Puget Sound Stormwater Retrofit Cost Estimate Appendix A

Prepared for

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ACRONYMS AND ABBREVIATIONS

BMP	best management practice
C-CAP	Coastal Change Analysis Program
COV	coefficient of variation
CSC	Coastal Services Center
CWSRF	Clean Water State Revolving Fund
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
GFC	General Facilities Charge
GIS	geographic information system
LID	low impact development
NOAA	National Oceanographic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
PAH	polycyclic aromatic hydrocarbon
PSD	particle size distribution
ROW	right-of-way
SSC	suspended solids concentrations
TSS	total suspended solids
USGS	U.S. Geological Survey
WRIA	water resource inventory area
WSDOT	Washington State Department of Transportation

1. INTRODUCTION AND SUMMARY OF FINDINGS

Previous work by the Puget Sound Partnership and others has identified stormwater as a primary contributor to degradation of Puget Sound (State of Sound Report 2009; Stormwater Work Group for Puget Sound 2010). 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. Washington State has been a recognized national leader in stormwater handling and treatment since 1992 with publication of the Washington State Department of Ecology (Ecology) first stormwater manual (Ecology 1992), which built on the leading edge 1990 King County Surface Water Management Design Manual. However, most of the development that exists in the Puget Sound drainage (the land area that drains into the Puget Sound, extending from the Olympic and Cascade Mountain crests to the marine shoreline) today was constructed prior to adoption and implementation of the state manual. As a result, greater than 90 percent of developed land in Puget Sound discharges undetained, untreated stormwater, and retrofit of these existing untreated areas has been suggested as an important next step toward progress in reducing stormwater impacts to Puget Sound.

As requested by the Partnership, this appendix provides a "40,000-foot" analysis of the potential costs and benefits of providing stormwater retrofits to untreated urban and urbanizing areas throughout Puget Sound. As such, there are clear limitations in the approach taken. At the same time, the authors hope that this analysis will provide a solid stepping stone for moving forward.

1.1 OVERVIEW OF APPROACH

The following approach was taken:

- Use geographic information system (GIS) data sets to estimate impervious acreage in the Puget Sound watersheds pre- and post-Ecology manual (1996 and 2006, respectively) and by water resource inventory area (WRIA) and county.
- Select a reasonable proxy for water quality improvement, in this case 80 percent total suspended solids (TSS) removal, which is the current Ecology TSS standard.
- Identify and develop costs for best management practices (BMPs) that can be implemented, without additional land acquisition, to meet water quality improvement goals (using proxy) and apply costs to estimated imperviousness acreage.
- Using the proxy, identify and develop potential benefits (TSS removal) that could result from a wide-scale retrofit investment.

1.2 FINDINGS

- There are about 8,700,000 acres in the Puget Sound drainage excluding Puget Sound itself.
- Impervious acreages for the Puget Sound Region were estimated (as shown below in Table 1-1).

Table 1-1. Puget Sound Imperviousness

Category of Percent Imperviousness (1/4 acre mapping unit)		0–19%	20–49%	50–79%	80–100%	Total
Total 1996 Impervious Acres within Category:		36,747	120,462	101,995	60,206	319,409
Total 2006 Impervious Acres within Category:		46,478	128,189	115,960	67,214	357,840
Percent increase 1996 to 2006:		26%	6%	14%	12%	12%
Total Puget Sound Acres	**8,700,000**					
Total Percent Impervious – 1996	3.7%					
Total Percent Impervious – 2006	4.1%					

- Thirteen BMPs were identified that could meet or exceed 80 percent TSS removal and which required no additional land acquisition. For each of these BMPs, installation and annual maintenance costs for treating 1 acre with 100 percent imperviousness were established. Costs ranged from roughly $20,000 to $78,000 per acre for installation and $300 to $3,200 per acre for annual maintenance. While many other low impact development (LID) techniques are available, the land acquisition component was felt to add excessive uncertainty to these preliminary estimates.
- As shown in Table 1-2, retrofitting all of the land with impervious coverage of 50 to 100 percent (roughly 162,000 acres) would cost on the order of $8 billion with annual costs of $285 million; capturing the additional area with imperviousness between 20 and 50 percent would bring the total area addressed to roughly 162,288 acres of imperviousness, at a potential cost of $14 billion with annual maintenance costs of about $500 million. Table 1-2 shows the potential range of retrofit investment and maintenance costs for each of the ranges of imperviousness.

Table 1-2. Increasing Level of Potential Average Capital Investment to Retrofit Land from Most to Least Impervious (1996 Imperviousness)

Range of Imperviousness Addressed:	80–100%	50–100%	20–100%	0–100%
Acres with Impervious Area Addressed (1996):	60,206	162,201	282,663	319,409
Potential Capital Investment: *(Average of Low and High Estimate in Figure 3-1)*	$3,010M	$8,110M	$14,133M	$15,645M
Potential Annual Maintenance Investment: *(Average of Low and High Estimate in Figure 3-1)*	$111M	$300M	$523M	$561M

- Rough estimates of retrofit investments needed by WRIA and county are shown in Tables 1-3 and 1-4, respectively.

Table 1-3. Rough Estimate of Capital and Maintenance Investment Needs by County in Puget Sound

County	Impervious Acres with 50% to 100% Coverage (1996 Imperviousness)	Treatment of 50 to 100%	
		Average Capital Costs ($1M)	Average Annual Maintenance ($1M)
Clallam	5,025	$251	$9
Island	3,313	$166	$6
Jefferson	1,154	$58	$2
King	66,754	$3,338	$123
Kitsap	6,649	$332	$12
Mason	1,618	$81	$3
Pierce	32,509	$1,625	$60
San Juan	550	$28	$1
Skagit	7,359	$368	$14
Snohomish	22,499	$1,125	$42
Thurston	6,227	$311	$12
Whatcom	8,543	$427	$16
Totals	**162,201**	**$8,110**	**$300**

Includes only portions of counties within the Puget Sound drainage.

Table 1-4. Rough Estimate of Capital and Maintenance Investment Needs by Puget Sound WRIA

WRIA No.	WRIA Name	Impervious Acres with 50% to 100% Coverage (1996 Imperviousness)	Treatment of 50 to 100%	
			Average Capital Costs ($1M)	Average Annual Maintenance ($1M)
1	Nooksack	8,306	$415	$15
2	San Juan	550	$28	$1
3	Lower Skagit / Samish	7,034	$352	$13
4	Upper Skagit	747	$37	$1
5	Stillaguamish	1,502	$75	$3
6	Island	3,313	$166	$6
7	Snohomish	12,509	$625	$23
8	Cedar-Sammamish	42,500	$2,125	$79
9	Duwamish-Green	27,733	$1,387	$51
10	Puyallup-White	18,718	$936	$35
11	Nisqually	2,387	$119	$4
12	Chambers-Clover	15,711	$786	$29
13	Deschutes	5,438	$272	$10
14	Kennedy-Goldsborough	1,464	$73	$3
15	Kitsap	8,087	$404	$15
16	Skokomish-Dosewallips	150	$8	$0
17	Quilcene-Snow	1,293	$65	$2
18	Elwha-Dungeness	4,655	$233	$9
19	Lyre-Hoko	192	$10	$0
	Totals	**162,290**	**$8,115**	**$300**

Note: Totals for WRIAs are slightly higher than county totals. Two counties (Grays Harbor and Lewis) have relatively small upland areas that contribute to total WRIA acreage but are inconsequential in terms of contribution to impervious areas in the 50 to 100 percent range.

- Rough estimates of TSS removed through retrofitting are shown in Tables 4-3 and 4-4.

2. ESTIMATING PUGET SOUND IMPERVIOUS SURFACES

2.1 APPROACH

- Used GIS-based impervious surface data to calculate acres of impervious land surface in the Puget Sound drainage by county and WRIA for the years 1996 and 2006.
- Used GIS-based land cover data to calculate acres of forested land cover in the Puget Sound drainage by county for 2006.

2.2 ASSUMPTIONS AND LIMITATIONS

- The majority of urban or urbanizing land developed prior to adoption of the Ecology Manual in 1996 would not have stormwater treatment. Therefore, the measurable impervious area from Ecology's 1996 Impervious Surface data (which is available at http://www.ecy.wa.gov/services/gis/data/landcover/basins.htm) would provide a reasonable first cut of the extent of area that may need retrofit for urban stormwater treatment.
- Ecology's 1996 impervious surface data have the following characteristics:
  - Originated from the Landsat Thematic Mapper satellite imagery acquired by the U.S. Geological Survey (USGS) for its 2001 National Land Cover Database and Impervious data set.
  - Computer-based classification process using limited field verification to generate 2001 impervious data. Imperviousness was classified based on Landsat spectral data using the methods described by Homer et al. (2004) and Yang et al. (2003).
  - 1996 impervious data created using change detection between 1996 and 2001 satellite data and masking out areas from the 2001 data set that were not impervious in 1996.
  - Refined the classifications for coastal areas by National Oceanographic and Atmospheric Administration (NOAA) Coastal Services Center (CSC) Coastal Change Analysis Program (C-CAP).
  - Classifications further refined in some areas of western Washington by Ecology based on local knowledge.
  - Raster-based data with a single impervious surface percentage assigned to each 98.425′ x 98.425′ (~1/4 acre) cell (that is, the characteristics of imperviousness of the land within each cell is an "average" value of what is on the landscape).
  - Impervious surface values for raster cells are percent impervious values from 20 to 100.
  - Areas with percent impervious below 20 were not classified (set to 0).
  - Percent impervious values for surface water (e.g., lakes and Puget Sound) were set to 0, meaning that all precipitation falling onto those open waterbodies would be absorbed and none would run off onto adjacent lands.
- To assess current conditions, Ecology's 2006 Impervious Surface data were used to evaluate the distribution of impervious acres between National Pollutant Discharge

Elimination System (NPDES)-permitted and non-permitted cities and counties. For King and Kitsap Counties, public land ownership, including roads, were also estimated.

- Ecology's 2006 Impervious Surface data have the following characteristics different from Ecology's 1996 Impervious Surface data:
  - Updated from the USGS 2001 Impervious data set using more recent Landsat Thematic Mapper multispectral images.
  - Impervious surface values range between 1 and 100.
- For the King County and Kitsap County public lands analysis, general road right-of-way (ROW) widths and widths of impervious surface were applied based on road classification.
  - King County:
    - Freeway: 100-foot ROW, 80 feet of impervious.
    - Primary: 60-foot ROW, 40 feet of impervious.
    - Collector: 60-foot ROW, 40 feet of impervious.
    - Minor: 50-foot ROW, 30 feet of impervious.
    - Local: 40-foot ROW, 30 feet of impervious.
  - Kitsap County:
    - State Highway: 100-foot ROW, 80 feet of impervious.
    - Collector/Arterial: 60-foot ROW, 40 feet of impervious.
    - Local Road: 40-foot ROW, 30 feet of impervious.
    - Local Access (easement): 40-foot ROW, 30 feet of impervious.
- Ecology's 2006 Land Cover data were used to calculate current forest cover by county. This data set has the following characteristics:
  - Originated from the Landsat Thematic Mapper satellite imagery acquired by USGS for its 2001 and 2006 National Land Cover Database.
  - USGS' 2006 land cover update was based on updating the change areas between the 2001 and 2006 imagery, and overlaying the results over 2001 land cover.
  - C-CAP then overlaid the classified change areas on its 2001 product to create a 2006 C-CAP classification.
  - Raster-based data with a single land cover classification assigned to each 98.425 feet x 98.425 feet (~1/4 acre) cell (that is, the land cover assigned to each cell is the predominant land cover type on the landscape).
  - Land cover was classified into 26 categories, and three of these represent forested land cover:
    - Deciduous Forest—areas dominated by trees generally greater than 5 meters tall and accounting for more than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

- Evergreen Forest—areas dominated by trees generally greater than 5 meters tall and accounting for more than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. The canopy is never without green foliage.
- Mixed Forest—areas dominated by trees generally greater than 5 meters tall and accounting for more than 20 percent of total vegetation cover; neither deciduous nor evergreen species are more than 75 percent of total tree cover. Both coniferous and broad-leaved evergreens are included in this category.

2.3 ANALYSIS

- Analysis performed using ArcGIS 9.3.
- Used NOAA CSC's original C-CAP land cover classification scheme to categorize percent impervious into three Development Categories:
  - Developed, High Intensity—80 to 100 percent impervious, includes heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of land uses.
  - Developed, Medium Intensity—50 to 79 percent impervious, commonly includes multi- and single-family housing areas, especially in suburban neighborhoods, but may include all types of land use.
  - Developed, Low Intensity—21 to 49 percent impervious, commonly includes single-family housing areas, especially in rural neighborhoods, but may include all types of land use.
- Calculated impervious acres for each county (clipped to the Puget Sound drainage) and WRIA (within the Puget Sound drainage) separately.
  - Extracted impervious surface data from the Ecology's 1996 and 2006 Impervious Surface data.
  - Used the attribute table from extracted data to calculate total acres and acres of impervious surface. The table has one record for each percent impervious value. The table has two fields:
    - Impervious Value = percent impervious (as an integer).
    - Cell Count = number of raster cells (~1/4-acre units) with each Impervious Value.
  - Calculated Total Acres = Cell Count * Conversion to acres = Cell Count * ([98.425 feet * 98.425 feet] / 43560 square feet per acre).
  - Calculated Impervious Acres = Calculated Total Acres * Impervious Value Converted from Integer to Percentage = Calculated Total Acres * (Impervious Value/100).
  - Summed Total Acres and Impervious Acres for each Development Category.
  - Subtracted acres of Puget Sound (surface water area) from Total Acres of county or WRIA within the Puget Sound drainage.

- Combined county boundaries and city limits (within the Puget Sound drainage) and categorized resulting areas as follows. This overlay was combined with Ecology's 2006 Impervious Surface data (converted from raster to polygon format) and summarized by county.
  - Non-NPDES City (areas within any city not covered by an NPDES Phase I or II permit).
  - Non-NPDES County (areas within any county not covered by an NPDES Phase I or II permit but outside any city).
  - NPDES City (areas within any city covered by an NPDES Phase I or II permit).
  - NPDES County (areas within any county covered by an NPDES Phase I or II permit but outside any city).
- Identified public lands within King and Kitsap Counties.
  - Combined Washington Department of Natural Resources surface-owned parcels with other major public lands (local, state, and federal).
  - Calculated impervious road surface areas using buffer widths identified above based on road classification.
  - Combined publicly owned lands with impervious road surface areas.
- Combined county boundaries (within the Puget Sound drainage) with Ecology's 2006 Land Cover data (converted from raster to polygon format) and summarized acres of forested land by county.
- Data sets derived as part of this analysis are available by request through the Puget Sound Partnership.

2.4 FINDINGS AND RECOMMENDATIONS

- Tables 2-1 and 2-2 provide summaries of impervious acres in 20 percent imperviousness increments, by county and by WRIA.
- Table 2-3 summarizes impervious acres by NPDES permit status for each county.
- Table 2-4 provides estimates of public land ownership in King and Kitsap Counties.
- Table 2-5 provides estimates of forested land by county.

Table 2-1. 1996 Impervious Surface Acres by County

	Percent Impervious Category (Acres)				
County	**0–19%**	**20–49%**	**50–79%**	**80–100%**	**Total Acres**
Clallam	1,129	3,660	3,434	1,591	**9,814**
Island	957	4,047	2,410	903	**8,317**
Jefferson	379	1,758	830	324	**3,292**
King	13,637	38,145	39,942	26,812	**118,535**
Kitsap	1,830	7,428	4,492	2,157	**15,908**
Mason	563	2,713	1,179	439	**4,894**
Pierce	7,207	22,926	20,333	12,176	**62,643**
San Juan	273	1,554	407	143	**2,377**
Skagit	1,795	6,446	4,929	2,430	**15,599**
Snohomish	5,216	17,624	14,595	7,904	**45,338**
Thurston	1,582	5,946	4,205	2,022	**13,755**
Whatcom	2,178	8,214	5,239	3,304	**18,936**
Total Acres	**36,747**	**120,462**	**101,995**	**60,206**	**319,409**

Note: Because of the nature of analysis using polygon-based county boundaries, WRIA boundaries, and Puget Sound surface water area with raster-based data, small differences in totals are common. These are the result of how ArcGIS processes polygon clips of raster-based data to retain whole individual raster cells.

Table 2-2. 1996 Impervious Surface Acres by WRIA

WRIA No.	WRIA Name	Percent Impervious Category (Acres) 0–19%	20–49%	50–79%	80–100%	Total Acres
1	Nooksack	2,082	7,707	5,050	3,256	**18,094**
2	San Juan	273	1,554	407	143	**2,377**
3	Lower Skagit / Samish	1,611	5,356	4,667	2,367	**14,001**
4	Upper Skagit	330	1,791	599	148	**2,868**
5	Stillaguamish	552	2,743	1,109	393	**4,798**
6	Island	957	4,047	2,410	903	**8,317**
7	Snohomish	3,192	12,045	8,216	4,293	**27,746**
8	Cedar-Sammamish	8,861	25,660	27,812	14,688	**77,020**
9	Duwamish-Green	5,199	12,258	14,248	13,485	**45,189**
10	Puyallup-White	3,991	11,980	11,209	7,509	**34,689**
11	Nisqually	821	3,930	1,505	882	**7,139**
12	Chambers-Clover	3,159	8,585	10,219	5,492	**27,456**
13	Deschutes	1,313	4,663	3,596	1,842	**11,413**
14	Kennedy-Goldsborough	481	2,239	1,071	393	**4,183**
15	Kitsap	2,394	10,326	5,582	2,505	**20,807**
16	Skokomish-Dosewallips	100	617	126	24	**867**
17	Quilcene-Snow	413	1,884	938	355	**3,589**
18	Elwha-Dungeness	997	3,017	3,132	1,523	**8,669**
19	Lyre-Hoko	71	354	162	30	**618**
	Total Acres	**36,796**	**120,756**	**102,059**	**60,231**	**319,842**

Notes: Because of the nature of analysis using polygon-based county boundaries, WRIA boundaries, and Puget Sound surface water area with raster-based data, small differences in totals are common. These are the result of how ArcGIS processes polygon clips of raster-based data to retain whole individual raster cells.

Totals for WRIAs are slightly higher than county totals. Two counties (Grays Harbor and Lewis) have relatively small upland areas that contribute to total WRIA acreage but are inconsequential in terms of contribution to impervious areas in the 50 to 100 percent range.

Table 2-3. 2006 Impervious Surface Acres by NPDES Permit Status and County

		All Lands in the Puget Sound Drainage			NPDES Only		
County	**NPDES Status**	**Land Acres**	**Impervious Acres**	**Percent Impervious**	**Land Acres**	**Impervious Acres**	**Percent Impervious**
Clallam	Non-NPDES City	4,006	1,216	30.37%			
	Non-NPDES County	619,320	7,054	1.14%			
	NPDES City	6,790	2,221	32.71%			
	Clallam Total:	**630,115**	**10,491**	**1.67%**	**6,790**	**2,221**	**32.71%**
Island	Non-NPDES City	1,399	298	21.30%			
	Non-NPDES County	127,509	7,370	5.78%			
	NPDES City	6,022	1,895	31.47%			
	Island Total:	**134,930**	**9,563**	**7.09%**	**6,022**	**1,895**	**31.47%**
Jefferson	Non-NPDES City	4,493	983	21.88%			
	Non-NPDES County	477,543	3,373	0.71%			
	Jefferson Total:	**482,036**	**4,356**	**0.90%**	**0**	**0**	**N/A**
King	Non-NPDES City	8,336	1,380	16.56%			
	NPDES City	260,193	92,753	35.65%			
	Ph I NPDES County	1,132,457	27,887	2.46%			
	King Total:	**1,400,985**	**122,020**	**8.71%**	**1,392,649**	**120,640**	**8.66%**
Kitsap	NPDES City	43,897	5,811	13.24%			
	Ph II NPDES County	211,442	12,850	6.08%			
	Kitsap Total:	**255,339**	**18,662**	**7.31%**	**43,897**	**5,811**	**13.24%**
Mason	Non-NPDES City	3,682	880	23.91%			
	Non-NPDES County	477,976	5,587	1.17%			
	Mason Total:	**481,658**	**6,467**	**1.34%**	**0**	**0.00**	**0.00%**
Pierce	Non-NPDES City	2,408	533	22.12%			
	NPDES City	94,166	34,965	37.13%			
	Ph I NPDES County	944,256	35,475	3.76%			
	Pierce Total:	**1,040,830**	**70,973**	**6.82%**	**1,038,422**	**70,440**	**6.78%**
San Juan	Non-NPDES City	1,387	320	23.05%			
	Non-NPDES County	111,670	2,574	2.30%			
	San Juan Total:	**113,057**	**2,894**	**2.56%**	**0**	**0**	**N/A**
Skagit	Non-NPDES City	2,253	359	15.95%			
	NPDES City	20,946	6,270	29.94%			
	Ph II NPDES County	1,100,232	11,735	1.07%			
	Skagit Total:	**1,123,431**	**18,365**	**1.63%**	**20,946**	**6,270**	**29.94%**

(Table Continues)

Table 2-3. 2006 Impervious Surface Acres by NPDES Permit Status and County (Continued)

County	NPDES Status	All Lands in the Puget Sound Drainage			NPDES Only		
		Land Acres	Impervious Acres	Percent Impervious	Land Acres	Impervious Acres	Percent Impervious
Snohomish	Non-NPDES City	6,410	1,515	23.64%			
	NPDES City	78,550	26,499	33.73%			
	Ph I NPDES County	1,263,082	25,593	2.03%			
	Snohomish Total:	**1,348,042**	**53,607**	**3.98%**	**1,341,632**	**52,092**	**3.88%**
Thurston	Non-NPDES City	4,707	728	15.47%			
	NPDES City	29,093	8,616	29.61%			
	Ph II NPDES County	231,313	8,429	3.64%			
	Thurston Total:	**265,113**	**17,773**	**6.70%**	**29,093**	**8,616**	**29.61%**
Whatcom	Non-NPDES City	9,083	2,121	23.35%			
	NPDES City	22,162	6,424	28.99%			
	Ph II NPDES County	1,355,335	13,106	0.97%			
	Whatcom Total:	**1,386,581**	**21,651**	**1.56%**	**22,162**	**6,424**	**28.99%**
Puget	**Non-NPDES City**	**48,163**	**10,334**	**21.46%**			
Sound	**NPDES City**	**561,819**	**185,453**	**33.01%**			
Drainage	**Non-NPDES County**	**1,814,018**	**25,957**	**1.43%**			
	Ph I NPDES County	**3,339,795**	**88,955**	**2.66%**			
	Ph II NPDES County	**2,898,323**	**46,121**	**1.59%**			
	Puget Sound Drainage Total:	**8,662,117**	**356,822**	**4.12%**	**3,901,614**	**274,408**	**7.03%**

Notes:
1. For this analysis, the raster-based 2006 Impervious Surface data were converted to polygon format; therefore, some county totals may differ slightly from those shown in other tables.
2. For Phase II NPDES counties, the permits only apply to urban areas around permitted cities. Consequently, Phase II NPDES counties were not included in the calculations of NPDES-permitted land and impervious acres. However, urban growth areas outside of NPDES-permitted cities were not included in the analysis, so the total NPDES-permitted land and impervious acres for these counties are underestimated.

Table 2-4. Acres of Public Lands in King and Kitsap Counties

County	Land Acres	Impervious Acres	Public Land Ownership		
			Road (Impervious Surface Area)	Other	Total
King	1,400,985	122,020	42,088	631,843	673,931
Kitsap	255,339	18,662	8,482	42,041	50,523

Table 2-5. 2006 Forested Acres by County

County	Deciduous Forest	Evergreen Forest	Mixed Forest	Total Forest Land	Total Land	Forest as a Percent of Total Land
Clallam	13,385	408,591	30,233	452,210	630,115	71.8
Island	10,519	40,050	21,326	71,896	134,930	53.3
Jefferson	15,807	295,945	26,233	337,985	482,036	70.1
King	43,686	608,790	164,563	817,039	1,400,985	58.3
Kitsap	22,930	105,552	39,269	167,750	255,339	65.7
Mason	13,054	292,017	25,934	331,005	481,658	68.7
Pierce	24,871	469,000	85,669	579,540	1,040,830	55.7
San Juan	1,190	67,059	4,825	73,075	113,057	64.6
Skagit	41,970	604,565	68,539	715,075	1,123,431	63.7
Snohomish	56,172	704,029	134,081	894,282	1,348,042	66.3
Thurston	14,335	87,420	31,584	133,339	265,113	50.3
Whatcom	43,556	705,145	61,944	810,646	1,386,581	58.5
Total	**301,474**	**4,388,165**	**694,201**	**5,383,840**	**8,662,117**	**62.2**

2.5 REFERENCES AND RESOURCES

1996 and 2006 Impervious Surface data layers and 2006 Land Cover data layer available at Ecology's Western Washington Land Cover Change Analysis Project website http://www.ecy.wa.gov/services/gis/data/landcover/basins.htm>

County boundaries, WRIA boundaries, and Puget Sound surface water area from Ecology's GIS data website <http://www.ecy.wa.gov/services/gis/data/data.htm>

City limits from Washington Department of Transportation's (WSDOT's) GIS data website http://www.wsdot.wa.gov/mapsdata/geodatacatalog/default.htm

Homer, C. C. Huang, L. Yang, B. Wylie, and M. Coan. 2004. Development of a 2001 National Landcover Database for the United States. Photogrammetric Engineering and Remote Sensing Vol. 70, No. 7, July 2004, pp. 829-840. <http://www.mrlc.gov/pdf/July_PERS.pdf>

Public lands from Washington Department of Natural Resources' GIS data website <http://fortress.wa.gov/dnr/app1/dataweb/dmmatrix.html>

Kitsap County road centerlines from Kitsap County GIS data website <http://kitsapgov.com/gis/metadata/> (downloaded October 2009 for Parametrix's GIS library)

King County streets from King County GIS, January 2010 release, purchased for Parametrix's GIS library (ordering information available at http://www.kingcounty.gov/operations/GIS/GISData/StandardDisc.aspx)

NPDES Phase I and II cities and counties from Ecology <http://www.ecy.wa.gov/programs/wq/stormwater/municipal/MuniStrmWtrPermList.html>

Yang, L., C. Huang, C. Homer, B. Wylie, and M. Coan. 2003. An approach for mapping large-area impervious surfaces: Synergistic use of Landsat 7 ETM+ and high spatial resolution imagery. Canadian Journal of Remote Sensing Vol. 29, No. 2, pp. 230-240. <http://landcover.usgs.gov/pdf/imppaperfinalwithall.pdf>

3. ESTIMATING THE COST TO RETROFIT PUGET SOUND FOR STORMWATER

3.1 APPROACH

- Estimate the stormwater flow rates and volumes that would require treatment from 1 acre with 100 percent imperviousness using MGSFlood and WWHM modeling programs.
- Use Ecology's standard of 80 percent removal of TSS as a proxy for water quality improvement and a target for identifying potential retrofit facilities for the urban and urbanizing landscape.
- Identify existing technologies, or emerging technologies, from the Ecology Stormwater Manual and from the Ecology Emerging Technologies list for proprietary systems with general use, conditional use, and pilot level use designations for basic water quality treatment that, as a result, meet or exceed the 80 percent TSS standard.
- From the selected facilities, size and develop capital and operations/maintenance costs for providing 80 percent TSS removal based on manufacturers' representative estimates, professional experience, and jurisdictional input.
- Multiply costs for 1 acre with 100 percent imperviousness by number of impervious acres developed for counties and WRIAs.

3.2 ASSUMPTIONS AND LIMITATIONS

- Eighty percent removal of TSS is an imperfect proxy for estimating the wide variability of pollutant removal that could be achieved through retrofits, but represents both a current standard and as tangible a measure as is currently available.
- A conservative scenario of 100 percent impervious and 1 acre within the central Puget Sound drainage provides a level playing field for cost analysis and a modular unit that can be applied to GIS imperviousness calculations.
- Most if not all urban areas have basic drainage to prevent flooding from frequently occurring storms; therefore, conveyance systems are available to direct stormwater to water quality treatment facilities as well as to receive overflows.
- Cost estimates provided by vendors reflect the actual installation costs, equipment costs, and annual maintenance costs based on the design criteria provided from the estimated flows.
- Precipitation rates in the central Puget Sound-Seattle area are an adequate representation of the variable precipitation rates within the Puget Sound drainage as a whole.
- Some water quality treatment facilities are more cost efficient with larger areas. (Wet vault construction costs are most efficient, assuming more than 50,000 cubic feet of storage; 1 acre 100 percent impervious produces approximately 6,000 cubic feet of storage needs).

- Some water quality treatment facilities will be more or less efficient or expensive than represented here based on the physical conditions and tributary area where they may be used.
- Some water quality treatment facilities require purchase of land for construction, whereas others are more conducive to retrofit. This analysis assumed retrofit of already owned facilities and associated land or treatment facilities that would readily fit within existing ROWs.
- Costs associated with flow control, which vary depending on the situation (e.g., downtown urban cores versus suburban parking areas), were not included.

3.3 ANALYSIS

The following parameters were used to analyze runoff quantity:

- WWHM model input parameters:
  - North Seattle location
  - Gage: Seattle Precipitation Factor 0.8
  - 1 acre 100 percent impervious on moderately sloped roadway
- WWHM water quality results for an online BMP (all flows conveyed through facility)
  - Online water quality treatment volume 0.0953 acre-ft (4,151 cubic feet)
  - 15-minute flow rate 0.14 cubic feet per second
- MGSFlood model input parameters:
  - Climatic Region 3
  - Precipitation Station L 980040 Puget West 40 in MAP
  - 1 acre impervious area
- MGSFlood water quality results for an online BMP
  - Online water quality treatment 5,500 cubic feet
  - 2-year, 24-hour peak flow
  - 15-minute water quality flow rate 0.17 cubic feet per second
- From output generated by both models, the higher flow rate and volume were selected as a conservative measure (MGSFlood) to size water quality treatment facilities.
- Once the water quality treatment technologies were identified and flow rates were obtained, vendors were contacted for costs of installation and maintenance of each system. Costs were graphed based on installation costs and maintenance costs.

3.4 FINDINGS AND RECOMMENDATIONS

- Water quality treatment facilities ranged in capital installation costs from $20,000 to $78,000 per acre.
- Facilities that were designed to fit in a small footprint, such as a large catch basin or manhole, had the lowest installation costs, whereas systems that required large footprints, such as roadside slopes or volume-based vaults/ponds, had the highest installation costs.
- Maintenance costs of treatment systems that contained proprietary media for filtration varied widely from $300/year to $3,200/year depending on need of a contracted maintenance service. Non-proprietary systems that required minimum time for maintenance, such as mowing or vactor removal services, ranged from $300/year to $1,000/year.
- Several of the systems provide additional water quality treatment beyond TSS removal. Many provided total phosphorus removal, oil/grease treatment, and heavy metals removal.
- All of the water quality treatment systems that were evaluated are appropriate for TSS removal. The Filterra system appears to provide the most versatility for different installation locations such as parking lots, streets, and residential neighborhoods; it also has the second lowest installation cost of the systems reviewed and the second lowest maintenance costs. This system does not require a proprietary maintenance contract or heavy equipment for maintenance.
- Phase 1 jurisdictions are under NPDES permit requirements to retrofit stormwater quantity detention facilities for water quality treatment purposes. The analysis presented here is assumed to provide a range of costs that would accommodate the costs of the detention pond retrofit work for the purposes of this level of estimate of need. Figure 3-1 depicts installation and maintenance costs for treating a unit impervious acre.
- Existing BMPs and emerging technologies are expected to remove other pollutants beyond TSS (as shown in Table 3-1) to varying degrees.
- Estimates for retrofitting properties in Puget Sound are shown in Tables 3-2 through 3-5. Figures 3-2 through 3-6 illustrate total impervious acres in 1996 and 2006 by county and WRIA.

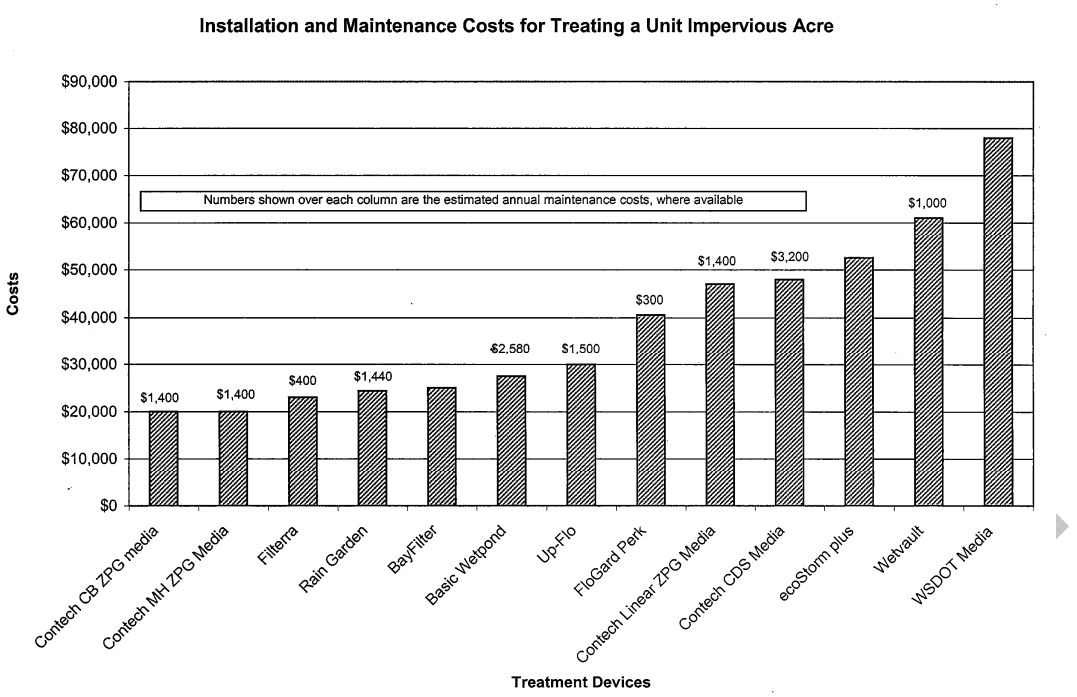

Figure 3-1. Installation and Maintenance Costs for Treating a Unit Impervious Acre

Table 3-1. Other Pollutants Potentially Removed by Emerging Technologies

Emerging Technologies	TSS	Total Phosphorus	Oil/Grease	Heavy Metals	Zinc	Copper
BayFilter®	x	x			x	
CONTECH Stormwater Solutions, Inc. CDS Media Filtration System	x		x			
CONTECH Stormwater Solutions, Inc. Storm filter using ZPG Media (catch basin storm filter)	x					
CONTECH Stormwater Solutions, Inc. Storm filter using ZPG Media (manhole inserts)	x		x	x		
CONTECH Stormwater Solutions, Inc. Storm filter using ZPG Media (linear grate storm filter)	x		x	x		
WSDOT Media Filter Drain	x	x		x	x	x
Americast Filterra® System	x	x	x	x		
Aqua Shield Aqua-Filter Concentrator	x	x	x	x		
Royal Environmental Systems, Inc. ecoStorm plus	x	x		x		
Kristar FloGard Perk Filter®	x		x	x		
Hydro International, Inc. Up-Flo™ Filter	x	x		x		

Table 3-2. Coarse Estimate of Capital and Annual Costs to Retrofit Cumulative Impervious Areas by County (1996 Imperviousness)

County	Number of Impervious Acres (1996 Imperviousness)				Total Acres	Average Capital Costs ($1M)	Average Annual Maintenance ($1M)	Acreage			Average Capital Costs ($1M)			Average Annual Maintenance Costs ($1M)		
	0–19%	20–49%	50–79%	80–100%				80–100%	50–100%	20–100%	80–100%	50–100%	20–100%	80–100%	50–100%	20–100%
Clallam	1,129	3,660	3,434	1,591	**9,814**	$434.25	$16.07	1,591	5,025	8,685	$79.55	$251.25	$434.25	$2.94	$9.30	$16.07
Island	957	4,047	2,410	903	**8,317**	$368.00	$13.62	903	3,313	7,360	$45.15	$165.65	$368.00	$1.67	$6.13	$13.62
Jefferson	379	1,758	830	324	**3,292**	$145.60	$5.39	324	1,154	2,912	$16.20	$57.70	$145.60	$0.60	$2.13	$5.39
King	13,637	38,145	39,942	26,812	**118,535**	$5,244.95	$194.06	26,812	66,754	104,899	$1,340.60	$3,337.70	$5,244.95	$49.60	$123.49	$194.06
Kitsap	1,830	7,428	4,492	2,157	**15,908**	$703.85	$26.04	2,157	6,649	14,077	$107.85	$332.45	$703.85	$3.99	$12.30	$26.04
Mason	563	2,713	1,179	439	**4,894**	$216.55	$8.01	439	1,618	4,331	$21.95	$80.90	$216.55	$0.81	$2.99	$8.01
Pierce	7,207	22,926	20,333	12,176	**62,643**	$2,771.75	$102.55	12,176	32,509	55,435	$608.80	$1,625.45	$2,771.75	$22.53	$60.14	$102.55
San Juan	273	1,554	407	143	**2,377**	$105.20	$3.89	143	550	2,104	$7.15	$27.50	$105.20	$0.26	$1.02	$3.89
Skagit	1,795	6,446	4,929	2,430	**15,599**	$690.25	$25.54	2,430	7,359	13,805	$121.50	$367.95	$690.25	$4.50	$13.61	$25.54
Snohomish	5,216	17,624	14,595	7,904	**45,338**	$2,006.15	$74.23	7,904	22,499	40,123	$395.20	$1,124.95	$2,006.15	$14.62	$41.62	$74.23
Thurston	1,582	5,946	4,205	2,022	**13,755**	$608.65	$22.52	2,022	6,227	12,173	$101.10	$311.35	$608.65	$3.74	$11.52	$22.52
Whatcom	2,178	8,214	5,239	3,304	**18,936**	$837.85	$31.00	3,304	8,543	16,757	$165.20	$427.15	$837.85	$6.11	$15.80	$31.00
Totals	**36,747**	**120,462**	**101,995**	**60,206**	319,409	**$14,133.15**	**$522.92**	**60,206**	**162,201**	**282,663**	**$3,010.30**	**$8,110.05**	**$14,133.15**	**$111.39**	**$300.07**	**$522.92**

Table 3-3. Coarse Estimate of Capital and Annual Costs to Retrofit Cumulative Impervious Areas by WRIA (1996 Imperviousness)

WRIA No.	WRIA Name	Number of Impervious Acres (1996 Imperviousness)				Total Acres	Average Capital Costs ($1M)	Average Annual Maintenance ($1M)	Acreage			Average Capital Costs ($1M)			Average Annual Maintenance Costs ($1M)		
		0–19%	20–49%	50–79%	80–100%				80–100%	50–100%	20–100%	80–100%	50–100%	20–100%	80–100%	50–100%	20–100%
1	Nooksack	2,082	7,707	5,050	3,256	**18,094**	$801	$29.62	3,256	8,306	16,013	$162.80	$415.30	$800.65	$6.02	$15.37	$29.62
2	San Juan	273	1,554	407	143	**2,377**	$105	$3.89	143	550	2,104	$7.15	$27.50	$105.20	$0.26	$1.02	$3.89
3	Lower Skagit / Samish	1,611	5,356	4,667	2,367	**14,001**	$620	$22.92	2,367	7,034	12,390	$118.35	$351.70	$619.50	$4.38	$13.01	$22.92
4	Upper Skagit	330	1,791	599	148	**2,868**	$127	$4.70	148	747	2,538	$7.40	$37.35	$126.90	$0.27	$1.38	$4.70
5	Stillaguamish	552	2,743	1,109	393	**4,798**	$212	$7.85	393	1,502	4,245	$19.65	$75.10	$212.25	$0.73	$2.78	$7.85
6	Island	957	4,047	2,410	903	**8,317**	$368	$13.62	903	3,313	7,360	$45.15	$165.65	$368.00	$1.67	$6.13	$13.62
7	Snohomish	3,192	12,045	8,216	4,293	**27,746**	$1,228	$45.42	4,293	12,509	24,554	$214.65	$625.45	$1,227.70	$7.94	$23.14	$45.42
8	Cedar-Sammamish	8,861	25,660	27,812	14,688	**77,020**	$3,408	$126.10	14,688	42,500	68,160	$734.40	$2,125.00	$3,408.00	$27.17	$78.63	$126.10
9	Duwamish-Green	5,199	12,258	14,248	13,485	**45,189**	$2,000	$73.98	13,485	27,733	39,991	$674.25	$1,386.65	$1,999.55	$24.95	$51.31	$73.98
10	Puyallup-White	3,991	11,980	11,209	7,509	**34,689**	$1,535	$56.79	7,509	18,718	30,698	$375.45	$935.90	$1,534.90	$13.89	$34.63	$56.79
11	Nisqually	821	3,930	1,505	882	**7,139**	$316	$11.69	882	2,387	6,317	$44.10	$119.35	$315.85	$1.63	$4.42	$11.69
12	Chambers-Clover	3,159	8,585	10,219	5,492	**27,456**	$1,215	$44.95	5,492	15,711	24,296	$274.60	$785.55	$1,214.80	$10.16	$29.07	$44.95
13	Deschutes	1,313	4,663	3,596	1,842	**11,413**	$505	$18.69	1,842	5,438	10,101	$92.10	$271.90	$505.05	$3.41	$10.06	$18.69
14	Kennedy-Goldsborough	481	2,239	1,071	393	**4,183**	$185	$6.85	393	1,464	3,703	$19.65	$73.20	$185.15	$0.73	$2.71	$6.85
15	Kitsap	2,394	10,326	5,582	2,505	**20,807**	$921	$34.06	2,505	8,087	18,413	$125.25	$404.35	$920.65	$4.63	$14.96	$34.06
16	Skokomish-Dosewallips	100	617	126	24	**867**	$38	$1.42	24	150	767	$1.20	$7.50	$38.35	$0.04	$0.28	$1.42
17	Quilcene-Snow	413	1,884	938	355	**3,589**	$159	$5.88	355	1,293	3,177	$17.75	$64.65	$158.85	$0.66	$2.39	$5.88
18	Elwha-Dungeness	997	3,017	3,132	1,523	**8,669**	$384	$14.19	1,523	4,655	7,672	$76.15	$232.75	$383.60	$2.82	$8.61	$14.19
19	Lyre-Hoko	71	354	162	30	**618**	$27	$1.01	30	192	546	$1.50	$9.60	$27.30	$0.06	$0.36	$1.01
Totals		**36,796**	**120,756**	**102,059**	**60,231**	**319,842**	**$14,152**	**$523.64**	**60,231**	**162,290**	**283,046**	**$3,011.55**	**$8,114.50**	**$14,152.30**	**$111.43**	**$300.24**	**$523.64**

Note: Totals for WRIAs are slightly higher than county totals. Two counties (Grays Harbor and Lewis) have relatively small upland areas that contribute to total WRIA acreage but are inconsequential in terms of contribution to impervious areas in the 50 to 100 percent range.

Table 3-4. Coarse Estimate of Capital and Annual Costs to Retrofit Cumulative Impervious Areas by County (2006 Imperviousness)

County	Number of Impervious Acres (2006 Imperviousness)				Total Acres	Average Capital Costs ($1M)	Average Annual Maintenance ($1M)	Acreage			Average Capital Costs ($1M)			Average Annual Maintenance Costs ($1M)		
	0–19%	20–49%	50–79%	80–100%				80-100%	50-100%	20-100%	80-100%	50-100%	20-100%	80-100%	50-100%	20-100%
Clallam	1,287	3,828	3,651	1,767	**10,533**	$462	$17.10	1,767	5,418	9,246	$88.37	$270.91	$462.29	$3.27	$10.02	$17.10
Island	1,496	4,431	2,681	1,001	**9,609**	$406	$15.01	1,001	3,682	8,113	$50.06	$184.10	$405.66	$1.85	$6.81	$15.01
Jefferson	1,336	1,849	888	335	**4,407**	$154	$5.68	335	1,223	3,072	$16.74	$61.13	$153.59	$0.62	$2.26	$5.68
King	10,550	39,843	43,386	28,508	**122,287**	$5,587	$206.71	28,508	71,894	111,738	$1,425.39	$3,594.71	$5,586.88	$52.74	$133.00	$206.71
Kitsap	3,518	7,978	4,969	2,313	**18,779**	$763	$28.23	2,313	7,283	15,261	$115.66	$364.13	$763.04	$4.28	$13.47	$28.23
Mason	1,963	2,837	1,242	441	**6,482**	$226	$8.36	441	1,682	4,519	$22.03	$84.12	$225.95	$0.82	$3.11	$8.36
Pierce	7,995	24,668	24,218	14,384	**71,265**	$3,164	$117.05	14,384	38,602	63,270	$719.21	$1,930.10	$3,163.51	$26.61	$71.41	$117.05
San Juan	785	1,582	410	145	**2,922**	$107	$3.95	145	555	2,137	$7.25	$27.75	$106.83	$0.27	$1.03	$3.95
Skagit	3,422	6,797	5,434	2,771	**18,423**	$750	$27.75	2,771	8,204	15,001	$138.53	$410.21	$750.06	$5.13	$15.18	$27.75
Snohomish	7,498	19,191	17,799	9,289	**53,777**	$2,314	$85.62	9,289	27,088	46,279	$464.46	$1,354.38	$2,313.94	$17.18	$50.11	$85.62
Thurston	3,153	6,602	5,473	2,648	**17,875**	$736	$27.24	2,648	8,120	14,722	$132.38	$406.02	$736.11	$4.90	$15.02	$27.24
Whatcom	3,476	8,583	5,810	3,612	**21,481**	$900	$33.31	3,612	9,422	18,005	$180.60	$471.09	$900.26	$6.68	$17.43	$33.31
Totals	**46,478**	**128,189**	**115,960**	**67,214**	**357,840**	**$15,568**	**$576.02**	**67,217**	**183,173**	**311,362**	**$3,360.68**	**$9,158.65**	**$15,568.11**	**$124.35**	**$338.87**	**$576.02**

Table 3-5. Coarse Estimate of Capital and Annual Costs to Retrofit Cumulative Impervious Areas by WRIA (2006 Imperviousness)

WRIA No.	WRIA Name	Number of Impervious Acres (2006 Imperviousness)				Total Acres	Average Capital Costs ($1M)	Average Annual Maintenance ($1M)	Acreage			Average Capital Costs ($1M)			Average Annual Maintenance Costs ($1M)		
		0–19%	20–49%	50–79%	80–100%				80-100%	50-100%	20-100%	80-100%	50-100%	20-100%	80-100%	50-100%	20-100%
1	Nooksack	3,250	8,084	5,629	3,565	20,528	$864	$31.96	3,565	9,194	17,278	$178.26	$459.70	$863.88	$6.60	$17.01	$31.96
2	San Juan	785	1,582	410	145	2,922	$107	$3.95	145	555	2,137	$7.25	$27.75	$106.83	$0.27	$1.03	$3.95
3	Lower Skagit / Samish	2,111	5,620	5,122	2,702	15,555	$672	$24.87	2,702	7,824	13,444	$135.10	$391.20	$672.20	$5.00	$14.47	$24.87
4	Upper Skagit	1,511	1,858	636	152	4,157	$132	$4.89	152	788	2,646	$7.58	$39.40	$132.29	$0.28	$1.46	$4.89
5	Stillaguamish	2,011	2,947	1,425	471	6,855	$242	$8.96	471	1,896	4,844	$23.55	$94.81	$242.18	$0.87	$3.51	$8.96
6	Island	1,496	4,431	2,681	1,001	9,609	$406	$15.01	1,001	3,682	8,113	$50.06	$184.10	$405.66	$1.85	$6.81	$15.01
7	Snohomish	6,068	13,465	10,429	5,240	35,202	$1,457	$53.90	5,240	15,669	29,134	$261.99	$783.44	$1,456.70	$9.69	$28.99	$53.90
8	Cedar-Sammamish	5,431	26,759	30,534	15,743	78,466	$3,652	$135.11	15,743	46,276	73,035	$787.14	$2,313.81	$3,651.75	$29.12	$85.61	$135.11
9	Duwamish-Green	3,387	12,708	15,436	14,364	45,896	$2,125	$78.64	14,364	29,801	42,509	$718.22	$1,490.03	$2,125.45	$26.57	$55.13	$78.64
10	Puyallup-White	4,104	12,884	13,297	9,034	39,319	$1,761	$65.15	9,034	22,331	35,215	$451.69	$1,116.55	$1,760.74	$16.71	$41.31	$65.15
11	Nisqually	2,851	4,309	1,981	984	10,125	$364	$13.46	984	2,965	7,274	$49.19	$148.26	$363.72	$1.82	$5.49	$13.46
12	Chambers-Clover	1,940	9,075	11,894	6,215	29,124	$1,359	$50.29	6,215	18,108	27,183	$310.75	$905.42	$1,359.16	$11.50	$33.50	$50.29
13	Deschutes	2,290	5,174	4,565	2,401	14,430	$607	$22.46	2,401	6,966	12,140	$120.04	$348.28	$607.00	$4.44	$12.89	$22.46
14	Kennedy-Goldsborough	1,225	2,332	1,109	386	5,052	$191	$7.08	386	1,495	3,827	$19.29	$74.74	$191.34	$0.71	$2.77	$7.08
15	Kitsap	5,324	11,132	6,286	2,745	25,486	$1,008	$37.30	2,745	9,030	20,162	$137.23	$451.50	$1,008.12	$5.08	$16.71	$37.30
16	Skokomish-Dosewallips	818	634	128	24	1,605	$39	$1.46	24	153	787	$1.22	$7.63	$39.33	$0.04	$0.28	$1.46
17	Quilcene-Snow	1,318	1,991	1,009	367	4,685	$168	$6.23	367	1,376	3,367	$18.37	$68.82	$168.35	$0.68	$2.55	$6.23
18	Elwha-Dungeness	800	3,152	3,322	1,693	8,967	$408	$15.11	1,693	5,015	8,167	$84.66	$250.74	$408.34	$3.13	$9.28	$15.11
19	Lyre-Hoko	310	367	177	31	884	$29	$1.06	31	207	574	$1.54	$10.37	$28.71	$0.06	$0.38	$1.06
Totals		**47,031**	**128,504**	**116,070**	**67,262**	**358,866**	**$15,592**	**$576.89**	**67,262**	**183,331**	**311,835**	**$3,363.08**	**$9,166.56**	**$15,591.75**	**$124.43**	**$339.16**	**$576.89**

Note: Totals for WRIAs are slightly higher than county totals. Two counties (Grays Harbor and Lewis) have relatively small upland areas that contribute to total WRIA acreage but are inconsequential in terms of contribution to impervious areas in the 50 to 100 percent range.

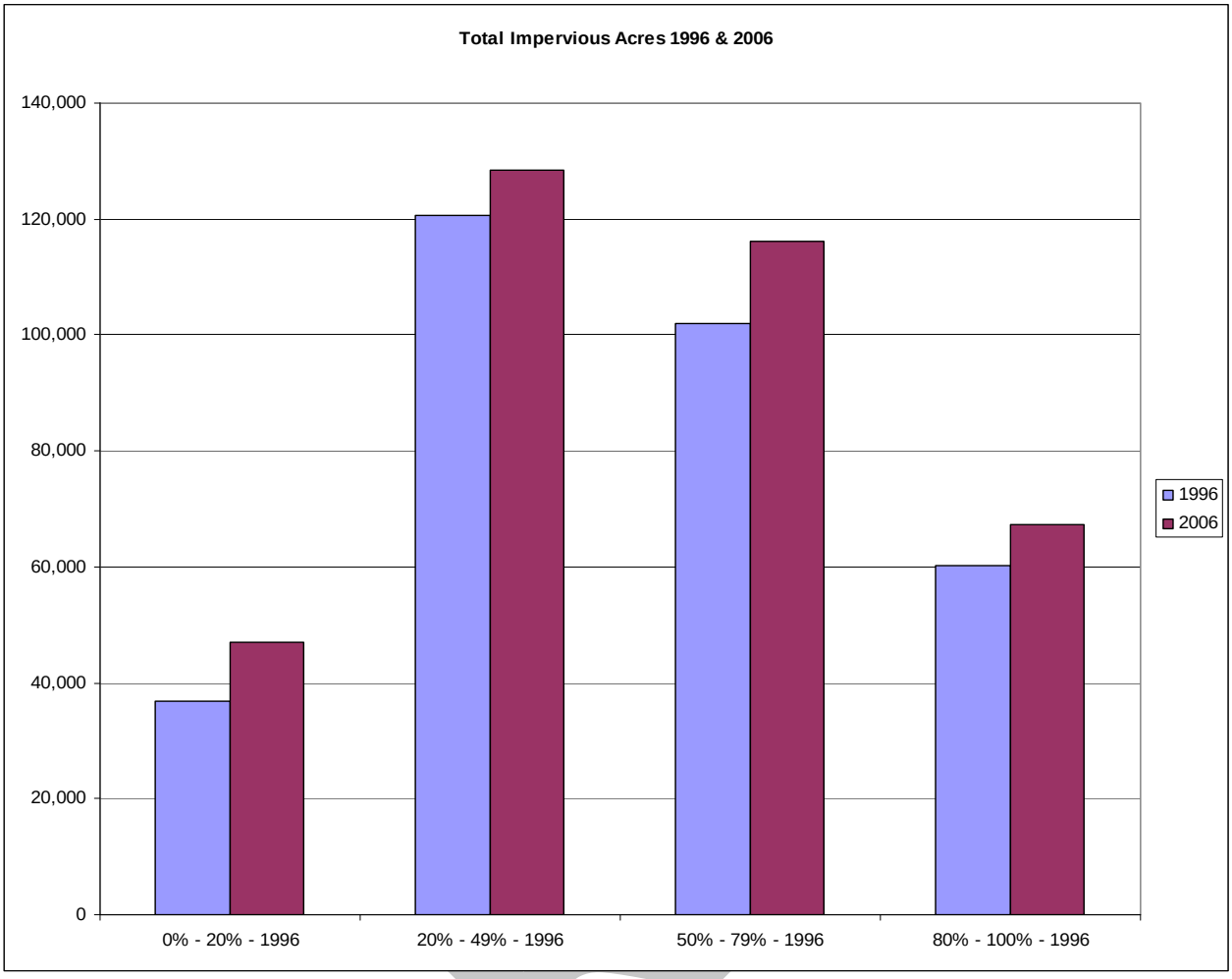

Figure 3-2. Total Impervious Acres 1996 and 2006

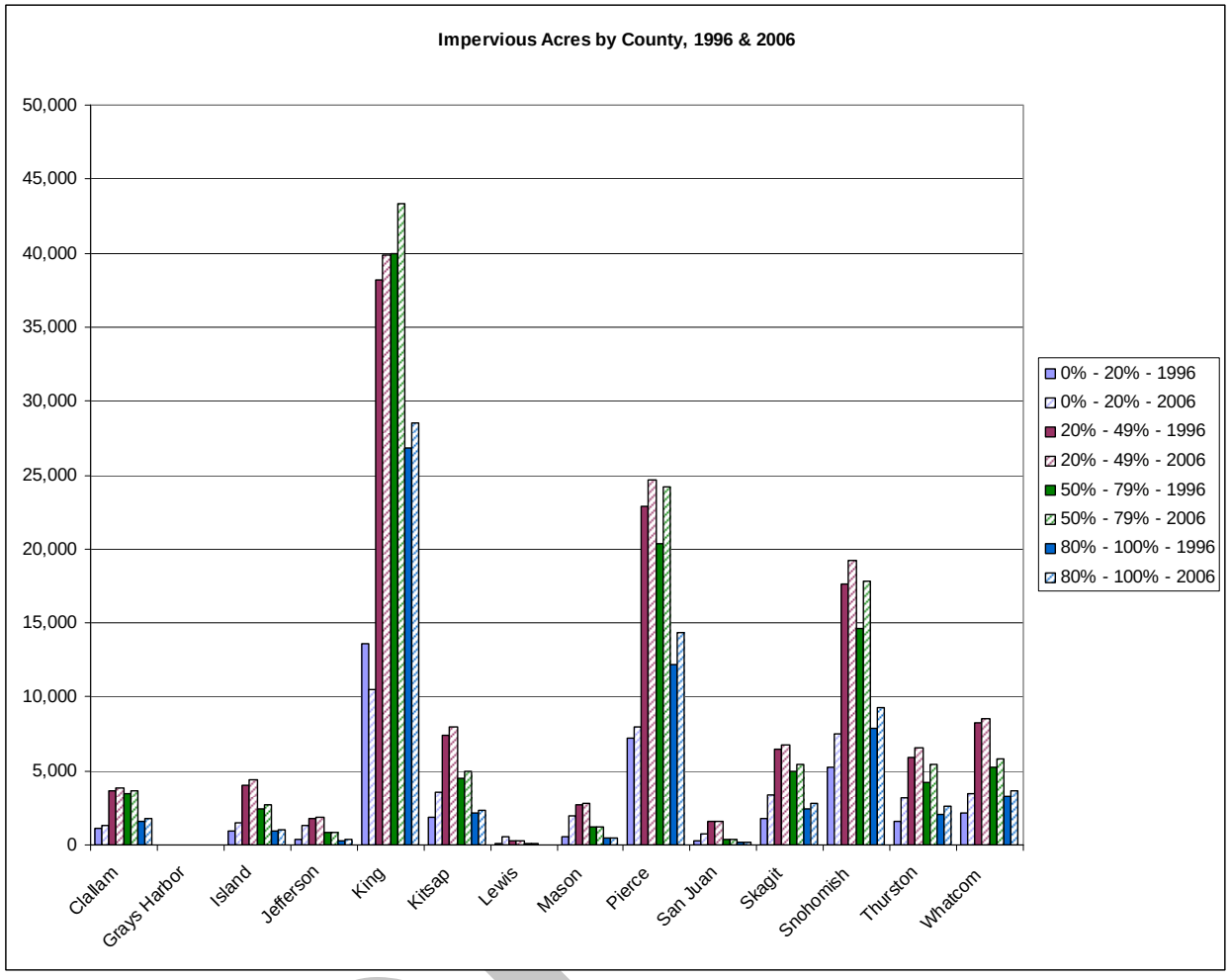

Figure 3-3. Impervious Acres by County 1996 and 2006

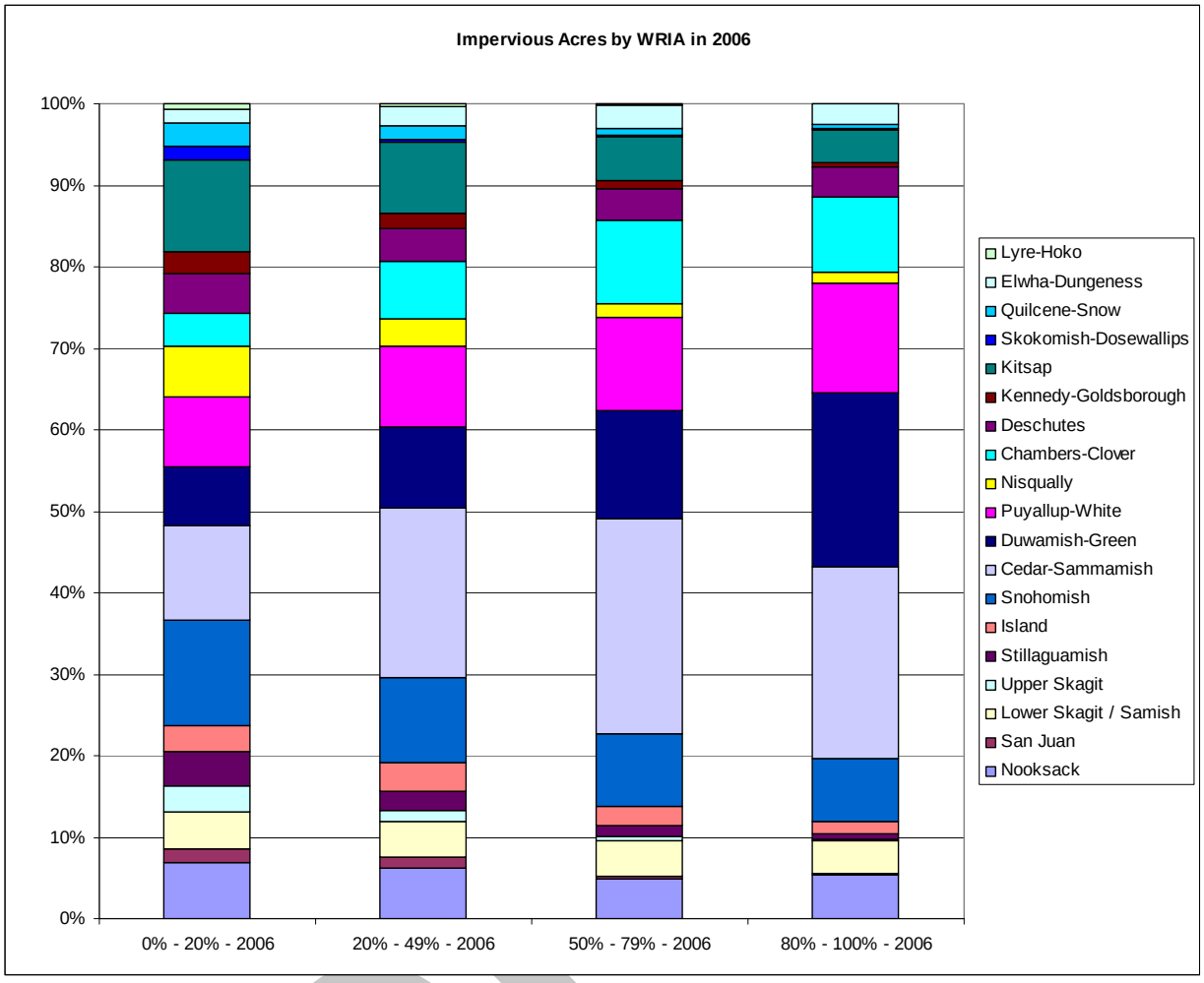

Figure 3-4. Percent of Total Impervious Acres by WRIA in 2006

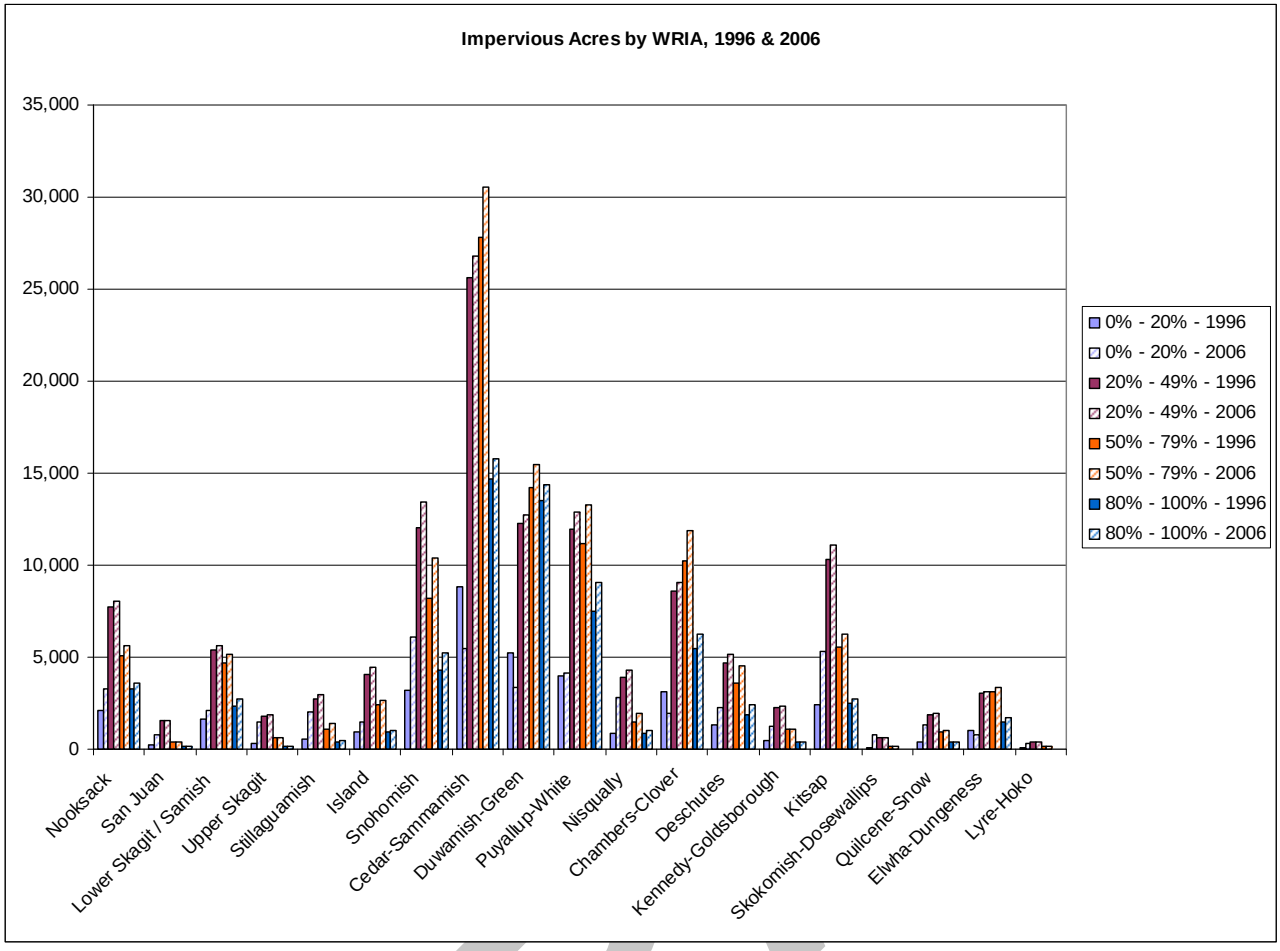

Figure 3-5. Impervious Acres by WRIA, 1996 and 2006

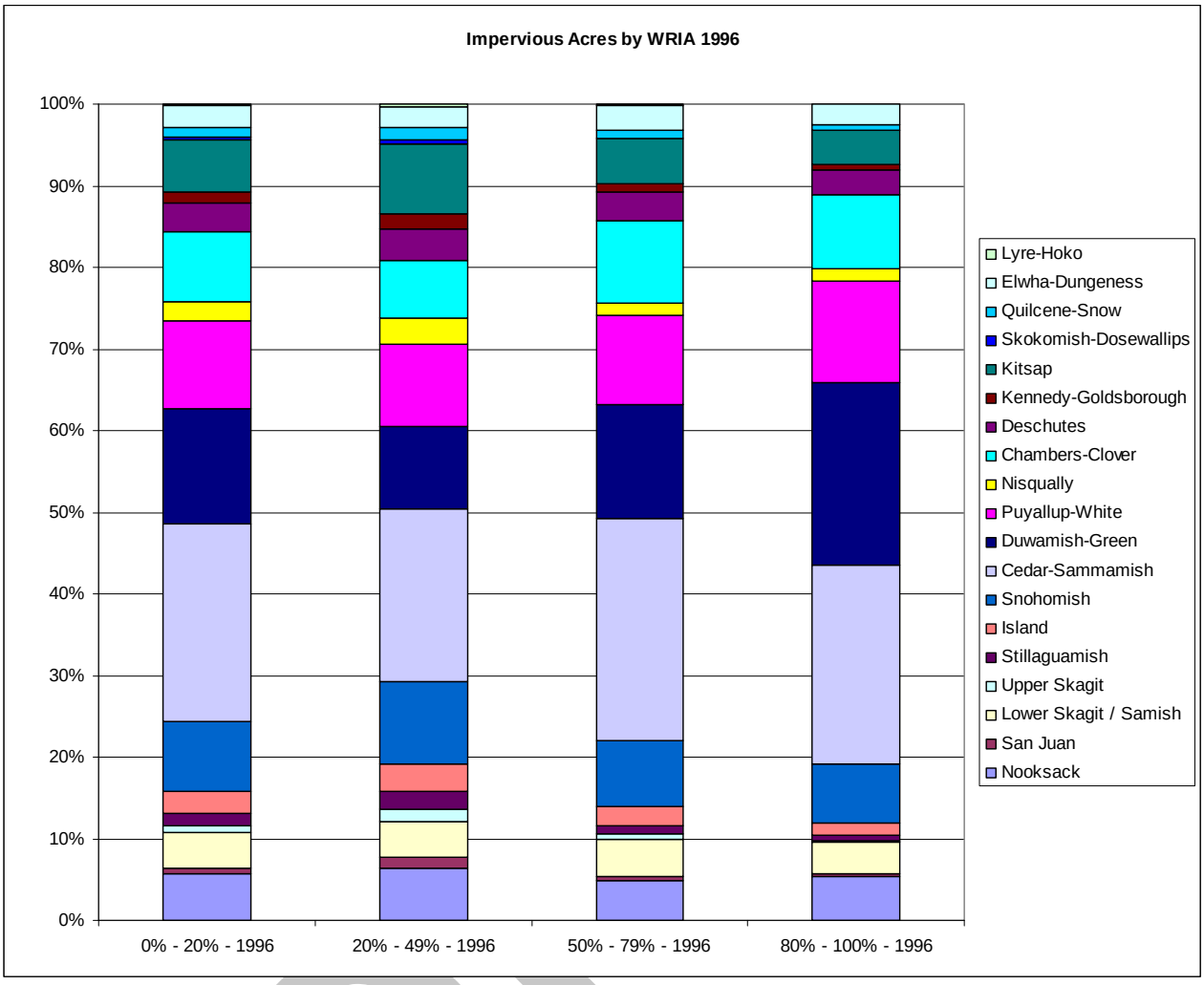

Figure 3-6. Percent of Total Impervious Acres by WRIA in 1996

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4. BENEFITS FROM TREATING UNIT IMPERVIOUS ACRE

4.1 APPROACH

Estimate the water quality benefits from retrofitting pre-1996 impervious surfaces by:

- Presupposing that basic stormwater treatment facilities remove a minimum of 80 percent of the TSS present in stormwater.
- Assigning a mass for additional pollutants adhered and adsorbed to suspended solids.
- Calculating the mass of TSS and associated pollutants removed by retrofitting untreated impervious surfaces to a minimum of basic water quality stormwater treatment.

4.2 ASSUMPTIONS AND LIMITATIONS

- Determining benefits from stormwater treatment requires knowing or assuming:
  - Pre-treatment pollutant concentrations.
  - Pre-treatment pollutant loads.
  - Treatment efficiency in reducing pollutant loads.
  - Post-treatment pollutant concentrations.
  - Adverse pollutant effect concentrations to evaluate improvement in aquatic habitat health.
- Removal efficiencies are applied to load (80 percent removal of mass), not concentrations. However, toxicity (and adverse effect and associated improvement) are concentration-dependent.
- It is not possible to estimate discharge concentrations from stormwater treatment using mass-based percent removal efficiencies.
- WSDOT has adopted an alternative approach of using the statistical distribution of measured discharge concentrations in their Biological Assessment process to overcome this problem. However, use of this approach requires sophisticated statistical manipulations (e.g., Monte Carlo sampling) to develop a range of percentile ranges.
- This problem is compounded when different types of land uses are included, which range in discharge concentrations and levels of variability between sampling events (see Figure 4-1, reproduced from Lee et al. 2007).

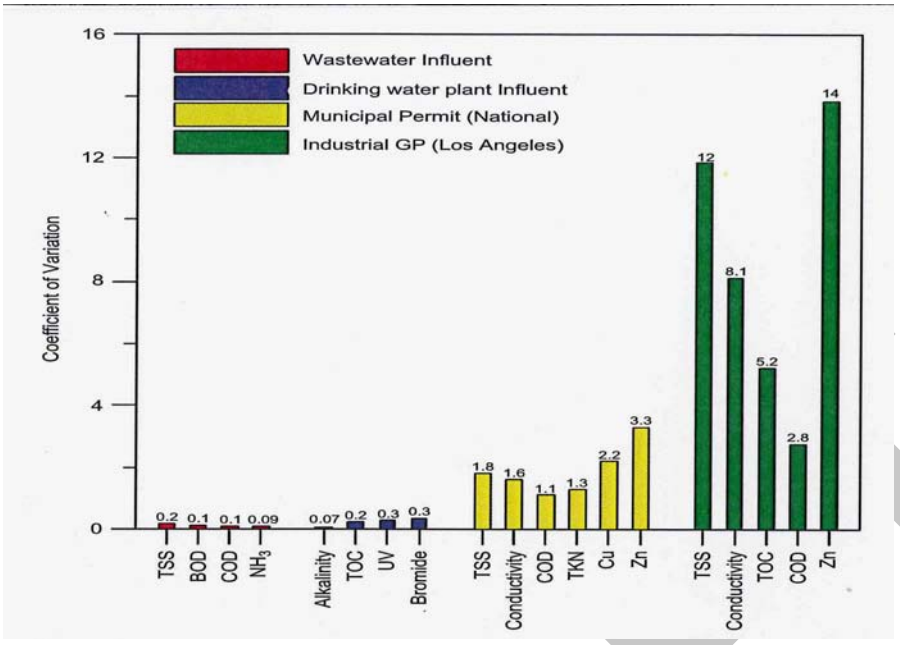

Figure 4-1. Coefficient of Variation in Various Water Sampling Programs for a Large Wastewater Treatment Plant, a Drinking Water Treatment Plant, and Two Stormwater Monitoring Programs, Illustrating the Different Amounts of Variability

Reproduced from Lee et al. (2007). Municipal Permit refers to EPA's Nationwide MS4 permit. Industrial GP is the City of Los Angeles Industrial General Stormwater Permit

- The coefficient of variation (COV), a measure of data dispersion around the mean, in TSS concentrations can range from 1.8 to 12, meaning the standard deviation ranges from 2 to 12 times the mean. For zinc stormwater concentrations, the standard deviation can range from 3 to 14 times the mean.
- Very few studies of the relationship between stormwater solids and adsorbed pollutants are available (Lau and Stenstrom 2005).
- Measured metal and polycyclic aromatic hydrocarbon (PAH) concentrations vary significantly by particle size distribution within measured stormwater solids (reflecting the current controversy as to whether to measure TSS, suspended solids concentrations [SSC], or particle size distribution [PSD] to appropriately characterize stormwater solids).
- Any effort to combine the levels of variability in each data set (TSS, removal efficiencies, PSD, pollutant adsorbed metals) will produce estimates with such a large range of uncertainty as to not allow for any scientifically valid conclusions as to the actual benefit achieved (such as improving water quality in water bodies impaired by stormwater to improve such that they would be removed from the state's 303(d) list). Additionally, such an effort would inevitably invite significant and justified criticism at any effort to directly link retrofitting with predicted improvements in receiving water quality.
- Ongoing effort to create a regional stormwater monitoring program (Puget Sound Stormwater Working Group 2010) is directly aimed at collecting data as to current

trends in Puget Sound water bodies and to determine treatment effectiveness. Field collected data will provide the specific types of information necessary to monitor the benefit of any retrofit program.

4.3 ANALYSIS

- The following can be said with relative certainty concerning the potential benefit of retrofitting for stormwater treatment:
  1. Retrofitting currently untreated stormwater with basic water quality treatment facilities will reduce large quantities of solids (in tons) moving from land to adjacent water bodies (see following analysis for an exercise in estimating the possible range of solids removal to be achieved by such an effort).
  2. Suspended solids in stormwater are associated with both heavy metals and PAHs.
  3. Removing suspended solids will remove associated and adsorbed metals and PAHs.
  4. TSS is not a significant component of aquatic toxicity associated with stormwater (for example, Ecology has not adopted a standard for TSS, instead regulating turbidity as the adverse effect of suspended solids in aquatic systems). Pollutants associated with solids—heavy metals and PAHs—are chemicals of concern in stormwater that are associated with degradation and impairment of Puget Sound aquatic habitats.
  5. Removing suspended solids from stormwater will, at a minimum, remove solid-associated pollutants.
- The magnitude of the solids removal that could be achieved from retrofitting the 50 percent to 100 percent impervious surface acreage in the Puget Sound Action area can be demonstrated by this exercise:
  - Establish a range of possible TSS concentrations from measured data (based on data from Han et al. 2006).

Constituent	Low Concentration	High Concentration
TSS	68 mg/L	360 mg/L

  - Determine the volume of water generated from an acre of 100 percent impervious surface (assuming no infiltration) in a year of average rainfall in the Puget Sound Lowlands.
  - Multiply concentrations by water volume to determine the low and high levels of TSS present in untreated stormwater per acre per year.
  - Multiply untreated low and high estimates by 20 percent to estimate the amounts of TSS that would remain present in treated low and high discharges, assuming 80 percent removal rates.

In summary, Tables 4-1 through 4-5 show levels of TSS removed annually by county, retrofit facilities, and WRIA, as well as the potential costs of removing TSS by county and WRIA. In addition, Tables 4-6 and 4-7 provide details on the amount of TSS in treated and untreated stormwater in a 2-year design storm by county and WRIA.

Table 4-1. Low and High Levels of TSS Removal Potentially Generated Annually from 1 Acre with 100 Percent Impervious Coverage by County

County	Untreated Tons (TSS – low)	Treated Tons (TSS – low)	Untreated Tons (TSS – High)	Treated Tons (TSS – High)
Clallam	2,722	545	14,411	2,883
Island	2,307	462	12,214	2,443
Jefferson	913	183	4,834	967
King	32,878	6,575	174,059	34,812
Kitsap	4,413	883	23,359	4,672
Mason	1,358	271	7,187	1,437
Pierce	17,375	3,474	91,986	18,398
San Juan	659	132	3,491	698
Skagit	4,327	865	22,906	4,581
Snohomish	12,575	2,515	66,575	13,315
Thurston	3,815	763	20,199	4,040
Whatcom	5,253	1,051	27,806	5,561
Totals	**88,592**	**17,720**	**469,026**	**93,806**

Table 4-2. Potential Costs of Removing TSS (Low and High Estimates) by County

	LOW ESTIMATE					HIGH ESTIMATE					AVERAGE ESTIMATE OF TSS REMOVED (TSS)		
County	Tons of Untreated Water (TSS – low)	Tons of TSS Remaining in Treated Water (TSS – low)	Treated Tons Removed (Low)	Capital Cost ($1M) per treated ton*imp ac	Annual Cost ($1M) per treated ton*imp ac	Tons of Untreated Water (TSS – High)	Tons of TSS Remaining in Treated Water (TSS – high)	Treated Tons Removed (high)	Capital Cost ($1M) per treated ton*imp ac	Annual Cost ($ per treated ton*imp ac)	Average Estimate of TSS Removed (TSS)	Average Estimate of Capital Cost per Ton TSS Removed ($M/Ton)	Average Estimate of Maintenance Cost per Ton TSS Removed ($M/Ton)
Clallam	2,722	545	2,177	0.115	0.004	14,411	2,883	11,528	0.022	0.001	68,53	0.069	0.003
Island	2,307	462	1,845	0.090	0.003	12,214	2,443	9,771	0.017	0.001	5,808	0.053	0.002
Jefferson	913	183	730	0.079	0.003	4,834	967	3,867	0.015	0.001	2,298	0.047	0.002
King	32,878	6,575	26,302	0.127	0.005	174,059	34,812	139,247	0.024	0.001	82,775	0.075	0.003
Kitsap	4,413	883	3,530	0.094	0.003	23,359	4,672	18,687	0.018	0.001	11,109	0.056	0.002
Mason	1,358	271	1,087	0.074	0.003	7,187	1,437	5,750	0.014	0.001	3,418	0.044	0.002
Pierce	17,375	3,474	13,900	0.117	0.004	91,986	18,398	73,588	0.022	0.001	43,744	0.070	0.003
San Juan	659	132	527	0.052	0.002	3,491	698	2,793	0.010	0.000	1,660	0.031	0.001
Skagit	4,327	865	3,461	0.106	0.004	22,906	4,581	18,325	0.020	0.001	10,893	0.063	0.002
Snohomish	12,575	2,515	10,060	0.112	0.004	66,575	13,315	53,260	0.021	0.001	31,660	0.066	0.002
Thurston	3,815	763	3,052	0.102	0.004	20,199	4,040	16,159	0.019	0.001	9,606	0.061	0.002
Whatcom	5,253	1,051	4,202	0.102	0.004	27,806	5,561	22,245	0.019	0.001	13,223	0.060	0.002
Totals	**88,592**	**17,720**	**70,874**	**0.114**	**0.004**	**469,026**	**93,806**	**375,220**	**0.022**	**0.001**	**223,047**	**0.068**	**0.003**

Table 4-3. Average Cost for TSS Removed through Retrofit Facilities

Average Estimate of TSS Removed (TSS)	Average Estimate of Capital Cost per Ton TSS Removed ($M/Ton)	Average Estimate of Maintenance Cost per Ton TSS Removed ($M/Ton)
$223,335	$0.068	$0.003

Table 4-4. Low and High Levels of TSS Removal Potentially Generated Annually from 1 Acre with 100 Percent Impervious Coverage by WRIA

WRIA No.	WRIA Name	Untreated Tons (TSS – low)	Treated Tons (TSS – low)	Untreated Tons (TSS – High)	Treated Tons (TSS – High)
1	Nooksack	5,019	1,004	26,570	5,314
2	San Juan	659	132	3,491	698
3	Lower Skagit / Samish	3,883	777	20,560	4,112
4	Upper Skagit	796	159	4,212	842
5	Stillaguamish	1,330	266	7,045	1,409
6	Island	2,307	462	12,214	2,443
7	Snohomish	7,696	1,539	40,744	8,148
8	Cedar-Sammamish	21,363	4,273	113,098	22,619
9	Duwamish-Green	12,534	2,507	66,357	13,272
10	Puyallup-White	9,621	1,925	50,937	10,188
11	Nisqually	1,980	396	10,482	2,097
12	Chambers-Clover	7,615	1,523	40,316	8,063
13	Deschutes	3,166	633	16,760	3,352
14	Kennedy-Goldsborough	1,161	233	6,143	1,229
15	Kitsap	5,771	1,154	30,553	6,110
16	Skokomish-Dosewallips	240	49	1,273	255
17	Quilcene-Snow	995	200	5,270	1,054
18	Elwha-Dungeness	2,404	481	12,731	2,546
19	Lyre-Hoko	171	34	907	182
Totals		**88,712**	**17,744**	**469,662**	**93,932**

Note: Totals for WRIAs are slightly higher than county totals. Two counties (Grays Harbor and Lewis) have relatively small upland areas that contribute to total WRIA acreage but are inconsequential in terms of contribution to impervious areas in the 50 to 100 percent range.

Table 4-5. Potential Costs of Removing TSS (Low and High Estimates) by WRIA

	LOW ESTIMATE					HIGH ESTIMATE					AVERAGE ESTIMATE OF TSS REMOVED (TSS)		
WRIA Name	Tons of Untreated Water (TSS – low)	Tons of TSS Remaining in Treated Water (TSS – low)	Treated Tons Removed (Low)	Capital Cost ($1M) per treated ton*imp ac	Annual Cost ($1M) per treated ton*imp ac	Tons of Untreated Water (TSS – high)	Tons of TSS Remaining in Treated Water (TSS – high)	Treated Tons Removed (high)	Capital Cost ($1M) per treated ton*imp ac	Annual Cost ($1M) per treated ton*imp ac	Average Estimate of TSS Removed (TSS)	Average Estimate of Capital Cost per Ton TSS Removed ($M/Ton)	Average Estimate of Maintenance Cost per Ton TSS Removed ($M/Ton)
Nooksack	5,019	1,004	4,015	0.115	0.004	26,570	5,314	21,256	0.022	0.001	12,635	0.068	0.003
San Juan	659	132	527	0.053	0.002	3,491	698	2,793	0.010	0.000	1,660	0.031	0.001
Lower Skagit / Samish	3,883	777	3,106	0.126	0.005	20,560	4,112	16,449	0.024	0.001	9,778	0.075	0.003
Upper Skagit	796	159	637	0.062	0.002	4,212	842	3,370	0.012	0.000	2,003	0.037	0.001
Stillaguamish	1,330	266	1,065	0.089	0.003	7,045	1,409	5,636	0.017	0.001	3,350	0.053	0.002
Island	2,307	462	1,845	0.100	0.004	12,214	2,443	9,771	0.019	0.001	5,808	0.059	0.002
Snohomish	7,696	1,539	6,158	0.127	0.005	40,744	8,148	32,595	0.024	0.001	19,376	0.076	0.003
Cedar-Sammamish	21,363	4,273	17,090	0.135	0.005	113,098	22,619	90,479	0.026	0.001	53,785	0.080	0.003
Duwamish-Green	12,534	2,507	10,028	0.149	0.005	66,357	13,272	53,085	0.028	0.001	31,556	0.088	0.003
Puyallup-White	9,621	1,925	7,696	0.145	0.005	50,937	10,188	40,749	0.027	0.001	24,223	0.086	0.003
Nisqually	1,980	396	1,584	0.094	0.003	10,482	2,097	8,385	0.018	0.001	4,985	0.056	0.002
Chambers-Clover	7,615	1,523	6,091	0.149	0.005	40,316	8,063	32,253	0.028	0.001	19,172	0.088	0.003
Deschutes	3,166	633	2,533	0.137	0.005	16,760	3,352	13,407	0.026	0.001	7,970	0.082	0.003
Kennedy-Goldsborough	1,161	233	928	0.081	0.003	6,143	1,229	4,914	0.015	0.001	2,921	0.048	0.002
Kitsap	5,771	1,154	4,616	0.098	0.004	30,553	6,110	24,443	0.018	0.001	14,530	0.058	0.002
Skokomish-Dosewallips	240	49	192	0.040	0.001	1,273	255	1,019	0.007	0.000	605	0.024	0.001
Quilcene-Snow	995	200	796	0.086	0.003	5,270	1,054	4,216	0.016	0.001	2,506	0.051	0.002
Elwha-Dungeness	2,404	481	1,924	0.130	0.005	12,731	2,546	10,184	0.025	0.001	6,054	0.077	0.003
Lyre-Hoko	171	34	137	0.076	0.003	907	182	725	0.014	0.001	431	0.045	0.002
Totals	**88,712**	**17,744**	**70,968**	**0.129**	**0.005**	**469,662**	**93,932**	**375,729**	**0.024**	**0.001**	223,349	0.077	0.003

Note: Totals for WRIAs are slightly higher than county totals. Two counties (Grays Harbor and Lewis) have relatively small upland areas that contribute to total WRIA acreage but are inconsequential in terms of contribution to impervious areas in the 50 to 100 percent range.

Table 4-6. Amount of Total Suspended Solids in the Volume of Treated and Untreated Stormwater in a 2-Year Design Storm by County

County	Untreated Tons (TSS – low)	Treated Tons (TSS – low)	Untreated Tons (TSS – High)	Treated Tons (TSS – High)
Clallam	521	105	2,763	552
Island	442	88	2,341	468
Jefferson	175	35	927	185
King	6,304	1,261	33,374	6,674
Kitsap	845	169	4,479	896
Mason	260	52	1378	276
Pierce	3,331	666	17,637	3,527
San Juan	127	25	669	133
Skagit	830	166	4,392	879
Snohomish	2,411	482	12,765	2,553
Thurston	732	147	3,872	775
Whatcom	1,008	202	5,332	1,066
Totals	**16,987**	**3,398**	**89,929**	**17,985**

Table 4-7. Amount of Total Suspended Solids in the Volume of Treated and Untreated Stormwater in a 2-Year Design Storm by WRIA

WRIA No.	WRIA Name	Untreated Tons (TSS – low)	Treated Tons (TSS – low)	Untreated Tons (TSS – High)	Treated Tons (TSS – High)
1	Nooksack	962	193	5,095	1,019
2	San Juan	127	25	669	133
3	Lower Skagit/Samish	744	149	3,942	788
4	Upper Skagit	152	31	808	162
5	Stillaguamish	255	51	1,350	270
6	Island	442	88	2,341	468
7	Snohomish	1,476	295	7,812	1,562
8	Cedar-Sammamish	4,096	819	21,685	4,336
9	Duwamish-Green	2,403	481	12,723	2,544
10	Puyallup-White	1,845	369	9,766	1,953
11	Nisqually	379	76	2,010	402
12	Chambers-Clover	1,461	292	7,731	1,547
13	Deschutes	607	121	3,213	643
14	Kennedy-Goldsborough	223	44	1,177	236
15	Kitsap	1,107	222	5,858	1,172
16	Skokomish-Dosewallips	46	9	244	49
17	Quilcene-Snow	191	39	1,011	202
18	Elwha-Dungeness	461	93	2,441	488
19	Lyre-Hoko	33	7	174	35
	Totals	**17,010**	**3,403**	**90,049**	**18,010**

Note: Totals for WRIAs are slightly higher than county totals. Two counties (Grays Harbor and Lewis) have relatively small upland areas that contribute to total WRIA acreage but are inconsequential in terms of contribution to impervious areas in the 50 to 100 percent range.

4.4 FINDINGS AND RECOMMENDATIONS

- Stormwater concentrations are so variable as to make development of a specific benefit (such as the reduction of copper concentrations in Puget Sound lowland streams) infeasible.
- Treatment percent removal efficiencies are used to estimate loads, while impairment and toxicity are the result of concentrations, further hampering any effort to estimate the resulting concentrations in receiving environment.
- Calculating amounts of load reduction does not allow for any estimate of whether waters would then meet state water quality standards.
- Calculating amounts of load reduction does provide an estimate of how much less pollutants will be moving into waterways of Puget Sound. Retrofitting currently untreated stormwater with basic water quality treatment facilities will reduce large quantities of solids (in tons) moving from land to adjacent water bodies (see

Section 4.3 for an exercise in estimating the possible range of solids removal to be achieved by such an effort).

- Suspended solids in stormwater are associated with both heavy metals and PAHs.
- Removing suspended solids will remove associated and adsorbed metals and PAHs.
- TSS is not a significant component of aquatic toxicity associated with stormwater (for example, Ecology has not adopted a standard for TSS, instead regulating turbidity as the adverse effect of suspended solids in aquatic systems). Pollutants associated with solids—heavy metals and PAHs—chemicals of concern in stormwater that are associated with degradation and impairment of Puget Sound aquatic habitats.
- Removing suspended solids from stormwater will, at a minimum, remove solid-associated pollutants.

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5. COMPARABLE WATER QUALITY RETROFIT EFFORTS

This section provides a snapshot of the federal investment in other infrastructure to achieve significant progress toward clean water.

5.1 FEDERAL INVESTMENT IN WASTEWATER TREATMENT

- Upgrading public wastewater treatment systems from primary to secondary and secondary to tertiary, where needed, including investments from 1970 to 1995 of $61.1 billion in Federal Construction Grants Program funds and from 1970 to 1988 $16.1 billion in State Revolving Loan Funds.
- The total national capital investment in this time frame (1970 to 1995) was well over $200 billion with a comparable amount for operations and maintenance.

Figure 5-1 depicts annual funding provided by construction grants from the U.S. Environmental Protection Agency (EPA) and Clean Water State Revolving Fund (CWSRF) programs (1970 to 1999) to assist municipalities with constructing infrastructure for water pollution control.

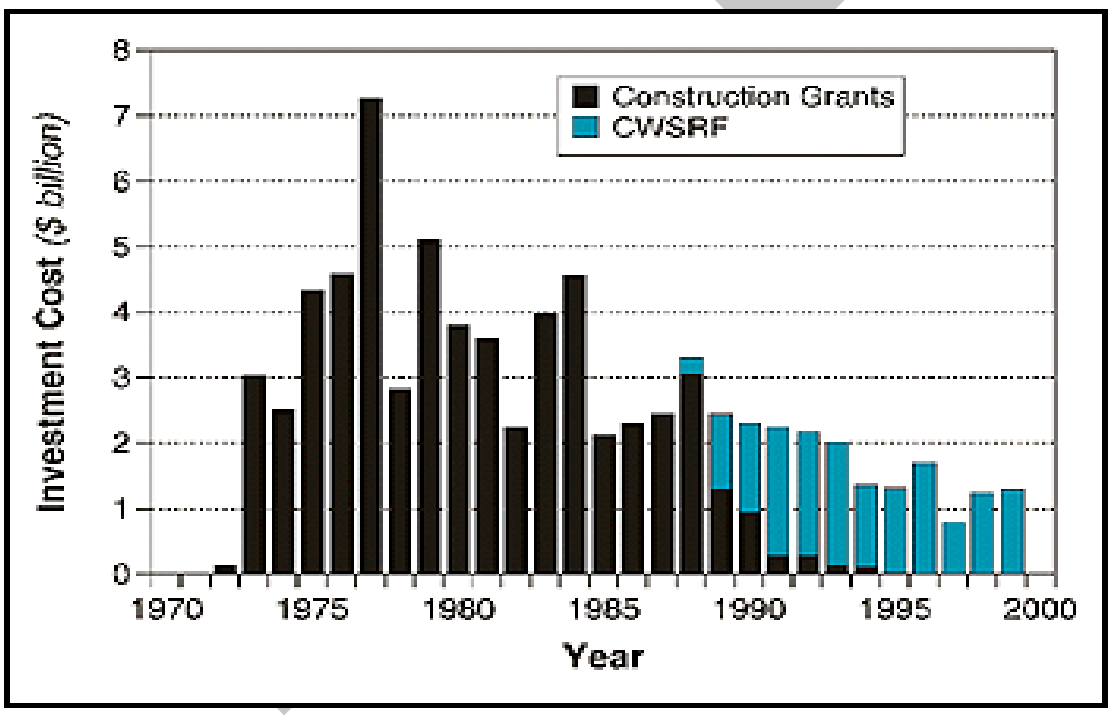

Figure 5-1. Annual Funding Provided by EPA's Construction Grants and CWSRF Programs to local municipalities for improvements in water pollution control infrastructure from 1970 to 1999. Costs reported in current year dollars.

5.2 CONVERTING PUGET SOUND SEPTIC SYSTEMS TO SEWER

Table 5-1 provides a coarse-grained analysis of converting from on-site wastewater disposal to a publicly owned wastewater treatment system using the LOTT system as a reference

point. Table 5-2 presents data on the number of households in Puget Sound converting from septic to sewer systems.

Table 5-1. On-site to Public Sewer System Conversion

	PURPOSE	COST ESTIMATE[a]
1.	Public Sewer Infrastructure (if not existing)	$15,000–$22,000+
2.	Side Sewer Construction to House (double if pump is needed)	$2,500–$3,500
3.	Septic Tank Abandonment	$800–$1,200
4.	Connection Fees	$4,091
	LOTT Alliance GFC (Treatment Plant)	Waived[b]
	City Wastewater GFC	$140–$750
	Permits for Sewer Connection Fees (Subtotal)	$4,230–$4,840
	Total:	**$7,500–$33,000+**

[a] The above estimates were made in 2010 and should be adjusted accordingly.

[b] The City Wastewater General Facilities Charge (GFC) is waived per OMC 13.08.205(C) for properties with an existing septic system that connects to the sewer system within 2 years following notice of sewer availability.

Table 5-2. Converting Puget Sound Households from Septic to Sewer

Number of households using septic systems in Puget Sound (including Hood Canal) = One-Third[a]	2000	2008
Total households[b]	1,283,000.00	1,435,087.00
Households with septic systems	423,390.00	473,578.71
Conversion of Septic to Sewer (Low Range) = $7,500/household[c]	$3,175,425,000.00	$3,551,840,325.00
Conversion of Septic to Sewer (High Range) = $33,000/household[c]	$13,971,870,000.00	$15,628,097,430.00

[a] Puget Sound Partnership estimate <http://www.psparchives.com/puget_sound/psfacts.htm>.

[b] Puget Sound Regional Council data <http://www.psrc.org/data/regionalprofile/regionalprofile-pop>.

[c] Based on 2010 estimates from City of Olympia.

5.3 REFERENCES

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