental effect refers to the general adverse environmental quality, even when population contact with an environmental hazard is unknown or uncertain. Each Z-score indicator was converted to a separate raster layer. The cell assignment types were set to “cell center” meaning the polygon attribute that overlaps the center of the cell yields the cell attribute and cell size was set to 10. The Reclassify tool was used to reclassify the raster layers into equal interval classifications on a 1-5 impact rank range, with an impact rank of “5” considered the greatest potential impact for environmental effect indicators compared to an impact rank of “1”. The darker the blue-green, the greater the environmental effect, or the more harmful the effect.

### ***Proximity to Hazardous Waste Generators and Facilities***

Hazardous waste generators and facilities produce various forms of hazardous compounds that pose an increased environmental risk to communities nearby [11, 12, 13, 14, 15, 23, 24, 25]. Living near these facilities puts communities at a greater risk of adverse health impacts [11, 12, 13, 14, 15, 23, 24, 25]. Living near these facilities puts communities at a greater risk of negative health impacts due to the adverse environmental quality created but does consider exposure routes, and thus is considered an environmental effect. Figure 8 the proximity to hazardous waste generators and facilities in King County and the area of interest.

This indicator represents the count of all commercial Hazardous Waste Treatment, Storage, and Disposal Facilities within 5 km of a block’s centroid, divided by distance, as population-weighted averages of block groups summed over census tracts [15, 40]. Data used for the calculation was downloaded from EJSCREEN 2017 [15, 40].

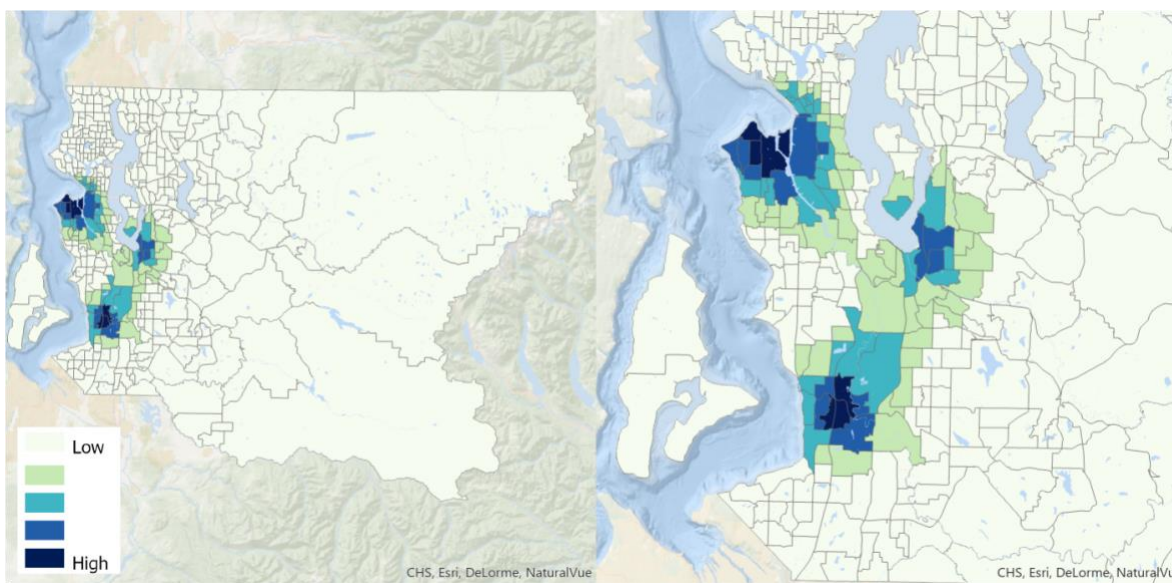


**Figure 8.** Proximity to hazardous waste generators and facilities indicator, King County (left) and area of interest (right).

### *Proximity to Superfund Sites*

Sites placed on the National Priorities List, a subset of all Superfund sites that includes sites of national priority among known or threatened releases, produce various forms of hazardous compounds that pose an increased environmental risk to communities nearby [11, 12, 13, 14, 15, 23, 24, 25]. Living near these facilities puts communities at a greater risk of adverse health impacts [11, 12, 13, 14, 15, 23, 24, 25]. The EPA places sites on the National Priorities List after the completion of the Hazard Ranking System screening, which is a tool used by the EPA to assess the relative threat of a site that is releasing or has the potential to releases contaminants that pose significant harm to human health or the environment [15, 40]. Cleanup for National Priorities sites do not fall under the Department of Ecology’s MCTA but rather is the responsibility of the EPA under CERCLA (Superfund law) [2, 15, 40]. Living near these facilities puts communities at a greater risk of negative health impacts due to the adverse environmental quality created but does consider exposure routes, and thus is considered an environmental effect. Figure 9 visualizes the proximity to Superfund sites in King County and the area of interest.

This indicator represents the count of sites proposed and listed on the National Priorities List within 5 km of a block’s centroid, divided by the distance, as population-weighted averages of blocks summed over census tracts [15, 40]. Data used for the calculation was downloaded from EJSCREEN 2017 [15, 40].



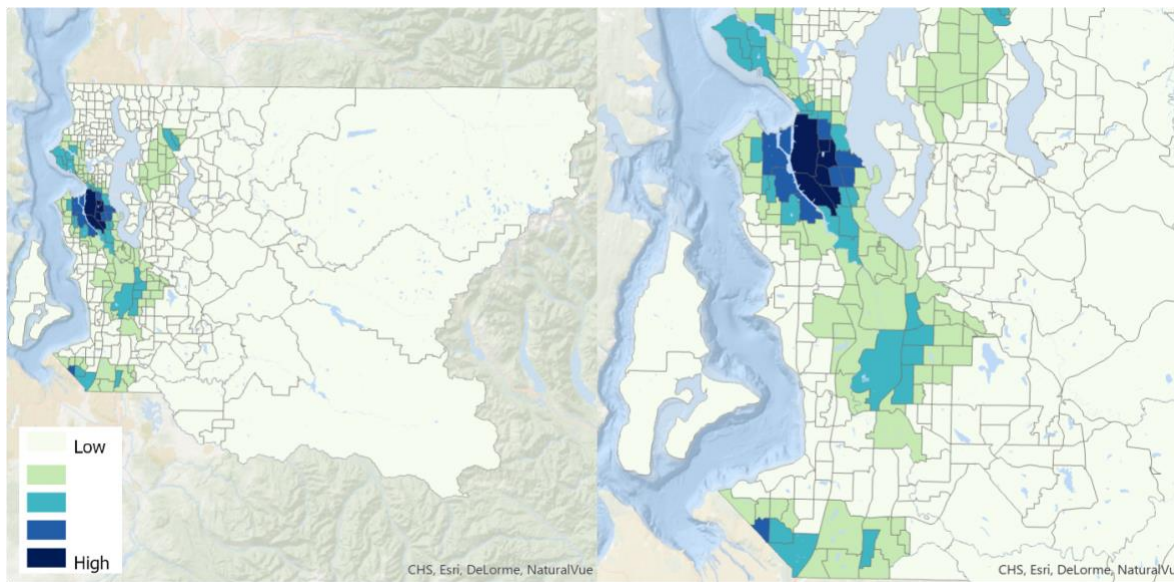
**Figure 9.** Proximity to Superfund sites indicator, King County (left) and area of interest (right).

### *Proximity to Facilities with Highly Toxic Substances*

These facilities use highly toxic substances with potential flammable or explosive qualities and are required to establish a Risk Management Plan with the EPA. These compounds pose an increased environmental risk to communities nearby [11, 12, 13, 14, 15, 23, 24, 25]. Living near these facilities puts communities at a greater risk of adverse health impacts [11, 12, 13, 14, 15, 23, 24, 25]. Living near these facilities puts communities at a greater risk of negative health impacts due to the adverse environmental quality created but does consider exposure routes, and

thus is considered an environmental effect. Figure 10 visualizes the proximity to facilities with highly toxic substances in King County and the area of interest.

This indicator represents the count of facilities that have Risk Management Plans within 5 km of a block's centroid, divided by distance, as population-weighted averages of block groups summed over census tracts [15, 40]. Data used for the calculation was downloaded from EJSCREEN 2017 [15, 40].

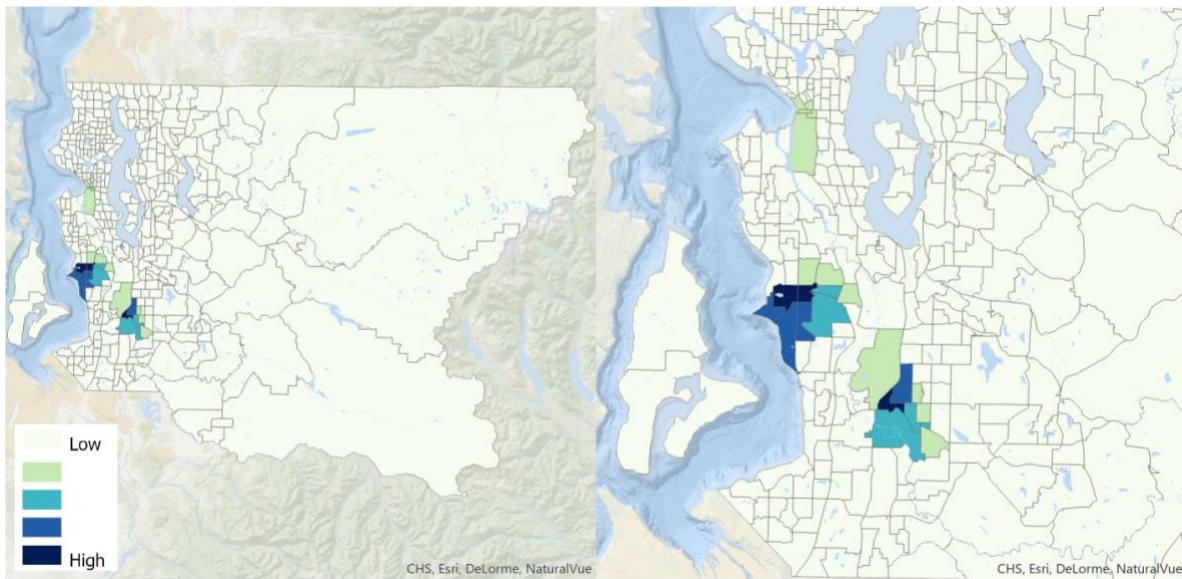


**Figure 10.** Proximity to facilities with highly toxic substances indicator, King County (left) and area of interest (right).

### *Wastewater Discharge*

Wastewater discharge can directly and indirectly contaminate surface and groundwater with chemicals and are associated with adverse human health and ecological effects [15, 40]. Figure 11 visualizes the proximity to wastewater discharge in King County and the area of interest.

This indicator considers pollutant loadings from the Discharge Monitoring Report Loading Tool (includes wastewater discharge data reported on Discharge Monitoring Reports under the Clean Water Act National Pollutant Discharge Elimination System permit program) for contaminants reported to the Toxics Release Inventory. The data was inputted into the RSEI model to consider chemical toxicity, fate, and transport to estimate concentrations in downstream water bodies (stream reaches) to develop a toxicity-weighted concentration. It represents the toxicity-weighted concentration in stream reaches within 5 km of a block group's centroid, divided by distance, as population-weighted averages of block groups summed over census tracts [15, 40], or the proximity to toxicity-weighted wastewater discharges. This does not take into account whether there is a discharge of pollutants, the waterbody discharged into, or potential exposure to discharged pollutants and thus is considered an environmental effect and not an exposure. Data used for the calculation was downloaded from EJSCREEN 2017 [15, 40].

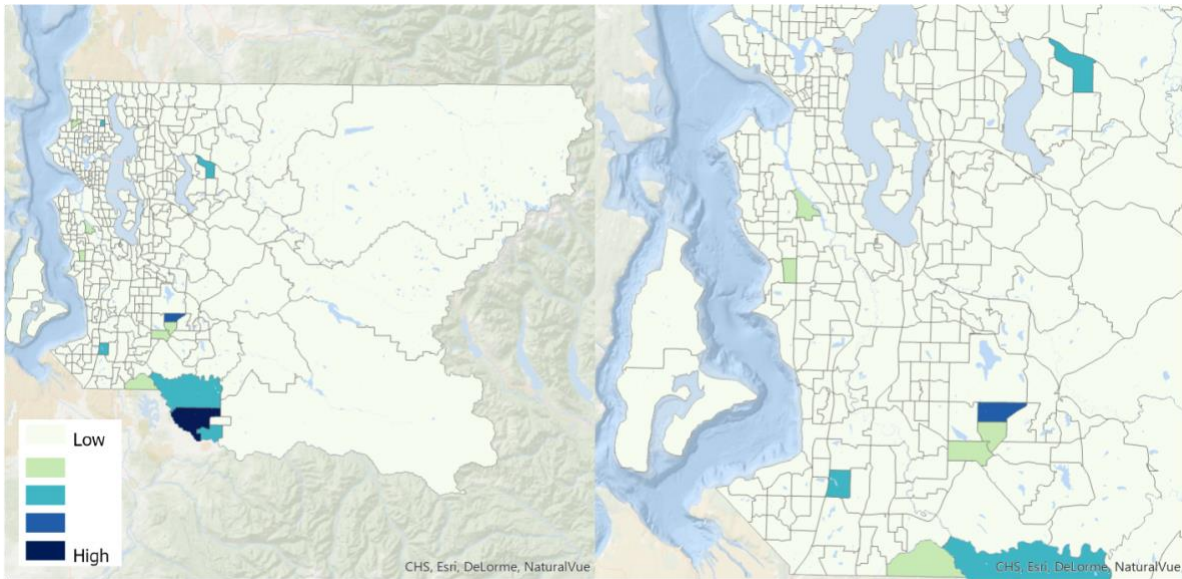


**Figure 11.** Proximity to toxicity-weighted wastewater discharge indicator, King County (left) and area of interest (right).

#### *Land Area in 100-Year Floodplain*

Flooding events cause an increase in the diffusive flux of contaminants, mobilizes contaminants into the water column, and transports resuspended contaminants from their original deposition site [21]. These disturbances further change the chemical and physical environment, causing potential significant environmental and public health risks [21]. Increases in frequency and intensity of flooding events will exacerbate these issues. The area of land within the 100-year flood zone was considered an environmental effect as it creates an adverse living environment. Figure 12 visualizes the census tract’s area in the 100-year flood zone in King County and the area of interest. Comparing Figure 5 to Figure 12 emphasizes why it is important to consider both population and land area concerning hazard exposure. Census tracts’ population differs from its land area in the 100-year floodplain. A census tract may have a greater proportion of its land area in the flood zone but may not have a large population presence or vice versa, which changes the cumulative impacts of hazards.

The area of land in each census tract at risk from a 100-year flood was calculated according to the Federal Emergency Management Agency’s (FEMA) coding scheme, which includes moderate to low-risk areas, high-risk areas, high-risk coastal areas, and undetermined risk areas, and presented as a percentage [33]. The Q3 flood data was used for the calculation, which is derived from the Flood Insurance Rate Maps (FIRMs) published by FEMA [33]. The calculation was performed by the Washington State Department of Health.

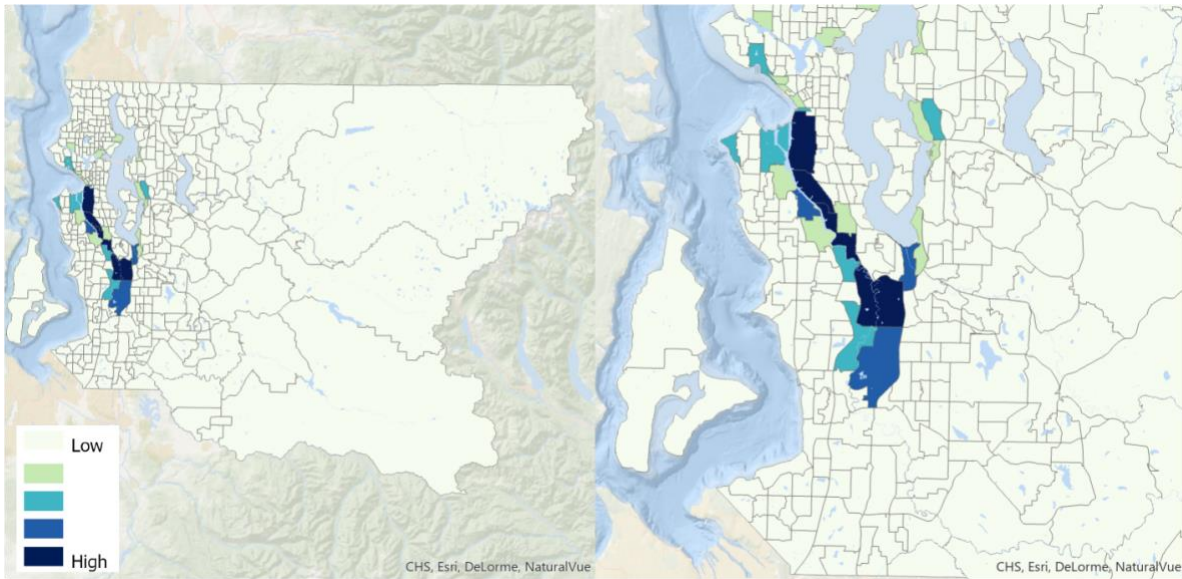


**Figure 12.** Land area in 100-year floodplain indicator, King County (left) and area of interest (right).

### *Sea Level Rise Impacted Area*

Understanding not only the population that is at risk of sea level rise, but the general area impacted can help identify natural and built environments at risk of rising water levels, enabling better formulation of mitigation and adaptation strategies. The need to develop improved disaster preparedness and climate change adaptation strategies to reduce vulnerability to weather extremes is significant when making projections of future increases in extreme precipitation events into account [8]. The area of land potentially impacted by sea level rise was considered an effect as it creates an adverse living environment from rising water levels and potential transported chemicals. Figure 13 visualizes census tract's area of land potentially impacted by sea level rise in King County and the area of interest. Comparing Figure 6 to Figure 13 emphasizes why it is important to consider both population and land area concerning hazard exposure. Census tracts' population differs from the area of land potentially affected by rising sea levels. A census tract may have a greater proportion of its area of land potentially affected by rising sea levels but may not have a large population presence or vice versa, which changes the adverse impact of the hazard.

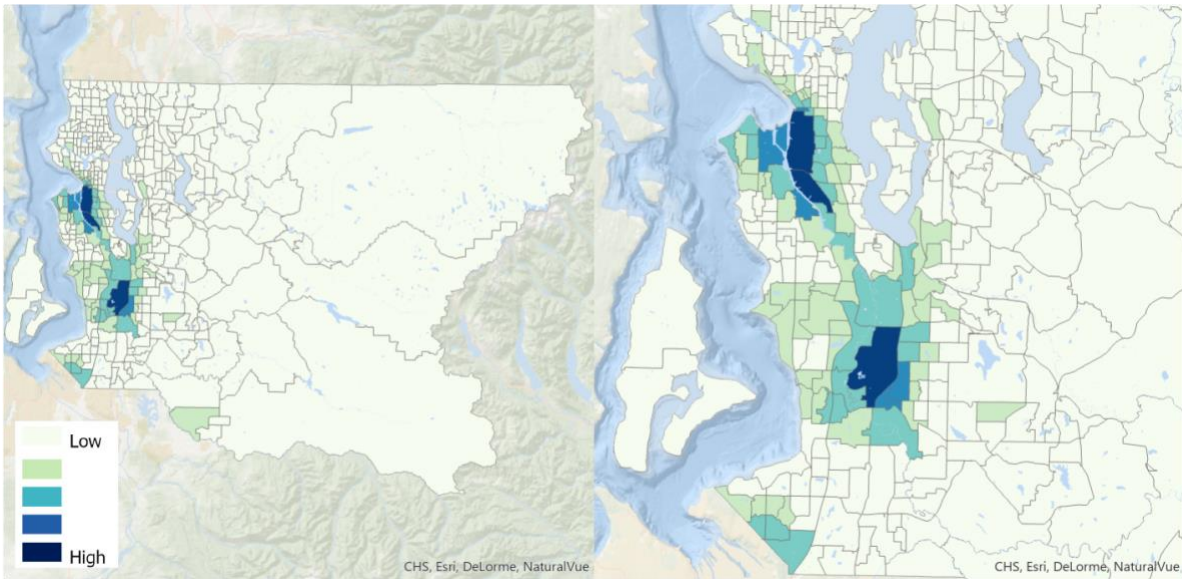
The area of land in each census tract at risk from potential sea level rise was calculated by dividing a census tract's total area by the total area of sea level in rise in acres within the census tract. The calculation was based on the Washington State Department of Health *area in the 100-year flood zone* calculation [33]. Refer to the *Population in Sea Level Rise* indicator for calculation of sea level rise.



**Figure 13.** Sea level rise impacted area indicator, King County (left) and area of interest (right).

*Environmental Effects Component*

All indicators defined as an environmental effect were summed, averaged, then reclassified on a 1-5 impact rank range to create an environmental effects component impact. Figure 14 visualizes the environmental effects component in King County and the area of interest.



**Figure 14.** Environmental effects component, King County (left) and area of interest (right).

## ***ii. Indicators in Social Vulnerability***

Secondary data was utilized from the Washington State Department of Health Tracking Network for both socioeconomic and sensitive population indicators. Data was obtained from the Office of Financial Management and US Census 5-year American Community Survey (ACS) (2015-2019) and were spatially joined to Census Tracts in King County to create polygon shapefiles with attached demographic data [34, 35, 36, 48, 49]. The American Community Survey (ACS) 5-year statistics, based on data collected from 2015 to 2019, cover social, economic, demographic, and housing characteristics [46].

The data were normalized by calculating the Z-score for all socioeconomic and sensitive population indicators. Each Z-score indicator was converted to a separate raster layer and reclassified into equal interval classifications based on the appointed impact rank ranges. Once all indicators were reclassified, the social vulnerability was calculated.

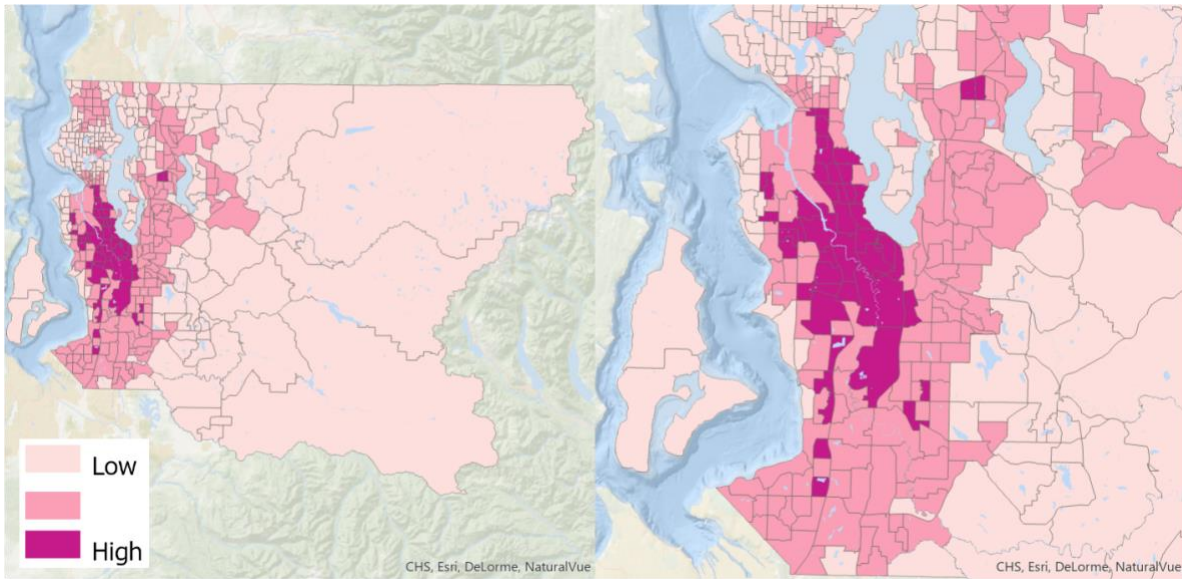
Data collection and original calculations for social vulnerability indicators were calculated by the agencies listed under the data source column in Table 4 unless otherwise noted.

### ***Socioeconomic Factors 1-3***

Each Z-score indicator was converted to a separate raster layer. The cell assignment types were set to “cell center” meaning the polygon attribute that overlaps the center of the cell yields the cell attribute and cell size was set to 10. The Reclassify tool was used to reclassify the raster layers into equal interval classifications on a 1-3 impact rank range, with an impact rank of “3” considered the greatest potential impact from socioeconomic factors compared to an impact rank of “1”. The darker the pink, the greater the socioeconomic vulnerability.

### ***People of Color***

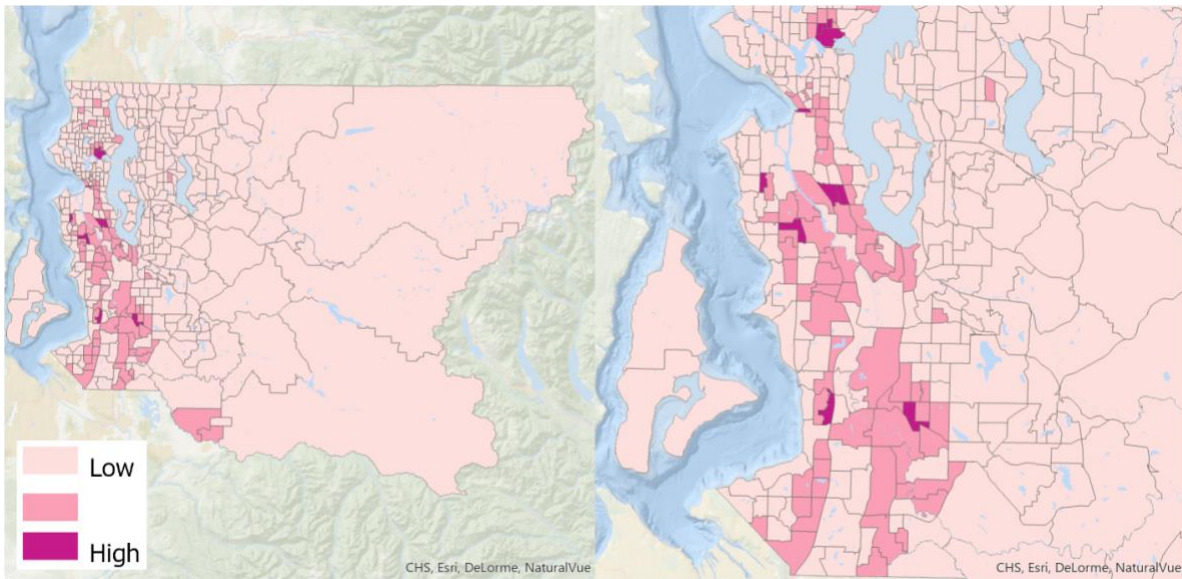
Marginalized racial and ethnic groups are disproportionately affected by environmental risk factors and are more likely to experience unequal adverse health outcomes from such factors [12, 13, 14, 23, 24, 25]. These communities have historically been in closer proximity to Hazardous Waste Generators and Facilities, Superfund sites, and Facilities with Highly Toxic Substances when compared to predominantly white communities [12, 13, 14, 23, 24, 25]. These communities are also more likely to be impacted by toxic releases from facilities and wastewater discharge pollutants [12, 13, 14, 23, 24, 25]. Thus, these communities are at a greater exposure risk as well as are more likely to experience greater adverse health outcomes. This indicator is the sum of all race/ethnicity categories besides White/Non-Hispanic [4]. It includes the total percentage of Black, American Indian/Alaskan Native, Asian, Native Hawaiian-Other Pacific Islander, and two or more races per census tract in King County [4]. Figure 15 visualizes people of color in King County and the area of interest.



**Figure 15.** People of color indicator, King County (left) and area of interest (right).

*Population Living in Poverty*

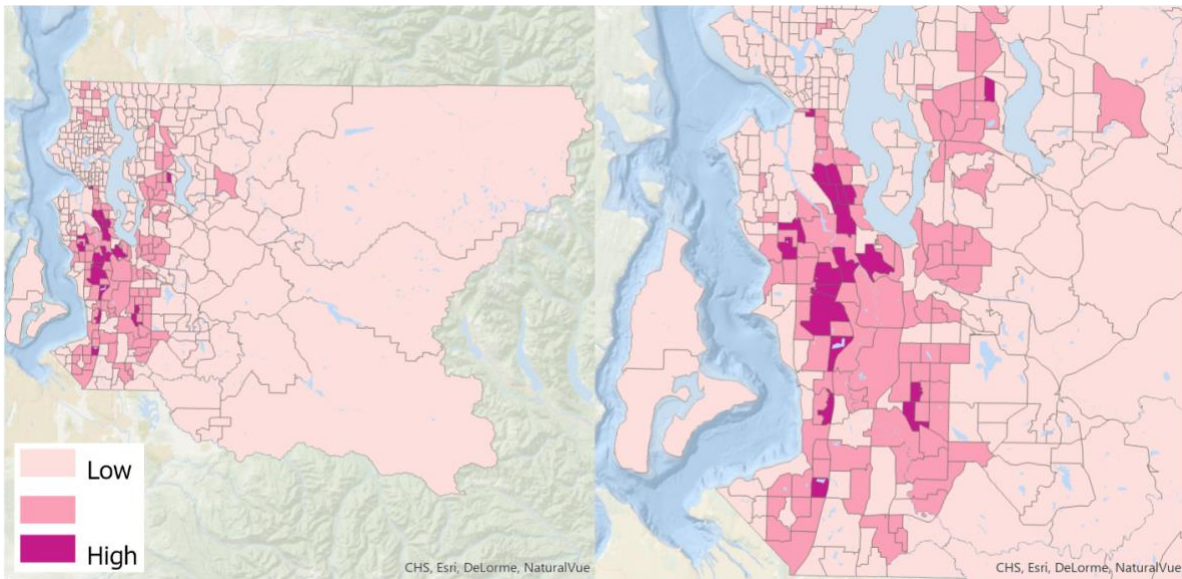
Low-income communities are disproportionately affected by environmental risk factors and are more likely to experience unequal adverse health outcomes from such factors when compared to high-income communities [12, 13, 14, 23, 24, 25]. These communities also have a lower resiliency when responding to environmental risk factors due to their limited access to risk management instruments, lack of basic services, poor infrastructures, etc. [12, 13, 14, 23, 24, 25]. Persons living in poverty experience chronic stress, lack of resources, lack of education, poor physical and mental health, etc., that already negatively impact their biological susceptibility or extrinsic vulnerabilities when coupled with environmental risk factors [12, 13, 14, 23, 24, 25]. This indicator represents the percentage of the total population whose income was less than or equal to 185% of the federal poverty level within the past 12 months [35] designated by the Washington State Department of Health Washington Tracking Network. Figure 16 visualizes the population living in poverty in King County and the area of interest.



**Figure 16.** Population living in poverty indicator, King County (left) and area of interest (right).

*Limited English Proficiency*

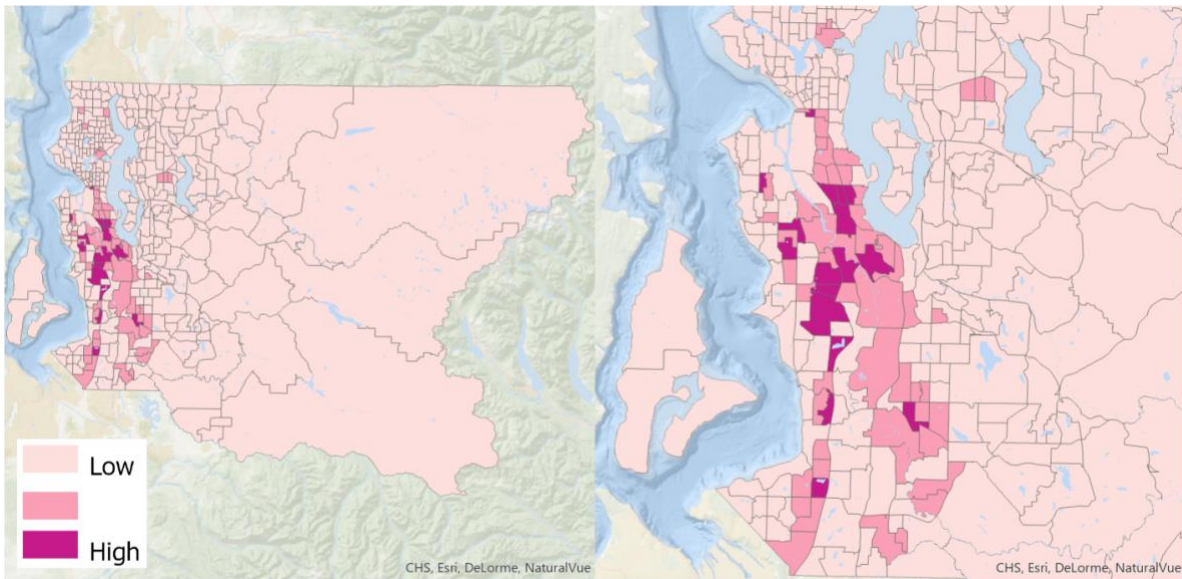
Spoken language has been identified as an indicator of social vulnerability to disaster response [12, 13, 14]. Language barriers make it difficult to understand environmental risk factor warnings and data, affecting a person’s ability to act during natural hazard events [12, 13, 14]. Communities with a high level of linguistic isolation live in closer proximity to Hazardous Waste Generators and Facilities, Superfund sites, and Facilities with Highly Toxic Substances than communities with lower levels of linguistic isolation [12, 13, 14]. Communities with high levels of linguistic isolation experience greater civil engagement barriers that affect environmental policies, leading to environmental disparities that the community cannot effectively respond to [12, 13, 14]. This indicator represents the percentage of the total population five years and older that speak English less than “very well” or “not at all” [30]. Figure 17 visualizes limited English proficiency in King County and the area of interest.



**Figure 17.** Limited English proficiency indicator, King County (left) and area of interest (right).

*Socioeconomic Component*

All indicators defined as a socioeconomic factor were summed, averaged, then reclassified on a 1-3 impact rank range to create a socioeconomic component impact. Figure 18 visualizes the socioeconomic component in King County and the area of interest.



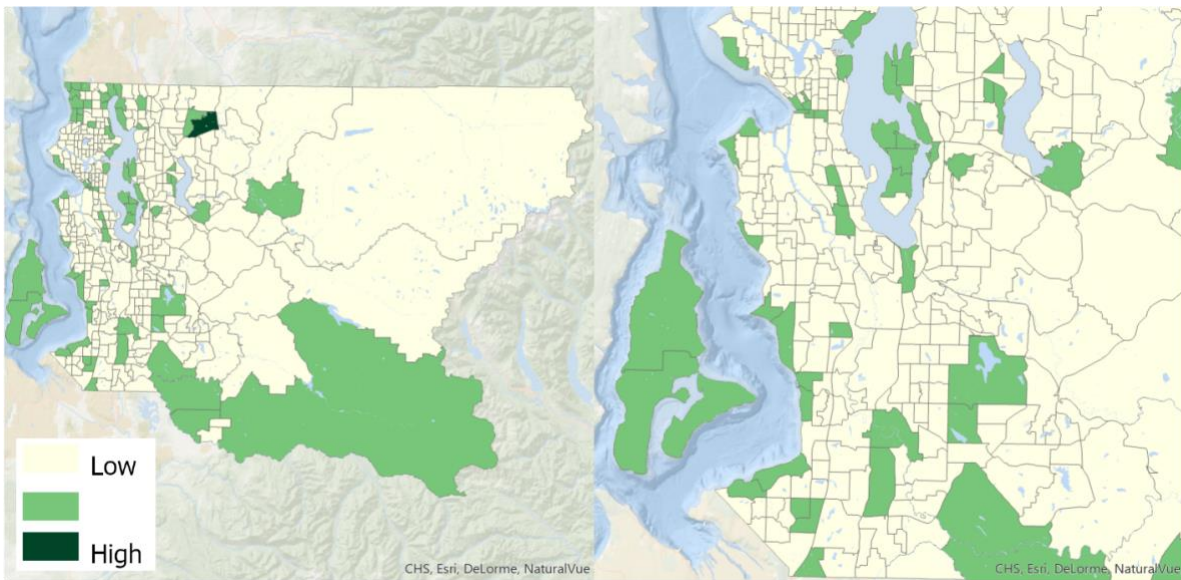
**Figure 18.** Socioeconomic factors component, King County (left) and area of interest (right).

### ***Sensitive Population Factors 1-3***

Each Z-score indicator was converted to a separate raster layer. The cell assignment types were set to “cell center” meaning the polygon attribute that overlaps the center of the cell yields the cell attribute and cell size was set to 10. The Reclassify tool was used to reclassify the raster layers into equal interval classifications on a 1-3 impact rank range, with an impact rank of “3” considered the greatest potential impact from sensitive population factors compared to an impact rank of “1”. The darker the green, the greater the sensitive population vulnerability.

#### ***Persons Over the Age of 65***

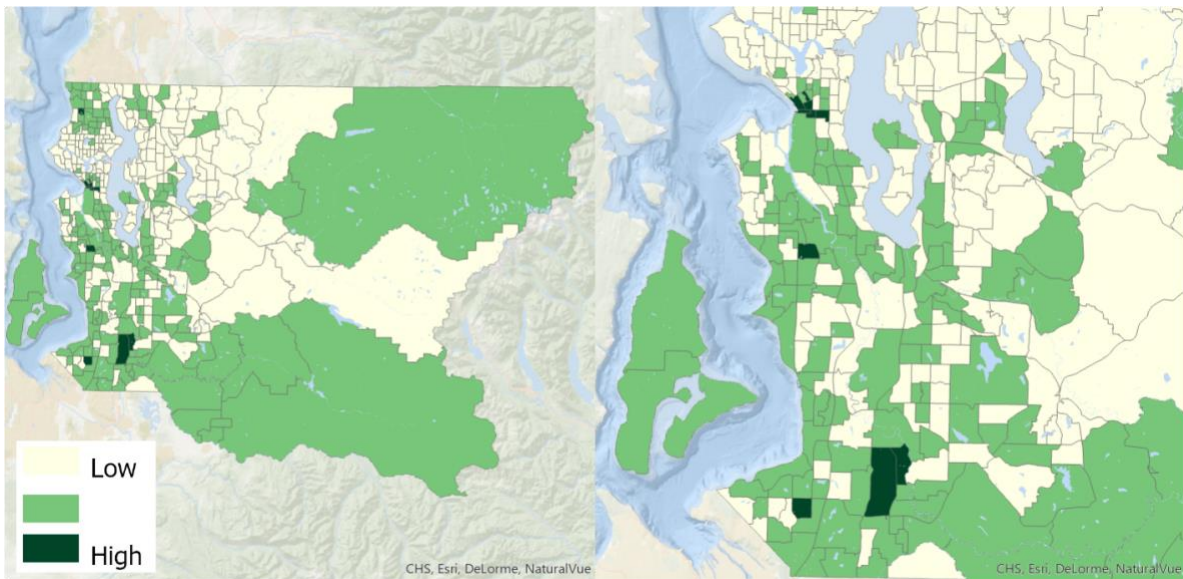
Persons over the age of 65 are more likely to have pre-existing medical conditions and compromised mobility, subsequently making it more difficult to tolerate and respond to environmental risk factors [12, 13, 14]. Living alone with no support system can make it tougher to respond to and recover from environmental risk factors while living with others could increase the burden of care to others [12, 13, 14]. These individuals’ susceptibility places them at an increased risk when exposed to environmental hazards. This indicator represents the percentage of the population 65 years old or older [49]. Figure 19 visualizes persons over the age of 65 in King County and the area of interest. The darker the green, the greater the sensitive population vulnerability.



**Figure 19.** Persons over the age 65 indicator, King County (left) and area of interest (right).

#### ***Population with a Disability***

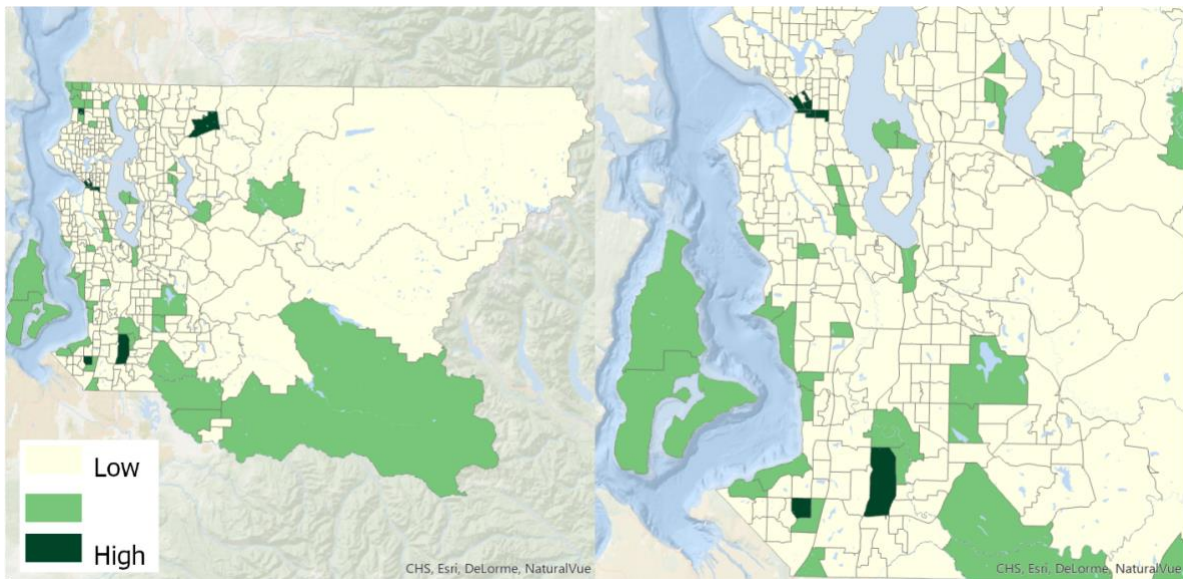
Persons with a disability are at a greater risk of adverse impacts from natural hazard events from built social and environmental barriers, including the absence of specific evacuation plans, inaccessible warning information, and lack of accessible evacuation transport [16, 17]. These individuals’ susceptibility places them at an increased risk when exposed to environmental hazards. This indicator represents the percentage of the population with a disability, defined as hearing, vision, cognitive, ambulatory, self-care, or independent living difficulty [48]. Disability status is defined as having one or more of these difficulties [48]. Figure 20 visualizes population with a disability in King County and the area of interest.



**Figure 20.** Population with a disability indicator, King County (left) and area of interest (right).

*Sensitive Population Component*

All indicators defined as a sensitive population factor were summed, averaged, then reclassified on a 1-3 impact rank range to create a sensitive population component impact. Figure 21 visualizes the sensitive population component in King County and the area of interest.



**Figure 21.** Sensitive populations component, King County (left) and area of interest (right).

## C. Socioeconomic Factors and Chemical Waste Hazards

After completing the analysis for the indicator and component maps, two follow-up questions arose: 1) Are higher socioeconomic vulnerable communities within closer proximity to chemical waste hazards compared to lower socioeconomic vulnerable communities in Southwestern King County? 2) Are there disparities in decision-making when it comes to evaluating chemical waste hazards in Southwestern King County? The extent of this analysis was isolated to Southwestern King County where the majority of chemical waste hazards are located, particularly the Duwamish Valley, an area that has been the focus of cleanup efforts since 2001 when the EPA declared it a Superfund site [50].

### *i. Proximity Analysis*

To address question one, a proximity analysis was performed to determine whether census tracts with high socioeconomic vulnerabilities were in closer proximity to chemical waste hazards. Proximity to chemical waste hazards referred to only three environmental effect indicators: 1. Proximity to Hazardous Waste Generators, 2. Proximity to Superfund sites, and 3. Proximity to Facilities with Highly Toxic Substances. These indicators were considered based on background literature exploration of their significance. The three indicators were summed then averaged, creating one raster layer with calculated ranks (1 to 5 impact rank range) [11, 23]. This proximity raster layer was reclassified using equal intervals as the classification method with a 1-5 impact rank range [11, 31]. The raster layer was converted to a vector layer to create polygons and spatially joined to the census tract polygon layer, assigning each census tract a chemical waste hazard proximity impact rank. An impact rank of “1” indicates the lowest potential hazard impact while an impact rank of “5” indicates the greatest potential hazard impact, or the greater the chemical waste hazard proximity impact rank, the closer a community is to those hazards and their potential adverse impacts. Communities that are within close proximity to chemical waste hazards are at an increased environmental risk to discharged contaminants and experience greater adverse health impacts [11, 12, 13, 14, 15, 23, 24, 25]. However, not all communities will experience the same adverse impacts from chemical waste hazards due to their socioeconomic makeup. Lower-income communities of color have historically been in closer proximity to Hazardous Waste Generators and Facilities, Superfund sites, and Facilities with Highly Toxic Substances when compared to predominantly white, high-income communities [11, 12, 13, 14, 15, 23, 24, 25]. Thus, the socioeconomic vulnerability of communities must be considered in relation to chemical waste hazard proximity.

The socioeconomic indicators (people of color, population living in poverty, and limited English proficiency) were considered based on background literature exploration of their significance in relation to proximity to chemical waste hazards. These indicators were summed then averaged, creating one raster layer with calculated ranks (1 to 3 impact rank range) [11, 23]. The raster layer was reclassified using equal intervals as the classification method with a 1-3 impact rank range [11, 23]. The raster layer was converted to a polygon layer and spatially joined to the census tract polygon layer, assigning each census tract a socioeconomic impact rank. A socioeconomic impact rank of “1” indicates low socioeconomic vulnerability, “2” indicates medium socioeconomic vulnerability, and “3” indicates high socioeconomic vulnerability [11, 23].

The Summarize Within tool was utilized to calculate the average and standard deviations of chemical waste proximity hazard impact ranks within the socioeconomic impact ranks [47]. The socioeconomic impact ranks were the “zones” and the chemical waste proximity hazard impact ranks provided the statistics. The results are displayed in Table 5 and supports current environmental injustice research on chemical waste hazards and socioeconomic disparities.

<i>Socioeconomic Vulnerability Classification*</i>	<i>Average Chemical Waste Hazard Proximity Impact Rank**</i>	<i>Standard Deviation</i>
<i>Low (Impact Rank 1)</i>	1.7	0.9
<i>Medium (Impact Rank 2)</i>	2.2	1.3
<i>High (Impact Rank 3)</i>	2.8	1.4
<i>All Classifications</i>	2.1	1.2

**Table 5.** Average chemical waste hazards proximity impact ranks and standard deviations within socioeconomic vulnerability rank classifications.

\*A socioeconomic impact rank of “1” indicates low socioeconomic vulnerability, “2” indicates medium socioeconomic vulnerability, and “3” indicates high socioeconomic vulnerability.

\*\* The greater the chemical waste hazard proximity impact rank, the closer a community is to those hazards.

The low *Socioeconomic Vulnerability Classification* group’s (impact rank 1) 1.7 chemical waste hazard proximity rank is less than the average of 2.1. The medium *Socioeconomic Vulnerability Classification* group’s (impact rank 2) 2.2 chemical waste hazard proximity rank is slightly but not significantly above the average of 2.1. The high *Socioeconomic Vulnerability Classification* group’s (impact rank 3) 2.8 chemical waste hazard proximity rank is greater than the average of 2.1. High socioeconomic vulnerable communities are within closer proximity to chemical waste hazards compared to low socioeconomic vulnerable communities. Communities with high socioeconomic vulnerability face greater difficulties in responding and adapting to chemical waste hazards and their discharges, which further amplifies the disparities gap [11, 12, 13, 14, 15, 23, 24, 25]. Site clean-up efforts and mitigation strategies should be focused on assisting high socioeconomic vulnerable communities.

## ***ii. Site Hazard Assessment Evaluation***

Question two is dependent upon whether sites have been visited or not and thus if they have been given a Site Hazard Assessment rank. Secondary chemical waste hazard data was utilized from the Department of Ecology [32]. This dataset includes confirmed and suspected hazardous/dangerous waste sites, defined as sites that are undergoing cleanup or awaiting further investigation or cleanup. Figure 22 illustrates the site cleanup definitions. Sites used in this analysis included awaiting cleanup, cleanup started, and tracked by EPA so communities understand the types of sites that are within proximity to them. An excel spreadsheet was directly downloaded from the Department’s website. Each site includes a cleanup site ID, facility site ID, site name, alternate site names, site status, site rank, address, city, zip code, county, region, responsible unit, latitude, longitude, contaminant name, and whether contaminants are in groundwater, surface water, soil, sediment, and air [32]. Data from the Excel spreadsheet was uploaded and points were geographically mapped based on the latitude and longitude of each site.

**Awaiting Cleanup:** The site has been discovered. There may have been an initial investigation, Phase I or Phase II site assessment. A remedial investigation has not been started. No independent, Voluntary Cleanup Program, or Ecology supervised work has occurred toward cleaning up the site.

**Cleanup Started:** Site remedial investigation or cleanup work has begun. Includes completed interim actions. Includes Ecology or EPA supervised sites, Voluntary Cleanup Program sites, and independent sites where an emergency action, remedial investigation, interim action, feasibility study, site characterization, or any other type of cleanup work has begun.

**Construction Complete-Performance Monitoring:** Cleanup construction and source control are complete. Performance monitoring is underway to “confirm that the cleanup action has attained cleanup standards, remediation levels, or other performance standards.”

**Cleanup Complete-Active O&M/Monitoring:** All construction and physical cleanup work has been done and cleanup standards met, but some active operation, maintenance, and/or monitoring work is required on an ongoing basis to maintain cleanup standards.

**No Further Action:** Sites that have received a No Further Action determination (NFA) at the Initial Investigation or Site Hazard Assessment, received an NFA letter (not ranked), or have been removed from the Hazardous Sites List (if ranked).

**Tracked by EPA:** Sites where EPA is the Responsible Unit and Superfund lead, and cleanup occurs under CERCLA only.

**Figure 22.** Current status of the cleanup for the site [32].

The Department of Ecology assigns a site rank, known as a Site Hazard Assessment rank, that “confirms the presence of hazardous substances and determines the relative risk the site poses to human health and the environment using the Washington Ranking Method (WARM). A WARM score is a number between 1 and 5, where “1” represents the highest level of risk and “5” the lowest. Some factors that enter into site hazard ranking include the amount and type of contaminants present, and how easily contaminants could come into contact with people and the environment” [32].

The Site Hazard Assessment rank ranges from 0-5 and is as follows [31]:

- 0: NPL/Federal Superfund
- 1: Highest Assessed Risk
- 2: Moderate-High Risk
- 3: Moderate Risk
- 4: Low-Moderate Risk
- 5: Lowest Assessed Risk

However, not all sites have been given a Site Hazard Assessment rank because they have not been visited and assessed. The point layer was aggregated based on the cleanup sites’ unique IDs which summed the number of chemicals per site [48]. Given the chosen parameters stated above, within King County there were 2,068 confirmed and suspected hazardous/dangerous waste sites. Of those sites, only 549 sites have been assessed and assigned a Site Hazard Assessment rank, leaving 1,519 sites not yet evaluated. Within Southwestern King County, there were 1,568 known or suspected hazardous sites. Over half of the total sites within King County are located

within Southwestern King County. Of those sites, only 464 sites have been assessed and assigned a Site Hazard Assessment rank, leaving 1,104 sites not yet evaluated.

A new attribute field was created and if a site has been evaluated it was assigned a “1”, if it has not yet been evaluated it was assigned a “0”. Each assignment type was exported and then spatially joined to the census tract polygon layer to create a join count for the number of sites visited, the number of sites not visited, and the total number of sites within each census tract. The number of sites not visited was divided by the total number of sites to calculate the percentage of sites not visited in each census tract. The Summarize Within tool was utilized to calculate the average and standard deviation percentages of unvisited sites within the socioeconomic impact ranks [47]. The socioeconomic impact ranks were the “zones” and the percent of unvisited sites provided the statistics. The results are displayed in Table 6 and indicate there are not disparities in decision-making when it comes to evaluating known or suspected hazardous sites.

<i>Socioeconomic Vulnerability Rank Classification*</i>	<i>Average Percent of Unvisited Sites**</i>	<i>Standard Deviation</i>
<i>Low (Impact Rank 1)</i>	71%	37%
<i>Medium (Impact Rank 2)</i>	72%	34%
<i>High (Impact Rank 3)</i>	65%	35%
<i>All Classifications</i>	70%	36%

**Table 6.** Average percent of unvisited sites and standard deviations within socioeconomic vulnerability rank classifications.

\*A socioeconomic impact rank of “1” indicates low socioeconomic vulnerability, “2” indicates medium socioeconomic vulnerability, and “3” indicates high socioeconomic vulnerability.

\*\*Sites that have not been visited and assigned a Site Hazard Assessment rank.

The high *Socioeconomic Vulnerability Classification* group (impact rank 3) seems to be the focus of site evaluation and possible clean-up efforts, having an average percent of unvisited sites at 65%, which is less than the overall average of 70%. In comparison, the low and medium *Socioeconomic Vulnerability Classification* groups (impact rank 1 and 2, respectively) had average precents of unvisited sites (71% and 72%, respectively) greater than the overall average of 70%. These findings support current clean-up efforts concentrated around the Duwamish Valley, an area that experiences high environmental exposures, effects, and socioeconomic vulnerability (Figures 7, 14, and 18 respectively). Decision-making should continue to prioritize evaluation and cleanup actions in socioeconomic vulnerable communities, who face greater difficulties in responding and adapting to such sites and their chemicals, further amplifying the disparities gap [11, 12, 13, 14, 15, 23, 24, 25]. Sites that have not been visited and assigned a subsequent hazard assessment rank cannot be prioritized for clean-up actions, allowing them to continue contaminating the environment and exposing communities to chemicals. These findings also highlight the urgency for site assessments.

Further analysis on the percent of visited sites within *Socioeconomic Vulnerability Classification* groups characterized the distribution of site risk within socioeconomic vulnerability classifications. The Summarize Within tool was utilized to calculate the percent of visited sites within Site Hazard Assessment ranks based on the socioeconomic vulnerability classifications, displayed in Table 7. The high *Socioeconomic Vulnerability Classification* group (impact rank 3)

had the greatest percent of visited sites assigned a Site Hazard Assessment rank of 0 and 5 (NPL/Federal Superfund and Lowest Assessed Risk, respectively). The medium *Socioeconomic Vulnerability Classification* group (impact rank 2) had the greatest percent of visited sites assigned a Site Hazard Assessment rank of 2 and 4 (Moderate-High Risk and Low-Moderate Risk, respectively). The low *Socioeconomic Vulnerability Classification* group (impact rank 1) had the greatest percent of visited sites assigned a Site Hazard Assessment rank of 1 and 3 (Highest Assessed Risk and Moderate Risk, respectively). Besides high socioeconomic vulnerable groups having the greatest percent of high-risk sites (NPL/Federal Superfund), the distribution of site risk within socioeconomic vulnerability classifications did not allude to any further disparities in evaluation of sites and their associated risk.

<i>Socioeconomic Vulnerability Classification*</i>	<i>Site Hazard Assessment Rank**</i>	<i>Percent of Visited Sites***</i>
<i>Low (Impact Rank 1)</i>	0: NPL/Federal Superfund	4.91%
	1: Highest Assessed Risk	30.56%
	2: Moderate-High Risk	10.47%
	3: Moderate Risk	23.30%
	4: Low-Moderate Risk	15%
	5: Lowest Assessed Risk	15.82%
	Average Visited Sites	29%
<i>Medium (Impact Rank 2)</i>	0: NPL/Federal Superfund	3.51%
	1: Highest Assessed Risk	20.47%
	2: Moderate-High Risk	11.11%
	3: Moderate Risk	20.18%
	4: Low-Moderate Risk	28.95%
	5: Lowest Assessed Risk	15.79%
	Average Visited Sites	28%
<i>High (Impact Rank 3)</i>	0: NPL/Federal Superfund	11.17%
	1: Highest Assessed Risk	14.08%
	2: Moderate-High Risk	7.37%
	3: Moderate Risk	15.42%
	4: Low-Moderate Risk	21.45%
	5: Lowest Assessed Risk	30.50%
	Average Visited Sites	35%

**Table 7.** Socioeconomic vulnerability rank classifications’ average percent of sites within Site Hazard Assessment rank categories.

\*A socioeconomic impact rank of “1” indicates low socioeconomic vulnerability, “2” indicates medium socioeconomic vulnerability, and “3” indicates high socioeconomic vulnerability.

\*\* Department of Ecology’s confirmed and suspected hazardous/dangerous waste sites’ relative risk.

\*\*\*Percent of sites that have been visited and assigned a Site Hazard Assessment rank.

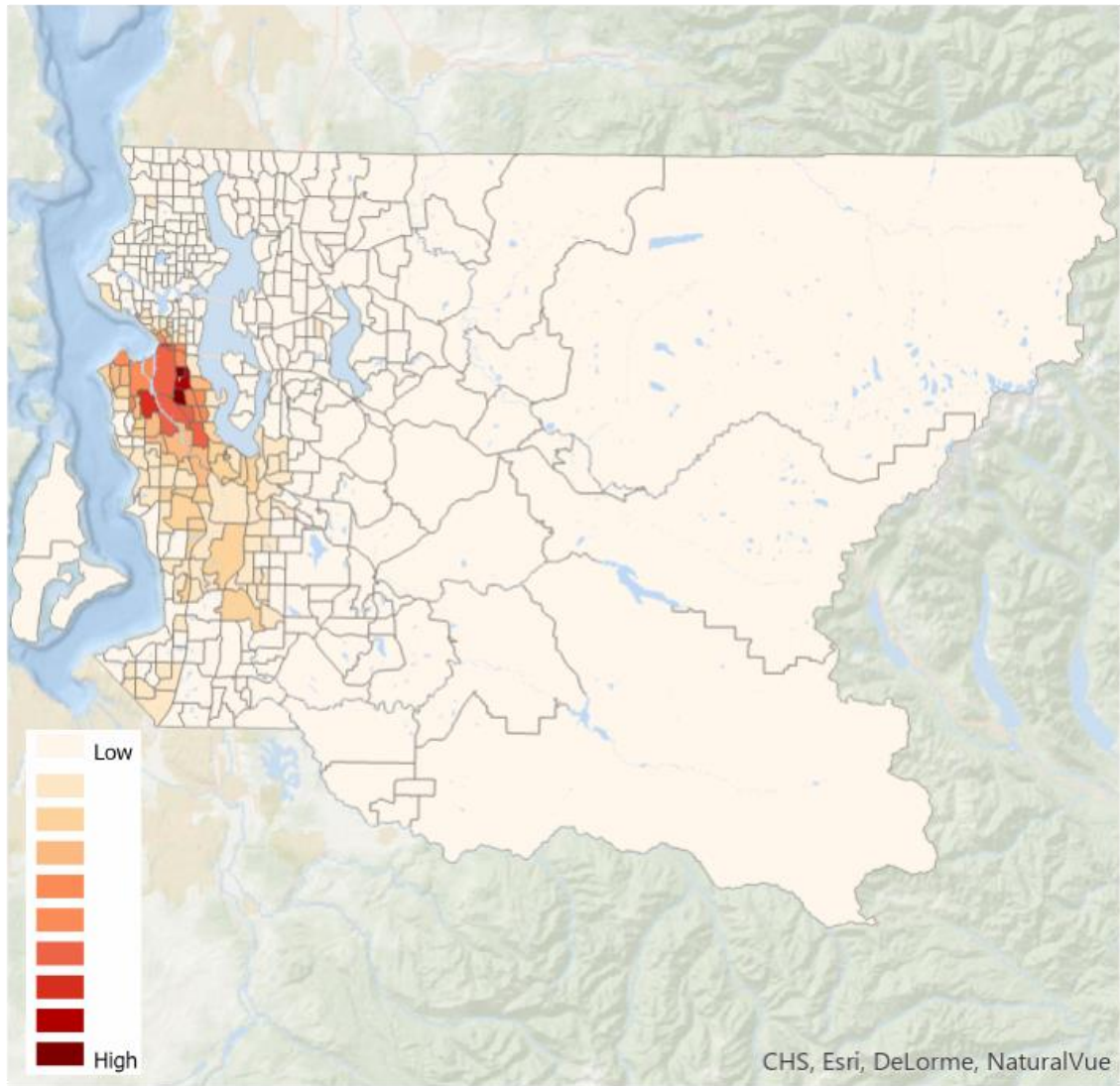
## 4. CUMULATIVE IMPACT MAP ANALYSES

### A. Aim 1) Chemical Waste Hazards Cumulative Impacts

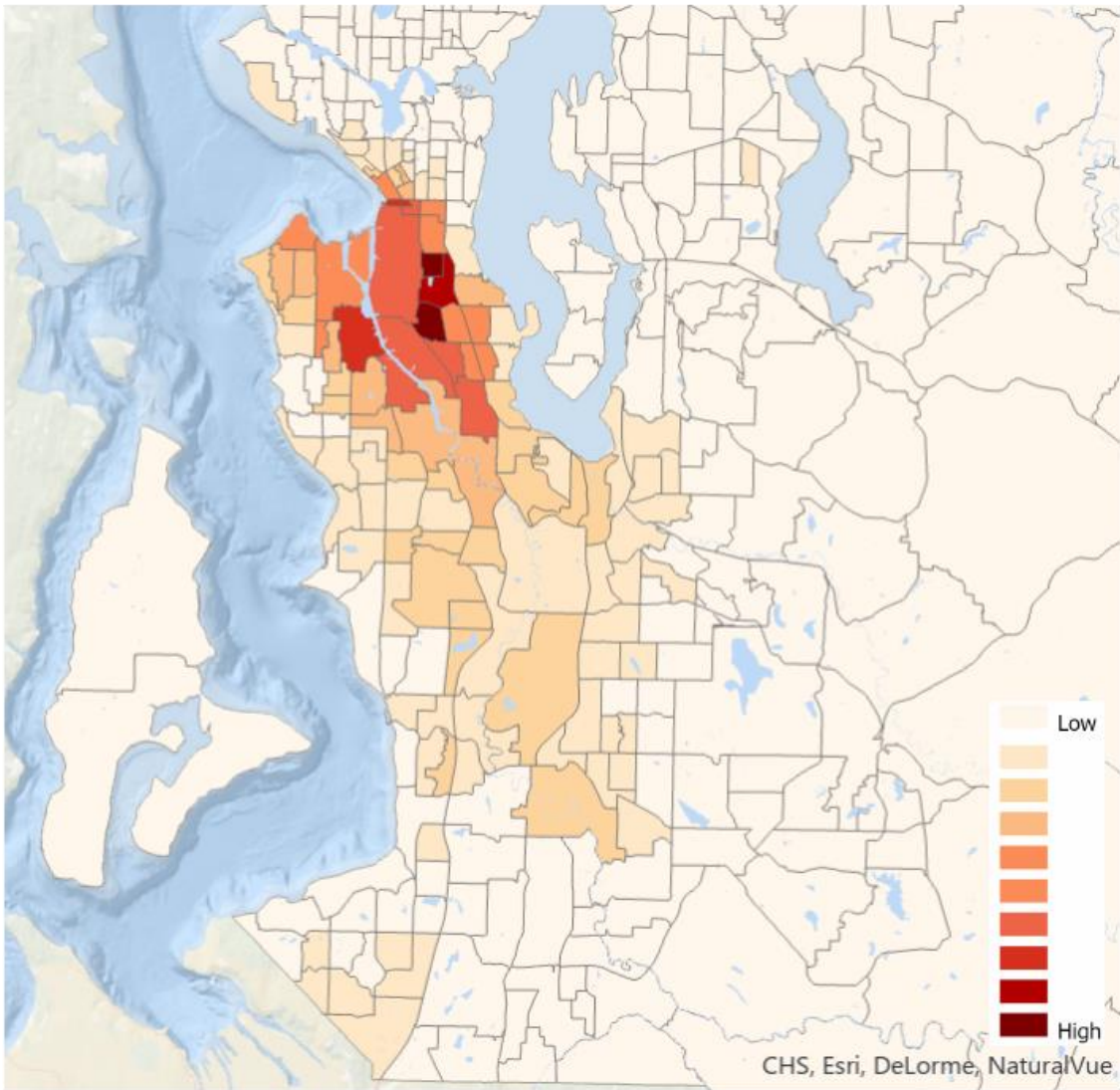
Ten indicators' reclassified layers were used to characterize the *Chemical Waste Hazards Cumulative Impacts*. Figure 23 illustrates the ten *environmental threat* and *social vulnerability* indicator layers, while Figure 24 and 25 visualize the cumulative impacts for King County and the area of interest. Focusing on the area of interest (Figure 25), South Downtown (SODO) and the industrial district experience the greatest potential cumulative impacts, while the Duwamish Valley also experiences notable impacts.

<b>Chemical Waste Hazards Cumulative Impacts</b> <i>Cumulative Impacts = Environmental Threat X Social Vulnerability</i>			
<b>Environmental Threat</b> Environmental Threat Score = Average Environmental Exposure Indicators + Average Environmental Effect Indicators		<b>Social Vulnerability</b> Social Vulnerability Score = Average Socioeconomic Indicators + Average Sensitive Population Indicators	
<b>Environmental Exposures (1-10)</b>	<b>Environmental Effects (1-5)</b>	<b>Socioeconomic Factors (1-3)</b>	<b>Sensitive Populations (1-3)</b>
Toxic Releases from Facilities [40]	Proximity to Hazardous Waste Generators and Facilities [40] Proximity to Superfund Sites [40] Proximity to Facilities with Highly Toxic Substances [40] Wastewater Discharge [40]	People of Color [34] Population Living in Poverty (<= 185% of Federal Poverty Level) [35] Limited English Proficiency [36]	Persons Over the Age 65 [39] Population with a Disability [38]

**Figure 23.** Chemical waste hazards cumulative impact indicators and formula.



**Figure 24.** Chemical waste hazards cumulative impact at the extent of King County.



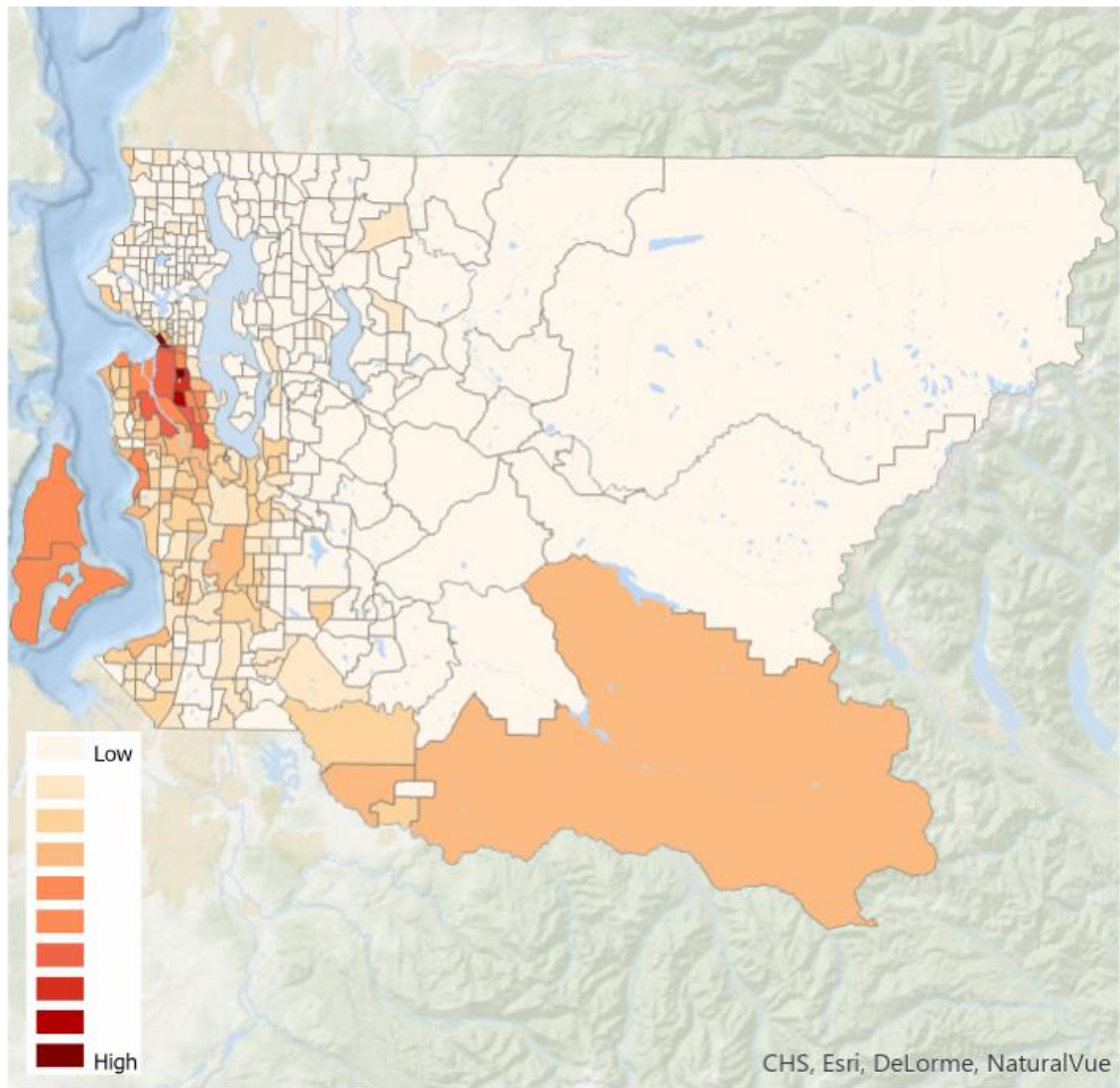
**Figure 25.** Chemical waste hazards cumulative impacts at the extent of the area of interest.

## B. Aim 2) Floodplains and Chemical Waste Hazards Cumulative Impacts

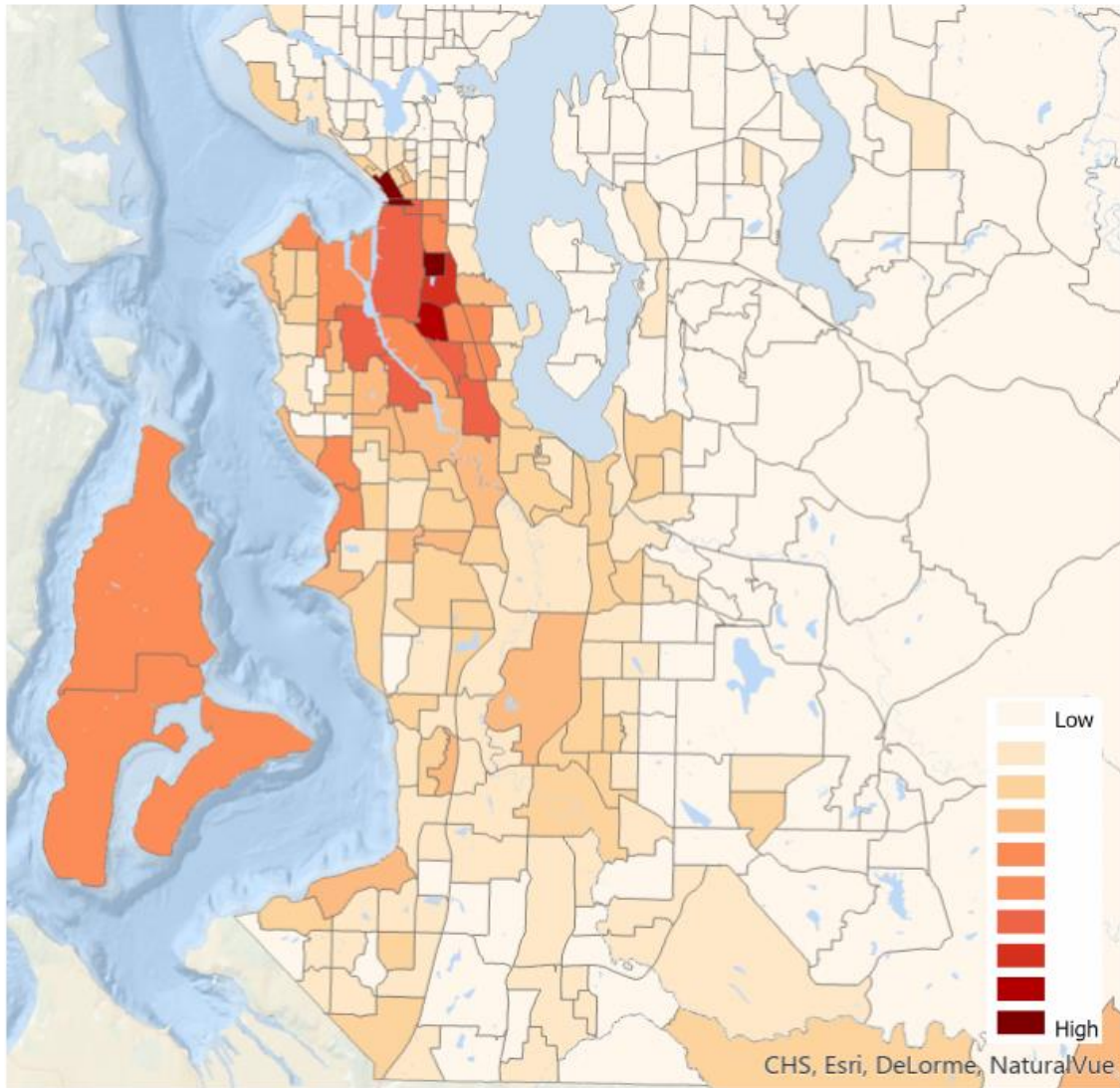
Twelve indicators' reclassified layers were used to characterize the *Floodplains and Chemical Waste Hazards Cumulative Impacts*. This cumulative impact analysis added *Population in the 100-Year floodplain* and *Land Area in the 100-Year Floodplain* as new *environmental threat* indicators to Aim 1's *Chemical Waste Hazards Cumulative Impacts*. Figure 26 illustrates the twelve *environmental threat* and *social vulnerability* indicator layers, while Figure 27 and 28 visualize the cumulative impacts for King County and the area of interest. Focusing on the area of interest (Figure 28), SODO and the industrial district experience the greatest potential cumulative impacts, while the Duwamish Valley and Vashon also experience notable impacts.

<b>Floodplains and Chemical Waste Hazards Cumulative Impacts</b> <i>Cumulative Impacts = Environmental Threat X Social Vulnerability</i>			
<b>Environmental Threat</b> Environmental Threat Score = Average Environmental Exposure Indicators + Average Environmental Effect Indicators		<b>Social Vulnerability</b> Social Vulnerability Score = Average Socioeconomic Indicators + Average Sensitive Population Indicators	
<b>Environmental Exposures (1-10)</b>	<b>Environmental Effects (1-5)</b>	<b>Socioeconomic Factors (1-3)</b>	<b>Sensitive Populations (1-3)</b>
Toxic Releases from Facilities [40] Population in the 100-Year Floodplain [37]	Proximity to Hazardous Waste Generators and Facilities [40] Proximity to Superfund Sites [40] Proximity to Facilities with Highly Toxic Substances [40] Wastewater Discharge [40] Land Area in the 100-Year Floodplain [33]	People of Color [34] Population Living in Poverty (<= 185% of Federal Poverty Level) [35] Limited English Proficiency [36]	Persons Over the Age 65 [39] Population with a Disability [38]

**Figure 26.** Floodplains and chemical waste hazards cumulative impacts indicators and formula. Population in the 100-Year Floodplain and Land Area in the 100-Year Floodplain were added as new *environmental threat* indicators.



**Figure 27.** Floodplains and chemical waste hazards cumulative impacts at the extent of King County.



**Figure 28.** Floodplains and chemical waste hazards cumulative impacts at the extent of the area of interest.

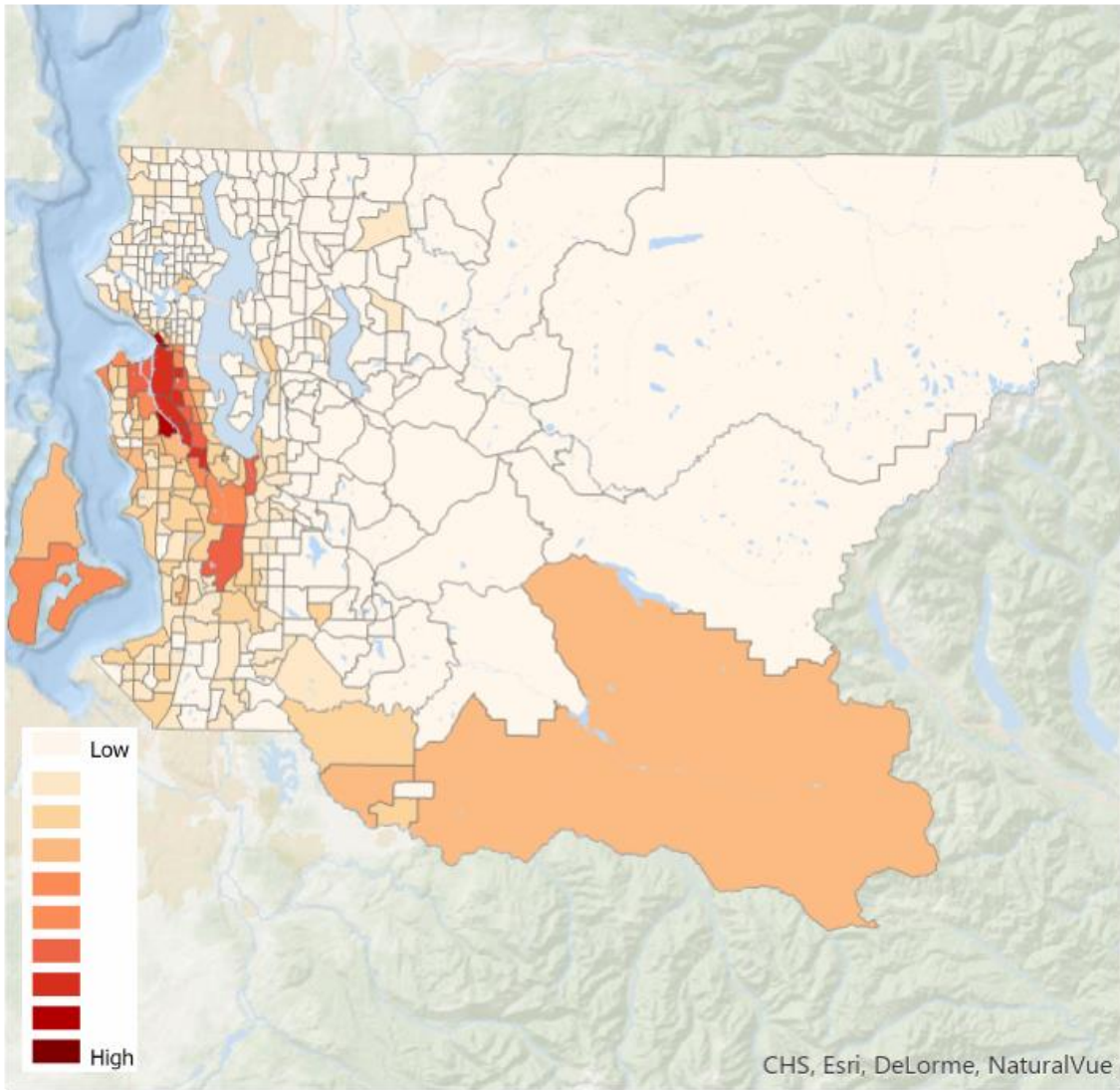
### **C. Aim 3) Sea Level Rise, Floodplains, and Chemical Waste Hazards Cumulative Impacts**

Lastly, sea level rise was added to the cumulative impact assessment. Fourteen indicators’ reclassified layers were used to characterize the *Sea Level Rise, Floodplains, and Chemical Waste Hazards Cumulative Impacts*. This cumulative impact analysis added *Population in Sea Level Rise Impacted Area* and *Sea Level Rise Impacted Area* as new *environmental threat* indicators to Aim 2’s *Floodplains and Chemical Waste Hazards Cumulative Impacts*. Figure 29 illustrates the fourteen *environmental threat* and *social vulnerability* indicator layers, while Figure 30 and 31 visualize the cumulative impacts for King County and the area of interest.

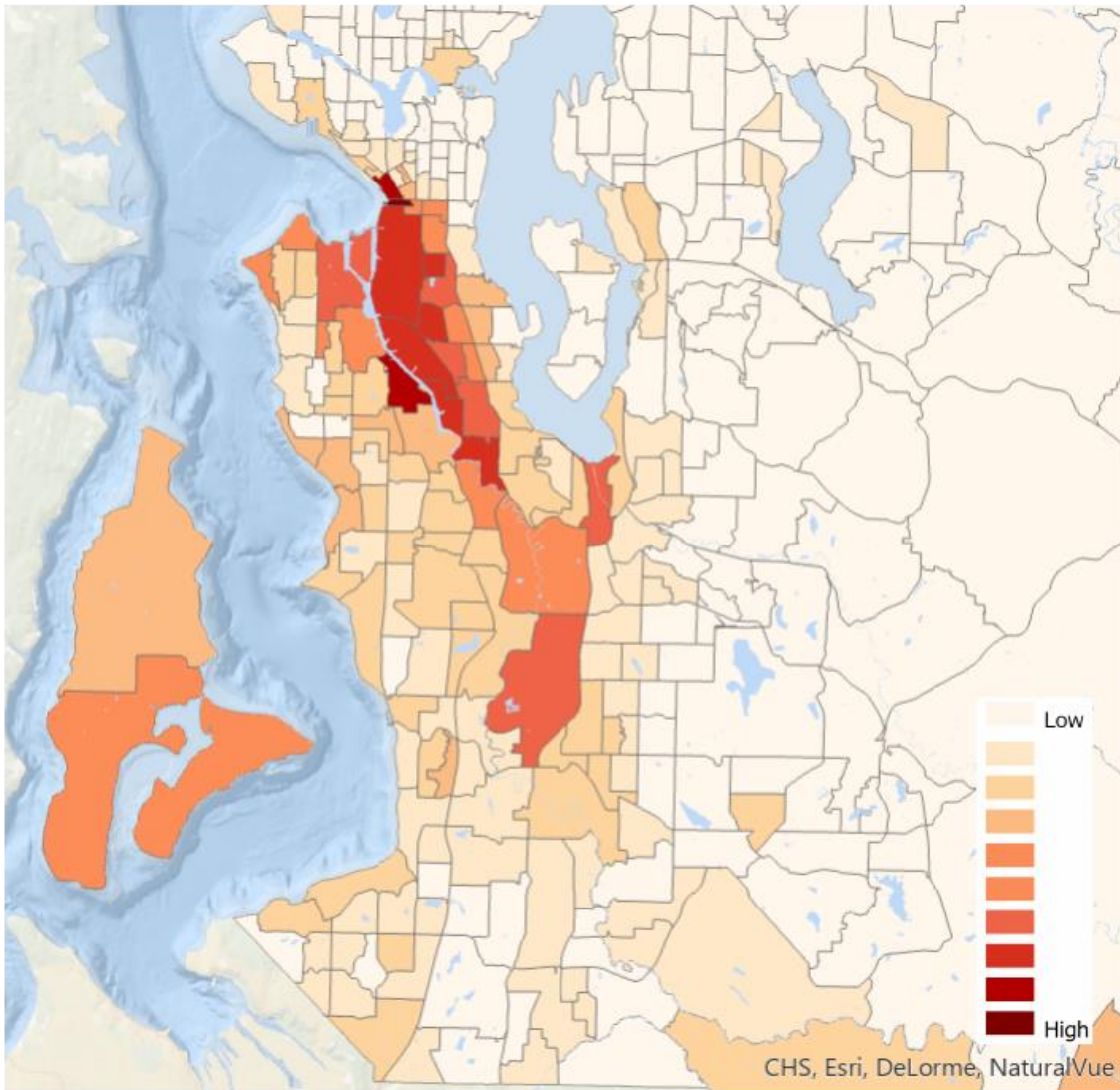
Focusing on the area of interest (Figure 31), the Duwamish Valley experiences the greatest potential cumulative impacts, while Vashon and census tracts along the coast also experience notable impacts.

<b>Sea Level Rise, Floodplains, and Chemical Waste Hazards Cumulative Impacts</b> <i>Cumulative Impacts = Environmental Threat X Social Vulnerability</i>			
<b>Environmental Threat</b> Environmental Threat Score = Average Environmental Exposure Indicators + Average Environmental Effect Indicators		<b>Social Vulnerability</b> Social Vulnerability Score = Average Socioeconomic Indicators + Average Sensitive Population Indicators	
<b>Environmental Exposures (1-10)</b>	<b>Environmental Effects (1-5)</b>	<b>Socioeconomic Factors (1-3)</b>	<b>Sensitive Populations (1-3)</b>
Toxic Releases from Facilities [40] Population in the 100-Year Floodplain [37] Population in Sea Level Rise Impacted Area [37, 41]	Proximity to Hazardous Waste Generators and Facilities [40] Proximity to Superfund Sites [40] Proximity to Facilities with Highly Toxic Substances [40] Wastewater Discharge [40] Land Area in the 100-Year Floodplain [33] Sea Level Rise Impacted Area [41]	People of Color [34] Population Living in Poverty (<= 185% of Federal Poverty Level) [35] Limited English Proficiency [36]	Persons Over the Age 65 [39] Population with a Disability [38]

**Figure 29.** Sea level rise, floodplains, and chemical waste hazards cumulative impacts indicators and formula. Population in Sea Level Rise Impacted Area and Sea Level Rise Impacted Area were added as new *environmental threat* indicators.



**Figure 30.** Sea level rise, floodplains, and chemical waste hazards cumulative impacts at the extent of King County.



**Figure 31.** Sea level rise, floodplains, and chemical waste hazards cumulative impacts at the extent of the area of interest.

## 5. DISCUSSION

As climate change worsens, increases in flood frequency and severity [1] makes it critical to have cumulative impact maps of *environmental threats* and *social vulnerabilities* to help mitigate exposure and subsequent health effects. The Washington State Environmental Health Disparities Map and the Duwamish Valley Cumulative Health Impacts Analysis assessments provide valuable information on environmental threats and social vulnerabilities for communities. However, both projects do not have a map that illustrates the impacts of demographic factors, chemical waste hazards, floodplain zones, and sea level rise that alter communities' cumulative impacts.

The purpose of this research was to create and compare three cumulative impact maps for King County, WA that considered the previously stated components. The indicator maps illustrate potential impacts that *environmental exposures*, *environmental effects*, *socioeconomic factors*, and *sensitive populations* can have solely have on communities, while the cumulative impact maps provide greater insight into the total impact of *environmental threats* and *social vulnerabilities*. Comparing the cumulative impact maps emphasizes how environmental threats can change a community's overall risk, providing the opportunity for more targeted mitigation and adaptation public health strategies.

Additional questions of interest in this analysis included: 1) are higher socioeconomic vulnerable communities within closer proximity to chemical waste hazards compared to lower socioeconomic vulnerable communities in Southwestern King County?; and 2) are there disparities in decision-making when it comes to evaluating chemical waste hazards in Southwestern King County? These findings support previous research on environmental inequities of chemical waste hazards and socioeconomic factors (Table 5) as well as supports current evaluation and clean-up priorities (Table 6 and 7). Lower-income communities of color have historically been in closer proximity to Hazardous Waste Generators and Facilities, Superfund sites, and Facilities with Highly Toxic Substances when compared to predominantly white, high-income communities [11, 12, 13, 14, 15, 23, 24, 25]. Communities with high socioeconomic vulnerability face greater difficulties in responding and adapting to chemical waste hazards and their discharges, which further amplifies the disparities gap [11, 12, 13, 14, 15, 23, 24, 25]. Displayed in Table 5, the low *Socioeconomic Vulnerability Classification* group also had the lowest chemical waste hazard proximity rank compared to the high *Socioeconomic Vulnerability Classification* group which had the greatest chemical waste hazard proximity rank. The results in Table 6 indicate there are not disparities in decision-making when it comes to evaluating known or suspected hazardous sites since the high *Socioeconomic Vulnerability Classification* group was the only group that had a below average percent of unvisited sites. Table 7 further supports that the distribution of site risk within socioeconomic vulnerability classifications did not allude to any major disparities in evaluation of sites and their associated risk.

All findings in this analysis support current research on cumulative impacts of environmental threats and social vulnerabilities. Figures 24-25, 27-28, and 30-31 illustrate that communities with greater social vulnerabilities experience an unequal burden of environmental threats and struggle to respond and cope with such hazards [11, 12, 13, 14, 15, 23, 24, 25], decreasing the community's resiliency and increasing social disparities [11, 15, 23, 42]. High social vulnerabilities tended to overlap with high environmental threat areas, specifically the Duwamish Valley, an area that experiences high environmental exposures, environmental effects, and socioeconomic vulnerabilities (Figures 7, 14, and 18 respectively) [11, 15, 23, 42]. This cycle perpetuates inequity of environmental threats and social vulnerabilities. Having a variety of maps that illustrate communities' impacts of single and combined environmental threats and social vulnerabilities can aid in more effective environmental and public health strategies, helping to decrease the inequities communities experience.

## **A. Potential Uses in Policy and Practice**

The three cumulative impact maps identified communities most impacted by environmental threats and social vulnerabilities and visualized how their impacts changed between cumulative impact assessments (Figures 24-25, 27-28, and 30-31). This demonstrated the effects these environmental threats would have on present-day communities. Results from the maps can help create targeted priorities for different census tracts.

For example, census tract 53033011200 experienced a cumulative impact rank of 7 while census tract 53033012100 experienced a cumulative impact rank of 2 for the chemical waste hazards assessment. When the 100-year floodplain hazards were added to the calculation, census tract 53033011200 stayed at the same cumulative impact rank of 7 while census tract 53033012100 increased from a cumulative impact rank of 2 to a 4. Finally, when sea level rise hazards were added to the equation, census tract 53033011200 increased from a cumulative impact rank of 7 to a 9 while census tract 53033012100 stayed at the same cumulative impact rank of 4. Sea level rise will not affect every census tract in King County but can significantly impact communities that fall within water rise predictions. Similarly, a community can be significantly impacted by the 100-year floodplain but not sea level rise, or chemical waste hazards but not the 100-year floodplain. Understanding each census tract's unique hazards highlights the need for strategic public health planning.

Another potential benefit is the ability to identify census tracts with high cumulative impacts and foster more meaningful community engagement [15]. Government agencies may give communities impacted with high environmental health disparities less support compared to other communities and may utilize colorblind adaptation strategies [15]. This research did not analyze the specifics of current community engagement potential barriers in King County and is an area of recommended future research. Some additional barriers found that highly burdened communities face in community engagement participation includes exclusionary outreach, language barriers, literacy differences, and a lack of resources to attend meetings [12, 13, 14, 15]. Community engagement has been shown to reduce health disparities from improved knowledge and self-efficiency as well as improves community-stakeholder relationships, which helps identify new concerns and develops data sources that address those concerns [12, 13, 14, 15].

## **B. Limitations and Recommendations for Future Research**

Since census tracts were utilized for the geographical unit of this analysis, it is not ideal for examining neighborhood differences. For example, residents in one half of the census tract that is located closer to a floodplain zone are likely to have different exposure and subsequent impacts compared to the other half of the census tract that is not near a floodplain zone. Census tracts as the geographical unit of analysis in this research were used to ultimately visualize a relative overview of census tract's environmental hazards and cumulative impacts. Recommended future research should analyze block groups or zip codes to discern the smaller scale geographical unit impacts to address obscured differences among neighborhoods.

The analysis assumed the census tract population living within the 100-year floodplain and sea level rise impacted areas would be exposed to environmental threats from chemical waste hazards or chemicals that already exist in the environment, along with other potential diseases from biological agents that can become mobilized. Recommended future research should analyze a smaller scale geographical unit to more accurately pinpoint the population residing in the 100-year floodplain and sea level rise impacted areas.

This analysis did not consider the influence different indicators could hold. For example, chemical waste hazards that fall within the 100-year floodplain that also have a high site hazard assessment score should have a greater "weight" (hazard significance) than a site not within the 100-year floodplain that has a low site hazard assessment score. Another example would be sites or the 100-year floodplain that fall within the 0–2-foot band of sea level rise rather than the 8-10-foot as the 0–2-foot band has a higher probability of occurrence. A weighted overlay analysis would take these nuisances into account with relative weights, but more background literature is needed to assign weight significance properly.

Cumulative impacts guidelines should be developed and adopted to help assist in conducting the screening of cumulative impact analyses, specifically how to evaluate the data to assign a proper weighting factor and analyze certain types of data [31]. Along those lines, continuing to build upon this methodology can help develop more comprehensive cumulative impact analyses [31]. In time, these limitations should be addressed with more research.

An important caveat to note regarding climate change and predicted flooding events is that floods vary significantly from year to year and thus short-term trends are difficult to discern [4]. The long-term persistence trends occurring are poorly understood as more research and data are needed to validate these trends [4]. Thus, there is a need for the generation of improved and updated data sets for flood zones based on climate predictions as well as human exposure to chemical and biologic agents based on different environmental medias and subsequent health effects [2, 4, 8, 20]. Precipitation data should also be included in future flood impact research as it is an important climate driver for flooding events. Non-climate drivers like land-use changes, urbanization, demographic change, and developments in technology were not taken into account for this project but are important to consider for future research as there is a need to integrate climate and non-climate drivers to further delve into the scope of flooding [2, 4, 8, 20].

Lastly, while some datasets used in this analysis were included in a community-driven framework performed by the Washington Tracking Network Health Disparities Map team in 2019, the 100-year floodplain and sea level rise datasets were not. Future research should include community concerns on those environmental hazards to further identify their unique environmental exposure and effects.

## **C. Conclusions**

This analysis created three cumulative impact maps that considered demographic data, chemical waste hazards, 100-year floodplain, and sea level rise characteristics of census tracts in King County, WA. These maps provide greater insight into the social vulnerability, chemical, flood, and sea level rise impacts on communities that policymakers, public agencies, and community-

based organizations can utilize to make better informed decisions. Ultimately, the maps provide a valuable resource for new policies, better mitigation, adaptation strategies, and resource allocation for impacted communities, diminishing health consequences from environmental hazards and decreasing social vulnerability disparities.

## LIST OF REFERENCES

- [1] Washington State Department of Ecology. (n.d.). Floods & floodplain planning. *Hazards*. Retrieved from <https://ecology.wa.gov/Water-Shorelines/Shoreline-coastal-management/Hazards/Floods/floodplain-planning>
- [2] Ecology.wa.gov. (n.d.). *Cleanup sites - Washington State Department of Ecology*. Retrieved from <https://ecology.wa.gov/Spills-Cleanup/Contamination-cleanups/Cleanup-sites>
- [3] YCC Team. (2021, May 18). Increases in extreme precipitation cost the U.S. \$73 billion over three decades. *Yale Climate Connections*. Retrieved from: <https://yaleclimateconnections.org/2021/05/increases-in-extreme-precipitation-cost-the-u-s-73-billion-over-three-decades/>
- [4] Mastin, M., Konrad, C., Veilleux, A., & Tecca, A. (2016). *Magnitude, Frequency, and Trends of Floods at Gaged and Ungaged Sites in Washington, Based on Data through Water Year 2014* (USGS Numbered Series No. 2016–5118; Scientific Investigations Report). U.S. Geological Survey. Retrieved from: <https://pubs.er.usgs.gov/publication/sir20165118>
- [5] Neiman, P., Schick, L., Ralph, M., Hughes, M., & Wick, G. (2011). *Flooding in Western Washington: The Connection to Atmospheric Rivers*. 1337–1358. <https://doi.org/10.1175/2011JHM1358.1>
- [6] Seattle Office of Emergency Management. (2014). *Weather Hazards: Flooding* (Weather Hazards). Seattle Office of Emergency Management. Retrieved from: [https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiKq\\_2irjwAhW0FzQIHb7KA2AQFjARegQIFBAD&url=https%3A%2F%2Fwww.seattle.gov%2FDocuments%2FDepartments%2FEmergency%2FPlansOEM%2FSHIVA%2FSHIVA%2F7.0-Flood.pdf&usg=AOvVaw22Wh62n82JeNzisoLhO2](https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiKq_2irjwAhW0FzQIHb7KA2AQFjARegQIFBAD&url=https%3A%2F%2Fwww.seattle.gov%2FDocuments%2FDepartments%2FEmergency%2FPlansOEM%2FSHIVA%2FSHIVA%2F7.0-Flood.pdf&usg=AOvVaw22Wh62n82JeNzisoLhO2)
- [7] Dickerson-Lange, S., & Mitchell, R. (2013). *Modeling the effects of climate change projections on streamflow in the Nooksack River basin, Northwest Washington*. 28(20), 5236–5250. <https://doi.org/10.1002/hyp.10012>
- [8] Olga V. Wilhelmi, Rebecca E. Morss, Integrated analysis of societal vulnerability in an extreme precipitation event: A Fort Collins case study, *Environmental Science & Policy*, Volume 26, 2013, Pages 49-62, ISSN 1462-9011. <https://doi.org/10.1016/j.envsci.2012.07.005>
- [9] Sweet, William; Park, Joseph; Marra, John; Zervas, Chris; Gill, Stephen, Center for Operational Oceanographic Products and Services (U.S.), Sea level rise and nuisance flood frequency changes around the United States (2014), NOAA technical report NOS CO-OPS ; 073. Retrieved from: <https://repository.library.noaa.gov/view/noaa/30823>
- [10] Huppert, D.D., Moore, A., Dyson, K. (2009). Chapter 8 in *The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate*, Climate Impacts Group, University of Washington, Seattle, Washington. <https://doi.org/10.7915/CIGOMS3K2>

- [11] Alexeeff, G. V., Faust, J. B., August, L. M., Milanes, C., Randles, K., Zeise, L., & Denton, J. (2012). A screening method for assessing cumulative impacts. *International journal of environmental research and public health*, 9(2), 648–659.  
<https://doi.org/10.3390/ijerph9020648>
- [12] E.E. Koks, B. Jongman, T.G. Husby, W.J.W. Botzen, Combining hazard, exposure and social vulnerability to provide lessons for flood risk management, *Environmental Science & Policy*, Volume 47, 2015, Pages 42-52, ISSN 1462-9011, <https://doi.org/10.1016/j.envsci.2014.10.013>. Retrieved from:  
[https://www.sciencedirect.com/science/article/pii/S1462901114002056?casa\\_token=1Cu9wweCmCIAA AAA:g0Z4kso5BZZ4C5XrxIWWRYgVrBFUhVncBl7-l028X-khog0yyUX5rcaahbmsPk6X3yxv-6JaQ#bib0070](https://www.sciencedirect.com/science/article/pii/S1462901114002056?casa_token=1Cu9wweCmCIAA AAA:g0Z4kso5BZZ4C5XrxIWWRYgVrBFUhVncBl7-l028X-khog0yyUX5rcaahbmsPk6X3yxv-6JaQ#bib0070)
- [13] S.L. Cutter, S. Carolina, B.J. Boruff, W.L. Shirley. Social Vulnerability to Environmental Hazards. *Soc. Sci. Quart.*, 84 (2) (2003), pp. 242-261.  
<https://doi.org/10.1111/1540-6237.8402002>
- [14] A. Fothergill, E.G. Maestas, J.D. Darlington. Race, ethnicity and disasters in the United States: a review of the literature. *Disasters*, 23 (1999), pp. 156-173.  
<https://doi.org/10.1111/1467-7717.00111>
- [15] Min, E., Gruen, D., Banerjee, D., Echeverria, T., Freeland, L., Schmeltz, M., Saganić, E., Piazza, M., Galaviz, V. E., Yost, M., & Seto, E. (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.  
<https://doi.org/10.3390/ijerph16224470>
- [16] Hemingway, L., & Priestley, M. (2006). Natural hazards, human vulnerability and disabling societies: A disaster for disabled people?. *Review of Disability Studies: An International Journal*, 2(3). Retrieved from: <https://www.rdsjournal.org/index.php/journal/article/download/337/1037>
- [17] Abbott, D., & Porter, S. (2013). Environmental hazard and disabled people: from vulnerable to expert to interconnected. *Disability & Society*, 28(6), 839-852.  
<https://doi.org/10.1080/09687599.2013.802222>
- [18] Vakis, R. N. (2006). *Complementing natural disasters management: The role of social protection*. World Bank, Social Protection. Retrieved from:  
<https://web.worldbank.org/archive/website01047/WEB/IMAGES/0543.PDF>
- [19] Asher, C., Froyland, H. and O'Dowd, S. (2017). *Adaptation Strategies for Resilient Cleanup Remedies: A Guide for Cleanup Project Managers to Increase the Resilience of Toxic Cleanup Sites to the Impacts from Climate Change*. Toxics Cleanup Program. [online] Olympia: Department of Ecology. Retrieved from:  
<https://apps.ecology.wa.gov/publications/documents/1709052.pdf>
- [20] Balbus, J., Boxall, A., Fenskle, R., McKone, T., & Zeise, L. (2012). *Implications of global climate changes for the assessment and management of human health risks of chemicals in the natural environment*. 32 (1), 62-78.  
<https://doi.org/10.1002/etc.2046>

- [21] Fatemeh Izaditame, Matthew G. Siebecker, Donald L. Sparks, Sea-level-rise-induced flooding drives arsenic release from coastal sediments, *Journal of Hazardous Materials*, Volume 423, Part B, 2022, 127161, ISSN 0304-3894.  
<https://doi.org/10.1016/j.jhazmat.2021.127161>
- [22] Sarah E. Crawford, Markus Brinkmann, Jacob D. Ouellet, Frank Lehmkuhl, Klaus Reicherter, Jan Schwarzbauer, Piero Bellanova, Peter Letmathe, Lars M. Blank, Roland Weber, Werner Brack, Joost T. van Dongen, Lucas Menzel, Markus Hecker, Holger Schüttrumpf, Henner Hollert, Remobilization of pollutants during extreme flood events poses severe risks to human and environmental health, *Journal of Hazardous Materials*, Volume 421, 2022, 126691, ISSN 0304-3894.  
<https://doi.org/10.1016/j.jhazmat.2021.126691>.
- [23] Gould L, Cummings BJ. Duwamish Valley Cumulative Health Impacts Analysis. Seattle, WA: Just Health Action and Duwamish River Cleanup Coalition/Technical Advisory Group. March 2013. Retrieved from:  
[https://static1.squarespace.com/static/5d744c68218c867c14aa5531/t/5e0edc05d2e16f330fa0071d/1578032180988/CHIA\\_low\\_res+report.pdf](https://static1.squarespace.com/static/5d744c68218c867c14aa5531/t/5e0edc05d2e16f330fa0071d/1578032180988/CHIA_low_res+report.pdf)
- [24] Collins, T., Grineski, S., Chakraborty, J., & Flores, A. (2019). *Environmental injustice and Hurricane Harvey: A household-level study of socially disparate flood exposures in Greater Houston, Texas, USA*. 179.  
<https://doi.org/10.1016/j.envres.2019.108772>
- [25] Hardy, D., Milligan, R., & Heynen, N. (2017). *Racial coastal formation: The environmental injustice of colorblind adaptation planning for sea-level rise*. 87.  
<https://doi.org/10.1016/j.geoforum.2017.10.005>
- [26] US EPA. 2022. *Superfund: National Priorities List (NPL) | US EPA*. [online] Retrieved from: <https://www.epa.gov/superfund/superfund-national-priorities-list-npl>
- [27] Qiang, Y. (2018). *Disparities of population exposed to flood hazards in the United States*. 232.  
<https://doi.org/10.1016/j.jenvman.2018.11.039>
- [28] Map units, display units, and location units—ArcGIS Pro | Documentation. (2022). Retrieved from: <https://pro.arcgis.com/en/pro-app/latest/help/mapping/navigation/map-units-location-units-and-display-units.htm>
- [29] Michael F. Goodchild, Scale in GIS: An overview, *Geomorphology*, Volume 130, Issues 1–2, 2011, Pages 5-9, ISSN 0169-555X.  
<https://doi.org/10.1016/j.geomorph.2010.10.004>
- [30] Guarneri, J. C. and Weih, R. C. Jr. (2012). "Comparing Methods for Interpolation to Improve Raster Digital Elevation Models," *Journal of the Arkansas Academy of Science*: Vol. 66, Article 16.  
<https://doi.org/10.54119/jaas.2012.6609>
- [31] Alexeeff G., Faust J., Meehan August L., Milanes C., Randles K., Zeise L. "Cumulative Impacts: Building a Scientific Foundation," Office of Environmental Health Hazard Assessment. California Environmental Protection Agency; Sacramento, CA USA: 2010. [(accessed on 14 June 2011)]. Retrieved from: <http://oehha.ca.gov/ej/cipa123110.html>

- [32] *Confirmed and Suspected Contaminated Sites List (Site Register & Contaminated Sites Lists)*. (2021). Department of Ecology State of Washington. Retrieved from: <https://apps.ecology.wa.gov/cleanupsearch/reports/cleanup/contaminated>
- [33] Washington Tracking Network, Washington Department of Health. Web. "Area in 100-year Flood Zone". Data obtained from the Federal Emergency Management Agency. Published: 29 March 2016. Retrieved from: <https://fortress.wa.gov/doh/wtn/WTNPortal#!q0=878>
- [34] Washington Tracking Network, Washington Department of Health. Web. "People of Color". Data obtained from the Office of Financial Management and ACS. Published by WTN on 15 October 2018. Retrieved from: <https://fortress.wa.gov/doh/wtn/WTNPortal#!q0=4707>
- [35] Washington Tracking Network, Washington State Department of Health. Web. "Poverty - Households Living Below 185% Poverty Level". Data obtained from US Census American Community Survey, 2019. Published on WTN: 15 Dec 2019. Retrieved from: <https://fortress.wa.gov/doh/wtn/WTNPortal#!q0=3625>
- [36] Washington Tracking Network, Washington State Department of Health. Web. "Population Age 5+ Speaking English Less than Very Well". Data obtained from US Census American Community Survey, 2021. Published: 15 Sept 2021. Retrieved from: <https://fortress.wa.gov/doh/wtn/WTNPortal#!q0=620>
- [37] Washington Tracking Network, Washington Department of Health. Web. "Population in 100-year Flood Zone". Data obtained from the Federal Emergency Management Agency. Published: September 2021. Retrieved from: <https://fortress.wa.gov/doh/wtn/WTNPortal#!q0=884>
- [38] Washington Tracking Network, Washington State Department of Health. Web. "Population with a Disability". Data obtained from US Census American Community Survey, 2021. Published on WTN: 15 Sept 2021. Retrieved from: <https://fortress.wa.gov/doh/wtn/WTNPortal#!q0=623>
- [39] Washington Tracking Network, Washington State Department of Health. Web. "Population 65+". Data obtained from US Census American Community 5-year Survey, 2021. Published in WTN: 15 Sept 2021. Retrieved from: <https://fortress.wa.gov/doh/wtn/WTNPortal#!q0=7857>
- [40] Environmental Health Disparities, Washington State Department of Health. Web. "Index Calculated for King County". Data obtained from EJSscreen 2017. Published on King County Open GIS Portal: 17 June 2021. Retrieved from: <https://gis-kingcounty.opendata.arcgis.com/datasets/kingcounty::wadoh-environmental-health-disparities-index-calculated-for-king-county-wadohehdindex-area/about>
- [41] National Oceanic and Atmospheric Association. (2017). NOAA Office for Coastal Management Sea Level Rise Data: 1-10 ft Sea Level Rise Inundation Index. [dataset]. Retrieved from: <https://coast.noaa.gov/slrdata/>
- [42] University of San Diego Energy Policy Initiatives Center. (2021). *Chula Vista Climate Equity Index*. [online] San Diego: City of San Diego. Retrieved from: <https://www.chulavistaca.gov/home/showpublisheddocument/22779/637582410674500000>
- [43] FEMA High Risk Flood Area (100-year Floodplain) / fema floodplain 100yr area. (2020). Retrieved from: <https://gis-kingcounty.opendata.arcgis.com/datasets/kingcounty::fema-high-risk-flood-area-100-year-floodplain-fema-floodplain-100yr-area/about>

- [44] Exploring digital elevation models—ArcGIS Pro | Documentation. (2022). Retrieved from: <https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/exploring-digital-elevation-models.htm>
- [45] Miller, I.M., Morgan, H., Mauger, G., Newton, T., Weldon, R., Schmidt, D., Welch, M., Grossman, E. (2018). Projected Sea Level Rise for Washington State – A 2018 Assessment. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project. Retrieved from: [https://cig.uw.edu/wp-content/uploads/sites/2/2019/07/SLR-Report-Miller-et-al-2018-updated-07\\_2019.pdf](https://cig.uw.edu/wp-content/uploads/sites/2/2019/07/SLR-Report-Miller-et-al-2018-updated-07_2019.pdf)
- [46] American Community Survey 5-Year Data (2009-2019). (2020). Retrieved 23 February 2022. Retrieved from: <https://www.census.gov/data/developers/data-sets/acs-5year.html>
- [47] Pro.arcgis.com. 2022. *Summarize Within (Analysis)*—ArcGIS Pro | Documentation. [online] Retrieved from: <https://pro.arcgis.com/en/pro-app/2.8/tool-reference/analysis/summarize-within.htm>
- [48] Pro.arcgis.com. 2022. *Dissolve (Data Management)*—ArcGIS Pro | Documentation. [online] Retrieved from: <https://pro.arcgis.com/en/pro-app/2.8/tool-reference/data-management/dissolve.htm>
- [49] Pro.arcgis.com. 2022. *IDW (Spatial Analyst)*—ArcGIS Pro | Documentation. [online] Retrieved from: <https://pro.arcgis.com/en/pro-app/2.8/tool-reference/spatial-analyst/idw.htm>
- [50] Cumulis.epa.gov. 2022. *Superfund Site: LOWER DUWAMISH WATERWAY SEATTLE, WA*. [online] Retrieved from: <https://cumulis.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction=second.cleanup&id=1002020>