CHAPTER 3.
HYDROLOGY

3.1 MODELING METHOD

3.1.1 Software Used

The HSPF model (version 10) used for this report is a versatile model that allows for a complete range of hydrologic analysis. King County generally encourages the use of HSPF for tributary areas larger than 200 acres. The Patterson Creek Basin is approximately 12,700 acres, and individual subbasins modeled range in size from 1,156 to 2,908 acres. Other strengths of using HSPF for this project include its ability to do the following:

- Model, link, and route many separate subbasins
- Calibrate a model to local site conditions
- Account for the groundwater component of stream flow
- Address groundwater connections and perform low-flow analysis
- Handle complex hydrologic accounting.

The HSPF model was supplemented by the use of the hydrologic data management program ANNIE (version 1). ANNIE is used to store, retrieve, list, plot, check, and update spatial, parametric, and time-series data for hydrologic models. HSPF Version 11 and ANNIE Version 4 are the most current versions of these programs, but the earlier versions were used because of problems extracting peak hourly flow data from ANNIE Version 4.

3.1.2 Analyses Conducted

The hydrologic models were used to provide statistical analyses including a flow frequency analysis, average daily flows, low flow analysis, and a duration analysis. Two land-use conditions were modeled:

- Predevelopment, which assumes 100 percent forest cover and predevelopment wetlands cover, except for open bodies of water
- Existing land use based on 2001 data provided by King County.

The scope of work for this study did not include calibration with existing gage data. However, results of the model were compared to gage data as described in subsequent section 3.1.7.

Future buildout was considered as part of the overall basin analysis but was not modeled using HSPF.

3.1.3 Precipitation Variation

King County provided precipitation data from Landsburg and evaporation data from Puyallup (water year 1949 through 1997) for the analysis. Rainfall data from Carnation was deemed to be unreliable by King County gauging staff. Due to its orientation and its elevation variation (from 70 feet to 1,400 feet), the basin experiences rainfall variation that generally follows elevation gain. Rainfall regions and regional scale factors defined in the *King County Surface Water Design Manual* (King County, 1998; Figure 3.2.2.A) were used to estimate the rainfall difference between Landsburg and the study site. These factors were developed for scaling runoff rates, but in the absence of direct scaling factors for precipitation they are suitable for approximating rainfall variations. Three rainfall zones were defined in the Patterson Creek Basin:

- Rainfall in Subbasins, 1, 2a and 2b was assumed to be 0.8 times the rainfall at Landsburg.
- Rainfall in Subbasin 2c was assumed to be 0.85 times the rainfall at Landsburg.
- Rainfall in Subbasins, 3, 4 and 5 was assumed to be 1.05 times the rainfall at Landsburg.

As a validation of these scaling factors. the rainfall between Landsburg and Carnation was compared for the period from February 20 to March 9, 1950. The correction factor for this period was 0.83, which is in the range of the scaling factors used in this analysis.

Snowmelt was not considered in the Patterson Creek Basin. This is because elevations in the Patterson Creek Basin are low enough that runoff within the basin is not significantly impacted by a melting snow pack.

3.1.4 Land Coverage

The land cover analysis described in Chapter 2 established the categories of coverage for each subbasin. The land cover, soil type, topography and basin boundaries were used as inputs for the HSPF model. Regionalized HSPF parameters supplied by King County were used for this analysis.

3.1.5 Channel Characteristics

No detailed survey information was available for the RCHRES segments defined for this project. Consequently, channel features were estimated based on a field visit and interpretation from limited available U.S. Geological Survey (USGS) topographic mapping. A channel cross-section was estimated for each channel reach. Surface area, volume, and outflow were computed for varying depths using Manning's equation. In general, Patterson Creek channel characteristics are very similar from the mouth at the confluence with the Snoqualmie to the headwaters in Subbasin 1. A Manning's "n" value of 0.035 was used for most channel cross-sections. The channel cross-section in RCHRES 100 was assigned a Manning's "n" value of 0.030 and the channel cross-section in RCHRES 400 was assigned a Manning's "n" of 0.05. The changes were made because these segments exhibited slightly different channel characteristics from the rest of the segments in the basin. A Manning's "n" of 0.05 to 0.08 was used for floodplain areas. The channel cross-section data and f-tables are shown in Appendix B of this report.

3.1.6 Qualitative Analysis of Future Buildout Conditions

For the future buildout condition of the Patterson Creek Basin a qualitative analysis based on predicted future impervious area was conducted. Future effective impervious area within the basin was compared to existing (2001) effective impervious area in order to predict a range of future peak flows within the basin.

3.1.7 Model Validation

Calibration was not included in the scope of work for this project. However, King County provided data for several stream gauges on Patterson Creek. King County staff deemed data from Gauge 48c, located at the lower end of Subbasin 1, to be unreliable. Gauge 48a, located further downstream at the lower end of Subbasin 2c on the Aldarra Golf Course, had four years of data that King County staff determined to be reliable. In a comparison for several significant storms, the modeled flows matched fairly well with the gauge data for peak flow and base flow. Figure 3-1 shows 16 days of actual and simulated flow data for an April 1991 storm event in cubic feet per second (cfs). Landsburg precipitation data is given for the same time period at the top of the chart. Note that runoff peaks are approximately a day later than the precipitation peak. This lag is expected and is a good indication that precipitation and peak flows are correlated properly within the model.

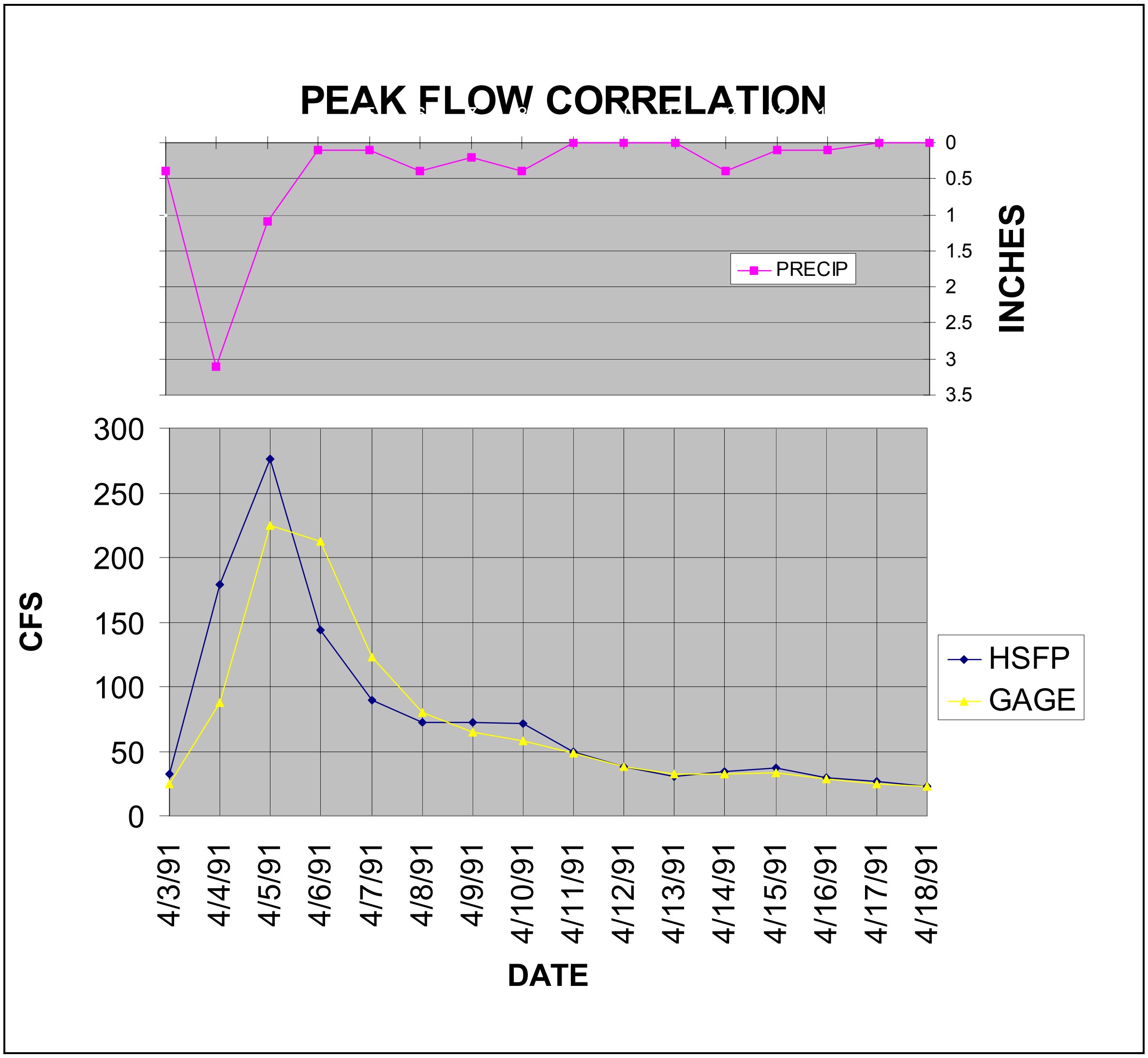

Figure 3-1. Actual and Simulated Average Daily Flow with Precipitation

Modeled peak flows were found to not match the peak flows recorded at the USGS Gauging Station 12146000, located near the mouth of Patterson Creek. This gauging station recorded at least 10 years of data and had a predicted 100-year flow (based on gauge height) of 477 cfs. The HSPF simulated 100-year flow in this reach was 1,593 cfs.

Since the gauge data recorded at King County Gauge 48a matches very closely with the simulated flow, it is unclear why there is such a large discrepancy with the USGS data. In trying to explain this difference, rainfall for the peak storm event from Carnation in February 1950 was compared to the rainfall from Landsburg. When applying the published rainfall correction factor for Landsburg data to the Carnation data, the Landsburg rainfall was approximately 11 percent higher from February 20 to March 9, 1950. This difference is not of the same magnitude as the large difference in predicted 100-year flows. However, since King County gauging staff have expressed a high level of confidence in Gauge 48a, we feel the model correlates fairly closely to known and reliable data. Figure 3-2 shows an hourly rainfall comparison for Carnation and Landsburg.

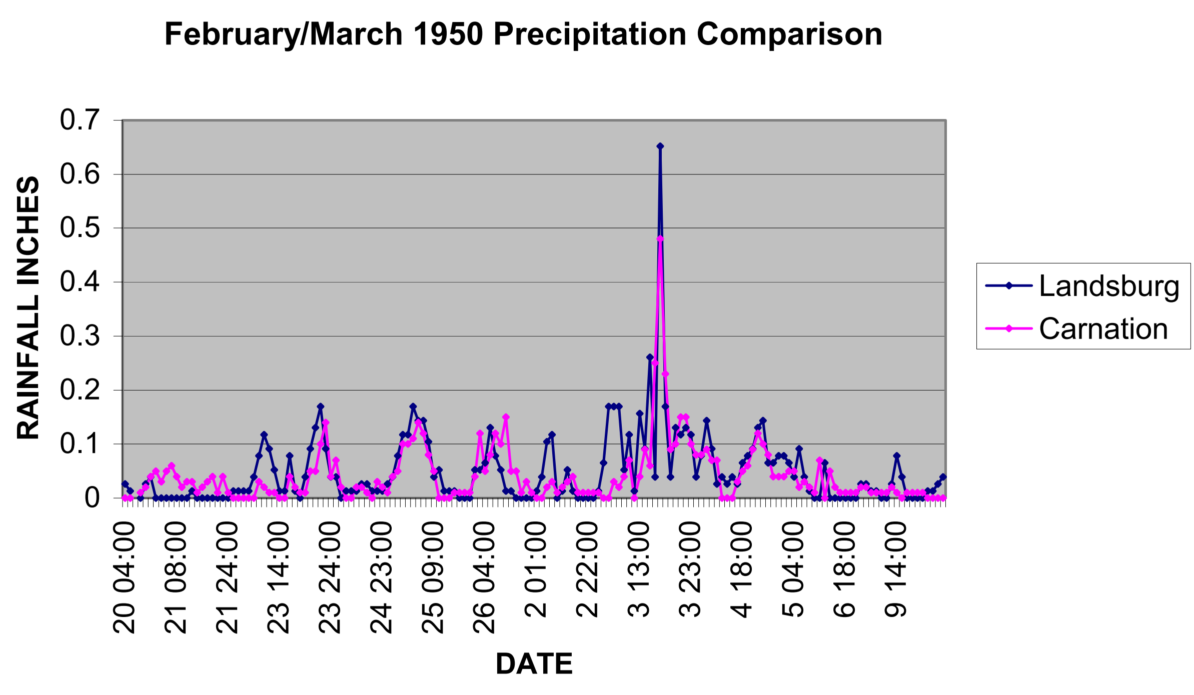

Figure 3-2. Hourly Rainfall Comparison

3.2 MODELING RESULTS

3.2.1 Flow Frequency Analysis

Table 3-1 shows results of the flow frequency analysis for predevelopment and existing (2001) basin conditions for each channel segment. Annual peak flow rates are shown for each segment and are a summation of all upstream routed flows.

TABLE 3-1.
FLOW FREQUENCY ANALYSIS

	Peak Annual Discharge (cfs)									
	2-yr		5-yr		10-yr		25-yr		100-yr	
RCHRES Segment	Predeveloped	Existing	Predeveloped	Existing	Predeveloped	Existing	Predeveloped	Existing	Predeveloped	Existing
100	65	72	124	124	171	167	238	233	351	357
200	78	86	131	133	172	169	227	222	318	315
210	68	76	110	113	139	140	177	177	235	240
220	111	133	183	204	237	257	312	331	436	457
230	156	187	247	277	313	344	401	437	542	596
300	269	314	404	455	502	563	632	719	843	994
400	213	203	346	335	455	449	619	629	922	984
500	321	349	479	499	593	614	746	780	993	1,071
510	498	515	740	746	912	920	1,141	1,167	1,505	1,593

Results are very similar for predeveloped and existing flow frequencies because predevelopment and existing conditions in the basin are similar. Effective impervious area for predeveloped conditions was assumed to be zero. Under existing (2001) conditions effective impervious area increased only to 3.2 percent basinwide. The greatest increase (4.9 percent) was in Subbasin 2c, which contributes flow to RCHRES 230. In Subbasins 1, 2a, and 4, which correspond to RCHRES segments 100, 200, and 400 respectively, some of the peak discharges for the predeveloped condition actually exceed the peak discharges for the existing condition. These segments all are high up in the drainage basin and they have the smallest increases in effective impervious area. It is our opinion that the predeveloped flow rates are in some cases larger than the existing flow rates because the model is not sensitive enough to differentiate the small change in effective impervious area. In particular, the Log-Pearson “best fit” methodology for computing flow frequencies used in the Bulletin 17b was not responsive to such minor changes in effective impervious area as the 1.5- to 3-percent range that occurred in those subbasins. Segments further downstream in the basin and with larger increases in effective impervious area show a greater difference between existing and predeveloped flow rates.

Figure 3-3 shows predeveloped and existing discharge rates for Reach 510 for return frequencies from 2 to 100 years. Peak discharge rates for smaller storm events are nearly identical. For larger storm events the difference in discharge rates increases.

3.2.2 Mean Daily Flow

Table 3-2 lists the average daily flow rates averaged monthly over the 49-year Landsburg precipitation record (October 1, 1949 through September 30, 1997) for predeveloped and existing (2001) basin conditions for each channel segment. A complete tabulation of mean daily flows for the entire record is included in the appendix. Flow rates for each reach are a summation of all upstream routed flows.

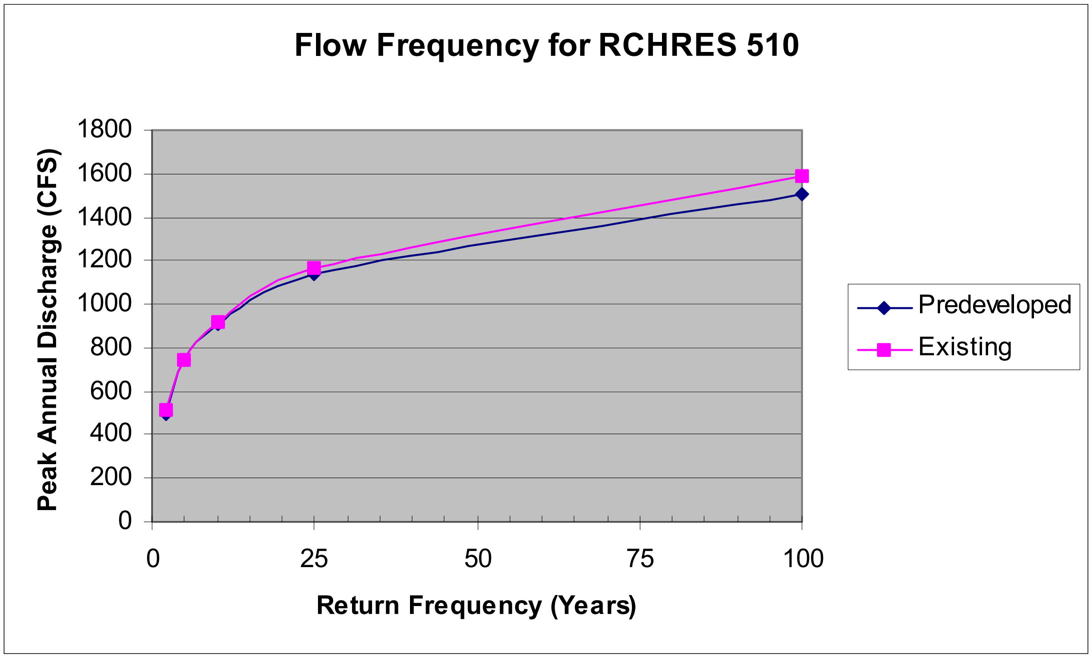

Figure 3-3. Peak Annual Discharge for RCHRES 510 from 2-yr to 100-year Return Frequency

In all cases the mean daily flow is greater for existing conditions than for predeveloped conditions. This is expected due to the higher EIA with existing conditions. This is most apparent in the early rainy season when the runoff from the EIA is conveyed directly to the channels rather than infiltrating into the ground. As the rainy season decreases and groundwater rises, the difference is less apparent.

3.2.3 Low Flow Characteristics

Table 3-3 lists the mean 7-day low flow over the entire record for predeveloped and existing conditions for each channel segment. Flows shown for each segment are a summation of all upstream routed flows. In all cases the mean 7-day low flow is greater under existing conditions than under predeveloped conditions. This could be due to a number of factors.

Predeveloped conditions were modeled entirely as forested except for wetlands, streams, and lakes. Basinwide, the percentage of forested area was 92.1 percent. In this condition, there is very little runoff. Stormwater either undergoes transpiration, evaporation, or is absorbed into the ground, where it becomes interflow or groundwater, which feeds surface water such as streams. Existing conditions were modeled with only 56.5 percent forested area, about 61 percent of the forested area of the predevelopment condition. A large percentage of forested area was converted to agricultural uses and is now pasture or grass land. There was only a 3.2 percent increase in impervious area basinwide. Because of the low basinwide total of effective impervious area, runoff does not increase significantly. Also, increased evaporation under existing conditions would tend to decrease low flows. However, due to the lack of transpiration, a larger amount of rainfall is now available to soak into the ground and become interflow or groundwater, thus feeding area streams. These combined factors of decreased transpiration and increased impervious area would lead to an increase in existing condition summer base flows over the predeveloped condition.

TABLE 3-2.
MEAN DAILY FLOW RATES PER MONTH FOR PERIOD OF RECORD

	Mean Daily Flow (cfs)								
	100	200	210	220	230	300	400	500	510
October									
Predeveloped	0.8	1.5	1.5	2.9	4.2	6.6	3.3	8.0	11.3
Existing	1.1	2.3	2.3	4.2	6.4	10.0	4.9	12.6	17.6
November									
Predeveloped	1.6	3.3	3.3	6.4	9.9	16.5	10.2	20.7	30.9
Existing	2.6	5.5	5.5	10.1	15.7	24.5	13.1	30.9	44.0
December									
Predeveloped	3.5	7.2	7.2	14.0	21.3	33.3	17.8	40.9	58.6
Existing	4.3	9.0	9.0	16.9	25.8	39.0	19.3	47.7	67.1
January									
Predeveloped	5.6	11.2	11.2	21.6	32.4	47.7	22.6	57.4	80.0
Existing	6.1	12.3	12.3	23.4	35.1	51.1	23.5	61.4	84.9
February									
Predeveloped	5.7	11.5	11.5	22.3	33.1	47.9	21.5	57.1	78.6
Existing	5.9	11.9	11.9	22.9	34.0	49.1	21.7	58.5	80.2
March									
Predeveloped	5.2	10.4	10.4	20.2	29.9	43.1	18.8	51.2	70.1
Existing	5.3	10.6	10.6	20.5	30.3	43.6	19.0	51.9	70.8
April									
Predeveloped	4.1	8.2	8.2	16.0	23.6	34.1	14.9	40.6	55.6
Existing	4.1	8.2	8.2	16.1	23.7	34.3	15.0	40.8	55.9
May									
Predeveloped	2.4	4.8	4.8	9.5	13.9	20.6	9.1	24.6	33.7
Existing	2.4	4.8	4.8	9.5	13.9	20.7	9.2	24.8	34.0
June									
Predeveloped	1.7	3.5	3.5	6.9	10.2	15.3	6.9	18.3	25.3
Existing	1.8	3.7	3.7	7.2	10.6	15.9	7.3	19.2	26.4
July									
Predeveloped	1.1	2.3	2.3	4.5	6.5	9.8	4.3	11.7	15.9
Existing	1.2	2.3	2.3	4.6	6.6	10.0	4.5	12.1	16.6
August									
Predeveloped	0.8	1.7	1.7	3.3	4.7	7.0	3.0	8.3	11.3
Existing	0.9	1.8	1.8	3.4	5.0	7.5	3.3	9.1	12.4
September									
Predeveloped	0.7	1.4	1.4	2.7	4.0	6.1	2.7	7.3	10.0
Existing	0.9	1.8	1.8	3.3	4.9	7.5	3.5	9.2	12.7

TABLE 3-3.
MEAN 7-DAY LOW FLOW

RCHRES Segment	Mean 7-Day Low Flow (cfs) Predeveloped	Mean 7-Day Low Flow (cfs) Existing
100	0.6	0.7
200	1.2	1.3
210	1.2	1.3
220	2.3	2.5
230	3.4	3.5
300	5.0	5.3
400	2.1	2.4
500	6.0	6.5
510	8.1	8.9

Additional low flow analyses, for the mean 1-day, 2-day, 3-day, 10-day, 30-day, 60-day, 90-day, 183-day, and 365-day low flows, are included in Appendix B.

3.2.4 Duration Analysis Results

A duration analysis was conducted for predeveloped and existing conditions for each channel segment. Table 3-4 compares the percent of time a flow rate is at or above the listed flow rate for existing (2001) conditions and pre-developed conditions for Reach 510. For example, given a flow rate of 100 cfs, predeveloped condition flow rates are equal to or greater than 100 cfs 8.19 percent of the time, and existing condition flow rates are equal to or greater than 100 cfs 9.47 percent of the time. See Appendix B for the duration analysis data for all the reaches. Figure 3-4 compares predeveloped and existing conditions for flows from 50 percent of the predeveloped 2-year flow rate up to the predeveloped 100-year flow rate.

TABLE 3-4.
FLOW RATE DURATION ANALYSIS FOR RCHRES 510

	Percent of Time at or Above Given Flow			Percent of Time at or Above Given Flow	
Flow (cfs)	Predeveloped	Existing	Flow (cfs)	Predeveloped	Existing
0.00	100.00%	100.00%	51.00	25.73%	27.27%
1.00	100.00%	100.00%	64.00	18.90%	20.33%
1.30	100.00%	100.00%	81.00	12.64%	13.95%
1.60	100.00%	100.00%	100.00	8.19%	9.47%
2.00	100.00%	100.00%	130.00	4.30%	5.33%
2.50	100.00%	100.00%	160.00	2.36%	3.19%
3.20	100.00%	100.00%	200.00	1.25%	1.79%
4.00	100.00%	100.00%	260.00	0.62%	0.92%
5.00	99.81%	99.96%	320.00	0.33%	0.50%
6.40	98.76%	99.53%	410.00	0.14%	0.20%
8.00	92.67%	96.84%	510.00	0.06%	0.09%
10.00	84.24%	88.99%	650.00	0.03%	0.04%
13.00	72.92%	78.23%	810.00	0.01%	0.01%
16.00	64.72%	69.83%	1000.00	0.00%	0.01%
20.00	56.63%	60.99%	1300.00	0.00%	0.00%
25.00	49.12%	52.66%	1600.00	0.00%	0.00%
32.00	41.67%	44.35%	2100.00	0.00%	0.00%
40.00	34.10%	35.98%			

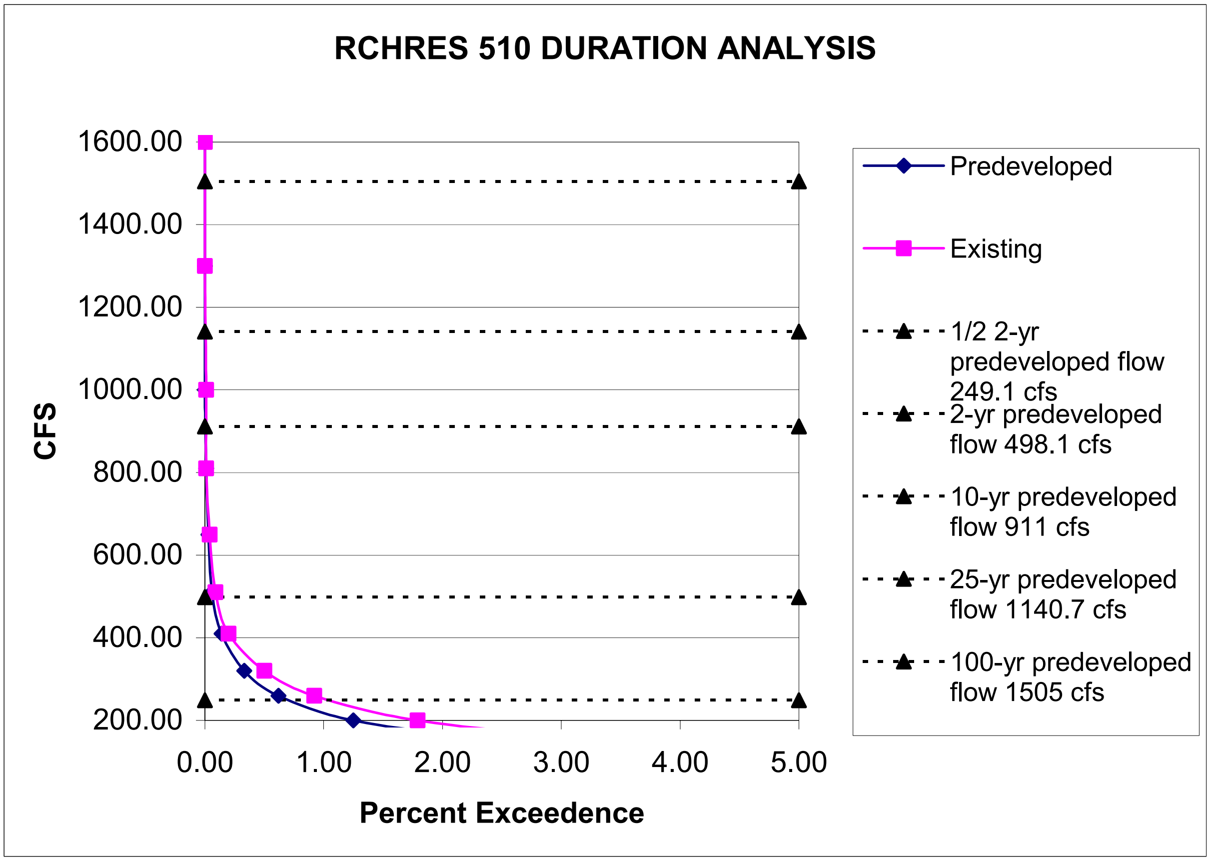

Figure 3-4. Percent Exceedance for Predeveloped and Existing Conditions

3.3 QUALITATIVE ANALYSIS OF FUTURE BUILDOUT CONDITIONS

Future buildout conditions were estimated based on the change of effective impervious area as the basin transitions from the current development level to future full buildout based on current zoning. Effective impervious area for buildout was based on King County and City of Sammamish zoning. Table 3-5 compares the land cover, including effective impervious area, for existing and buildout conditions, and shows the calculations for estimating future flows.

To estimate future flows, the percent difference in EIA and flow between existing conditions and predeveloped conditions was calculated. Subbasins 1, 2a, and 2b showed no increase in flow rate, but a minimum increase of 1 percent was assigned to these basins. The percent increase in EIA from predeveloped to future conditions was then calculated (predeveloped conditions were assumed to have zero percent EIA, so the increase is equal to the future EIA.) Next, the ratio of future percent EIA to existing percent EIA was determined. This ratio was multiplied by the percent increase in flow from predeveloped to existing conditions, to represent the percent increase in future flows over predeveloped flows. That percentage was then multiplied by the predeveloped flow to estimate the increase in flow, and the increase was added to the predeveloped flow to give a predicted future flow. This mathematical representation of increased flows is intended to give an order of magnitude increase in future flows.

TABLE 3-5.
25-YEAR FUTURE FLOW ESTIMATE PER SUBBASIN

Subbasin	1	2a	2b	2c	3	4	5
A. Subbasin Area (acres)	1,156	1,167	2,215	1,974	2,038	2,908	1,253
B. % EIA Predeveloped	0	0	0	0	0	0	0
C. % EIA Existing	2.5	2.9	3.9	4.9	4.6	1.7	2
D. Change % EIA **(C – B)**	2.5	2.9	3.9	4.9	4.6	1.7	2
E. Predeveloped 25-Year Flow (cfs)	238	227	177	401	632	619	1,141
F. Existing 25-Year Flow (cfs)	233	222	177	437	719	629	1,167
G. Existing % Flow Increase **(F/E)**	1.0	1.0	1.0	9.0	13.8	1.6	2.3
H. EIA % Future	3.8	3.9	4.1	8	8.1	3.2	2.4
I. Change % EIA **(H – B)**	3.8	3.9	4.1	8	8.1	3.2	2.4
J. % Increase Future/Exist **(I/D)**	1.52	1.34	1.05	1.63	1.76	1.88	1.20
K. Future % Flow Increase **(J x G)**	1.52	1.34	1.05	14.7	24.2	3.0	2.7
L. Increase in flow (cfs) **(K x E/100)**	3.57	2.95	1.95	58.95	152.94	18.57	30.81
M. Future 25-Year Flow (cfs) **(E + L)**	242	230	179	460	785	638	1,172

3.4 FURTHER ACTION/RECOMMENDATIONS

The HSPF model developed for this analysis of the watershed should be viewed as preliminary, and further data gathering, monitoring and calibration are recommended. The following additional information is desirable to refine the model for future use:

- Evaluation of the Carnation rainfall data to determine if any of it is reliable and can be used for analysis. This data, along with data from existing King County rain gauges in the basin, should be put into a format suitable for calibration with the existing model.
- Continued stream flow records from King County Gauge 48a.
- Survey of channel characteristics (cross-sections, slope, overbank characteristics, etc.) in order to get a more accurate representation of storage/routing of flows through the basin.
- Accurate topographic information defining floodplain storage.
- A more detailed drainage system inventory and survey identifying stream culverts and structures. This information could be used to more accurately represent channel storage and peak flow attenuation.
- HSPF analysis of future flows.