Prioritizing Areas for Green Stormwater Infrastructure: A King County Landscape Analysis

Swale on Yale

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We would like to thank Dr. Robert Aguirre, Dr. Suzanne Withers and Dr. Tim Nyerges. Without their vision, support and guidance we wouldn't be where we are today. Their passion for all things geographic information systems is infectious, and something we hope to make a focus of our careers. This project came to fruition through the creative imagination of The Nature Conservancy. The Nature Conservancy is leading the way in creating sustainable cities.

From Sage Tezak
The encouragement and support of my husband, Dave, who always supported me and declared time and time again, "keep your eye on the ball!" Thank you! And to my grandma, who sacrificed spending time with me, so I could follow my dreams. And last, but certainly not least, my parents, who have been my anchor. I think I've reached my limit. I'm done with formal schooling!

From David Danker
The support and encouragement of family is priceless. You have encouraged me and supported me over the past two years.

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RECOMMENDED COURSE OF ACTION

Our recommended course of action is three-fold, and if accomplished, will position The Nature Conservancy at the hub of green stormwater infrastructure development in Puget Sound. Additionally, carrying out these recommendations will align with TNC's Cities Initiative.

First, we recommend TNC further investigate basins within the following municipalities: Seattle (99 basins; 42 sq. km), Kent (4 basins; 3 sq. km), Renton (4 basins; 2 sq. km), Redmond (5 basins; 0.14 sq. km). The basins identified here rank among the upper ten percent (of the municipalities included in our analysis) as having a high relative measure of importance in regards to targeting areas for green stormwater infrastructure development. A further step may be identifying vacant parcels within these priority basins.

Secondly, we recommend further investigation into how stormwater drainage basins are developed. By gaining a greater understanding of the methodologies used to delineate basins, TNC will position themselves at the forefront of stormwater management. The first municipality of inquiry should be Mukilteo. The city of Mukilteo developed a stormwater management plan resulting in a case study analysis that aimed to answer the following question: which areas of the City would benefit most from investments in Low Impact Development, stormwater retrofit, stream and wetland mitigation projects, and/or property acquisition? The Mukilteo study aligns with the parameters of this project.

Finally, we recommend TNC develop a partnership with the Washington Stormwater Center. The Center provides guidance to permittees and stormwater managers as they navigate the complexities and challenges of managing stormwater. The Washington Stormwater Center initiated the Standardized Mapping Framework Project in an effort to create a framework for stormwater system mapping that would support a regional stormwater system map and inventory. For our experience, it appears the grant for this effort has ended, and the project has gone by the wayside.

INTRODUCTION

The Puget Sound, as defined in the *2015 State of the Sound Report*, comprises all saltwaters between Washington and the international boundary of British Columbia. Puget Sound extends east through the Strait of Juan de Fuca to the intersection of the Pacific Ocean, and includes the land areas bounded by rivers and streams draining into the estuarine waters (Figure 1). Considered the largest estuary by volume in the United States, Puget Sound has long been a centerpiece for the state's economy, recreation, food, water and other essential quality of life benefits. However, over the past hundred years, an increasing human population has brought about more development, more infrastructure and more pollution. Consequently, the water quality and natural habitats of Puget Sound has become degraded, causing a decline in the viability of species and altering food webs (Hamel et al. 2015).

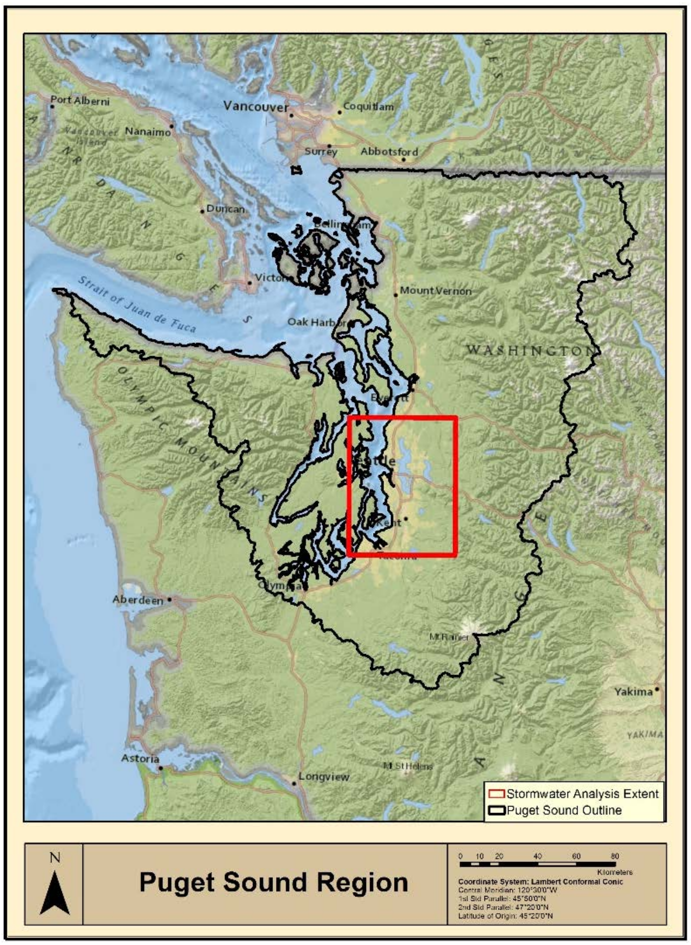

Figure 1. Puget Sound region & area of analysis.

In partnership with The Nature Conservancy (TNC), this study examines stormwater drainage systems within King County, and identifies areas suitable for green stormwater infrastructure. Ultimately, TNC, under the Cities Initiative – a global effort to advance conservation in urban settings – is in the planning phase of addressing Puget Sound's polluted stormwater runoff and impacts to salmon, Puget Sound marine ecosystem and local communities. By the year 2020, TNC has set a goal to reduce levels of toxic runoff into Puget Sound and improve the lives of wildlife, habitat and people.

POLLUTANTS IN PUGET SOUND

Stormwater runoff carries with it many pollutants that originate from a variety of sources, including fertilizers, herbicides and insecticides from agricultural lands and residential areas; sediment from construction sites and eroding streambanks; bacteria from pet waste and failing septic systems; soaps from washing cars or equipment; and oil, grease, metals and coolants from vehicles (Science of Stormwater - King County 2016).

While there are many sources of pollutants in stormwater runoff, our study focuses on roadways. Roadways are a primary source of stormwater pollution (Sartor et al. 1974, Adamiec et al. 2016). Vehicles deposit a variety of non-exhaust emissions (Table 1) onto roadways. During storm events these deposits or "road dust" move into the stormwater drainage system, and eventually end up in nearby streams, rivers or lakes, all of which eventually connect to Puget Sound.

Table 1. Common road runoff pollutants and sources (excerpt from Krobringer 1984).

Constituent	Primary Sources
Particulates	Pavement wear, vehicles, atmosphere, maintenance, snow/ice abrasives, sediment disturbance
Nitrogen (N), Phosphorus (P)	Atmosphere, roadside fertilizer use, sediments
Lead (Pb)	Leaded gasoline, tire wear, lubricating oil and grease, bearing wear, atmospheric fallout
Zinc (Zn)	Tire wear, motor oil, grease
Iron (Fe)	Auto body rust, steel highway structures, engine parts
Copper (Cu)	Metal plating, bearing wear, engine parts, brake lining wear, fungicides and insecticides use
Cadmium (Cd)	Tire wear, insecticide application
Chromium (Cr)	Metal plating, engine parts, brake lining wear
Nickel (Ni)	Diesel fuel and gasoline, lubricating oil, metal plating, brake lining wear, asphalt paving
Manganese (Mn)	Engine parts
Bromide (Br-)	Exhaust
Cyanide	Anticake compound used to keep deicing salt granular
Sodium (Na), Calcium (Ca)	Deicing slats, grease
Chloride	Deicing salts
Sulfate	Roadway beds, fuel, deicing salts
Petroleum	Spills, leaks, blow-by motor lubricants, antifreeze, hydraulic fluids, asphalt surface leachate
PCBs, pesticides	Spraying of highway right of ways, atmospheric deposition, PCB catalyst in synthetic tires
Pathogen bacteria	Soil litter, bird droppings, trucks hauling livestock/stockyard waste
Rubber	Tire wear
Methanol	Windshield wiper fluid, brake fluid
Asbestos*	Clutch and brake lining wear
* No mineral asbestos has been identified in runoff, however some breakdown products of asbestos have been measured.	

When evaluating vehicular emissions, several factors need to be considered, including volume of traffic, particularly during storm events; precipitation characteristics (antecedent dry days, storm duration and intensity); and site specific conditions (size of area, surrounding land use; Barrett et al. 1995). Additional considerations include the type of road surface (asphalt or concrete), vehicle speed and road features, such as roundabouts, motorway roads and traffic lights. According to Duong and Lee (2011), tire abrasion is greater on concrete surfaces, and at higher speeds. Duong and Lee (2011) determined the concentration of metals in road dust from motorways are twice those found near roundabouts and downtown areas (Duong and Lee 2011). Whereas, Adamiec et al. (2016) determined the greatest overall vehicle wear occurs during acceleration, braking and cornering. According to Adamiec et al. (2016) road dust collected from an urban roadway (35 km/h average speed) was 30% more contaminated with zinc, copper, lead and iron than motorway (103 km/h average speed) dust (Adamiec et al. 2016).

Although study results have proven contrary when evaluating road dust and the likely contributing factors – one thing remains certain – vehicles emit pollutants. Whether more pollutants originate from vehicular exhaust or non-exhaust emissions, these pollutants are finding their way into our waterways. Pollutants entering waterways are detrimental for salmonid species, and in particular, coho salmon *(Oncorhynchus kisutch)*. Puget Sound coho salmon have been identified as a Species of Concern under the Endangered Species Act (Fisheries, NOAA 2016). Coho salmon live in the lowland streams of Puget Sound, and spend a full year or more in these fresh waters (Figure 2). Coincidently, these areas are also prime habitat for humans, thus making coho salmon a "sentinel species for ecological resilience in a watershed impacted by urbanization and stormwater runoff from roads, parking lots, and other impervious surfaces" ("Stormwater Science: Ecological Impacts - Northwest Fisheries Science Center" 2016).

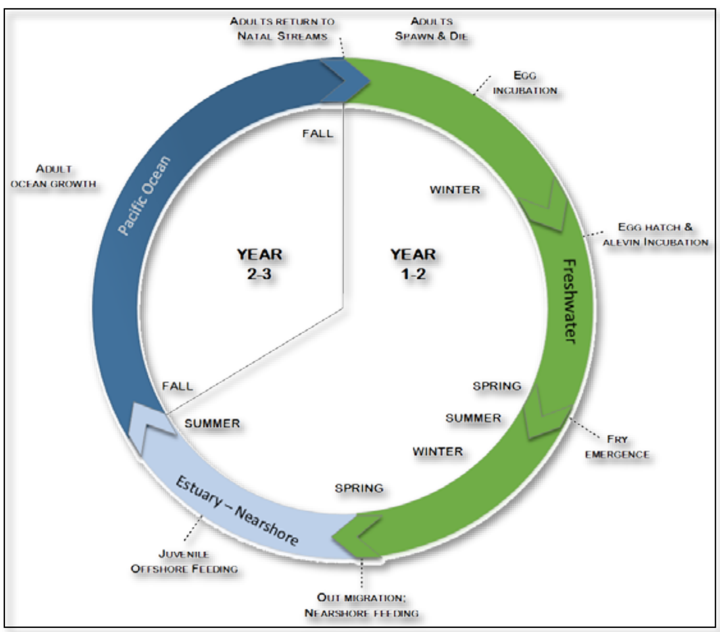

Figure 2. Life cycle of Puget Sound coho salmon (adapted from Seattle Public Utilities 2016).

Researchers continue to investigate the effect stormwater runoff has on aquatic species. McIntyre et al. (2015) found that juvenile coho salmon placed in stormwater runoff collected and placed in a tank were not able to survive and died within twelve hours of exposure.

Conversely, juvenile coho placed in filtered well-water experienced no life-altering effects. The stormwater runoff contained a suite of contaminants, including heavy metals, polycyclic aromatic hydrocarbons (PAH) and organic matter (McIntyre et al. 2015). Heavy metals are likely not primary source contributing to the decline of coho salmon. Stormwater runoff contains a substantial amount of dissolved organic matter. This dissolved organic matter sequesters metal ions, reducing, to a large extent, the bioavailability of metal to aquatic species (Santore et al. 2001, McIntyre et al. 2008, McIntyre et al. 2014).

Researchers have narrowed the cause of coho deaths to histotoxic hypoxia. Histotoxic hypoxia is the inability of cells to absorb oxygen from the bloodstream, despite normal delivery of oxygen to the cells and tissues (McIntyre et al. 2015). In spite of this discovery, scientist have yet to determine the cause of the hypoxia. The leading hypothesis points to polycyclic aromatic hydrocarbons; however, the class of contaminants that are causing histotoxic hypoxia has yet to be determined.

Fortunately, there are measures in place to help alleviate impacts and protect waters from point and non-point source pollution, but as we have learned, it's not enough. The Clean Water Act (1972), administered by the Environmental Protection Agency (EPA), regulates point sources of pollutants from industrial and municipal sources through the National Pollutant Discharge Elimination System (NPDES) Permit Program. Under the Clean Water Act, the EPA authorizes Washington State's Department of Ecology to issue NPDES permits. Additionally, commercial, industrial and municipal operations that discharge waste materials into the ground or into a publicly-owned treatment plant must have a State Wastewater Discharge Permit.

In 1987, the EPA recognized stormwater runoff (non-point source pollution) as a leading contributor to water quality degradation. Through the NPDES Stormwater Program, the Washington State Department of Ecology, in accordance with the EPA regulates discharge from municipal separate storm sewer systems, construction activities, and industrial activities (Municipal Stormwater General Permits 2016). There are two phases for the NPDES Stormwater Program. The Phase I permit applies to incorporated cities with a population over 100,000 and unincorporated counties with populations of more than 250,000. Phase II includes all regulated small municipal separate storm sewer systems. Appendix I identify the cities and counties in western Washington that fall into one of these two permit phases. Municipal Stormwater Permits specify a suite of activities that municipalities must undertake to reduce pollution in stormwater runoff. As a permit condition, each municipality is required to prepare and implement a stormwater management program that aims to improve the quality of the water discharged from the city's stormwater drainage system. Common strategies include regular and scheduled street sweeping, an education campaign, public involvement and participation, and an illicit discharge detection program. Although measures are in place to regulate stormwater runoff, the urban environment has become too populated and impervious to improve conditions without taking additional measures.

Green Stormwater Infrastructure

Green stormwater infrastructure or low impact development mimics natural systems and is a viable solution for reducing pollutants in stormwater runoff within urban environments (US EPA 2016). Green stormwater infrastructure can slow runoff and filter contaminants before the water enters into nearby streams, rivers, lakes and ocean environments. The Environmental Protection Agency has identified several methods for slowing runoff and filtering pollutants from stormwater (Appendix II). Furthermore, green stormwater infrastructure, particularly those planted with vegetation, help to eliminate particulate matter from the air. Subsequently, with fewer particulates floating in the atmosphere, there is evidence showing lower rates of asthma (Value of Green Infrastructure 2011).

The goal of this project is to investigate the feasibility of assessing stormwater drainage basins within King County and determining areas that are likely contributing stormwater runoff pollution into nearby lakes, streams and Puget Sound. Outcomes from this project will be useful to The Nature Conservancy (TNC), decision-makers, and city and county planners and managers. We examined four variables: 1) roadways, 2) coho salmon-bearing streams, 3) asthma hospitalization rates, and 4) impervious surfaces.

DESIGN & METHODS

Study Area and Units of Analysis

Our area of focus is bounded by King County, and targets forty-two (42) municipalities, plus the Port of Seattle. The units of analysis for our study are stormwater drainage basins within each municipality. These units of analysis were requested by our project sponsor, TNC.

Data collection was one of the biggest challenges with this project. In order to gather the necessary stormwater drainage basin data, each municipality had to be individually contacted, and in some cases we needed to complete a formal public request form. Quickly, it became apparent that each municipality is managed differently, from data management to the availability of GIS or CAD data, to overall responsiveness. Additionally, some municipalities charged a fee for data, and in some cases, were not willing to waive the fee. In addition to the request for data, we also inquired about the methodologies used to delineate each stormwater drainage basin. Repeatedly, responses mentioned the following elements: 1) topography, 2) the assemblage of stormwater drainage pipes, and 3) expert/local knowledge of the stormwater program manager or technician. In total we collected stormwater drainage basins from fifteen (15) municipalities and stormwater drainage pipes/structures from twenty (20) municipalities (Appendix III). Some cities have yet to delineate their stormwater drainage basins, hence the difference between the number of basins and pipes/structures collected. However, due to time constraints, our analysis does not take into consideration stormwater drainage pipes/structures.

To better visualize our units of analysis we describe how stormwater drainage basins compare with other, more well-known units of analysis. Within King County there are five Water Resource Inventory Areas (WRIAs; areas draining into a river, lake, or another waterbody). The WRIAs include: Puyallup-White, Duwamish-Green, Cedar-Sammamish, Snohomish and Kitsap (Vashon Island). Within each WRIA there are smaller watersheds. For example, in WRIA 9, there are four (4) sub-watersheds (HUC 10). Within the sub-watersheds (HUC 10) there are yet smaller divisions of watersheds (HUC 12), which for example can range from two to four within the sub-watersheds. Our units of analysis – stormwater drainage basins – are nested within all of these watersheds.

Another reference includes, assessment units as defined within the Puget Sound Watershed Characterization Project. These units of analysis are much coarser than the stormwater drainage basins we utilized for our study. Furthermore, King County's data highlighting basin conditions is yet another dataset that is coarser for the most part, than the stormwater drainage basins. However, for Vashon Island, we used these basin condition delineations.

Of the fifteen (15) municipalities analyzed, some municipalities had only ten (10) stormwater drainage basins (Des Moines), whereas Federal Way and Seattle had 277 and 241 basins, respectively. The project analysis units (stormwater drainage basins) range in size from 0.000443 square kilometers (443 sq. meters) in Seattle to 17.225 square kilometers in Kirkland, with a median of 0.196 square kilometers. Combined, we analyzed 1,234 stormwater drainage basins throughout King County.

A social-ecological systems (SES) table was created to show the controlling variables of our study (Table 2). The SES table is a brief and comprehensive view of the social, ecological and economic factors affecting different focal scales within our study.

Table 2. Social-Ecological Systems table.

	Social	Ecological	Economic
Stormwater Drainage Basins	Bioswales planted with vegetation help to remove particulates from the air, which may help to reduce asthma rates	Wildlife and communities will benefit from bioswales as increased green space and as gathering areas	Improvement of local air and water quality can reduce healthcare costs to residents
Municipality	Stakeholders value clean water and environmental mitigation of stormwater pollutants	Maintaining clean water coming from stormwater outfalls, reducing point source pollution and resident health	Funding is needed to fully understand stormwater systems and the areas they serve
Puget Sound Urban Growth Area/King County	Working across municipal boundaries and with various stakeholders will present a challenge but will reap great rewards	Sensitive fish populations in Puget Sound, valued by anglers, tribes, and local communities	Water resources across the Puget Sound sustain fisheries and health benefits that create great economic benefits

Figure 3 illustrates the interplay between the resiliency of Puget Sound and the linkages to each domain. Understanding these relationships is critical to understanding the behavior of a system, such as the Puget Sound.

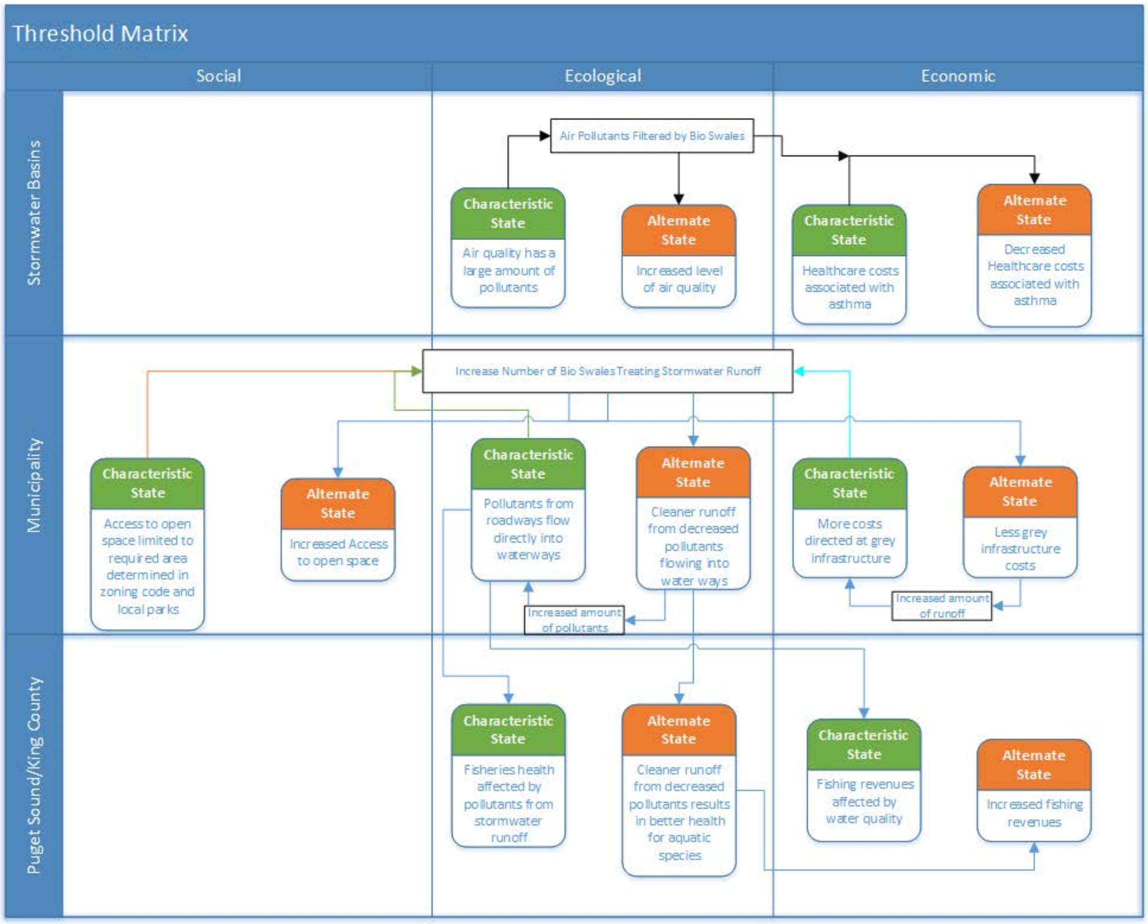

Figure 3. Threshold matrix of the ecological, social & economic facets of the analysis.

For our analysis, each municipality was analyzed individually. Our reasoning for processing the data in this manner was two-fold. During data collection it became evident that each municipality manages their stormwater drainage systems differently, thus we felt our analysis would be more robust if each city was measured on its own merits. Secondly, we believed the analysis would be more useful to TNC if each municipality was examined individually. Finally, in some cases, municipalities had overlapping stormwater drainage basins, and without having inside expert knowledge we did not believe redesigning the basins was appropriate. For example, data received from Kent and Renton overlapped and do not mirror one another.

King County Transportation Network

We were interested in determining the kilometers of roadways per basin weighted by road class. Figure 4 highlights the variation between the various road classes within King County.

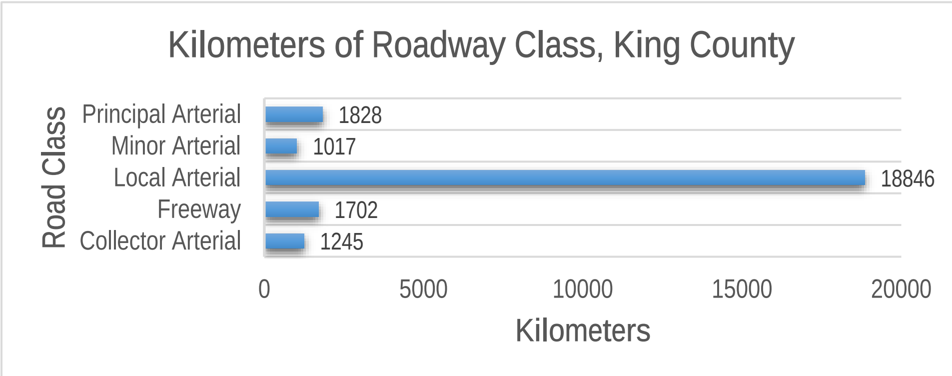

Figure 4. Kilometers of road class in King County.

The *Summarize Within* tool (ArcGIS Pro) was used to isolate roadways within each unit of analysis within each municipality. The *Summarize Within* tool also allows for grouping of data by a specific field, and in our case, we grouped data by road class. After running the tool for each municipality, two files – a feature class and a summary table were generated. The feature class was joined with the table using the "Join ID" field for each municipality. The *Summarize Within* tool automatically created the "JoinID" field. The data were joined and exported to a new feature class.

The roadway proxy developed for our study assumes there is more vehicle emissions during stop and go travel than when traveling on a freeway (Adamiec et al. 2016). For this reasoning, we created a weighting system that gave more weight to local arterial roadways than principal arterial roadways and freeways (Table 3).

Table 3. Road classes of King County.

Road Class	Code	Weight by Road Class
Freeway	F	1
Principal Arterial	P	2
Minor Arterial	M	3
Collector Arterial	C	4
Local Arterial	L	5

Two new fields were added to the newly created feature class – RdClassWeight and KmWeightedRdClass. A python script was used to easily convert each road class code into its respective weight. The weight was then used to calculate the number of kilometers of road class within each basin. For example, in Bellevue's Valley Creek basin there are 5.23 kilometers of freeway. Given a weight of 1, the Valley Creek basin has 5.23 kilometers of weighted freeways. Within this same basin there are 35.33 kilometers of local arterial roadways. Given a weight of 5, the Valley Creek basin has 176.65 kilometers of weighted local arterial roadways.

Next, the JoinID field was used to *Summarize* the kilometers of weighted road class for each basin. The resulting table was joined with the original basin feature class. Then a new field was added to the new feature class – RdDensity. Because kilometers of roads are directly proportional to the size of the basin, we calculated road density per basin. Road density (RdDensity) was calculated by dividing the total kilometers within each basin by the area of the basin.

Coho Salmon-Bearing Streams

The State-wide Integrated Fish Distribution from Washington Department of Fish and Wildlife and the Northwest Indian Fish Commission was used to determine coho-bearing streams within each stormwater drainage basin. In order to only evaluate coho salmon-bearing streams we first separated only data that identified coho salmon in the species field. Although the dataset identified rearing and spawning areas, we did not differentiate between the various life phases. We evaluated all coho salmon habitat equally. The *Summarize Within* tool (ArcGIS Pro) was used to isolate coho-bearing streams and calculate the kilometers of coho-bearing stream within each project analysis unit. A new feature class was created. Then a new field was added to the new feature class – CohoStrmLengthKm. Again, due to the possibility of the length of a stream being directly proportional to the size of the basin, we calculated stream density.

Asthma Hospitalization Rates

Asthma hospitalization rates were downloaded from the Washington Department of Health's Tracking Network. Asthma hospitalization is defined by hospitalization that ends with the primary discharge diagnosis identified as asthma. Commonly, individuals with an asthma attack will visit the emergency department, and relatively few of these visits transpire into impatient hospital admission. Thus, asthma hospitalization data do not provide a comprehensive overview of severe or unmanaged asthma cases among Washington residents. Currently, there is no statewide database of emergency room visits in Washington (Washington Tracking Network).

The downloaded asthma data was delineated by zip codes throughout Washington State. We used a 5-year time period (2010-2014) and combined age classes. First the data was selected to include only the zip codes within our study area. Secondly, the data had to be downscaled in order to align with the stormwater drainage basins. This was done using the areal interpolation method, which is a kriging method that takes into account polygons from another dataset. The first step was to generate an areal interpolation model using the *Geostatistical Analyst and the Geostatistical Wizard*. Our data included asthma rates per zip code, thus we used the rate (binomial) method. Figure 5 shows the initial results after we selected the K-Bessel model. To better fit our data to the model we reduced our lag size and lattice spacing to 8,000. Next, we used default values for the Searching Neighborhood step. The last step was to look at the cross validation results and evaluate the results of the model. The model we generated turned out well as shown in Figure 6 – the root-mean-square standardized value is close to one with the others being much closer to zero.

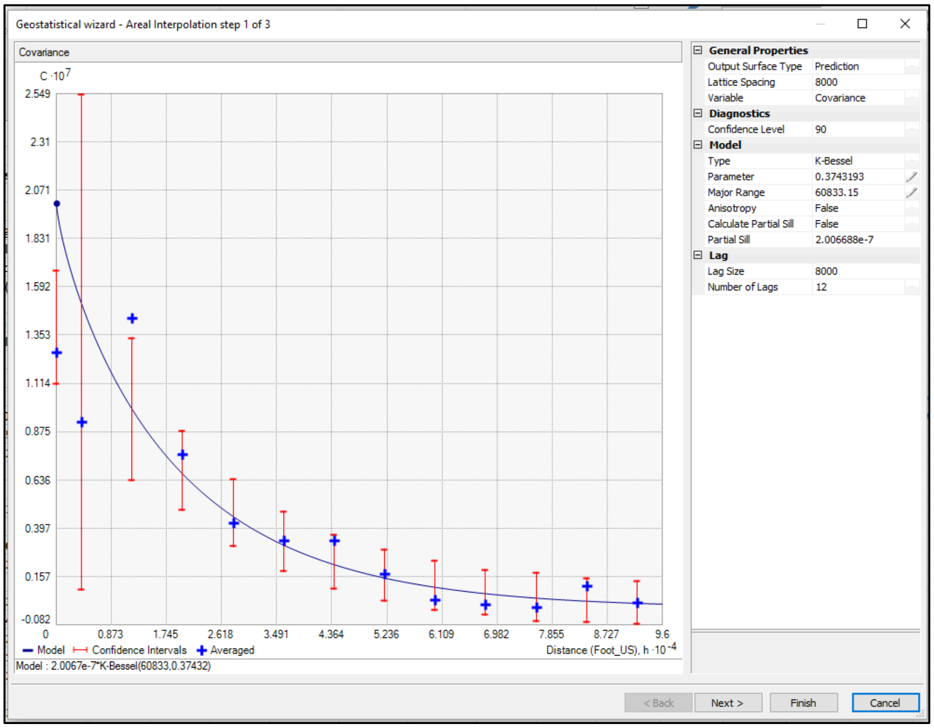

Figure 5. Covariance graph and model inputs.

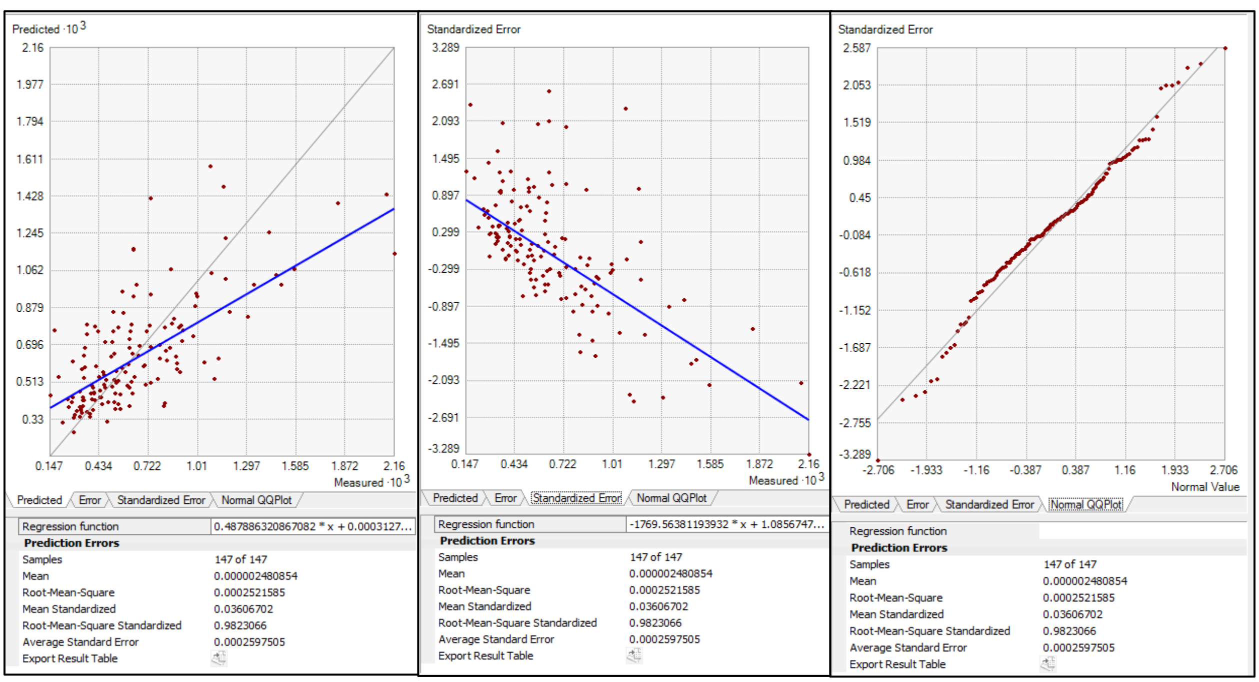

Figure 6. Cross validation results.

IMPERVIOUS SURFACES

In addition to roadways, we wanted to examine other impervious surfaces in King County, such as parking lots, sidewalks and driveways, which can accumulate pollutants that eventually end up in the stormwater drainage system. Data from the National Land Cover Database 2011 (Xian et al. 2011), created by the Multi-Resolution Land Characteristics (MRLC) Consortium was downloaded and applied to our study. These data have a spatial resolution of 30 meters. Values range from 1 to 100% and represent the proportion of urban impervious surface estimated for each 30-meter cell. These data provided the average percentage of impervious surfaces within each basin.

After downloading the raster data file, we used the *Raster to Polygon Tool* in order convert the raster dataset to polygon features represented by the stormwater drainage basins. Then we used the *Summarize Within* tool (ArcGIS Pro) to get the average percentage per basin. This process was repeated for each municipality.

STORMWATER TREATMENT COMPOSITE INDEX

In order to evaluate our variables equally and without units of measurements, we computed a z-score ($z = (X - \mu) / \sigma$ where z equals the z-score, X is the value of the element, μ is the population mean, and σ is the standard deviation) for the four variable for each basin. In doing so, we are able to keep the same relative distribution and determine how far above or below the mean the value is. Then we created a composite index from the four z-score values, which provides one relative value of comparison for each stormwater drainage basin. The composite index was calculated by adding the z-score of each variable and dividing by the number of variables included in the analysis. Rationale for the composite index is explained in Table 4.

Table 4. Decision matrix for composite index.

	Low	Moderate	Moderate High	High
Roadways (km of road class per sq. km)	Freeway ➔ Principal Arterial ➔ Minor Arterial ➔ Collector Arterial ➔ Local Arterial			
Coho-Bearing Streams (km of streams per sq. km)	0 km within project analysis unit ➔11.5 km within project analysis unit (per sq. km)			
Asthma Hospitalization Rates	Low Prediction ➔ High Prediction			
Impervious Surfaces (mean percentage)	Little Impervious Surfaces ➔ Mostly Impervious Surfaces			

A file geodatabase was created for this project. Appendix IV lists the feature datasets, feature classes and data sources for each data element. Appendix V is a schematic of the file geodatabase. Figure 7 is a diagram highlighting the steps used to process the data.

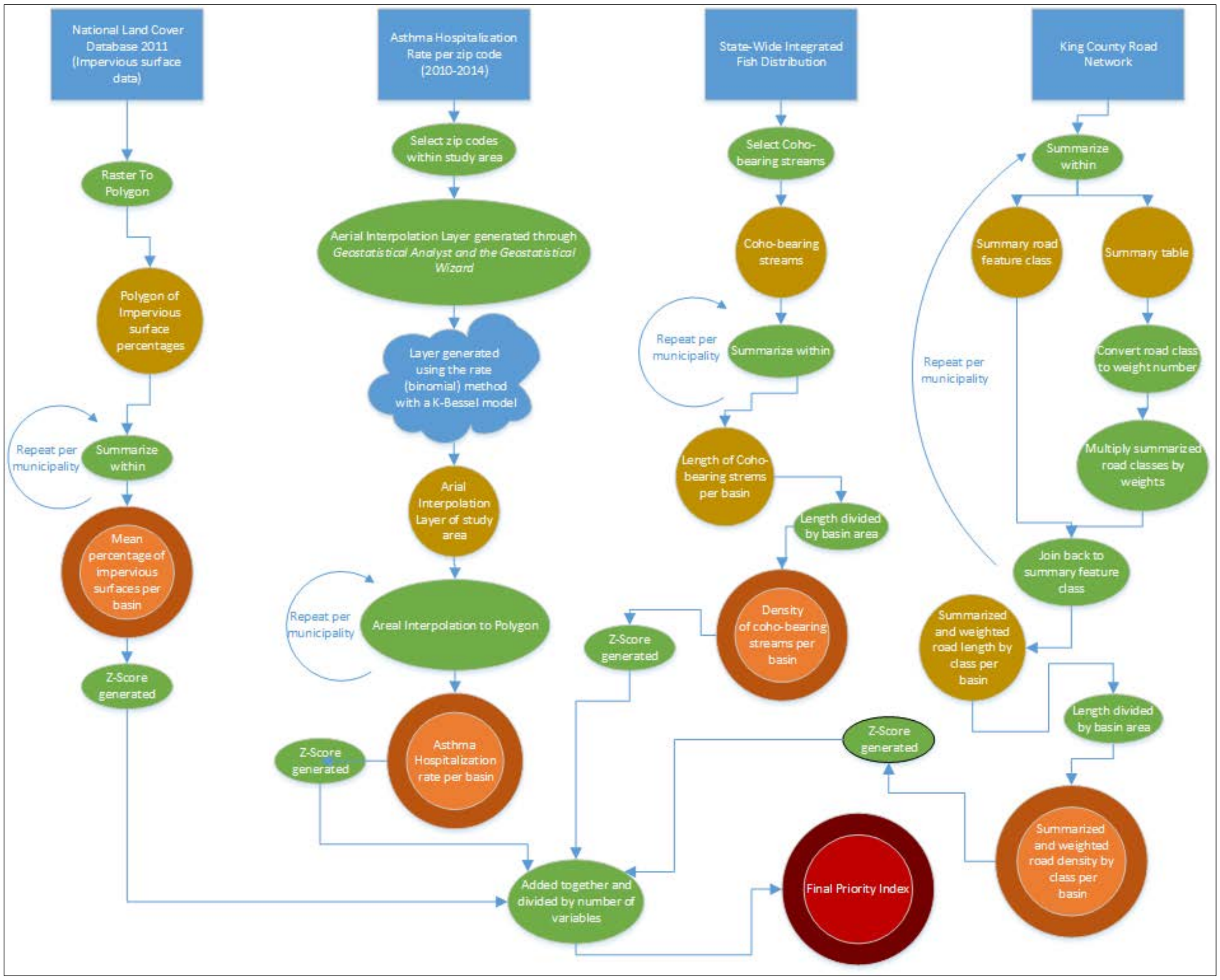

Figure 7. Diagram highlighting data processing procedures.

Assumptions & Limitations

Early in our research, we found reference to a measurement (0.98g/km/vehicle) used to determine pollutant loading per vehicle per kilometer traveled (Driscoll et al. 1990). However, after consulting with a field expert, we learned such a measurement is not advisable, particularly due to the area of study, as well as inaccuracies with the measurement (per. comm. Masoud Kayhanian).

Without a reliable measurement, we utilized road class to develop a proxy for traffic. Our roadway analysis is based on the assumption that vehicular deposition is greatest on local arterial roads, and less on freeways. There is published evidence that supports this assumption, as well as research that contradicts such a statement. Additionally, our research does not account for the volume of traffic. Furthermore, our research does not take into consideration the amount of traffic. Although deposition may be greatest on local roads, if there is only one vehicle per hour, the overall deposition will be low. Conversely, freeways have a considerable amount of traffic. The sheer number of vehicles may amount to more pollutants even though there may be less vehicle deterioration.

Secondly, when evaluating different basins, we did not take into consideration the accumulation of pollutants as they move down stream (down pipe). Basins in the farther reaches would have a higher priority due to the accumulation of pollutants as they move through the system. Similarly, in our analysis we weighted all variables equally. Certain stakeholders may view one variable of greater importance than another; however, for our purposes, we did not impose these weights.

Finally, one of the foremost limitations of our study is the units of analysis. The units of analysis vary by municipality, and may be a result of the techniques used to delineate the basins. The smallest basin measuring 468 sq. meters, and the largest area measuring over 17 sq. kilometers. This variation in the units of measurement are reason for concern, especially when attempting to utilize regional data. Additionally, our units of analysis may provide issues in the future due to differences in scale. For example, TNC is interested in adding soils data to the analysis; however, this may be problematic when considering scales.

RESULTS

The multi-scale approach of this project can help inform broad-based decisions; however, this study was not carried-out at a scale that lends itself to advise on specific locations and or designs. We believe we have developed a methodology that, with some adjustments, can provide a credible path forward for TNC.

Figures (8-12) shown in this section, and in Appendix VI are represented using quantile classification method. This technique classifies data into categories with each containing the same fraction of the total population.

Figure 8 shows the I-5 corridor and the area just south of downtown Seattle, that is undoubtedly urban and shows a high composite index value. Surprisingly, there is an area in Redmond that ranks high when compared across the region. However, the surrounding basins show relatively low to moderate composite index levels. Results from our analysis highlight basins near Seattle that could have the greatest relative impact if bioswales were constructed.

Figure 12 shows the results of the composite index for Bellevue. Figure 13 depicts the results (z-score) of each variable. In comparing Figures 12 and 13, the Kelsey Creek Basin located near Bellevue center is rated high for coho and asthma, and moderate high for roads and impervious surfaces and thus receives a high composite index ranking. The influence or non-influence of asthma can be seen in the Coal Creek Basin located in the southwest area of Figure 13. Coal

Creek has a low ranking overall composite index; however, the relative measure of asthma is high, with moderate high measure for coho.

Of the fifteen (15) municipalities analyzed, 6 municipalities were within the upper ten (10) percent when compared throughout the region (Table 5). Table 6 shows municipalities ranking in the upper ten (10) percent when compared within municipalities. Of note, Kirkland is the only municipality not represented in Table 6. It is important to note that Mercer Island did not have any coho-bearing streams, thus when creating the composite index for Mercer Island only three variables were evaluated. This resulted in Mercer Island only being compared within its municipality. Additionally, the stormwater drainage basins of Bothell extend beyond King County, and for our analysis, data for all the variables were clipped to the King County boundary, thus the analysis of many of the stormwater drainage basins of Bothell are not accurately depicted. Appendix VI has a complete set of maps for each municipality included in our analysis.

Table 5. Cities ranking in the top ten percent compared across the region.

Municipality	Number of Basins	Total Area (sq. km)
Seattle	99	42.00912
Kent	4	3.095402
Renton	4	2.184725
Issaquah	1	0.194617
Redmond	5	0.13785
Woodinville	1	0.018588

Table 6. Municipalities ranking in the top ten percent compared within each municipality.

Municipality	Number of Basins	Total Area (sq. km)
Vashon	11	25.47758
Kent	10	19.32586
Bellevue	3	17.22921
Renton	11	10.14081
Federal Way	21	5.115341
Bothell	5	3.378946
Shoreline	5	2.552684
Kenmore	3	2.429648
Des Moines	4	1.691664
Issaquah	7	1.508058
Redmond	10	1.182583
Seattle	18	1.128936
Woodinville	6	0.730984

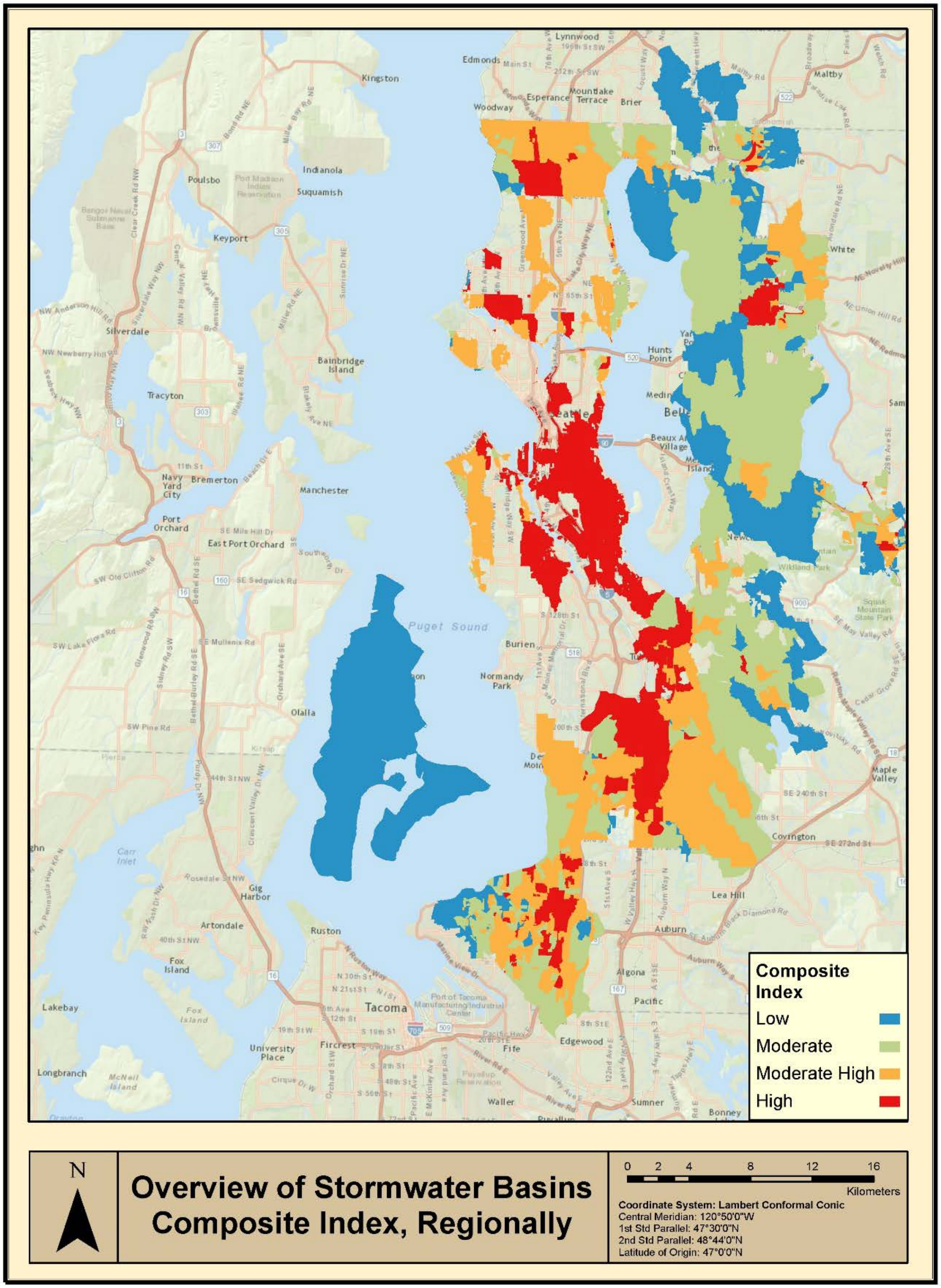

Figure 8. Ranking of stormwater drainage basins in King County (quartile classification).

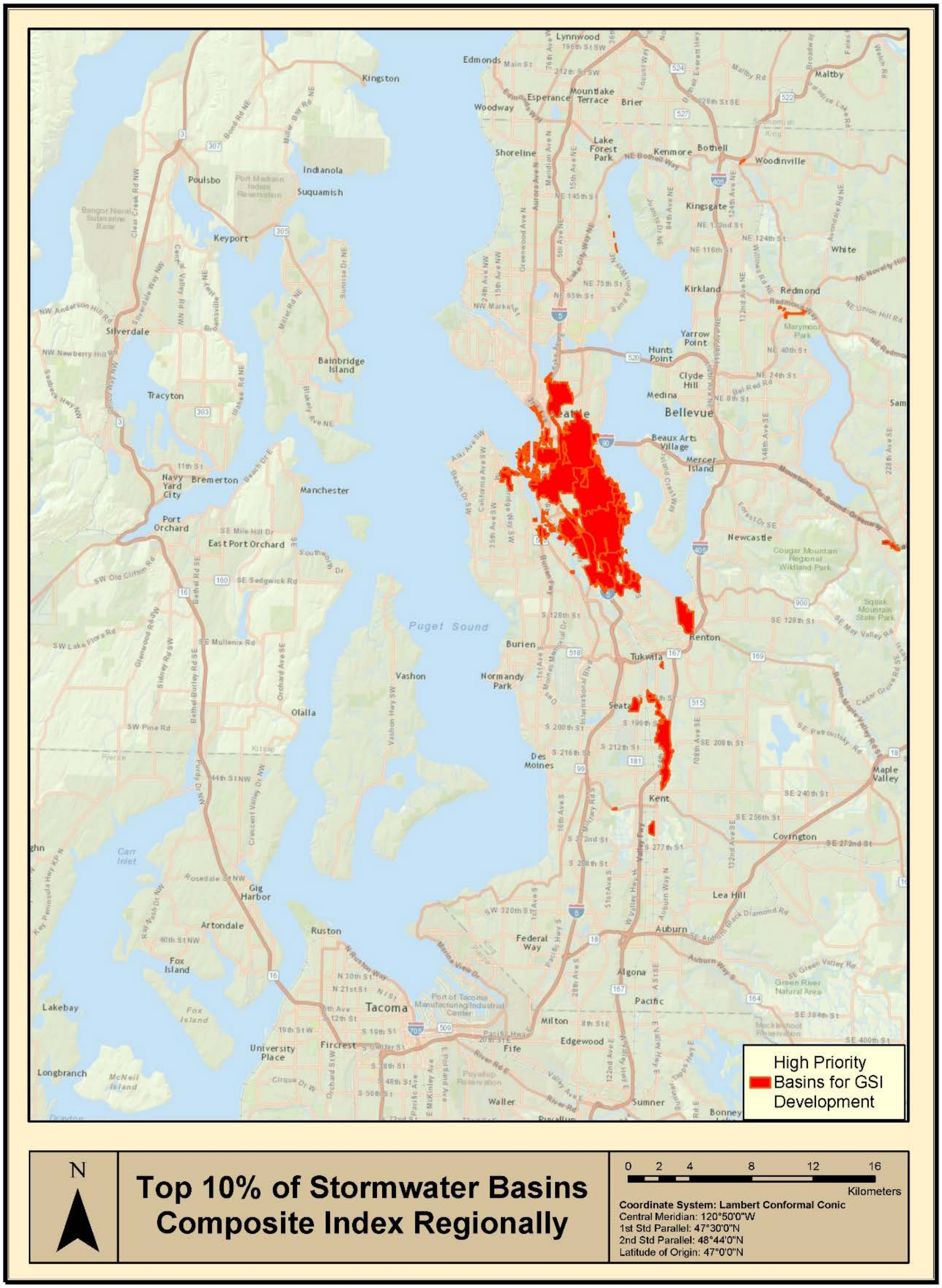

Figure 9. Upper ten percent of basins with high priority for green stormwater infrastructure across the region.

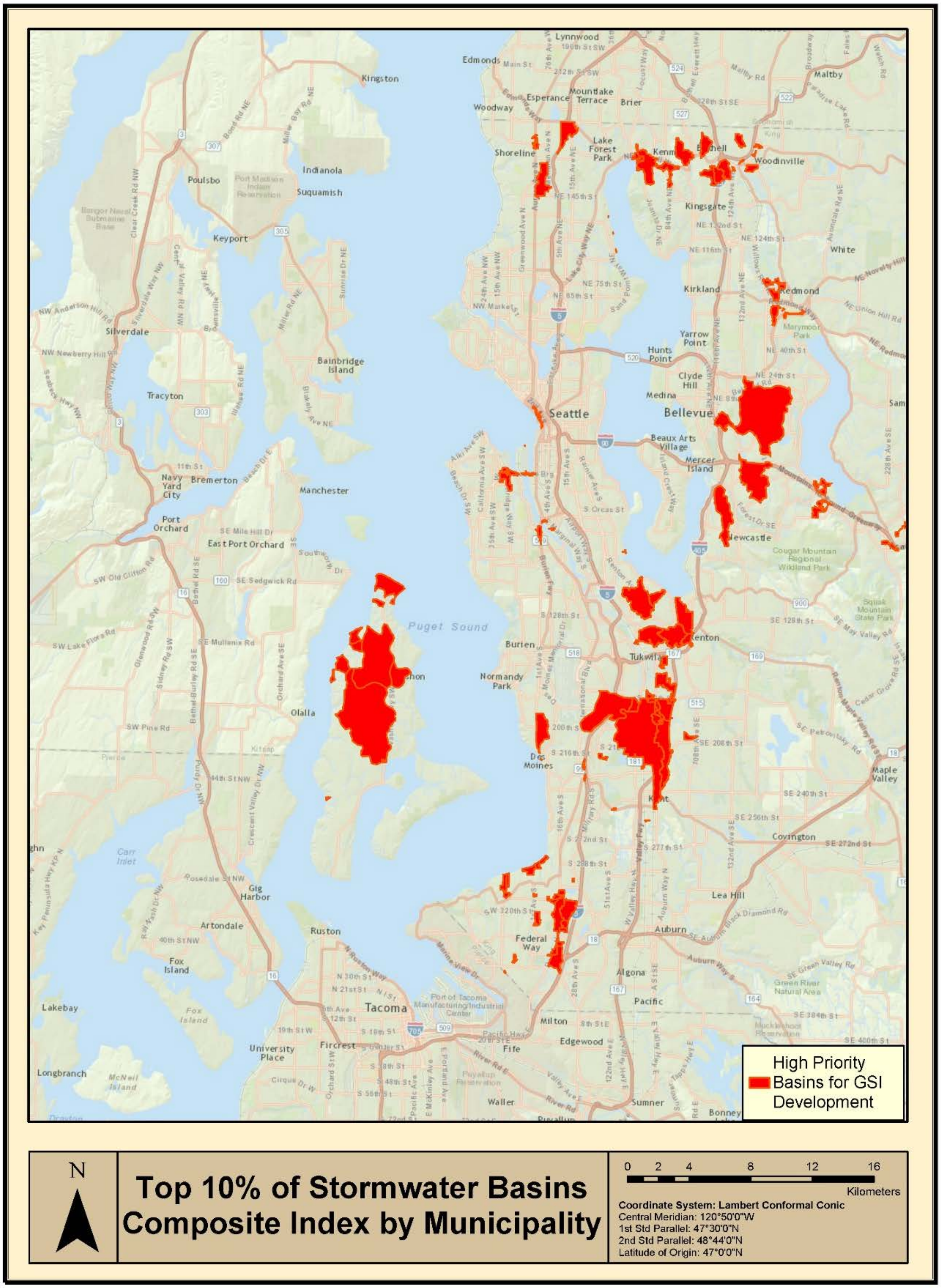

Figure 10. Upper ten percent of basins with high priority for green stormwater infrastructure by municipality.

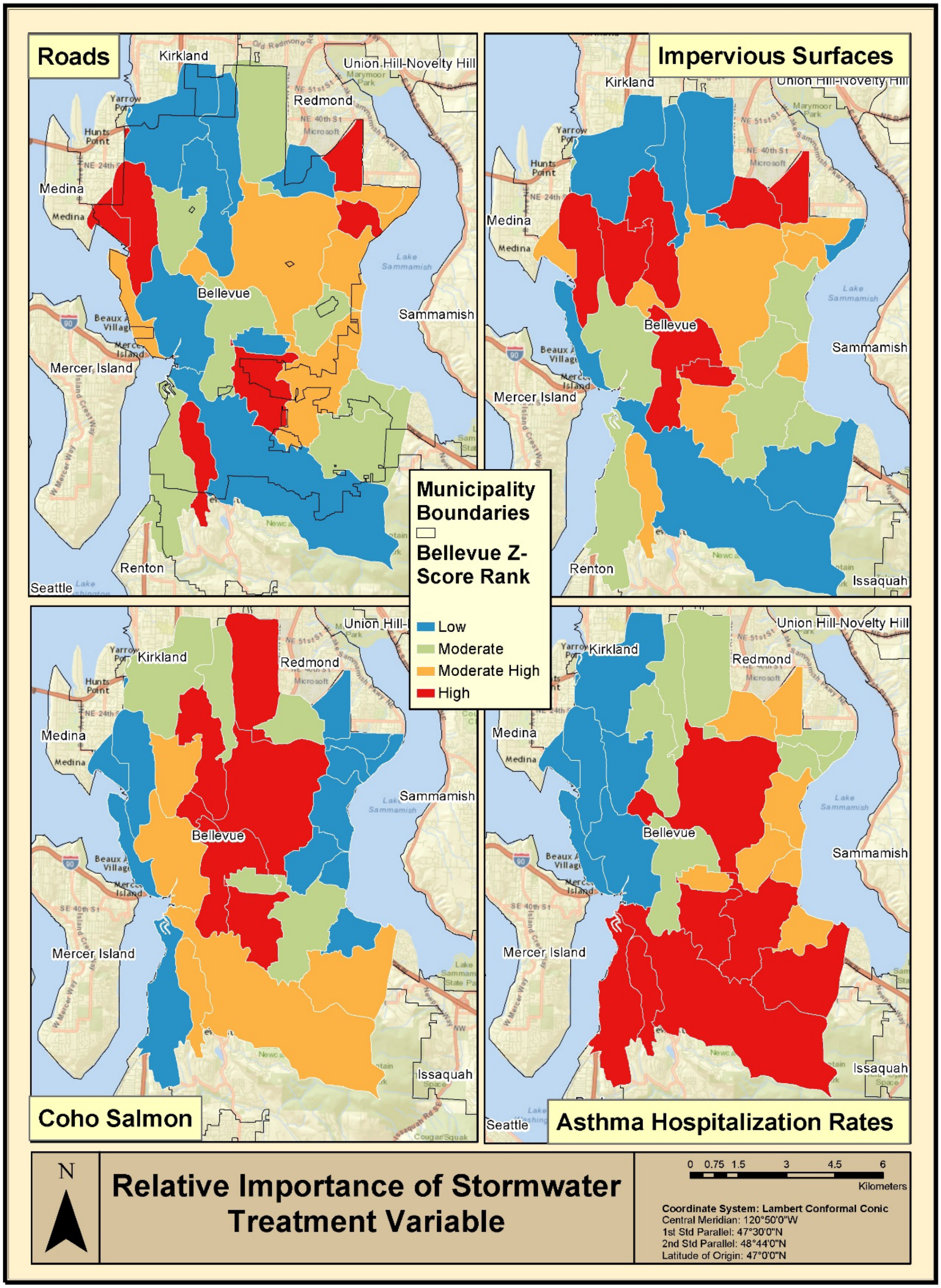

Figure 11. Variables used to create composite index for Bellevue (quartile classification).

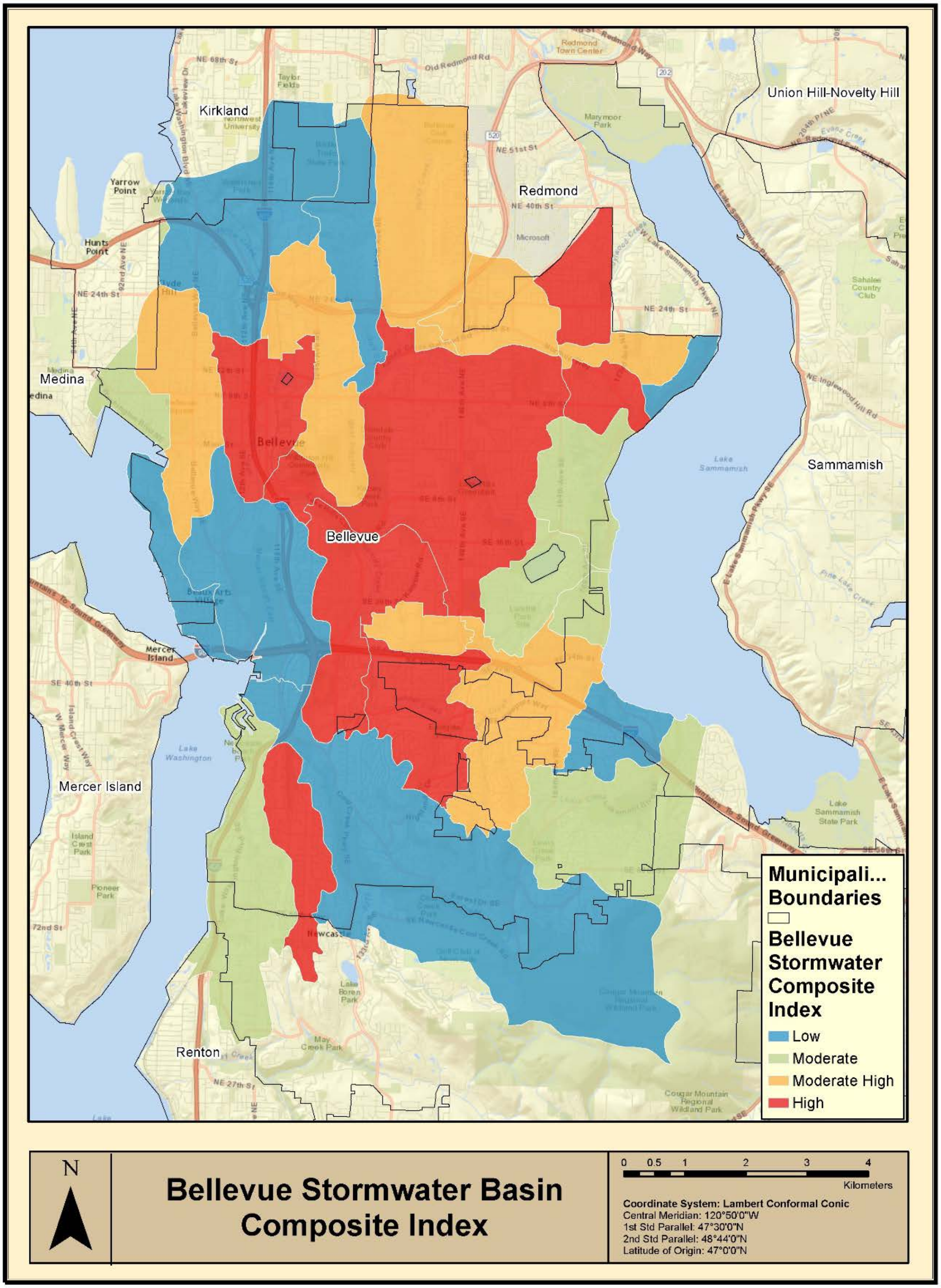

Figure 12. Composite index indicating priority level for green stormwater infrastructure development.

DISCUSSION

Currently, two bills are before Congress. These bills, if passed will aim to improve the health of Puget Sound. The first bill is the *Promoting United Government Efforts to Save Our Sound Act* or the *PUGET SOS Act*. This Act was introduced into the House of Representatives in September 2015 by Congressman Denny Heck. The bill proposes to amend the Clean Water Act to provide federal Puget Sound recovery efforts in coordination with state, local and tribal involvement (Heck 2015). In broad terms, the proposed bill will bring about a Puget Sound Recovery National Program Office within the Environmental Protection Agency; a Puget Sound Federal Leadership Task Force; and most importantly, a Save America's Puget Sound Fund within the Department of the Treasury for recovery and protection efforts identified in the Puget Sound Partnership's Action Agenda. The second bill is the *Green Stormwater Investment Act*. If passed, this bill will provide incentives for investment in green stormwater infrastructure (Kilmer 2016).

While we await Congressional decisions, efforts are underway to protect and reverse the negative impacts affecting Puget Sound. The Nature Conservancy plans to work with communities, mayors, planners and developers to incorporate natural solutions into cities within the Puget Sound urban growth area. The information provided here can serve as a communication tool for TNC while in communications with various municipalities.

As shown in Figure 4, there are nearly 10 times the number of local arterial roadways compared to the other road classes. This discrepancy between road classes may be a leading factor contributing to pollution in Puget Sound. As traffic becomes increasingly congested on the freeways, more vehicles may be utilizing local and collector arterials, thus placing greater impacts on the potential for stormwater runoff pollution. We recommend further analysis of roadways that includes the consideration of annual average traffic per road segment, the average pollutant load and the rates of runoff per basin. This will provide a more accurate estimate of the impact traffic volume has on the amount of pollutants entering Puget Sound (per. comm. Masoud Kayhanian)

While asthma data was included in our analysis we believe there are better measurements to investigate social elements of the system. There are privacy issues surrounding asthma data, which limits data availability. However, if asthma is the preferred measurement, it may be advantageous to consider age classes. Healthy People, a national health promotion and disease prevention initiative (Healthy People 2020) has set targets for various ages to meet by the year 2020. Measurements of air quality may lead to similar linkages to respiratory conditions and may be more complete and readily available. Further sociological data elements may include investigating open space requirements of each municipality. Leveraging this concept with various municipalities may help to develop green stormwater infrastructure within cities that have neglected designing open space for the community.

A condition of a Municipal Stormwater Permit requires municipalities to reduce pollution in stormwater runoff and prepare and implement a stormwater management program. One strategy that is common throughout municipalities is regular and scheduled street sweeping. Kim et al. (2015) discovered that sweep schedules may not be occurring enough to make a difference. We hypothesize that cities with a lower per capita income will have less consistent street sweep schedule. Investigations into street sweeping schedules for municipalities across the region may lead to discoveries that have simple solutions, such as additional financial support earmarked for street sweeping equipment and personnel.

Early in the development of our study, we contemplated delineating stormwater drainage basins for each municipality within King County. Quickly, we learned this was not feasible given time constraints, as well as the necessity of expert/local knowledge; however further knowledge in this aspect of stormwater drainage basins may provide benefits in regards to finding solutions to runoff pollution. For example, an interesting finding of the stormwater drainage basins includes the number of basins within different municipalities. For example, Federal Way has 277 stormwater drainage basins, while other cities (Des Moines) have only 10 basins. Determining the factors affecting this variation may help to inform the methodology of delineating stormwater drainage basins. For example, are areas with less slope more dependent on stormwater drainage pipes and thus create more basins?

Despite finding the Puget Sound Stormwater Infrastructure Framework, which, at first review, appeared to be "the golden ticket", in terms of obtaining stormwater basin GIS data, the results fell short. The Puget Sound Stormwater Infrastructure Framework Project of the Washington Stormwater Center initiated a process defining common stormwater features using standardized vocabulary; however, their grant has ended, and this work seems to have halted. Initial steps included requesting every city and county in the state with an NPDES municipal stormwater permit provide data of their stormwater maps. Today, the results of that effort does not appear to have progressed. Several data from various municipalities is not functional. For these reasons we believe there is an opportunity for TNC to develop a partnership with the Washington Stormwater Center, and coordinate an effort to standardize data methodologies and management.

If we can curb the amount of untreated stormwater entering into our waterways, we may be able to save Puget Sound coho salmon populations, along with other aquatic species that are impacted by polluted stormwater runoff.

BUSINESS CASE & IMPLEMENTATION PLAN

There are a multitude of directions TNC can pursue in furthering this project. Here we present possible options given our experience to date.

As The Nature Conservancy embarks on their Cities Initiative, a primary focus is stormwater management. This study is the first step in identifying municipalities and stormwater drainage basins to target in regards to low impact development or green stormwater infrastructure.

As we further investigate basin delineations, we find it curious why some municipalities have only a handful of basins, while other areas have several hundred. It may be worth investigating how these basins are delineated, and why there is such variation between municipalities. Greater understanding of how basins are developed may provide an opportunity to re-delineate various areas, which may also provide an opportunity to aim for equal sizes, if feasible. Re-delineations of basins may help to develop optimum areas compatible with areas ideal for a bioswale.

During our research, we came across a case study conducted in Mukilteo. This case study was an off shoot from the Puget Sound Watershed Characterization Project. This case study investigated stormwater drainage basins by using high resolution LiDAR digital elevation model (DEM), high resolution stream mapping and city stormwater infrastructure maps. We recommend consulting with the developers of this project.

Important to analyze each municipality separately, thus in order to reduce the work load we propose developing an automated process.

As part of the Global Cities Initiative, we implore TNC to work hand in hand with the Washington Stormwater Center, is striving to be a leader and collaborative partner in all things stormwater. It is recommended that the Washington State Department of Ecology require each municipality that receives a National Pollutant Discharge Elimination System (NPDES) permit is required to report their stormwater drainage systems to the Washington Stormwater Center every other year. Currently, there are attempts to consolidate stormwater drainage systems at Washington Stormwater Center; however, the level of information varies from city to city, and data standards are not consistent. It is recommended that as a requirement of your permit, each applicant must provide the best available GIS data of their system. The Puget Sound Stormwater Infrastructure Framework Project defined common stormwater features using a standardized vocabulary organized into a hierarchical structure. The original work was done under a Washington Department of Ecology grant involving the participation of thirty-six municipalities within the Puget Sound Region.

Another avenue of exploration may include working with the Washington Stormwater Center and their Low-Impact Development (LID) Program. Make green stormwater infrastructure the cool thing to do! The LID online mapping feature has room for further development. For example, implementing an education campaign that encourages community members to enter their green stormwater infrastructure build into the online mapping tool will help to create a social norm.

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ONLINE RESOURCES

- Mukilteo
  - A Case Study from the Puget Sound Watershed Characterization Project
  - Watershed-based Stormwater Retrofit Plan & Pre-design - Background
- The Conservation Fund → Green Infrastructure Resources
- Center for Neighborhood Technology (CNT) → Green Values Stormwater Toolbox
- StreamStats 4.0 USGS → http://streamstatsags.cr.usgs.gov/streamstats/
- Washington Stormwater Center's LID Online Mapping Tool – http://www.wastormwatercenter.org/lid-database

APPENDIX I: WESTERN WASHINGTON MUNICIPAL STORMWATER PERMITEES

PHASE I	
CITIES	COUNTIES
Seattle	King County
Tacoma	Clark County
	Snohomish County
	Pierce County

PHASE II				
CITIES				COUNTIES
Aberdeen	Des Moines	Lakewood	Port Angeles	Cowlitz County
Algona	DuPont	Longview	Port Orchard	Kitsap County
Anacortes	Duvall	Lynden	Poulsbo	Skagit County
Arlington	Edgewood	Lynnwood	Puyallup	Thurston County
Auburn	Edmonds	Maple Valley	Redmond	Whatcom County
Bainbridge Island	Enumclaw	Marysville	Renton	
Battleground	Everett	Medina	Sammamish	
Bellevue	Federal Way	Mercer Island	SeaTac	
Bellingham	Ferndale	Mill Creek	Sedro-Woolley	
Black Diamond	Fife	Milton	Shoreline	
Bonney Lake	Fircrest	Monroe	Snohomish	
Bothell	Gig Harbor	Mountlake Terrace	Snoqualmie	
Bremerton	Granite Falls	Mount Vernon	Steilacoom	
Brier	Issaquah	Mukilteo	Sumner	
Buckley	Kelso	Newcastle	Tukwila	
Burien	Kenmore	Normandy Park	Tumwater	
Burlington	Kent	Oak Harbor	University Place	
Camas	Kirkland	Olympia	Vancouver	
Centralia	Lacey	Orting	Washougal	
Clyde Hill	Lake Forest Park	Pacific	Woodinville	
Covington	Lake Stevens	Pacific		

APPENDIX II: TYPES OF GREEN STORMWATER INFRASTRUCTURE

Downspout Disconnection

Drain rainwater into rain barrels or cisterns and store for later use, or allow stormwater to infiltrate into the soil rather than into the storm or sewer system. Downspout disconnection is particularly beneficial to cities with combined sewer systems.

Rainwater Harvesting

Collect and store rainfall for later use. This technique helps to slow and reduce runoff and provide a source of water. This practice is particularly valuable in arid regions, where it could reduce demands on increasingly limited water supplies.

Rain Gardens – Bioretention – BioInfiltration

Versatile features that can be installed in any unpaved space. They are shallow, vegetated basins that collect and absorb runoff from rooftops, sidewalks, and streets. These features mimic natural hydrology by infiltrating, and evaporating and transpiring—or "evapotranspiring"—stormwater runoff.

Planter Boxes

Planter boxes are urban rain gardens with vertical walls and either open or closed bottoms. They collect and absorb runoff from sidewalks, parking lots, and streets and are ideal for space-limited sites in dense urban areas and as a streetscaping element.

Bioswales

Vegetated, mulched, or xeriscaped channels that provide treatment and retention as they move stormwater from one place to another. Vegetated swales slow, infiltrate, and filter stormwater flows. As linear features, they are particularly well suited to being placed along streets and parking lots.

Permeable Pavements

Permeable pavements infiltrate, treat, and/or store rainwater where it falls. They can be made of pervious concrete, porous asphalt, or permeable interlocking pavers. This practice could be particularly cost effective where land values are high and flooding or icing is a problem.

Green Streets and Alleys

Green streets and alleys are created by integrating green infrastructure elements into their design to store, infiltrate, and evapotranspire stormwater. Permeable pavement, bioswales, planter boxes, and trees are among the elements that can be woven into street or alley design.

Green or Living Roof

Enable rainfall infiltration and evapotranspiration of stored water. This technique is cost-effective in urban areas where land values are high and on large industrial or office buildings where stormwater management costs are high.

Urban Tree Canopy

Plant and maintain trees within urban environments to reduce and slow stormwater by intercepting precipitation in tree leaves and branches. Homeowners, businesses and community groups can participate in planting and maintaining trees throughout the urban environment.

Land Conservation

Protection of open spaces and sensitive natural areas within and adjacent to cities can improve water quality and flooding impacts. Primary areas of focus include natural areas, such as riparian zones, wetlands and steep hillsides.

Adapted from Environmental Protection Agency - https://www.epa.gov/green-infrastructure/what-green-infrastructure

APPENDIX III: METADATA FOR MUNICIPALITIES WITHIN KING COUNTY URBAN GROWTH AREA

Appendix III is an accumulation of cities within the urban growth area of King County that were solicited for stormwater drainage data.

	SWD Basin	SWD Pipes	SWD Structures	Source and/or Email	Notes
1. Algona	No	Yes	Yes	Stormwater Framework	http://www.wastormwatercenter.org/stormwater-framework-archives/
2. Auburn	No	No	No	--	Charges for data; Requires data request form; city would not waive fees
3. Beaux Arts Village	No	No	No	--	n/a for Municipal Stormwater Permit (MSP)
4. Bellevue	Yes	Yes	Yes	KPaulsen@bellevuewa.gov	http://www.bellevuewa.gov/GIS_map_data_info.htm
5. Black Diamond	No	No	No	Emailed Dept. Public Works publicworks@ci.blackdiamond.wa.us	No response
6. Bothell	Yes	Yes	Yes	http://www.ci.bothell.wa.us/238/GIS-Data	Website download
7. Burien	No	Yes	Yes	Emailed Fernando Llamas Jr FernandoL@burienwa.gov	Waiting for response; sent 2nd email July 23; information received August 1
8. Carnation	No	No	No	--	n/a for Municipal Stormwater Permit (MSP); Phase 1 MSP in unincorporated
9. Clyde Hill	No	No	No	--	
10. Covington	No	Yes	Yes	Emailed sbuck@covingtonwa.gov	No response; Stormwater Framework
11. Des Moines	Yes	Yes	Yes	Emailed GIS Dept. MKoppelman@desmoineswa.gov	--
12. Duvall	No	No	No	--	--
13. Enumclaw	No	No	No	Emailed GIS Dept. DDochow@ci.enumclaw.wa.us	Spoke with Dianne Dochow Sr. Engineering Technician, CESCL Stormwater Program Coordinator City of Enumclaw Public Works 360-615-5668; city is planning to change from CAD to GIS; no data received as promised
14. Fall City	No	No	No	--	--
15. Federal Way	Yes	Yes	Yes	Emailed GIS Coordinator	Accessed FTP site for downloads

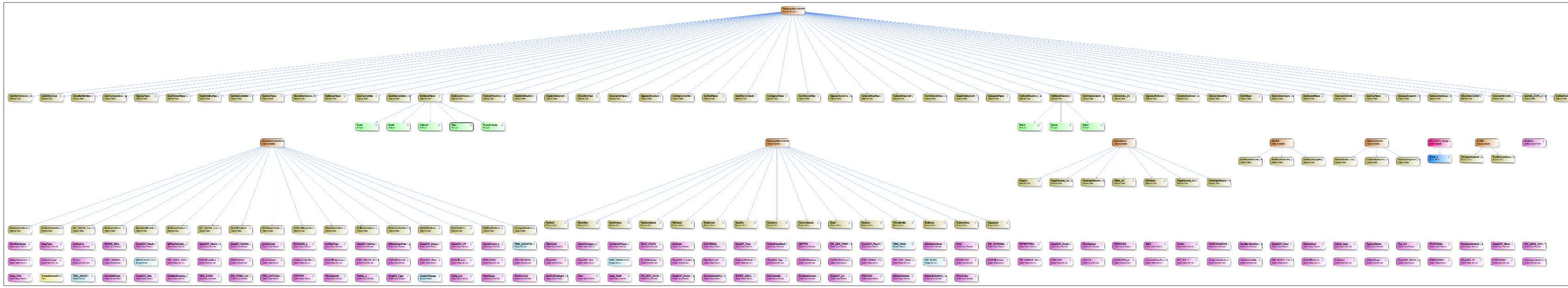
	SWD Basin	SWD Pipes	SWD Structures	Source and/or Email	Notes
				Theresa.Thurlow@cityoffederalway.com	
16. Hunts Point	No	No	No	--	n/a for Municipal Stormwater Permit (MSP)
17. Issaquah	Yes	Yes	Yes	Emailed GIS Coordinator briano@issaquahwa.gov	--
18. Kenmore	Yes	No	No	Emailed city; Submitted data request rsawyer@kenmorewa.gov	Richard Sawyer; Will have data by July 29; SWD Pipes & structures are available but didn't meet deadline for project
19. Kent	Yes	Yes	Yes	Stormwater Framework	http://www.wastormwatercenter.org/stormwater-framework-archives/
20. Kirkland	Yes	Yes	Yes	Emailed Public Works Dept. stormwater@kirklandwa.gov	Emailed on July 23, 2016; information received
21. Lake Forest Park	No	No	No	Emailed Public Works Dept. frank@ci.lake-forest-park.wa.us	Received ArcMap file; User didn't know how to package file; still working with individual
22. Maple Valley	No	Yes	Yes	Emailed city Ken Srilofung Ken.Srilofung@maplevalleywa.gov	Received access to FTP site; ftp://ftp.maplevalleywa.gov Username/Password: gisguest; Do not have stormwater drainage basin delineated
23. Medina	No	No	No	Emailed Public Works Dept. Ryan Osada rosada@medina-wa.gov	Emailed on July 23, 2016
24. Mercer Island	Yes	Yes	No	Emailed GIS Dept. Mike Helten Mike.Helten@mercergov.org	--
25. Milton	No	No	No	--	--
26. Newcastle	No	Yes	Yes	Emailed Public Works Dept. Angela Gallardo AngelaG@ci.newcastle.wa.us	Do not have stormwater drainage basin delineated
27. Normandy Park	No	No	No	Emailed Public Works Dept. Ken Courter kenc@ci.normandy-park.wa.us David Nemens davidn@ci.normandy-park.wa.us	Emailed on July 23, 2016; Email from David Nemens, "Normandy Park's GIS system is not currently operational, and it's GIS database is not currently accessible, so none of our mapping data is available for inclusion in your project analysis."
28. North Bend	No	Yes	Yes	Stormwater Framework	http://www.wastormwatercenter.org/stormwater-framework-archives/

	SWD Basin	SWD Pipes	SWD Structures	Source and/or Email	Notes
					n/a for Municipal Stormwater Permit (MSP)
29. Pacific	No	No	No	--	--
30. Port of Seattle	No	No	No	Marilyn Guthrie	
31. Redmond	Yes	Yes	No	Emailed GIS Services Don Swayne dswayne@REDMOND.GOV	--
32. Renton	Yes	Yes	Yes	Stormwater Framework	http://www.wastormwatercenter.org/stormwater-framework-archives/
33. Sammamish	No	No	No	Emailed GIS Coordinator Beth Carpenter bcarpenter@sammamish.us	No response from July 8; second email sent July 23, 2016; data is available but did not meet project deadline
34. SeaTac	No	Yes	Yes	Emailed GIS Coordinator Zinta Smidchens zsmidchens@ci.seatac.wa.us	Sea Tac doesn't have stormwater drainage basins delineated; Recommend contacting Port of Seattle
35. Seattle	Yes	Yes	Yes	Emailed GIS Dept. Jade Redfield Jade.Redfield@seattle.gov	City of Seattle; UW GIS Portal to City of Seattle Data
36. Shoreline	Yes	Yes	Yes	Website download	http://www.cityofshoreline.com/government/departments/public-works-/gis/download
37. Skykomish	No	No	No	--	n/a for Municipal Stormwater Permit (MSP)
38. Snoqualmie	No	No	No	Emailed Public Works Ops. Manager Nancy Davidson ndavidson@ci.snoqualmie.wa.us	No response; Email sent July 12; Sent 2nd email July 23, 2016 to Director of Public Works
39. **Tanner**	No	No	No	--	--
40. Tukwila	No	No	No	Emailed Public Works Dept. publicworks@tukwilawa.gov	No response; Emailed July 16; 2nd email sent July 23, 2016
41. **Vashon Island**	Yes	--	--	--	Basin was created from Topo Basins of King Co.
42. Woodinville	Yes	Yes	No	Stormwater Framework	http://www.wastormwatercenter.org/stormwater-framework-archives/
43. Yarrow Point	No	No	No	--	n/a for Municipal Stormwater Permit (MSP)

Additionally, within King County's urban growth area there are twenty-four (24) census-designated places (CDP). These locations are not required to obtain a stormwater permit, and are regulated under King County's Phase I Municipal Stormwater Permit, and thus were not targeted areas for inclusion in our study. Furthermore, census-designated places do not have a centralized government able to manage a stormwater drainage system. Moreover, several locations have been annexed within neighboring cities.

Census-designated Places within King County			
Ames Lake	Eastgate (Neighborhood of Bellevue)	Lakeland South (Near Auburn)	Union Hill-Novelty Hill (Near Redmond)
Baring	Hobart	Lea Hill (Neighborhood in Auburn)	West Lake Sammamish
Bryn Mawr-Skyway	Inglewood-Finn Hill (Near Kirkland)	Maple Heights-Lake Desire	White Center
Cascade-Fairwood	Kingsgate (Neighborhood in Kirkland)	Mirrormont	
Cottage Lake	Lake Marcel-Stillwater	Ravensdale (Near Covington and Maple Valley)	
East Hill-Meridian (Area near Kent)	Lake Morton-Berrydale	Riverbend (Near Tanner and North Bend)	

APPENDIX IV: GEODATABASE SCHEMA.

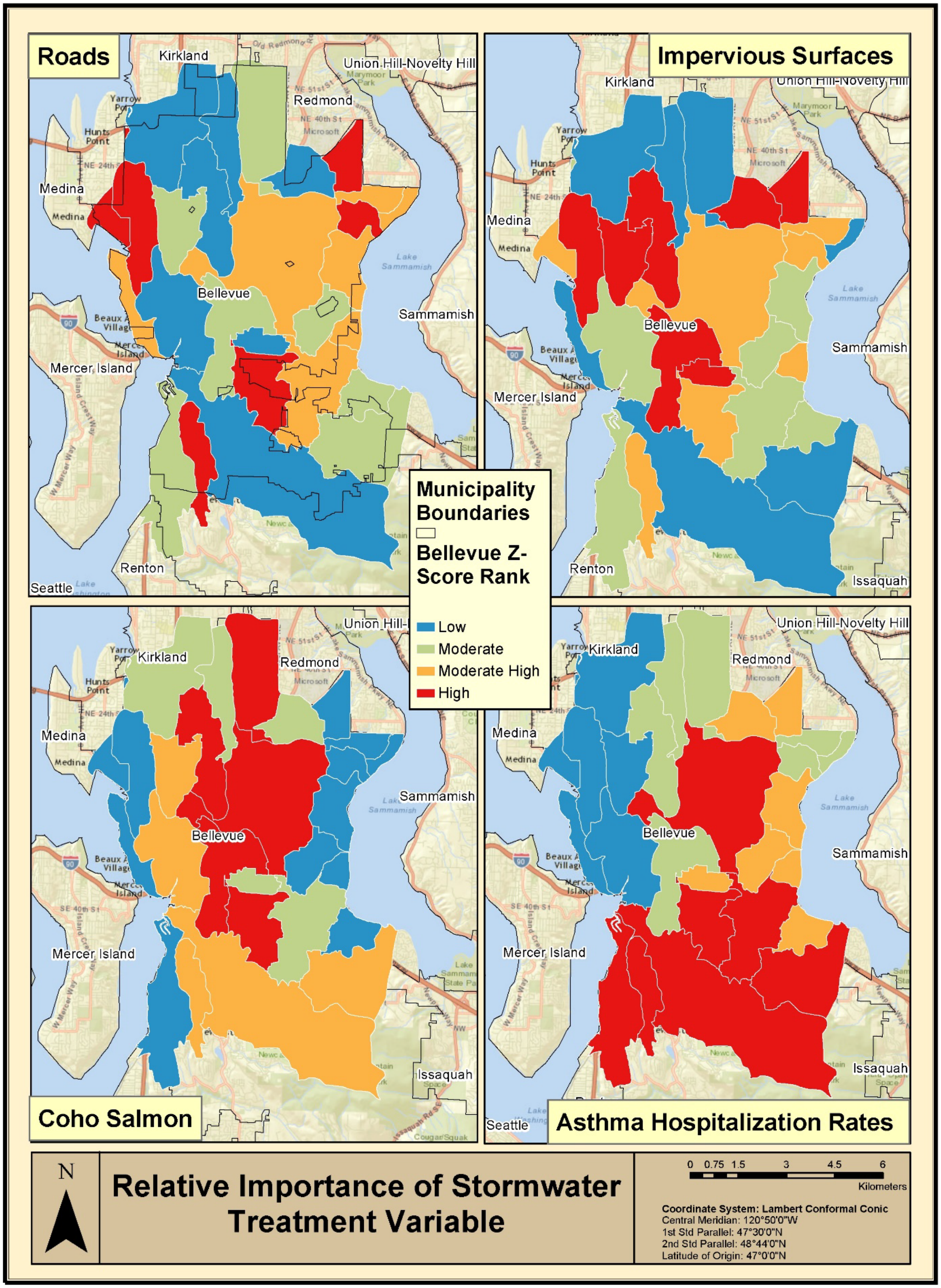


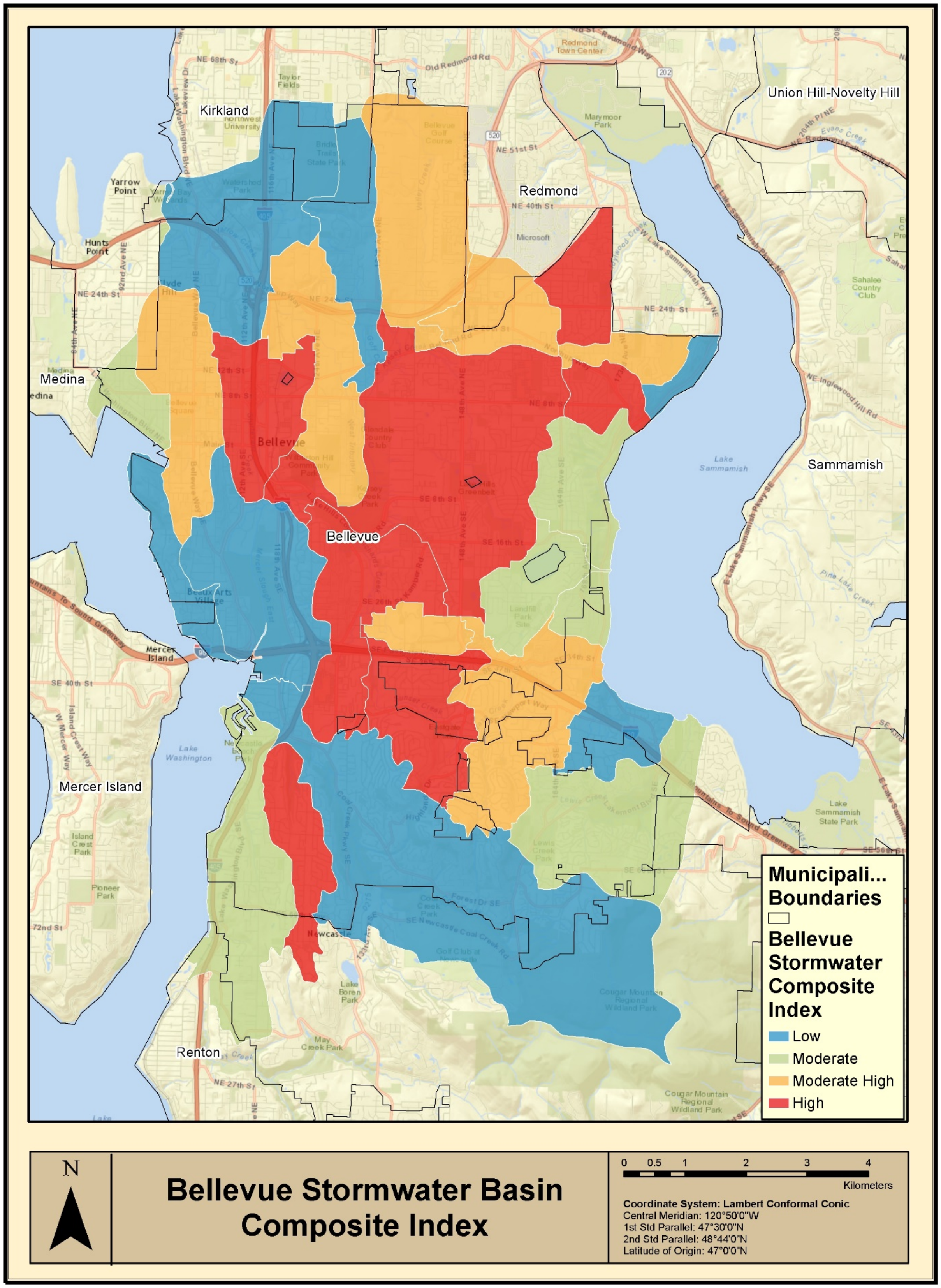
APPENDIX V: FEATURE DATASETS & FEATURE CLASSES OF THE GEODATABASE

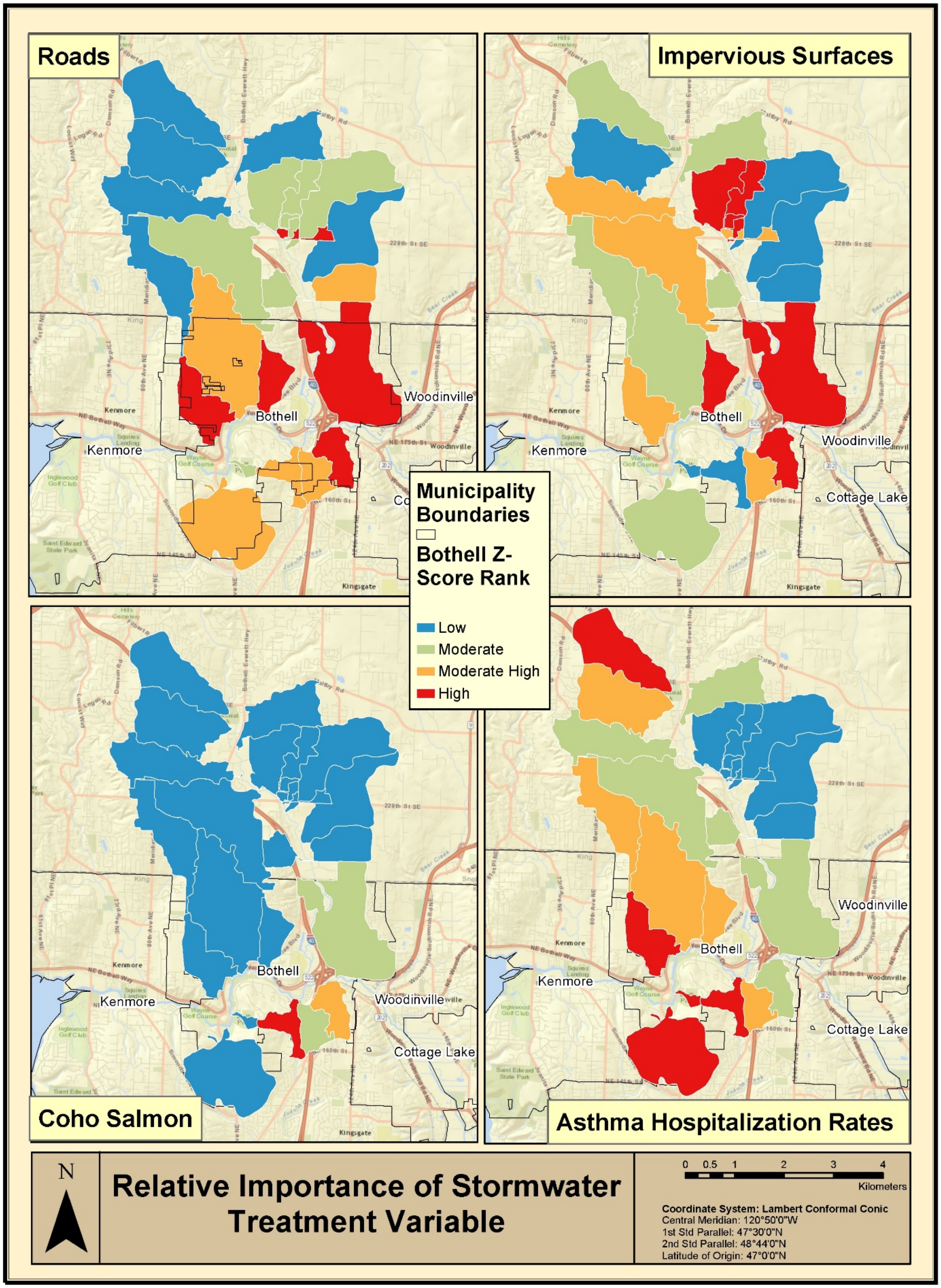
Feature Dataset	Feature Classes	Data Source
Basin Priority Indices	Bellevue Bothell Des Moines Federal Way Issaquah Kenmore Kent Kirkland Mercer Island Redmond Renton Seattle Shoreline Vashon Island Woodinville	Data was processed and compiled throughout project
Boundaries	Cities_KC	King County data portal – http://www5.kingcounty.gov/gisdataportal/Default.aspx
	KingCo	King County data portal – http://www5.kingcounty.gov/gisdataportal/Default.aspx
	MunicipalStormwaterPermitAreas_WA	King County data portal – http://www5.kingcounty.gov/gisdataportal/Default.aspx
	MunicipalStormwaterPermitAreasKingCo	King County data portal – http://www5.kingcounty.gov/gisdataportal/Default.aspx
	PugetSound_Outline	Puget Sound Characterization Project – http://www.ecy.wa.gov/services/gis/data/inlandWaters/pugetsound/characterization.htm
	PugetSound_UGA	Puget Sound Characterization Project – http://www.ecy.wa.gov/services/gis/data/inlandWaters/pugetsound/characterization.htm
	WAState	King County data portal – http://www5.kingcounty.gov/gisdataportal/Default.aspx
Health	AsthmaByZipWA AsthmaRatesKingCo AsthmaRatesWithPopKingCo	Washington State Dept. of Health – https://fortress.wa.gov/doh/wtn/WTNPortal/home/#!q0=891
HydroFeatures	CohoOnlyStateIntegratedFishDistribution_KingCo StateIntegratedFishDistribution_KingCo	Washington Department of Fish and Wildlife (WDFW) and the Northwest Indian Fish Commission (NWIFC) – http://geography.wa.gov/data-products-services/data/data-catalog
	WaterBodies_WA	King County data portal - http://www5.kingcounty.gov/gisdataportal/Default.aspx

Feature Dataset	Feature Classes	Data Source
	WaterCourses_KingCo	King County data portal - http://www5.kingcounty.gov/gisdataportal/Default.aspx
MunicipalitiesSWDBasinsOriginal	Bellevue Bothell Des Moines Federal Way Issaquah Kenmore Kent Kirkland Mercer Island Redmond Renton Seattle Shoreline Vashon Island Woodinville	Appendix III provides contact information and availability of data
MunicipalitiesSWDPipesStructures	See gdb to a complete list of municipalities	
Traffic	TransportationNetworkCar_KC	King County data portal - http://www5.kingcounty.gov/gisdataportal/Default.aspx
--	ImperviousSurfaces	National Land Cover Database 2011 - http://www.mrlc.gov/nlcd2011.php

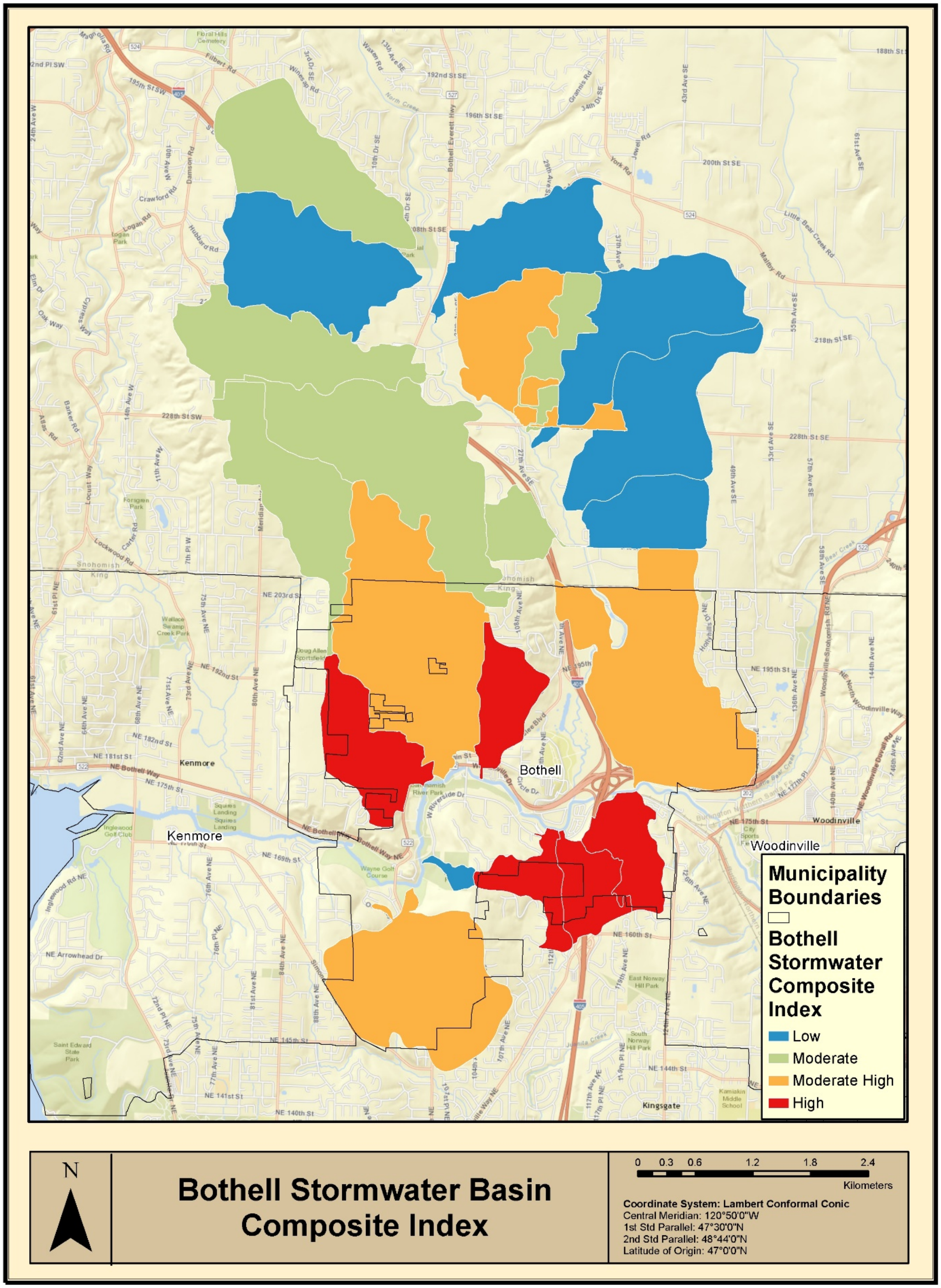
APPENDIX VI: MAPS OF EACH MUNICIPALITY

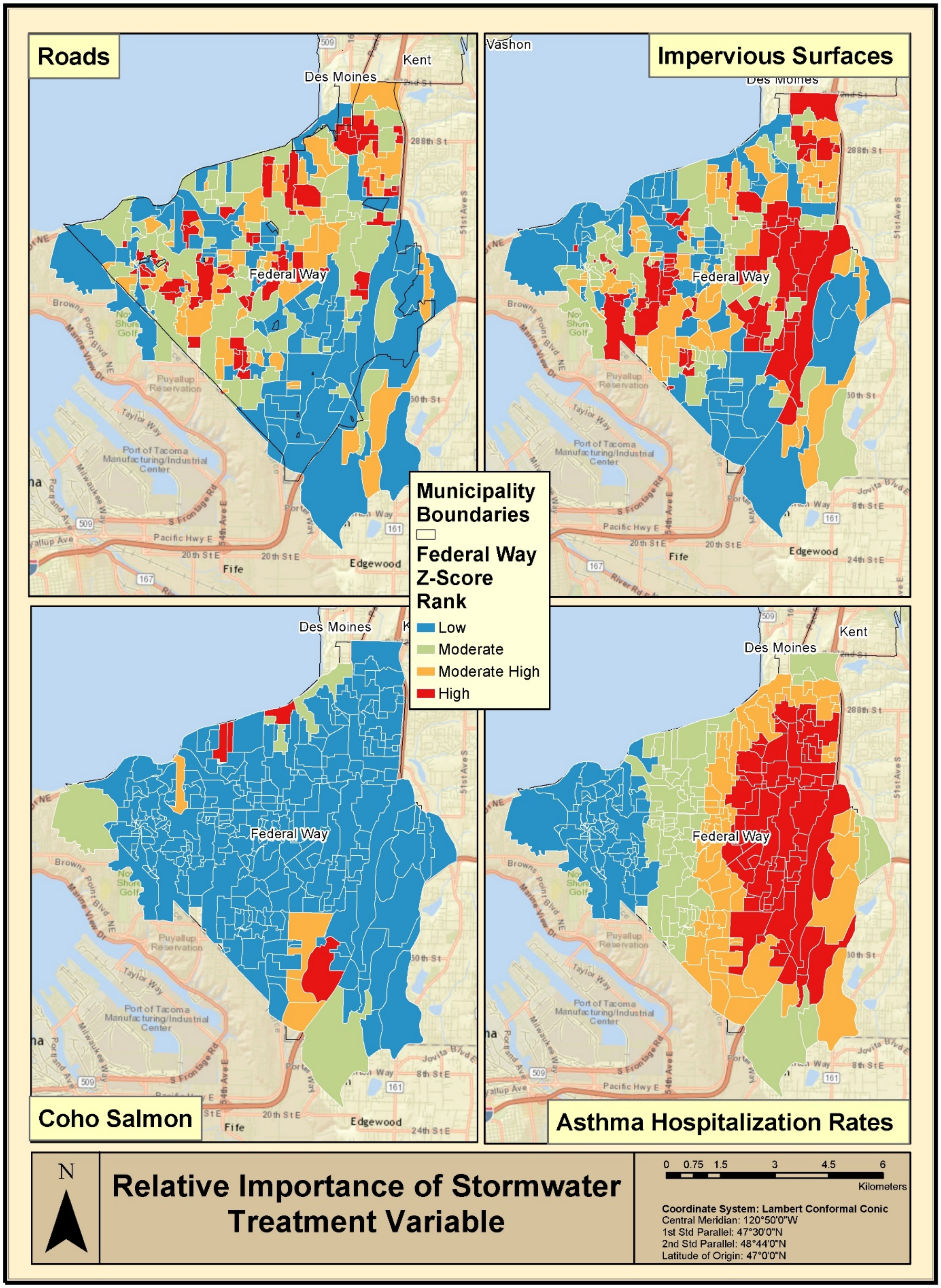


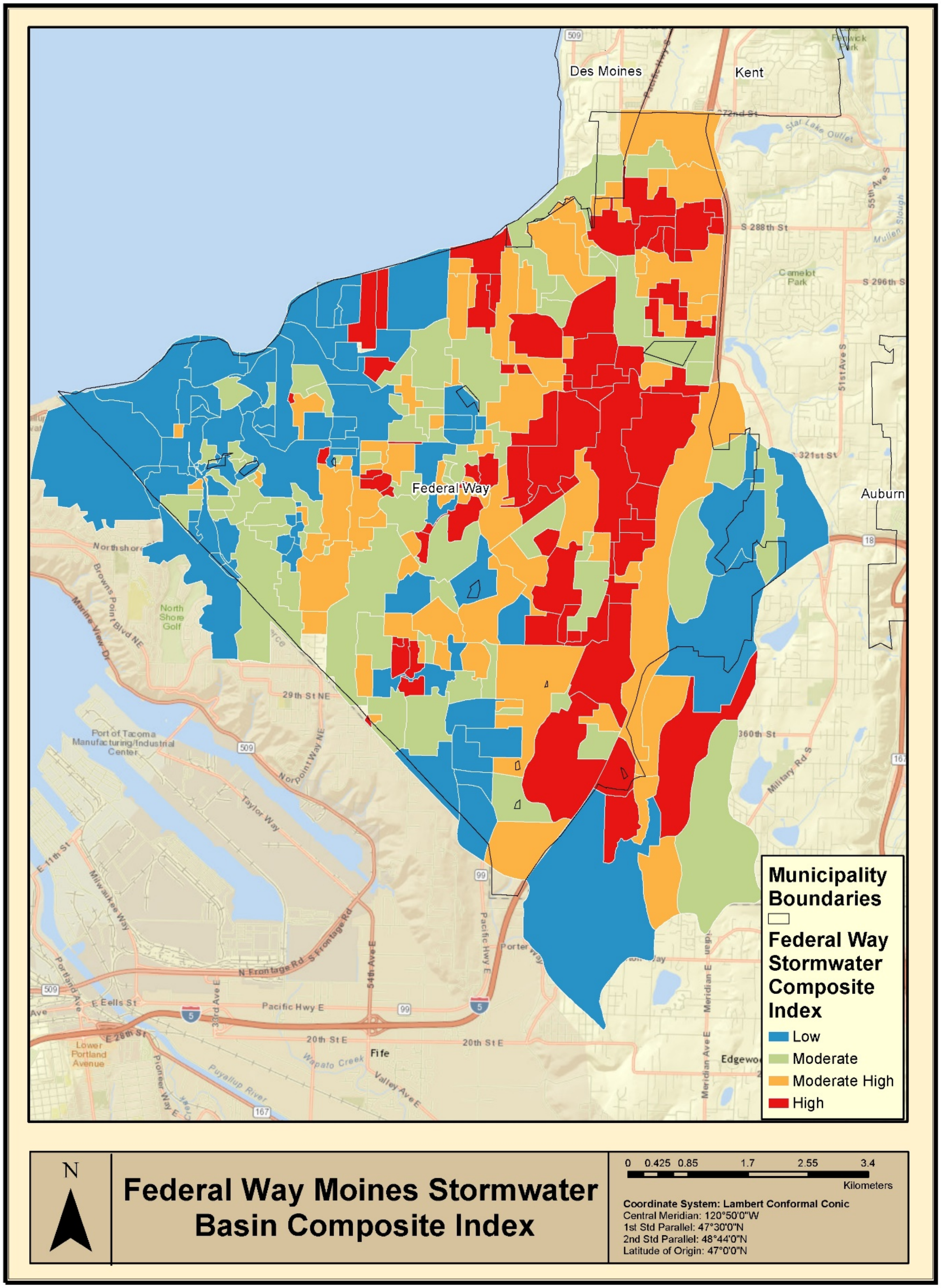

Bellevue Stormwater Basin Composite Index
Municipali... Boundaries
Bellevue Stormwater Composite Index
Low
Moderate
Moderate High
High
N
0 0.5 1 2 3 4
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N
Kirkland
Redmond
Union Hill-Novelty Hill
Yarrow Point
Hunts Point
Medina
Bellevue
Sammamish
Mercer Island
Renton
Lake Washington
Lake Sammamish



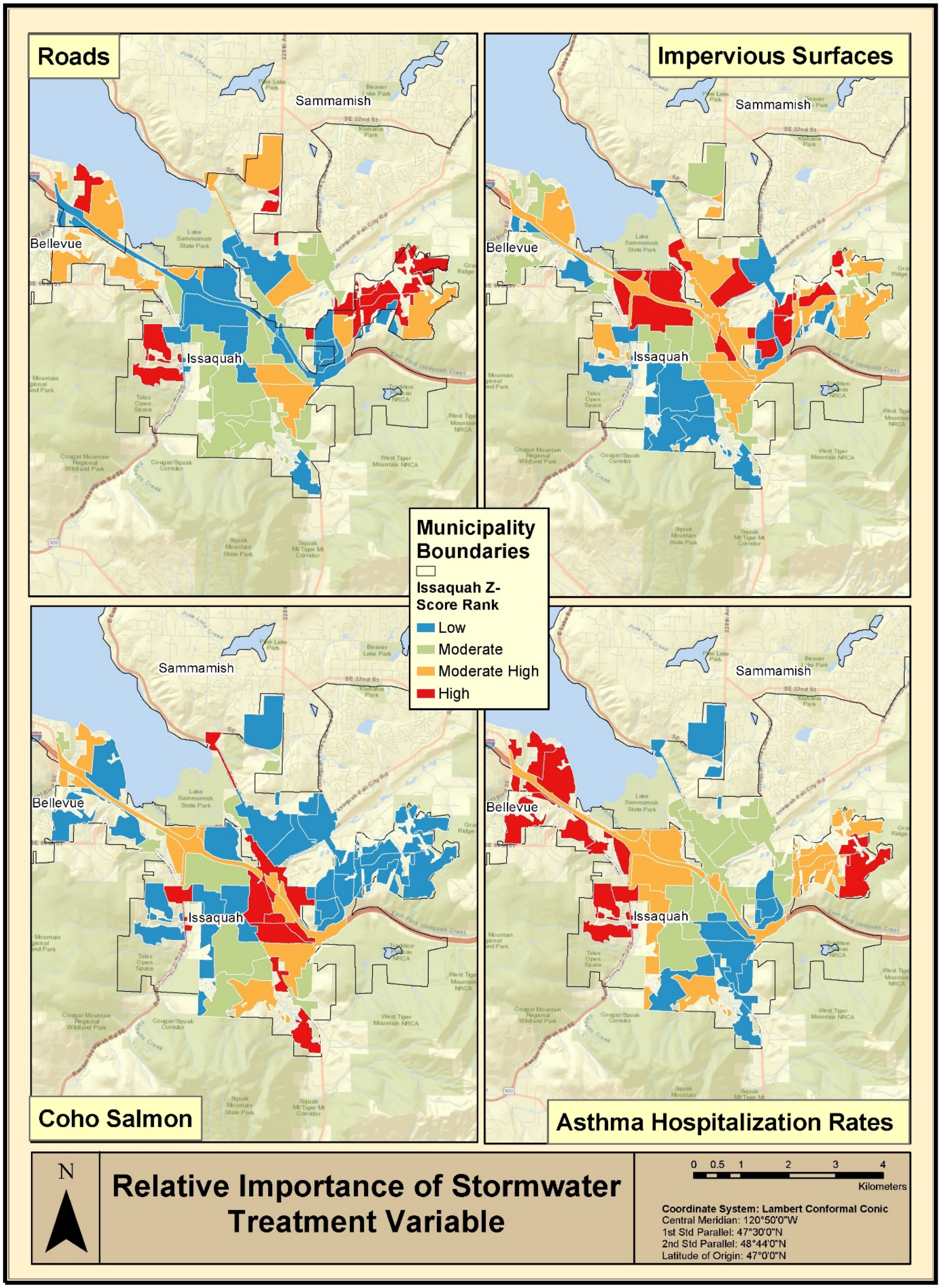
Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Municipality Boundaries
Bothell Z-Score Rank
Low
Moderate
Moderate High
High
Woodinville
Bothell
Kenmore
Cottage Lake
N
Relative Importance of Stormwater Treatment Variable
0 0.5 1 2 3 4
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

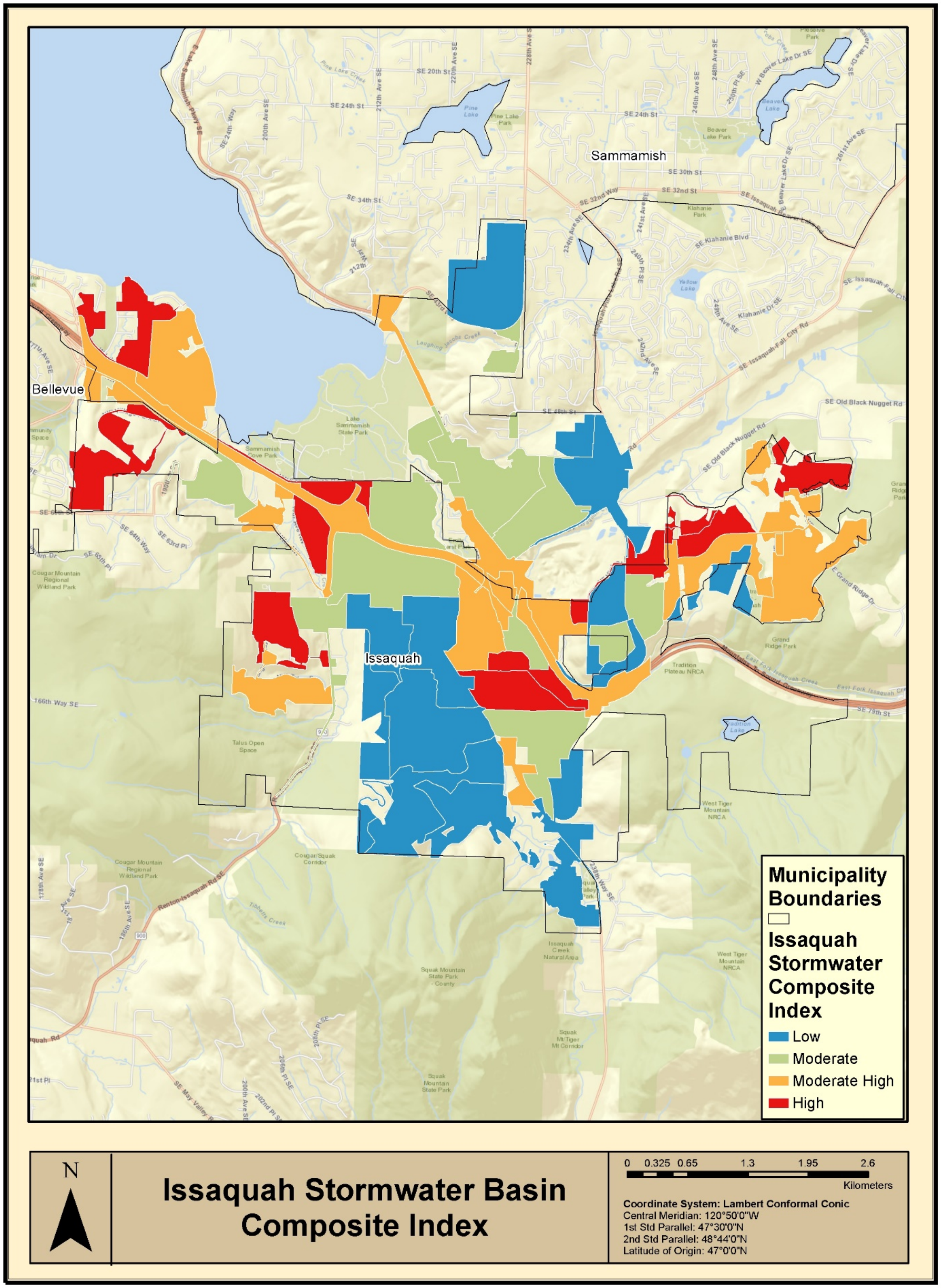

Bothell
Kenmore
Woodinville
Municipality Boundaries
Bothell Stormwater Composite Index
Low
Moderate
Moderate High
High
N
Bothell Stormwater Basin Composite Index
0 0.3 0.6 1.2 1.8 2.4
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

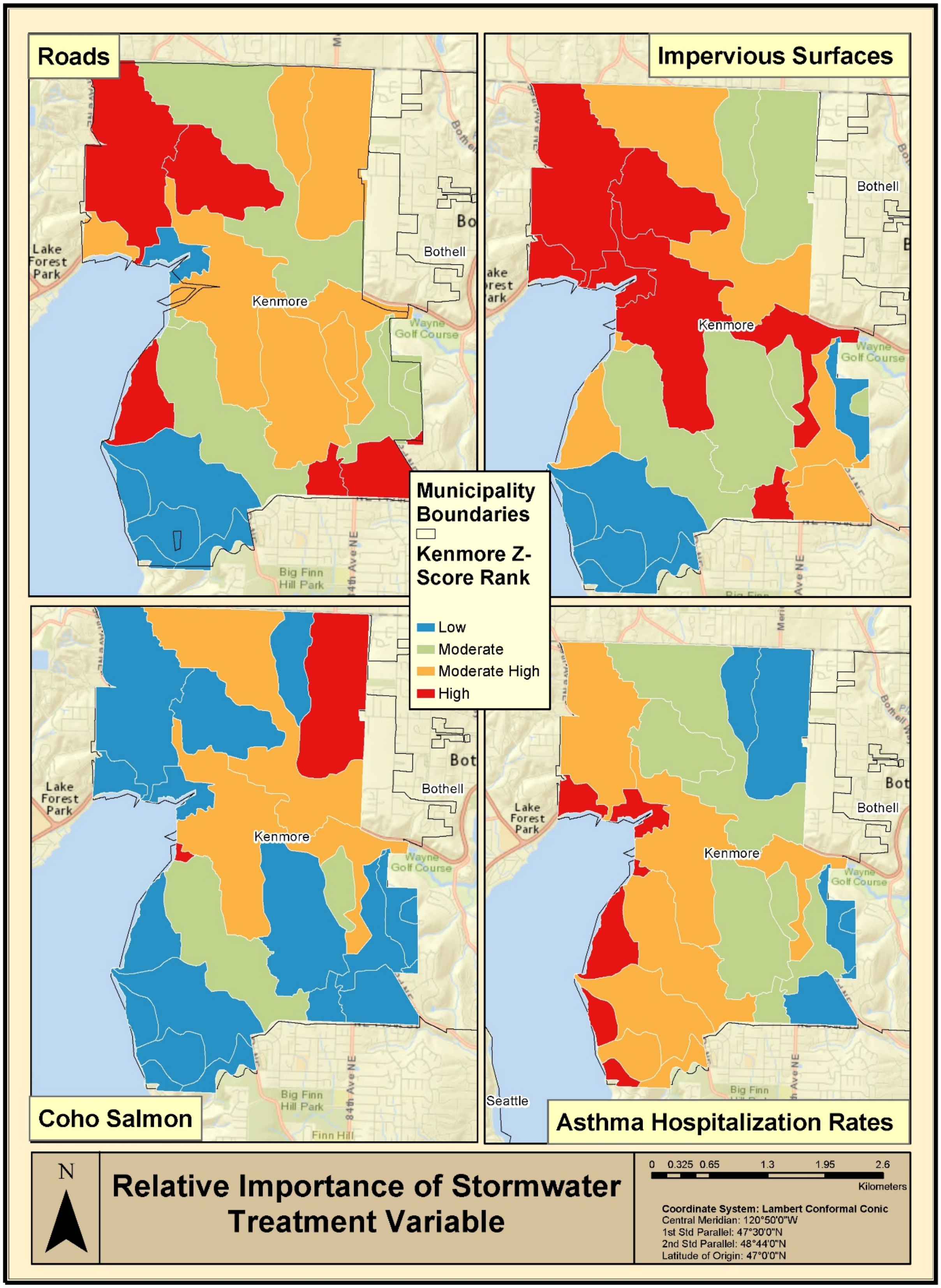

Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Municipality Boundaries
Federal Way Z-Score Rank
Low
Moderate
Moderate High
High
Federal Way
Des Moines
Kent
Vashon
Fife
Edgewood
Puyallup Reservation
Port of Tacoma Manufacturing/Industrial Center
N
Relative Importance of Stormwater Treatment Variable
0 0.75 1.5 3 4.5 6
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

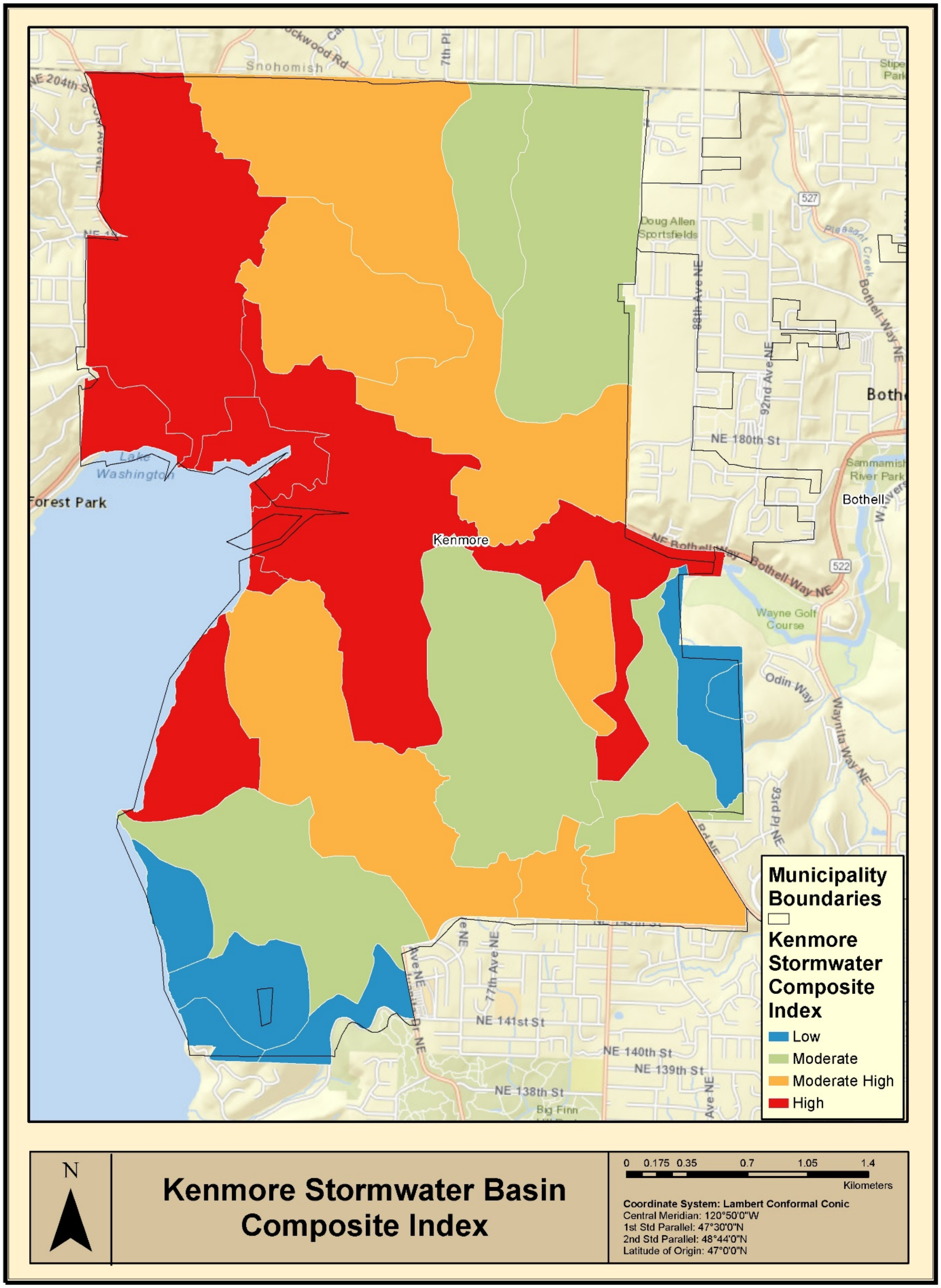


Federal Way Moines Stormwater Basin Composite Index

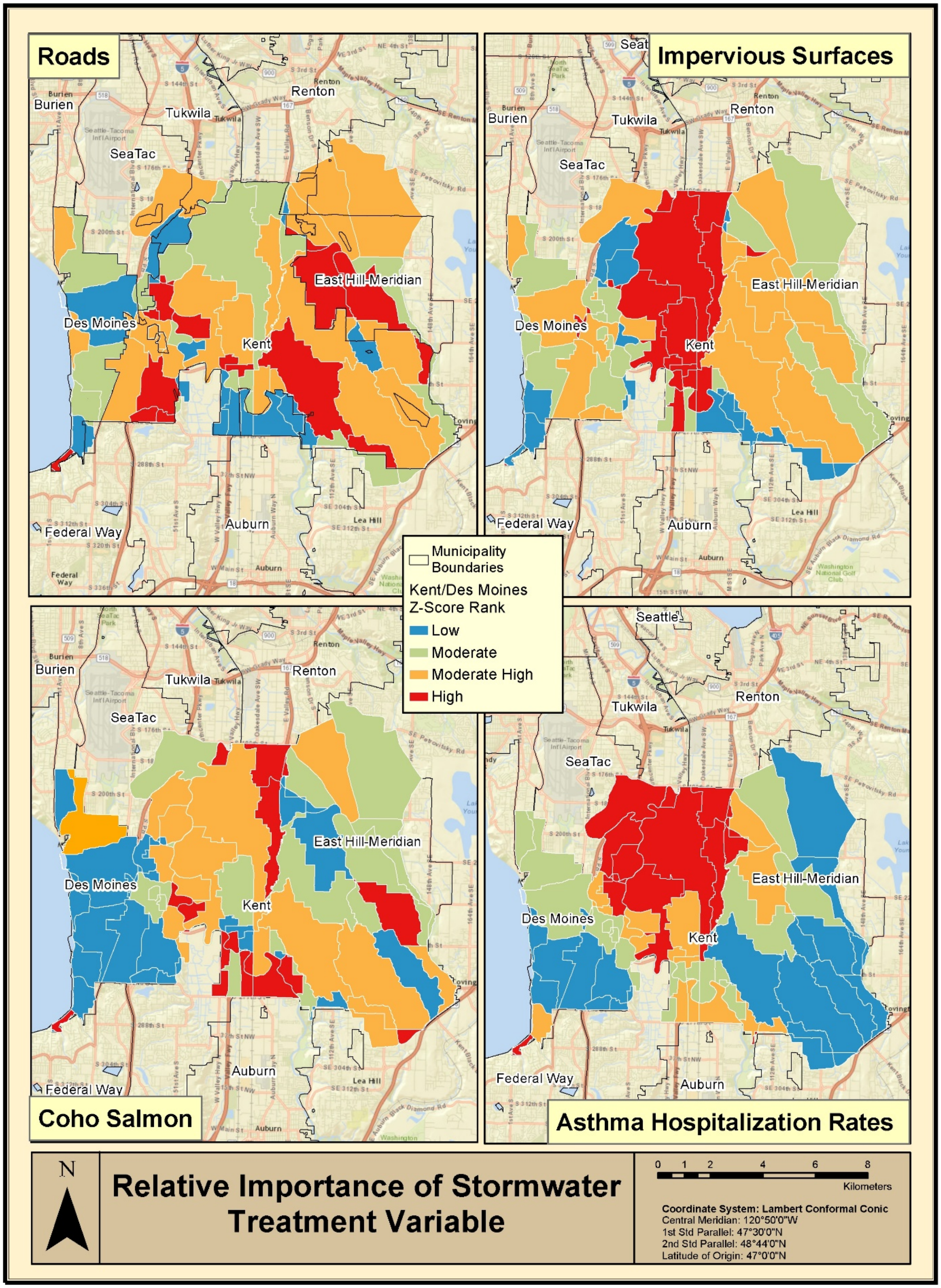

Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Sammamish
Bellevue
Issaquah
Municipality Boundaries
Issaquah Z-Score Rank
Low
Moderate
Moderate High
High
N
Relative Importance of Stormwater Treatment Variable
0 0.5 1 2 3 4
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

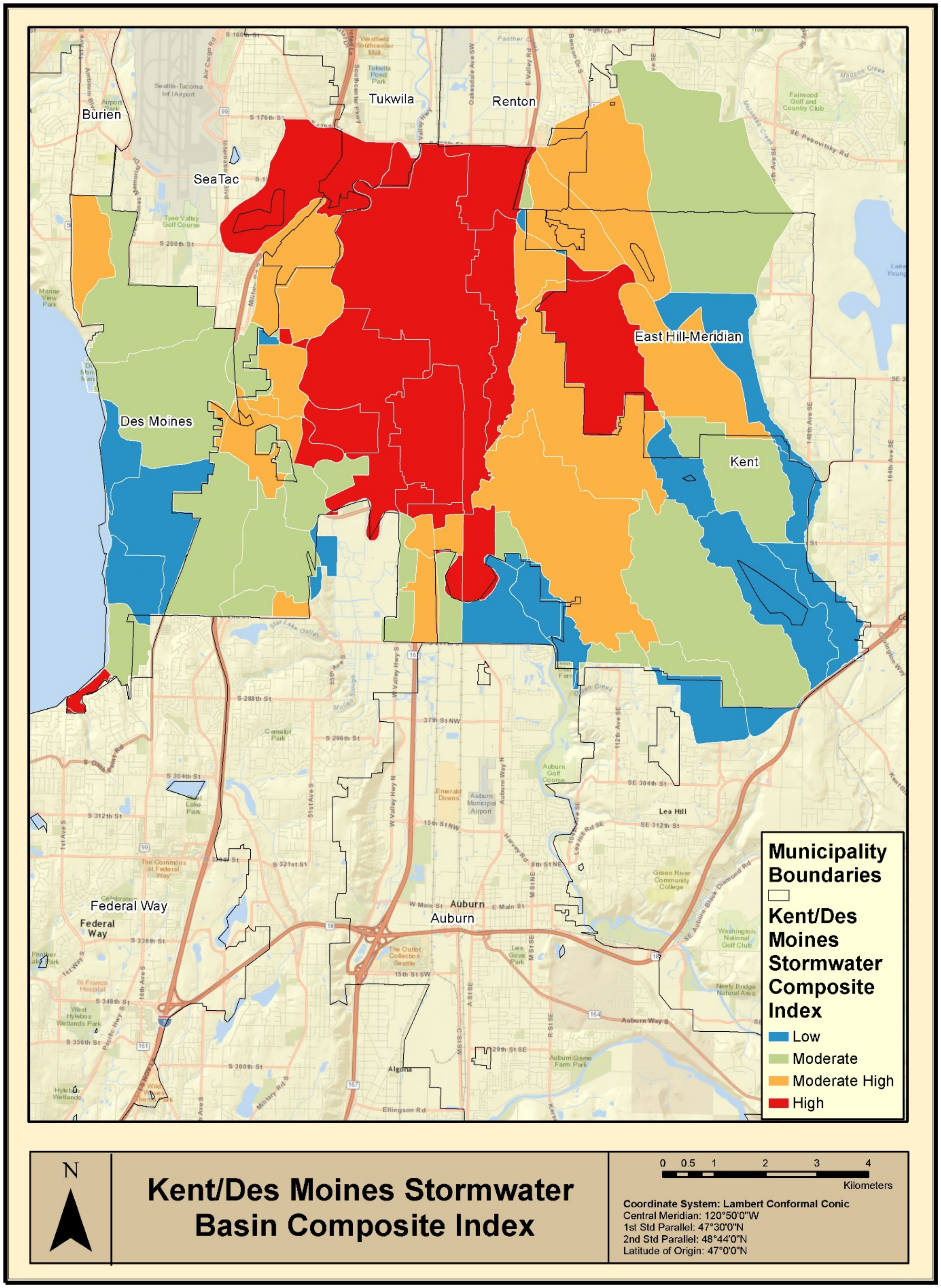

Sammamish
Bellevue
Issaquah
Municipality Boundaries
Issaquah Stormwater Composite Index
Low
Moderate
Moderate High
High
Issaquah Stormwater Basin Composite Index
N
0 0.325 0.65 1.3 1.95 2.6
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

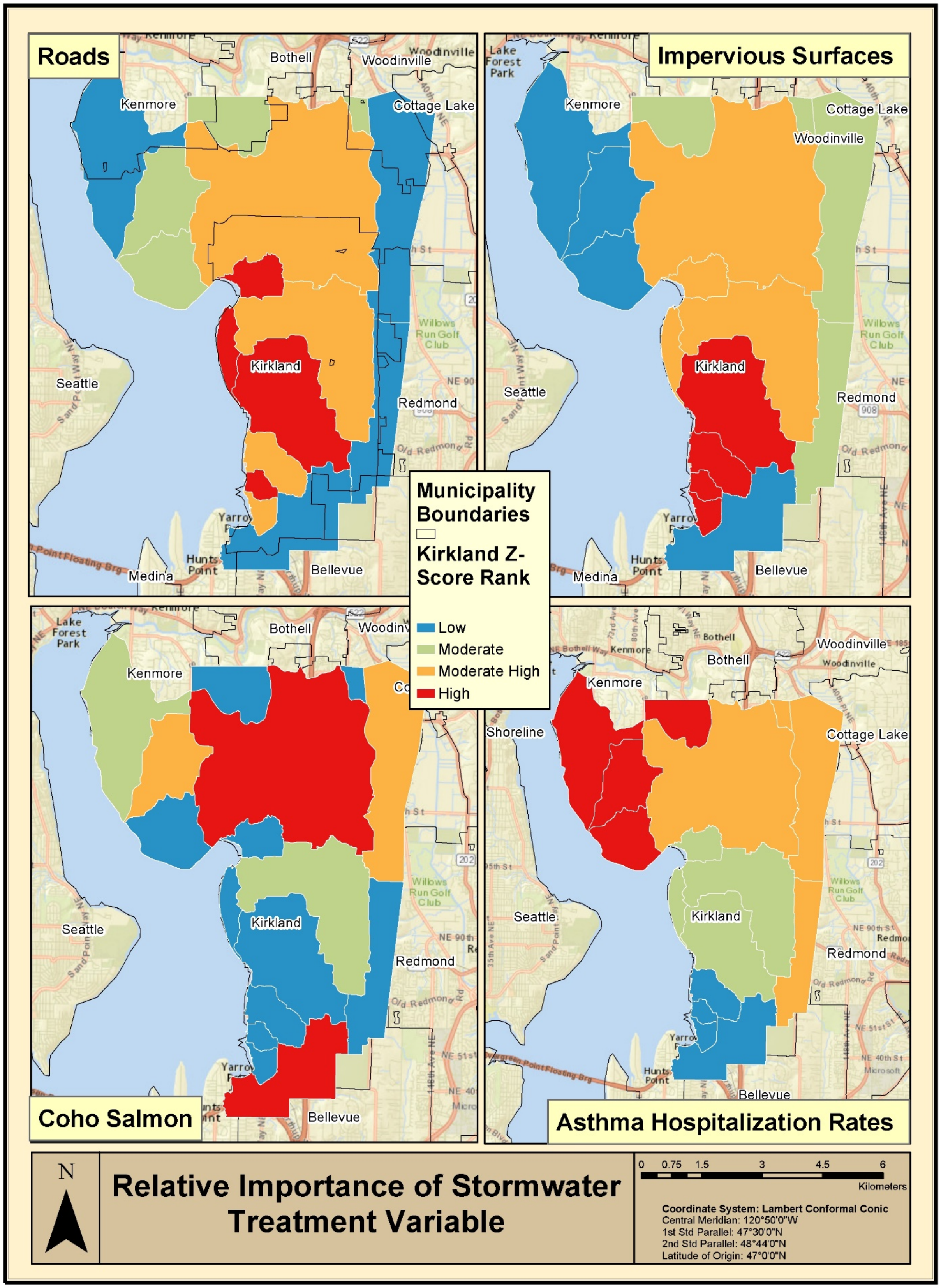

Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Municipality Boundaries
Kenmore Z-Score Rank
Low
Moderate
Moderate High
High
Kenmore
Bothell
Lake Forest Park
Wayne Golf Course
Big Finn Hill Park
84th Ave NE
Seattle
N
Relative Importance of Stormwater Treatment Variable
0 0.325 0.65 1.3 1.95 2.6
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

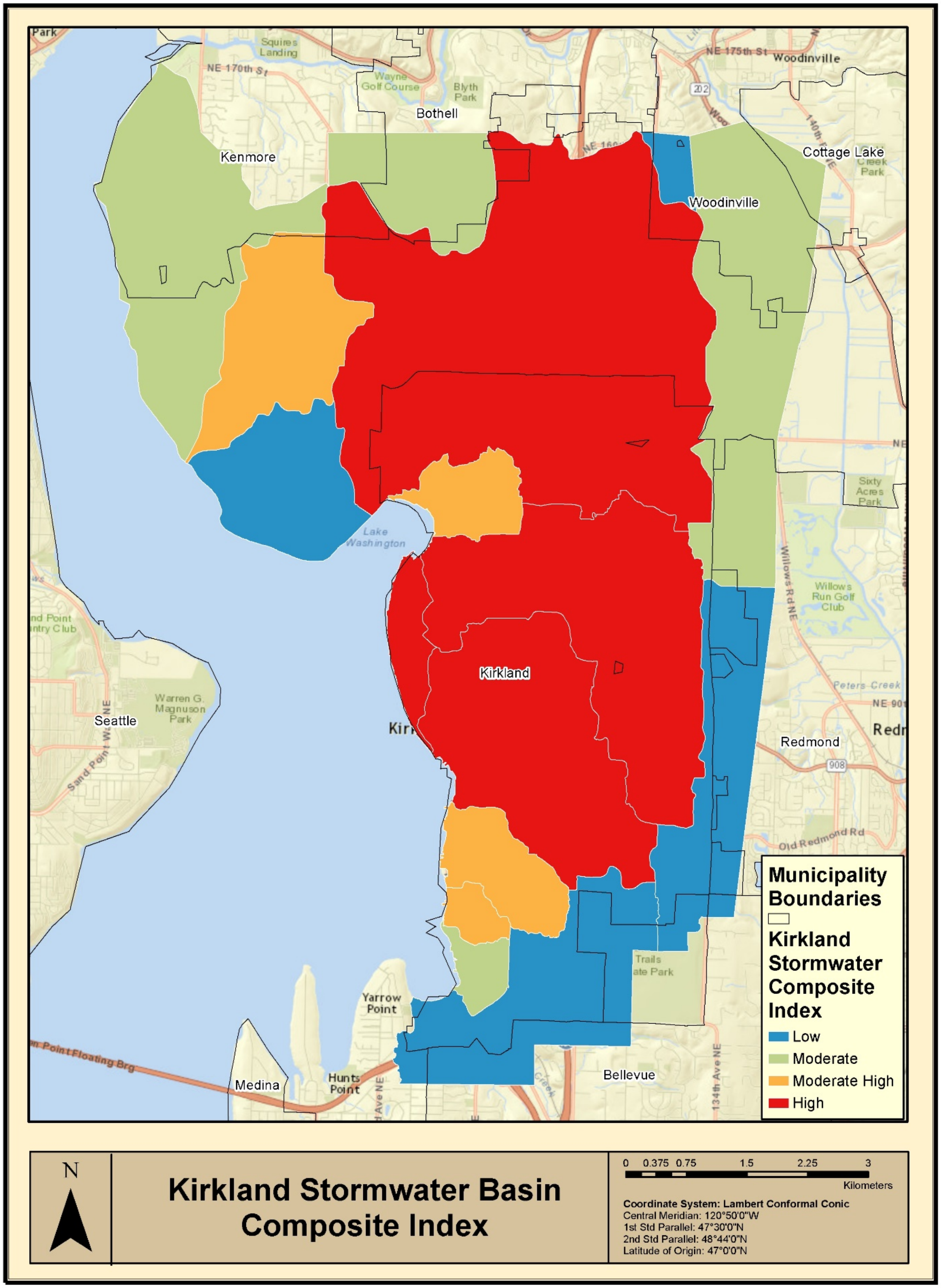


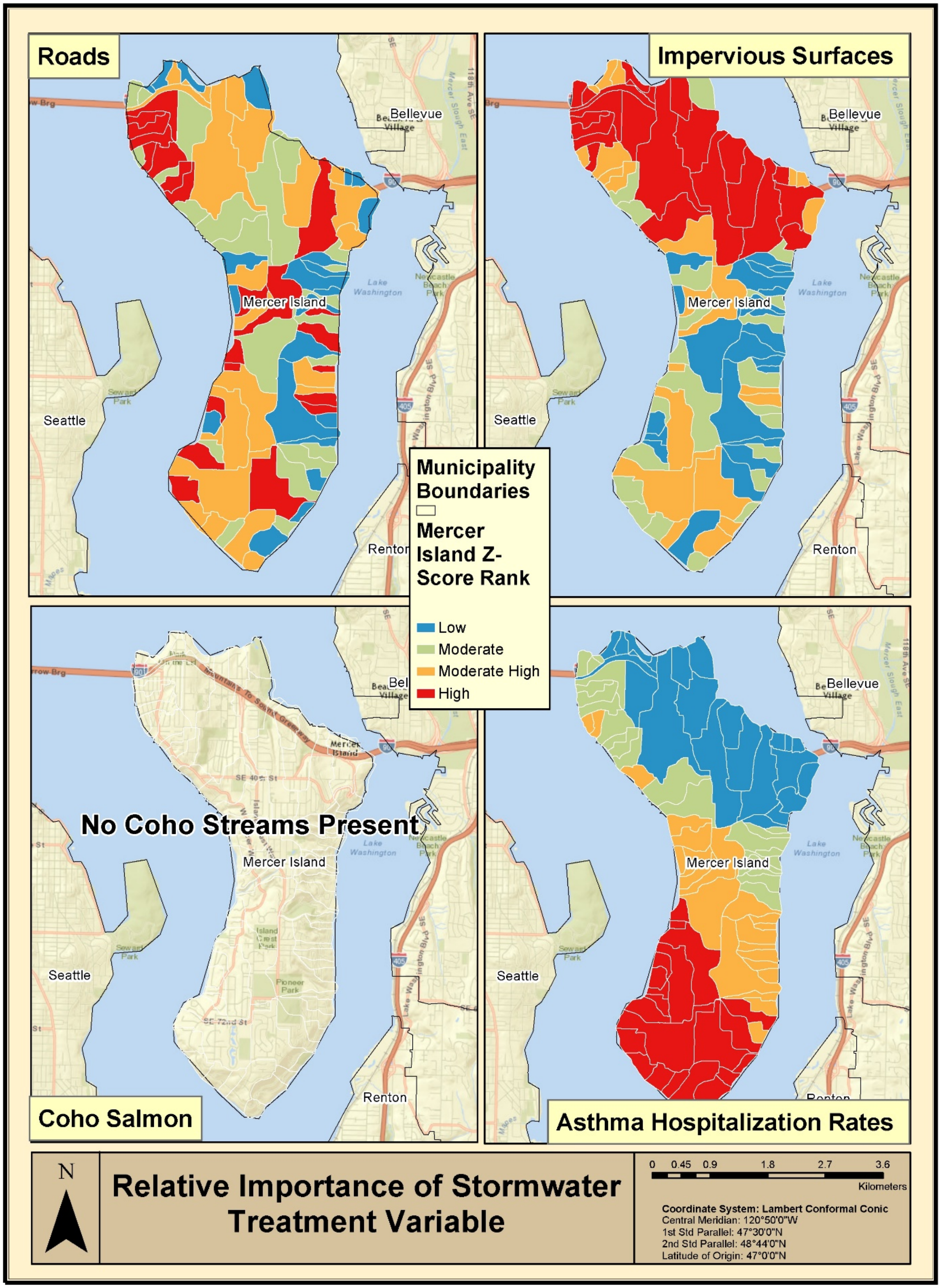
Municipality Boundaries
Kenmore Stormwater Composite Index
Low
Moderate
Moderate High
High
Kenmore
Lake Washington
Forest Park
Bothell
Doug Allen Sportsfields
Sammamish River Park
Wayne Golf Course
NE 180th St
NE 141st St
NE 140th St
NE 139th St
NE 138th St
88th Ave NE
92nd Ave NE
77th Ave NE
Bothell Way NE
Odin Way
Waynita Way NE
Snohomish
N
Kenmore Stormwater Basin Composite Index
0 0.175 0.35 0.7 1.05 1.4
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

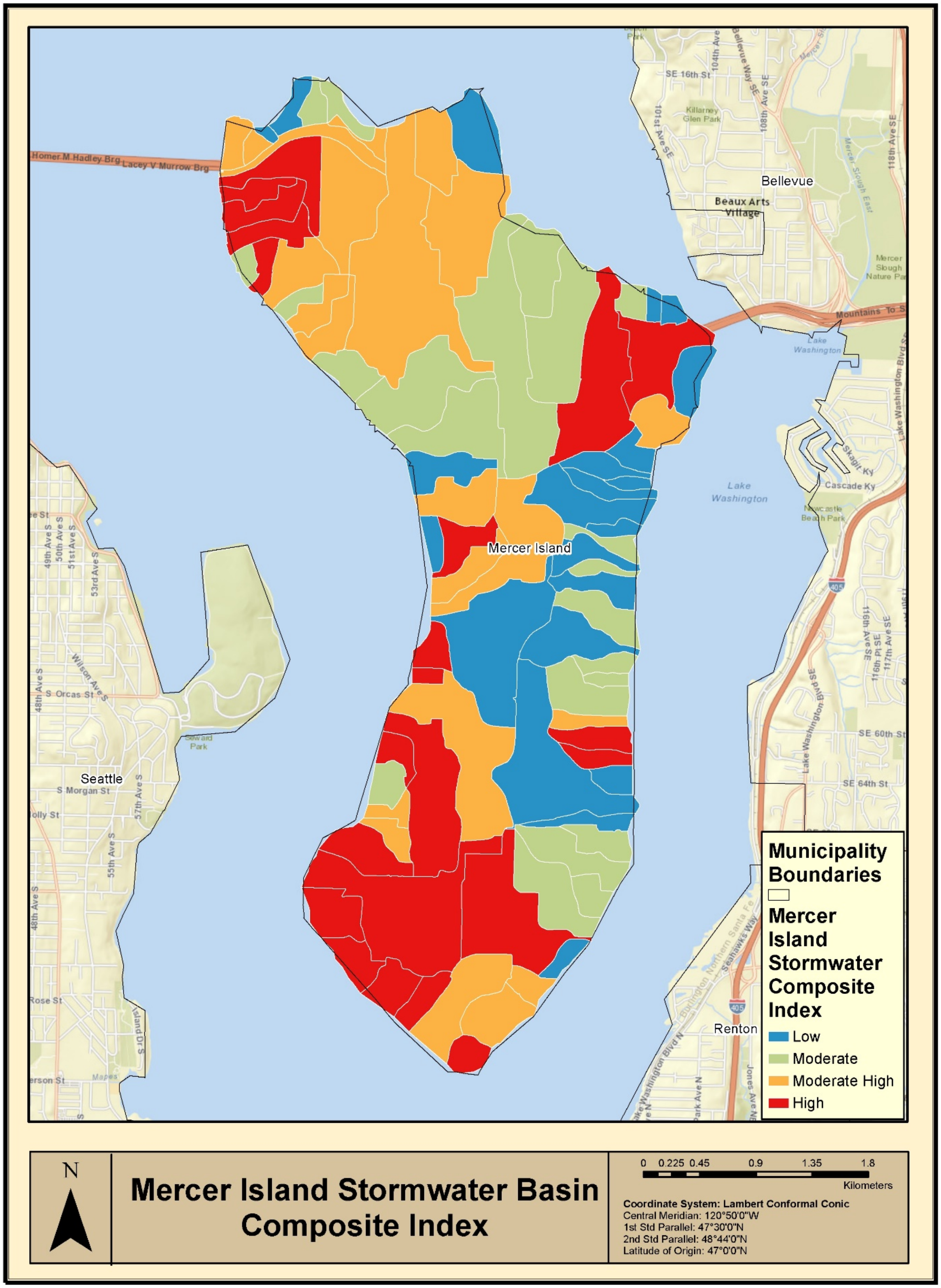

Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Burien
Tukwila
Renton
SeaTac
East Hill-Meridian
Des Moines
Kent
Auburn
Federal Way
Municipality Boundaries
Kent/Des Moines Z-Score Rank
Low
Moderate
Moderate High
High
N
Relative Importance of Stormwater Treatment Variable
0 1 2 4 6 8
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

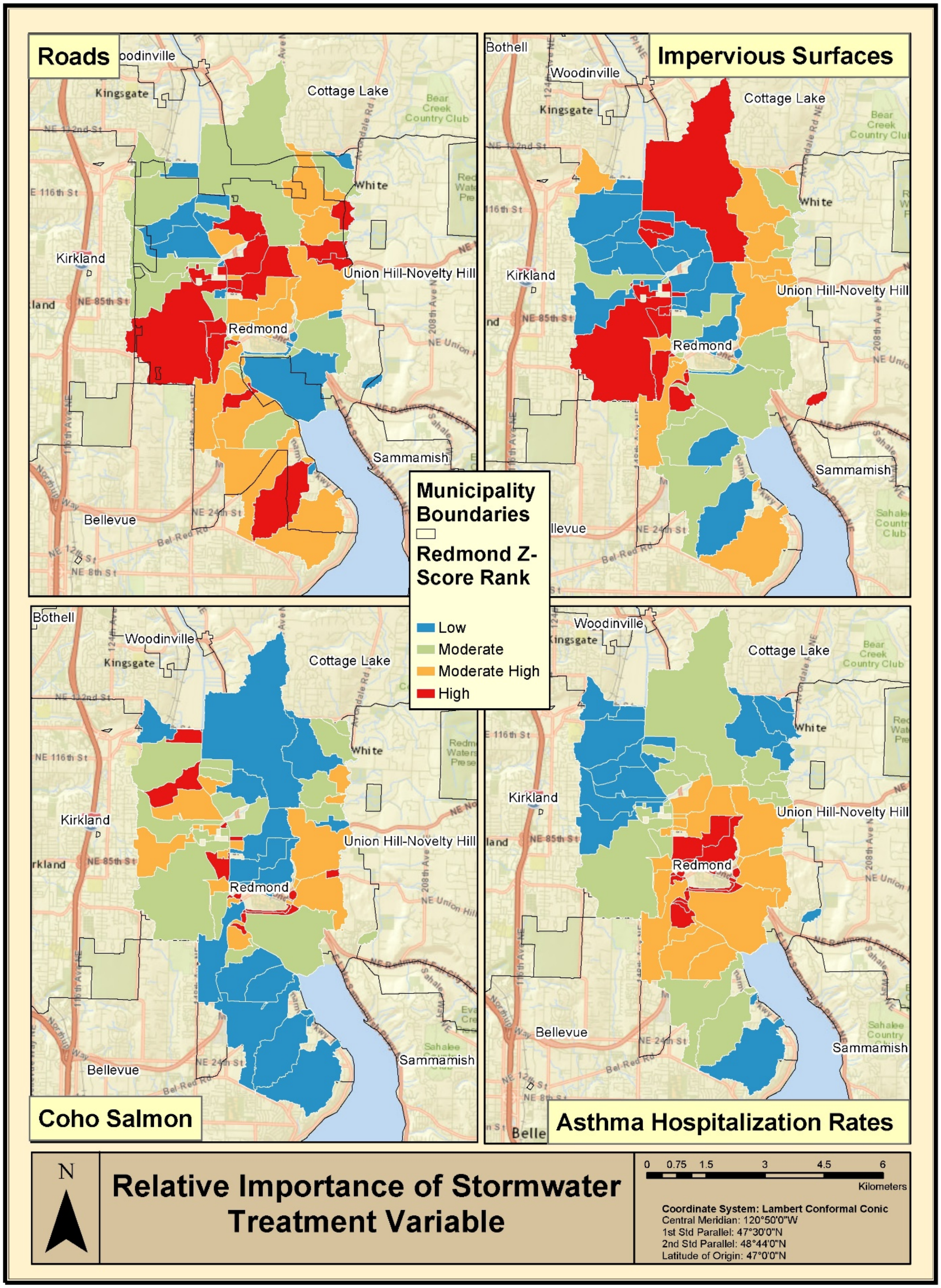

Burien
Tukwila
Renton
SeaTac
East Hill-Meridian
Des Moines
Kent
Federal Way
Auburn
Municipality Boundaries
Kent/Des Moines Stormwater Composite Index
Low
Moderate
Moderate High
High
N
Kent/Des Moines Stormwater Basin Composite Index
0 0.5 1 2 3 4
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

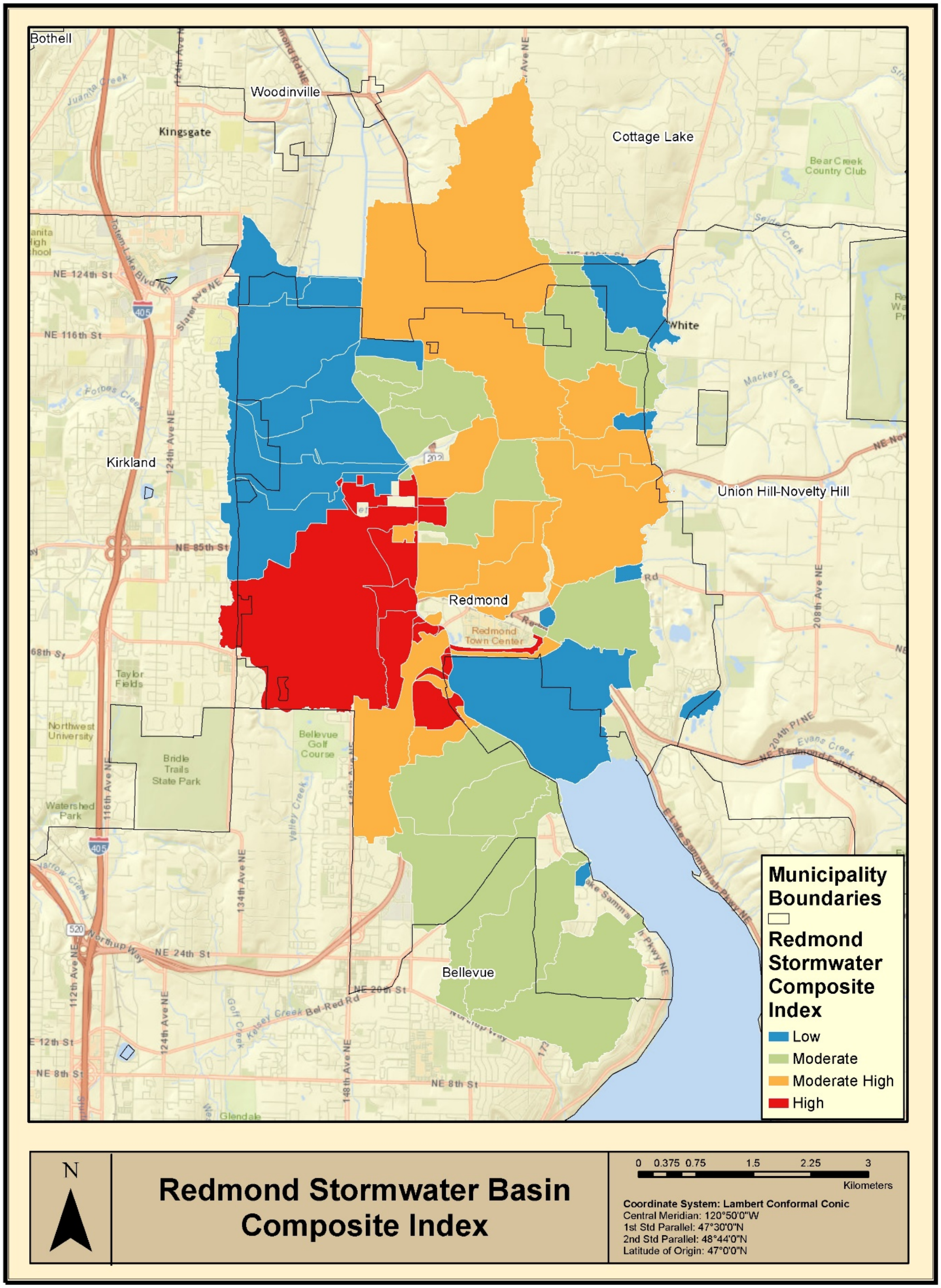

Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Municipality Boundaries
Kirkland Z-Score Rank
Low
Moderate
Moderate High
High
N
Relative Importance of Stormwater Treatment Variable
0 0.75 1.5 3 4.5 6
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

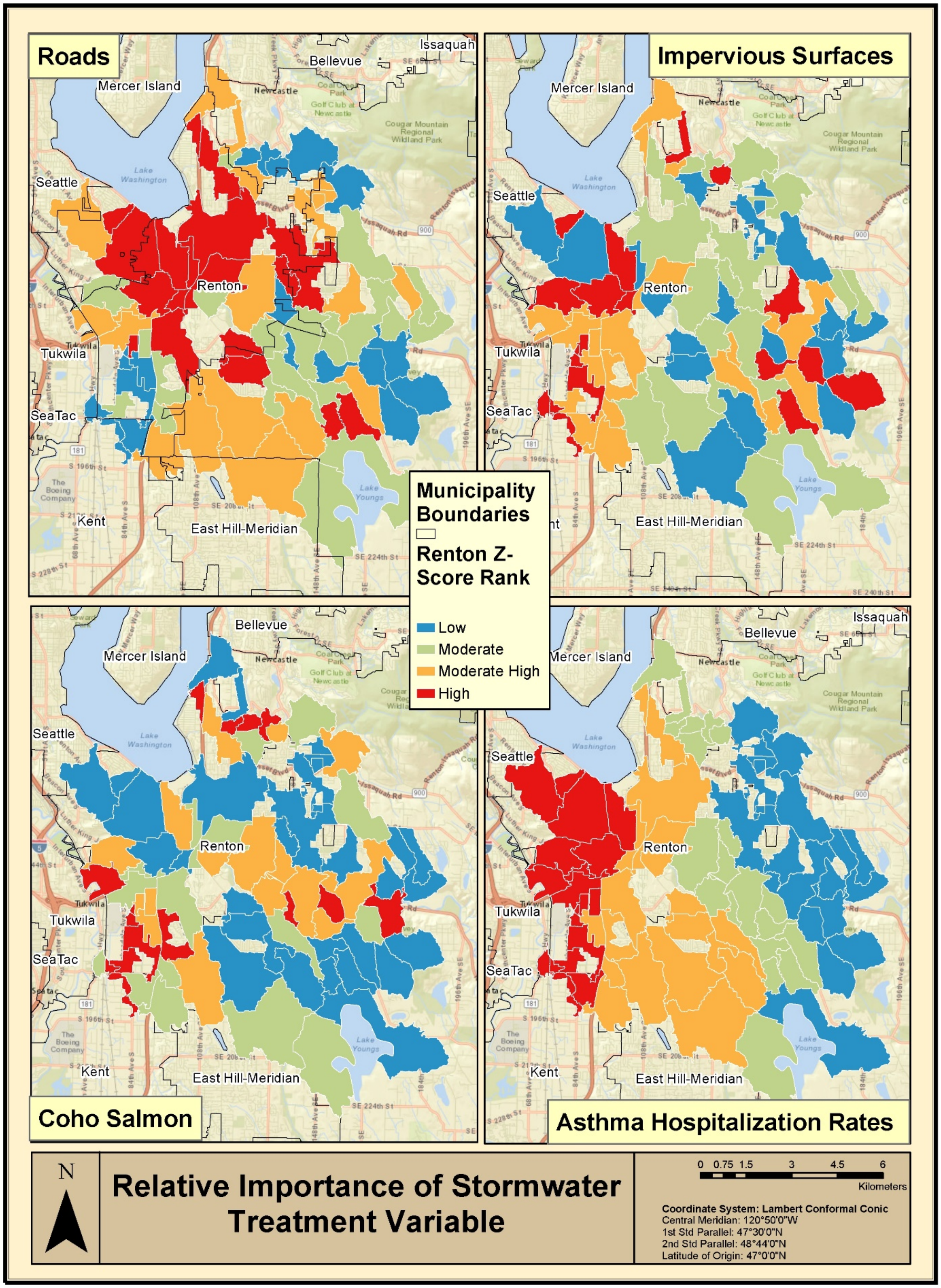

Municipality Boundaries
Kirkland Stormwater Composite Index
Low
Moderate
Moderate High
High
Kirkland Stormwater Basin Composite Index
0 0.375 0.75 1.5 2.25 3
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N
N
Kenmore
Bothell
Woodinville
Cottage Lake
Kirkland
Seattle
Redmond
Bellevue
Medina
Yarrow Point
Hunts Point
Lake Washington

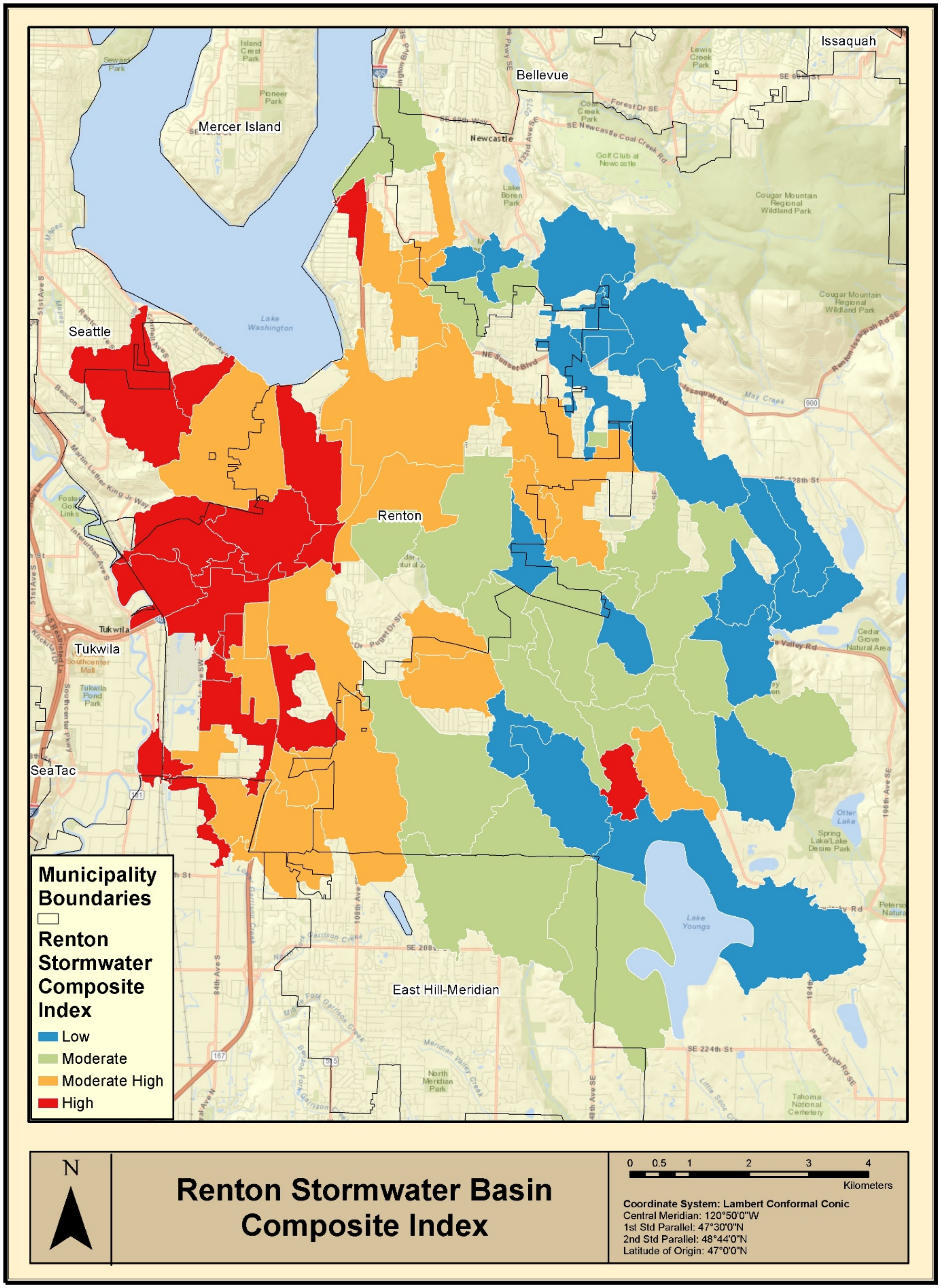

Roads
Impervious Surfaces
Coho Salmon
No Coho Streams Present
Asthma Hospitalization Rates
Municipality Boundaries
Mercer Island Z-Score Rank
Low
Moderate
Moderate High
High
Seattle
Bellevue
Mercer Island
Renton
Lake Washington
N
Relative Importance of Stormwater Treatment Variable
0 0.45 0.9 1.8 2.7 3.6
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N


Mercer Island Stormwater Basin Composite Index
Municipality Boundaries
Mercer Island Stormwater Composite Index
Low
Moderate
Moderate High
High
N
0 0.225 0.45 0.9 1.35 1.8
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N
Mercer Island
Bellevue
Beaux Arts Village
Seattle
Renton
Lake Washington
Homer M Hadley Brg
Lacey V Murrow Brg
Mountains To Sound
SE 16th St
Seward Park
S Orcas St
S Morgan St
Cascade Ky
SE 60th St
SE 64th St

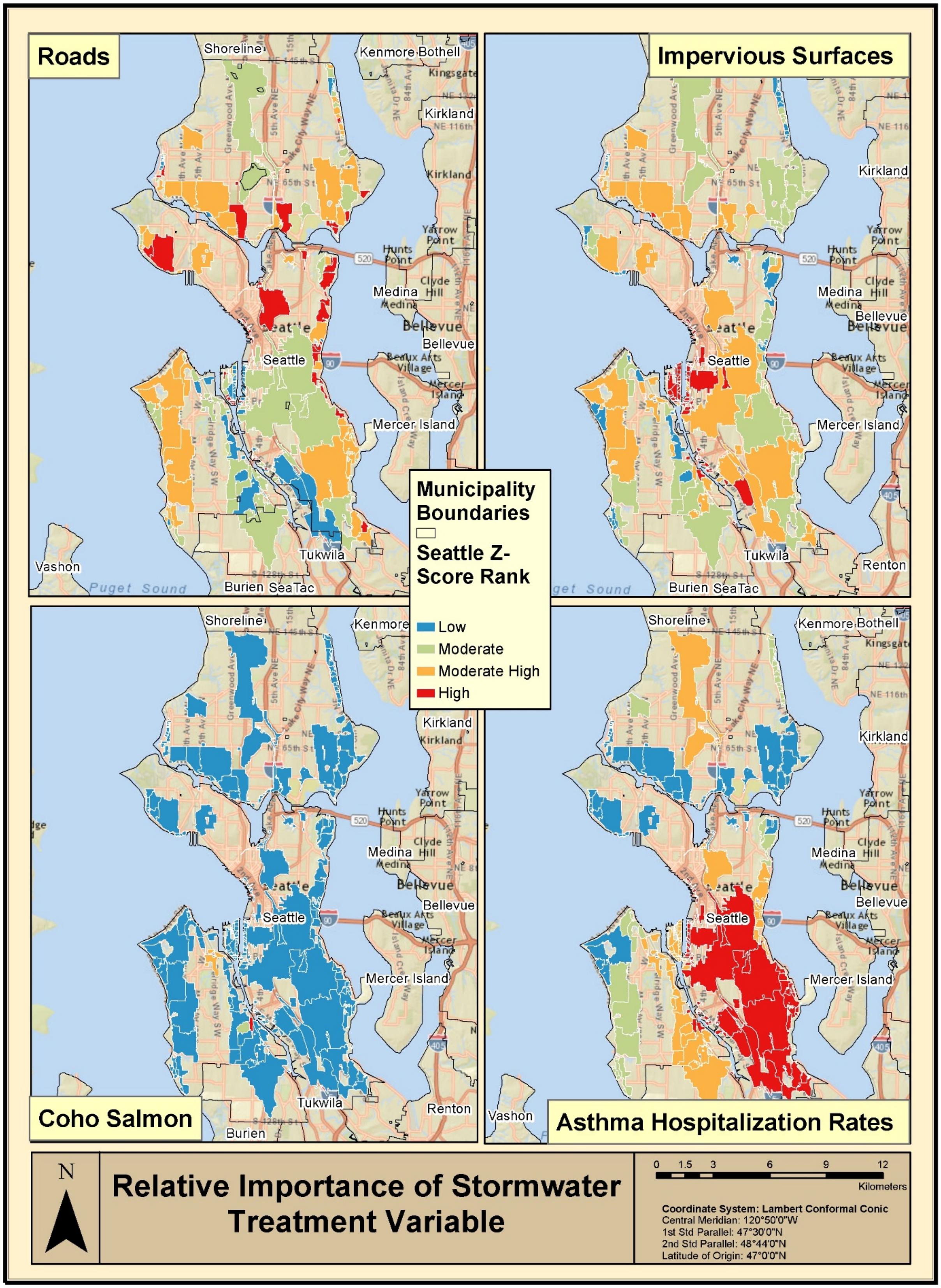

Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Municipality Boundaries
Redmond Z-Score Rank
Low
Moderate
Moderate High
High
Woodinville
Kingsgate
Cottage Lake
Bothell
Kirkland
Redmond
Union Hill-Novelty Hill
Sammamish
Bellevue
N
Relative Importance of Stormwater Treatment Variable
0 0.75 1.5 3 4.5 6
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

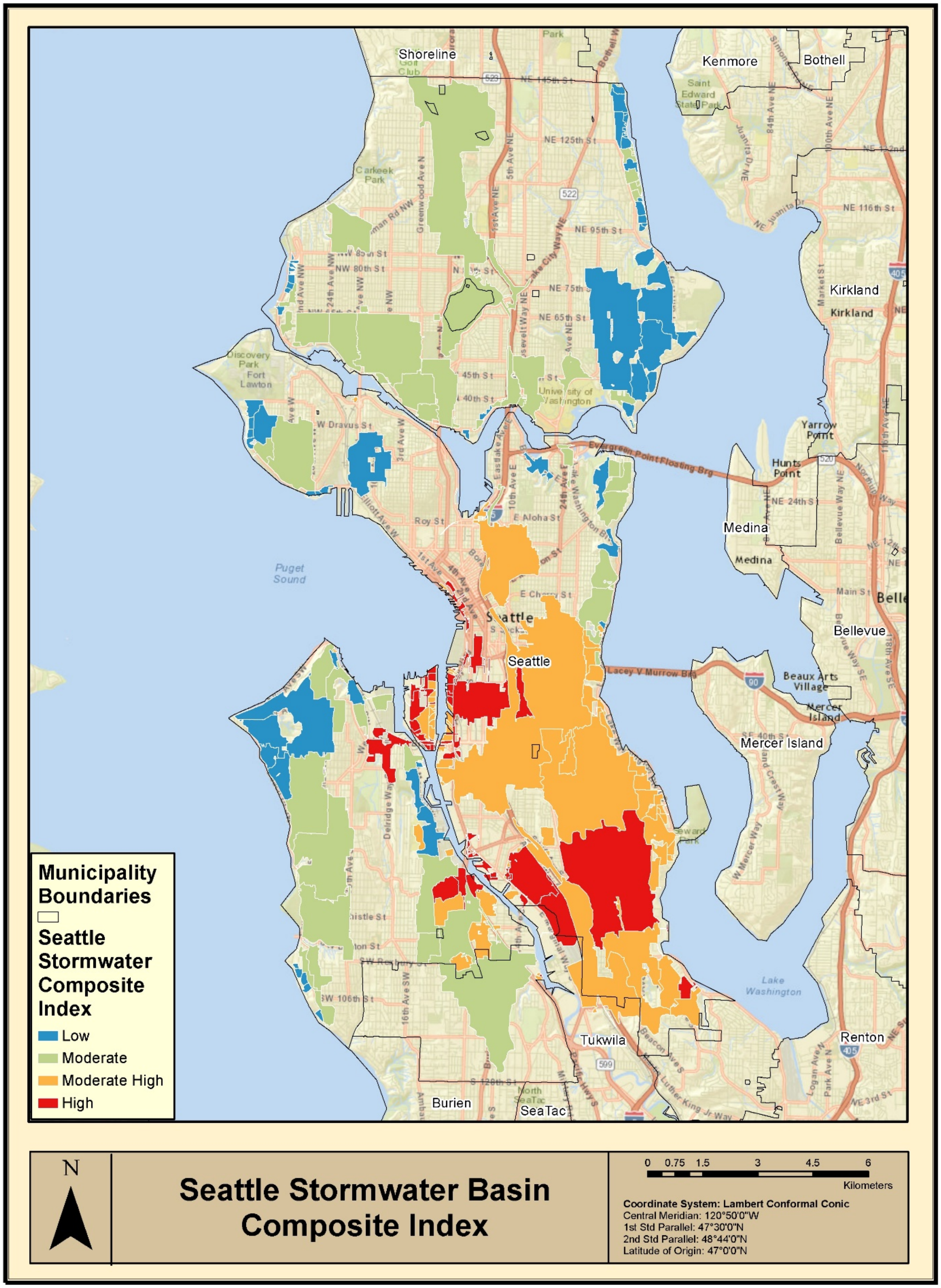

Bothell
Woodinville
Kingsgate
Cottage Lake
Bear Creek Country Club
Kirkland
White
Union Hill-Novelty Hill
Redmond
Redmond Town Center
Taylor Fields
Northwest University
Bridle Trails State Park
Bellevue Golf Course
Watershed Park
Bellevue
NE 124th St
NE 116th St
NE 85th St
NE 24th St
NE 20th St
NE 8th St
Municipality Boundaries
Redmond Stormwater Composite Index
Low
Moderate
Moderate High
High
N
Redmond Stormwater Basin Composite Index
0 0.375 0.75 1.5 2.25 3
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

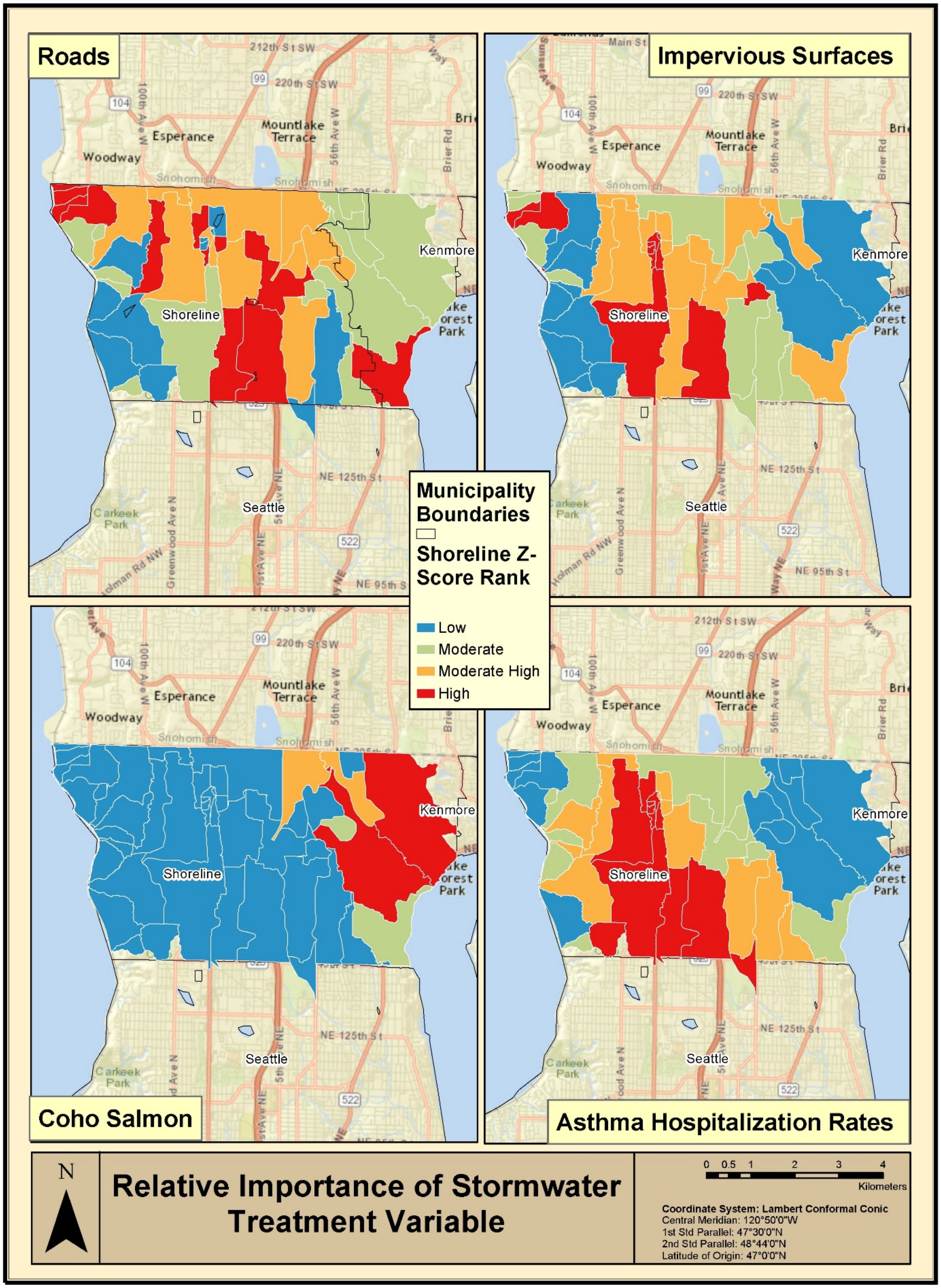

Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Municipality Boundaries
Renton Z-Score Rank
Low
Moderate
Moderate High
High
Mercer Island
Bellevue
Issaquah
Newcastle
Seattle
Renton
Tukwila
SeaTac
Kent
East Hill-Meridian
N
Relative Importance of Stormwater Treatment Variable
0 0.75 1.5 3 4.5 6
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

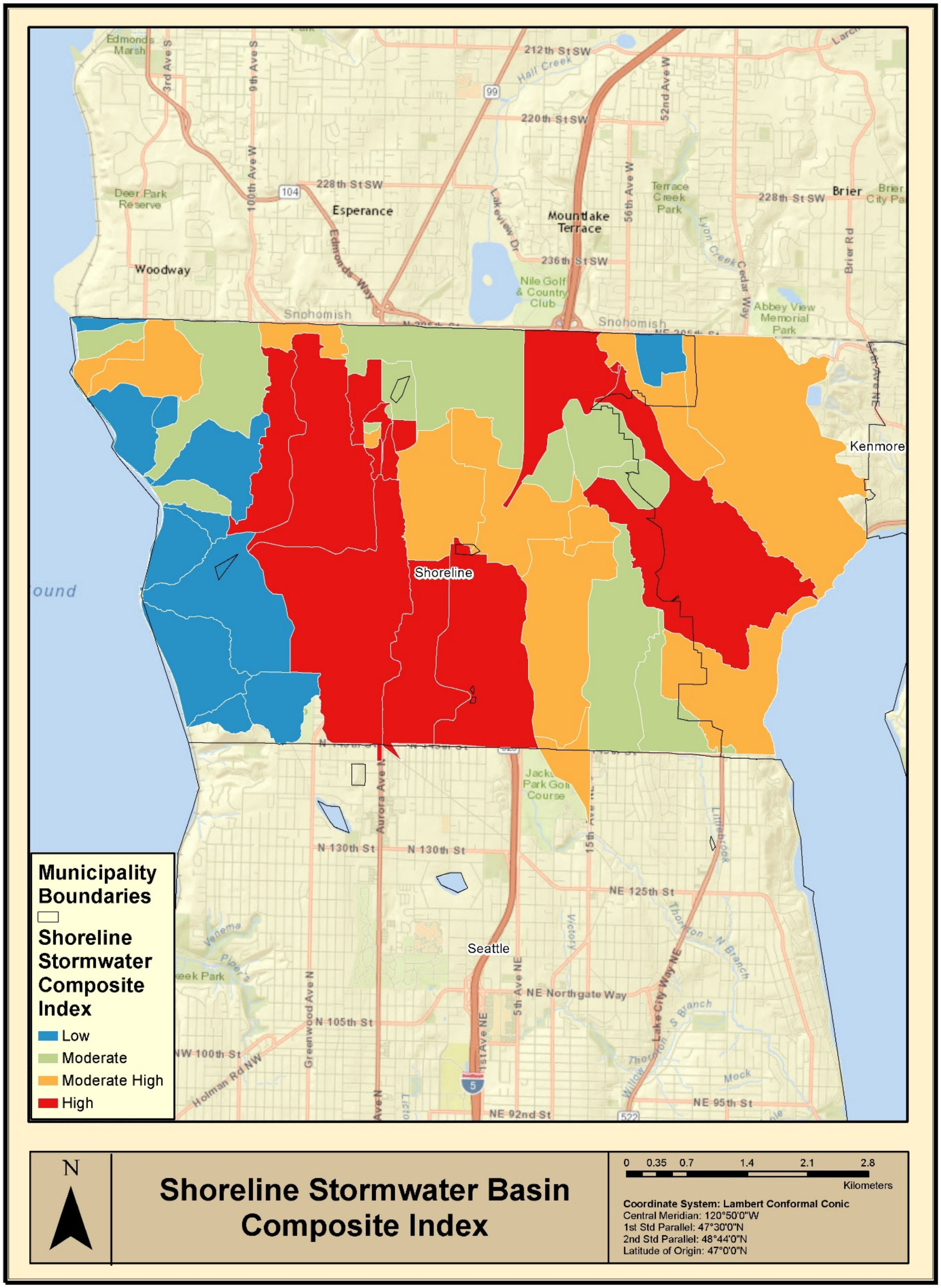


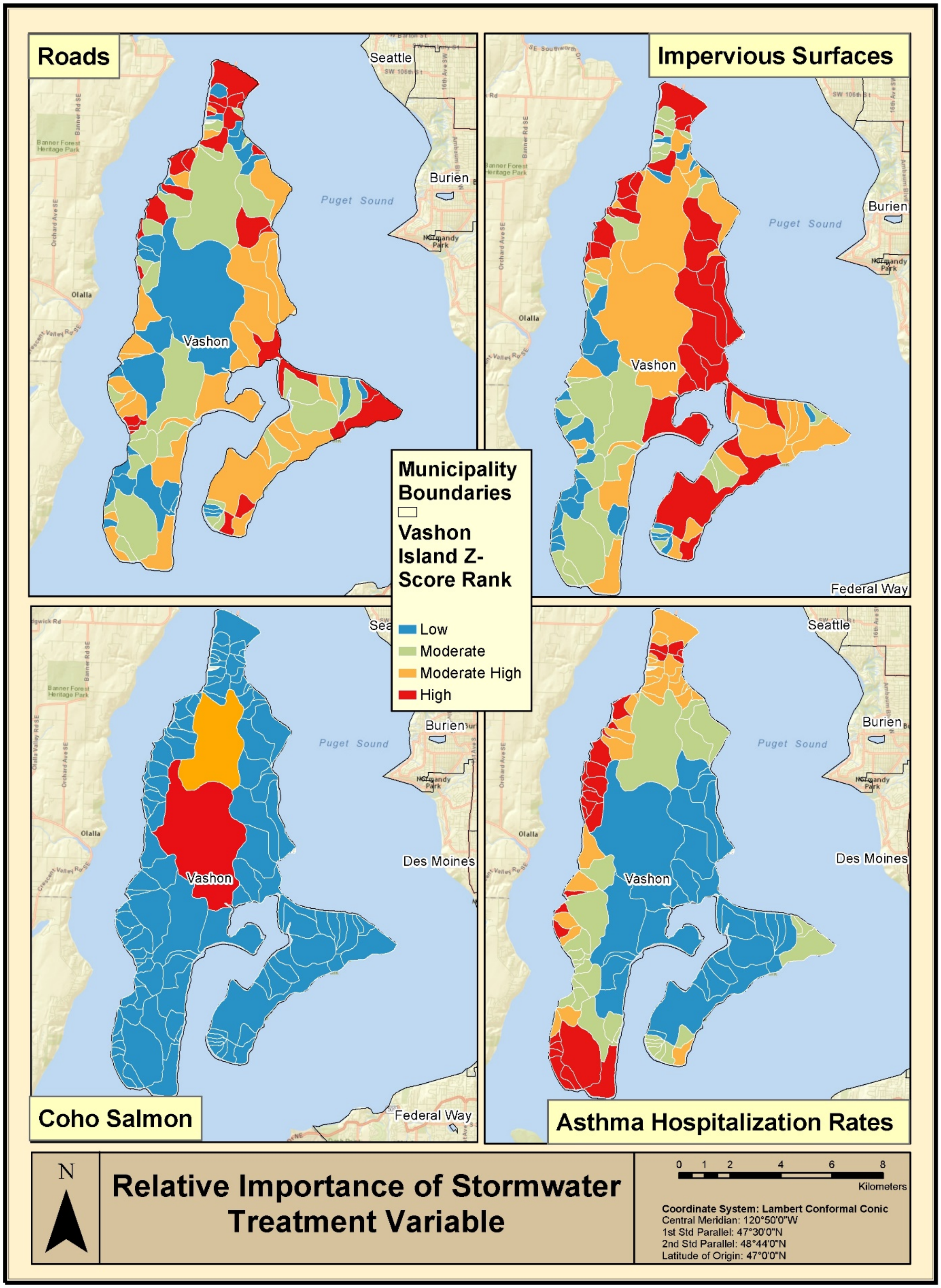
Issaquah
Bellevue
Mercer Island
Newcastle
Seattle
Renton
Tukwila
SeaTac
East Hill-Meridian
Lake Washington
Lake Youngs
Cougar Mountain Regional Wildland Park
Municipality Boundaries
Renton Stormwater Composite Index
Low
Moderate
Moderate High
High
N
Renton Stormwater Basin Composite Index
0 0.5 1 2 3 4
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

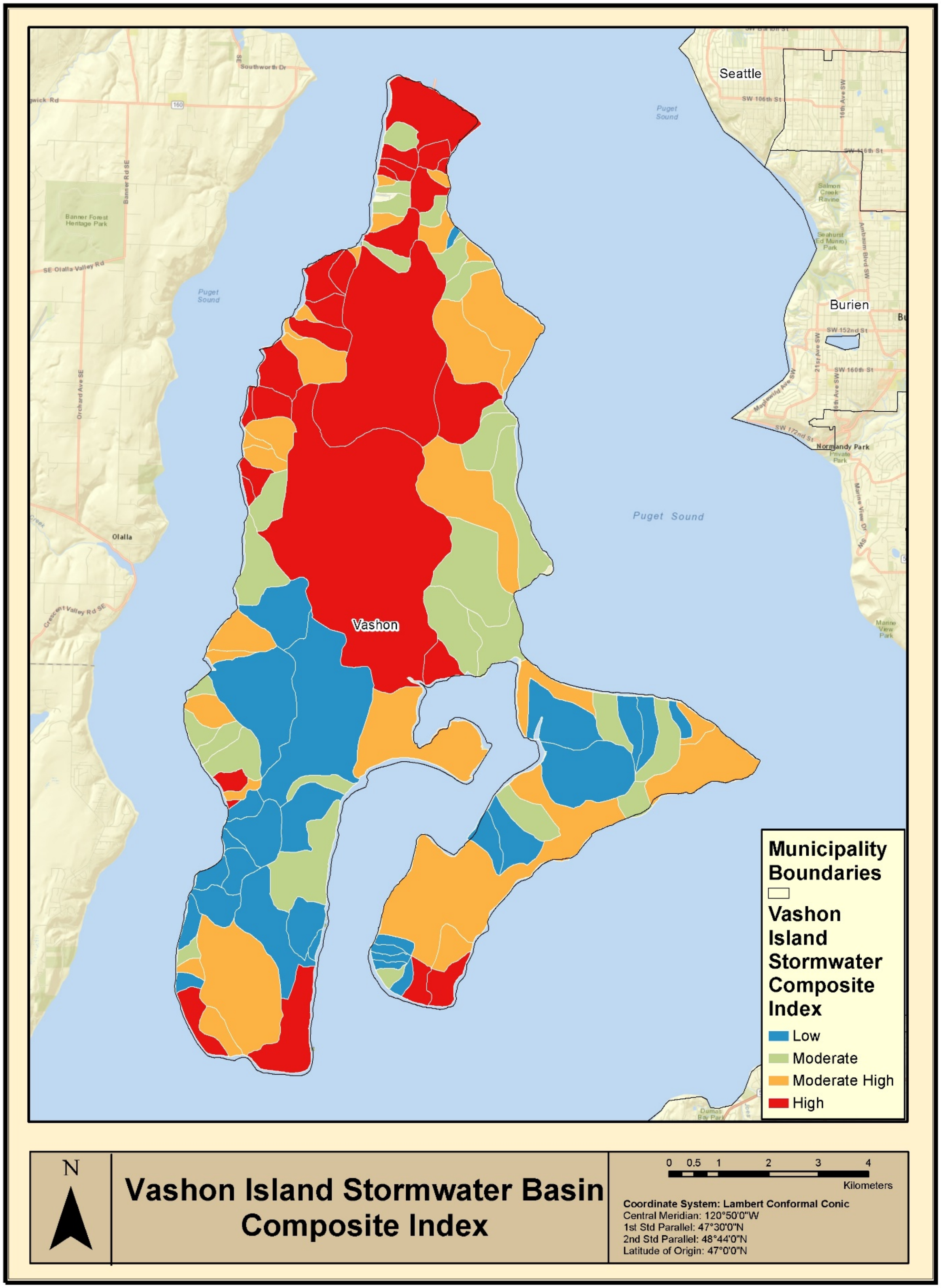

Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Municipality Boundaries
Seattle Z-Score Rank
Low
Moderate
Moderate High
High
Shoreline
Kenmore
Bothell
Kirkland
Yarrow Point
Hunts Point
Clyde Hill
Medina
Bellevue
Seattle
Beaux Arts Village
Mercer Island
Tukwila
Renton
Vashon
Burien
SeaTac
Puget Sound
N
Relative Importance of Stormwater Treatment Variable
0 1.5 3 6 9 12
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

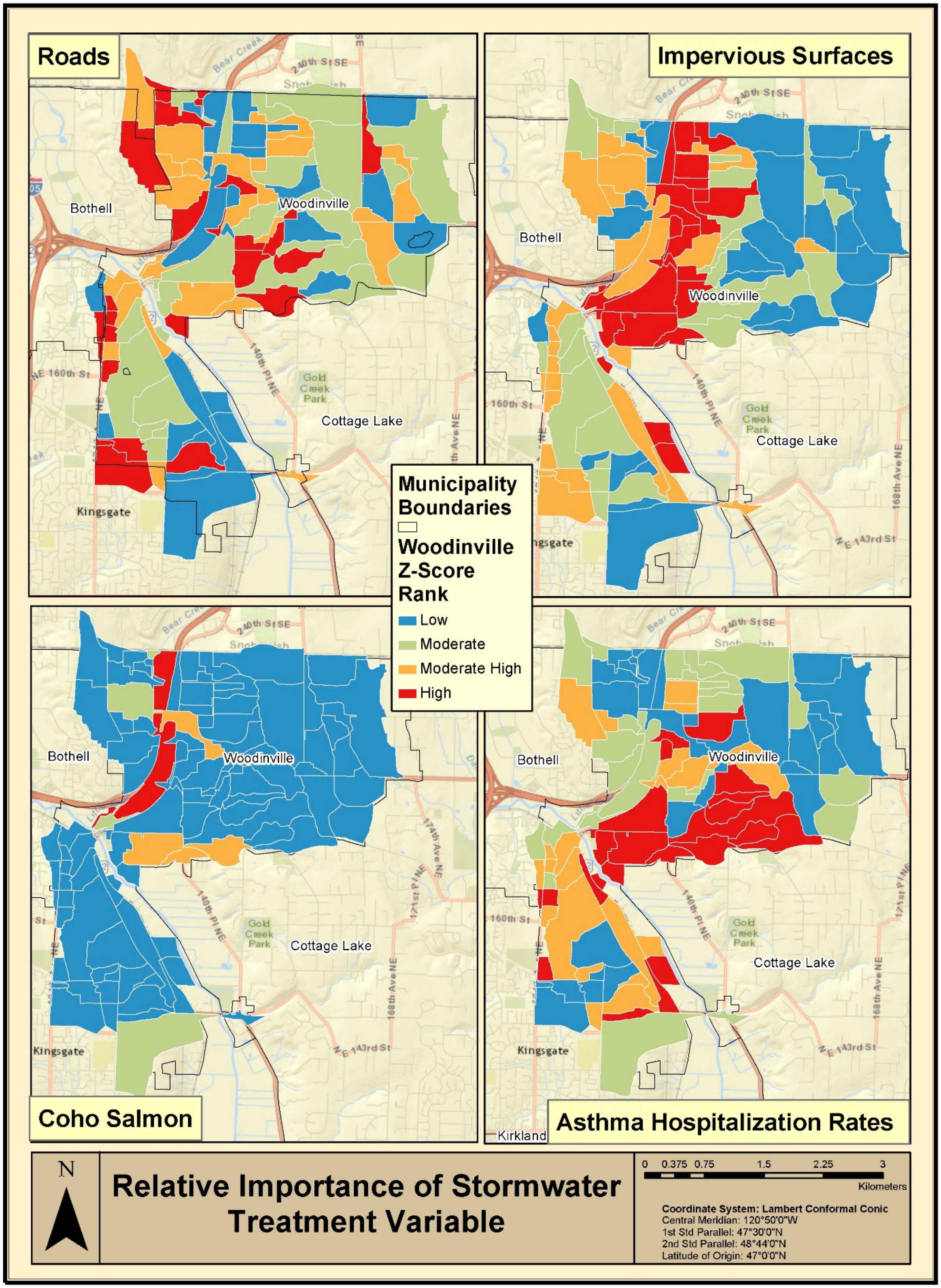

Municipality Boundaries
Seattle Stormwater Composite Index
Low
Moderate
Moderate High
High
Shoreline
Kenmore
Bothell
Kirkland
Seattle
Medina
Bellevue
Mercer Island
Tukwila
Burien
SeaTac
Renton
Puget Sound
Lake Washington
N
Seattle Stormwater Basin Composite Index
0 0.75 1.5 3 4.5 6
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N

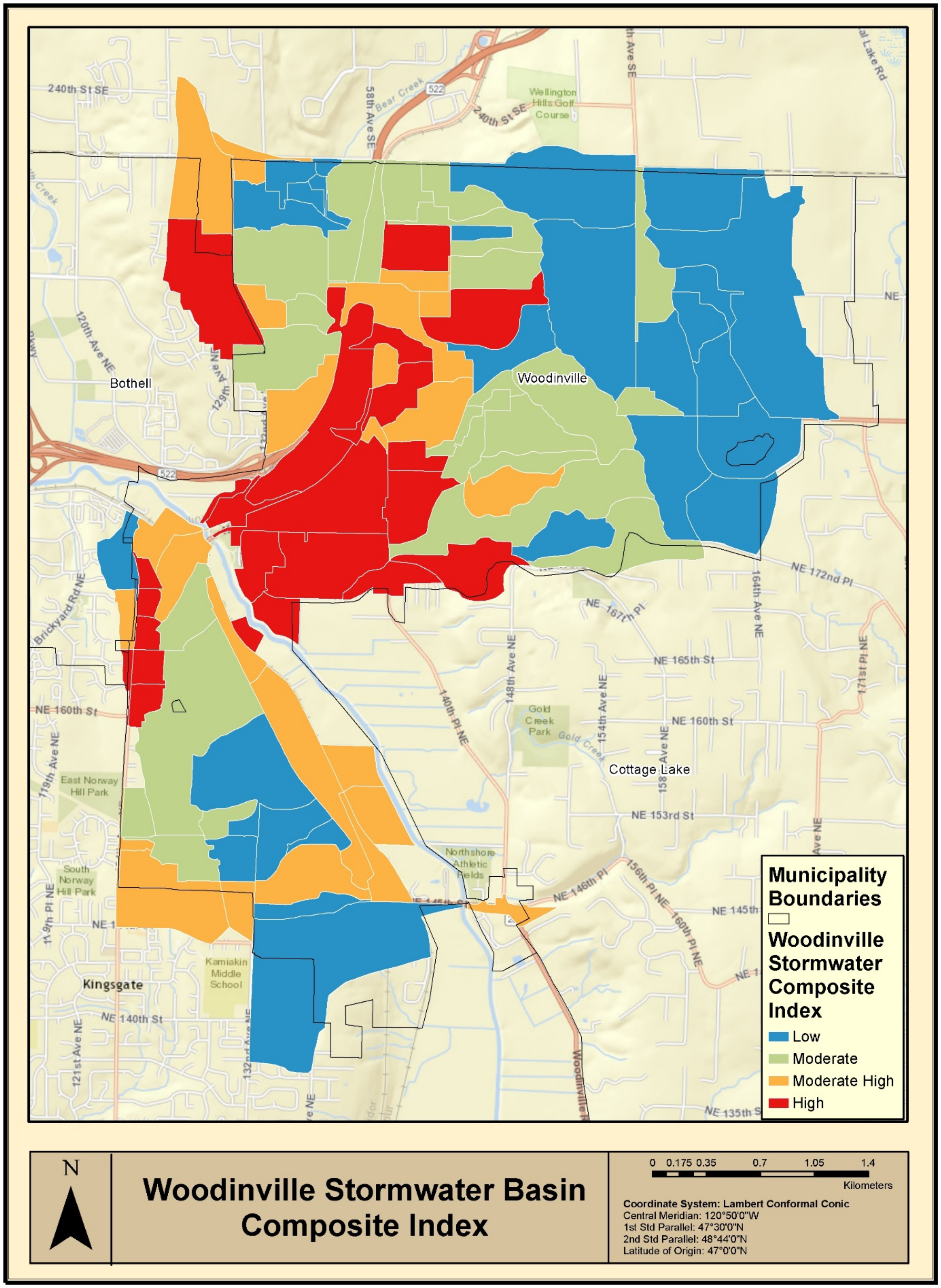

Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Municipality Boundaries
Shoreline Z-Score Rank
Low
Moderate
Moderate High
High
Esperance
Woodway
Mountlake Terrace
Kenmore
Shoreline
Lake Forest Park
Seattle
Carkeek Park
212th St SW
220th St SW
NE 125th St
NE 95th St
100th Ave W
56th Ave W
Brier Rd
Greenwood Ave N
N
Relative Importance of Stormwater Treatment Variable
0 0.5 1 2 3 4
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N


Municipality Boundaries
Shoreline Stormwater Composite Index
Low
Moderate
Moderate High
High
Shoreline
Seattle
Kenmore
Mountlake Terrace
Esperance
Woodway
Brier
Shoreline Stormwater Basin Composite Index
N
0 0.35 0.7 1.4 2.1 2.8
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N


Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Municipality Boundaries
Vashon Island Z-Score Rank
Low
Moderate
Moderate High
High
Vashon
Seattle
Burien
Puget Sound
Normandy Park
Des Moines
Federal Way
Olalla
N
Relative Importance of Stormwater Treatment Variable
0 1 2 4 6 8
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N


Seattle
Burien
Vashon
Puget Sound
Olalla
Municipality Boundaries
Vashon Island Stormwater Composite Index
Low
Moderate
Moderate High
High
N
Vashon Island Stormwater Basin Composite Index
0 0.5 1 2 3 4
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N


Roads
Impervious Surfaces
Coho Salmon
Asthma Hospitalization Rates
Bothell
Woodinville
Kingsgate
Cottage Lake
Gold Creek Park
Kirkland
Municipality Boundaries
Woodinville Z-Score Rank
Low
Moderate
Moderate High
High
Relative Importance of Stormwater Treatment Variable
N
0 0.375 0.75 1.5 2.25 3
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N



Municipality Boundaries
Woodinville Stormwater Composite Index
Low
Moderate
Moderate High
High
Woodinville
Bothell
Cottage Lake
Kingsgate
240th St SE
NE 160th St
NE 165th St
NE 153rd St
NE 140th St
NE 172nd Pl
NE 145th St
NE 146th Pl
Wellington Hills Golf Course
Gold Creek Park
East Norway Hill Park
South Norway Hill Park
Kamiakin Middle School
Northshore Athletic Fields
N
Woodinville Stormwater Basin Composite Index
0 0.175 0.35 0.7 1.05 1.4
Kilometers
Coordinate System: Lambert Conformal Conic
Central Meridian: 120°50'0"W
1st Std Parallel: 47°30'0"N
2nd Std Parallel: 48°44'0"N
Latitude of Origin: 47°0'0"N