CHAPTER 3.
HYDROLOGY

3.1 HYDROLOGIC 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 Boise Creek Basin is 9,861 acres, and individual subbasins range from 534 acres to 3,256 acres. 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 additional software programs including ANNIE (versions 1 and 4), a computer program for interactive hydrologic data management, and PEAKFQ (version 4) and SWSTAT (version 4), which were created by the U.S. Geological Survey (USGS) to calculate peak flows and conduct other statistical hydrologic analyses.

3.1.2 Analyses Conducted

Two land use scenarios were modeled: predevelopment, for which it was assumed that the basin is entirely forested; and existing land use, as described in Chapter 2. Future land use allowed by current zoning was not explicitly modeled, but anticipated future flow rates were inferred based upon changes in land cover, including effective impervious area. For predeveloped and existing land use, the following stream flow parameters were analyzed:

- Mean daily flow over the modeling period
- Flow duration
- Low flow characteristics (e.g., 7-day mean low flow)
- Flow frequency.

3.1.3 Rainfall Variation

Due to its orientation and its elevation variation (from less than 600 feet to more than 3,900 feet), the Boise Creek Basin experiences rainfall variation that generally follows elevation gain. The County provided precipitation data from Landsburg for the analysis as well as evaporation data from Puyallup (water year 1949 through 1997). 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 Boise Creek Basin:

- Rainfall in Subbasins 1 and 2 was assumed to be the same as at Landsburg.
- Rainfall in Subbasins, 3, 4 and 5 was assumed to be 1.2 times the rainfall at Landsburg.
- Rainfall in Subbasins 6 and 7 was assumed to b 1.35 times the rainfall at Landsburg. These basins lie beyond the scale factor map in the King County Design Manual, so a scale factor was estimated using GIS coverage of annual precipitation published by the Water and Climate Center of the Natural Resources Conservation Service. This scaling factor fit the trend observed using the flow-scaling factor for the lower elevation subbasins.

3.1.4 Land Coverage and Impervious Area

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. Original regionalized HSPF parameters were supplemented by a calibrated HSPF model from the Issaquah area that added a soils category consisting of thin soils over bedrock. It was found that this soil category covers extensive areas in the upper Boise Creek subbasins. Pasture was not included as a land cover category.

King County provided a table of estimated EIA values for existing land cover categories except for the “Mixed Urban/Low Density” and “Urban/High Density” categories. For these categories, Tt/KCM developed, and the County accepted, EIA estimates based on development in the areas and EIA estimates from previous work. The future land use analysis estimated EIA using typical values for the zoning categories in the study area.

The pervious portion of developed residential areas in the basin was assumed to be predominantly grass, but 10 percent of this pervious area was assumed to be forested in order to represent buffers and other untouched forested areas often incorporated into residential developments.

3.1.5 Channel Characteristics

No survey information was available for this project. Consequently, channel features were estimated based on a field visit and interpretation from limited available USGS topographic mapping. A channel cross-section was estimated for each of the 10 channel reaches. Rating curves were developed for each reach using these cross-sections, estimates for channel roughness, and normal flow assumptions. Information from the rating curves was put into the format suitable for use with HSPF.

3.1.6 Effect of Mill Pond

The original Weyerhauser millpond was filled in 1994 to expand an existing log storage yard. In the pond’s place, a large storage channel was excavated to carry streamflow around the former pond to the downstream reach. A flow control structure was constructed at the end of the channel to try to regulate downstream flows to prior flows. The lumberyard maintains a stream diversion for use in lumber processing.

3.2 MODEL DEVELOPMENT

3.2.1 Groundwater

Based on average daily flows recorded at the USGS gauging station about 0.1 miles from the mouth of Boise Creek (Station 12099600), initial HSPF model runs indicated that the model overestimated base flow in Boise Creek. Consequently, 50 percent of the groundwater associated with outwash soils in the basin was assumed to flow into the nearby White River or adjacent streams rather than to Boise Creek. There are large areas of outwash soils along the basin divides, so there likely are corridors for this subsurface flow to leave the basin. Stream base flow matched much better after making this modeling change.

3.2.2 Rainfall

Excessive flow volume in the HSPF results also is likely associated with the rainfall differences between Landsburg and local rainfall. The Landsburg rainfall data was compared to rainfall recorded by the U.S. Army Corps of Engineers at Mud Mountain Dam. Landsburg is about 12 miles north of Enumclaw and the Mud Mountain Dam gauge is about 3 miles east of Enumclaw. Significant differences in rainfall distribution were noted between these locations. An example of these differences is shown in Figure 3-1.

The variation of rainfall with elevation in the basin also is not accurately known. A second rainfall gauge at a higher elevation would help define the correct variation within the basin. Snowfall and corresponding snowmelt also may play a significant role in contributing to stream flow. Winter precipitation in the lower basin may fall as rain while in the upper basin it falls as snow. As a result, the upper basin precipitation would not contribute to stream flow immediately, but it would do so during spring thaw.

Hourly precipitation data was used in the HSPF model. Stochastically derived 15-minute precipitation data that was derived from the hourly data was not used because of the long time of concentration in the basin (about 6 hours).

3.2.3 Average Daily Stream Flow

The average daily stream flows were checked for reasonableness by comparing gauged data to the simulated daily flows. Figure 3-2 is an excerpt of average daily simulated versus recorded stream flow that contains a large winter flood as well as summertime low flows. This graph indicates general agreement with storm recession and low flow periods. Many of the storm peaks do not agree due to the rainfall variation issues previously described. Mean daily flows are useful in identifying overall trends but will not necessarily identify stream flow variability that one would expect from smaller developing basins.

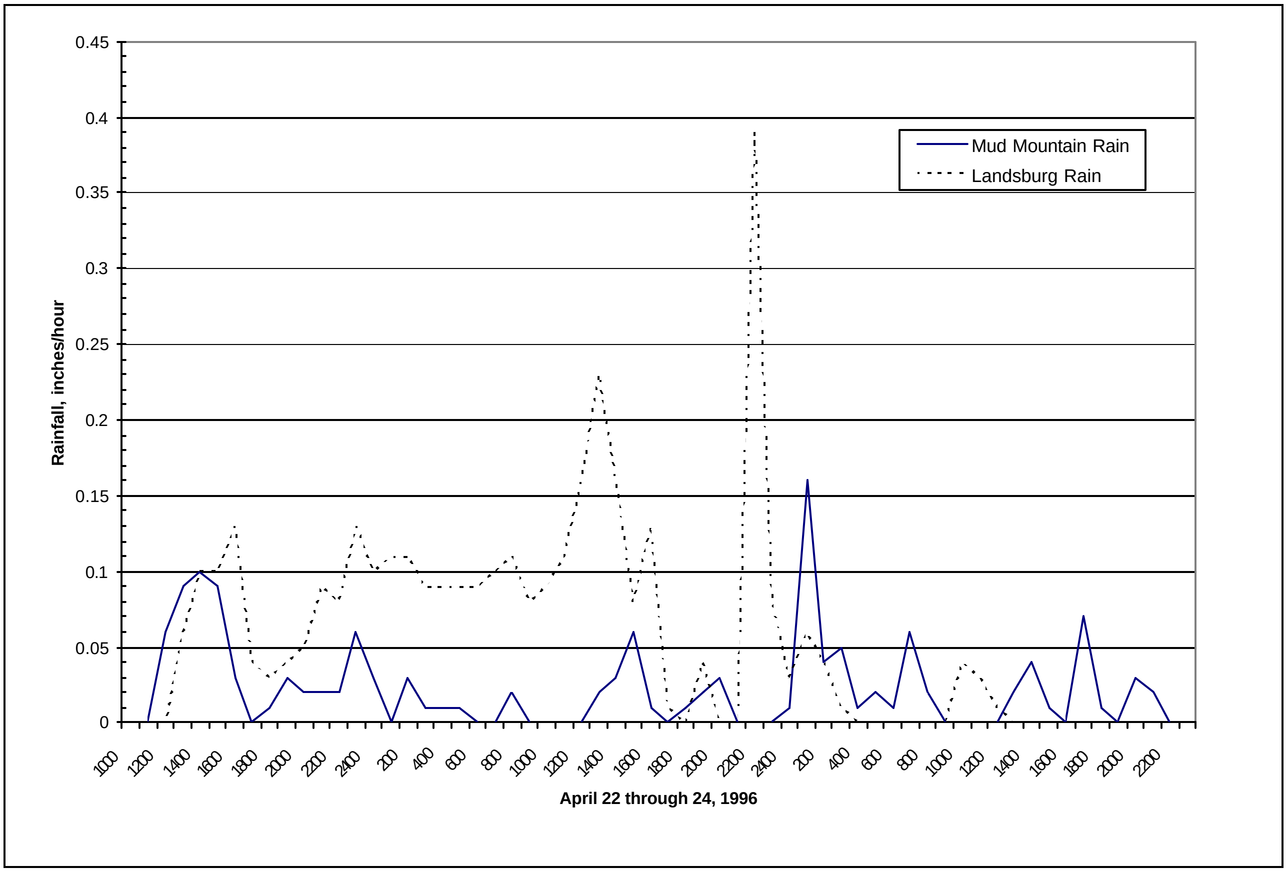

Figure 3-1. Hourly Rainfall Comparison

3.2.4 Stream Segment Volume

A sensitivity check was made to observe the influence of stream segment volume, and indirectly channel geometry, on runoff. RCHRES 100 receives runoff from the Enumclaw developed area. Since this developed area has the largest impervious contribution, which should result in flashy runoff, increases to the volume of this segment should result in reduction of peak flow.

Doubling the volume of RCHRES 100, however, resulted in only a 2-percent peak flow reduction. This may represent the relative insensitivity of a single stream segment's volume in this basin, meaning that the approximation of channel geometry would likely not drastically impact results. However, it may also mean that the large quantity of runoff generated from the basin overwhelms the volume of increase in this single segment, implying that more extensive volume changes would be required through several segments before a significant flow reduction becomes apparent. This condition was observed during modifications to the RCHRES 200 series when adjustments to represent floodplain storage were made.

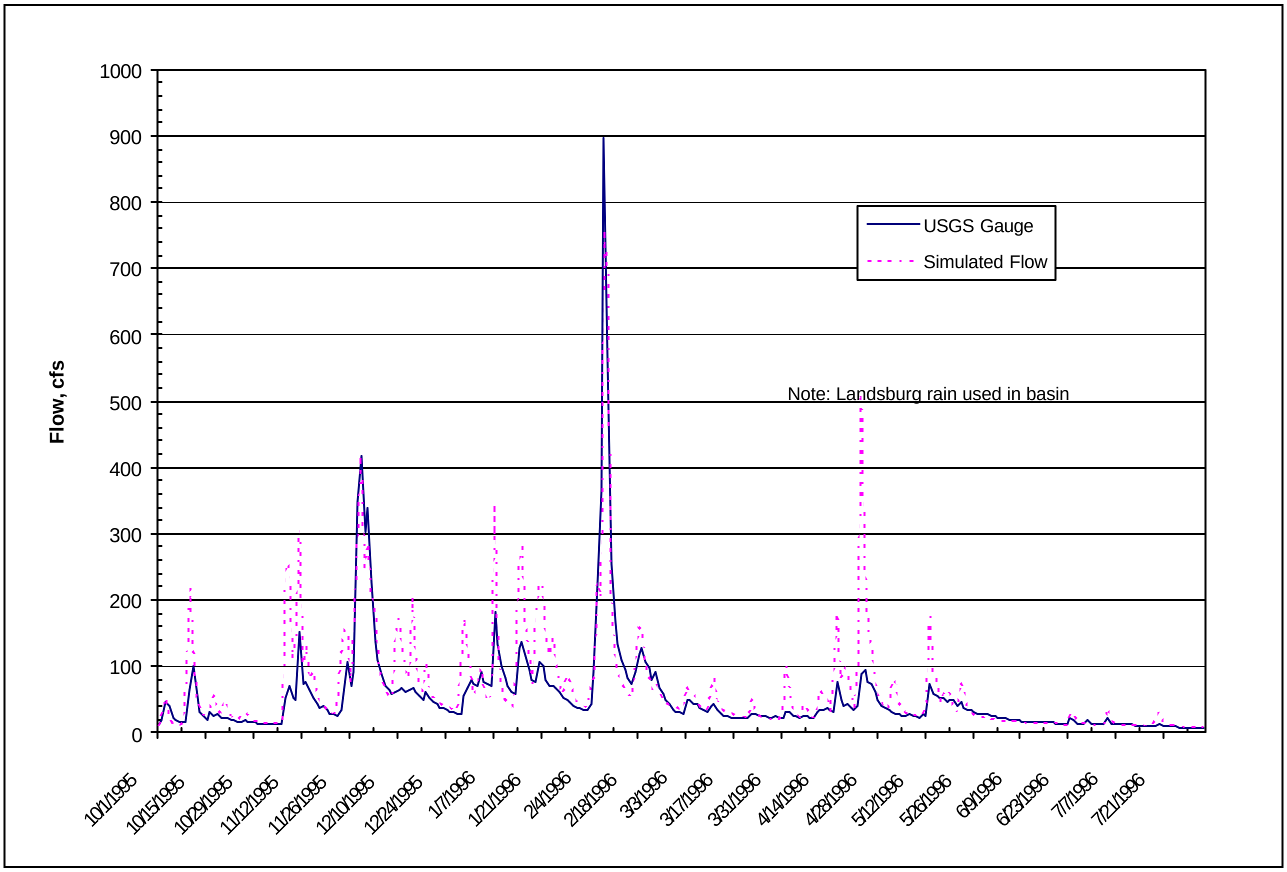

Figure 3-2. Gauged vs. Simulated Mean Daily Flow

3.3 MODELING RESULTS

3.3.1 Mean Daily Flow

Table 3-1 summarizes the mean daily flow calculated for each channel segment over the model period of October 1, 1948 through September 30, 1997 for predeveloped and existing land use conditions. The results, in cubic feet per second (cfs), show that existing mean daily flows are slightly higher than predeveloped flows throughout the basin. This may be interpreted as the consequence of increased runoff from impervious areas and the conversion of forested areas to other pervious areas, such as grass, that promote more runoff. The largest increase is about 7 percent at the creek mouth (RCHRES 100).

3.3.2 Flow Duration

The flow duration analysis is an accounting of how many one-hour periods over the modeling period experienced flows within each of a number of specified ranges. The results for the most downstream channel reach (RCHRES 100) are shown in Table 3-2 and Figure 3-3. Complete results for all stream segments are included in Appendix B. The results indicate that there are more extreme flow conditions, both lower and higher, under existing conditions than under predevelopment conditions. Also, existing flows are higher, in general, for the same duration.

TABLE 3-1.
MEAN DAILY FLOW RATE

RCHRES Segment	Mean Daily Flow (cfs) Predeveloped Land Use	Existing Land Use
700	16.1	16.2
610	24.0	24.6
600	24.0	24.6
500	25.7	26.5
400	28.6	29.8
300	5.2	5.6
220	33.9	35.4
210	37.3	39.6
200	37.3	39.6
100	40.4	43.3

3.3.3 Low Flow Characteristics

Low flow characteristics of each channel segment were analyzed for 1-, 2-, 3-, 7-, 10-, 30-, 60-, 90-, and 183-day periods. Table 3-3 lists the mean 7-day low flows over the entire model period for predeveloped and existing basin conditions. Other low-flow results are provided in Appendix B. The average 7-day low flow under predevelopment conditions was higher than under existing conditions for developing areas but about the same in forested or undeveloped areas. This follows the typical trend in a developing watershed of impervious area reducing groundwater recharge and hence groundwater inflow to streams, which is most evident during low-flow periods.

3.3.4 Flow Frequency Analysis

A log-Pearson Type III distribution analysis using the Bulletin 17B procedure was used to estimate flow frequencies in each stream reach. Table 3-4 lists the results of the flow frequency analysis for predeveloped and existing conditions. Annual peak flow rates shown for each stream segment are a summation of all upstream routed flows. The frequency results for the creek mouth (RCHRES 100) show a typical characteristic of a developing watershed: the severity of flood flows increases with increased impervious area and loss of forest cover. The 100-year flood flow for existing conditions increased about 23 percent over predeveloped conditions.

These results at the mouth of Boise Creek were compared to flood frequency results prepared by the U.S. Geological Survey (USGS 1998). The USGS analysis used 19 years (1978-1996) of peak flow recorded at the Boise Creek gauge site (12099600). The results are summarized in Table 3-5.

TABLE 3-2.
RCHRES 100 HOURLY FLOW RATE DURATION ANALYSIS

Flow Range (cfs)		Predeveloped Land Use		Existing Land Use	
Greater than or Equal to	But Less Than	Number of Cases[a]	Percent of All Intervals	Number of Cases[a]	Percent of All Intervals
0.0	1.0	2	0.00	2	0.00
1.0	1.3	1	0.00	1	0.00
1.3	1.6	0	0.00	0	0.00
1.6	2.0	1	0.00	1	0.00
2.0	2.5	0	0.00	1	0.00
2.5	3.2	1	0.00	161	0.04
3.2	4.0	1,132	0.26	1,574	0.37
4.0	5.0	6,286	1.46	6,668	1.55
5.0	6.3	21,526	5.01	22,620	5.27
6.3	7.9	30,519	7.11	30,859	7.18
7.9	10.0	35,965	8.37	34,344	8.00
10.0	13.0	38,435	8.95	36,571	8.51
13.0	16.0	30,528	7.11	30,328	7.06
16.0	20.0	31,917	7.43	30,532	7.11
20.0	25.0	28,083	6.54	29,937	6.97
25.0	32.0	33,304	7.75	35,539	8.27
32.0	40.0	32,248	7.51	31,424	7.32
40.0	50.0	30,117	7.01	28,794	6.70
50.0	63.0	28,413	6.61	26,901	6.26
63.0	80.0	25,139	5.85	23,596	5.49
80.0	100.0	18,697	4.35	17,771	4.14
100.0	130.0	16,126	3.75	15,918	3.71
130.0	160.0	8,677	2.02	9,069	2.11
160.0	200.0	5,513	1.28	6,438	1.50
200.0	250.0	3,297	0.77	4,160	0.97
250.0	320.0	1,859	0.43	2,869	0.67
320.0	400.0	877	0.20	1,382	0.32
400.0	500.0	445	0.10	912	0.21
500.0	630.0	206	0.05	591	0.14
630.0	800.0	149	0.03	361	0.08
800.0	1000.0	49	0.01	137	0.03
1000.0	1300.0	16	0.00	63	0.01
1300.0	1600.0	0	0.00	4	0.00
1600.0	2000.0	0	0.00	0	0.00
2000.0	—	0	0.00	0	0.00

a. Number of cases is the number of one-hour intervals in which the flow was within the specified range over the model period of October 1, 1948 through September 30, 1997.

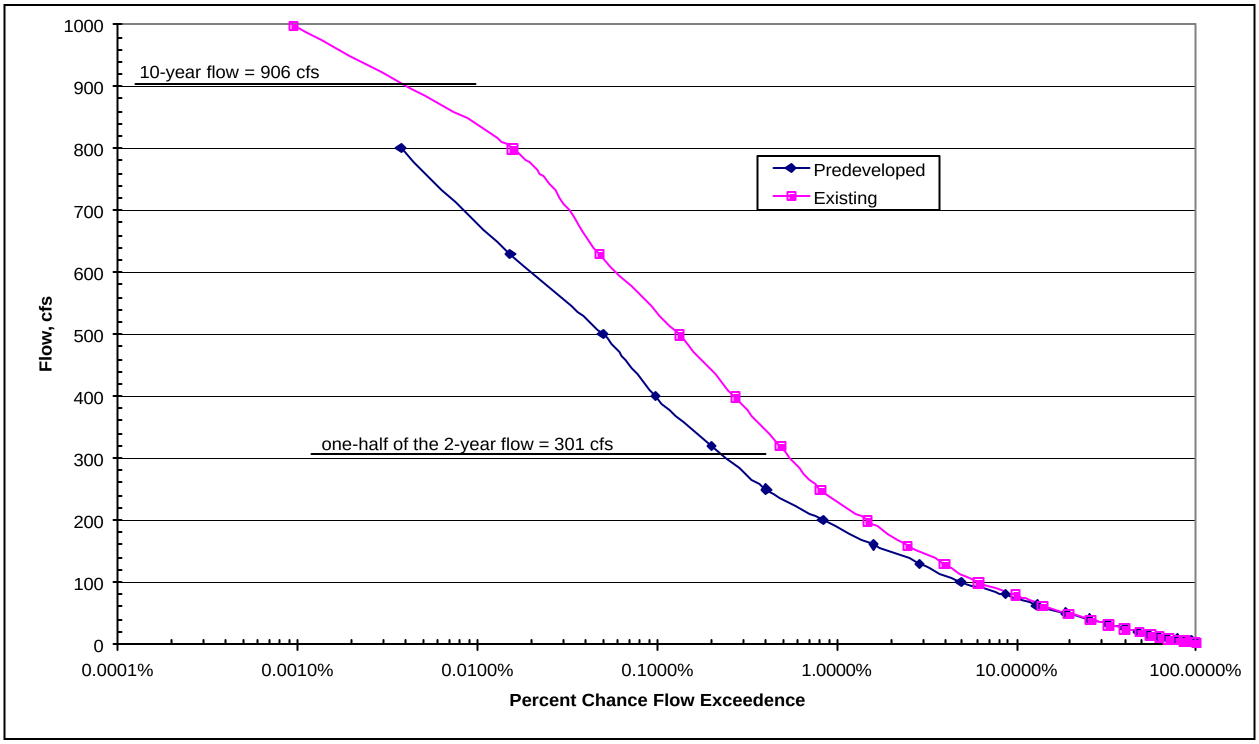

Figure 3-3. RCHRES 100 Flow Duration Comparison

TABLE 3-3.
BOISE CREEK MEAN 7-DAY LOW FLOW

RCHRES Segment	Mean 7-Day Low Flow (cfs) Predeveloped	Existing
100	6.53	6.16
200	5.98	5.74
210	5.98	5.75
220	5.38	5.32
300	.85	.82
400	4.51	4.49
500	3.96	3.96
600	3.58	3.59
610	3.58	3.59
700	1.88	1.93

TABLE 3-4.
FLOW FREQUENCY ANALYSIS

RCHRES Segment	Peak Annual Discharge (cfs) 2-yr Predeveloped	2-yr Existing	5-yr Predeveloped	5-yr Existing	10-yr Predeveloped	10-yr Existing	25-yr Predeveloped	25-yr Existing	100-yr Predeveloped	100-yr Existing
100	601.9	821.8	791.1	1,014.6	906.0	1,137.8	1,041.4	1,290.2	1,226.4	1,512.6
200	536.4	682.3	696.7	844.1	797.5	950.7	920.1	1,086.0	1,094.9	1,289.7
210	546.9	706.4	725.2	893.2	840.4	1017.6	983.4	1,176.6	1,192.6	1,418.1
220	494.6	634.2	687.7	846.8	825.0	987.3	1,009.3	1,165.0	1,306.5	1,431.0
300	144.0	201.8	207.7	262.5	252.0	300.8	310.2	347.7	401.1	414.8
400	390.3	490.0	561.2	691.0	684.7	833.1	852.5	1,022.6	1,126.7	1,325.7
500	352.7	422.8	523.7	637.0	658.0	806.7	853.4	1,055.8	1,202.9	1,505.8
600	344.0	406.0	519.9	622.6	660.6	797.3	868.7	1,057.2	1248.6	1,535.3
610	366.9	445.3	575.9	699.5	750.3	913.7	1,017.4	1,244.9	1,527.3	1,185.0
700	280.0	306.0	433.1	478.8	557.4	620.7	743.4	835.3	1,088.1	1,237.8

TABLE 3-5.
USGS FLOOD FREQUENCY ANALYSIS

Flood Event	Flood Discharge (cfs)	95% Confidence Interval (cfs)
2-year	485	394-600
10-year	935	739-1320
25-year	1,170	897-1770
50-year	1,350	1,010-2,130
100-year	1,530	1,120-2,520

For the existing land use condition, HSPF flood frequency analysis results are generally within the 95-percent confidence interval prepared by the USGS. The HSPF results tend to be high for the more frequent floods but about match the USGS 100-year flood. The differences could be due to the use of the Landsburg rainfall data, snowfall in the upper basin, modeling historical meteorological conditions with static current land use cover, the short period of record used in the USGS analysis, or other concerns described previously. The model should be refined using basin-specific information, but it may be used in the meantime to indicate trends, such as base flows, as development occurs in the basin.

3.4 QUALITATIVE ANALYSIS OF FUTURE BUILDOUT CONDITIONS

The future buildout condition is defined as development to the maximum density allowed by current zoning. Table 3-6 summarizes impervious area by subbasin for predevelopment, existing and future conditions. The table shows that impervious area increased from 0.5 to

6.8 percent in the transition from predevelopment to existing conditions and will increase only another 0.3 percent (to 7.1 percent total) with development to buildout. Slight changes in hydrology may result from the predicted increase in impervious surface, but they are more apt to result from a conversion of low runoff forested areas to grassed areas that generate greater runoff. Consequently, future peak flows, especially for the more frequent events, may increase slightly, with a slight reduction of low flows due to some loss of subsurface storage when the forest canopy and forest duff are removed.

TABLE 3-6.
SUBBASIN CHARACTERISTICS TO ASSESS FUTURE FLOWS

Subbasin	Subbasin Area (acres)	Impervious Area (acres)			Percent EIA		
		Predeveloped	Existing	Future[a]	Predeveloped	Existing	Future
7	3,256	0.0	20.3	20.3	0.0	0.6	0.6
6	2,257	46.0	118.4	131.7	2.0	5.2	5.8
5	534	0.0	35.9	35.9	0.0	6.7	6.7
4	785	2.8	82.2	82.2	0.4	10.5	10.5
3	1,195	0.8	26.0	38.6	0.0	2.2	3.2
2	960	0.0	215.8	219.9	0.0	22.5	22.9
1	874	0.01	168.9	168.9	0.0	19.3	19.3
Entire Basin	9,861	49.6	667.5	697.6	0.5	6.8	7.1

a. When future impervious area was found to be less than existing, future impervious area was set equal to existing.

3.5 CONCLUSIONS AND RECOMMENDATIONS

The HSPF model developed for this analysis of the basin should be viewed as preliminary; further data gathering, monitoring and calibration are recommended. The model should be refined using additional basin-specific information. However, the model may be used to indicate trends, such as changes in base flows and flow magnitudes, as development occurs in the basin. The following additional efforts are desirable to refine the model for future use:

- Calibrate the model based on local precipitation data
- Current orthophotos of the basin could be digitized and specific cover types and EIA areas computed.
- Model snowfall and snowmelt.
- Survey channel characteristics (cross-sections, slope, overbank features, etc.).
- Obtain accurate topographic information for defining floodplain storage.
- Perform a drainage system inventory and survey culverts and bridges.