Promoting Equitable Climate Resilience in King County: Mapping Communities Vulnerable to Heavy Precipitation

Dane Carson, Michael Hamilton, Jennifer Paton
University of Washington Professional Master's Program in GIS
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King County Department of Natural Resources and Parks Project Goal

"This effort seeks to design, build, populate, and launch an online mapping product that guides pro-equity human health climate preparedness actions of public, civic, and private actors."

Recommended Course of Action

In light of the work completed towards the above mentioned online mapping product, we recommend that subsequent efforts seek to expand the information provided to stakeholders, i.e. researching and augmenting risk indices relevant to other potential catastrophic events. This should be done with the understanding that we have created a baseline to work from with the intent that future work would not need to start from scratch, but rather use our work as a guide and model for developing a modular tool that can be customized to the user's specific concerns. Additionally, further aesthetic refinement of the final product may be needed depending on the nature of the data used or changing needs as communicated by the sponsor, so we have attempted to make the tool as flexible as possible.

Introduction

This project was envisioned to create a scenario of a heavy precipitation event in King County, Washington. The effects of an event such as this are widespread and potentially severe and access to basic and emergency resources were evaluated by looking at the social factors of community resilience, equity, and social justice. In a study associating a geographical context and the impacts from a heavy precipitation event, an index was created and evaluated to determine whether or not current access to resources sufficiently serves King County residents, and to assess who would face the most severe effects.

King County includes almost 237 sq. miles of land that can be characterized as steep or a potentially dangerous slope, not including the areas with data not available (King County GIS, City of Seattle GIS, WAGDA). This heavy precipitation impact zone, which most locations of critical resources are not located within due to building codes requirements, has a widespread effect on the access to those resources. The unique topography of the different areas of the county consequently reflect the potential difficulties based on accessing those resources in a heavy precipitation event. The transportation network and the potential closure of portions of it can severely limit resource allocation and access. Discussing and evaluating this seemingly natural or environmental impact on Equity and Resiliency is the key to this study. The issue of separate allocation of resources, independent of topography allows a larger and more detailed analysis.

Heavy precipitation, especially in the Pacific Northwest and particularly in King County, is a constant and serious concern. The topography and development of King County plays a major role in the potential impacts of such an event. Equitable access to resources and the resilience of each area of the county and their ability to respond to such an event, requires an in-depth study. The two geographic descriptors of hazard areas that we chose to pursue and base an analysis on are slope impacts and flood area impacts.

Precipitation in all of its forms, snow, rain, and sleet, is an ever-present force in the Northwest. In order to look at its impacts to certain areas in King County, we chose to use the research done by Groiseman, Knight and Karl, within which they proposed the following standard: heavy and extreme events are based on the number of days with precipitation above fixed thresholds. Values are mean annual number of days with 24-h daily precipitation above 50.8 mm (heavy) and 101.6 mm (very heavy) (Groiseman, et al. 2001).

The available NOAA Climate data shows that over that last five years, based on the measurements at Seattle Tacoma International airport weather station, there have been 8 events that met the heavy precipitation criteria and none that met the threshold of an extreme event.

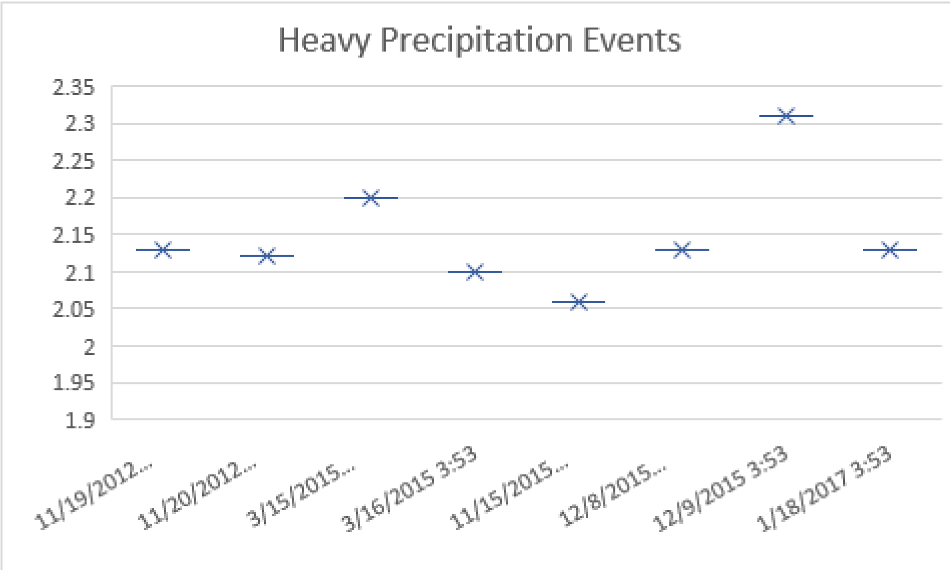


Figure 1 Heavy Precipitation Events 2012-2017

https://www.ncdc.noaa.gov/cdo-web/

These 8 events averaged 2.15 inches over a 24-hour period. Two sets of events were characterized by a multiple day events, 11/19-20/2012 and 12/8-9/2015. Establishing the specific factors or temporal length of an event could easily lead a short term heavy precipitation occurrence to enter the extreme event scenario.

The above variables lead to the establishment of geographic impact areas. These standards of specific amounts allow a definable point in which to view precipitation totals. Steep slopes are considered areas that have more than a 35-degree slope and floodplains represent a once in 100 years flood (or a 1% chance of flooding every year). Once these geographically impacted areas are determined, we overlaid this on numerous social, economic and environmental factors, which allowed us to contrast different areas of King County to evaluate resiliency from several perspectives.

Once these areas were established, an index of multiple variables was introduced to "compare". This index allowed a weighted or more equitable valuation of the areas that are to be compared. Once this index was established and the geographically affected zones were identified, we were able to interpret and better understand the impact on resource allocation and availability. This, in particular, is key to how the issue of heavy precipitation is more than simply a question of “where”. In other words, resource allocation and availability transform this from an examination of geographical factors alone into a sustainability management problem with very concrete effects on members of the population who already face significant challenges within the current socio economic environment.

Within the produced impacted areas, the social and resource variables and the weighted index were added to a static visual or GIS mapping component. This took several forms, including a web based application. The interface must be, more than anything, flexible. The public must be able to access this data in a meaningful manner, as well as numerous governmental agencies.

Our group gathered pertinent data, developed a geodatabase repository of that data, analyzed scenarios for specific locations, then incorporated these findings in multiple ways. An overriding goal of this group is to build a sustainable model that makes clear the relationships between ecological, social, and economic factors. In other words, we built something that is flexible enough to incorporate future scenarios, thereby creating a “path” for others to follow. This included revisioning of previous accomplishments. specifically, the extreme heat vulnerability index is to be re-evaluated using improved variables to help guide further analysis.

Deliverables

- Analysis Methodology
- ESRI StoryMap
- ArcGIS Online Web Map
- File Geodatabase
- Heat Vulnerability Index
- Precipitation Vulnerability Index
- Static Maps

Design and Methods

King County Department of Natural Resources and Parks has expressed interest in evaluating pro-equity human health climate preparedness through likely climate change trends and events such as:

- Extreme heat events
- Heavy precipitation events
- Sea level rise
- Air quality decline

Specifically, our group was requested to examine data regarding heavy precipitation events and evaluate preparedness based on a combination of demographic, topographic, and social elements. We decided early on to emulate some of the methodology of last year's cohort in creating indices derived from z-scores with regards to the demographic and some of the social data. The built environment aspects of social data, such as sandbag availability, were mapped for visual reference but not included in any index. The topographic data was analyzed with an eye for slope and the effect that has on flooding which, in conjunction with the above, can help in risk analysis in terms of available infrastructure.

Data Sources and Processing

The challenge of looking at and evaluating a heavy precipitation event and its impact on multiple communities in the King County was a daunting one. The topographic, social, environmental and economic diversity of the area coupled with the strong desire of the community to address resiliency issues, lead to challenges but also presented the opportunity for powerful solutions.

In the process of evaluating the hazardous factors of a heavy precipitation event, geographical study areas needed to be established. However, due to the constraints and coverage limitations of each of the pertinent data sources, for multiple variables, different levels of geographical scale were required. It was decided to select census based parcel references, and potentially narrow down to county property parcel level, to potentially allow a very small scale, detailed neighborhood view. After consideration of these factors, as well as in an attempt to keep the tool as flexible as possible, census tracts were selected as our focal level. Census tracts provided the most comprehensive economic and social data, but did not fit as well with the geographically specific environmental factors, such as topography and land cover. That data, and specifically hazard zones, do not follow political boundaries. The end challenge was to bring together the environmental data, or hazards, in a way to allow comparison of these factors, both topographical and social, among different political boundaries.

Three levels of analysis were completed, census tracts, census block groups and census blocks to allow viewing at different levels depending on the users and scale of data request.

One of the greatest advantages of modern GIS and especially, web based maps, is the ability to view information at different scales. We built the hazard information in a way that would allow this to be fully realized. Hence the desire for multiple “levels” of analysis, i.e. census tracts, census block groups, census blocks and potentially at the property parcel level, although this is particularly intensive and potentially not practical for incorporating into a web based tool.

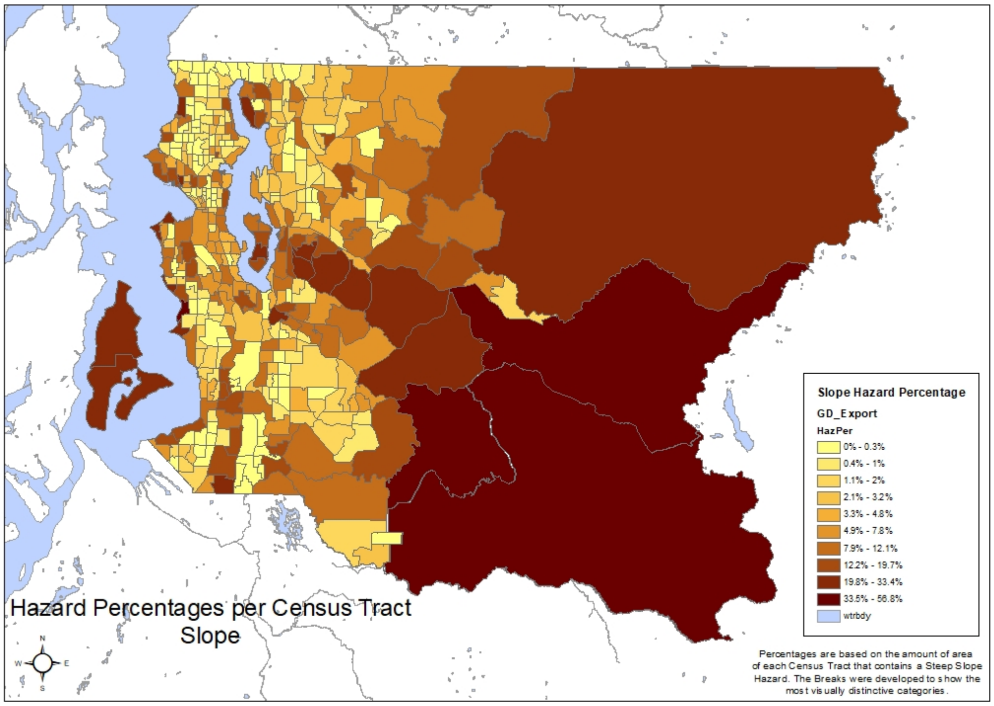


Figure 2. Dangerous Slope Percentages

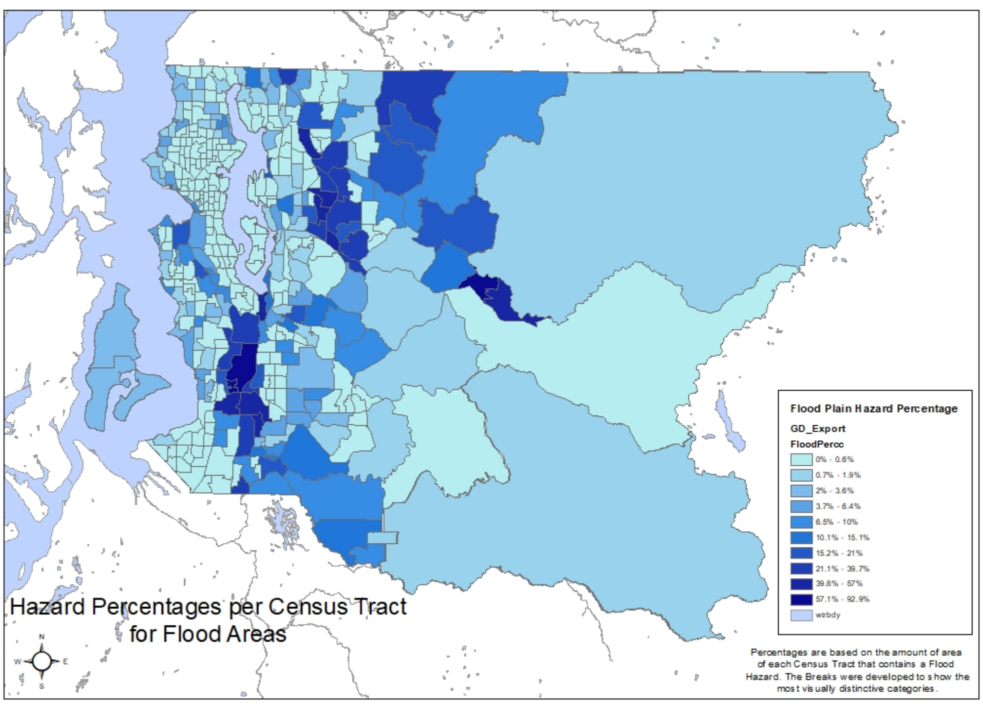


Figure 3. Flood Prone Area Percentages

Heavy Precipitation Event

The effects of a heavy precipitation event can be assessed by looking at the topographic impacts. Heavy rainfall can cause flooding and potential landslides. These impacts can and will affect the ability of a certain area to access emergent and day to day resources. The transportation network of King County is extensive and has more than 16000 miles of transportation conveyances in the county. The Developed Hazard area model determined that approx. 11500 miles of that network are directly impacted by those potential hazards, network sections that are in the 500yr flood plain or in Census tracts with a greater that 30% slope (King County GIS Portal, Metro Transportation Network (TNET)). This impact is spread around the county but areas of increased influence are apparent due to the difference in topography and prevalence of higher slope and flood plains. The dominance of mountainous terrain in the eastern half of the county also create unique considerations.

Slope

The negative impact of slope in a heavy precipitation event is based on and derived from numerous factors: soil type, slope degree, percentage of slope effected, and the amount of precipitation introduced. Field investigation of unstable terrain is aided by recognition of certain topographic, geologic, soil, hydrologic, and vegetative indicators. (Sidle, Pearce, O'Laughlin, 1989) The variety of these different factors make more than a cursory and large scale analysis of this study impractical. However, as much of the unique attributes of the different datasets as possible were incorporated to provide some large-scale discussion of potential impacts.

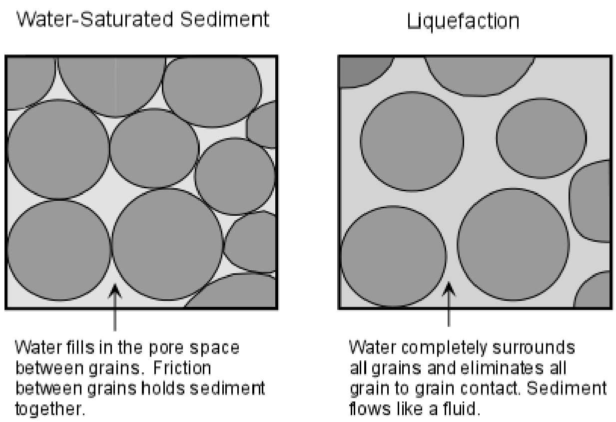
Shallow landsliding in the Seattle, Washington area has caused the occasional loss of human life and millions of dollars in damage to property. The effective management of this hazard requires an understanding of the rainfall conditions that result in landslides (Godt, J., 2005).

The majority of steep or potentially dangerous slope areas with the highest impact on the greatest population, surround the waterbodies and floodplains of the county. Slope immediately adjacent to Lake Washington, Lake Sammamish, Puget Sound, the Green River/Duwamish and Auburn areas compromise the relative centers of slope and landsliding danger. Yet, the variety of the topography in the county does not limit the effect to those areas. Lower population density in the eastern half of the county tend to mitigate the impacts created by mountainous and slope prone areas.

King County and Washington State authorities have established a definition of what is a potential hazardous slope and introduced it into the legislative code. Steep Slopes: WAC 365-190-080(4)(d) defines a steep slope as a slope of at least 40% with a vertical relief of 10 or more feet. King County adopted 40%/10ft for steep slopes. Pierce County's new ordinance revised the definition from 30%/10ft to 40%/15ft. Based on the best available science, Thurston County's definition for steep slope is proposed to change from 50% to 40% slope with a vertical height of 15 ft. Sidle's ranges, discussed above, shows a lower limit of slope gradient of 40% for debris avalanches, slides, and flows (Sidle, Pearce, et al., 1989). This basic system of evaluation was the starting point of selection for certain topographical features, but many other studies based on the wide variety of landslide types and situations were considered. Some of these studies suggested that a slope percentage of around 20% dependent on precipitation intrusion and soil type might lead to an unstable slope (Nguyen, et al., 2010). The City of Seattle's steep slope dataset included areas of slope with a gradient of less than 6% and this was used as a lower limit.

The basic process of slope analysis and the effect of rainfall or precipitation is considerate of the following factors; slope degree, the soil type, the amount of precipitation involved, and the duration of precipitation and other factors. King County has a wide variety of the above factors but for this scenario, the following considerations were taken into account.

Shallow Slope Failures occur, in general, during and after intense rainfall and/or snowmelt during or after spring. The rapid infiltration of rainfall and rapid melting of snowpack cause soil saturation and a temporary rise in pore water pressures, thereby reducing the sheer strength of the soil slope, which subsequently leads to failures. (Abramson, L. W., 2002) Similarly, infiltration of rainwater through an unsaturated zone results in the formation of a wetted zone near the slope surface, and this may lead to failure during periods of prolonged rainfall. (Cho, S., et al., 2002)



Nleson, Stephen A., EENS 3050, *Natural Disasters, Tulane University, 2017*

Figure 4. Water Infiltration and Liquefaction

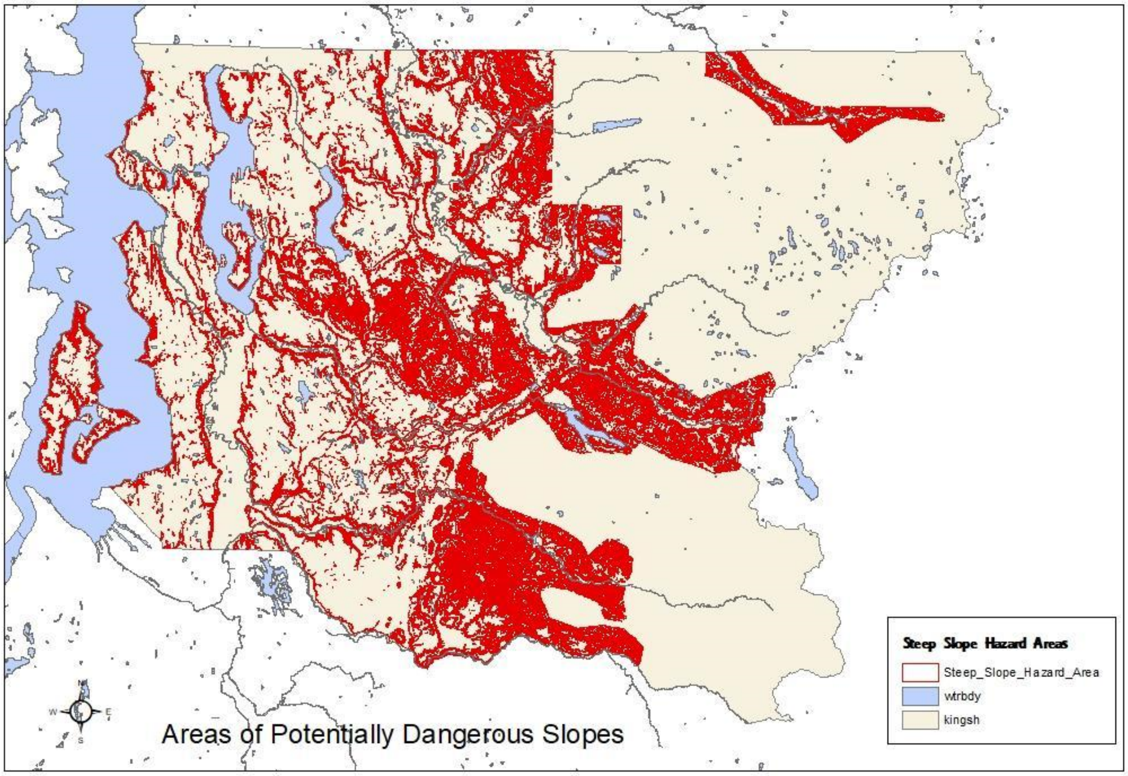


Figure 5. Slope Impact Areas, Note the areas of incomplete data coverage

Floods

Floods and flooding are the other factors that we are using to quantify the impacts of a heavy precipitation event in King County. Similar to dangerous landslides and their damage potential, floods are a prevalent occurrence in the King County area. Climatic, topographic, and urban development all play key roles in the extent and impacts of flooding. Average annual precipitation in western Oregon and Washington varies from less than 20 inches to over 150 inches, in obvious general relation to the topographic influences of the Coast and Cascade mountain ranges. (Schermerhorn, W. 1967)

215 sq. miles of King County have been designated to fall within the 500yr Flood Plain. The total combined area of King County is 2150 sq. miles not removing the other major waterbodies. This high percentage of vulnerable areas shows the critical importance of impact of flooding. The FEMA FIRM (Flood Insurance Rating Maps) maps are the national basis for determining flood

areas and were used in a similar role in this study. Recently FEMA in conjunction with National Flood Insurance Program (NFIP) and local jurisdictions, have been migrating to new digital maps, DFIRM, based on 2013 data. King County has had preliminary DFIRM maps produced and every effort was made to include this updated data.

Primary sources of flood hazard mapping for most communities are Flood Insurance Rate Maps (FIRMs) and Flood Insurance Studies published by FEMA. King County and other National Flood Insurance Program communities implement land development regulations using FEMA's 100-year floodplain and floodway and other available flood data. However, FEMA maps are based on current or historical land use. Changing land use conditions and climate trends lead to changing rates and volumes of runoff, so maps can become outdated and not accurately represent the current flood hazard. When watershed conditions change, the 100-year floodplain can expand and flood depths can increase, inundating properties not currently mapped as being within the FEMA floodplain. With additional research allowing predictions of changes in precipitation due to climate change, temperature and snow levels, hydrologic, and hydraulic analyses can be used to evaluate how such changes affect river flooding (King County, 2013). As much as was possible, the new updated preliminary data was used for this study.

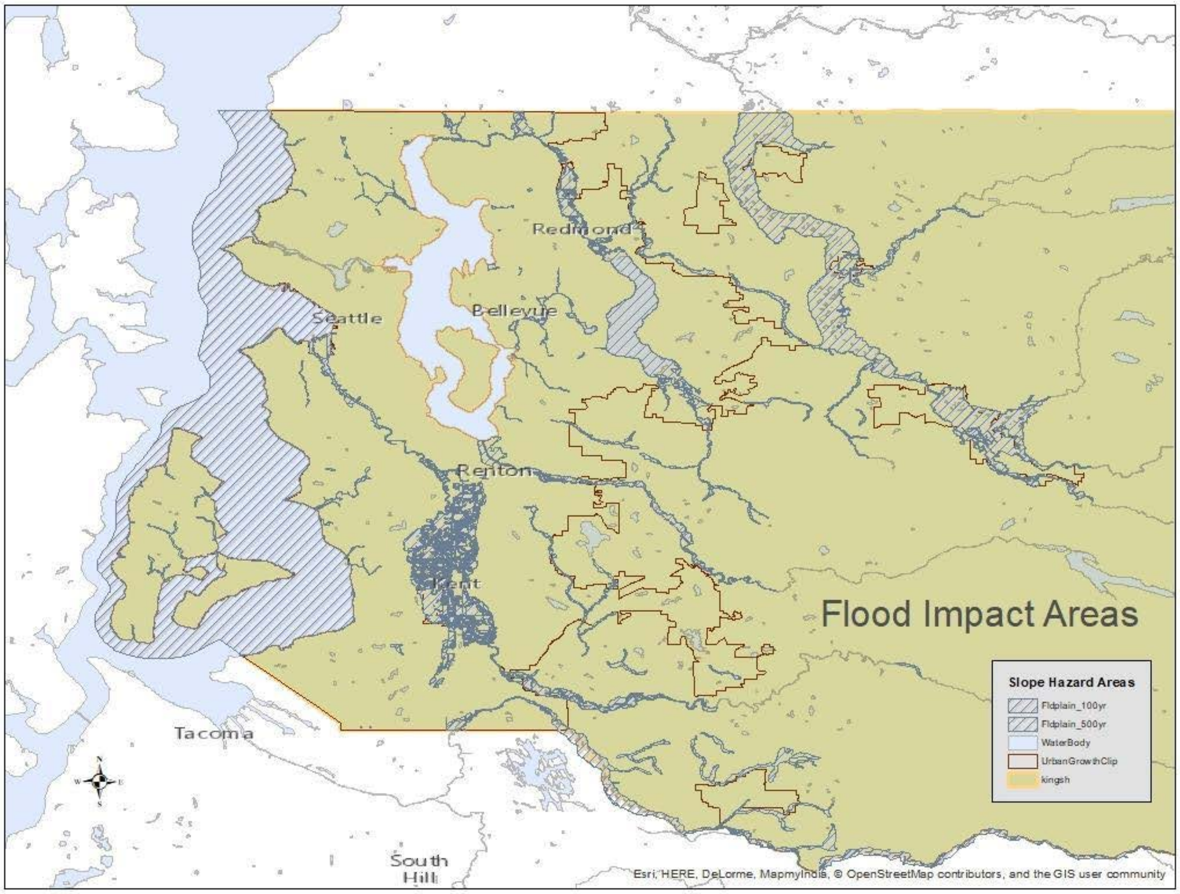


Figure 6. Flood Prone Areas

Specific Event Modeling Process

The Slope Model was created as a combination of multiple feature classes acquired from a variety of sources. An attempt was made to include data that gave a realistic representation of areas of potentially dangerous slopes in King County. King County is highly diverse in topography, with alpine peaks in the eastern half of the county and a combination of river valleys and bluffs in the western portion of the county. There was a disconnect between the data sources and common parameters of what was a potentially dangerous slope, which necessitated data from multiple sources, data types, and methods for analysis. While there are comprehensive data sources including DEM (Digital Elevation Models) and Lidar scans, the size of the data was tremendous. The mountainous terrain of the eastern half of the county provided large sections that were primarily dangerous slopes. However, the lower population of such areas deferred the potential impacts. The data that was used was a combination of City of Seattle data and King County Department of Natural Resources and parks, as well as 10m DEMs. City of Seattle data referencing what they refer to as steep slope, potential land slide areas and slide areas were merged to give a base layer for the city limits of Seattle. The joined steep slope data and the associated attributes of slope percentage were used as a parameter for later joining dis-similar datasets.

A 10m Digital Elevation Model was mosaiced then converted to a point dataset next. Comparing this point file and where it intersected known slope degree values (City of Seattle Steep Slope) allowed a slope model based on DEM data. A polygon feature class was created from the referenced points. This polygon feature class was analyzed and merged appropriately with the King County GIS Data portals, lsr_sds_modhazpot.shp and lsr_sds_sevhazpot.shp., areas of landslides with moderate and severe hazard potential, respectively. When these slope datasets were completed, they were joined to a slope dataset from the KC DNRP and then merged to produce one layer representing potentially dangerous areas of slopes and landslides. Every attempt was made to incorporate as many parameters of each file. A generalization was made Using the City of Seattle’s Steep slope as a base to allow a consistent parameter for evaluation .

The applicable Flood modeling process revolved mostly around the latest FEMA DFIRM data. This included both the 100yr and 500 yr. Floodplains. Numerous other sources such as King County’s Channel Migration Flood Areas were considered but using the FEMA DFIRM data encapsulated these other datasets with a common boundary of impacted areas. When overlaid on top the other areas they provided a common reference to the potential impacts of flooding during a heavy precipitation event.

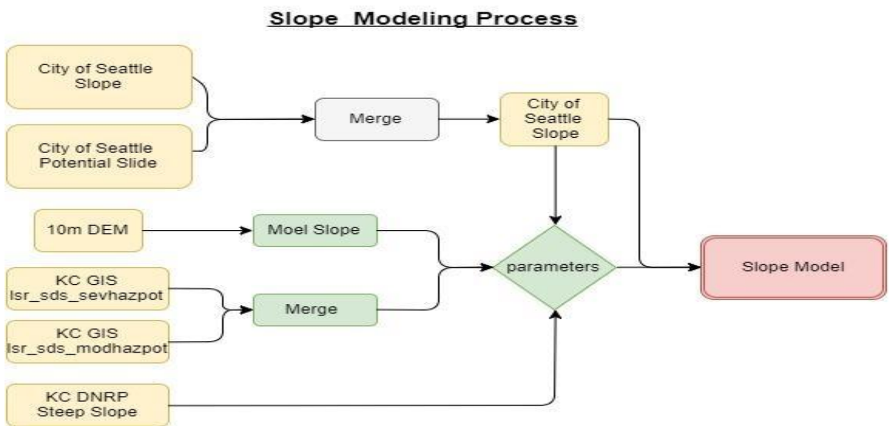


Figure 7. Slope Feature Class Modelling Process

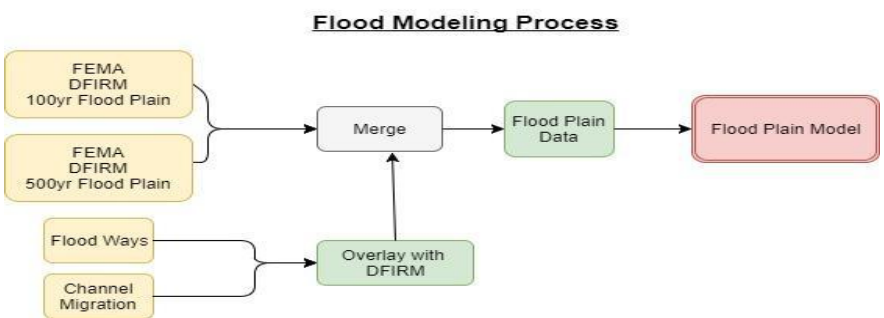


Figure 8. Flood Data Modelling Process

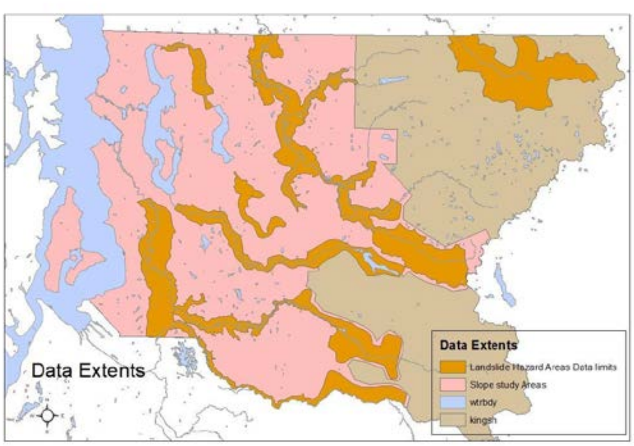


Figure 9. Slope Data Extent Limits

Index and Classification Methodology

We decided the most comprehensible way to create meaningful results would be to calculate normalized indices that allow for comparison across several attributes. These vary greatly, with some comprised of financial data while others are based on slope in a particular area or percentage of population. Z-scores provide a relatively easy way to combine such data into combined indices that are read as a spectrum, with a mean of zero and are interpreted as high scores signifying high vulnerability, while low scores indicate low vulnerability.

Z-score calculation relies on using both the mean and the standard deviation for the attribute in question.

Z Score=(observed value - mean)/standard deviation

In cases where the implications of a higher z-score do not match our classification scheme, such as income data for example, this value can be multiplied by negative one to achieve the correct orientation. This formula standardizes the values which makes it possible to merge data that may have originally existed within a specific measurement. A z-score is calculated for every relevant variable, all of which are then combined into a composite index.

In response to considering the need for ease of use with regards to a publicly available Climate Resiliency Tool, indices have been divided thematically. In particular, we created a core vulnerability index based on the Social Vulnerability Index detailed below but with updated, King County specific data swapped in where possible, a re-worked extreme heat event index, and a precipitation event index. The logic behind this is primarily the usability of a story map or web map tool, as users will be able to add layers consistent with the information they are trying to analyze.

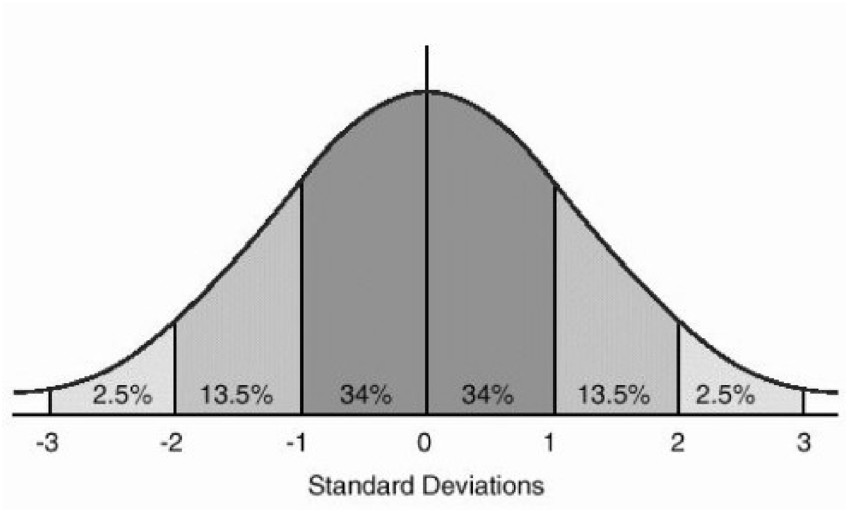


Figure 10. Normal distribution of z scores, showing up to three standard deviations from the mean

Each index utilizes the same labeling scheme, i.e. lowest, low, moderate, high, and highest vulnerability. These are classified based on quintiles, with moderate values ranging from approximately -0.5 to 0.5. This prevents indices that fall over one standard deviation from the mean or zero from showing as extreme inherently. Additionally, vulnerability is subject to the user's needs and will be interpreted from whichever layers are being used, meaning that an area that may show high social vulnerability could hypothetically show low vulnerability for extreme heat, and true vulnerability is based on interpretation of the two layers together.

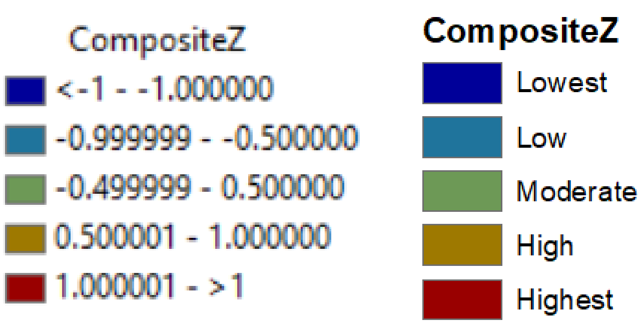


Figure 11. Example showing classification scheme with standard deviations on the left and labels on the right

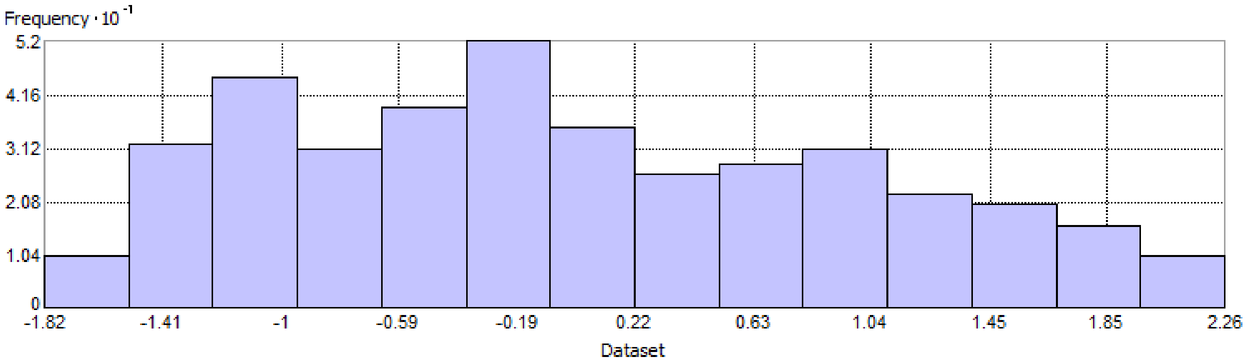


Figure 12. Distribution of Composite Z score data

Social Vulnerability Index

Through first attempts to develop additional indices, in regards to climate change vulnerability, it become very apparent that some variables would play an important role in any index. Specifically, spatial portrayals of demographics and risk. The Agency for Toxic Substances & Disease Registry has developed an index that refers to the resiliency of a community when confronted by external stresses on human health such as climate change. In this index, four themes are used to measure resiliency; Socioeconomic Status, Household Composition & Disability, Minority Status & Language, and Housing & Transportation. 15 variables in total make up these four themes and together “help public health officials and emergency response planners identify and map the communities that will most likely need support before, during, and after a hazardous event.”(SVI, 2013) It is for this reason that four themes in The Agency for Toxic Substances & Disease Registry Social Vulnerability Index (SVI) will be represented in all subsequent indices.

Variables Used

American Community Survey (ACS), 2010-2014 (5-year) data for the following estimates:

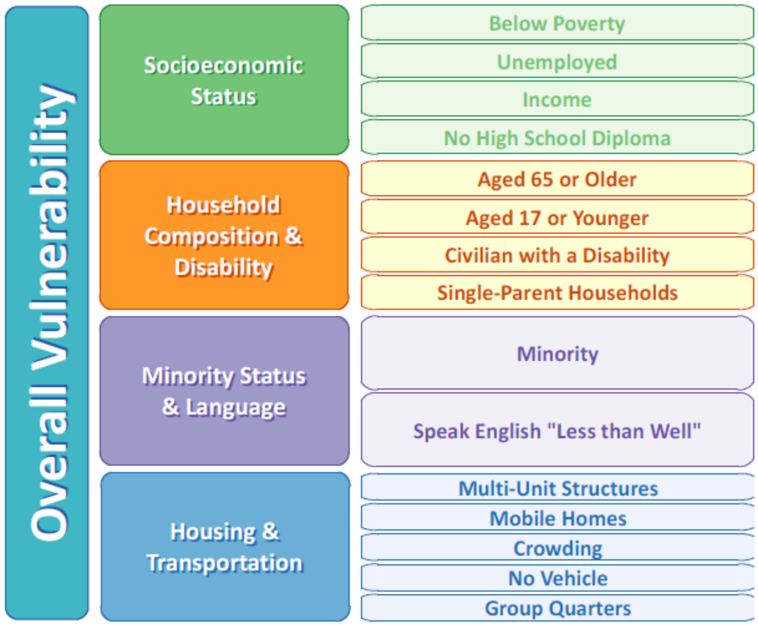


Figure 13. Variables used in the Social Vulnerability Index

Three variables were improved upon in the SVI. Using the "Demographics" data set supplied by King County GIS Center; Minority, Speaking English "Less than Well", and Income were updated as the demographic data set supplied is more recent/accurate than the Census data used in the SVI.

Extreme Heat Event

Previous work has been conducted in implementing a total Heat Vulnerability Index. As methodologies have changed so have the variables used in this index. Specifically, the implementation of the SVI required re-evaluation of the Heat Vulnerability Index.

Variables used in the Heat Vulnerability Index:

- Socioeconomic Status
- Household Composition & Disability
- Minority Status & Language

- Housing & Transportation
- Health Conditions
- Impervious Surface Coverage
- Outdoor Labor Force
- Access to Heat Pumps

The first four variables were compiled from the SVI and are apart of all other indices. Impervious surface coverage remained in the heat vulnerability index for previously documented reasons (see “Promoting Equitable Climate Resilience in King County: Mapping Communities Vulnerable to Extreme Heat”). Outdoor labor force was included as it is those who have increased exposure to climate change events have increased vulnerability. Richard Harris a writer for NPR states, “Working outdoors or playing sports on a hot, muggy day can be dangerous, even deadly.”(Harris, 2013) Finally, while we may never have a complete understanding of who has access to an air conditioning, thanks to the Assessor's office, we do know locations served by heat pumps. A heat pump draws heat from where you don’t want it (indoors during summer) and puts it where you do (outside). This means a heat pump can cool a home by moving, or pumping, heat from inside to the out. It is for this reason access to heat pumps have been added to the heat vulnerability index.

Precipitation Vulnerability Index

As previously discussed, the Precipitation Vulnerability Index is to include the Social Vulnerability Index. In addition to the SVI, outdoor labor force, populations served by on-site sewage systems (septic systems), populations served by private wells, concentrations of drainage complaints, steep slope area, and floodplain areas were examined.

Precipitation Vulnerability Index Variables:

- Socioeconomic Status
- Household Composition & Disability

- Minority Status & Language
- Housing & Transportation
- Outdoor Labor Force
- Population served by a Septic System
- Population served by a Private Well
- Drainage Complaints
- Steep Slope Area
- Floodplain Area

The percent of parcels served by On-site Sewage Systems (OSS) was included in this index as it is homeowners whose plumbing is connected to an OSS that will be without facilities. "Septic systems should not be used immediately after floods. Drain fields will not work until underground water has receded. Septic lines may have broken during the flood."

The percent of parcels served by a private well was included in this index as, "People drinking or washing with water from a private well that has been flooded will risk getting sick."

Esri StoryMap Construction

Using the ESRI's Map Journal Builder, a web mapping application was developed titled, "Climate Change Resiliency Tool". This format was chosen to help guide users based on likely climate change outcomes such as a heavy precipitation event. Helpful information is found to the left of each map regarding what is depicted and more importantly why. One such example is the inclusion of parcels served by septic systems under the heavy precipitation theme.

Before the construction of the final web mapping application could be done, a web map was created. It is here, in the web map, that all the symbology, zoom based scaling, data classification, and pop-up content was configured.

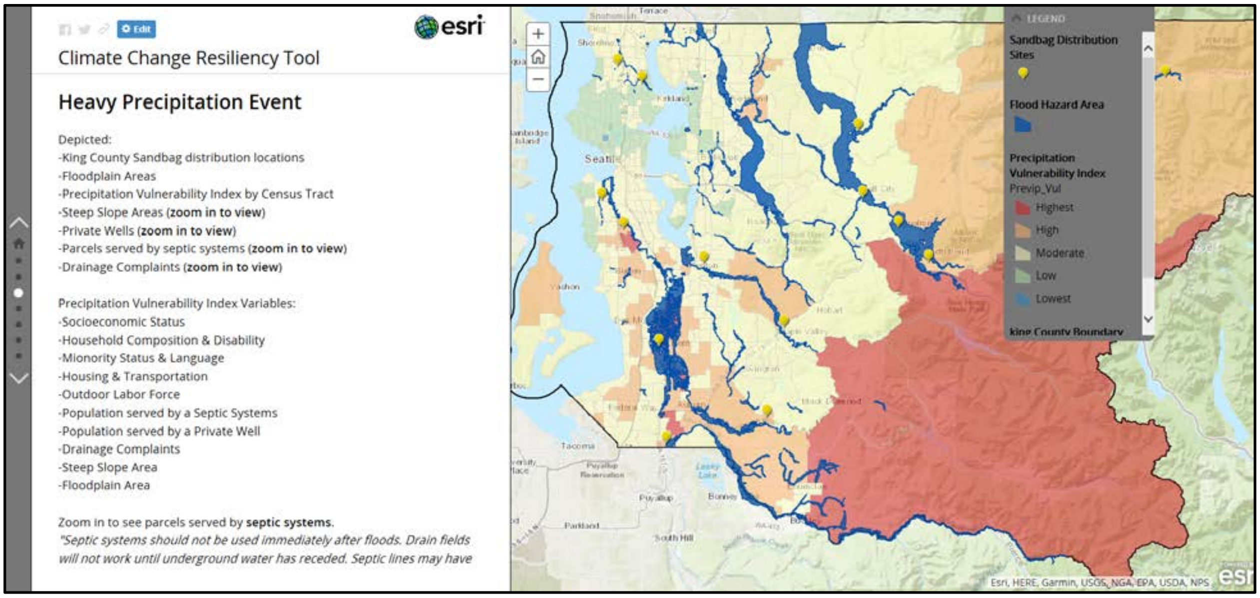


Figure 14. Heavy Precipitation Event Story Map

Zoom based scaling was used to help guide users to areas of vulnerability based on the vulnerability index for that specific theme. The above screenshot shows the initial view extent of the Heavy Precipitation Event where the precipitation vulnerability index is shown. Zooming in, presumably to areas of high vulnerability, will enable additional layers to help the user understand vulnerability on a much finer scale.

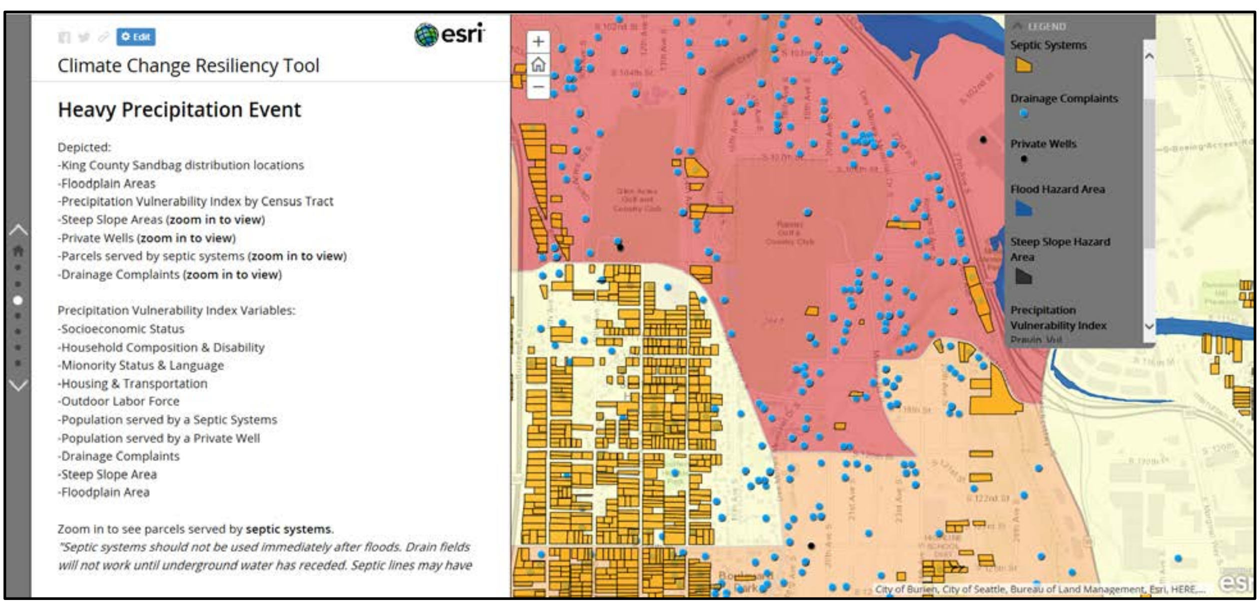


Figure 15. Detail of Heavy Precipitation Event Story Map

A second basic web mapping application was developed to be embedded in the Climate Change Resiliency Tool to enable users to explore all layers used in the project independently. This functionality was requested by King County staff as this tool has potential to aid several different agencies with many topics regarding climate change. The implementation of this functionality can be found by navigating to the last section or clicking the link “skip to the end” found on the home screen.

Depicting sea level rise needed to be done in such a way that different scenarios could be selected. To solve this, “Story Actions” were used to turn on layers in the map on the main stage. Selecting the story action for a sea level rise scenario would de-activate any other scenario and activate the layer associated with the selected extent.

Results

The Heavy Precipitation event scenario for King County was defined and a scope of work established. Determining what would represent the needs of the sponsor and the specific scenario was the next process. The data that would be needed for modelling and interpretation continued the process. Continued development of methodology that allowed consistent, reliable, appropriate modeling was established and implemented. The primary goal of allowing the sponsor, in this case, King County Department of Natural Resources and Parks (KC DNRP), to make defendable fact based decisions was critically important. Anecdotal evidence was present but to provide data to the general public and decisions makers based on research and reproducible results was the end goal.

We found that a heavy precipitation event is not only likely, but is a regular occurrence in King County. It is a county wide event that impacts all of the different communities and geographical areas, independent of socioeconomic factors. The topographical differences and their unique geographical impacts were the specific event layers. Floodplain and slope or potentially dangerous landslide areas represented that topographic variable. The eastern half of the county is mountainous and has widespread areas of slide prone areas. However, the population density is lower. The western half of the county does have areas of high potential landslide impact but consequently is prone, due to topographical differences, to flooding. The western half has a significantly higher population density.

We introduce a wide and comprehensive variable list to look at the county wide focal scale, yet allow for future study of different scenarios.

<u>-Socioeconomic Status</u>

The Socioeconomic Status map, also known as theme one of the Social Vulnerability Index, showed that the highest impacts were to the Southwest regions of the county. Previous work regarding demographics has been conducted by King County, including research in spatial portrayals of income in King County. This work as well as theme one of the Social Vulnerability Index confer that; Federal Way, Kent, Auburn, and Tukwila are areas of higher vulnerability. Flooding results in areas surrounding the Green River and Duwamish waterway intersect with these areas of higher vulnerability and should be the area of the highest concern from a Socioeconomic Status perspective.

<u>-Household Composition & Disability</u>

The Housing Composition & Disability map, also known as theme two of the Social Vulnerability Index, showed that the highest impacts were to the Southwest regions of the county. Flooding results in areas surrounding the Green River and Duwamish waterway intersect with areas of higher vulnerability and should be the area of the highest concern from a Housing composition & Disability perspective. The highest values of impact for this variable were located in the Auburn, Kent valley area and scattered pockets in the county, with no observable and reproducible variable factors.

<u>-Minority Status & Language</u>

The Minority Status & Language map, also known as theme three of the Social Vulnerability Index, showed that the highest impacts were to the Southwest regions of the county. Previous work regarding demographics has been conducted by King County, including research in spatial portrayals of people of color and those who speak english less than well in King County. This work as well as theme three of the Social Vulnerability Index confer that; Federal Way, Kent, Auburn, and Tukwila are areas of higher vulnerability. Flooding results in areas surrounding the Green River and Duwamish waterway intersect with areas of higher vulnerability and should be the area of the highest concern from a Minority Status & Language perspective. The highest values of impact, were in the southwestern and central western portions of the county.

-Housing & Transportation

The Housing & Transportation map produced a more diffused and not specific model. There were pockets spread across the western half of the county. The major discrepancy between the western and eastern portions of the county can be explained by the crowding and corresponding transportation services for housing groups. The flooding results in areas surrounding the Green River and Duwamish waterway intersect with areas of higher vulnerability and should be the area of the highest concern from a Housing & Transportation perspective.

-Outdoor Labor Force

One of the Clearest delineation, the eastern half of the county had the highest impacted census tracts. Areas of high vulnerability surrounding the Snoqualmie River are those of the highest concern from an outdoor labor force perspective. More specifically; Duvall and Carnation are locations of concern.

-Population served by a Septic System

Logically, this was in conjunction with areas of lesser urbanized and prevalent public utility areas. Areas of high vulnerability with excessive flooding surrounding the Snoqualmie River are those of the highest concern from a Septic System perspective. More specifically; Duvall and Carnation are locations of concern.

-Population served by a Private Well

Areas of lesser urbanized and prevalent public utility areas. Areas of high vulnerability with excessive flooding surrounding the Snoqualmie River are those of the highest concern from an Private Well perspective. More specifically; Duvall and Carnation are locations of concern.

-Drainage Complaints

This model produced some interesting results, in that it did create pockets of higher concentration of impacts but the only wide spread area of consistent lower complaint volume was the Northwestern portion of the county. Rural versus urban areas do seem to increase complaints but that is not consistent across the county. A smaller focal scale study, potentially based on census blocks or even tax parcels should be undertaken to better understand spatial portrayals of drainage complaints.

-Steep Slope Area

King County is not a flat area. Even in the Puget Sound Lowlands portion there are numerous areas of high slope and therefore high landslide potential throughout. Prevalent cliffs, bluffs and steep shoreline, are present. The eastern half is dominated by the Cascade Mountains, so areas of high slope and increased landslides are common. 76 of the 299 census tracts contain more than 10% of area that falls within the City of Seattle's "steep slope" parameters. 23 Points of Critical importance also lie within 100ft of a slope hazard zone. They include Fire stations, Medical Facilities and municipal buildings

-Floodplain Area

There are a selection of rivers and and river valleys in the County. Some are large and encompass a significant amount of land. The 100 and 500 yr DFIRM floodplains mirror those land impacts. While the western half of the county is impacted more by these plains, Transportation and service access impacts are county wide. 8 of the 22 major medical facilities in King County have portions of the transportation network that will be impacted by the 500 yr flood plain within ½ mile of that facility. This will impact access to varying extents but should be a consideration of the impacts to access to those services. 22 points of critical infrastructure points are located within the FEMA DFIRM 500yr flood plain. These include the full gammet of Police, Fire, Medical and Governmental facilities. Approximately 900 miles of the transportation network of King County directly intersects with the 500yr Floodplain.

The Index of variables and their specific impacts to King County represent what we feel is a comprehensive, Social, Economic and Environmental model. They attempt to provide a base of the potential impacts, specifically in this case, a heavy precipitation event. But also can be used in the future for other scenarios.

-Precipitation Vulnerability Index

Concentrations of lower vulnerability can be found near North Seattle, while areas to the South near Kent, Tukwila, and Algona as well as a large rural area to the Southeast of the county we find higher vulnerability scores.

Static maps for the above results can be found in the appendix of this paper and the full online mapping tool "Climate Change Resiliency Tool" can be found here: http://arcg.is/059LDW

Access can be gained using King County ArcGIS Online login credentials.

Discussion

While the body of work presented in this paper was successful in implementing an analysis of vulnerable communities in King County, there were shortcomings. Health related data and methodologies identified in the previous work from 2016 cohort in the Master of GIS program at the University of Washington has yet to be completed. Two data sources were to be combined into one measure. According to King County staff the 2016 cohort was not successful in this pursuit. The health related data used in this project is one half of the proposed analysis, hospitalizations for three related health outcomes. The other piece to the puzzle, health condition prevalence, still needs to be obtained.

The use of a multicriteria evaluation needs to be implement. For the scope of this project, equal weights were used for all variables in all indices. To make the tool more versatile and meaningful, different scenarios should be developed in which unequal weights are assigned to the variables used in this analysis.

Due to the comprehensive nature of the data and the differences in the topographical impacts, no clear and consistent specific location impacts could be determined. Specific Social, Environmental and Economic factors created different hot spots or geo specific effects for this heavy precipitation event. It would be feasible, and even preferable, to narrow down or specify a focus of Socio economic or environmental factors that a potential future study required, for a more definable result.

A utility service provider would be able to use the base slope/floodplain layers and then might look at the population served by a septic system, population served by private wells and drainage complaints variables to make a water system service decision. A Social services group looking at implementing a food distribution system and how that would be affected by a heavy precipitation event would possible select the more census based demographic variables.

One of the base precepts that our group attempted was to develop a platform that could be adapted to many different scenarios. The individually selected, and potentially all the variables, could be used in multiple ways for a decision support matrix for as many stakeholders as possible.

The logical progression of this work is to complete a final index including all climate change themes; heavy precipitation, extreme heat, air quality decline, and sea level rise. This final index should include the four themes from the SVI as well as all the unique variables used in the climate change themes. Thus far, the unique variables in the extreme heat index and the heavy precipitation index have been combined with the four SVI themes; Socioeconomic Status

Household Composition & Disability,Minority Status & Language, Housing & Transportation. To complete this work, unique variables should be identified and developed for sea level rise and air quality decline.

Business Case and Implementation Plan

With so much potential for climate change driven catastrophes, there are several models that will need to be created and examined in order to allow for a comprehensive picture of King County resilience. This should take the form of event layers being researched and built to be added onto the existing Esri StoryMap, allowing for a clear illustration of the myriad interactions between core vulnerability and potential event outcomes based on geographically specific elements and data. The development of a multi-criteria evaluation needs to be implemented to add value to the variable used in this analysis.

Continuing to collaborate with University of Washington graduate students allows for fewer costs while providing real world, important project experience.While continued collaboration with the University of Washington Additionally, the use of Esri Online’s cloud based format allows for minimal on site data storage and processing needs while allowing various discrete agencies and private citizens the ability to view, access, and interpret the information provided.

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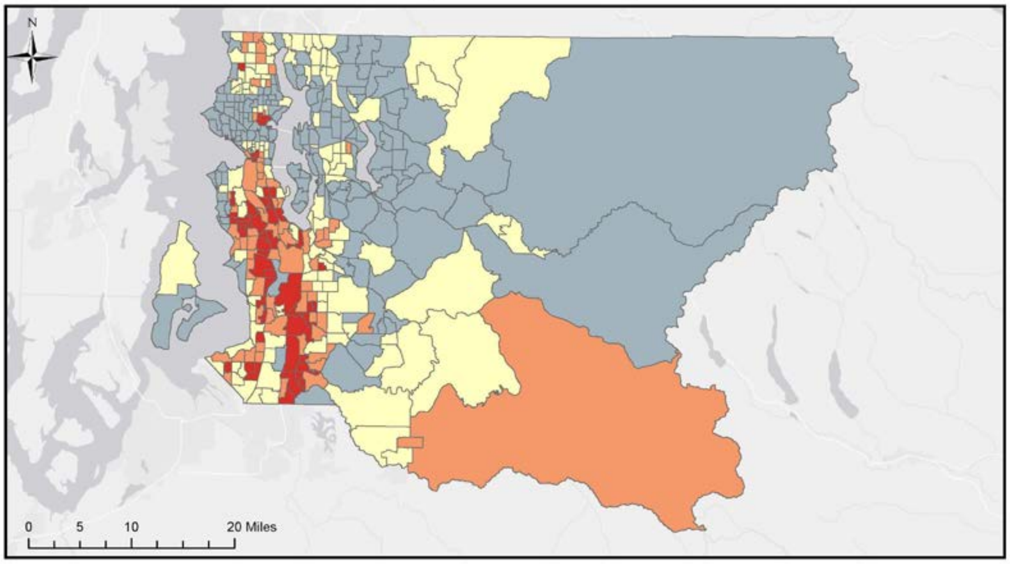
Social Vulnerability Index Theme 1 King County, WA



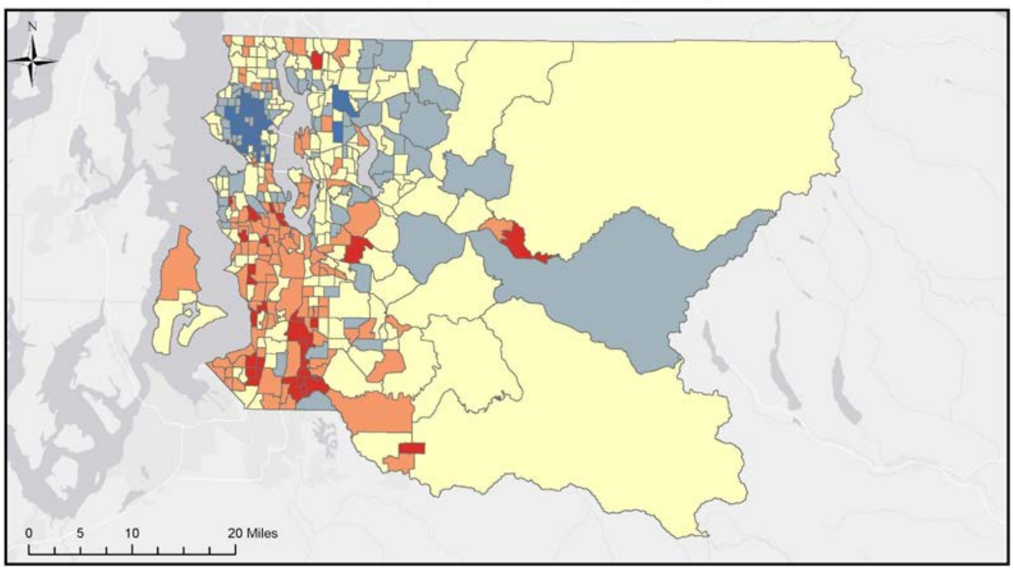
Socioeconomic Status

- Lowest
- Low
- Moderate
- High
- Highest

This map shows theme 1 of the
Social Vulnerability Index (Socioeconomic Status)
King County, WA by Census Tracts.
A higher score represents a more vulnerable population

Date: 7/25/17
Author: Dane Carson, Mike Hamilton, Jennifer Paton
Data Source: Agency for Toxic Substances and Disease Registry

Social Vulnerability Index Theme 2 King County, WA



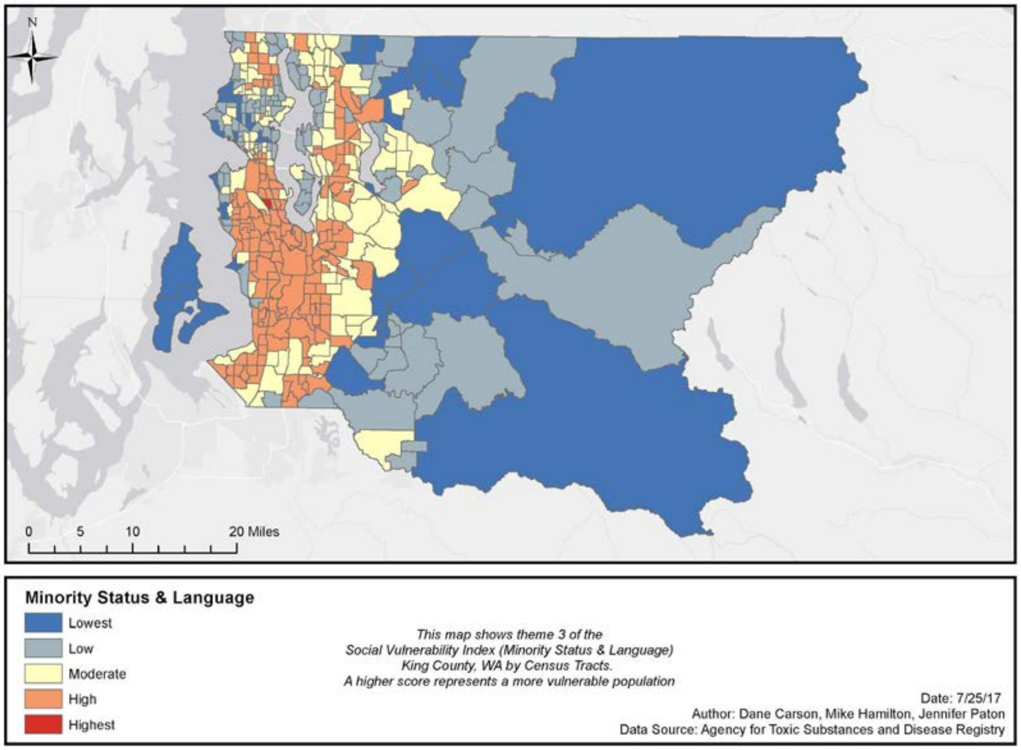
Housing Composition & Disability

- Lowest
- Low
- Moderate
- High
- Highest

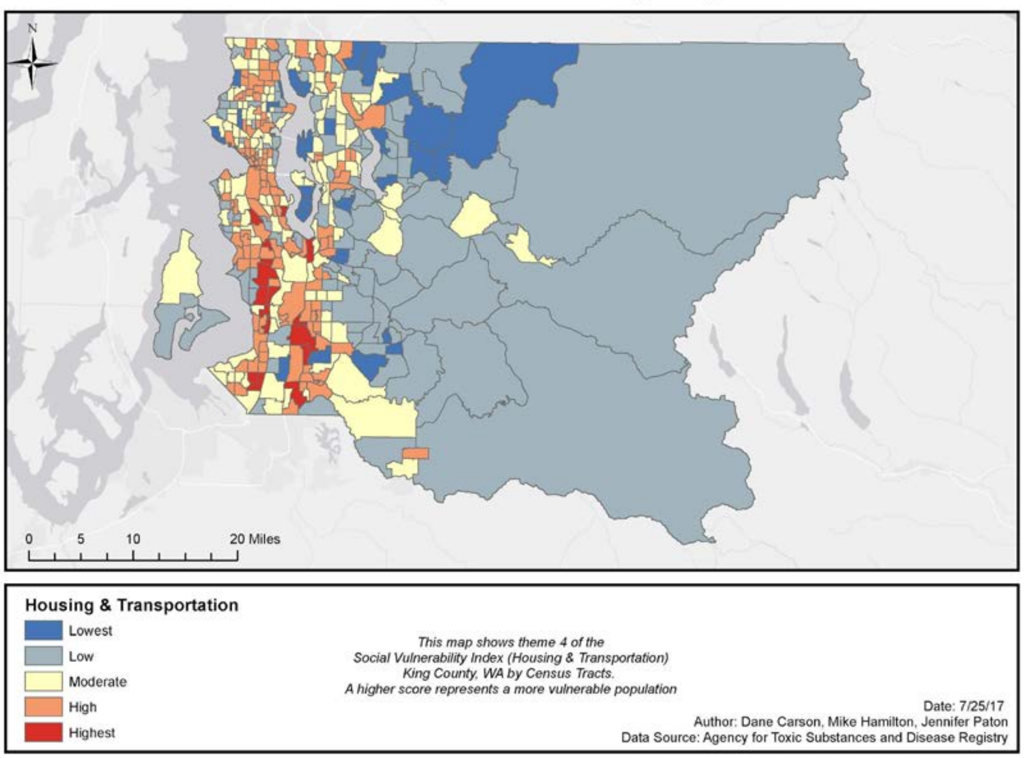
This map shows theme 2 of the
Social Vulnerability Index (Housing Composition & Disability)
King County, WA by Census Tracts.
A higher score represents a more vulnerable population

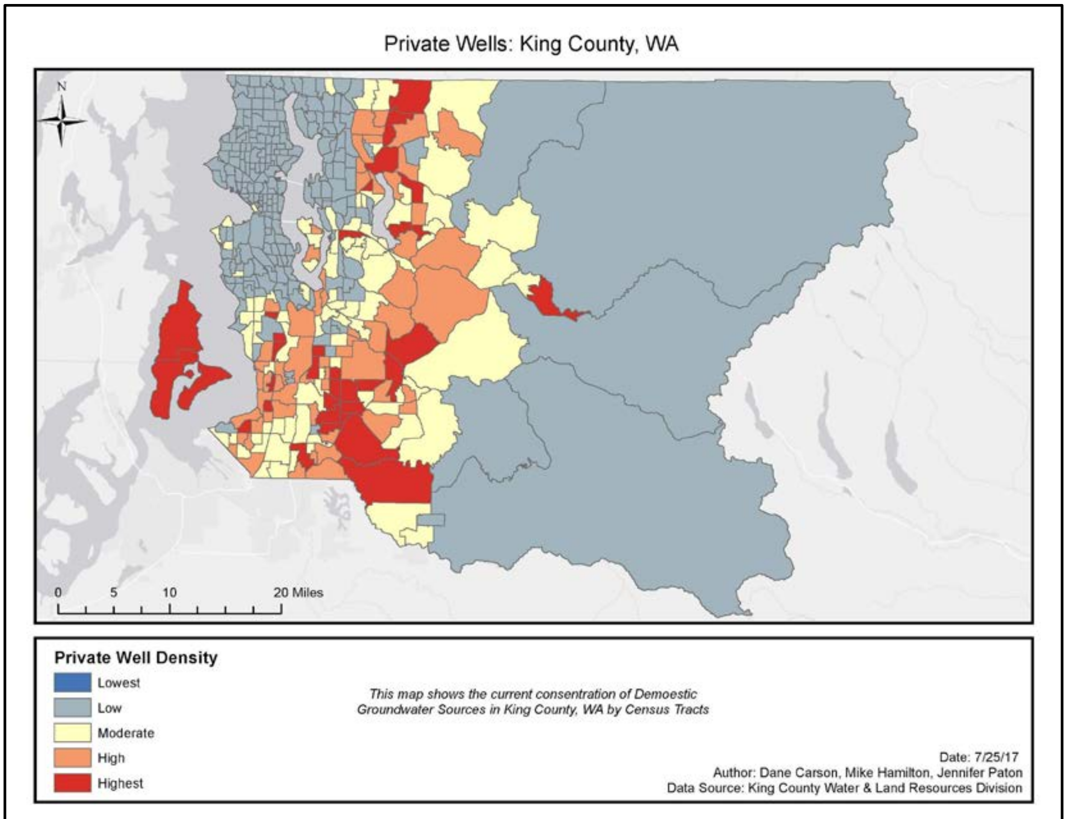
Date: 7/25/17
Author: Dane Carson, Mike Hamilton, Jennifer Paton
Data Source: Agency for Toxic Substances and Disease Registry

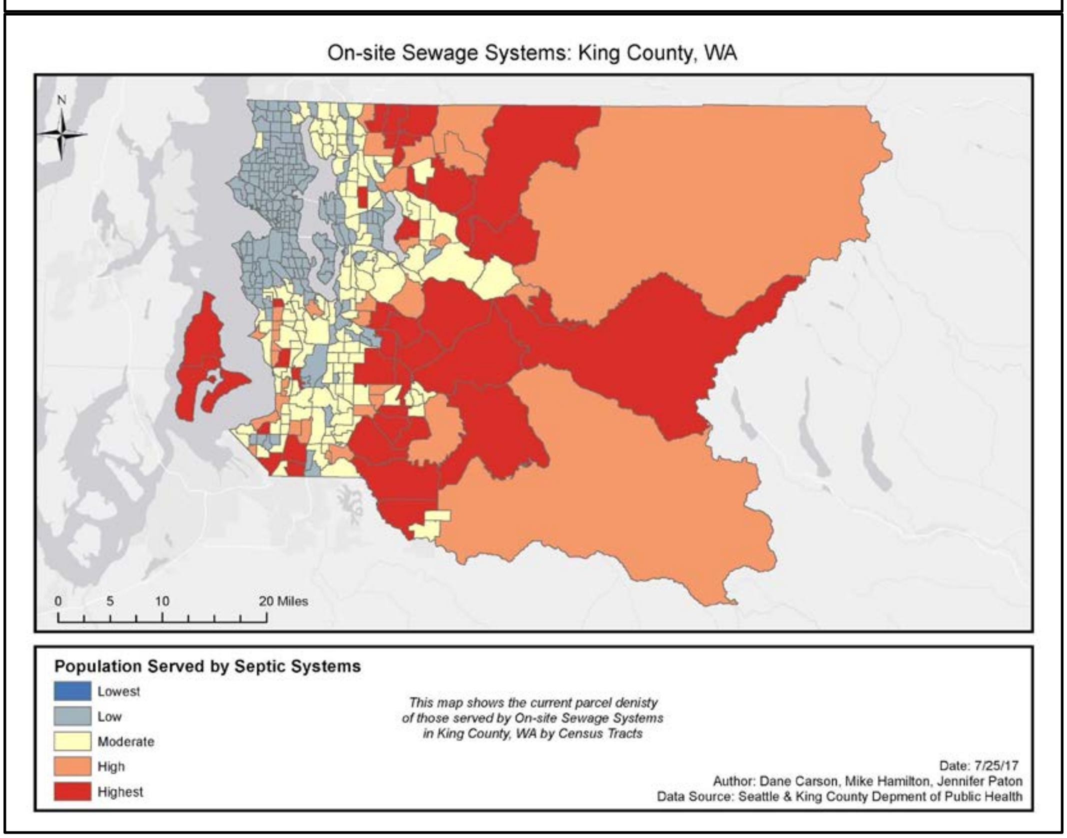
Social Vulnerability Index Theme 3 King County, WA

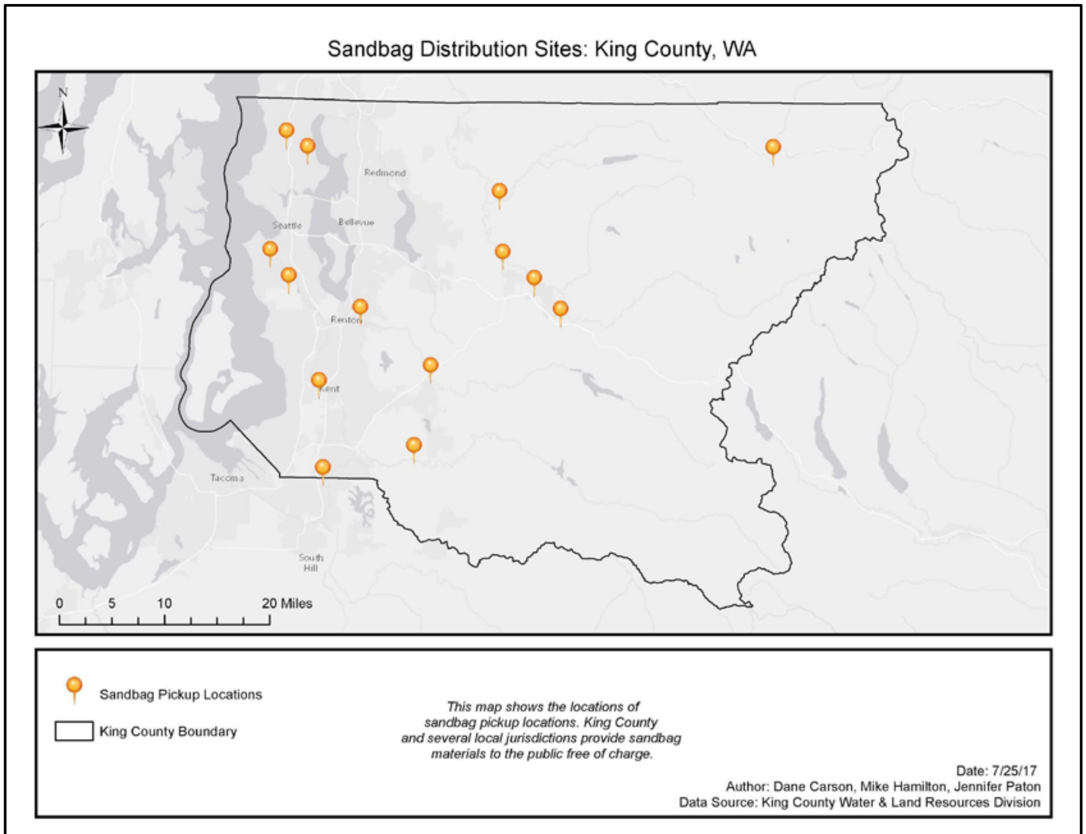


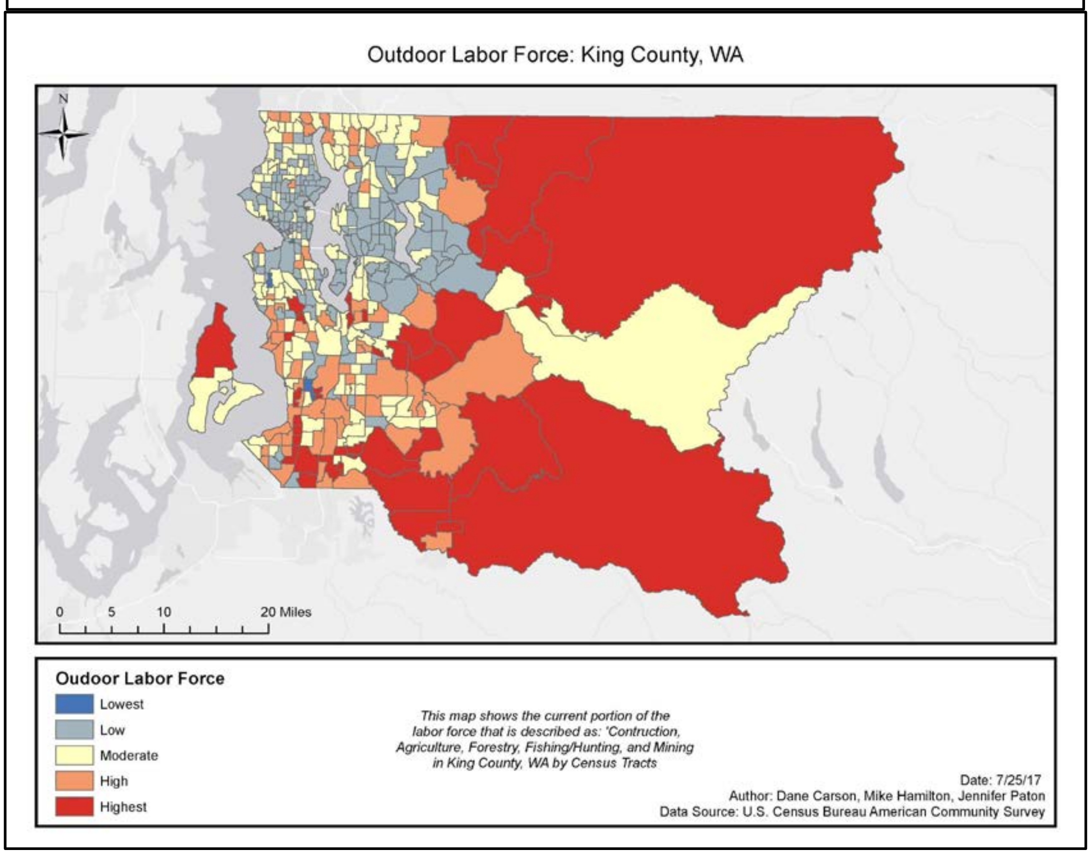
Social Vulnerability Index Theme 4 King County, WA

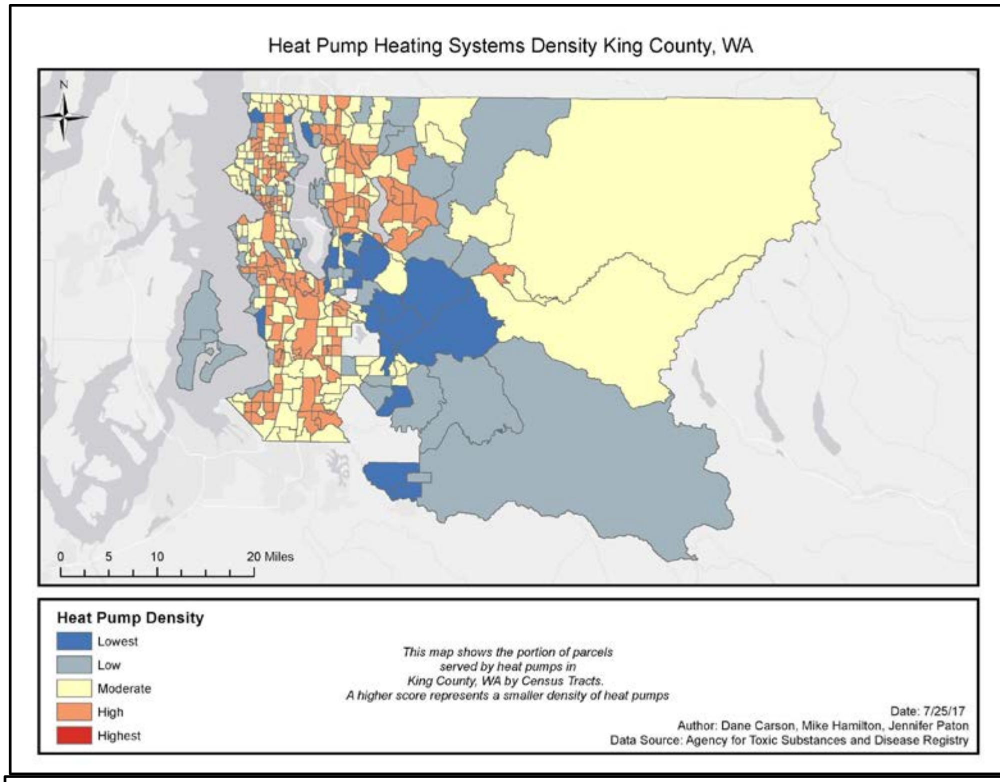


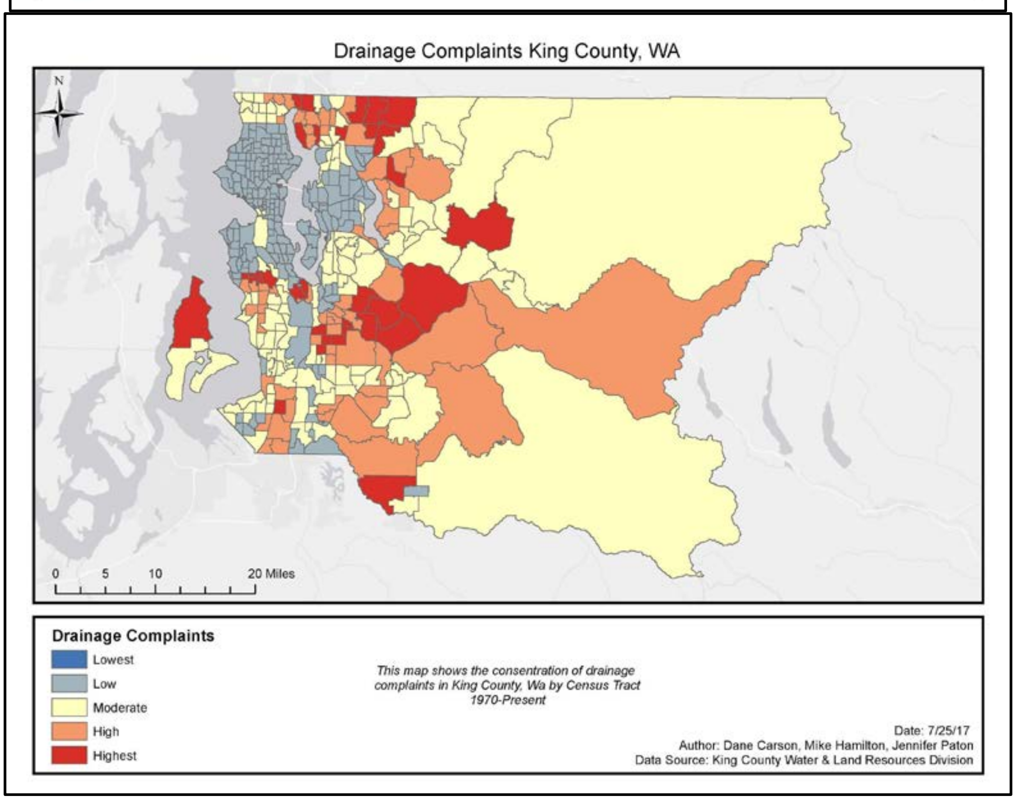

Private Wells: King County, WA
N
0 5 10 20 Miles
Private Well Density
Lowest
Low
Moderate
High
Highest
This map shows the current consentration of Demoestic Groundwater Sources in King County, WA by Census Tracts
Date: 7/25/17
Author: Dane Carson, Mike Hamilton, Jennifer Paton
Data Source: King County Water & Land Resources Division

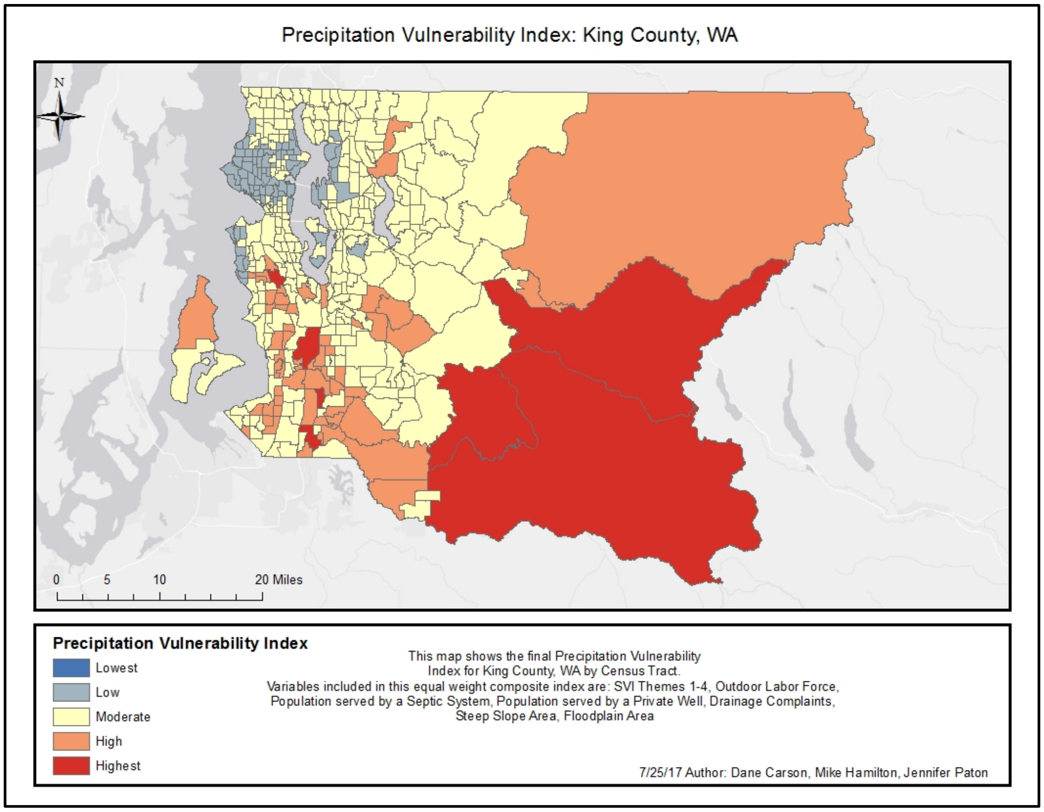

On-site Sewage Systems: King County, WA
N
0 5 10 20 Miles
Population Served by Septic Systems
Lowest
Low
Moderate
High
Highest
This map shows the current parcel denisty of those served by On-site Sewage Systems in King County, WA by Census Tracts
Date: 7/25/17
Author: Dane Carson, Mike Hamilton, Jennifer Paton
Data Source: Seattle & King County Depment of Public Health

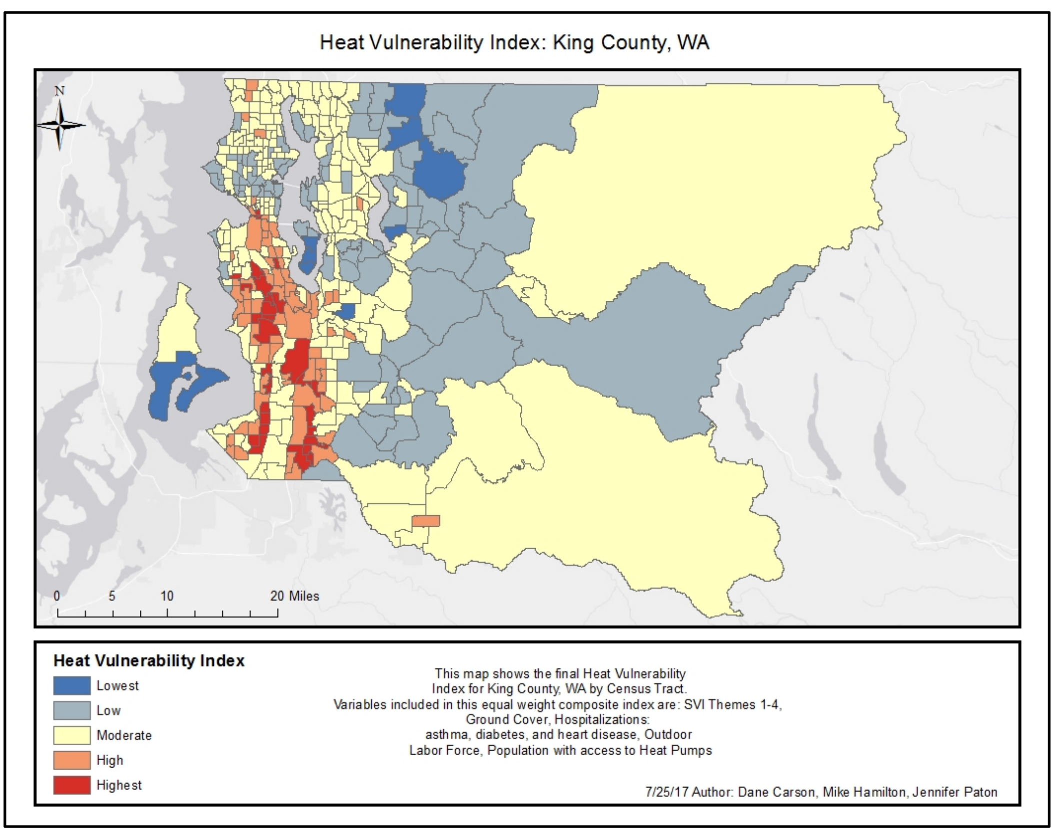

Sandbag Distribution Sites: King County, WA
N
Redmond
Seattle
Bellevue
Renton
Kent
Tacoma
South Hill
0 5 10 20 Miles
Sandbag Pickup Locations
King County Boundary
This map shows the locations of sandbag pickup locations. King County and several local jurisdictions provide sandbag materials to the public free of charge.
Date: 7/25/17
Author: Dane Carson, Mike Hamilton, Jennifer Paton
Data Source: King County Water & Land Resources Division

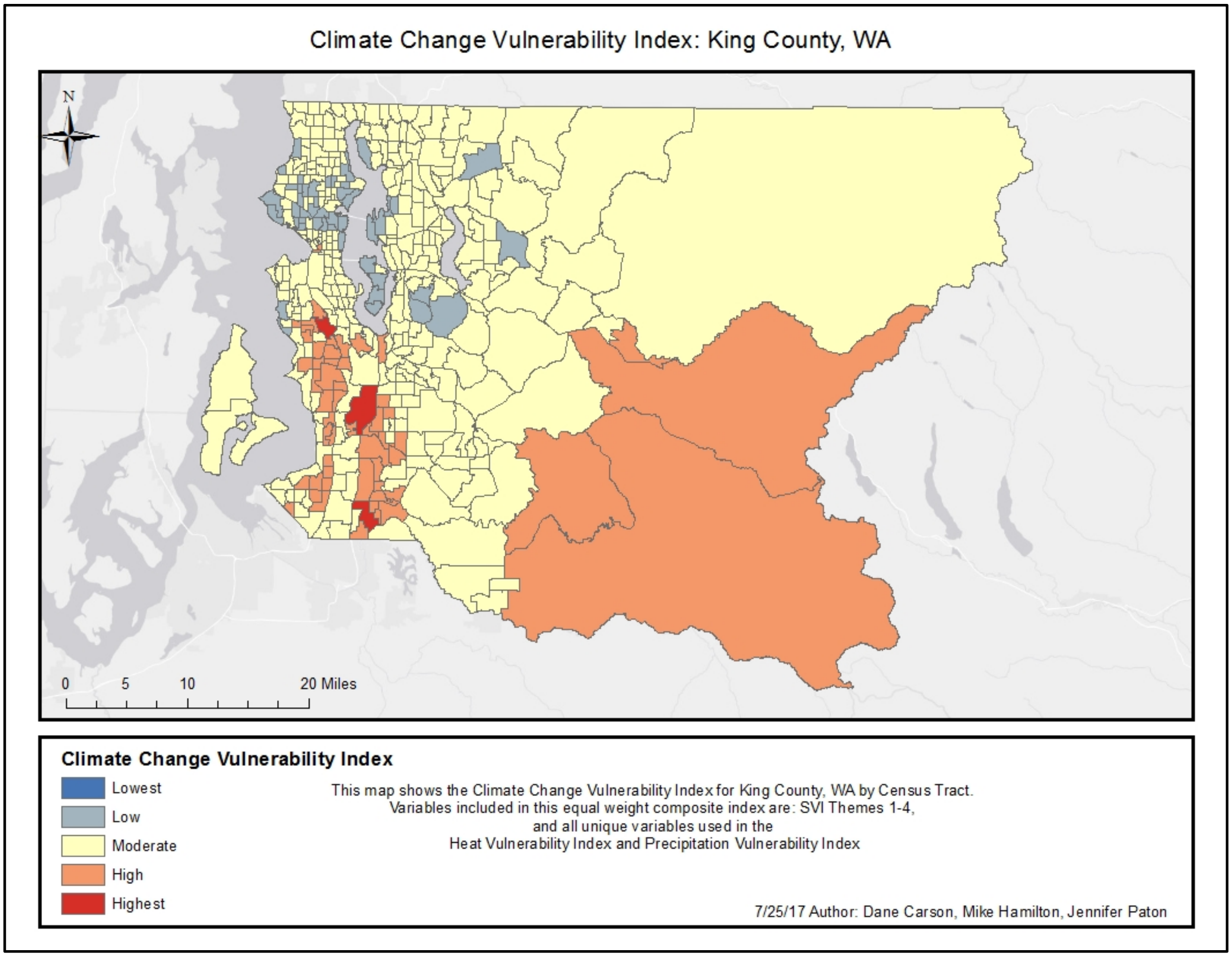

Outdoor Labor Force: King County, WA
N
0 5 10 20 Miles
Oudoor Labor Force
Lowest
Low
Moderate
High
Highest
This map shows the current portion of the labor force that is described as: 'Contruction, Agriculture, Forestry, Fishing/Hunting, and Mining in King County, WA by Census Tracts
Date: 7/25/17
Author: Dane Carson, Mike Hamilton, Jennifer Paton
Data Source: U.S. Census Bureau American Community Survey


Heat Pump Heating Systems Density King County, WA
N
0
5
10
20 Miles
Heat Pump Density
Lowest
Low
Moderate
High
Highest
This map shows the portion of parcels
served by heat pumps in
King County, WA by Census Tracts.
A higher score represents a smaller density of heat pumps
Date: 7/25/17
Author: Dane Carson, Mike Hamilton, Jennifer Paton
Data Source: Agency for Toxic Substances and Disease Registry


Drainage Complaints King County, WA
N
0
5
10
20 Miles
Drainage Complaints
Lowest
Low
Moderate
High
Highest
This map shows the consentration of drainage
complaints in King County, Wa by Census Tract
1970-Present
Date: 7/25/17
Author: Dane Carson, Mike Hamilton, Jennifer Paton
Data Source: King County Water & Land Resources Division


Precipitation Vulnerability Index: King County, WA
N
0 5 10 20 Miles
Precipitation Vulnerability Index
Lowest
Low
Moderate
High
Highest
This map shows the final Precipitation Vulnerability Index for King County, WA by Census Tract. Variables included in this equal weight composite index are: SVI Themes 1-4, Outdoor Labor Force, Population served by a Septic System, Population served by a Private Well, Drainage Complaints, Steep Slope Area, Floodplain Area
7/25/17 Author: Dane Carson, Mike Hamilton, Jennifer Paton


Heat Vulnerability Index: King County, WA
N
0 5 10 20 Miles
Heat Vulnerability Index
Lowest
Low
Moderate
High
Highest
This map shows the final Heat Vulnerability Index for King County, WA by Census Tract. Variables included in this equal weight composite index are: SVI Themes 1-4, Ground Cover, Hospitalizations: asthma, diabetes, and heart disease, Outdoor Labor Force, Population with access to Heat Pumps
7/25/17 Author: Dane Carson, Mike Hamilton, Jennifer Paton


Climate Change Vulnerability Index: King County, WA
N
0
5
10
20 Miles
Climate Change Vulnerability Index
Lowest
Low
Moderate
High
Highest
This map shows the Climate Change Vulnerability Index for King County, WA by Census Tract.
Variables included in this equal weight composite index are: SVI Themes 1-4,
and all unique variables used in the
Heat Vulnerability Index and Precipitation Vulnerability Index
7/25/17 Author: Dane Carson, Mike Hamilton, Jennifer Paton