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APPENDIX A

Stormwater Pollution

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ACRONYMS

AGR	Agriculture
BAR	Barren Land
BIBI	Benthic Index Biological Integrity
BMP	Best Management Practice
Cd	Cadmium
COV	Coefficient of Variation
CSO	Combined Sewer Overflow
Cu	Copper
CWA	Clean Water Act
DCIA	Directly Connected Impervious Area
DOT	Department of Transportation
Ecology	Washington Department of Ecology
EIA	Effective Impervious Area
EMW	Emergent Wetland
FOR	Forested
GSR	Grassland
HID	High/Medium-Intensity Development
LID	Low-Intensity Development
MS4	Municipal Separated Stormwater Sewer Systems
NPDES	National Pollutant Discharge Elimination System
NURP	National Urban Runoff Program
OSD	Open Space Developed
PAH	Polycyclic Aromatic Hydrocarbon
PSRC	Puget Sound Regional Council
SCB	Scrub/Shrub
UGA	Urban Growth Area
TIA	Total Impervious Area
WDW	Woody Wetland
WRIA	Water Resource Inventory Area
WSDOT	Washington Department of Transportation
WTR	Open Water
WWTP	Wastewater Treatment Plant
Zn	Zinc

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INTRODUCTION

Stormwater has been identified as a primary contributor to degradation of Puget Sound (Puget Sound Partnership, 2009; Stormwater Work Group for Puget Sound 2009). Untreated stormwater conveys large amounts of a variety of pollutants from a number of non-point land uses to the surface and marine waters of the Sound. Of these land uses, the local transportation network has often been identified as one of the major sources of stormwater pollutants (Johnson 2010). This perspective is supported by data from the National Stormwater Quality Database, where the median concentrations of pollutants in freewaystormwater are greater than the concentrations in stormwater from other types of land uses (Pitt et al. 2004; Pitt and Maestre 2005), and from the untreated stormwater concentrations measured for western Washington highways (Herrera, 2007; Barber et al. 2006).

Starting with the first comprehensive study of pollutants in stormwater—the National Urban Runoff Program (EPA 1983)—a detailed model of the sources and types of pollutants present in stormwater, the role of stormwater in conveying these pollutants to fresh and marine receiving waters, and the contribution of these pollutants to observed water quality impairment has emerged with broad scientific consensus. Specifically, numerous regional, national, and international investigations have established that:

1. Increases in impervious surfaces—roads, driveways, buildings, parking lots, sidewalks, and impacted soils—lead to increases in stormwater runoff peak flows and volumes, which in turn alter the physical characteristics of receiving waters.[1]
2. Stormwater runoff from these impervious surfaces contains a wide variety of pollutants—solids and sediments, nutrients, pathogens, organics, metals, and elevated temperature.
3. Runoff from different land uses—residential, commercial, industrial, freeways, and open space—vary in the types and amounts of pollutants present.
4. Pollutant concentrations vary significantly within and between individual discharge events, related in part to factors controlling deposition (types of land use and levels of pollutant generating activities) and wash off (the number of previous dry days, storm duration, storm intensity, and total seasonal rainfall).
5. Stormwater pollutants discharged to freshwater and marine environments contribute to decreased water quality and habitat degradation.

This appendix presents a summary of available scientific evidence documenting pollution in stormwater, along with areas of uncertainty and ongoing research efforts as they apply to the design and conduct of an effort to remediate legacy Puget Sound stormwater systems. It provides an overview of land development in the Puget Sound and associated impervious surfaces. The relationship between the transportation network, the stormwater infrastructure, and impervious surfaces is demonstrated, and the information is then used in the design and conduct of a Puget Sound stormwater retrofit program.

[1] The impacts of peak flows and volumes on receiving waters have been extensively dealt with in the existing literature and through current standards and are not further dealt with here.

STORMWATER POLLUTANTS

Stormwater has been recognized as a contributing source of pollutants to our nation's waters for several decades, particularly since the first major effort to quantify stormwater pollutant levels, the National Urban Runoff Program (NURP) in 1983 (EPA 1983a,b). The NURP research effort established the presence of metals, organic priority pollutants (e.g., plasticizers, pesticides, and polycyclic aromatic hydrocarbons [PAHs]), pathogens, nutrients, and Total Suspended Solids (EPA 1983a). Equally notable, the NURP project recognized the high levels of variability inherent in stormwater pollutant levels and the general inability to predict discharge concentrations based on either geography, land use, or individual storms (EPA 1983a,b).

In 1990, EPA extended the National Pollutant Discharge Elimination System (NPDES) permitting program to cover medium and large cities operating Municipal Separate Storm Sewer Systems (MS4) (termed Phase 1 by EPA http://cfpub.epa.gov/npdes/stormwater/munic.cfm), resulting in a wide expansion of the geographic locations and types of land uses monitored for stormwater. The first 10 years of data collected through this program have been analyzed through the National Stormwater Quality Database (NSQD, version 1.1) (Pitt et al. 2004, Pitt and Maestre 2005) and have further confirmed the high levels of variability of pollutant concentrations present in stormwater (Table 1), as witnessed by the high coefficients of variation[2] (COV) for representative pollutants measured in stormwater form different land uses. The data from different land uses show very little variation in acidity (pH) from the different land uses (with COVs much less than 1.0), while the data for total suspended solids (TSS), fecal coliforms, ammonia, phosphorus, copper and zinc have COVs ranging from just under 1.0 to over 5.0 (with COVs greater than 1.0 typically indicating a highly variable dataset) (Table 1).

> Nation-wide studies have established that inorganic, organic, and nutrient pollutants are consistently detected in stormwater, that stormwater concentrations are highly variable between storms, and that pollutant concentrations vary by land use.

Another important finding from the NSQD, version 1.1 study was the finding, in contrast with the NURP project, that stormwater concentrations from different land use categories for all pollutants were statistically different (Pitt et al. 2004). This distinction between the findings of the two studies likely resulted from the greater number of samples from different types of land monitored in the Phase 1 NPDES program (Pitt et al. 2004). Overall, this national study found that freeway locations generally had the highest median values for TSS, ammonia, total and filtered copper, and total zinc (Table 1). Areas characterized by a mixture of freeways and other land uses had the highest phosphorus concentrations, while mixed industrial land uses showed the highest concentrations for filtered zinc (Table 1).

[2] The coefficient of variation (COV) is the ratio of the standard deviation to the mean, and describes the scatter of the data set around the mean. It is useful for comparing the degree of variation from one data series to another, even when the means are considerably different.

Table 1. Example Stormwater Data Included in National Stormwater Quality Database (reproduced from Pitt et al. 2004; Pitt and Maestre 2005)

	pH		TSS (mg/L)		Fecal Coliform (mpn/100 mL)		NH_3 (mg/L)		Phosphorus, Total (mg/L)	
Land Use Category	**Median**	**COV**	**Median**	**COV**	**Median**	**COV**	**Median**	**COV**	**Median**	**COV**
Residential (1042)*	7.2	0.1	49	1.8	7000	5.2	0.31	1.1	0.31	1.1
Mixed Residential (611)	7.5	0.1	66	1.6	11210	3.2	0.39	1.6	0.28	1.7
Commercial (527)	7.4	0.1	43	2	4600	3	0.5	1.2	0.22	1.2
Mixed Commercial (324)	7.6	0.1	54.5	1.3	5400	3	0.6	1	0.26	1.5
Industrial (566)	7.5	0.1	81	1.6	2400	5.7	0.42	1.3	0.25	1.4
Mixed Industrial (218)	7.7	0.1	82	1.4	3033	2.5	0.58	0.8	0.2	1.6
Freeways (185)	7.1	0.1	99	2.6	1700	2	1.07	1.3	0.25	1.8
Mixed Freeways (26)	7.7	0.1	88	1.1	2600	2.3			0.34	0.7
Open Space (49)	7.7	0.08	48.5	1.5	7200	1.1	0.18	1.24	0.31	3.5
Mixed Open Space (168)	7.9	0.1	78	1.6	3000	2.3	0.51	1.2	0.25	1.1

	Copper, Total (µg/L)		Copper, Filtered (µg/L)		Zinc, Total (µg/L)		Zinc, Filtered (µg/L)	
Land Use Category	**Median**	**COV**	**Median**	**COV**	**Median**	**COV**	**Median**	**COV**
Residential (1042)	12	1.8	7	2	73	1.3	31.5	0.8
Mixed Residential (611)	16	1.2	5.5	0.9	95	0.9	48	0.9
Commercial (527)	17	1.5	7.57	0.8	150	1.2	59	1.4
Mixed Commercial (324)	17.5	3	10	0.6	131.4	1.7	73	0.8
Industrial (566)	20.8	2	8	0.7	199	1.5	112	3.6
Mixed Industrial (218)	23	0.8	6	0.6	172	3.1	2100	1.2
Freeways (185)	34.7	1	10.9	1.5	200	1	51	1.9
Mixed Freeways (26)	14	1			130	0.9		
Open Space (49)	10	2			40	1.3		
Mixed Open Space (168)	9	1			80	1.1		

* The number in parentheses following each land use category represents the number of samples for each land use in the National Stormwater Quality Database

TSS = Total Suspended Solids COV = Coefficient of Variation mpn/100 mL = most probable number per 100 mL mg/L = milligrams per liter µg/L = micrograms per liter

HIGHWAY RUNOFF POLLUTANT LEVELS

A detailed picture of stormwater runoff from concentrations has been compiled for western Washington highways from 11 different studies monitoring 35 different locations within the region (Herrera Environmental Consultants 2007). The highway sampling locations were primarily located in the Seattle area (Herrera Environmental Consultants 2007). This summary study reports concentrations for suspended solids, a wide range of different metals and nutrients, various petroleum compounds, miscellaneous organics, bacteria, levels of chemical and biological oxygen demand, and a number of conventional parameters (such as pH, hardness, and conductivity) (Table 2).

Table 2. Summary Statistics for Highway Runoff in Western Washington (Reproduced from Herrera, 2007)

	Units	Mean	Median	STDEV	COV
Solids					
Total Suspended Solids	(mg/L)	118.9	93	82.5	0.69
Volatile Suspended Solids	(mg/L)	196.2	81	197.8	1.01
Metals					
Antimony, total	(µg/l)	4.93	4.93	5.33	1.08
Arsenic, total	(µg/l)	2.39	2.39	0.26	0.11
Barium, total	(µg/l)	82.4	82.4	2.26	0.03
Cadmium, total	(µg/l)	1.63	1.2	1.02	0.63
Chromium, total	(µg/l)	12.7	12.7	7.35	0.58
Cobalt, total	(µg/l)	3.15	3.15	1.76	0.56
Copper, total	(µg/l)	28	24.4	16.3	0.58
Copper, dissolved	(µg/l)	6.68	5.19	3.86	0.58
Lead, total	(µg/l)	296	120	345	1.17
Lead, dissolved	(µg/l)	2.1	2.1	1.56	0.74
Lead, total	(µg/l)	37.4	27.3	20.4	0.55
Lead, dissolved	(µg/l)	3.2	3.2	–	
Mercury, total	(µg/l)	0.02	0.02	–	
Molybdenum, total	(µg/l)	5.5	5.5	5.66	1.03
Nickel, total	(µg/l)	10.75	10.75	3	0.28
Vanadium, total	(µg/l)	10.54	10.54	6	0.57
Zinc, total	(µg/l)	162	116	111	0.69
Zinc, dissolved	(µg/l)	48.24	39.04	34.33	0.71
Nutrients					
Ammonia nitrogen	(mg/L)	1.84	1.84	1.16	0.63
Nitrate+nitrite nitrogen	(mg/L)	1.53	1.54	0.89	0.58
Total nitrogen	(mg/L)	9.66	6.5	10.8	1.12
Total Kjeldahl nitrogen	(mg/L)	1.17	0.77	1.12	0.96
Orthophosphate phosphorus	(mg/L)	0.13	0.1	0.14	1.08
Total phosphorus	(mg/L)	0.22	0.19	0.15	0.68
Organic Compounds – Petroleum Products					
Oil and grease, total	(mg/L)	71.5	43.5	78.5	1.10
Total petroleum hydrocarbon oil	(mg/L)	2.46	1.97	2.14	0.87
Total petroleum hydrocarbon diesel	(mg/L)	0.69	0.09	0.98	1.42

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Table 2. Summary Statistics for Highway Runoff in Western Washington (Reproduced from Herrera, 2007) (continued)

	Units	Mean	Median	STDEV	COV
Organic Compounds – Miscellaneous					
2,4-Dimethylphenol	(µg/l)	0.39	0.39	0.21	0.54
Bis(2-Ethylhexyl)phthalate	(µg/l)	4.68	4.68	–	–
Benzyl alcohol	(µg/l)	0.86	0.86	0.38	0.44
2-Methylphenol	(µg/l)	0.81	0.81	0.31	0.38
4-Methylphenol	(µg/l)	2.04	2.04	–	–
Benzoic acid	(µg/l)	5.06	5.06	4.56	0.90
Benzyl butyl phthalate	(µg/l)	0.63	0.63	0.13	0.21
Di-n-butyl phthalate	(µg/l)	2.25	2.25	2.35	1.04
Di-n-octyl phthalate	(µg/l)	1.34	1.34	0.8	0.60
N-nitrosodiphenylamine	(µg/l)	0.62	0.62	–	–
Phenol	(µg/l)	3.02	3.02	–	–
2,4-Dinitrophenol	(µg/l)	0.69	0.69	–	–
4,6-Dinitro-o-cresol	(µg/l)	0.35	0.35	–	–
3-Methylphenol	(µg/l)	0.39	0.39	–	–
4-Nitrophenol	(µg/l)	2.03	2.03	–	–
Organic Compounds – Polycyclic Aromatic Hydrocarbons (PAHs)					
Indeno(1,2,3-cd)pyrene	(µg/l)	0.34	0.15	0.36	1.06
Dibenzo(a,h)anthracene	(µg/l)	0.1	0.1	–	–
Oxygen Demand					
BOD5	(mg/L)	40.3	40.3	43.5	1.08
COD	(mg/L)	259.4	106	399.1	1.54
Bacteria					
Fecal Coliform Bacteria	(CFU/100mL)	1763	892	2849	1.62
Total Coliform Bacteria	(CFU/100mL)	9350	9350	–	–
Total E. Coli	(CFU/100mL)	784	551	796	1.02
Conventionals					
Alkalinity	(mg/L as CaCO3)	21.4	21.4	2.9	0.14
Hardness	(mg/L as CaCO3)	35.7	28.9	20.7	0.58
Total organic carbon	(mg/L)	32.8	21	45	1.37
Turbidity	(NTU)	62.5	84.4	40	0.64
pH		6.4	6.6	0.5	0.08
Specific Conductivity	(µS/cm)	71.6	71.6	–	–

µg/L = micrograms per liter
µS/cm = microsiemens per centimeter
BOD5 = 5 day Biological Oxygen Demand
CaCO3 = Calcium carbonate
CFU/100mL = Colony forming units per 100 mL
COD = Chemical Oxygen Demand
COV = Coefficient of Variation
mg/L = milligrams per liter
NTU = nephelometric turbidity units
STDEV = Standard Deviation

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A central finding of this study was that numerous stormwater pollutants types (metals, organics, nutrients, and bacteria) were found associated with (or bound to) suspended solids (Herrera, 2007). As such, many of the factors that correlate with increased suspended solids levels (such as intense storms that erode soils) also show an association with these pollutant types. This study found that highway runoff concentrations were not correlated with traffic levels (as measured by Average Daily Traffic or ADT[3]) as has also been reported for both national and regional studies, but instead showed a greater association with local rainfall patterns (e.g., stormwater intensity, storm volume, and the length of the antecedent dry period) and the number vehicles driven during a storm (Herrera 2007). Another additional factor associated with levels of suspended solids, metals, and nutrients was the type of land use associated with the monitored highways (Herrera 2007).

Pollutant levels in western Washington highway runoff were associated with local rainfall patterns, vehicles driven during storms, and associated land uses.

Overall, monitoring data showed that copper and zinc were very common in highway runoff at levels generally lower than those reported from national studies (Herrera 2007). In contrast, fecal coliform bacteria concentrations for western Washington were found to be higher than those from the national data. Little information was available in the monitoring data reviewed for the concentrations of organics (herbicides, pesticides, and PCBs) in highway runoff from western Washington, so no clear patterns were discerned for these types of chemicals. The five most common types of PAHs found in western Washington highway runoff were pyrene, fluoranthene, phenanthrene, chrysene, and benzo(a)anthracene. Lastly, the level of variability in concentrations (with few COVs greater than 1 and none greater than 1.6, Table 2) were generally lower than those observed in the Table 1 (were COVs were often greater than 2.0).

PREDICTING POLLUTANT CONCENTRATIONS

A consistent goal of stormwater research has been to understand and be able to predict the types and concentrations of pollutants discharged from different land uses. For roads and highways, much of this effort has focused on predicting metals concentrations in highway runoff based on measures of vehicle traffic such as ADT, under the principle that the greater the amount of pollutant-generating activity (cars), the greater the amount of pollutants that should be detectable in stormwater. However, a recent review of the available literature by Barber et al. (2006) found that "… *it can be concluded that AADT[4] is insufficient as a single predictor of both total and dissolved metal concentrations in highway runoff.*" Additional factors that have also been found (Barber et al. 2006) to affect highway runoff metals concentrations include:

- Traffic Volume Factors. ADT, traffic volume during storm, traffic volume during antecedent dry period, and traffic volume preceding storm.
- Precipitation Factors, Antecedent dry period, total duration of storm, total duration of preceding storm, total event rainfall, seasonal cumulative precipitation, and rainfall intensity.

[3] ADT is the average number of vehicles passing a specific point in both directions (two-way traffic) in a 24-hour period during a specific time of the year or season.

[4] AADT is the Annual Average Daily Traffic, is a representation of the average daily two-way traffic at a single spot over the entire year, averaging out seasonal differences in traffic level.

- Hydrologic Factors. Volume of flow per unit area of watershed and volume of flow per unit area of watershed during preceding storm.
- Environmental Factors. Age of pavement, surrounding land use, surrounding vegetation, watershed area, surrounding soil type, and soil infiltration rate.

Many factors affect the concentrations of metals in highway runoff (both loading and wash off). Currently there is no predictive equation available for highway runoff metals concentrations in Washington state.

Many of these factors show significant levels of interrelatedness which further confounds any effort to use a single predictive factor. Barber et al. (2006) concluded, based on their literature review and work with Ecology, WSDOT and other stakeholders, that there currently are insufficient data to develop a predictive equation for highway runoff metals concentrations that would be applicable to Washington state.

TRANSPORTATION STORMWATER

These studies establish some important attributes to consider and use in the development of a Transportation Stormwater Retrofit program.

1. Based on extensive national and regional studies, it is well established that untreated stormwater is contaminated with a number of inorganic and organic pollutants and that concentrations of these materials vary considerably geographically and between individual storms at a single location.
2. Pollutant types and amounts vary by land use.
3. Highway runoff frequently contains the highest concentrations of a number of pollutant types compared to other land uses.
4. Highway runoff concentrations are influenced by adjacent land uses.
5. Addressing the transportation system as a land use category with associated land use types (particularly commercial and industrial) is a more useful approach for characterizing untreated stormwater pollutant types and amounts than factors such as traffic levels.

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GROWTH OF IMPERVIOUS SURFACES

Stormwater runoff increases with the conversion of naturally existing pervious surfaces (such as forests and grasslands) to developed impervious surfaces (represented by roads, parking lots, buildings, driveways, and sidewalks). As noted above, the increases in the types of impervious surfaces (land uses) affects the types and amounts of pollutant discharged from these overall increases in impervious surfaces. For example, Bhaduri et al. (2000) found that an 18 percent conversion of agricultural lands to urban impervious surfaces in the Indianapolis, Indiana area. resulted in an estimated 76.5%, 56.2%, and 67.8% increases in lead, copper, and zinc loads from the watershed, respectively. The increase in copper pollution from industrial areas was the result of significantly higher copper pollution from industrial land uses compared to high-density residential areas.

In the Puget Sound lowland area, the amount of impervious surfaces in the four-county area has increased over the last 10 years, with the conversion of a mixture of 53 mile^2 of grassland, agriculture, forest, scrub/shrub, woody and emergent wetland, barren land, and open water to a combination of 53 mile^2 high-, medium-, and low-intensity development and developed open space (NOAA Coastal Services Center 2011). Alberti et al. (2010) found a similar pattern of development for this area between 1991 and 1999, which they characterized as typified by the loss of forested land and the intensification (infilling) of urban areas. The net changes in land use types in each of the four counties between 1996 and 2006 as well as the total area are presented in Table 3. Overall, each category of development—high-, medium-, and low-intensity and open space—increased in the amount of square miles in each county during this period. Land uses consisting primarily of pervious surfaces—grassland, forest, agriculture, woody and emergent wetlands, and barren lands—all showed a new decrease in coverage between 1996 and 2006 (Table 3). The exception to the pattern was the increase in scrub/shrub, primarily in Pierce County (Table 3).

Table 3. Net Changes in Land Use Types in Pierce, King, Snohomish, and Kitsap Counties Between 1996 and 2006 (values are in square miles). Data reproduced from the NOAA Coastal Services Center - http://www.csc.noaa.gov/digitalcoast/data/ccapregional/

Net Change, 1996-2006	Pierce County	King County	Snohomish County	Kitsap County	4 County Totals
High-/Medium-Intensity Development	10.05	9.08	7.47	1.26	27.86
Low-Intensity Development	5.74	6.42	4.46	1.90	18.52
Open Space Developed	1.75	2.63	1.17	1.07	6.62
Grassland	-4.80	-8.27	-5.31	-0.38	-18.76
Agriculture	-0.14	-1.25	0.89	0.05	-0.45
Forested	-52.51	-10.95	-7.06	-6.70	-77.22
Scrub/Shrub	43.91	6.05	6.19	3.23	59.38
Woody Wetland	-0.62	-0.37	-0.48	-0.03	-1.50
Emergent Wetland	0.00	-0.19	0.07	-0.01	-0.13
Barren Land	-3.36	-3.17	-7.25	-0.43	-14.21
Open Water	-0.02	0.00	-0.15	0.03	-0.14

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The specific gains and losses of each land use category can be seen in Figure 1, with the net gain or loss represented for each category marked by the addition of a (+) or (-). The pattern of intensification (infilling) noted by Alberti et al. (2010) can be seen by the almost uniform increase in High-/Medium-Intensity Development for each county, while there is a pattern of both gain and loss for Low-Intensity Development and Open Space Developed (Figure 1). Similarly, the patterns of landscape fragmentation noted by Alberti et al. (2010) between 1991 and 1999 can be seen in Figure 1 for Grasslands, Agriculture, Forests, Scrub/Shrub, and Barren Land to have continued between 1996 and 2006. This is particularly true for forested lands in Pierce, King, and Snohomish counties with both large losses and gains for this land use (Figure 1).

It is important to note that while development since 1992 has occurred under an increasingly rigorous set of stormwater management guidelines and requirements, the pattern of land use intensification and infilling (Figure 1, Alberti et al. 2010) means that stormwater from these newly developed land uses is contributing to and comingling with stormwater from pre-1992 developed areas. This pattern of change can be readily seen in a series of figures comparing levels of impervious surface for the main urban areas of the four-county region, with the Marysville to mid-Seattle area seen in Figures 2a (1986 impervious surfaces) and 2b (2006 impervious surfaces) and mid-Seattle to Tacoma in Figures 3a (1986 impervious surfaces) and 3b (2006 impervious surfaces). This pattern of infilling is particularly notable in areas of south of Everett and north of Seattle along the I-5, I-405, SR 527, and SR 522 corridors (Figures 2a and 2b) and throughout the I-5 and SR 167 corridors in Figures 3a and 3b.

The four-county area saw a considerable increase in impervious surface development between 1986 and 2006. The pattern of infilling and intensification means that stormwater from newly developed impervious surface is contributing to and comingling with stormwater from pre-1992 developed areas.

This pattern of intensifying land use development is even more apparent when examined in the Snoqualmie Valley area of east King County for the period of 1996 to 2006 (Figures 4a and 4b). Significant increases in impervious surfaces occur in this 10-year time period in the Issaquah-Sammamish area (Figure 4a), as well as the area to the north of SR 202. This pattern of growth primarily associated with existing centers of impervious surfaces can also be seen along SR 203 north-south corridor (Figure 4b).

Accounting for the patterns of land use conversion and the continually increasing levels of impervious surfaces and associated land uses will be important in the development and conduct of any stormwater remediation program.

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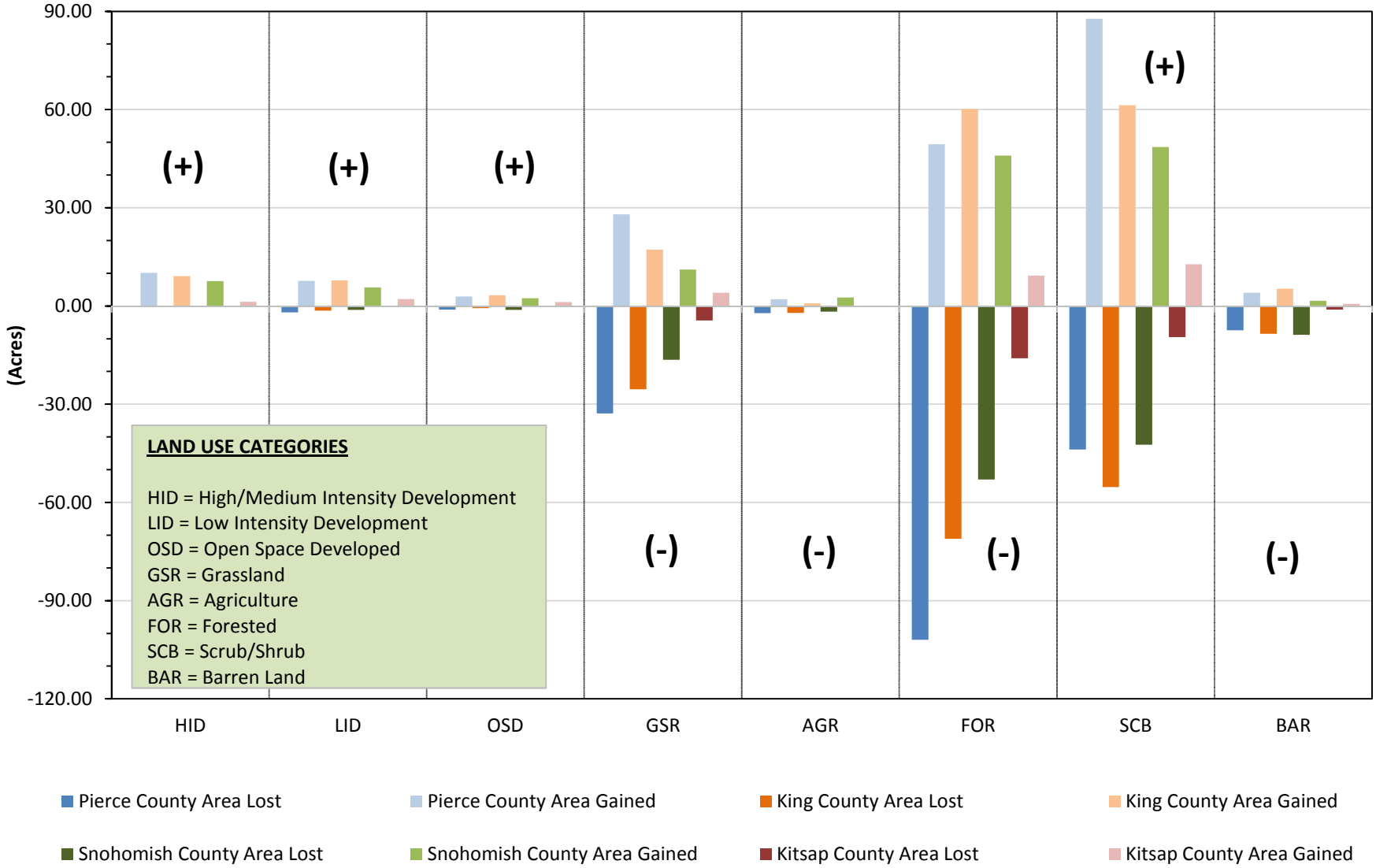
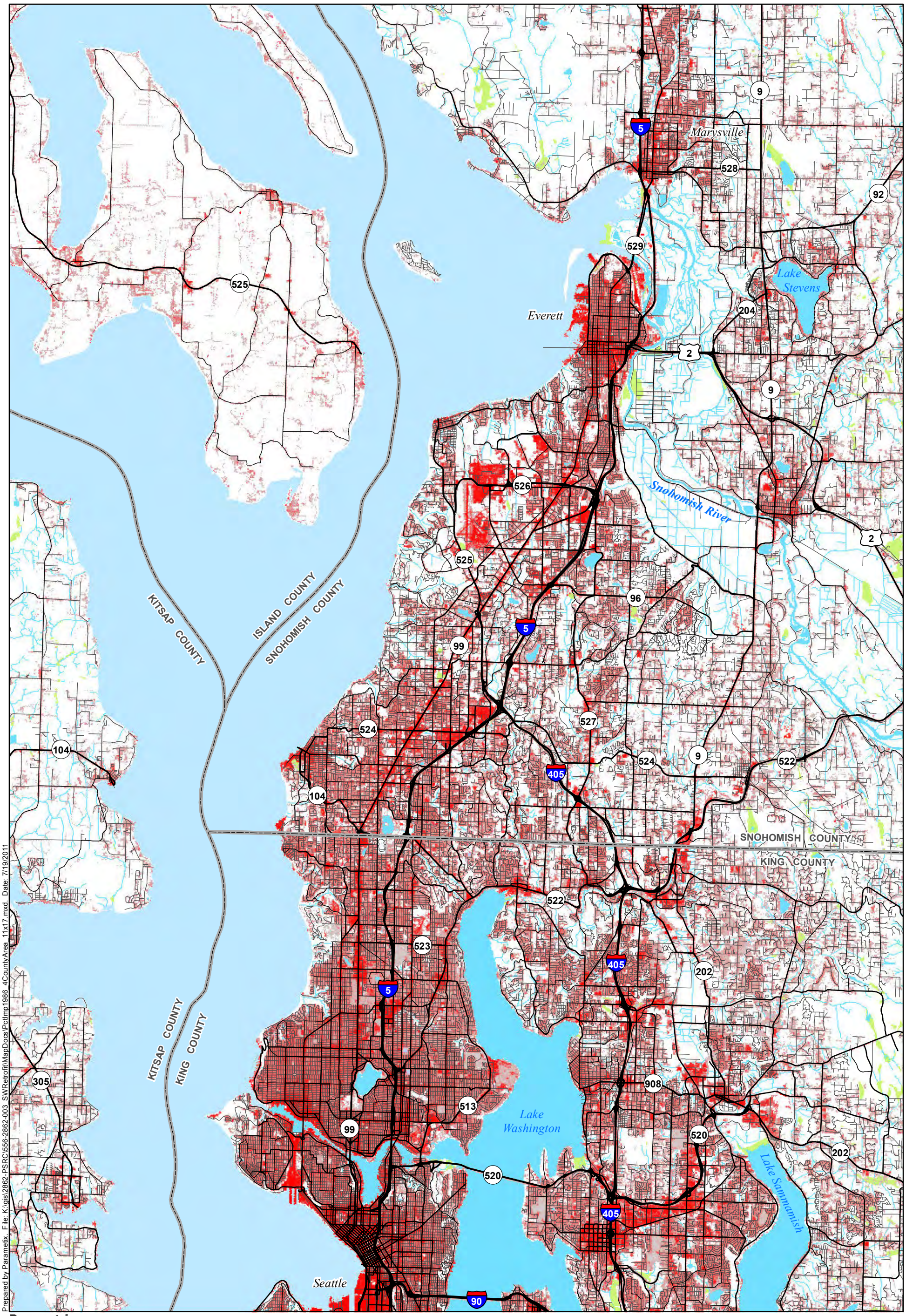


Figure 1. Loses and Gains in Land Use Acreage for the Four County Area between 1996 and 2006
(Data from the NOAA Coastal Services Center Land Cover Atlas - http://www.csc.noaa.gov/landcover/atlas/)



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Parametrix

N

0 0.5 1 1.5 2

Scale in Miles

Data Sources:
Washington Department of Ecology
Washington Department of Natural Resources
Washington Department of Transportation
Puget Sound Regional Council

Percent Impervious

0	30	70
1	40	80
10	50	90
20	60	100

Figure 2a.
1986 Impervious Surfaces in Puget Sound with Current Road Network (North Half)

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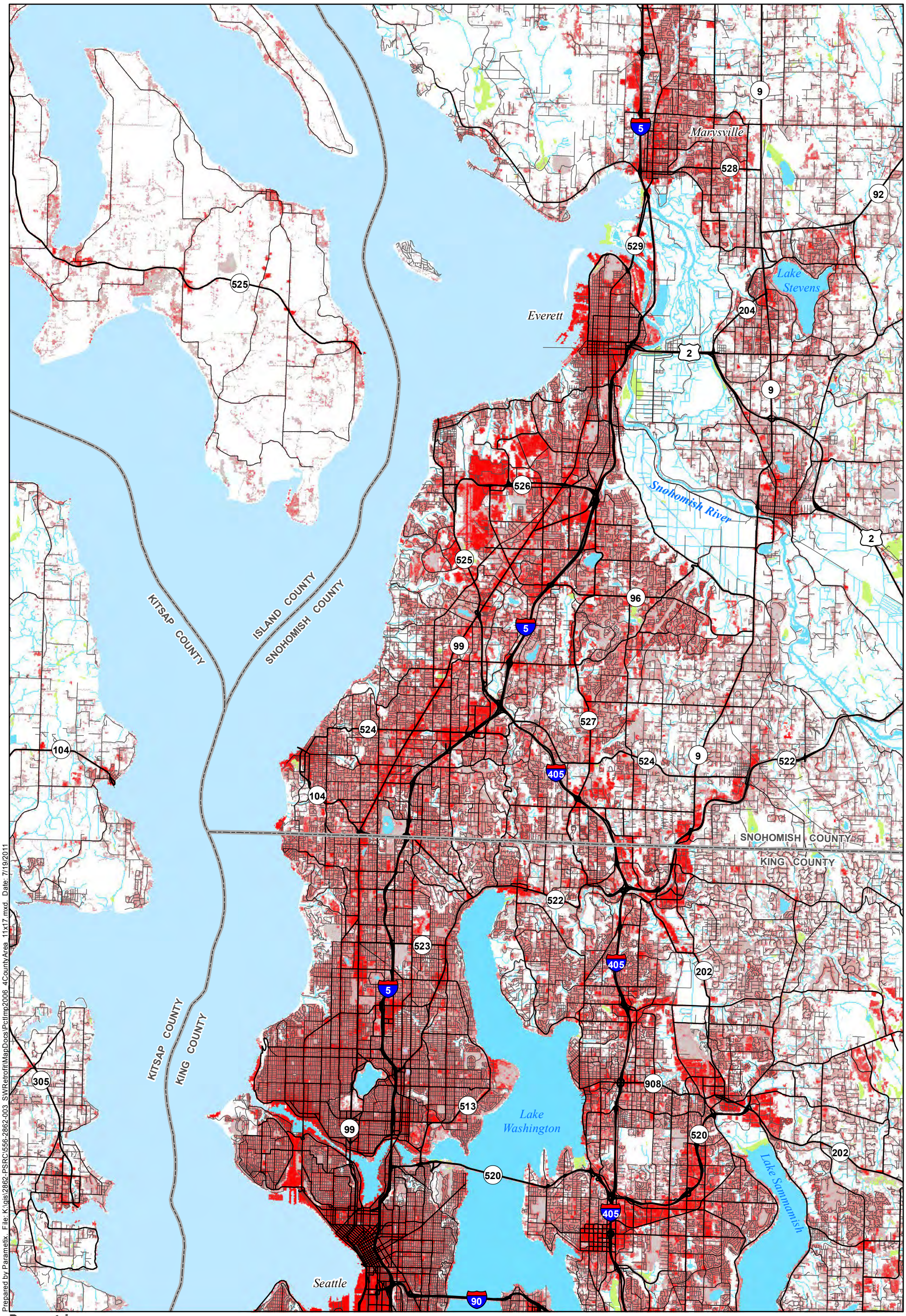

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Parametrix

N

0 0.5 1 1.5 2

Scale in Miles

Data Sources:
Washington Department of Ecology
Washington Department of Natural Resources
Washington Department of Transportation
Puget Sound Regional Council

Percent Impervious

0	30	70
1	40	80
10	50	90
20	60	100

Figure 2b.
2006 Impervious Surfaces in Puget Sound with Current Road Network (North Half)

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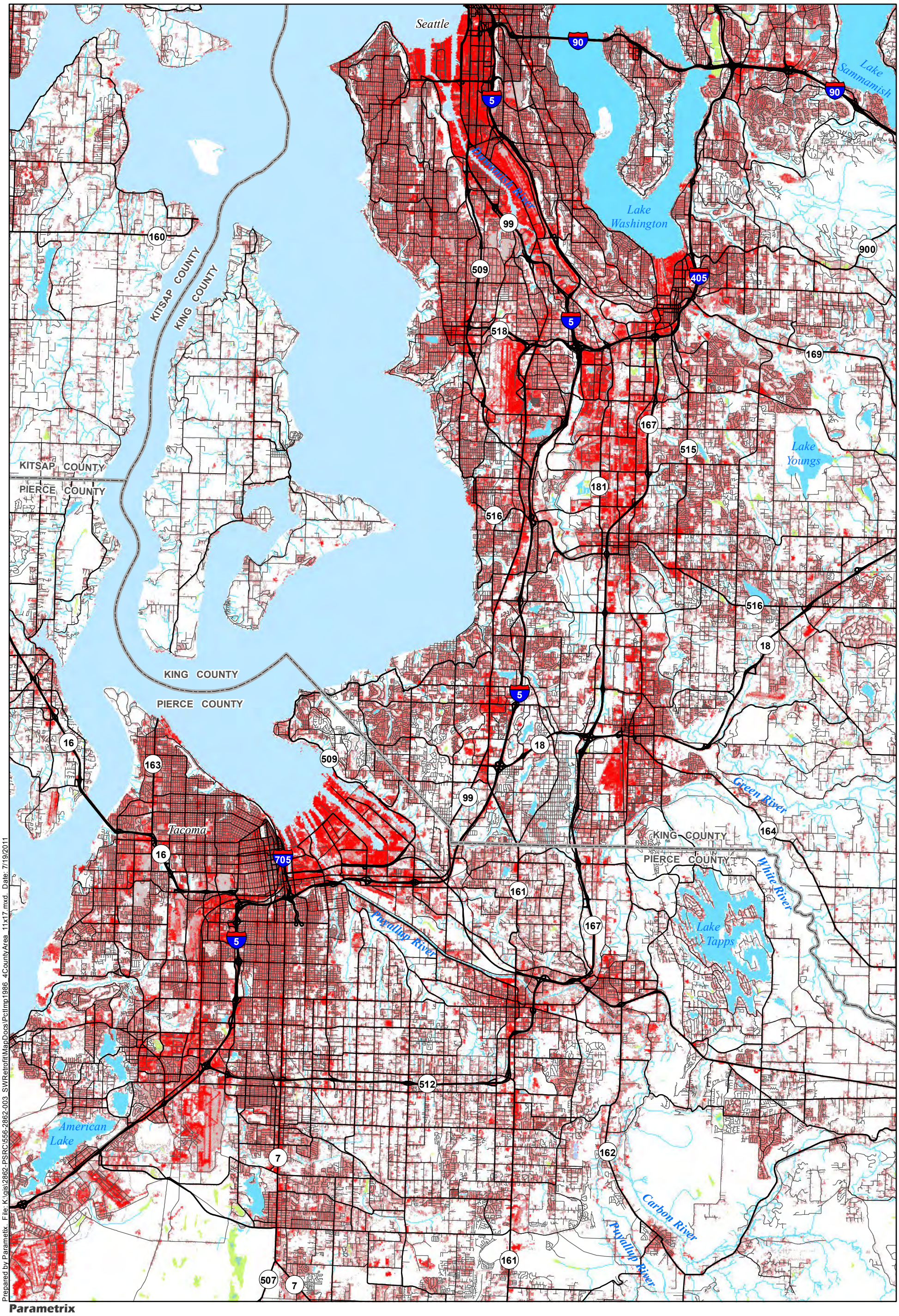

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Parametrix

N

0 0.5 1 1.5 2

Scale in Miles

Data Sources:
Washington Department of Ecology
Washington Department of Natural Resources
Washington Department of Transportation
Puget Sound Regional Council

Percent Impervious

0	30	70
1	40	80
10	50	90
20	60	100

Figure 3a.
1986 Impervious Surfaces in Puget Sound with Current Road Network (South Half)

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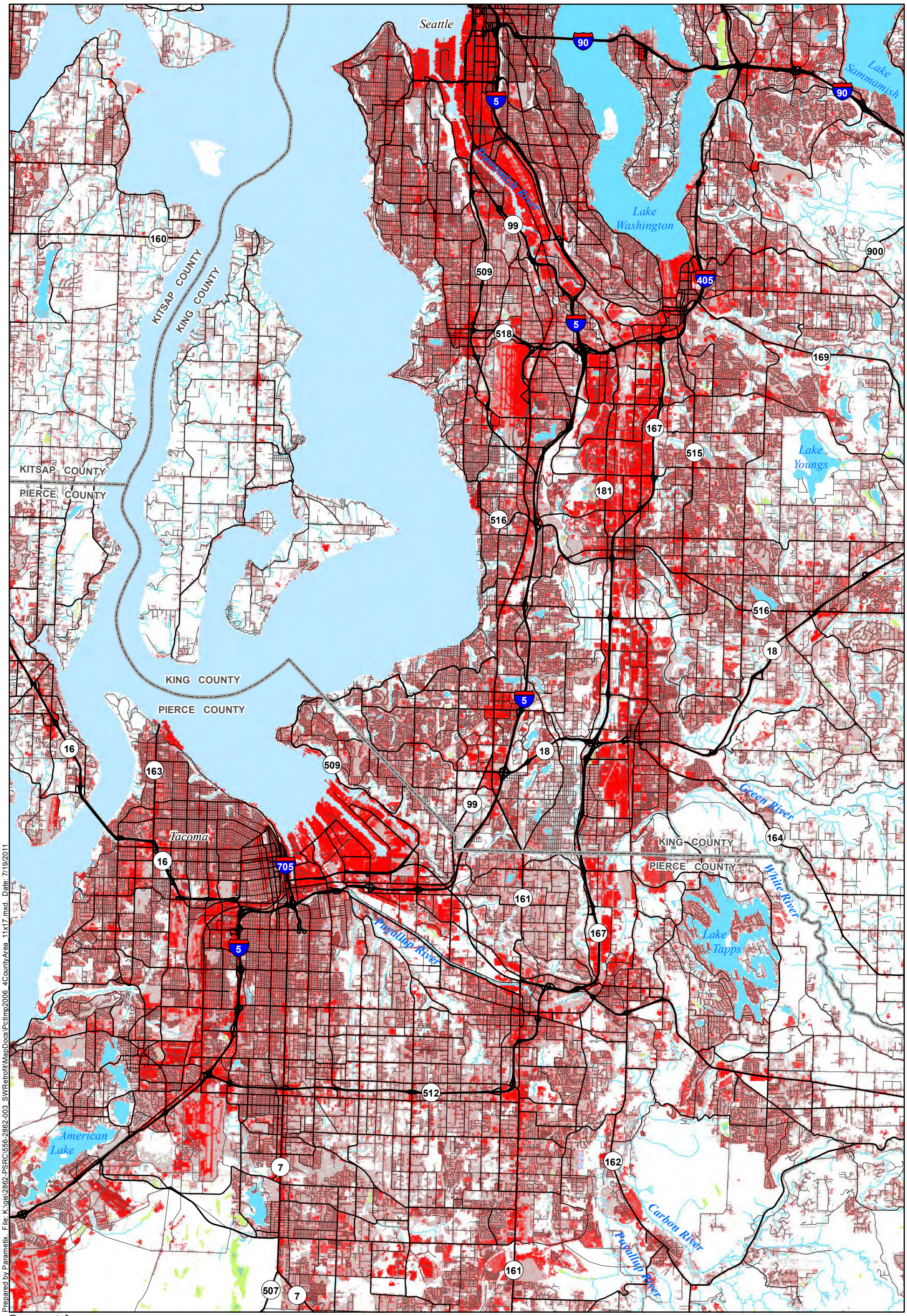

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Parametrix

N

0 0.5 1 1.5 2

Scale in Miles

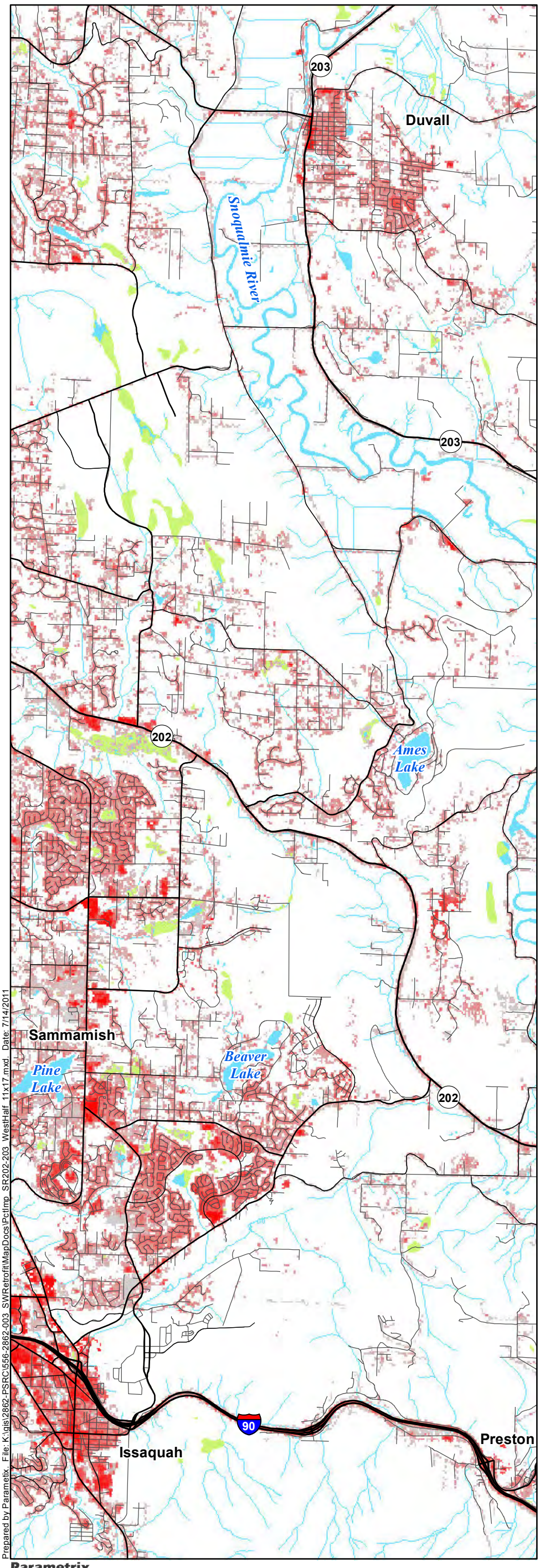
Data Sources:
Washington Department of Ecology
Washington Department of Natural Resources
Washington Department of Transportation
Puget Sound Regional Council

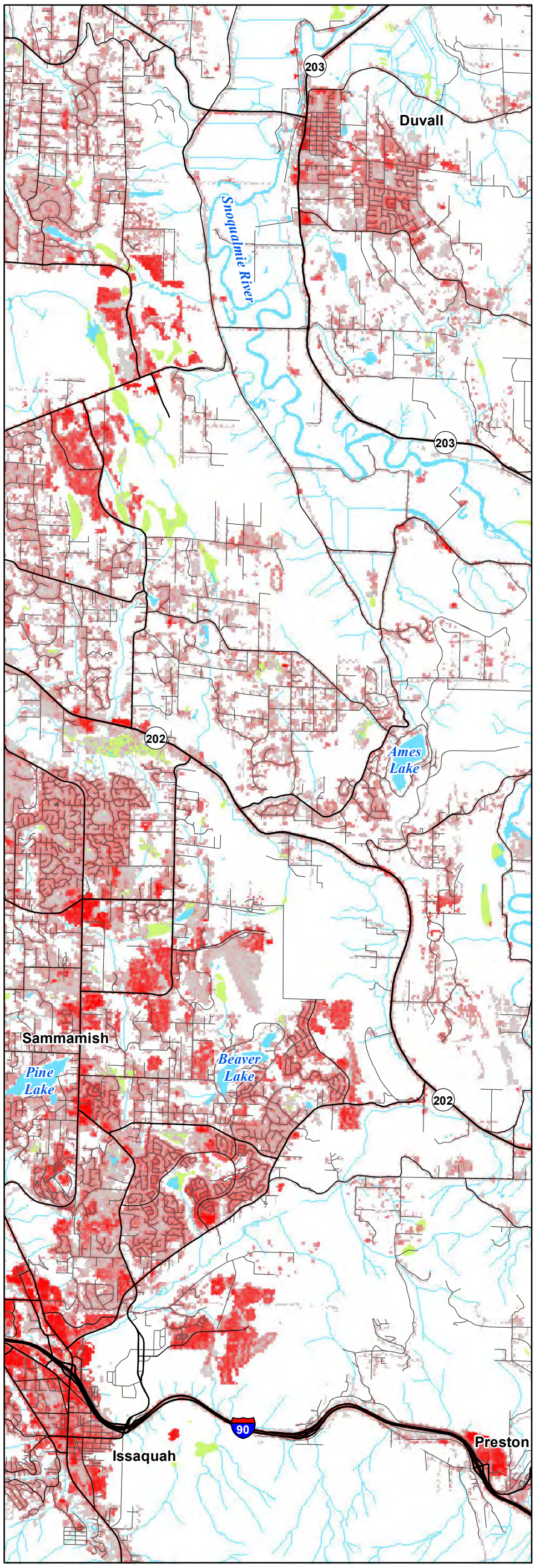
Percent Impervious

0	30	70
1	40	80
10	50	90
20	60	100

Figure 3b.
2006 Impervious Surfaces in Puget Sound with Current Road Network (South Half)

DRAFT





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Parametrix

1996 2006

Percent Impervious

0	30	70
1	40	80
10	50	90
20	60	100

N

0 0.5 1

Scale in Miles

Data Sources:
Washington Department of Ecology
Washington Department of Natural Resources
Washington Department of Transportation
Puget Sound Regional Council

Note: 1996 Impevious Surface data layer does not include areas less than 20% impervious. 1986 data shown for these areas.

Figure 4a.
State Route 202/203 Corridor:
1996 and 2006 Impervious Surfaces and Current Road Network (West Half)

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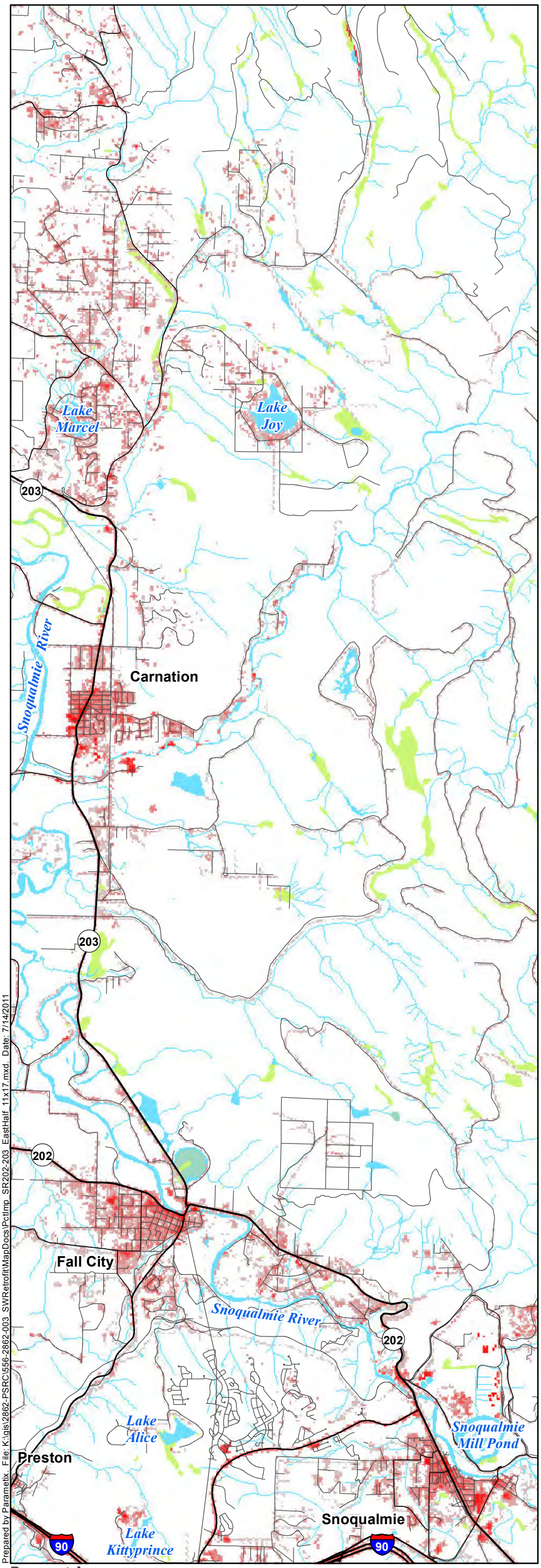

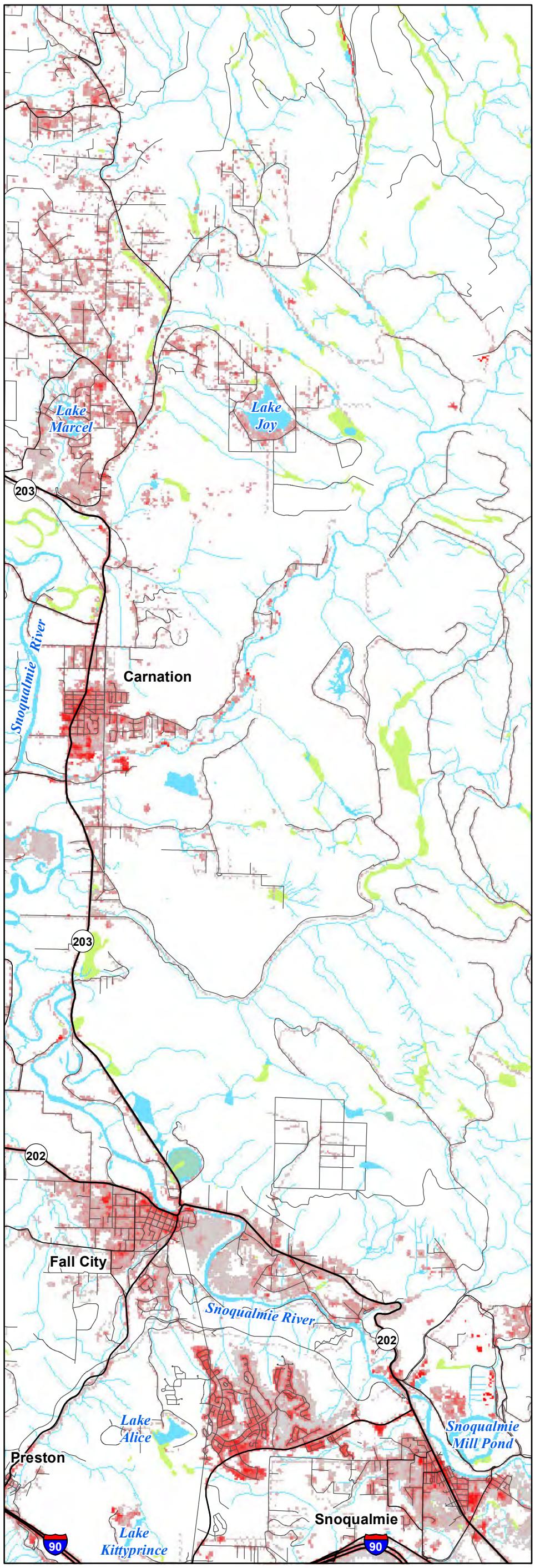

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Parametrix

1996 2006

Percent Impervious

0	30	70
1	40	80
10	50	90
20	60	100

N

0 0.5 1

Scale in Miles

Data Sources:
Washington Department of Ecology
Washington Department of Natural Resources
Washington Department of Transportation
Puget Sound Regional Council

Note: 1996 Impevious Surface data layer does not include areas less than 20% impervious. 1986 data shown for these areas.

Figure 4b.
State Route 202/203 Corridor:
1996 and 2006 Impervious Surfaces and Current Road Network (East Half)

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LAND USE CHANGE AND STORMWATER

The observed increases in impervious surfaces that have occurred over the last 20-25 years are important because they have resulted in (1) increases in stormwater peak flows and runoff volume, (2) increased concentrations and loads of stormwater pollutants with the increase in specific land use types, and (3) further levels of degradation in Puget Sound aquatic habitats and biological communities (Herrera 2011, Booth and Jackson 1997, Alberti et al. 2003, Alberti and Marzluff 2004).

The recently completed Phase 3 of Ecology's study of toxic chemical loading to the Puget Sound (Herrera 2011) has further confirmed the role of stormwater in contributing pollutants to the freshwater and marine waters of the Puget Sound. This study found that concentrations increased for almost all measured pollutants during storms relative to base flows for each of the land-use types considered (Herrera 2011), particularly for commercial/industrial and residential subbasins. More importantly, stormwater runoff for concentrations of several pollutants discharged from monitored land uses exceeded relevant water quality criteria or human health criteria (including dissolved copper, lead, and zinc; total mercury; bis(2-ethylhexyl) phthalate; and carcinogenic PAHs) (Herrera 2011). This was particularly true for commercial and industrial land uses, which discharged an order of magnitude higher concentration of certain organic chemicals than other land-use types (Herrera 2011). They also found that commercial/industrial, agricultural, and residential (in that order) land uses have substantially elevated levels of metals concentrations relative to undeveloped land uses. The findings of this report support the conclusion that changes in land use from undeveloped and less developed land uses to commercial, industrial, and residential translates into higher concentrations of stormwater pollutants discharged to local streams and lakes as well as nearshore marine areas of Puget Sound adjacent to these urban land uses.

- Increased levels of commercial, industrial, and residential land uses translate to higher concentrations of stormwater pollutants discharged to the environment.
- Increased levels of urbanization lead to decreased quality and function of downstream aquatic habitats.
- The patterns of urbanization and aggregations of different land use types are equally important in determining the decrease of watershed function and quality.

Studies of urbanization of this last 20 years have also developed a picture of watershed degradation resulting from these continuing increases of urbanization in the four county area. Booth and Jackson (1997) observed that urbanized watersheds resulted in reduced form and function in downstream aquatic systems, such reflected in changes in biotic integrity of stream invertebrates measured as B-IBI. Alberti and Marzluff (2004) observed that urbanization in the Puget Sound lowlands is characterized by an intermixing of high- and low-density built-up areas (as seen above for the patterns of development of impervious surfaces Figures 2a through 4b). They detected significant statistical relationships between certain landscape patterns and land use mixes with stream condition. Alberti and Marzluff (2004) go on to suggest that patterns of urban development affect watershed functions just as much as the conversion of the natural landscape to urban land uses. Finally, they found that both the increase in percentage impervious surface and its patterns of aggregation directly impacted stream macroinvertebrate populations (Alberti and Marzluff 2004). These patterns of aggregation involve land-use intensity and land-cover types, using measures such as "population" and "road" (Alberti et al. 2003). This body of work supports the interpretation that increase levels of urbanization translates into decreased quality and function of downstream aquatic habitats and that the patterns of urbanization and aggregations of different land use types are equally important in establishing the relationship between urbanization and watershed function and quality.

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LAND USES AND THE TRANSPORTATION NETWORK FORM A CONNECTED DISCHARGE

The final detail in assessing the utility of a transportation system-focused stormwater remediation effort is the concept of Effective Impervious Area (EIA), also termed Directly Connected Impervious Area (DCIA). Sutherland (1995) defined EIA as those impervious surfaces hydrologically connected to the curb or storm sewer systems that are exemplified as street surfaces, pave driveways, sidewalks, rooftops, and parking lots[5]. Recent studies have advanced the proposition that EIA is a better predictor of ecosystem condition than the total impervious area (TIA) of a watershed (Roy and Shuster 2009 and the references therein). DCIA was found to contribute a disproportionate amount of total stormwater runoff (Lee and Heaney 2002, 2003). Lee and Heaney (2002, 2003) determined that, while DCIA was only 44 percent of a catchment in the Miami, Florida area, it contributed up to 72 percent of the runoff over a 52-year period. This is particularly true due to runoff generated from the DCIA portion of this catchment from small volume storms which do not generate runoff from the non-DCIA portions of the same catchment (Lee and Heaney 2002, 2003).

Effective Impervious Area (EIA) is a better predictor of ecosystem condition than Total Impervious Area. Storm sewer systems associated with roads (both open and closed) represent the contribution of both roads and adjacent land uses (i.e., EIA) and provide a venue for addressing both sources in a stormwater retrofit and remediation program.

The relationship between development, roads, and the stormwater sewer system is demonstrated in the Meydenbauer Creek Basin of the City of Bellevue (Figures 5 and 6). This basin is typical of the highly urbanized areas distributed throughout the Puget Sound, with a high level of total impervious surface (59 percent), a broad spectrum of land uses (roads, commercial, and single and multi-family residential [although very little land use is industrial]), with almost 99 percent of surface flow channeled into the storm drain system versus open channel (142,906 feet versus 1,773 feet) (Figure 5). This basin discharges to Lake Washington, where Chinook salmon, coho salmon, sockeye, cutthroat trout, and rainbow trout are present (Figure 5).

While direct measurements of DCIA are not available for this basin, the relationship between impervious surfaces, roads, and the storm sewer system can readily be seen in Figure 6. The colocation of the city's infrastructure roads and storm sewers is very common for Puget Sound urban areas, as is the connection of adjacent land uses to the storm sewers underlying city streets. The separate road, storm sewer system, and impervious surfaces are combined in the final panel on the right of Figure 6, establishing the connections between these features. This graphical assessment of contributing sources to the stormwater discharged from Meydenbauer Creek Basin demonstrates that volume of stormwater and levels of pollutants flowing through the storm sewers adjacent to city roads is the combination of runoff and pollutants from adjacent land uses and runoff and pollutants of the road surfaces themselves. Establishing stormwater remediation approaches around the road-associated storm sewer system in these urban areas will treat flow not only from the roads, but also from associated land uses. The common co-location of ditches and other open stormwater conveyance systems along highways in less developed areas of Puget Sound would result in the same co-mingling of stormwater from roads and adjacent land uses and provide the same opportunities for treating both.

[5] EIA is only infrequently determined due to the difficulties and expensive of measuring this feature of urban watersheds (Sutherland 1995).

Meydenbauer Creek Basin

Lake Washington Watershed (WRIA 8)
State Stream #08-0258

LAND CHARACTERISTICS

Basin Area: 927 Total Acres (4% of the City)
Drainage Jurisdiction(s):
833.2 Acres - in Bellevue
94.2 Acres - in Clyde Hill

Highest Elevation: 391 Ft
Lowest Elevation: 18 Ft

Total Length of Open Channel: 1,773 Ft
Total Length of Storm Drainage Pipes: 142,906 Ft
Built Rain Storage Volume per Acre of Impervious Surface:
Less than 0.5 Inches

SALMON PRESENT in BASIN

Chinook*+ (Lake only)
Coho+ (Lake only)
Cutthroat trout (Lake only)
Rainbow trout (Lake only)
Sockeye

* Listed Federal Endangered Species
\+ City Species of Local Importance (Bellevue Land Use Code 20.25H.150A)

POPULATION

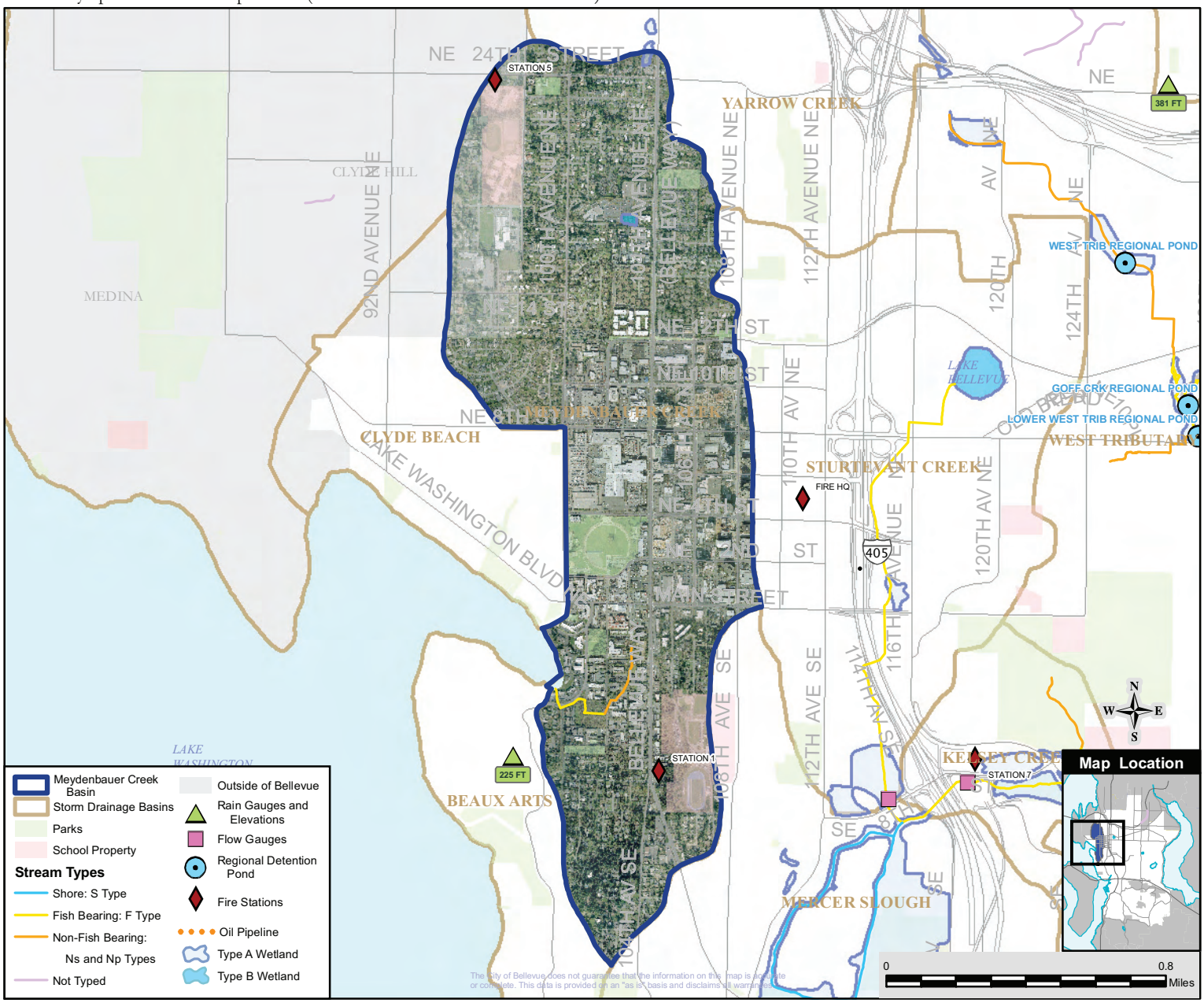
City Basin Population (2000): 6,700 (6.0% of the City)
Basin Population Density: 4,833 People/Square Mile
Number 23 of 26 Basins (One is the lowest density)

LAND USE (within Bellevue city limits)

Public Right of Way:	16.60%	153.95 Acres
Commercial/Office:	15.23%	126.9 Acres
Industrial:	0.20%	1.7 Acres
Institutional/Government:	5.67%	47.3 Acres
Mixed Use/Misc:	7.70%	64.2 Acres
Multi-Family Residential:	15.03%	125.2 Acres
Open Space/Park:	3.61%	30.1 Acres
Single Family Residential:	31.61%	263.4 Acres

LAND COVER

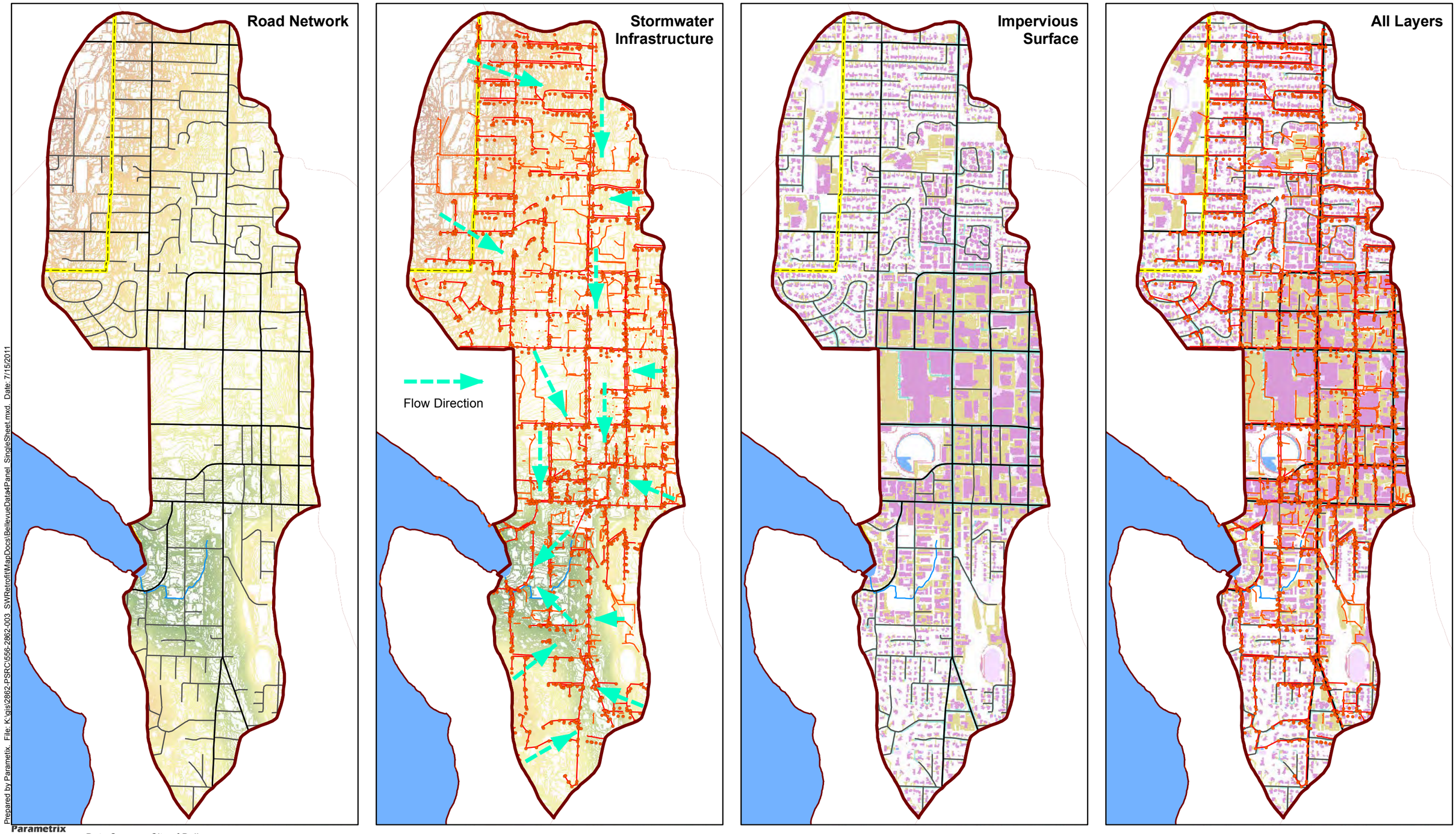
Impervious:	59%
Tree Canopy:	24%
Impervious in 100 Ft Stream Buffer:	36%
Tree Canopy in 100 Ft Stream Buffer:	44%



V:\utpl\ArcGIS\Storm\BasinFactSheets2010\MapBkPLTS\StormBasinFactSht21Jul2010_LegSW.mxd

Figure 5. Meydenbauer Creek Basin Plot Date: 7/27/2010

Source: http://www.bellevuewa.gov/pdf/Utilities/12-MEYDENBAUER_CREEK.pdf



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Parametrix

Data Source: City of Bellevue

0 N 1,500
Scale in Feet

Freeway
Arterial Street
Street

City Boundary
Major Stream
Storm Drain Site
Storm Drain Structure

Storm Drain Pipe
Private Storm Drain Pipe
Storm Drain Basin

Impervious Surface Class
Roof/Building
Road
Parking Lot/Driveway
Sidewalk
Overwater Structure
Other - Overwater
Other Impervious
Open Water

Figure 6.
Meydenbauer Creek Basin: Road Network, Stormwater Infrastructure, and Impervious Surface

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