Appendix G. Alternative Method for Computing Watershed Scale Load Estimates

The project team considered two methods for computing watershed scale absolute load estimates for the Phase 3 study of toxics in surface runoff to Puget Sound.

The preferred method was selected by the project team for use in this study because it is broadly used in other contaminant loading studies that are cited in the literature. In the preferred method, load estimates are derived by multiplying unit-area loading rates for each parameter, land use, and watershed combination by the area represented by that land use in each watershed. The unit-area loading rates in these calculations were derived from the subbasin-scale loading analysis that was performed for this study. This method is described in detail within the main text of this document. The load estimates that were computed using this method are also presented and discussed in detail within the main text.

This memorandum presents the alternative method for computing watershed scale load estimates that was considered by the project team during the planning phase of this study. This method uses mean annual runoff volumes from a hydrologic model that was developed for the Phase 2 study (Herrera 2010) of toxics in surface runoff to Puget Sound. A description of the computational steps that are performed in this method is provided below. Results for a subset of parameters are then compared to the results that were obtained using the preferred method.

Computational Steps

As noted above, this method of computing watershed scale load estimates uses mean annual runoff volumes from a hydrologic model that was developed for the Phase 2 study (Herrera 2010) of toxic loadings to Puget Sound.

This model computes mean annual runoff volumes for each land use as the difference between mean annual precipitation and mean annual evapotranspiration. This subtraction is completed in a spatially distributed form using GIS analyses to generate a Puget Sound map of mean annual runoff volumes. The precipitation map used in the GIS analysis is the Parameter-elevation Regressions on Independent Slopes Model (PRISM) annual average precipitation map for the Puget Sound region (Daly et al. 1994).

The actual evapotranspiration (AET) map used in this analysis was derived from outputs of a Variable Infiltration Capacity (VIC) model implementation developed by the University of Washington Climate Impacts Group (UW-CIG). The VIC model domain did not cover some parts of the Puget Sound Basin, most notably islands within the Puget Sound. For these areas, a constant evapotranspiration rate of 432 millimeters (17 inches) per year was applied based on a median AET value calculated from representative AET data for Puget Sound lowland watersheds (see Table 4 in Vaccaro et al. 1998).

Since runoff was calculated by subtracting AET (a positive quantity) from precipitation, there were some areas where the runoff value exceeded the precipitation value. In these areas, the mean annual runoff depth was set to zero. A more detailed description of this model is available in Herrera (2010).

The final runoff raster computed based on these steps is shown in Figure G-1. Within each individual watershed, the mean annual runoff depths were then disaggregated by land use and converted to a runoff volume for each land use based on its area. These mean annual runoff volumes are shown in Table G-1 for the Snohomish watershed and Puyallup watershed, respectively.

Table G-1. Mean annual runoff rates by land-use type in the Snohomish watershed and Puyallup watershed.

	Runoff Volume (cubic meters/year)		
Land Use	**Mean Annual [a]**	**Mean Annual [b] Baseflow**	**Mean Annual [b] Storm Event**
Snohomish Watershed			
Commercial	11,845,309	2,493,816.4	9,351,493.1
Residential	412,445,813	171,259,907.8	241,185,905.7
Agricultural	87,475,553	35,641,634.5	51,833,918.5
Forest	8,150,142,288	4,320,227,526.0	3,829,914,762.3
Puyallup Watershed			
Commercial	19,532,524	4,679,996.9	14,852,527.2
Residential	250,607,475	124,896,109.4	125,711,365.9
Agricultural	41,814,917	12,214,320.3	29,600,596.3
Forest	2,649,544,068	1,090,911,384.3	1,558,632,684.0

[a] Mean annual runoff volumes from a hydrologic model that was developed for the Phase 2 study (Herrera 2010) of toxic loadings to Puget Sound.

[b] Mean annual baseflow and storm event runoff volumes derived using percentages identified in Table G-2 from monitoring conducted at the subbasin scale for the Phase 3 study of toxic chemicals in surface runoff to Puget Sound.

To compute loading estimates from these mean annual runoff volumes for the Phase 3 study, we determined the proportion of the runoff volume in each watershed that is represented by baseflow and storm events using data obtained from the representative monitoring locations for each land use in each watershed.

To perform this task, we processed the continuous discharge data for each monitoring location using a hydrograph separation algorithm (Herrera 2007) to identify the baseflow and storm-event components of the hydrograph (see more detailed description of this process in the main text). We then pooled data from the individual monitoring locations to determine the percentage of total flow that is represented by baseflow and storm events for each land use in each watershed.

For example, to determine the percentage of total flow that is represented by baseflow and storm events for commercial land use in the Snohomish watershed, we pooled the data from the two monitoring locations for commercial land use in that watershed (CB335 and CBX). The percentages that were derived for each land use and watershed combination using this approach are summarized in Table G-2. We then applied these percentages to the mean annual runoff volumes for the Snohomish watershed and Puyallup watershed shown in Table G-1 to determine the proportion of this flow that is associated with baseflow and storm events, respectively; these data are also shown in Table G-1.

Table G-2. Percentage of total flow that is represented by baseflow and storm events by land-use type in the Snohomish watershed and Puyallup watershed.

Land Use	Volume (percent)	
	Baseflow	Storm Event
Snohomish Watershed		
Commercial	21.1%	78.9%
Residential	41.5%	58.5%
Agricultural	40.7%	59.3%
Forest	53.0%	47.0%
Puyallup Watershed		
Commercial	24.0%	76.0%
Residential	49.8%	50.2%
Agricultural	29.2%	70.8%
Forest	41.2%	58.8%

We then computed absolute loads for the baseflow component of the total runoff volume for each watershed by multiplying the baseflow volumes shown in Table G-1 by representative concentrations obtained from samples collected during baseflow. Similarly, we computed absolute loads for the storm-event component of the total runoff volume by multiplying the storm-event volumes shown in Table G-1 by representative concentrations obtained from samples collected during storm events.

In all these calculations, the following summary statistics were used as representative concentrations for each grouping of data: minimum, 25th percentile, median, 75th percentile, and maximum. We computed and qualified the summary statistics based on the following rules:

- If all data were non-detect values, we only reported the following summary statistics: number of samples, minimum reporting limit, maximum reporting limit, percentage of non-detect values (100 percent in all cases), and maximum value. The maximum value was assigned the same value as the maximum reporting limit and qualified with a less than (<) sign. All summary statistics were also assigned a “U” qualifier to indicate there were no detected values in the data.
- If there were detected values in the data, but the percentage of non-detect values represented 50 percent or more of the data, we computed all summary statistics identified above by assigning a value of one-half the maximum reporting limit to the non-detect values. All summary statistics were assigned an “E” qualifier to indicate they are estimates with relatively low accuracy due to the high number of non-detect values.

- If the percentage of non-detect values represented less than 50 percent of the data, we computed all summary statistics identified above by assigning a value of one-half the maximum reporting limit to the non-detect values. All summary statistics were then reported without qualification.

To account for bias that might be introduced in the load estimates due to non-detect values in the concentration data, we computed and qualified the load estimates based on the following rules:

- If all the concentration data were non-detect values, we computed the absolute load estimates based on the maximum reporting limit from the data. These absolute load estimates were qualified with a less than (<) sign. A "U" qualifier was also assigned to these load estimates to indicate there were no detected values in the concentration data.
- If there were detected values in the concentration data but the percentage of non-detect values represented 50 percent or more of the data, we computed the absolute load estimates based on all summary statistics identified above. All computed loads were assigned an "E" qualifier to indicate they are estimates with relatively low accuracy due to the high number of non-detect values in the concentration data.
- If the percentage of non-detect values represented less than 50 percent of the data, we computed the absolute load estimates based on all summary statistics identified above. All the computed load estimates were then reported without qualification.

Summary of Results

Tables G-3, G-4, and G-5 present the absolute load estimates for total zinc, total PCBs, and total suspended solids, respectively, that were derived using the alternate method described in the preceding section. Table G-6 compares the load estimates for these parameters (based on median concentration values) to estimates that were derived using the preferred method from the main text of this document.

Across all three parameters, Table G-6 shows that load estimates derived using the alternative method were consistently higher than those from the preferred method for all the land uses in the Snohomish watershed except commercial. In the Puyallup watershed, load estimates derived using the alternative method were consistently higher than those from the preferred method for the residential and forest land uses only.

Across both watersheds, the largest differences in load estimates between the alternative and preferred methods were observed for forest land use. For example, the root mean square error between the total zinc load estimates that were derived using the alternative and preferred methods was 2,276 kg/year for forest land use. In comparison, the root mean square error between the load estimates for the other three land uses ranged from 60 to 308 kg/year. This same pattern was also observed for total PCBs and total suspended solids (Table G-6).

The higher load estimates for forest land use from the alternative method are related to the higher runoff volumes that are calculated for forest land areas relative to the other land uses using the hydrologic model that was developed for the Phase 2 study. Specifically, higher elevation forest areas tend to receive more rainfall relative to developed lowland area; therefore, runoff estimates

Table G-3. Total zinc absolute loading rates (kg/year) by land use for the Snohomish watershed and Puyallup watershed.

Land Use	Baseflow							Storm Event						
	n	Minimum	25th Percentile	Median	75th Percentile	Maximum	Non-Detect Frequency Flag	n	Minimum	25th Percentile	Median	75th Percentile	Maximum	Non-Detect Frequency Flag
Snohomish Watershed														
Commercial	3	30	32	40	45	46		12	320	344	441	517	630	
Residential	4	428	428	428	839	1,267	E	12	603	965	2,026	2,629	3,449	
Agricultural	4	89	164	378	1,504	2,495		12	130	363	456	513	2,763	
Forest	4	10,801	10,801	10,801	22,033	33,266	E	12	9,575	9,575	9,575	9,575	71,619	E
Puyallup Watershed														
Commercial	3	42	50	75	109	120		12	229	475	502	575	804	
Residential	4	312	312	312	537	762	E	12	314	314	742	955	1,320	
Agricultural	4	31	31	82	145	158	E	12	74	201	329	684	1,865	
Forest	4					<5,455	U	12	3,897	3,897	3,897	3,897	33,978	E

kg/year: kilograms per year.

n: water quality sample size.

Non-detect frequency flag:

E: 50 percent or less of the data are detected values; reported values are considered estimates with relatively low accuracy.

U: None of the data are detected values; reported values were computed based on the maximum reporting limit..

Table G-4. Total PCBs absolute loading rates (g/year) by land use for the Snohomish watershed and Puyallup watershed.

Land Use	n	Baseflow						Storm Event						
		Mini-mum	25th Percentile	Median	75th Percentile	Maxi-mum	Non-Detect Frequency Flag	n	Mini-mum	25th Percentile	Median	75th Percentile	Maxi-mum	Non-Detect Frequency Flag
Snohomish Watershed														
Commercial	3	0.27	0.43	0.9	2.8	3.4		6	1.2	8.2	61	123	256	
Residential	4	1.6	1.7	3	36	68	E	6	11	24	66	278	454	
Agricultural	4	0.36	0.9	2.5	7.5	11	E	2	3.7		5.5		7	
Forest	4	48	80	272	1,004	1,577		6	38	136	190	383	640	E
Puyallup Watershed														
Commercial	3	1.1	1.2	1.5	5.1	6.3		6	10	11	30	38	91	
Residential	4	17	22	35	46	51	E	6	1.6	3.1	15	42	69	
Agricultural	4	1.9	3.4	4.9	7.8	11		2	12		16		19	
Forest	4	129	132	248	382	404	E	6	156	171	511	851	1,027	

kg/year: kilograms per year.

n: water quality sample size.

Non-detect frequency flag:
E: 50 percent or less of the data are detected values; reported values are considered estimates with relatively low accuracy.

Table G-5. Total suspended solids absolute loading rates (g/year) by land use for the Snohomish watershed and Puyallup watershed.

		Baseflow						Storm Event						
Land Use	n	Minimum	25th Percentile	Median	75th Percentile	Maximum	Non-Detect Frequency Flag	n	Minimum	25th Percentile	Median	75th Percentile	Maximum	Non-Detect Frequency Flag
Snohomish Watershed														
Commercial	3					<2.5	U	12	19	56	108	132	178	
Residential	4	171	257	343	428	514		12	1,206	2,134	4,221	9,286	28,460	
Agricultural	4	71	71	107	196	249		12	52	161	285	713	2,177	
Forest	4	8,640	8,640	8,640	12,961	17,281		12	1,915	7,660	15,320	44,810	157,027	E
Puyallup Watershed														
Commercial	3	2.3	4.1	9.4	9.4	9.4		12	45	111	149	245	639	
Residential	4	375	437	562	1,124	1,624		12	377	754	1,634	2,577	6,411	
Agricultural	4	12	24	37	43	49		12	59	89	207	622	1,480	
Forest	4	2,182	2,182	2,182	4,909	7,636		12	1,559	7,014	12,469	38,966	307,051	

kg/year: kilograms per year.

n: water quality sample size.

Non-detect frequency flag:
- E: 50 percent or less of the data are detected values; reported values are considered estimates with relatively low accuracy.
- U: None of the data are detected values; reported values were computed based on the maximum reporting limit.

Table G-6. Comparison of load estimates for total zinc, total PCBs, and total suspended solids that were derived using the alternative and preferred methods for computing these estimates.

Land Use	Baseflow			Storm Flow		
	Alternative Method	Preferred Method	Difference [a]	Alternative Method	Preferred Method	Difference [a]
Total Zinc (kg/year)						
Snohomish Watershed						
Commercial	39.7	33.6	6.1	441	373	68
Residential	428	363	65.1	2,026	1,720	306
Agricultural	378	311	66.8	456	375	81.1
Forest	10,801	8,280	2,520.6	9,575	7340	2,235
Puyallup Watershed						
Commercial	74.9	31.9	43.0	502	214	288.0
Residential	312	106	206.2	742	252	490
Agricultural	81.8	95.7	-13.9	329	383	-54.4
Forest	<5,455 [b]	<2,580 [b]	NA	3,897	1,850	2,047
Total PCBs (g/year)						
Snohomish Watershed						
Commercial	0.93	0.786	0.14	61	51.4	9
Residential	3.0	2.54	0.46	66	56.0	10
Agricultural	2.5	2.05	0.44	5.5	4.50	1.0
Forest	272	209	63	190	145	45
Puyallup Watershed						
Commercial	1.5	0.619	0.832	30	12.8	17.2
Residential	35	11.8	23	15	5.2	10
Agricultural	4.9	5.77	-0.82	16	18.4	-2.6
Forest	248	118	130	511	244	267
Total Suspended Solids (MT/year)						
Snohomish Watershed						
Commercial	<2.5 [b]	< 2.11 [b]	NA	108	90.9	17
Residential	343	290	53	4,221	3,580	641
Agricultural	107	88.0	19	285	235	50.1
Forest	8,640	6,610	2,030	15,320	11,700	3,620
Puyallup Watershed						
Commercial	9.4	4.0	5.36	149	63.3	85.2
Residential	562	191	371	1634	557	1077
Agricultural	37	43	-6.1	207	241	-34
Forest	2,182	1,040	1,142	12,469	5,930	6,539

[a] Alternative method load minus preferred method load.

[b] All of the data are non-detect values; reported values were computed based on the maximum reporting limit.

PCB: polychlorinated biphenyls.

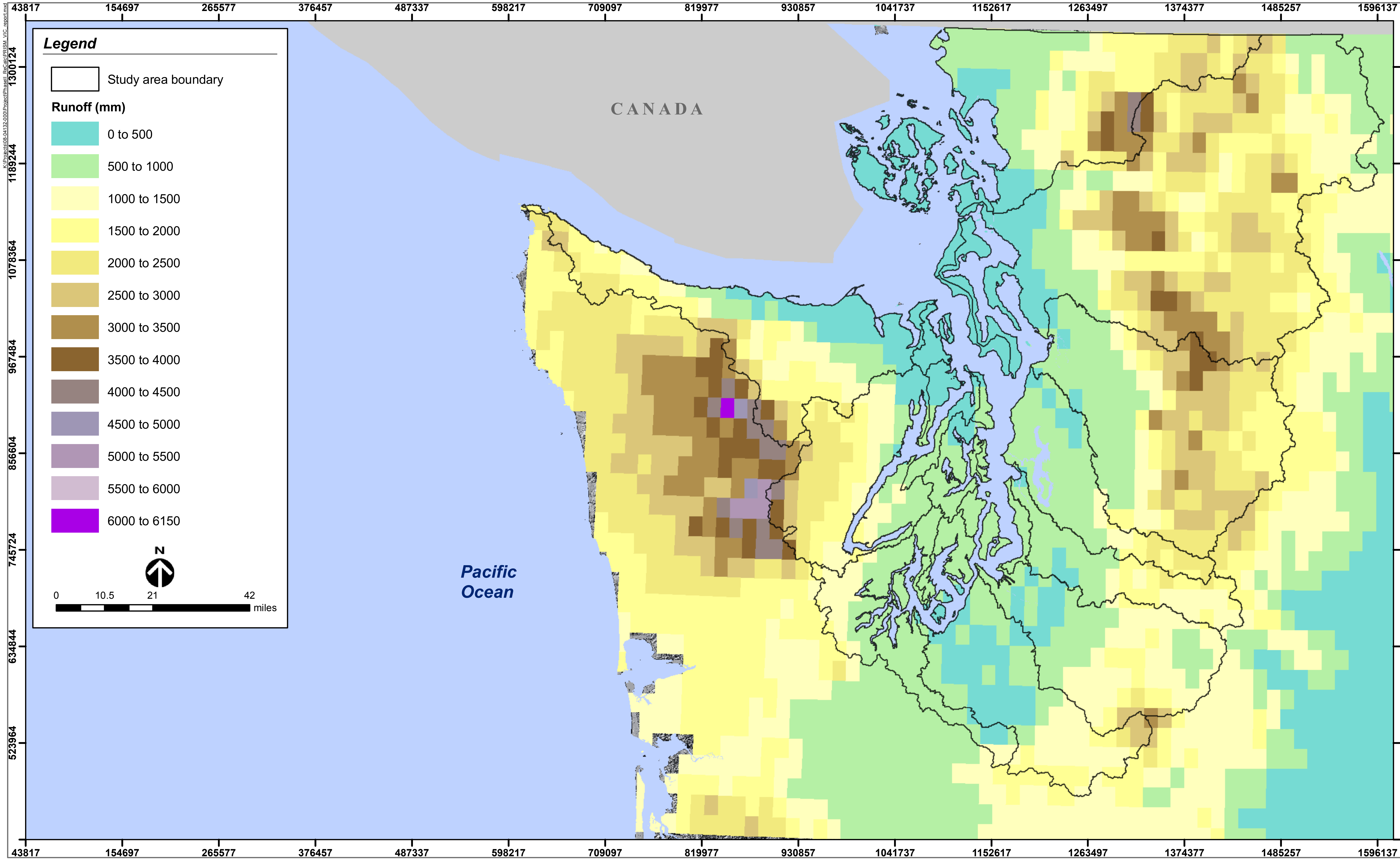

Figure G-1. Runoff map (PRISM precipitation minus VIC actual evapotranspiration).

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from the hydrologic model are higher for forest areas after factoring in evapotranspiration. These higher runoff estimates translate to higher loadings using the alternative method. In general, load estimates derived using the alternative and preferred methods were fairly similar for the other land-use types.

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