King County Watershed Modeling Services – Green River Water Quality Assessment, and Sammamish-Washington, Analysis and Modeling Program Watershed Modeling Calibration Report

In Progress

King County

Department of Natural Resources and Parks
Water and Land Resources Division
Science Section
King Street Center, KSC-NR-0600
201 South Jackson Street, Suite 600
Seattle, WA 98104
206-296-6519 TTY Relay: 711
dnr.metrokc.gov/wlr

Section 4—Little Bear Creek

July 2003

Prepared for:

King County
Department of Natural Resources and Parks
Water and Land Resources Division

201 S. Jackson St, Suite 600
Seattle, WA 98104
206-296-6519
http://www.metrokc.gov/

Prepared by:

AQUA TERRA CONSULTANTS
1509 Hewitt Avenue, Suite 121
Everett, Washington 98201
and
2685 Marine Way, Suite 1314
Mountain View, California 94043

In conjunction with King County

Alternative formats available

206-263-6317 TTY Relay: 711

4 LITTLE BEAR CREEK MODEL DEVELOPMENT

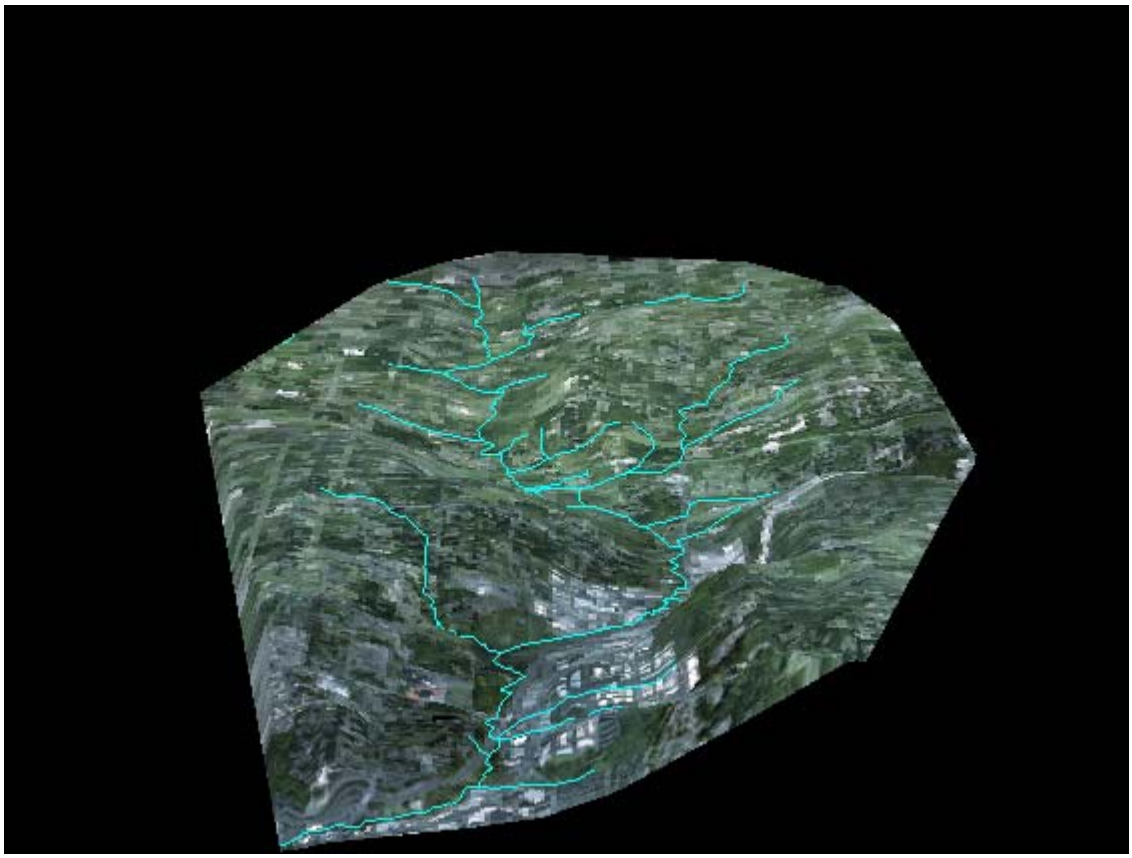


Table of Contents

4 LITTLE BEAR CREEK MODEL DEVELOPMENT 4-1

4.1 LITTLE BEAR CREEK WATERSHED DOMAIN 4-6
4.2 DATA REQUIREMENTS AND AVAILABILITY 4-7
4.2.1 INPUT / EXECUTION DATA FOR MODEL SIMULATIONS 4-7
4.2.1.1 Calibration Data 4-9
4.2.1.2 Water Quantity Calibration Data 4-15
4.2.1.3 Water Quality Calibration Data 4-18
4.2.2 WATERSHED / CONVEYANCE SYSTEM CHARACTERIZATION DATA 4-20
4.2.3 CALIBRATION / VALIDATION DATA 4-21
4.2.3.1 WATERSHED SEGMENTATION AND CHARACTERIZATION 4-21
4.3 MODEL CALIBRATION 4-32
4.3.1 WATER QUANTITY 4-32
4.3.1.1 Initial Calibration Parameter Values 4-32
4.3.1.2 HYDROLOGIC CALIBRATION AND KEY CALIBRATION PARAMETERS 4-32
4.3.1.3 Final Calibration Parameter List 4-34
4.3.1.4 COMPARISONS PERFORMED 4-40
4.3.1.5 CALIBRATION SUMMARY 4-52
4.3.2 WATER QUALITY 4-52
4.3.2.1 Initial Water Quality Parameter Set 4-52
4.3.2.2 Water Quality Calibration 4-52
4.3.2.3 Summary of Calibration Procedures 4-53
4.3.2.4 Calibration Discussion and Results 4-54
4.3.2.5 Unresolved Calibration Issues 4-69
4.4 MODEL LINKAGES 4-70
4.4.1 Spatial Linkage 4-70
4.4.2 Temporal Linkage 4-70
4.4.3 Linkage Formats 4-71
4.5 REFERENCES 4-71
4.5.1 Water Quality 4-71
4.5.2 Water Quantity 4-71

List of Figures

FIGURE 4.1-1 LITTLE BEAR CREEK SUBBASIN 4-6
FIGURE 4.2-1 NEARBY PRECIPITATION STATIONS 4-12
FIGURE 4.2-2 MAP OF METEOROLOGIC DATA STATIONS USED FOR LITTLE BEAR CREEK 4-14
FIGURE 4.2-3 FLOW AND WATER QUALITY GAGES 4-17
FIGURE 4.2-4 MAP OF WATER QUALITY DATA STATIONS USED FOR LITTLE BEAR CREEK 4-19
FIGURE 4.2-5 LITTLE BEAR CREEK CATCHMENTS 4-22
FIGURE 4.2-6 LITTLE BEAR CREEK SCHEMATIC 4-24
FIGURE 4.3-1 KING CO GAGE 30A DAILY FLOW TIME SERIES 4-45
FIGURE 4.3-2 KING CO GAGE 30A FLOW DURATION 4-45
FIGURE 4.3-3 KING CO GAGE 30A DECEMBER 1998 HOURLY FLOW TIME SERIES 4-46
FIGURE 4.3-4 KING CO GAGE 30A DECEMBER 1999 HOURLY FLOW TIME SERIES 4-46
FIGURE 4.3-5 KING CO GAGE 30A MONTHLY FLOW TIME SERIES 4-47
FIGURE 4.3-6 KING CO GAGE 30A SCATTER PLOT 4-47
FIGURE 4.3-7 OBSERVED AND SIMULATED DAILY WATER TEMPERATURE FOR LITTLE BEAR CREEK AT HIGHWAY 202 4-60
FIGURE 4.3-8 OBSERVED AND SIMULATED DAILY SUSPENDED SEDIMENT CONCENTRATIONS FOR LITTLE BEAR CREEK AT HIGHWAY 202 4-61
FIGURE 4.3-9 OBSERVED AND SIMULATED DAILY DISSOLVED OXYGEN CONCENTRATIONS FOR LITTLE BEAR CREEK AT HIGHWAY 202 4-61
FIGURE 4.3-10 OBSERVED AND SIMULATED DAILY AMMONIA CONCENTRATIONS FOR LITTLE BEAR CREEK AT HIGHWAY 202 4-62

FIGURE 4.3-11 OBSERVED AND SIMULATED DAILY NITRATE CONCENTRATIONS FOR LITTLE BEAR CREEK AT HIGHWAY 202 4-63
FIGURE 4.3-12 OBSERVED AND SIMULATED DAILY TOTAL NITROGEN CONCENTRATIONS FOR LITTLE BEAR CREEK AT HIGHWAY 202 4-64
FIGURE 4.3-13 OBSERVED AND SIMULATED DAILY ORTHOPHOSPHATE CONCENTRATIONS FOR LITTLE BEAR CREEK AT HIGHWAY 202 4-65
FIGURE 4.3-14 OBSERVED AND SIMULATED DAILY TOTAL PHOSPHORUS CONCENTRATIONS FOR LITTLE BEAR CREEK AT HIGHWAY 202 4-66
FIGURE 4.3-15 OBSERVED AND SIMULATED DAILY ALKALINITY CONCENTRATIONS FOR LITTLE BEAR CREEK AT HIGHWAY 202 4-67
FIGURE 4.3-16 OBSERVED AND SIMULATED DAILY ECOLI CONCENTRATIONS FOR LITTLE BEAR CREEK AT HIGHWAY 202 4-68
FIGURE 4.3-17 SIMULATED DAILY PH, TIC, AND ALKALINITY VALUES FOR LITTLE BEAR CREEK AT HIGHWAY 202 4-69

List of Tables

TABLE 4.2-1 DATA AVAILABILITY FOR MODEL SIMULATIONS 4-8
TABLE 4.2-2 DATA AVAILABILITY FOR MODEL CALIBRATION 4-9
TABLE 4.2-3 COMPARISON OF PRECIPITATION ANNUAL VOLUMES 4-11
TABLE 4.2-4 ADDITIONAL METEOROLOGIC DATA STATIONS FOR LITTLE BEAR CREEK 4-13
TABLE 4.2-5 ASOS TERMS 4-14
TABLE 4.2-6 LITTLE BEAR CREEK MAXIMUM STREAMFLOWS AT KING CO GAGE 30A 4-16
TABLE 4.2-7 LINKAGE OF SAMPLING STATION TO REACH NUMBER 4-18
TABLE 4.2-8 CONSTITUENTS AND PERIODS OF RECORD FOR WATER QUALITY MONITORING STATIONS ON LITTLE BEAR CREEK 4-20
TABLE 4.2-9 DATA AND GIS COVERAGES USED FOR CHARACTERIZATION OF THE WATERSHED AND CONVEYANCE SYSTEM. 4-21
TABLE 4.2-10 CATCHMENT AREAS 4-23
TABLE 4.2-11 LITTLE BEAR CREEK WATERSHED PERLND/IMPLND AREAS 4-27
TABLE 4.2-12 STREAM REACH DATA 4-30
TABLE 4.3-1 FINAL PERLND/IMPLND PARAMETER VALUES (PART 1) 4-34
TABLE 4.3-2 FINAL PERLND/IMPLND PARAMETER VALUES (PART 2) 4-35
TABLE 4.3-3 FINAL PERLND/IMPLND PARAMETER VALUES (PART 3) 4-37
TABLE 4.3-4 FINAL PERLND/IMPLND PARAMETER VALUES (PART 4): MONTHLY LZETP VALUES 4-39
TABLE 4.3-5 FINAL PERLND/IMPLND PARAMETER VALUES (PART 5) 4-40
TABLE 4.3-6 FLOW STATISTICS AT KING COUNTY GAGE 30A (OCT 1998 – SEP 2001) 4-40
TABLE 4.3-7 ANNUAL VOLUMES AT KING COUNTY GAGE 30A (OCT 1998 – SEP 2001) 4-41
TABLE 4.3-8 FLOW STATISTICS AT SNOHOMISH CO GAGE (MAR 2000 – SEP 2001) 4-41
TABLE 4.3-9 MEAN MONTHLY FLOW STATISTICS AT KING COUNTY GAGE 30A 4-42
TABLE 4.3-10 EXPERT SYSTEM STATISTICS AT KING CO GAGE 30A (OCT 1998 – SEP 2001) 4-43
TABLE 4.3-11 LITTLE BEAR CREEK MEAN ANNUAL WATER BALANCE (OCT 1998 – SEP 2001) 4-51
TABLE 4.3-12 AVERAGE ANNUAL NITROGEN LOADINGS 4-57
TABLE 4.3-13 AVERAGE ANNUAL PHOSPHORUS AND SEDIMENT LOADINGS 4-58
TABLE 4.3-14 MEAN SIMULATED VS. OBSERVED CONCENTRATIONS ON SAMPLE DATES 4-58
TABLE 4.3-15 AVERAGE AND RANGE OF SIMULATED/OBSERVED CONCENTRATION RATIOS FOR ALL LITTLE BEAR CREEK STATIONS 4-59

4.1 LITTLE BEAR CREEK WATERSHED DOMAIN

The physical domain of the HSPF model for this study is the entire Little Bear Creek watershed above the confluence with the Sammamish River, an area of approximately 15 square miles.

Figure 4.1-1 Little Bear Creek Subbasin

4.2 DATA REQUIREMENTS AND AVAILABILITY

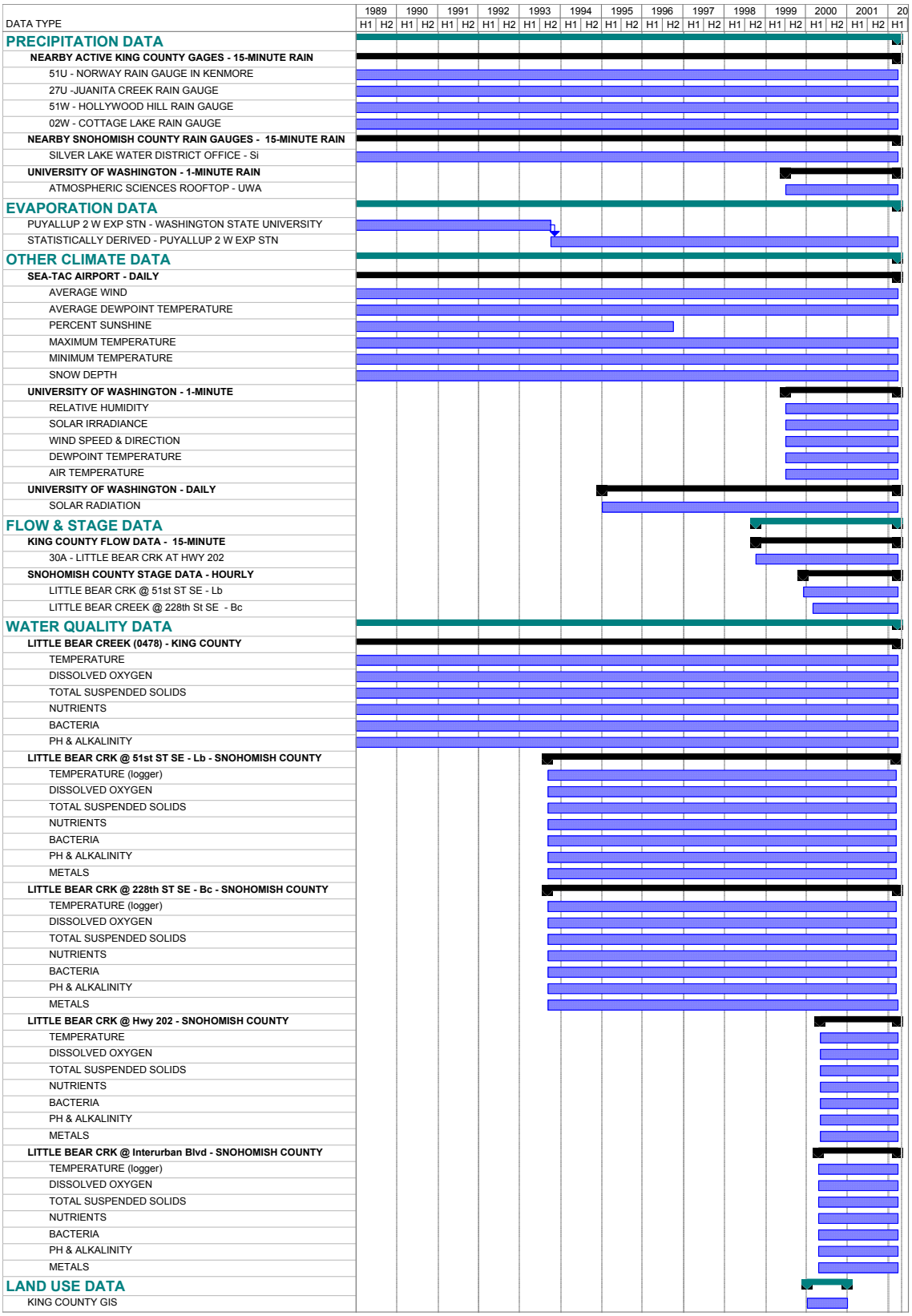
This section will describes the timeframe and constituents the data are capable of supporting for Little Bear Creek model simulations.

4.2.1 INPUT / EXECUTION DATA FOR MODEL SIMULATIONS

Input / execution data includes time series data that will drive the model simulations. For this application, the watershed model will require climatic data, point, import/export, diversion, and possibly other atmospheric data for water quality calibration. The output from this HSPF model will provide inputs to the Sammamish River CE-QUAL-W2 segments receiving Little Bear Creek inflows.

Table 4.2-1 provides a summary of the types of data that will be used as part of this modeling effort and the time periods over which they are available. These timelines are not intended to be all-inclusive but rather to provide an overall picture of available historical and current data. The references and sources used to develop the information in Table 4.2-1 include published reports (AQUA TERRA and King County, 2002b), USGS data, NOAA/NCDC data, the King County Hydrologic Information Center http://dnr.metrokc.gov/hydrodat/index.htm, and the Snohomish County Surface Water Management site http://www.co.snohomish.wa.us /publicwk/swm/, along with other personal communications and miscellaneous sources.

Table 4.2-1 Data Availability for Model Simulations



4.2.1.1 Calibration Data

Table 4.2-2 provides a summary of the types of data that will be used for the Little Bear Creek hydrology calibration and the time periods over which they are available.

Table 4.2-2 Data Availability for Model Calibration

Location	Data Type	Time Step	Starting Date	Ending Date	DSN
Puyallup	Evaporation	Daily	1948/10/01	2002/09/30	1
Cottage Lake	Precipitation	15-Minute	1992/10/01	2002/07/31	2
Little Bear Creek	Precipitation	15-Minute	2000/10/25	2002/11/11	3
SeaTac Airport	Precipitation	15-Minute	1948/10/01	1998/09/30	8
Silver Lake	Precipitation	15-Minute	1948/10/01	2001/09/30	12
Juanita Creek	Precipitation	15-Minute	1988/10/01	2002/09/15	27
Little Bear Creek	Streamflow	Hourly	1998/10/01	2002/02/04	30
Little Bear Creek	Streamflow	15-Minute	2000/03/09	2002/09/24	31
Norway Hill	Precipitation	15-Minute	1987/10/01	2002/09/15	51

4.2.1.1.1 Precipitation

Precipitation data are available at a 15-minute interval from four nearby King County gages and one gage in Snohomish County for the time intervals shown in Table 4.2-2. The four King County gages are generally located to the south of the watershed, typically less than three miles from the watershed's boundary. The gage operated in Snohomish County (i.e., Silver Lake – Si) is located less than two miles north of the northern tip of the watershed. The locations of the respective King County gages and the one Snohomish County gage can be seen in Figure 4.2-1 Nearby Precipitation Stations.

Selection of the most applicable precipitation record to use for the calibration process was based on the length of the record, the time period of the record related to availability of recorded streamflow data, and the location of the precipitation station to the Little Bear Creek watershed.

Only one precipitation station is located in the Little Bear Creek watershed. The specific location of the Little Bear Creek precipitation station is not known, but according to King County sources (Burkey, 2002) is located near the center of the watershed. Due to the shortness of its record (October 2000 through October 2002), it could not be used for the entire calibration period.

As shown in Table 4.2-3 and Figure 4.2-1, the other nearby precipitation stations' records were compared based on annual total volumes to determine which record was most representative of the Little Bear Creek watershed precipitation. Individual precipitation gages were considered for the calibration based on their location, length of record, and relationship to the PRISM isohyetals shown in Figure 4.2-1. No single precipitation record was found to accurately

represent the entire Little Bear Creek watershed for the calibration period of water years 1999 through 2001. Nor did the calibration period average annual precipitation at the four gages match well with the PRISM isohyet values. The PRISM isohyets show a much larger annual precipitation volume at the upstream northeast corner of the watershed than is supported by either topographic information or a comparison of the surrounding precipitation records. As such, the isohyets were used only as a secondary reference in the selection of the precipitation stations, their relative weighting, and the determination of an appropriate multiplication factor (MFACT) by which the composite record was scaled to represent the entire Little Bear Creek watershed.

The composite precipitation record was based on the four gages (Cottage Lake, Juanita Creek, Norway Hill, and Silver Lake) and with each gage representing one-quarter of the watershed. The averaged record was then multiplied by a factor of 1.05 (MFACT) to scale up the average precipitation to the watershed average.

Table 4.2-3 Comparison of Precipitation Annual Volumes

	King Co	King Co	King Co	Snohomish Co	King Co	
	02W	27U	51U			Watershed
	Cottage Lake	Juanita Creek	Norway Hill	Silver Lake	Little Bear	Average
Water Year	DSN 2	DSN 27	DSN 51	DSN 12	DSN 3	
1988			33.73	33.36		
1989		37.35	34.80	32.26		
1990		40.52	39.09	35.65		
1991		44.33	43.36	42.34		
1992		36.22	33.86	34.98		
1993	41.70	38.98	36.88	34.99		
1994	31.87	32.03	26.68	29.42		
1995	50.93	41.75	42.55	41.21		
1996	61.02	49.52	50.41	48.54		
1997	64.81	58.27	60.06	56.47		
1998	37.27	33.45	35.74	39.55		
1999	43.97	45.41	51.56	50.63		
2000	46.34	41.89	44.19	42.19		
2001	32.81	29.96	32.25	30.57	31.36	
2002	47.40	45.32	46.51		48.52	
Average						
Period of Record	45.81	41.07	40.78	39.44	39.94	
1999-2001	41.04	39.09	42.67	41.13		
PRISM at gage	46	40	39	43	44	46
Fraction of watershed	0.25	0.25	0.25	0.25		1.00

The average precipitaton record (DSN 97) was used for the calibration period of October 1998 through September 2001 (water years 1999-2001).

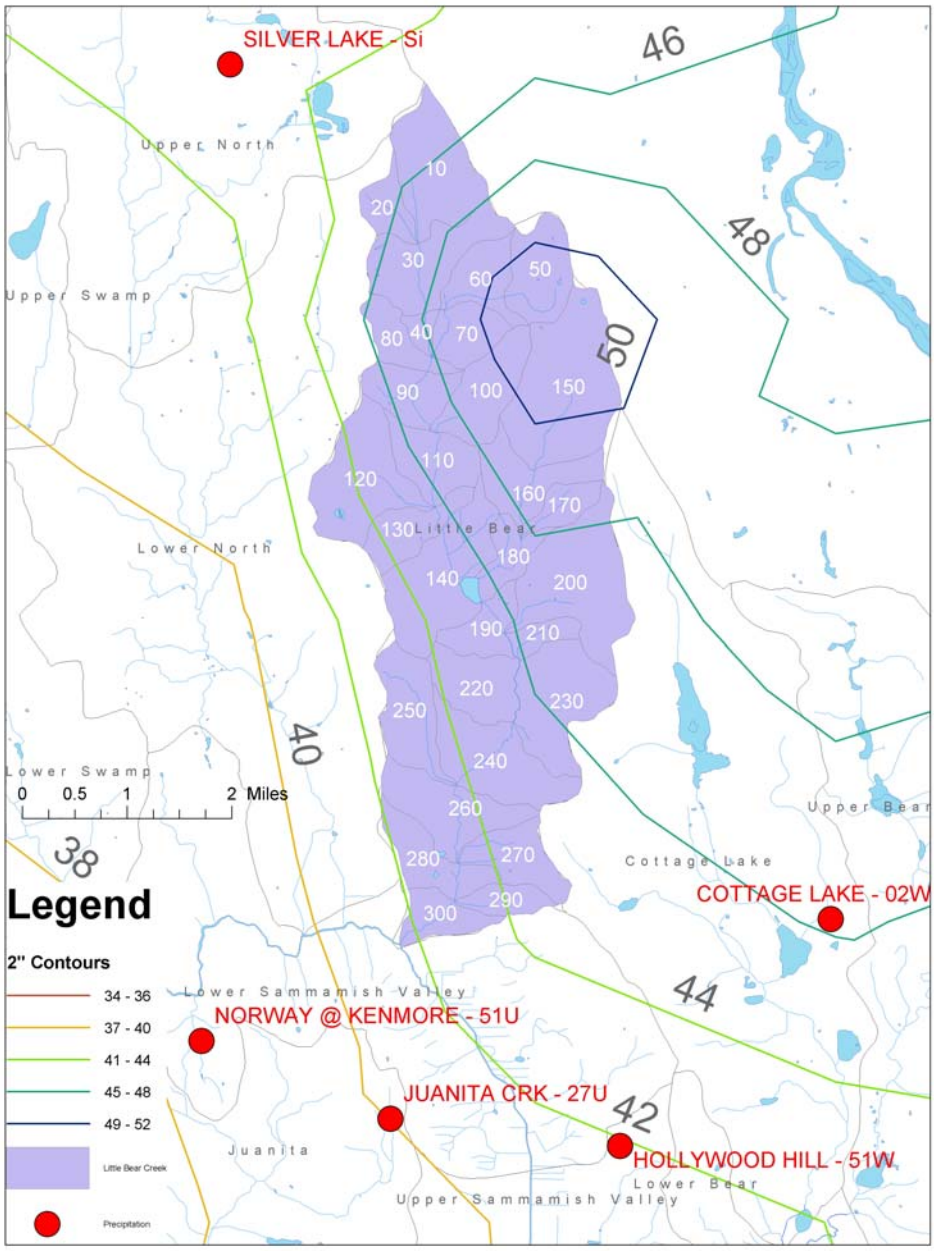


Figure 4.2-1 Nearby Precipitation Stations

4.2.1.1.2 Evaporation

Puyallup lies approximately 60 miles to the south of the Little Bear Creek watershed, but because evaporation does not vary greatly in the Puget Sound lowlands this distance is not considered significant (Farnsworth, et al, 1982). For more detail, see section 3.2.1.1.2. The calibration period is based on water years 1999 through 2001 and, as described in section 3.2.1, uses the 1960 data. The mean annual total for the calibration period is 30.32 inches.

Using the NOAA Technical Report NWS 33, the Little Bear Creek watershed coefficient was set to 0.78 and not adjusted during calibration.

4.2.1.1.3 Water Quality Required Meteorological Data

AQUA TERRA identified the station at Everett Snohomish County Airport (Paine Field) as the best source of data for the first four of these quantities, and Seattle Sand Point Weather Station Forecast Office as the best source for solar radiation data. Table 4.2-4 contains selected descriptive attributes of these stations. The map in Figure 4.2-2 shows the spatial relation of these stations to the Little Bear Creek watershed.

Table 4.2-4 Additional Meteorologic Data Stations for Little Bear Creek

StationID	STATION NAME	COUNTY	LAT (dec°)	LONG (dec°)	ELEV (m)	START	END
452670	EVERETT AIRPORT	SNOHOMISH	47.900	-122.283	184.7	6/1/48	12/31/01
457470	SEATTLE SAND PT WSFO	KING	47.683	-122.250	18.3	3/21/95	12/31/02

Data from the Everett Airport were obtained from the Western Regional Climate Center (WRCC) which collects, processes, and sells data from observation stations that are part of the Automated Surface Observing System (ASOS). Unfortunately, the data for Everett had not been processed and were delivered in “raw” format. AQUA TERRA processed the files in order to standardize the time interval and quantify the cloud cover estimations.

The time interval is hourly with the observation time in the last 10 minutes of the hour preceding that represented by the date and time labels. There were intermittent periods of missing data that were filled either by interpolation or by weighting values from nearby stations from the same time interval. For temperature and dew point, values were interpolated if there were 8 or fewer consecutive missing values. For cloud cover and wind, values were interpolated if there were 24 or fewer consecutive missing values. When filling longer gaps using data from nearby stations, the values were weighted by a factor equal to the ratio of the means at the two stations over the period of interest. Additionally, wind values were normalized from the anemometer height to a height of 2 feet.

The time interval is hourly with the observation time in the last 10 minutes of the hour preceding that represented by the date and time labels. There were intermittent periods of missing data that were filled either by interpolation or by weighting values from nearby stations from the same time interval. For temperature and dew point, values were interpolated if there were 8 or fewer consecutive missing values. For cloud cover and wind, values were interpolated if there were 24 or fewer consecutive missing values. When filling longer gaps using data from nearby

stations, the values were weighted by a factor equal to the ratio of the means at the two stations over the period of interest. Additionally, wind values were normalized from the anemometer height to a height of 2 feet.

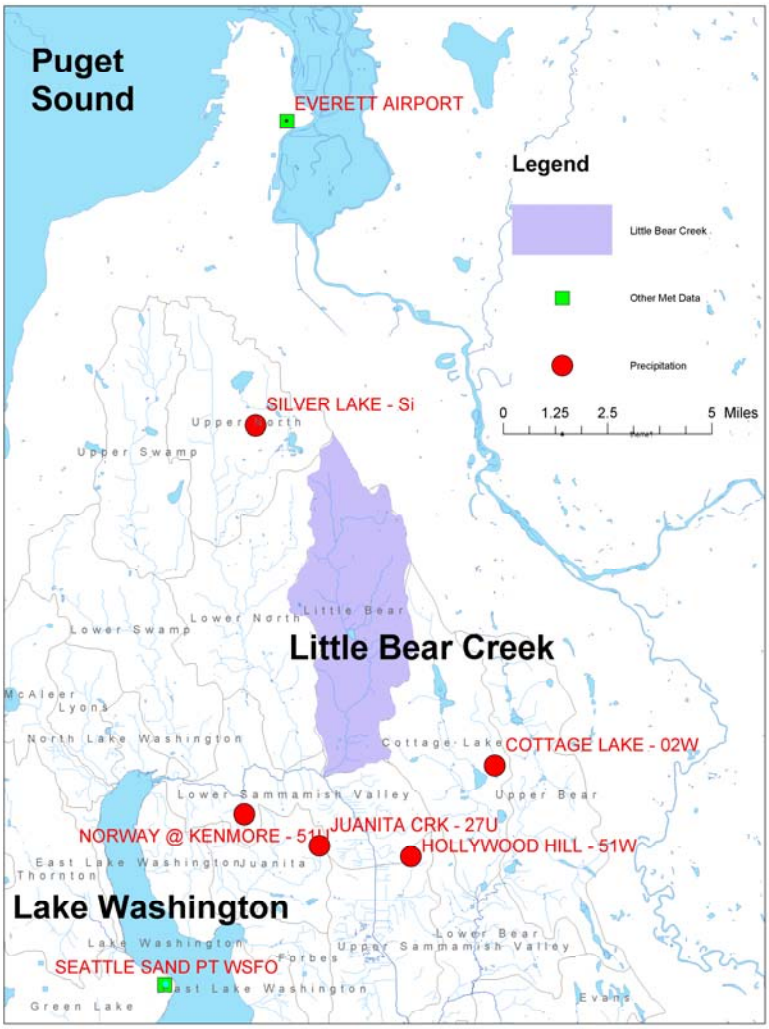


Figure 4.2-2 Map of Meteorologic Data Stations Used for Little Bear Creek

Cloud cover was recorded at one or more ceilings with a verbal description of CLR, FEW, SCT, BKN, or OVC. ASOS defines these terms as:

Table 4.2-5 ASOS Terms

Term	Description	Equivalent in Octas	Avg Decimal Equivalent
CLR	Clear	0/8	0.0
FEW	Few	1/8 to 2/8	0.1875
SCT	Scattered	3/8 to 4/8	0.4375

BKN	Broken	5/8 to 7/8	0.75
OVC	Overcast	8/8	1.0

HSPF requires a value of 0-10 to describe the degree of cloud cover; therefore, an algorithm was used to transform the descriptions to a numeric value in this range. For the first reported ceiling, the average decimal equivalent was multiplied by 10 and taken as the total cloud coverage. If additional ceilings were reported, an incremental increase in total coverage was calculated in the same manner, but was then multiplied by the fraction of remaining uncovered sky.

Solar radiation data were collected as part of the Integrated Surface Irradiance Study (ISIS) conducted by the Air Resources Laboratory, which operates the National Oceanic & Atmospheric Administration's national broadband solar radiation network. Measurements of shortwave global horizontal radiation were recorded every 15 minutes, so these values were aggregated into hourly values. Missing data were filled by estimating solar radiation from the cloud cover using the 'Compute' tool in WDMUtil.

4.2.1.1.3.1 Additional Water Quality Source Data

In addition to nonpoint loadings, other sources and losses of water quality constituents that must be represented in a model of this type are point sources, imports, diversions, and atmospheric deposition. There were no point sources or diversions identified in Little Bear Creek; and, while atmospheric deposition might be a non-negligible source of the some of the constituents in the model, these impacts cannot be differentiated from other nonpoint loadings due to the options being used in this application. Therefore, none of these quantities are considered in the water quality budget of Little Bear Creek. A comparison of the calibrated loading factors from impervious areas should be compared with available atmospheric deposition data to confirm this approach.

4.2.1.2 Water Quantity Calibration Data

4.2.1.2.1 Stream Flow

Recorded streamflow data are used to check the simulated streamflow results and evaluate the accuracy of the calibration. There are currently three streamflow stations along the Little Bear Creek that are actively collecting data. Two of these gages (one each operated by King County and Snohomish County) have been in operation long enough to develop an accurate rating curve.

The King County gage is the Little Bear Creek gage 30A at Highway 202. This gage has a rating curve, is located near the outlet of the Little Bear Creek watershed, and has been collecting data since October of 1998. The hydrology calibration will be limited to this rather short time period. As a result, there are insufficient streamflow data to support validation of the hydrology simulation.

Recorded streamflow data are available from this station for the period of October 1998 through January 2002. The period of record is complete. Maximum flow events for each water year are shown in Table 4.2-6. Each maximum flood event occurred in the autumn (November-December) in response to large rainfall events.

Table 4.2-6 Little Bear Creek Maximum Streamflows at King Co Gage 30A

Water Year	Maximum Flow (cfs)	Date of Event
1999	219	1998/12/13
2000	209	1999/11/12
2001	98	2000/11/27
2002*	297	2001/11/29

*October 2001 through 4 February 2002

For this same period of record low flows at King County gage 30A were in the range of 8 to 12 cfs.

The Snohomish County gage is located at the 228th Street SE bridge over Little Bear Creek. It has a shorter period of record than the King County gage. It started operation on 9 March 2000. Due to its short period of record Snohomish County gage was used as a check on the calibration, but with less emphasis than the longer King County gage. At this gage observed flows ranged from 6 to 50 cfs.

There is also a Snohomish County stream gage at 51st Avenue SE, south of 180th Street SE. Although a significant amount of water quality data has been located at this site, Snohomish County does not yet have a rating curve established for this gaging site. As such, the 51st Avenue SE gage could not be used in the hydrology calibration.

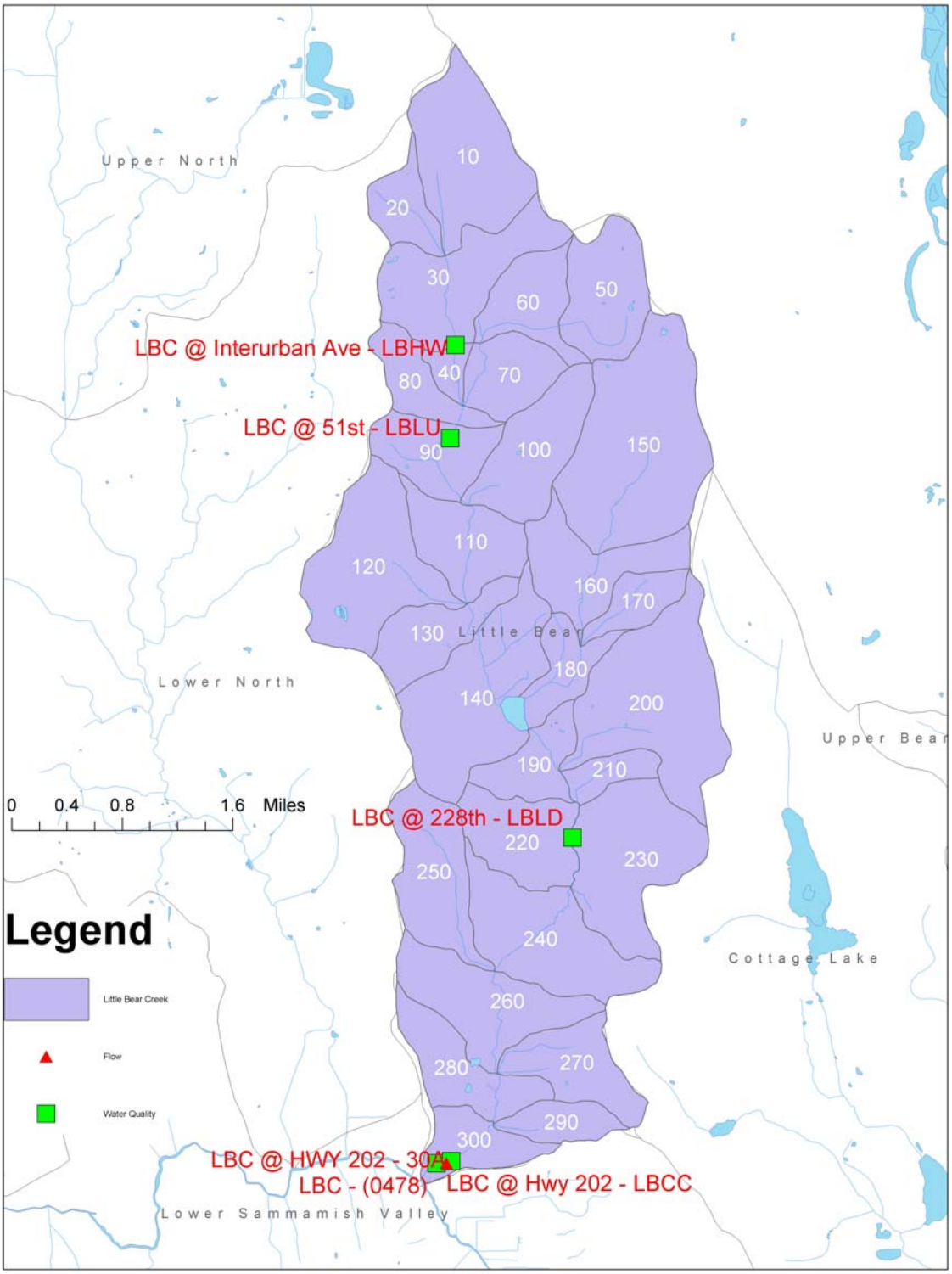


Figure 4.2-3 Flow and Water Quality Gages

4.2.1.3 Water Quality Calibration Data

Four water quality sampling stations were identified within the Little Bear Creek watershed. The first is sampled by King County, and data for that station were provided directly from the County. Snohomish County monitors at three other stations, and data for these were obtained from the Snohomish County Surface Water Management (SWM) online data application at http://198.238.192.103/spw_swhydro/geo-search.asp.

The map in Figure 4.2-4 shows the spatial relation of the stations to the study area. All stations are located on the Little Bear Creek (LBC).

The outlet station in King County (0478 – near Woodinville, WA and Highway 202) has data for many of the constituents of interest, and is the primary calibration station for the watershed. The three Snohomish County stations have data for only total phosphorus, nitrate, dissolved oxygen, TSS, and temperature. Since there are few or no direct measurements of organic material (BOD, total organic carbon, dissolved organic matter, etc), the calibration of organics was based on the apparent organic N and P values inferred from measured total N, total P, and the inorganic nutrient forms (i.e., nitrate, ammonia, and orthophosphate).

For purposes of comparing values during calibration, the values observed at a particular sampling station are compared to those simulated in the reach on which that station is located, unless the station is located just downstream from a reach outlet in which case the values are compared against those from the upstream reach. Using this reasoning, the following stations are compared against the corresponding reaches:

Table 4.2-7 Linkage of Sampling Station to Reach Number

Station	Reach
LBC @ Interurban Ave (LBHW)	30
LBC @ 51st (LBLU)	80
LBC @ 228th (LBLD)	220
LBC @ Hwy 202 (LBCC)	300
LBC (0478)	300

Since LBCC and 0478 are located very close to each other, and are both on Reach 300, these two stations are treated as one for comparison purposes.

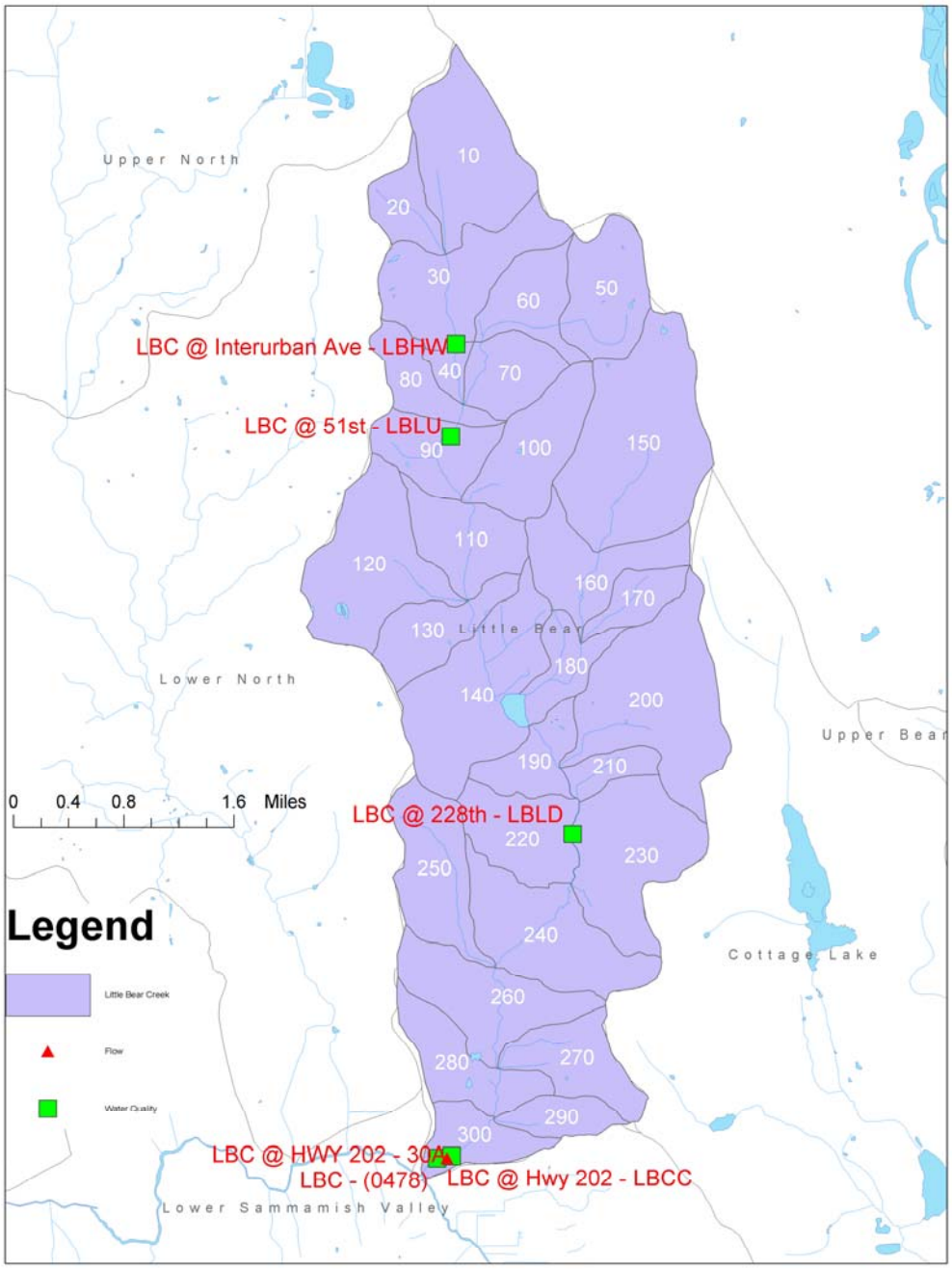


Figure 4.2-4 Map of Water Quality Data Stations Used for Little Bear Creek

All four stations are typically sampled on a monthly interval. Table 4.2-8 summarizes the period of record for the various constituents sampled at each station.

Table 4.2-8 Constituents and Periods of Record for Water Quality Monitoring Stations on Little Bear Creek

Constituent	Stations			
	LBHW	LBLU	LBLD	LBCC / 0478
Water Temperature	4/13/00-9/6/01	9/8/93-9/6/01	9/8/93-9/30/01	1/11/93-9/6/01
Dissolved Oxygen	4/13/00-9/6/01	9/8/93-9/6/01	9/8/93-9/6/01	1/11/93-9/6/01
BOD				
Suspended Sand				
Suspended Silt				
Suspended Clay				
Total Suspended Sediment	4/13/00-8/13/01	9/8/93-8/13/01	9/8/93-9/6/01	1/11/93-9/10/01
Ammonia / Ammonium				1/11/93-9/10/01
Nitrite / Nitrate	4/13/00-9/6/01	9/8/93-9/6/01	9/8/93-9/6/01	1/11/93-9/10/01
Organic Nitrogen				
Total Nitrogen				4/12/93-9/10/01
Phosphate				1/11/93-9/10/01
Organic Phosphorus				
Total Phosphorus	4/13/00-9/6/01	9/8/93-9/6/01	9/8/93-9/6/01	1/11/93-9/10/01
Total Organic Carbon				5/3/00-10/9/00
Total Inorganic Carbon				
Alkalinity				5/12/97-9/10/01
pH				
Silica				
E-Coli				10/21/98-1/10/01
Benthic Algae				

4.2.2 WATERSHED / CONVEYANCE SYSTEM CHARACTERIZATION DATA

Table 4.2-9 documents the various information, along with the respective sources, that was used in characterizing the watershed and conveyance system. The use of this information will be discussed in detail in Section 4.2.3.1.

Table 4.2-9 Data and GIS Coverages used for Characterization of the Watershed and Conveyance System.

Data / GIS Coverage	Source	Comment
Digital Elevation Model (DEM)	USGS	Required 4 individual 10 meter resolution DEMs to be mosaiced together
Slopes	AQUA TERRA Consultants	Developed using DEM and ArcView Spatial Analyst functionality
Land Use	King County	1995 Land Use
Soils	King County, AQUA TERRA Consultants	Coverage modified to group soils into following 4 classes: till, outwash, saturated, and bedrock
Hydrography/Stream Network	King County	Little Bear Creek and major tributaries
Stream and Meteorological Gages	King County, Snohomish County, NOAA	Locations of King and Snohomish County and nearby NOAA gages
Culverts	King County	Locations and attributes of culverts within the Little Bear Creek watershed; supplemented by field survey
Cross-sections	King County	Field survey

4.2.3 CALIBRATION / VALIDATION DATA

The hydrologic calibration and subsequent validation of a watershed model requires observed flow. Table 4.2-1 and the following sub-sections reflect knowledge of known monitoring that has been performed in Little Bear Creek. The stations discussed in the following sections are displayed in Figure 4.2-3.

4.2.3.1 WATERSHED SEGMENTATION AND CHARACTERIZATION

4.2.3.1.1 Catchment Delineation

The initial catchment delineation was performed by King County staff using the King County GIS hydrography/stream network data layer and later was slightly revised by AQUA TERRA Consultants. The initial delineation resulted in 30 catchments ranging in size from 0.09 to 1.30 square miles (Table 4.2-10). The catchments are shown in Figure 4.2-5; the schematic in Figure 4.2-6.

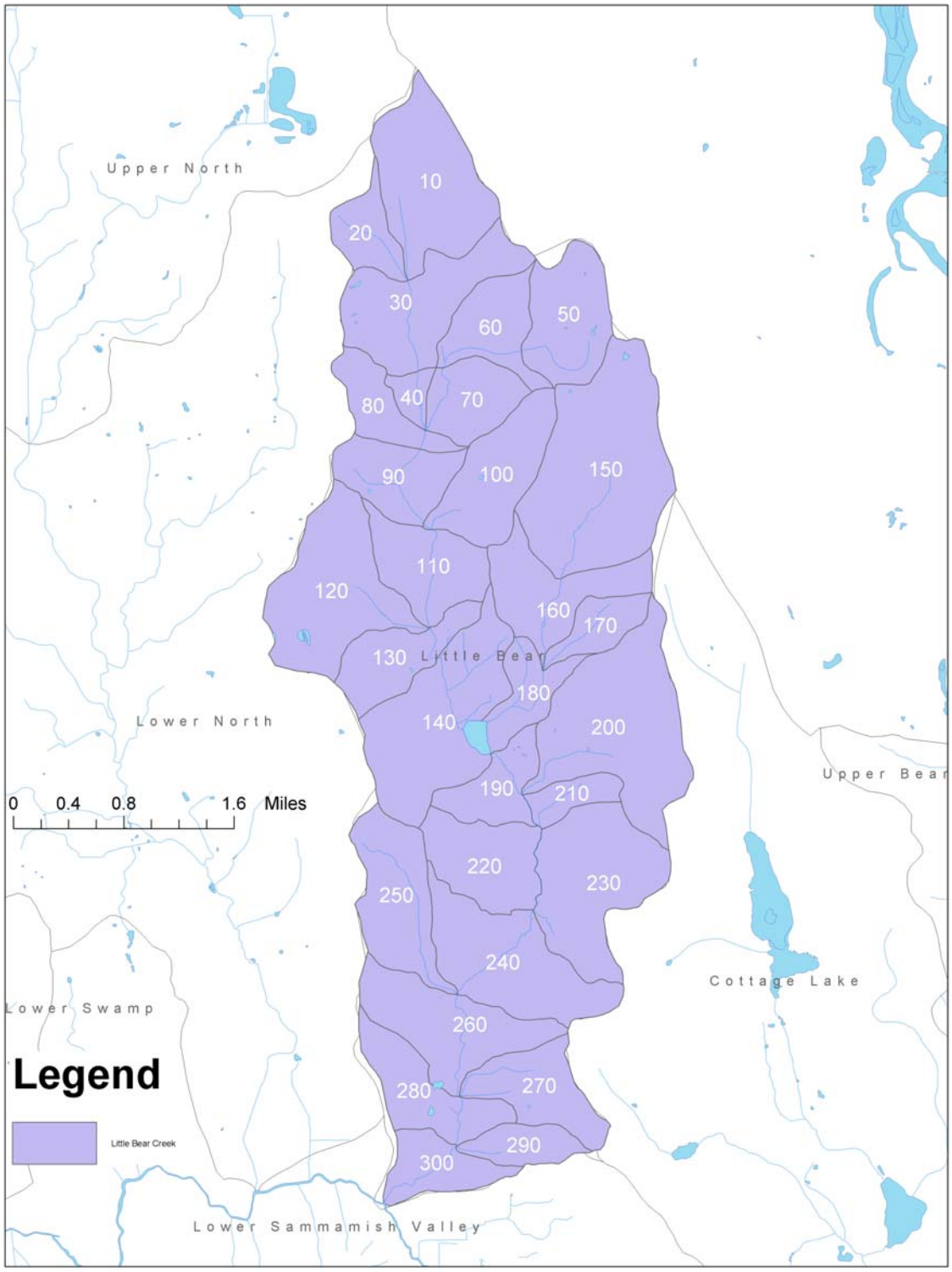
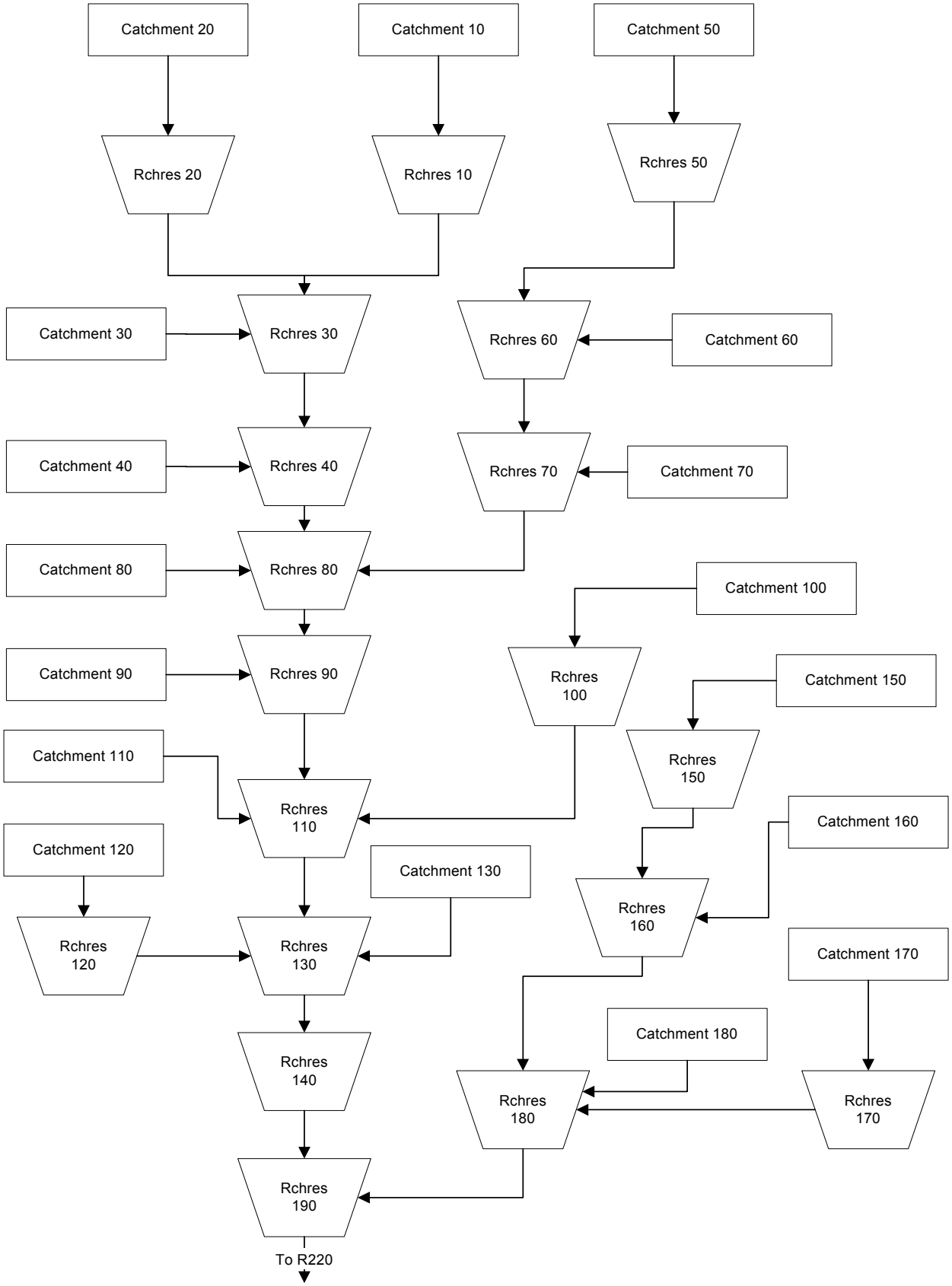


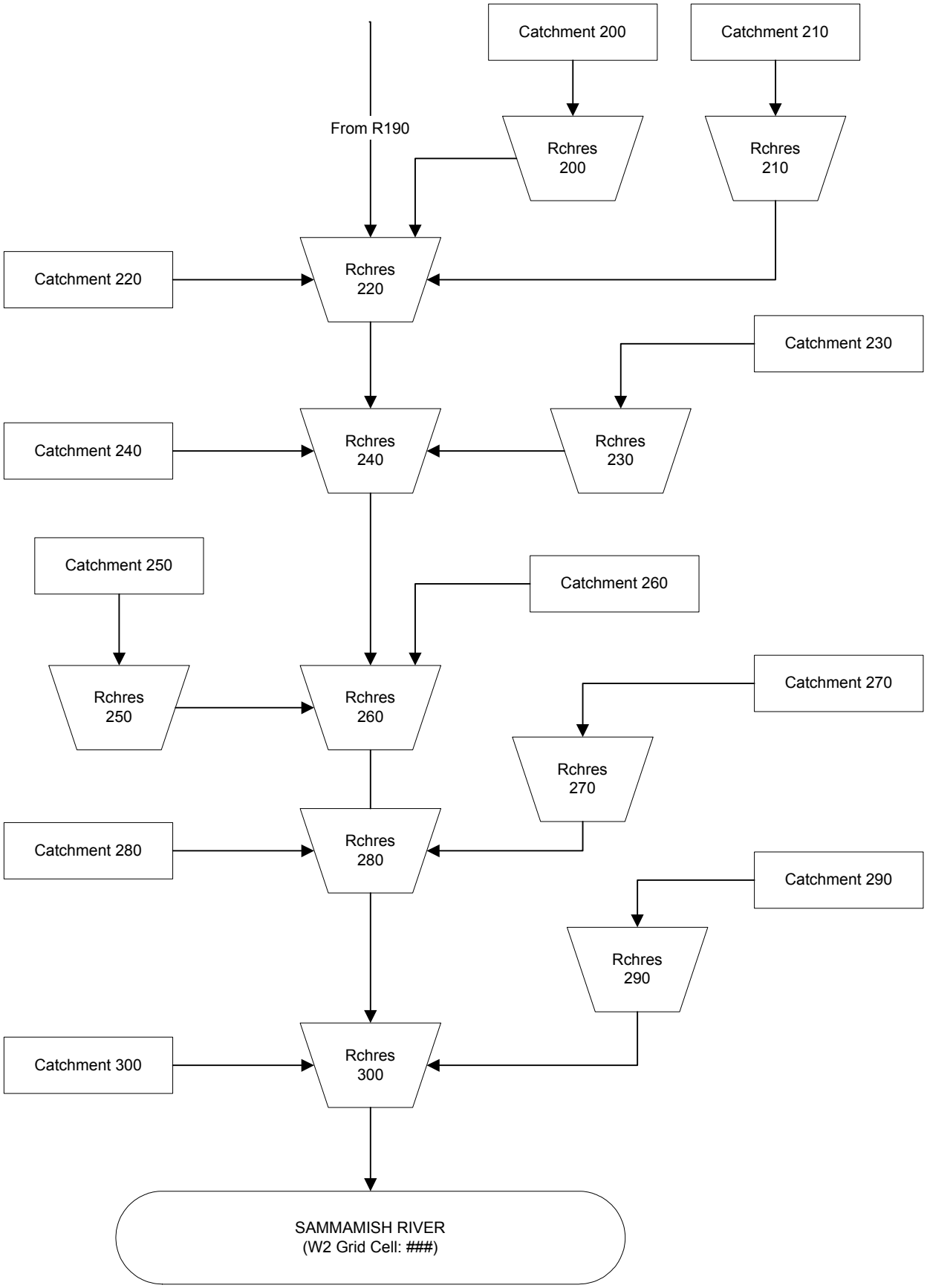
Figure 4.2-5 Little Bear Creek Catchments

Table 4.2-10 Catchment Areas

Catchment No.	Catchment Area (acres)	Stream Reach No.
10	494	10
20	153	20
30	443	30
40	58	40
50	328	50
60	236	60
70	216	70
80	179	80
90	255	90
100	350	100
110	294	110
120	548	120
130	240	130
140	619	140
150	785	150
160	323	160
170	134	170
180	174	180
190	191	190
200	697	200
210	100	210
220	635	220
230	194	230
240	498	240
250	364	250
260	406	260
270	271	270
280	277	280
290	132	290
300	187	300

Figure 4.2-6 Little Bear Creek Schematic


Catchment 20
Catchment 10
Catchment 50
Rchres 20
Rchres 10
Rchres 50
Catchment 30
Rchres 30
Rchres 60
Catchment 60
Catchment 40
Rchres 40
Rchres 70
Catchment 70
Catchment 80
Rchres 80
Catchment 100
Catchment 90
Rchres 90
Rchres 100
Catchment 150
Catchment 110
Rchres 150
Rchres 110
Catchment 160
Catchment 120
Catchment 130
Rchres 160
Rchres 120
Rchres 130
Catchment 170
Catchment 180
Rchres 140
Rchres 180
Rchres 170
Rchres 190
To R220


Catchment 200
Catchment 210
From R190
Rchres 200
Rchres 210
Catchment 220
Rchres 220
Catchment 230
Catchment 240
Rchres 240
Rchres 230
Catchment 250
Catchment 260
Rchres 250
Rchres 260
Catchment 270
Rchres 270
Catchment 280
Rchres 280
Catchment 290
Rchres 290
Catchment 300
Rchres 300
SAMMAMISH RIVER
(W2 Grid Cell: ###)

4.2.3.1.2 PERLND and IMPLND Categories

For the purpose of the Little Bear Creek simulation it is assumed that pasture is the same as agricultural animal (hobby farm) land use. The other pasture-related category of cropland may be used in other parts of the SWAMP and Green WQA study areas. No cropland or bedrock categories were identified in the Little Bear Creek watershed.

4.2.3.1.3 Catchment Characterization

The location, areas, and slopes of PERLND and IMPLND categories within each catchment were determined using the methods previously discussed. Additional attributes (e.g., average elevation) were also calculated within the GIS.

4.2.3.1.3.1 Physical Parameters

The Little Bear Creek watershed PERLND soil type and land use areas and IMPLND land use areas used in the HSPF model are summarized in Table 4.2-11. They are based on the GIS coverage and the delineation methodology described in Section 4.2.3.1.2.

Table 4.2-11 Little Bear Creek Watershed PERLND/IMPLND Areas

Land Use	Till (acres)	Outwash (acres)	Saturated (acres)	EIA (acres)	Total (acres)
Forest	2383	798	450	0	3632
Pasture/Ag	379	40	0	0	419
Forest Residential	917	132	13	0	1062
Low Density Residential	2036	838	76	178	3128
High Density Residential	446	329	13	483	1270
Commercial/Industrial	0	0	0	75	75
Roads	0	0	0	193	193
Total	**6162**	**2138**	**552**	**928**	**9780**

Table 4.2-11 Little Bear Creek Watershed PERLND/IMPLND Areas (cont'd)

Land Use	Till (%)	Outwash (%)	Saturated (%)	EIA (%)	Total (%)
Forest	24%	8%	5%	0%	37%
Pasture/Ag	4%	>1%	0%	0%	4%
Forest	9%	1%	>1%	0%	11%

Land Use	Till (%)	Outwash (%)	Saturated (%)	EIA (%)	Total (%)
Residential					
Low Density Residential	21%	9%	1%	2%	32%
High Density Residential	5%	3%	>1%	5%	13%
Commercial/Industrial	0%	0%	0%	1%	1%
Roads	0%	0%	0%	2%	2%
Total	**63%**	**22%**	**6%**	**9%**	**100%**

4.2.3.1.3.2 Additional Physical Data Needs for Water Quality Simulation

For Little Bear Creek, shading was roughly estimated by inspection of aerial photographs and from data contained in the report: *Habitat Inventory and Assessment of Three Sammamish River Tributaries: North, Swamp, and Little Bear Creeks* (Fevold, et al., 2001). Since water temperature processes are a function of air temperature and air pressure, stream elevations and the elevation of the air temperature gage are also needed. Stream elevations were determined from the DEM. Also, water temperatures in the Little Bear Creek model are affected by energy transfers between the water and the stream bed. Therefore, ground temperatures were estimated from groundwater temperatures in the King County area.

Little data are available to characterize Little Bear Creek erosion and bed sediments. Bed widths were estimated from the channel bottom width data developed for the FTABLES, and they were confirmed with data from Fevold et al. (2001).

4.2.3.1.4 CONVEYANCE SYSTEM SEGMENTATION AND CHARACTERIZATION

The current segmentation scheme is primarily the result of the catchment delineation. The modeling scheme incorporates a single HSPF reach per catchment. Originally some catchments were delineated such that they drain to the same reach as right and left contributions. These right/left catchments were combined into a single catchment for a corresponding HSPF reach.

4.2.3.1.4.1 HSPF Reach Network

The current network includes 30 reaches totaling approximately 20 miles in length; with the individual reaches ranging from approximately 0.25 to 0.86 miles in length. Within the channel module (RCHRES) of HSPF, each stream reach is represented by a hydraulic function table, called an FTABLE, which defines the flow rate, surface area, and volume as a function of the water depth in the channel reach. In order to develop an FTABLE, the channel's geometric and hydraulic properties (e.g., Manning's n) were first defined using observed data or estimated values. King County has provided culvert data to assist with the FTABLE development. Additional field survey work was conducted by AQUA TERRA staff to provide additional cross-section and hydraulic property information.

Once the geometry and hydraulic properties were defined, it was necessary to develop the FTABLE as a function of the depth of water at the outlet, in order to simulate the hydraulic

behavior of the reach. AQUA TERRA's XS2 program (based on Manning's equation) was used to develop FTABLEs using the supplied data for the stream reaches. Where culverts controlled or limited the flow from one stream reach to the next, backwater effects were calculated using the Federal Highway Administration's HY8 program. The stage-storage information from XS2 was then merged with the stage-discharge output from HY8 to provide an accurate FTABLE with stage-storage-discharge data. Table 4.3-1 shows the data used to construct the FTABLEs for Little Bear Creek.

Table 4.2-12 Stream Reach Data

RCHRES	Total Length (mi)	RCHRES Length (mi)	Upstream Elev (ft)	Downstream Elev (ft)	Change in Elev (ft)	Slope (%)	Channel Roughness	Floodplain Roughness	Downstream Control
10	**9.42**	**1.16**	**460**	**370**	**90**	**1.5%**	**0.050**	**0.1**	**culvert**
20	0.72	0.72	430	370	60	1.6%	0.050	0.1	channel
30	**8.26**	**0.68**	**370**	**335**	**35**	**1.0%**	**0.050**	**0.1**	**culvert**
40	**7.58**	**0.43**	**335**	**315**	**20**	**0.9%**	**0.050**	**0.1**	**channel**
50	2.20	1.01	580	500	80	1.5%	0.050	0.1	culvert
60	1.19	0.67	500	365	135	3.8%	0.050	0.1	culvert
70	0.52	0.52	365	315	50	1.8%	0.050	0.1	channel
80	**7.15**	**0.15**	**315**	**310**	**5**	**0.6%**	**0.050**	**0.1**	**culvert**
90	**7.00**	**0.64**	**310**	**285**	**25**	**0.7%**	**0.050**	**0.1**	**channel**
100	1.17	1.17	400	285	115	1.9%	0.050	0.1	channel
110	**6.36**	**0.73**	**285**	**230**	**55**	**1.4%**	**0.050**	**0.1**	**channel**
120	1.01	1.01	380	230	150	2.8%	0.050	0.1	channel
130	**5.63**	**0.30**	**230**	**210**	**20**	**1.3%**	**0.050**	**0.1**	**bridge**
140	**5.33**	**0.84**	**210**	**175**	**35**	**0.8%**	**0.045**	**0.1**	**culvert**
150	3.11	1.50	520	370	150	1.9%	0.050	0.1	culvert
160	1.61	0.73	370	290	80	2.1%	0.050	0.1	channel
170	0.70	0.70	500	290	210	5.7%	0.050	0.1	culvert
180	0.88	0.88	290	175	115	2.5%	0.050	0.1	culvert
190	**4.49**	**0.70**	**175**	**155**	**20**	**0.5%**	**0.045**	**0.1**	**bridge**
200	1.23	1.23	400	165	235	3.6%	0.050	0.1	culvert
210	0.60	0.60	400	155	245	7.7%	0.050	0.1	culvert
220	**3.79**	**0.69**	**155**	**130**	**25**	**0.7%**	**0.045**	**0.1**	**bridge**
230	0.64	0.64	400	130	270	8.0%	0.050	0.1	culvert

RCHRES	Total Length (mi)	RCHRES Length (mi)	Upstream Elev (ft)	Downstream Elev (ft)	Change in Elev (ft)	Slope (%)	Channel Roughness	Floodplain Roughness	Downstream Control
240	**3.10**	**0.97**	**130**	**100**	**30**	**0.6%**	**0.045**	**0.1**	**bridge**
250	1.49	1.49	400	100	300	3.8%	0.050	0.1	culvert
260	**2.13**	**0.95**	**100**	**70**	**30**	**0.6%**	**0.045**	**0.1**	**culvert**
270	0.78	0.78	300	70	230	5.6%	0.050	0.1	culvert
280	**1.18**	**0.37**	**70**	**55**	**15**	**0.8%**	**0.040**	**0.1**	**channel**
290	0.85	0.85	300	55	245	5.5%	0.050	0.1	culvert
300	**0.81**	**0.81**	**55**	**20**	**35**	**0.8%**	**0.040**	**0.1**	**culvert**

Note that the Little Bear Creek mainsteam reaches are shown in bold text.

4.3 MODEL CALIBRATION

The calibration of HSPF to the Little Bear Creek watershed follows the standard model calibration procedures as described in the HSPF Application Guide (Donigian et al., 1984), in numerous watershed studies over the past 20 years (see HSPF Bibliography [Donigian, 2002a]), and as recently summarized by Donigian (2002b). This model calibration presentation focuses solely on the hydrologic parameters; water quality calibration will follow and the calibration report will be updated with the water quality calibration discussion when it is completed.

4.3.1 WATER QUANTITY

General procedures on HSPF water quantity calibration can be found in Section 3.x.x

4.3.1.1 Initial Calibration Parameter Values

Calibration parameter values were initially based on past applications (i.e., regional HSPF parameter set) and the physical attributes found within the watershed. Some of these values were then modified to better represent the hydrologic processes observed in the Little Bear Creek watershed. The final values were selected through the calibration process and a comparison of the simulated and recorded streamflow. Table 4.3-1 through Table 4.3-5 present the final PERLND and IMPLND parameter values selected for the Little Bear Creek watershed.

4.3.1.2 HYDROLOGIC CALIBRATION AND KEY CALIBRATION PARAMETERS

For the Little Bear watershed LZSN values were increased for till soils (the predominate soil type in the watershed) from 4.5 to a range from 8.0 to 5.5 inches, dependent on slope (steeper slopes, lower LZSN values – see Table 4.3-1). Outwash LZSN values were correspondingly raised from 5.0 to 10.0 inches. LZETP values were adjusted monthly using the MON-LZETPARM Block in HSPF. LZETP monthly values varied by PERLND vegetation types (with forest values higher than pasture values, which in turn, are higher than residential landscaping values) and by season (winter low; summer high – see Table 4.3-4). For forest PERLNDs the monthly LZETP values are relatively constant and varied from 0.60 in January to 0.70 in August; pasture monthly values varied from 0.20 to 0.45. UZSN values were increased by 50 percent (Table 4.3-3) from their initial values to be consistent with the increase in LZSN values. DEEPFR was changed from its initial value of zero to 0.12 for till soils and 0.05 for outwash soils (Table 4.3-2). DEEPFR represents the fraction of groundwater that bypasses the stream gage and recharges the underlying aquifer or flows directly to the Sammamish River.

In the next step in hydrologic calibration, after an annual water balance was obtained, the seasonal or monthly distribution of runoff was adjusted with use of INFILT, the infiltration parameter defined above. This seasonal distribution was accomplished by INFILT by dividing the incoming moisture among surface runoff, interflow, upper zone soil moisture storage, and percolation to lower zone soil moisture and groundwater storage. Increasing INFILT reduced immediate surface runoff (including interflow) and increased the groundwater component; decreasing INFILT produced the opposite result.

The USGS regional values for till PERLNDs were used as a starting point and then varied by slope and land use. The forest INFILT value varied from 0.08 to 0.50 (steeper slope, lower INFILT – see Table 4.3-1). The pasture INFILT ranged from 0.07 to 0.04. The urban landscaping INFILT varied from 0.04 to 0.02 for the Little Bear Creek watershed.

The focus of the next stage in calibration was the baseflow component. This portion of the flow was adjusted in conjunction with the seasonal/monthly flow calibration (previous step) because

moving runoff volume between seasons often means transferring the surface runoff from storm events in wet seasons to low-flow periods during dry seasons. By increasing INFILT, runoff was delayed and occurred later in the year as an increased groundwater or baseflow. The shape of the groundwater recession; i.e., the change in baseflow discharge, is controlled by the following parameters:

AGWRC - groundwater recession rate (per day).

KVARY - index for nonlinear groundwater recession.

For the Little Bear watershed the AGWRC value was increased from the USGS regional value of 0.996 to 0.998 for till soils and forest land use (Table 4.3-1) and 0.997 for till pasture. AGWRC remained at 0.996 for till urban landscaping and all outwash. KVARY was found to differ slightly from the regional value of 0.50 for till and was set to 0.45. KVARY for outwash did not change from its regional value of 0.30.

In the final stage of hydrologic calibration, after an acceptable agreement was attained for annual/monthly volumes and baseflow conditions, simulated hydrographs for selected storm events were effectively altered with UZSN and the following parameters:

INTFW - Interflow inflow parameter (dimensionless).

IRC - Interflow recession rate (per day).

Both INTFW and IRC were used to adjust the shape of the hydrograph to better agree with observed values; both parameters are evaluated primarily from past experience and modeling studies, and then adjusted in calibration. Also, minor adjustments to the INFILT parameter were used to improve simulated hydrographs; however, adjustments to INFILT were minimal to prevent disruption of the established annual and monthly water balance. Examination of both daily and short-time interval (e.g., hourly) flows were made.

INTFW was varied from 1.00 to 0.70 for till forest (see Table 4.3-3). Lower values were used for steeper slopes to increase surface runoff and decrease interflow. For till pasture the values ranged from 0.90 to 0.60; till landscaping had values between 0.80 and 0.50. The reason for the low till INTFW values was because in the water quality calibration it was found that there was insufficient surface runoff to provide the measured loadings. Decreasing the till INTFW values produced more surface runoff (and less interflow) without significantly changing the hydrology calibration. Outwash INTFW values were set to the regional value of 0.0 (only surface runoff and groundwater are produced by outwash soils), as were saturated INTFW values (1.0).

IRC was set to 0.70 to produce relatively slow interflow runoff for forest and pasture on till soils, with no change for slope variability (Table 4.3-3). The till landscaping IRC value was lower (0.5). Outwash IRC values are set to 0.7 (regional values), but have no impact on the simulation because there is no outwash interflow, as noted above.

4.3.1.3 Final Calibration Parameter List

Table 4.3-1 Final PERLND/IMPLND Parameter Values (Part 1)

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
11	Till Forest Flat	8.0	0.080	350	0.028	0.45	0.998
12	Till Forest Low	7.0	0.070	300	0.072	0.45	0.998
13	Till Forest Med	6.0	0.060	250	0.116	0.45	0.998
14	Till Forest Steep	5.5	0.050	200	0.195	0.45	0.998
21	Till Pasture Flat	8.0	0.070	350	0.026	0.45	0.997
22	Till Pasture Low	7.0	0.060	300	0.070	0.45	0.997
23	Till Pasture Med	6.0	0.050	250	0.116	0.45	0.997
24	Till Past Steep	5.5	0.040	200	0.186	0.45	0.997
31	Till Forest Residential Flat	8.0	0.080	350	0.028	0.45	0.998
32	Till Forest Residential Low	7.0	0.070	300	0.072	0.45	0.998
33	Till Forest Residential Med	6.0	0.060	250	0.116	0.45	0.998
34	Till Forest Res Steep	5.5	0.050	200	0.195	0.45	0.998
41	Till Low Density Residential Flat	8.0	0.040	350	0.028	0.45	0.996
42	Till Low Density Residential Low	7.0	0.030	300	0.070	0.45	0.996
43	Till Low Density Residential Med	6.0	0.025	250	0.117	0.45	0.996
44	Till Low Density Res Steep	5.5	0.020	200	0.180	0.45	0.996
51	Till High Density Residential Flat	8.0	0.040	350	0.028	0.45	0.996
52	Till High Density Residential Low	7.0	0.030	300	0.071	0.45	0.996
53	Till High Density Residential Med	6.0	0.025	250	0.117	0.45	0.996
54	Till High Density Res Steep	5.5	0.020	200	0.169	0.45	0.996
61	Till Commercial/ Industrial Flat	8.0	0.040	350	0.030	0.45	0.996
62	Till Commercial/ Industrial Low	7.0	0.030	300	0.071	0.45	0.996
63	Till Commercial/ Industrial Med	6.0	0.025	250	0.114	0.45	0.996
64	Till Commercial/ Industrial Steep	5.5	0.020	200	0.172	0.45	0.996
71	Outwash Forest	10.0	2.0	300	0.089	0.30	0.996

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
72	Outwash Pasture	10.0	1.4	300	0.060	0.30	0.996
73	Outwash Forest Residential	10.0	2.0	300	0.089	0.30	0.996
74	Outwash Low Density Res	10.0	0.8	300	0.077	0.30	0.996
75	Outwash High Density Res	10.0	0.8	300	0.067	0.30	0.996
76	Outwash Commercial/Ind	10.0	0.8	300	0.067	0.30	0.996
81	Saturated Forest	4.0	2.0	150	0.048	0.50	0.998
82	Saturated Pasture	4.0	1.8	150	0.043	0.50	0.998
83	Saturated Forest Residential	4.0	2.0	150	0.048	0.50	0.998
84	Saturated Low Density Res	4.0	1.0	150	0.043	0.50	0.998
85	Saturated High Density Res	4.0	1.0	150	0.046	0.50	0.998
86	Saturated Commercial/Ind	4.0	1.0	150	0.075	0.50	0.998

LZSN: Lower Zone Storage Nominal (inches)
INFILT: Infiltration (inches per hour)
LSUR: Length of surface flow path (feet)
SLSUR: Slope of surface flow path (feet/feet)
KVARY: Variable groundwater recession
AGWRC: Active Groundwater Recession Constant (per day)

Table 4.3-2 Final PERLND/IMPLND Parameter Values (Part 2)

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
11	Till Forest Flat	2.0	2.0	0.12	0.02	0.0
12	Till Forest Low	2.0	2.0	0.12	0.02	0.0
13	Till Forest Med	2.0	2.0	0.12	0.02	0.0
14	Till Forest Steep	2.0	2.0	0.12	0.02	0.0
21	Till Pasture Flat	2.0	2.0	0.12	0.02	0.0
22	Till Pasture Low	2.0	2.0	0.12	0.02	0.0
23	Till Pasture Med	2.0	2.0	0.12	0.02	0.0
24	Till Past Steep	2.0	2.0	0.12	0.02	0.0
31	Till Forest Residential Flat	2.0	2.0	0.12	0.02	0.0
32	Till Forest Residential Low	2.0	2.0	0.12	0.02	0.0
33	Till Forest Residential Med	2.0	2.0	0.12	0.02	0.0
34	Till Forest Res Steep	2.0	2.0	0.12	0.02	0.0

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
41	Till Low Density Residential Flat	2.0	2.0	0.12	0.02	0.0
42	Till Low Density Residential Low	2.0	2.0	0.12	0.02	0.0
43	Till Low Density Residential Med	2.0	2.0	0.12	0.02	0.0
44	Till Low Density Res Steep	2.0	2.0	0.12	0.02	0.0
51	Till High Density Residential Flat	2.0	2.0	0.12	0.02	0.0
52	Till High Density Residential Low	2.0	2.0	0.12	0.02	0.0
53	Till High Density Residential Med	2.0	2.0	0.12	0.02	0.0
54	Till High Density Res Steep	2.0	2.0	0.12	0.02	0.0
61	Till Commercial/ Industrial Flat	2.0	2.0	0.12	0.02	0.0
62	Till Commercial/ Industrial Low	2.0	2.0	0.12	0.02	0.0
63	Till Commercial/ Industrial Med	2.0	2.0	0.12	0.02	0.0
64	Till Commercial/ Industrial Steep	2.0	2.0	0.12	0.02	0.0
71	Outwash Forest	2.0	2.0	0.05	0.02	0.0
72	Outwash Pasture	2.0	2.0	0.05	0.02	0.0
73	Outwash Forest Residential	2.0	2.0	0.05	0.02	0.0
74	Outwash Low Density Res	2.0	2.0	0.05	0.02	0.0
75	Outwash High Density Res	2.0	2.0	0.05	0.02	0.0
76	Outwash Commercial/Ind	2.0	2.0	0.05	0.02	0.0
81	Saturated Forest	10.0	2.0	0.00	0.00	0.7
82	Saturated Pasture	10.0	2.0	0.00	0.00	0.7
83	Saturated Forest Residential	10.0	2.0	0.00	0.00	0.7
84	Saturated Low Density Res	10.0	2.0	0.00	0.00	0.7
85	Saturated High Density Res	10.0	2.0	0.00	0.00	0.7
86	Saturated Commercial/Ind	10.0	2.0	0.00	0.00	0.7

INFEXP: Infiltration Exponent
INFILD: Infiltration ratio (maximum to mean)
DEEPFR: Fraction of groundwater to deep aquifer or inactive storage
BASETP: Base flow (from groundwater) Evapotranspiration fraction
AGWETP: Active Groundwater Evapotranspiration fraction

Table 4.3-3 Final PERLND/IMPLND Parameter Values (Part 3)

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
11	Till Forest Flat	0.20	1.50	0.35	1.00	0.70	Monthly
12	Till Forest Low	0.20	1.00	0.35	0.90	0.70	Monthly
13	Till Forest Med	0.20	0.60	0.35	0.80	0.70	Monthly
14	Till Forest Steep	0.20	0.45	0.35	0.70	0.70	Monthly
21	Till Pasture Flat	0.15	0.90	0.30	0.90	0.70	Monthly
22	Till Pasture Low	0.15	0.60	0.30	0.80	0.70	Monthly
23	Till Pasture Med	0.15	0.45	0.30	0.70	0.70	Monthly
24	Till Past Steep	0.15	0.30	0.30	0.60	0.70	Monthly
31	Till Forest Residential Flat	0.20	1.50	0.35	1.00	0.50	Monthly
32	Till Forest Residential Low	0.20	1.00	0.35	0.90	0.50	Monthly
33	Till Forest Residential Med	0.20	0.60	0.35	0.80	0.50	Monthly
34	Till Forest Res Steep	0.20	0.45	0.35	0.70	0.50	Monthly
41	Till Low Density Residential Flat	0.10	0.75	0.25	0.80	0.50	Monthly
42	Till Low Density Residential Low	0.10	0.45	0.25	0.70	0.50	Monthly
43	Till Low Density Residential Med	0.10	0.30	0.25	0.60	0.50	Monthly
44	Till Low Density Res Steep	0.10	0.15	0.25	0.60	0.50	Monthly
51	Till High Density Residential Flat	0.10	0.75	0.25	0.80	0.50	Monthly
52	Till High Density Residential Low	0.10	0.45	0.25	0.70	0.50	Monthly
53	Till High Density Residential Med	0.10	0.30	0.25	0.60	0.50	Monthly
54	Till High Density Res Steep	0.10	0.20	0.25	0.50	0.50	Monthly
61	Till Commercial/ Industrial Flat	0.10	0.75	0.25	0.80	0.50	Monthly
62	Till Commercial/ Industrial Low	0.10	0.45	0.25	0.70	0.50	Monthly
63	Till Commercial/ Industrial Med	0.10	0.30	0.25	0.60	0.50	Monthly
64	Till Commercial/ Industrial Steep	0.10	0.20	0.25	0.50	0.50	Monthly
71	Outwash Forest	0.20	0.75	0.35	0.0	0.70	Monthly
72	Outwash Pasture	0.15	0.75	0.30	0.0	0.70	Monthly

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
73	Outwash Forest Residential	0.20	0.75	0.25	0.0	0.70	Monthly
74	Outwash Low Density Res	0.10	0.75	0.25	0.0	0.70	Monthly
75	Outwash High Density Res	0.10	0.75	0.25	0.0	0.70	Monthly
76	Outwash Commercial/Ind	0.10	0.75	0.25	0.0	0.70	Monthly
81	Saturated Forest	0.20	3.00	0.50	1.0	0.70	Monthly
82	Saturated Pasture	0.15	3.00	0.50	1.0	0.70	Monthly
83	Saturated Forest Residential	0.20	3.00	0.50	1.0	0.70	Monthly
84	Saturated Low Density Res	0.10	3.00	0.50	1.0	0.70	Monthly
85	Saturated High Density Res	0.10	3.00	0.50	1.0	0.70	Monthly
86	Saturated Commercial/Ind	0.10	3.00	0.50	1.0	0.70	Monthly

CEPSC: Interception storage (inches)
UZSN: Upper Zone Storage Nominal (inches)
NSUR: Surface roughness (Manning's n)
INTFW: Interflow index
IRC: Interflow Recession Constant (per day)
LZETP: Lower Zone Evapotranspiration fraction (see Table 4.3-4 for monthly values)

Table 4.3-4 Final PERLND/IMPLND Parameter Values (Part 4): Monthly LZETP Values

No.	PERLND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
11-14	Till Forest	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60
21-24	Till Pasture	0.20	0.20	0.20	0.25	0.30	0.35	0.40	0.40	0.40	0.45	0.30	0.20
31-34	Till Forest Residential	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60
41-44	Till Low Density Residential	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
51-54	Till High Density Residential	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
61-64	Till Commercial/ Industrial	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
71	Outwash Forest	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60
72	Outwash Pasture	0.20	0.20	0.20	0.25	0.30	0.35	0.40	0.40	0.40	0.45	0.30	0.20
73	Outwash Forest Residential	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60
74	Outwash Low Density Res	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
75	Outwash High Density Res	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
76	Outwash Commercial/Ind	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
81	Saturated Forest	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
82	Saturated Pasture	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
83	Saturated Forest Residential	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
84	Saturated Low Density Res	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
85	Saturated High Density Res	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
86	Saturated Commercial/Ind	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50

Table 4.3-5 Final PERLND/IMPLND Parameter Values (Part 5)

No.	IMPLND	LSUR	SLSUR	NSUR	RETSC
91	Low Density Residential	150	0.01	0.10	0.10
92	High Density Residential	150	0.01	0.10	0.10
91	Commercial/Industrial	150	0.01	0.10	0.10
92	Road	150	0.01	0.10	0.10

LSUR: Length of surface flow path (feet) for impervious area
SLSUR: Slope of surface flow path (feet/feet) for impervious area
NSUR: Surface roughness (Manning's n) for impervious area
RETSC: Surface retention storage (inches) for impervious area

Additional information on the HSPF model parameters and algorithms can be found in the HSPF User's Manual for Release 12 (Bicknell, et al. 2002).

Parameter values are not included for saturated or bedrock categories because these PERLND categories are not included in the Little Bear Creek watershed GIS layers provided by King County.

4.3.1.4 COMPARISONS PERFORMED

The hydrologic calibration was performed for the time period of water year 1999 through water year 2001. The available flow data used the continuous flow records at the King County gage on Little Bear Creek at Highway 202 (Gage 30A) and the Snohomish County gage at 228th St SE. The following specific comparisons of simulated and observed values were performed:

Annual and monthly runoff volumes (inches)
Hourly and daily time series of flow (cfs)
Flow duration values (cfs)

Annual runoff volumes at Gage 30A for water years 1999 through 2001 are shown in Table 4.3-6 and Table 4.3-7. The average daily flows and annual volumes show that the simulated results match well with the observed values, only differing by 0.5 percent. The correlation coefficient is 0.92 and the model fit efficiency is 0.84. These values show an excellent calibration at this location.

Table 4.3-6 Flow Statistics at King County Gage 30A (Oct 1998 – Sep 2001)

	Sim (cfs)	Obs (cfs)	Diff (cfs)	Diff (%)
Mean	24.30	24.43	-0.13	-0.5%
Geometric Mean	18.36	19.32	-0.96	-5.0%
Correlation Coefficient	0.92			

	Sim (cfs)	Obs (cfs)	Diff (cfs)	Diff (%)
Coefficient of Determination	0.85			
Mean Error	0.138			
Mean Absolute Error	4.67			
RMS Error	8.72			
Nash Sutcliffe	0.16			
Model Fit Efficiency	0.84			
Skill Score				

The skill score is computed as 1 – (Root Mean Square Error/Standard Deviation of the observed flow). At King County Gage 30A the RMSE approximately equals the standard deviation of the difference. This results in a skill score of approximately zero.

A comparison of the annual volumes by water year in Table 4.3-7 shows some variability from water year to water year, with 2001 being low and 2000 being high, but in general an excellent match.

Table 4.3-7 Annual Volumes at King County Gage 30A (Oct 1998 – Sep 2001)

Water Year	Precip (in)	Sim (in)	Obs (in)	Difference (in)	Difference (%)
1999	54.12	25.83	27.03	-1.20	-4.4%
2000	49.32	24.53	22.85	1.68	7.4%
2001	35.48	14.45	15.29	-0.84	-5.5%
Average	46.31	21.60	21.72	-0.12	-0.6%

Annual runoff volumes at the Snohomish County gage at 228th St SE for the period of March 2000 through September 2001 are shown in Table 4.3-8. The annual volumes show that the simulated results match well with the observed values, only differing by 2.7 percent. The correlation coefficient is 0.83 and the model fit efficiency is 0.69. These values are lower than the values at the King County 30A gage, but they still reflect a good calibration at this location.

Table 4.3-8 Flow Statistics at Snohomish Co Gage (Mar 2000 – Sep 2001)

	Sim (cfs)	Obs (cfs)	Diff (cfs)	Diff (%)
Mean	12.16	11.84	0.32	2.7%
Geometric Mean	10.50	10.64	-0.14	-1.3%
Correlation Coefficient	0.83			
Coefficient of Determination	0.69			
Mean Error	-0.317			

	Sim (cfs)	Obs (cfs)	Diff (cfs)	Diff (%)
Mean Absolute Error	2.23			
RMS Error	4.41			
Nash Sutcliffe	0.31			
Model Fit Efficiency	0.69			
Skill Score				

At the Snohomish County Gage the RMSE approximately equals the standard deviation of the difference. This results in a skill score of approximately zero.

Mean monthly volumes for the King County 30A gage are shown in Table 4.3-9. The mean monthly simulated values are close to the observed values with the greatest differences occurring in the summer months of June, July, and August. The flows in these summer months are usually low flows; accordingly, the actual flow differences in these months are very small.

Table 4.3-9 Mean Monthly Flow Statistics at King County Gage 30A

Month	Sim (in)	Obs (in)	Diff (in)	Diff (%)
Jan	2.82	2.81	0.01	0.3%
Feb	3.02	2.72	0.30	11.2%
Mar	2.70	2.48	0.23	9.1%
Apr	1.79	1.74	0.05	2.9%
May	1.26	1.34	-0.08	-5.8%
Jun	1.02	1.22	-0.20	-16.5%
Jul	0.84	0.97	-0.13	-13.3%
Aug	0.72	0.80	-0.08	-10.4%
Sep	0.66	0.70	-0.04	-5.7%
Oct	1.11	1.25	-0.14	-11.1%
Nov	2.74	2.65	0.09	3.3%
Dec	2.92	3.05	-0.13	-4.1%
Total	21.60	21.72	-0.12	-0.6%

Table 4.3-10 uses the HSPF Expert System statistics to evaluate the accuracy of the calibration. The simulated and observed flow values were divided into a number of categories and then evaluated according to defined criteria that allow the user to target specific flow ranges and events, such as the highest 10% of the flows, 50% low flows, summer storm volumes, etc. The criteria values range from 10 percent error to 20 percent error, depending on the type of flow range. Of the 12 criteria show in **Table 4.3-10**, ten of the criteria are met. There is excellent agreement between simulated and observed for total flow, storm volume, winter

volume, and winter storms. Two criteria (average storm peak and summer storms) show only poor agreement between simulated and observed. The storm peaks and volume calculations were based on a total of 18 winter storm events and 13 summer storms during the three-year calibration period.

The calibration tends to over estimate the peak flows, but under estimate summer storm volumes. The Expert System results, even with these differences, when viewed together with the other calibration information, as shown in both tables and figures, support the conclusion that the calibration is sufficiently accurate for the purposes of this study.

Table 4.3-10 Expert System Statistics at King Co Gage 30A (Oct 1998 – Sep 2001)

	Sim (cfs)	Obs (cfs)	Diff (cfs)	Diff (%)	Criteria (%)	Meets Criteria
Total (in)	21.60	21.72	-0.12	-0.6%	10%	Excellent
10% high (in)	7.44	6.86	0.58	8.5%	10%	Fair
25% high (in)	12.44	11.57	0.87	7.5%	15%	Good
50% low (in)	4.53	5.26	-0.73	-13.9%	15%	Fair
25% low (in)	1.83	2.07	-0.24	-11.6%	15%	Fair
10% low (in)	0.67	0.72	-0.05	-6.9%	15%	Good
storm volume (in)	12.56	12.25	0.31	2.5%	20%	Excellent
average storm peak (cfs)	151.25	89.40	61.85	69.2%	15%	Poor
summer volume (in)	3.23	3.68	-0.45	-12.2%	15%	Fair
winter volume (in)	15.32	14.96	0.36	2.4%	10%	Excellent
summer storms (in)	0.71	0.84	-0.13	-15.5%	10%	Poor
winter storms (in)	11.85	11.40	0.45	3.9%	15%	Excellent

Figure 4.3-1 shows the daily simulated and observed streamflow at King County Gage 30A for the period of October 1998 through September 2001. Figure 4.3-2 shows the Gage 30A flow duration for the same period and demonstrates a good match.

Figure 4.3-3 and Figure 4.3-4 compare the 30A hourly simulated and observed streamflow values for the winter flow periods of December 1998 and December 1999, respectively.

Monthly simulated and observed flow volumes are shown in Figure 4.3-5. A scatter plot of the simulated and observed daily values is presented in Figure 4.3-6. The scatter plot shows a correlation coefficient of 0.94. A residual plot of the difference between the simulated and observed daily values is shown in Figure 4.3-6.

Because of the short period of record for the Snohomish County stream gage at 228th St SE fewer plots of simulated and observed flows were produced at this location.

Figure 4.3-8 shows the simulated and observed daily values for the period of March 2000 through September 2001. Figure 4.3-9 shows the flow duration plot for this same period of

record. The scatter plot for the Snohomish County gage site is presented in Figure 4.3-10 and the residual plot is presented in Figure 4.3-11.

Figure 4.3-1 King Co Gage 30A Daily Flow Time Series

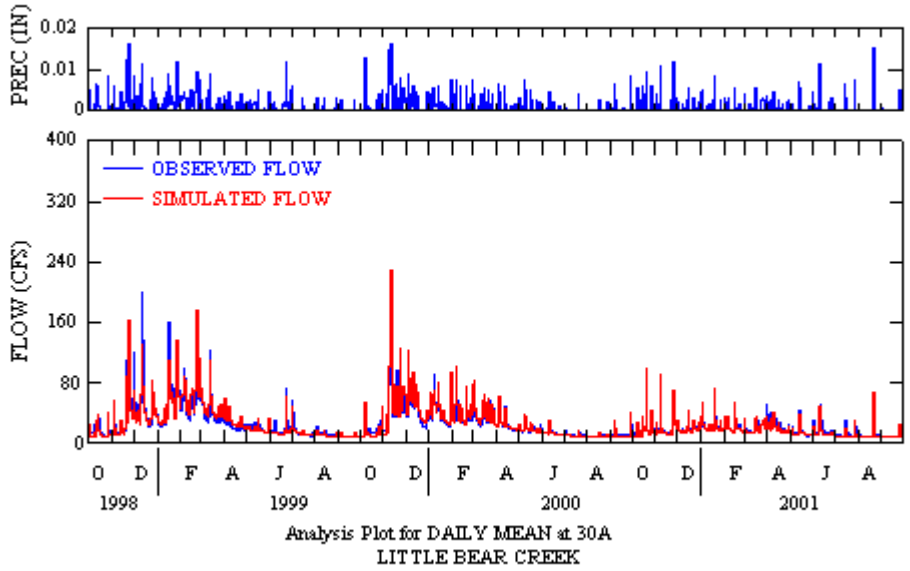


Figure 4.3-2 King Co Gage 30A Flow Duration

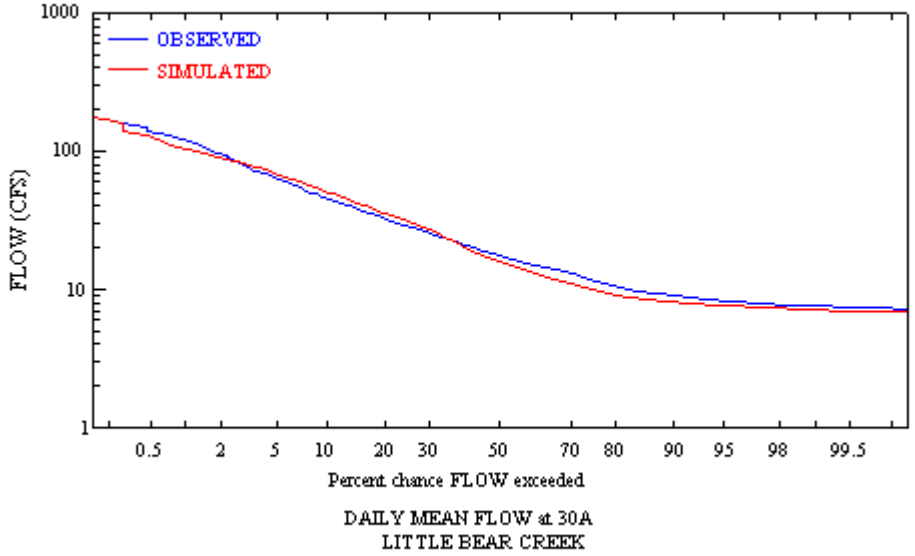


Figure 4.3-3 King Co Gage 30A December 1998 Hourly Flow Time Series

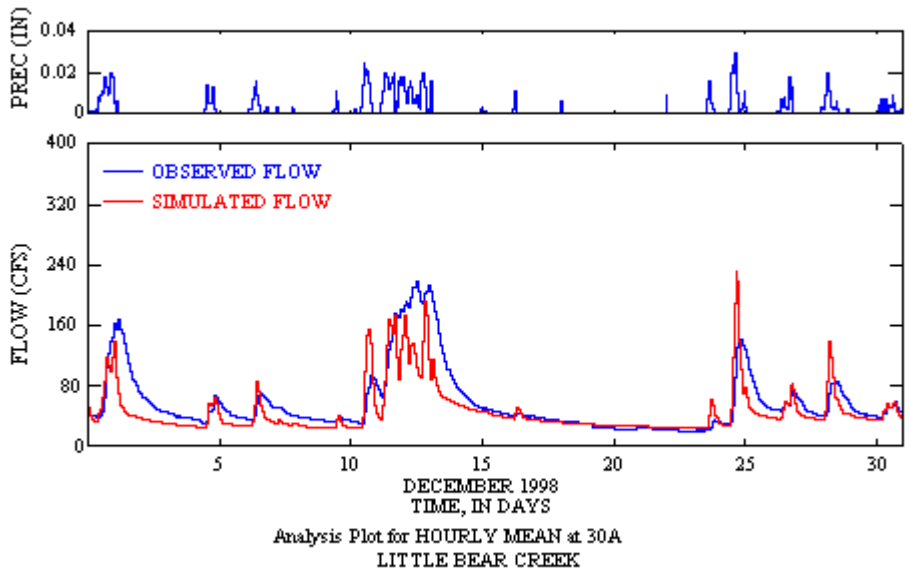


Figure 4.3-4 King Co Gage 30A December 1999 Hourly Flow Time Series

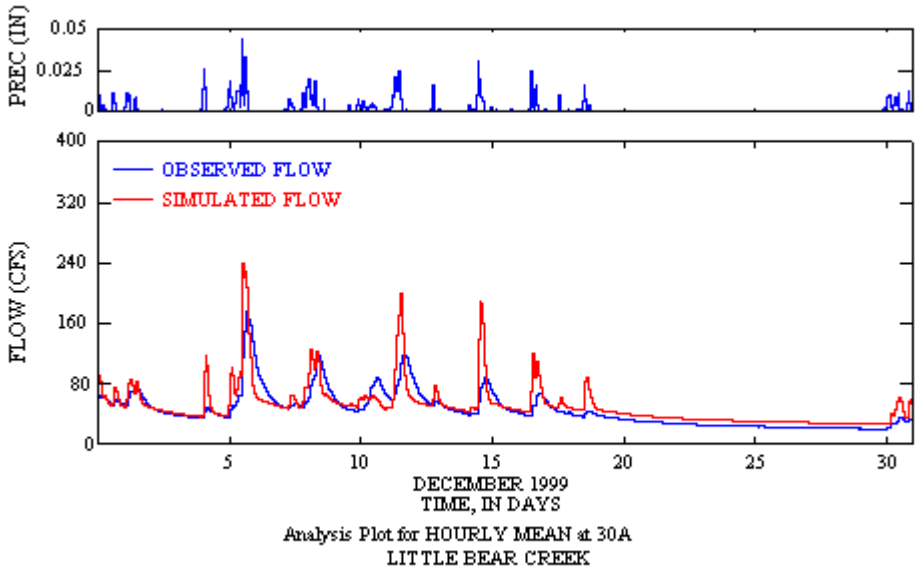


Figure 4.3-5 King Co Gage 30A Monthly Flow Time Series

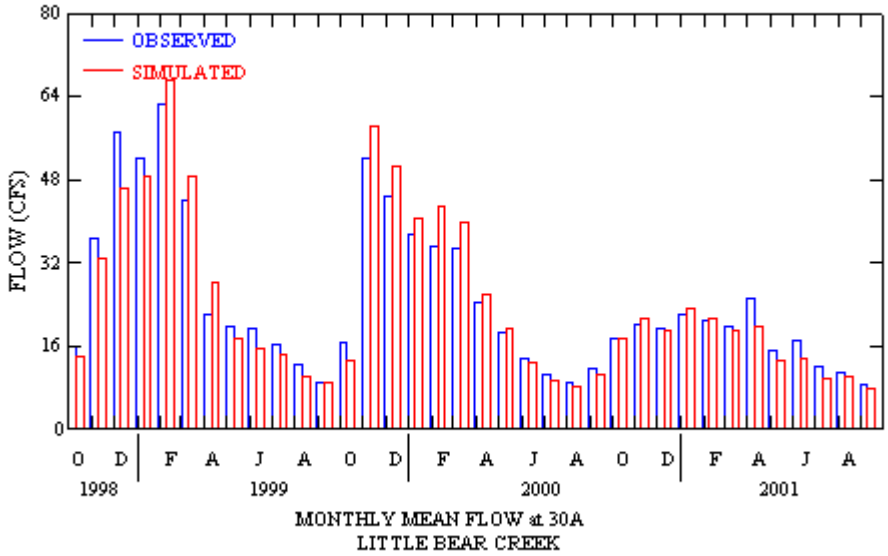


Figure 4.3-6 King Co Gage 30A Scatter Plot

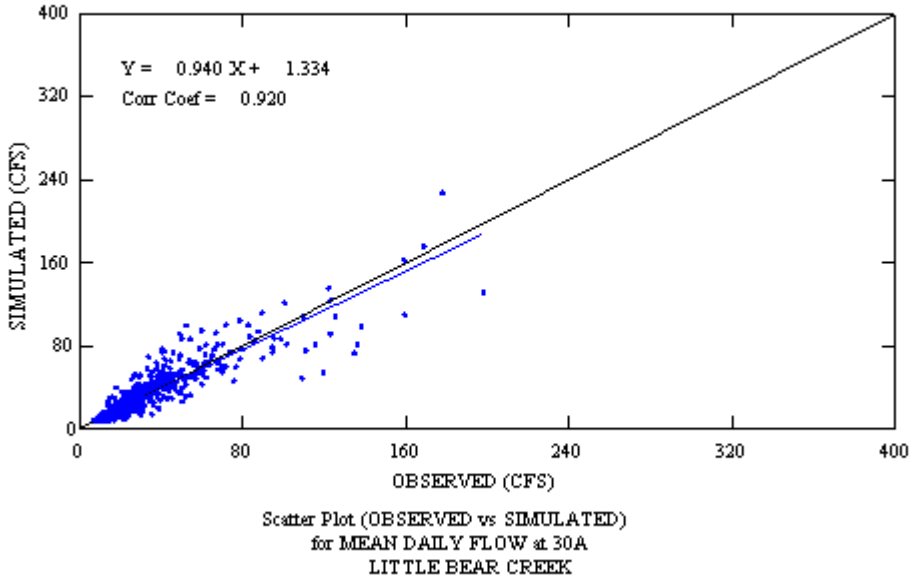


Figure 4.3-7 King Co Gage 30A Residual Plot

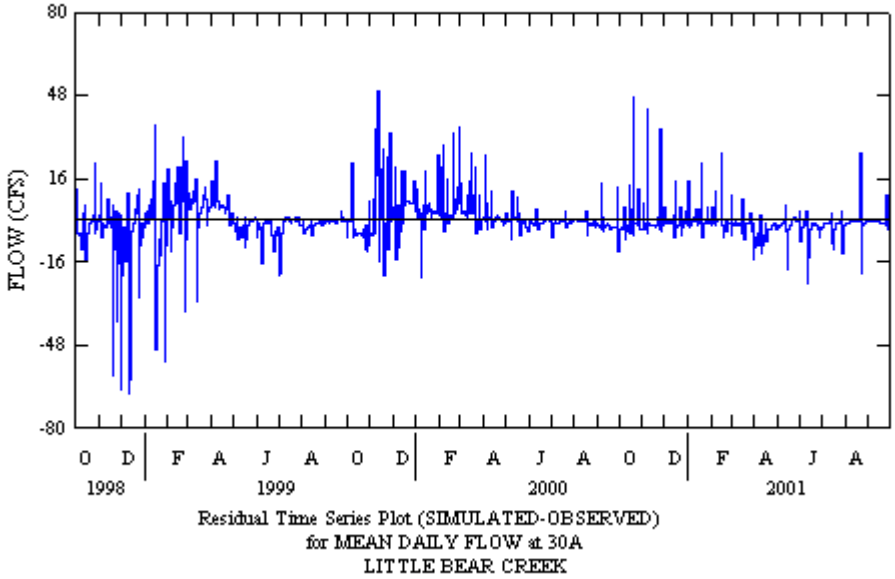


Figure 4.3-8 Snohomish Co Gage at 228th Daily Flow Time Series

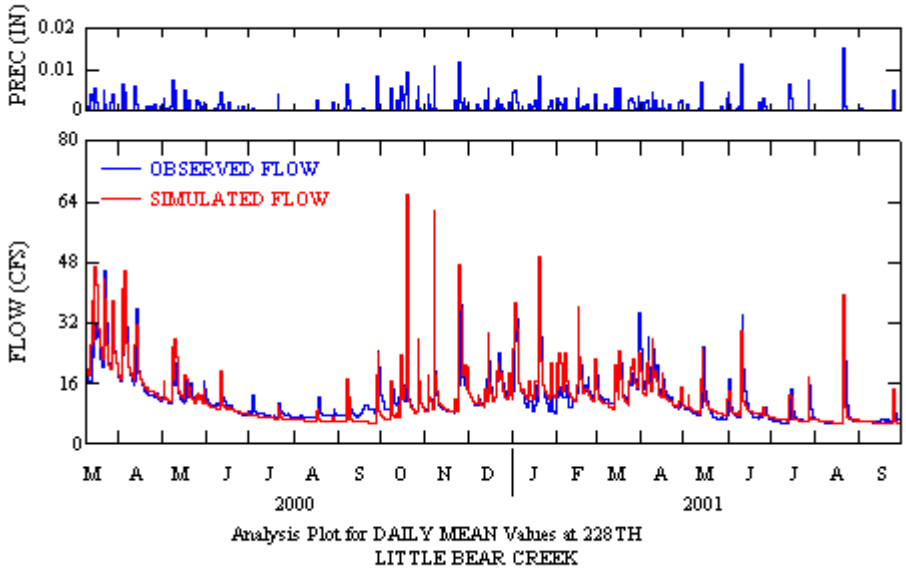


Figure 4.3-9 Snohomish Co Gage at 228th Flow Duration

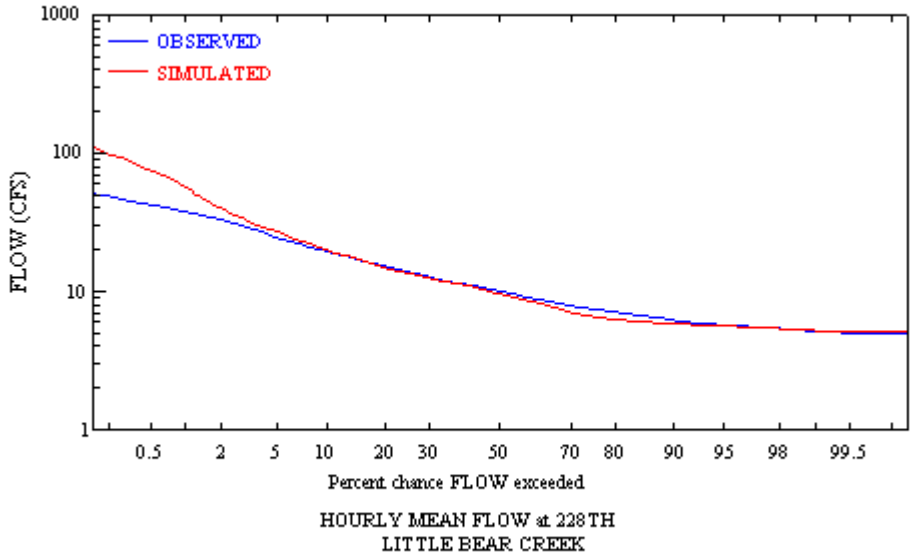


Figure 4.3-10 Snohomish Co Gage at 228th Scatter Plot

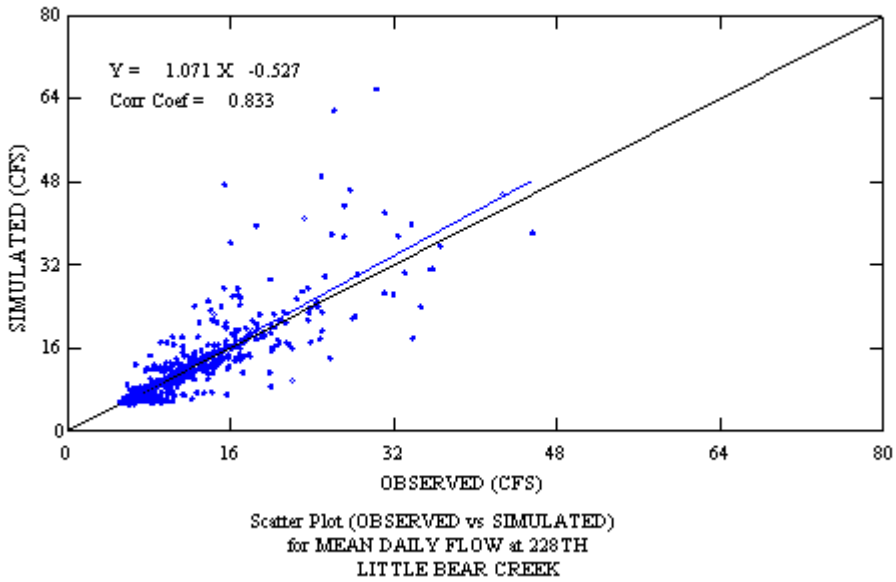
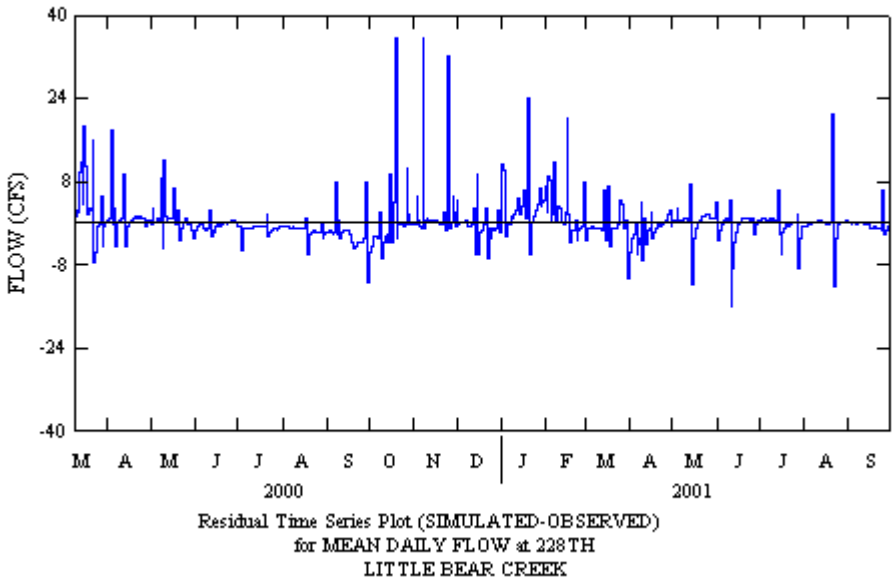


Figure 4.3-11 Snohomish Co Gage at 228th Residual Plot



In addition to the above comparisons, the water balance components (input and simulated) were reviewed for consistency with expected literature values for the Puget Sound region. This effort included displaying model results for individual land uses for the following water balance components:

- Precipitation
- Total Runoff (sum of following components)
- Surface Runoff/Overland Flow
- Interflow
- Groundwater/Baseflow

- Total Actual Evapotranspiration (ET) (sum of following components)
- Interception ET
- Upper zone ET
- Lower zone ET
- Baseflow ET
- Active groundwater ET

- Deep Groundwater Recharge/Losses

Although observed values are not be available for each of the water balance components listed above, the average annual values must be consistent with expected values for the region, as impacted by the individual land use categories. This is a separate consistency, or reality, check with data independent of the modeling (except for precipitation) to insure that land use categories and overall water balance reflect local conditions in the Little Bear Creek watershed.

The water balance components for the entire Little Bear Creek watershed are shown in Table 4.3-11. These values are weighed based on the contributing area of each Little Bear Creek PERLND for the period of record (water years 1999 through 2001). For this time period the mean annual precipitation was 43.03 inches, the total runoff was 21.61 inches, the groundwater flow to the stream was 14.10 inches, the potential evaporation was 23.65 inches, and the actual evaporation was 20.04 inches. These values are all close to or in the range of the expected values, as presented by Dinicola (1990).

Table 4.3-11 Little Bear Creek Mean Annual Water Balance (Oct 1998 – Sep 2001)

PERLND:	Till (in)	Out-wash (in)	Saturated (in)	EIA (in)	Watershed Average (in)	Expected (Dinicola, 1990) (in)
Influx						
Rainfall	43.03	43.03	43.03	43.03	43.03	35-50
Runoff						
Surface	1.79	0.05	3.12	33.38	4.48	
Interflow	5.00	0.00	4.40	0.00	3.40	
Baseflow	13.01	22.25	11.80	0.00	13.72	
Total	19.80	22.30	19.31	33.38	21.61	15-20
GW Inflow						
Deep	1.80	1.19	0.00	0.00	1.40	
Active	13.23	22.56	14.71	0.00	14.10	
Total	15.03	23.74	14.71	0.00	15.49	
Evaporation						
Potential	23.65	23.65	23.65	23.65	23.65	25
Interception Storage	10.68	10.43	11.34	9.65	10.56	
Upper Zone	4.60	1.18	7.78	0.00	3.60	
Lower Zone	5.68	7.54	1.36	0.00	5.30	
Ground Water	0.00	0.00	3.17	0.00	0.18	
Baseflow	0.47	0.47	0.00	0.00	0.40	
Total	21.43	19.63	23.65	9.65	20.04	18-20
Area (ac)	6,161.83	2,137.51	552.48	927.79	9,779.61	
Area (%)	63.01%	21.86%	5.65%	9.49%	100.00%	

A complete listing of the water balance components by individual PERLND is presented in Appendix A.

A weight of evidence approach is most widely used and accepted when models are examined and judged for acceptance as no single procedure or statistic is widely accepted as measuring, nor capable of establishing, acceptable model performance. Therefore, the calibration relied on numerous statistical tests (e.g., correlation tests, Model Fit Efficiency) and graphical plots (e.g., scatter, time series, frequency) to determine the model's ability to mimic the system.

4.3.1.5 CALIBRATION SUMMARY

Little Bear Creek was calibrated at two locations: King County gage 30A at Highway 202 in Woodinville and Snohomish County gage at 228th Street SE in unincorporated Snohomish County. Statistics and plots were produced for both locations to demonstrate the accuracy of the calibration.

Annual volumes matched well at each location, with errors of 2.7% at the Snohomish County gage and –0.5% at the King County gage.

The hydrology calibration is sufficiently accurate to proceed to the next step in the calibration process for Little Bear Creek, which is the calibration of the water quality data.

4.3.2 WATER QUALITY

4.3.2.1 Initial Water Quality Parameter Set

Initial water quality parameters for Little Bear, Swamp, and North Creeks were obtained from previous studies, with emphasis on the recent study to model the generation and delivery of loads from the state of Connecticut to Long Island Sound (ATC and HydroQual, 2001). Additional guidance in understanding local conditions and estimating the variation of pollutant loading and subsurface pollutant concentrations by land use was developed from several local studies of nutrient loading and concentrations in streams (Brett et al., 2002; Prych and Brenner, 1983; King County, 1994) and impacts of urbanization on streams (Booth et al., 2001). Many of the initial parameters were subsequently adjusted during calibration to better represent the water quality conditions in Little Bear, Swamp, and North Creeks. The final calibrated values are provided in the Little Bear Creek UCI file, in Appendix A.

4.3.2.2 Water Quality Calibration

The time period of the water quality calibration coincided with the hydrology calibration period, i.e., October 1996 – September 2001. Since some additional water quality data are available prior to 1996, the currently available precipitation dataset can be extended back to the start of the water quality and meteorologic data period (~1993) in order to allow a water quality validation for the period 1993-1996. One question to be answered in this case is whether the land use dataset is sufficiently applicable to the earlier period.

The calibration of Little Bear Creek was performed simultaneously and in concert with the calibration of North and Swamp Creeks in order to develop land use-specific water quality parameter sets for use in other parts of the SWAMP and Green-Duwamish Basins. Since the Little Bear Creek watershed is small and consists largely of forest and low density residential land (~78% fo the area), it was assumed that significant impacts of instream processes on

pollutant concentrations are unlikely. Therefore, the main emphasis of the calibration and parameter adjustments was the nonpoint loading, primarily via the subsurface (interflow and baseflow) concentrations, but also surface loading associated with surface runoff and sediment. However, the instream parameters were reviewed and adjusted as needed to ensure reasonable values for the specific stream reaches in these watersheds.

A key assumption of this water quality calibration is that the water quality parameters are constant within a land use category, and don't vary with soils (i.e., till, outwash, saturated, rock) or with the four slope classes. This assumes that appropriate differences in the water quality response will be caused by the differences in hydrologic responses that occur as result of the different hydrology parameters used to characterize these soils and slope classes.

4.3.2.3 Summary of Calibration Procedures

As noted earlier, the main goal of water quality calibration is to obtain acceptable agreement of observed and simulated concentrations, while maintaining the instream water quality parameters and processes within physically realistic bounds, and the nonpoint loading rates within the expected ranges from the literature or based on local experience and guidelines. The use of target nonpoint source loading rates is useful because the water quality concentrations measured at a particular location reflect the combined effects of contributions from multiple land uses, point sources, and instream processes. The target loading rates help to guide the calibration effort and ensure that simulated rates and fluxes from each land use category are reasonable and consistent with literature values and/or local knowledge. These nonpoint loading rates (also known as export coefficients) are highly variable with values ranging up to an order of magnitude, depending on local conditions. Therefore, AQUA TERRA compiled a set of targets with as much applicability to Puget Sound watersheds as possible. Additional data, not specific to Puget Sound were included where necessary to fill data gaps and compare with the locally derived information. These target data are presented in Section 3.2.3 of this document.

For most of the constituents, the calibration procedure involved an iterative series of simulations in which the following information was reviewed for the Little Bear, North and Swamp Creeks:

1. Comparison of land-use specific loading rates with the target export coefficients. The simulated loading rates for each land use category were computed as weighted averages based on the amount of land in each slope category of that land use.
2. Plots of simulated (average daily) and observed time series.
3. Statistics (mean, geometric mean, mean of ratio of simulated to observed, mean error, etc.) of corresponding (i.e., values on the same day) observed and simulated data points.
4. Summaries of the relative impacts of various constituent sources and processes within each stream segment.

Based on a review of this information, the monthly variable loading rate parameters for a constituent were adjusted by land use to improve the seasonal agreement for all watersheds and stations. The adjustments were made to try to improve the agreement of concentrations (statistically and graphically) while maintaining reasonable loading rates and reasonable/expected variation among the land use categories. When conflicts arose in the direction of adjustments, priority was given to agreement: 1) at the monitoring stations at the outlets of the three watersheds, since these models will be used primarily to evaluate impacts of total loads delivered to the Sammamish River; and 2) to agreement of concentrations/statistics over target loading rates; and 3) to maintenance of reasonable differences between land use categories. In some cases, if knowledge of local stream conditions was sufficient, instream

processes were adjusted to try to improve agreement. For example, algal growth and settling of organics was encouraged in some stream segments to represent the effects of wetland stream channels where lowered nutrient concentrations were observed at nearby downstream monitoring stations. This involved increasing the growth parameter, increasing the availability of light in the channel, reducing the respiration rate of algae, and increasing the settling rates of organics species.

4.3.2.4 Calibration Discussion and Results

The results of the calibration are presented on the following pages. Table 4.3-12 shows the average annual (over the five year simulation period) loading rates in pounds/acre/year for nitrogen species and compares them with the target rates. Table 4.3-13 shows the same information for phosphorus species and sediment. Table 4.3-14 presents the mean simulated and observed concentrations on sampling dates for the various constituents, and the ratio of the means. Table 4.3-15 shows the average (and range) of simulated/observed concentration ratios for all Little Bear Creek Stations. Finally, Figure 4.3-7 through Figure 4.3-17 show the time series plots of simulated daily and observed water quality constituent concentrations for the primary (outlet) station in Little Bear Creek, the station at Highway 202, near Woodinville. The following discussion is focused by constituent.

Water temperature calibration was done first, so that the various instream processes that are dependent on temperature would be modeled with reasonable temperature conditions. Initial temperatures were generally (but not always) oversimulated by up to 3 C in summer and undersimulated slightly in winter. Temperature adjustments were made as follows:

- Stream shading was checked with any available information; and adjusted to improve the agreement.
- The parameters that determine the temperature of runoff from pervious and impervious land areas were adjusted seasonally.
- Since these are shallow streams, the termperature of the ground beneath the stream was adjusted seasonally to increase the effect of heat transfers via this pathway. Generally, the water temperature is very well calibrated in Little Bear Creek as evidenced in Figure 4.3-7 and the statistical information shown below, with some remaining differences apparent in the comparisons of hourly data at the Snohomish County monitoring stations (shown in Appendix B).

Sediment - Target sediment loadings to the stream channel were estimated for each land use category from the available literature data. Table 3.2-1lists target loading rates that were developed for calibrating the nonpoint sediment loadings within the Little Bear Creek and other Puget Sound watersheds. The model categories are a function of soil type and slope class, in addition to land use, and therefore the loading rates should also be variable within a given land use to reflect the combined erodibility of the soil matrix and slope class.

KRER and KSER are the primary sediment erosion calibration parameters in HSPF. They governing detachment of soil particles by raindrop impact on the land surface and the subsequent transport of these particles by overland flow, respectively. KRER is usually estimated as equal to the erodibility factor, K, in the USLE, and then adjusted in calibration, while KSER is primarily evaluated through calibration and past experience. During the calibration of the Little Bear Creek watershed model, KRER was set to reflect the variability of the soil types while KSER was adjusted to achieve the expected range of loading rates amongst the land use categories. The loading rates by slope class were primarily dictated by the overland flow rates generated by the respective class. The parameters for vegetal cover

(COVER) and atmospheric fallout (NVSI) were not adjusted during the calibration process, but assumed to be constant, based on the type of land use.

Once the sediment loading rates were calibrated to provide reasonable loadings to the stream channel, the sediment calibration focused on the channel processes of deposition, scour, and transport. The sediment calibration involved iteratively performing several steps to determine the model parameters and appropriate adjustments needed to insure a reasonable simulation of the sediment transport and behavior of the channel system. The steps performed during the calibration were as follows:

1. Divided the nonpoint sediment loads into sand, silt, and clay fractions. For the Little Bear Creek model, the fractionation of the sediment was assumed to be: 5% sand, 70% silt, and 25% clay.
2. Ran the model to calculate bed shear and establish scour and deposition patterns – HSPF calculates the shear stress (TAU) as a function of the reaches hydraulic radius, slope, and density of water. For the silt and clay (i.e. cohesive) fractions, shear stress calculations are compared to user-defined critical, or threshold, values for deposition and scour. Thus, knowing the range of TAU values a reach experiences is critical in establishing the expected scour and depositional patterns.
3. Estimated initial parameter values and storages for all reaches. The key sand parameters are the coefficient (KSAND) and exponent (EXPSND) in the power function equation that defines sand transport, along with the sand particle characteristics. Initial KSAND and EXPSND values were estimated, and the sand particle characteristics were set at typical values found in the literature. The key silt and clay parameters are the critical bed shear threshold values for scour (TAUCS) and deposition (TAUCD), and the associated particle characteristics. Initial values for TAUCS and TAUCD were estimated on a reach by reach basis based on the simulated TAU values in each reach. In the absence of any channel bed composition data, the initial composition of each of the channel beds was assumed to be 65% sand, 15% silt, and 20% clay.
4. Historical information was not available to describe how each of the modeled streambeds were changing over time; therefore, the primary parameters for scour, deposition and transport were mainly adjusted to achieve channels that were stable with time (i.e., over the calibration period) for each of the size fractions.
5. Calibration was performed at gage 0478, located near the outlet of the watershed and operated by King County, along with the Snohomish County gages located at Interurban Ave, 51st Street, and 228th street. The Snohomish County sites served primarily as consistency checks of the overall sediment budgets and loading rates. The frequency and overall number of data points did not support any rigorous statistical tests. Therefore, the comparisons primarily consisted of graphical plots and simple statistics (e.g., comparison of means, geometric means, ratio of simulated vs. observed). The primary parameters for scour, deposition and transport were further adjusted to achieve agreement between simulated and observed concentrations, while maintaining the desired bed behavior and a reasonable distribution of sand, silt, and clay within the beds and water column.

Nitrogen Species- Calibration of nitrate and ammonia was largely done by adjusting the interflow and groundwater concentrations (and ammonia surface loading factors) by land use based on the relative amounts of land in each of the three watersheds, until the errors were minimized at the three outlet stations. The agreement was fairly good for nitrate at the downstream stations, where local effects of hotspots, significant groundwater transfers, etc are minimized. Unfortunately, the consistently high summer nitrate levels at Interurban Avenue and 51st Street were difficult to improve by land use-specific adjustments. The ammonia showed

reasonably good statistical agreement over the three watersheds, after adjustment of loading parameters by land use. However, there appears to be a trend in the data at all three outlet stations that is not correctly reproduced by the model. In 1997, concentrations were typically in the range of 0.03 – 0.07, while in 1999 – 2001, concentrations were generally in the range of 0.01 – 0.04. One possible explanation for this phenomenon is that 1997 was a wetter year than the other calibration years, and this effect has not been adequately incorporated into the parameters, for example by imposing much higher concentrations in interflow than in groundwater. Another possible reason is that the analytical method for measuring ammonia might have changed in that period, and caused the apparent shift in levels. Since total nitrogen loads are dominated by nitrate, the total nitrate agreement is fair, based on the graphical evidence; however, the statistical comparison suggests that an increase in organic N is warranted. Adjustments were made to the overall organics loading to improve organic N agreement, but further adjustments could be made by increasing the assumed organic N stoichiometric factor for dividing the total organic loading into N, P and C components. Under the current model set-up, algal growth and other biological processes have a very small impact on the nitrogen behavior.

Phosphorus Species - Orthophosphate concentrations were calibrated by adjusting the land use- specific concentrations and surface parameters (potency factors) seasonally to achieve a fit. The graphical and statistical measures indicate it is fairly well calibrated. Note that storms generate spikes of PO4 , but additional increases might be warranted. The slightly elevated observed concentrations in 1997, similar to the ammonia results, are better represented in the orthophosphate model. The apparent undersimulation of TP at the Highway 202 and the 228th Street stations suggests that increases in organic P may be needed. However, since most of the undersimulation appears to be occurring in very extreme (relative to the baseline) phosphorus loading events, simple increases in the organic P stoichiometric factor are not indicated.

Dissolved oxygen. The initial simulations produced fairly good agreement with the observed DO, because in relatively low impact streams and watersheds such as Little Bear Creek, the principal determinant of DO is water temperature, as opposed to algal growth and organic matter decay. Once the water temperature was fine-tuned, DO agreement was further improved as shown by the graphical and statistical information shown here for the Little Bear Creek outlet station at Highway 202. The time series plots for the Snohomish County stations shown in Appendix B show mixed results. It is assumed that the differences exhibited for the stations at Interurban Avenue and 51st Street are largely due to errors in the temperature simulation, since the differences consistently occur during all seasons. Impacts of biological processes on oxygen are generally small in winter. No instream parameter or process adjustments were performed.

Alkalinity was calibrated primarily by adjusting subsurface (interflow and groundwater) concentrations to obtain the seasonal variation while maintaining appropriate differences between land uses. Initial values and the land use variation were based on the monitoring data and very limited land use-specific sampling from Newaukum Creek presented by Prych and Brenner (1983). The graphical and statistical agreement in Little Bear Creek was good (e.g., average ratio of simulated to observed concentrations = 1.09), and it was fair in the other creeks. One difficulty noticed was the effect of storms that resulted in both sharp upward spikes (increases) and sharp downward spikes (dilutions) in close proximity to each other in time. Since pH is very sensitive to alkalinity, large variations in predicted pH resulted from this behavior. However, the observed pH data (and alkalinity data) in some streams suggest that there can be significant variation over relatively short periods. Furthermore, the sensitivity of pH

to alkalinity provided a more accurate indicator of error in the alkalinity calibration, and therby facilitated an improved calibration over that provided solely by alkalinity comparisons.

pH was modeled in all three creeks, but there were no monitoring data in Little Bear Creek. Therefore, the calibration focused on attaining reasonable values and seasonal variation, based on experience and the monitoring data in Swamp and North Creeks. The pH was sensitive to alkalinity as was noted above. It was also sensitive to total inorganic carbon (TIC) concentration. Initial simulated TIC concentrations from runoff (< 1 mg/L) resulted in unreasonably high values of predicted pH (~11). Based on fundamental chemical equilibrium equations relating pH, alkalinity, and TIC, it was determined that the observed alkalinity and pH levels would necessitate concentrations of TIC in the range of 16-19 mg/L, which are unattainable with the existing formulation in HSPF. Therefore, the existing algorithm was used as an indicator or index to the TIC loading, but the actual values were adjusted upwards by a constant factor of 40 to attain the necessary TIC to compute pH values that are in line with observations in Swamp and North Creeks.

E-Coli is notoriously variable and difficult to predict. One reason for this is that many of the larger loadings of bacterial material probably occur during somewhat random but "catastrophic" events, such as CSO events or failure of human waste disposal facilities, which can produce large, unpredictable concentrations. Examination of the observed E-Coli data suggests relatively little quantitative correlation with the storms. Therefore, efforts were made to attain general "agreement" between the simulated concentrations and the bulk of the observed values, which are on the order of 100's of CFUs/100 mL as opposed to the arithmetic mean (~1000), which is strongly biased by the several extreme values in the data record. Attempts to calibrate to these extremes in the observed data, e.g., by large increases in the surface runoff of E-Coli, produced large unreasonable loadings.

Table 4.3-12 Average Annual Nitrogen Loadings

	Constituents (Average lbs/acre/year loadings)							
	Nitrate-N		Ammonia-N		Organic N		Total N	
Land Category	Target	Simulated	Target	Simulated	Target	Simulated	Target	Simulated
Forest	1.4	4.5	0.2	0.07	0.4	0.44	2.0	5.0
Pasture/Ag	9.0	13.	1.3	0.53	2.5	1.7	13.	15.
Forest Residential	4.2	5.0	0.6	0.08	1.2	0.5	6.0	5.6
Low Density Residential	4.9	5.9	0.7	0.17	1.4	1.4	7.0	7.5
High Density Residential	6.3	6.1	0.9	0.3	1.8	1.8	9.0	8.2
Commercial/ Industrial	4.9	5.6	0.7	0.6	1.4	1.9	7.0	8.1

Table 4.3-13 Average Annual Phosphorus and Sediment Loadings

	Constituents (pounds/acre/year loadings)							
	Orthophosphate-P		Organic P		Total P		Sediment (tons)	
Land Category	Target	Simulated	Target	Simulated	Target	Simulated	Target	Simulated
Forest	0.05	0.04	0.07	0.025	0.12	0.065	0.15	0.04
Pasture/Ag	0.6	0.7	0.7	0.10	1.3	0.8	0.04	0.09
Forest Residential	0.09	0.07	0.16	0.03	0.25	0.10	0.02	0.06
Low Density Residential	0.2	0.2	0.3	0.08	0.5	0.28	0.14	0.16
High Density Residential	0.35	0.37	0.45	0.10	0.7	0.47	0.16	0.23
Commercial/ Industrial	0.5	0.8	0.9	0.1	1.4	1.0	0.36	0.49

Table 4.3-14 Mean Simulated vs. Observed Concentrations on Sample Dates

Constituent	Little Bear Creek at Highway 202			Little Bear Creek at 228th Street			Little Bear Creek at 51st Street			Little Bear Creek at Interurban Avenue		
	Simulated	Observed	Mean Daily Ratio *	Simulated	Observed	Mean Daily Ratio *	Simulated	Observed	Mean Daily Ratio *	Simulated	Observed	Mean Daily Ratio*
Water Temperature (C)	9.70	9.93	1.02 (91)	10.9	10.1	1.14 (577)	11.7	11.1	1.07 (163)	12.5	11.5	1.08 (124)
Suspended Sediment	24.1	23.4	1.09 (87)	8.92	7.25	1.25 (48)	7.59	8.07	1.01 (42)	2.05	6.53	0.57 (15)
Dissolved Oxygen	11.3	11.0	1.03 (89)	11.2	11.0	1.03 (56)	11.2	10.4	1.09 (57)	11.0	10.2	1.08 (18)
Nitrate-Nitrite as N	0.93	0.90	1.08 (92)	0.97	0.91	1.22 (55)	1.05	1.29	0.82 (57)	1.02	1.23	0.83 (18)
Ammonia as N	0.029	0.039	1.01 (68)									
Total Nitrogen	1.12	1.31	0.90 (77)									
Orthophosphate as P	0.026	0.032	0.99 (77)									
Total Phosphorus	0.041	0.085	0.62 (92)	0.038	0.055	0.77 (56)	0.045	0.054	0.98 (57)	0.045	0.064	0.75 (18)
Alkalinity as $CaCO_3$	50.6	48.6	1.09 (64)									
EColi (CFUs/100 ml)	148	277	0.86 (41)									

* Value is mean of Simulated:Observed ratios on sampling dates; sample size in parentheses

Table 4.3-15 Average and Range of Simulated/Observed Concentration Ratios for all Little Bear Creek Stations

Constituent	Average	Range
Water Temperature (deg C)	1.11	0.61 – 3.11
Suspended Sediment	1.07	0.02 – 9.02
Dissolved Oxygen	1.05	0.86 - 1.58
Nitrite-Nitrate as N	1.03	0.45 - 8.06
Ammonia as N	1.01	0.19 - 4.60
Total Nitrogen	0.90	0.33 - 1.47
Orthophosphate as P	0.99	0.22 - 2.58
Total Phosphorus	0.76	0.15 - 3.37
Alkalinity as $CaCO_3$	1.09	0.81 - 2.10
EColi	0.86	0.01 - 3.19

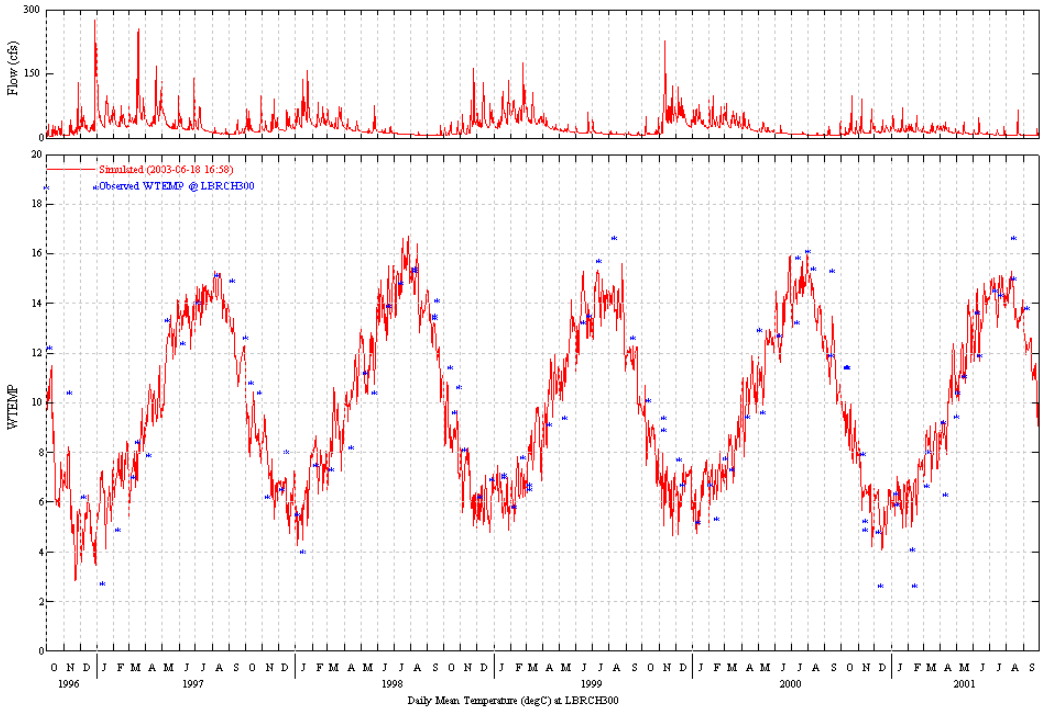


Figure 4.3-7 Observed and Simulated Daily Water Temperature for Little Bear Creek at Highway 202

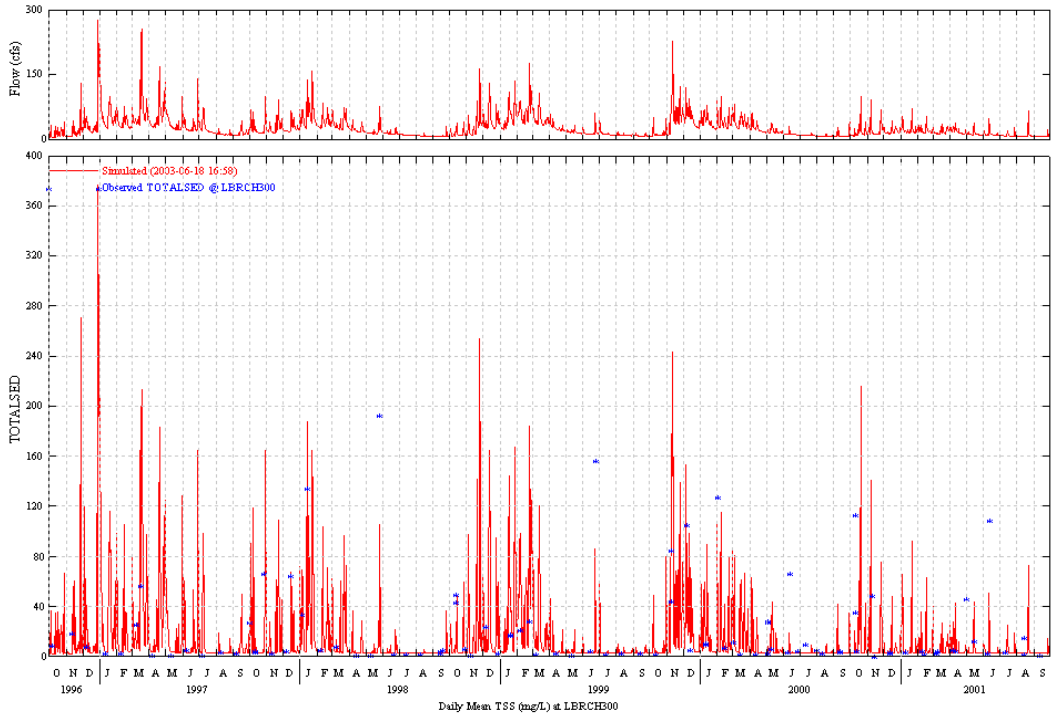


Figure 4.3-8 Observed and Simulated Daily Suspended Sediment Concentrations for Little Bear Creek at Highway 202

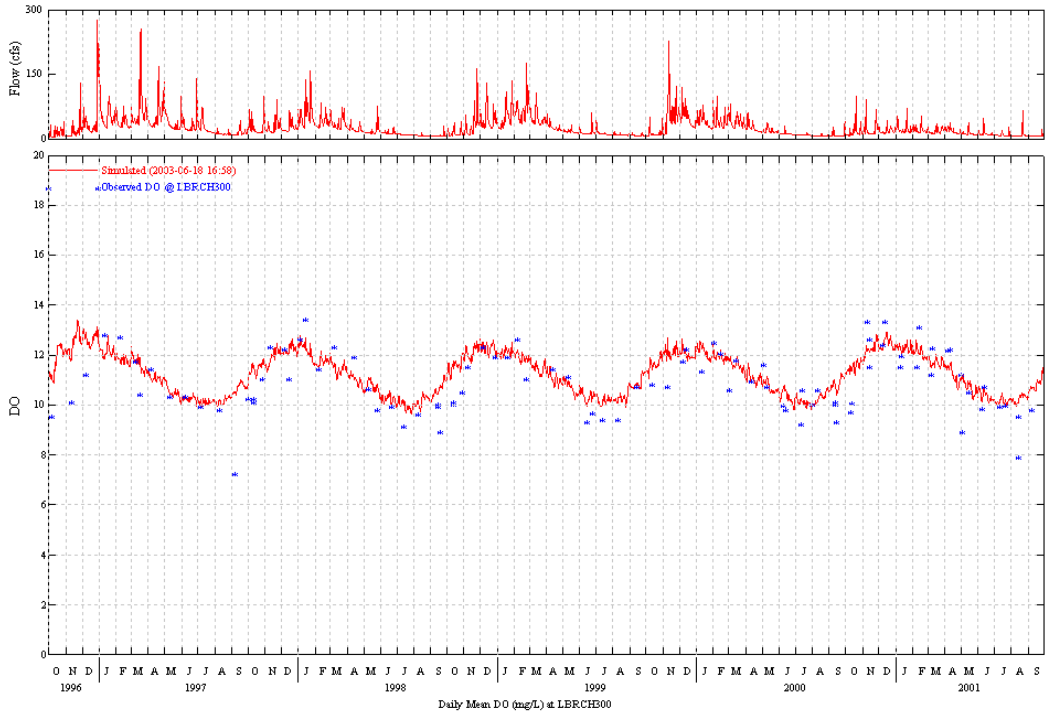


Figure 4.3-9 Observed and Simulated Daily Dissolved Oxygen Concentrations for Little Bear Creek at Highway 202

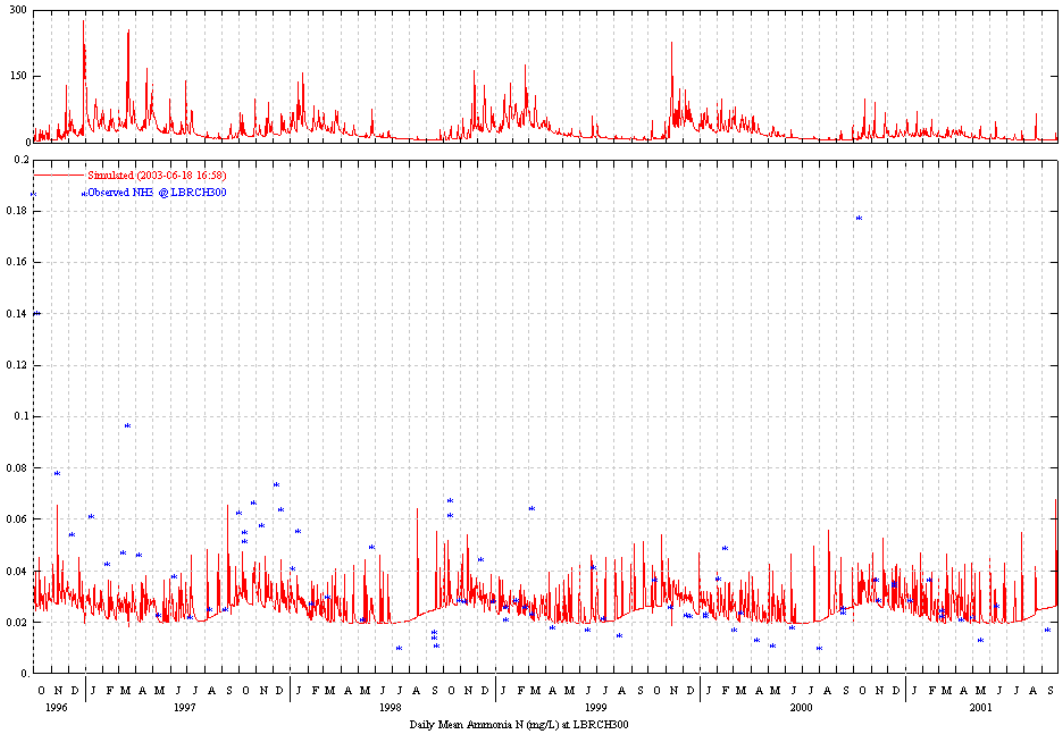


Figure 4.3-10 Observed and Simulated Daily Ammonia Concentrations for Little Bear Creek at Highway 202

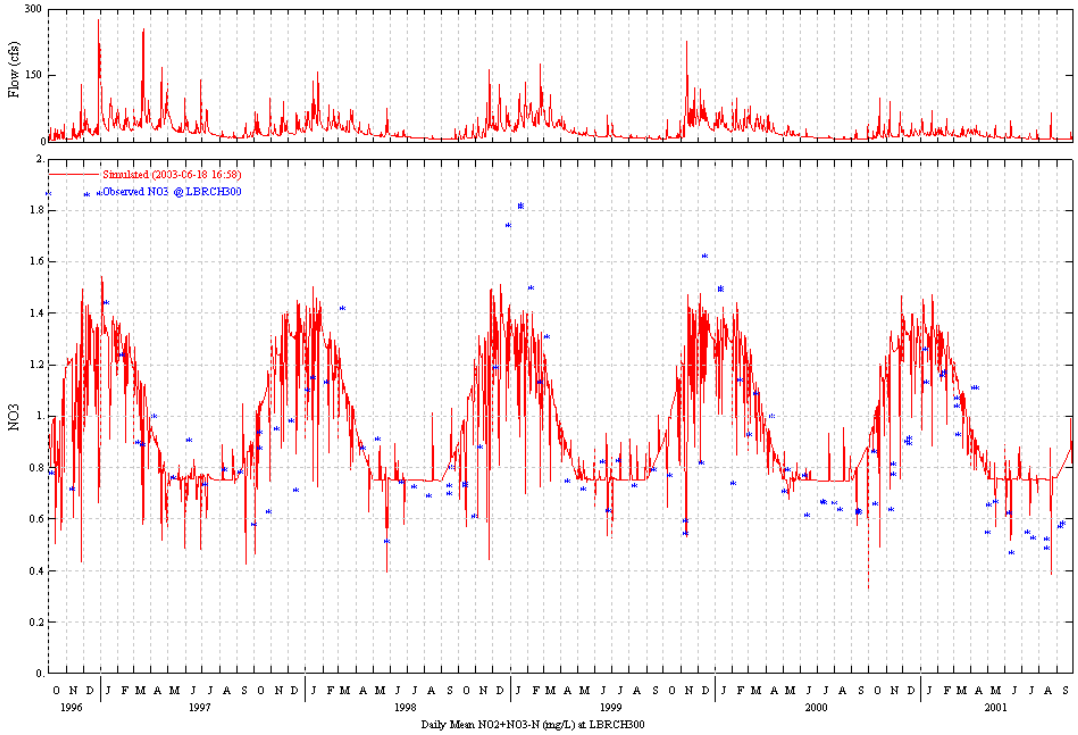


Figure 4.3-11 Observed and Simulated Daily Nitrate Concentrations for Little Bear Creek at Highway 202

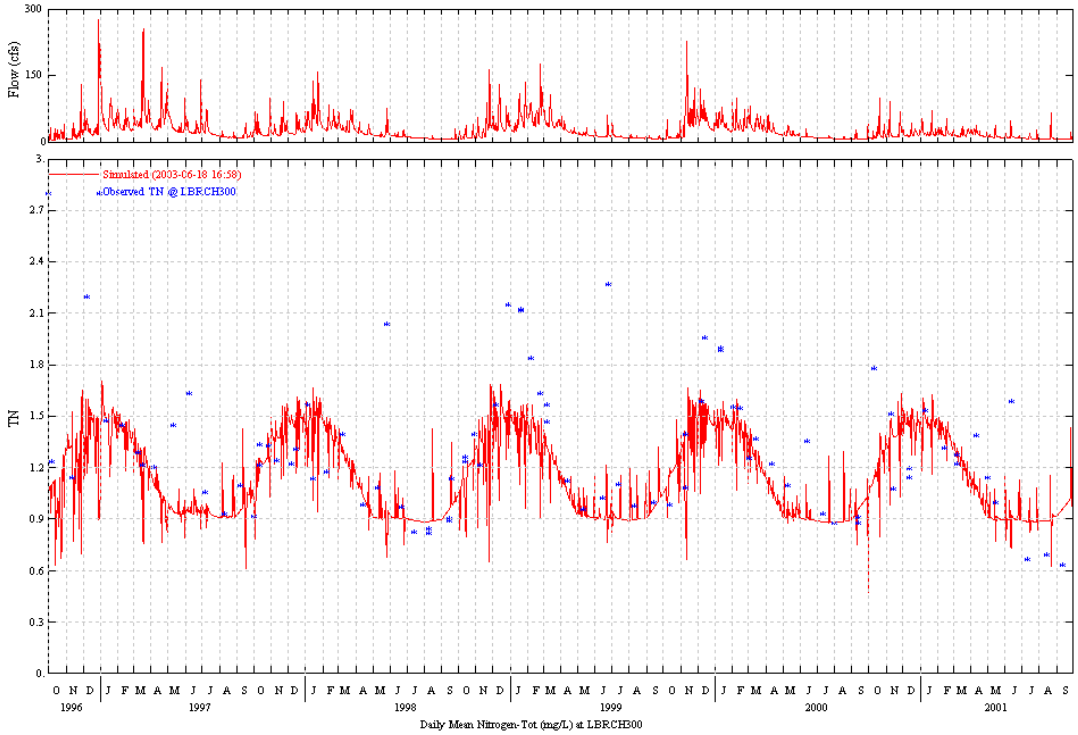


Figure 4.3-12 Observed and Simulated Daily Total Nitrogen Concentrations for Little Bear Creek at Highway 202

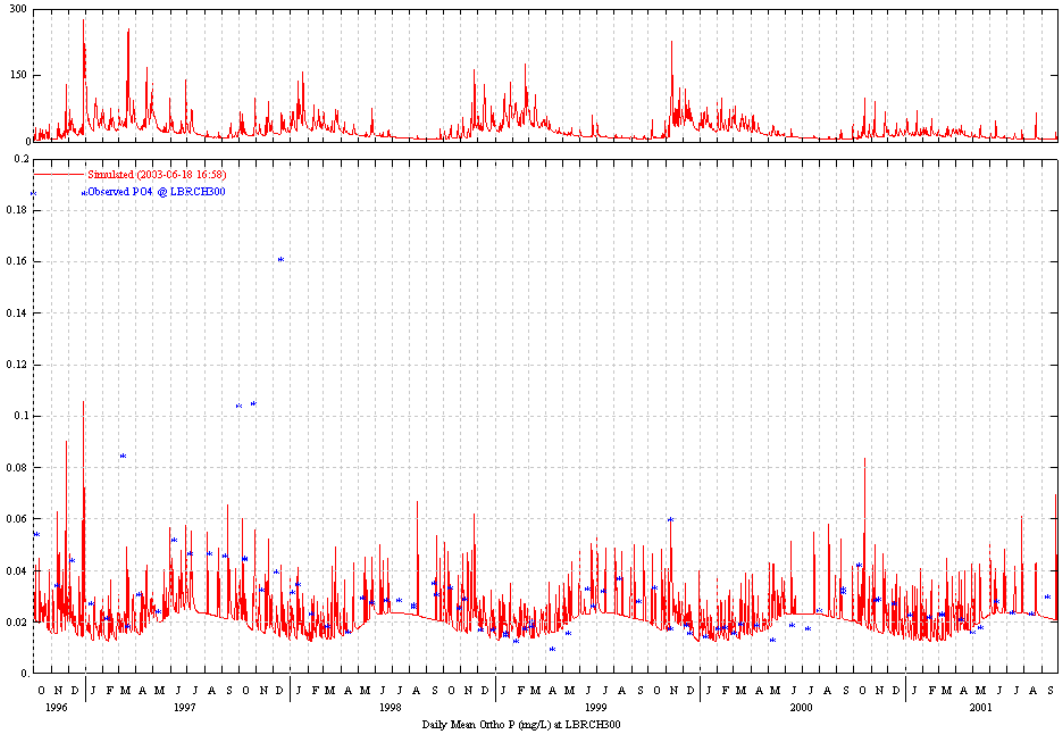


Figure 4.3-13 Observed and Simulated Daily Orthophosphate Concentrations for Little Bear Creek at Highway 202

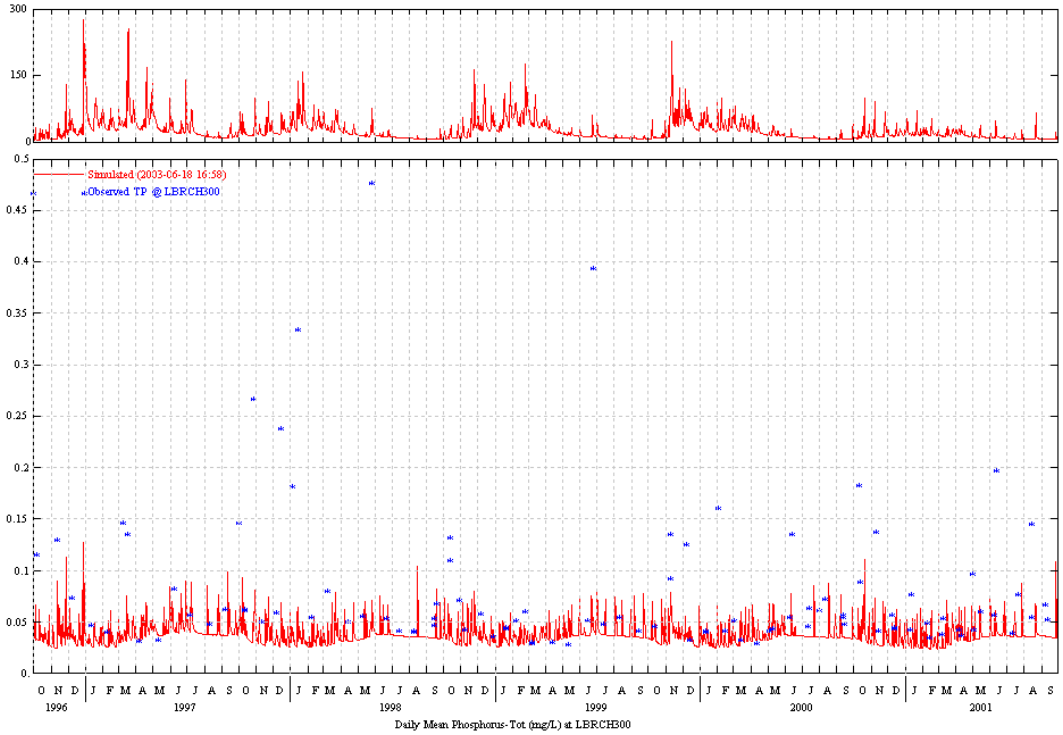


Figure 4.3-14 Observed and Simulated Daily Total Phosphorus Concentrations for Little Bear Creek at Highway 202

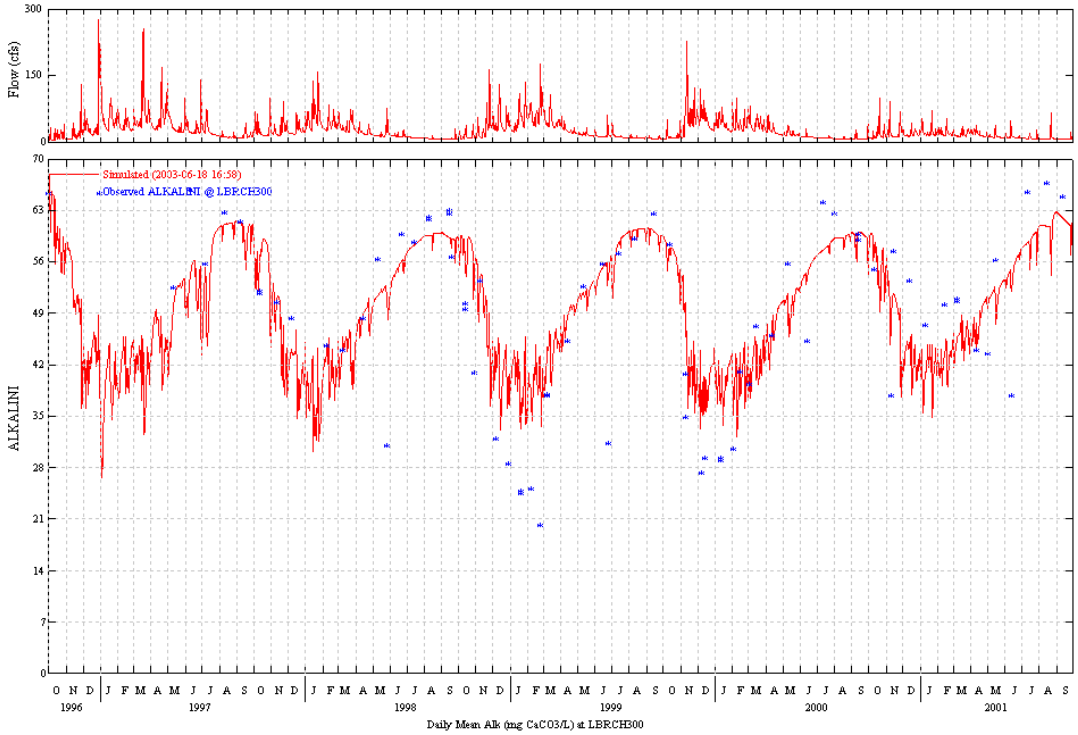


Figure 4.3-15 Observed and Simulated Daily Alkalinity Concentrations for Little Bear Creek at Highway 202

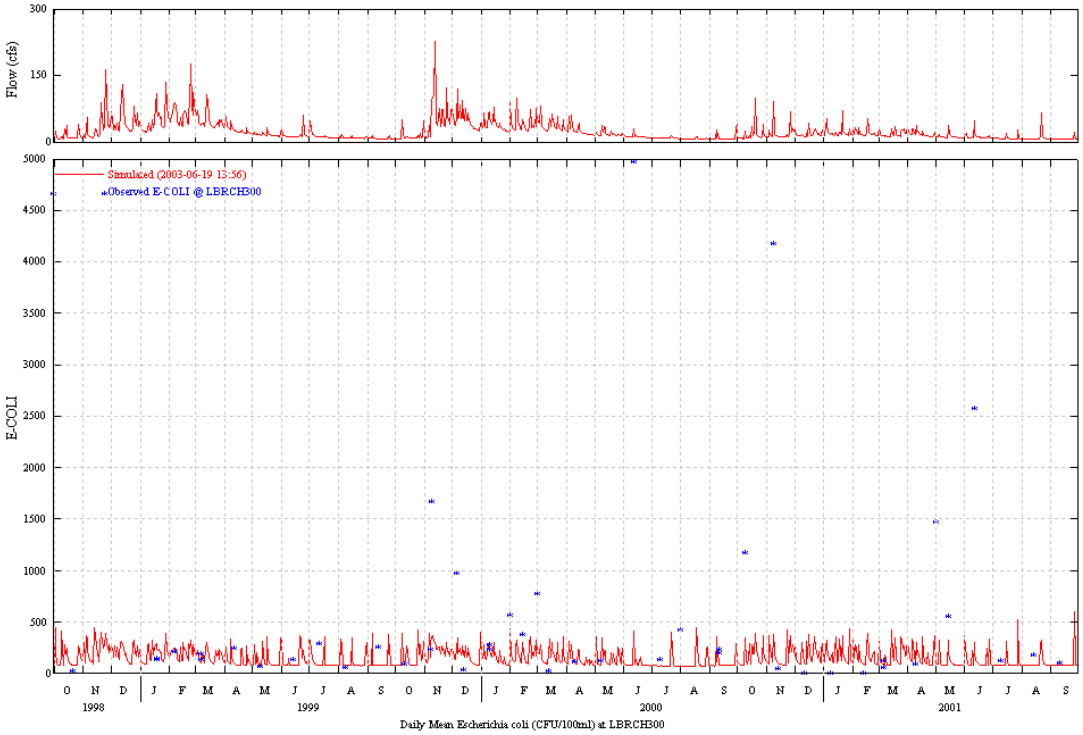


Figure 4.3-16 Observed and Simulated Daily EColi Concentrations for Little Bear Creek at Highway 202

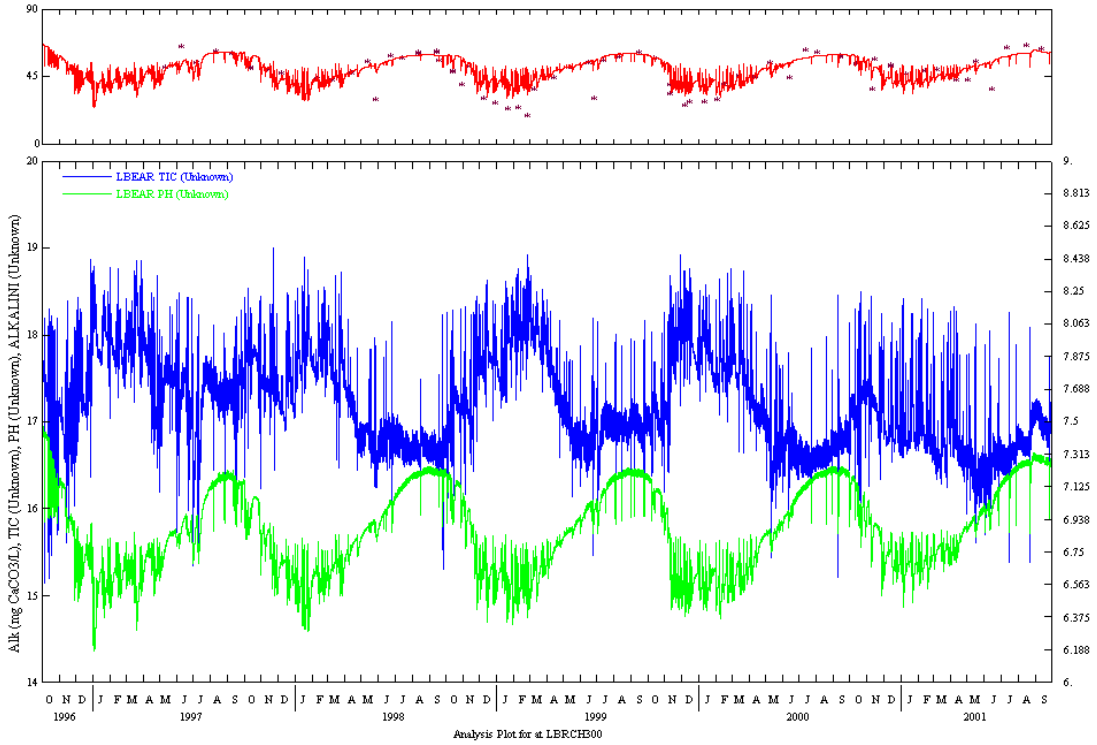


Figure 4.3-17 Simulated Daily pH, TIC, and Alkalinity Values for Little Bear Creek at Highway 202

4.3.2.5 Unresolved Calibration Issues

At the current time, several items related to this model are not complete or should at the least be considered further. Some of these are minor issues that will be addressed as the North and Swamp Creek Models are completed. Some of these issues are addressed below, and others should be noted in reviews by County staff.

- In the Simulation Plan, it was stated that atmospheric deposition data would be reviewed to determine whether this pollutant source is significant and needs to be accounted for explicitly in the model. An estimate of likely deposition fluxes should be made and compared to current model accumulation rates for impervious areas. This issue should be discussed between County staff and AQUA TERRA.

- In the current calibration, the simulation time span is the same as the hydrologic run span, which is limited by observed flow data. However, there are additional water quality monitoring data prior to the current starting time of the simulation, and there are also complete meteorologic datasets available to support the simulation period 1993 – 2001. These datasets are processed and ready for use. The Swamp, North, and Little Bear Creek Models will be run for these periods and an evaluation will be made about the value of this additional data.

- The “need” for small adjustments to some constituents (e.g., organic P) may be identified in the final runs, and these changes will be made in the North and Swamp models. Should such changes be made in the Little Bear model?

- While the instream water quality (biological) processes are currently operating in the model, they are not having much impact. This is partly because of the absence of any organic or other monitoring data which indicates their impact (e.g., on nutrient or oxygen concentrations) or which can be used to calibrate them. This issue should be investigated by AQUA TERRA (with guidance by the County) to determine whether additional emphasis on characterizing these processes is useful for these three watersheds.

4.4 MODEL LINKAGES

The Sammamish River Model (CE-QUAL-W2) requires a subset of the following quantities/constituents:

- Flow (m^3/s)
- Temperature (deg C)
- Sand (g/m^3)
- Silt (g/m^3)
- Clay (g/m^3)
- NO3-N (g/m^3)
- NH3-N (g/m^3)
- PO4-P (g/m^3)
- TDS (g/m^3)
- Silica-Si (g/m^3)
- Alkalinity as CaCO3 (g/m^3)
- Dissolved Oxygen (g/m^3)
- LDOM (g/m^3)
- RDOM (g/m^3)
- LPOM (g/m^3)
- RPOM (g/m^3)
- Indicator Bacteria (E-Coli) ($E6/m^3$ = #/mL = 100/100mL, etc.)

The Little Bear Creek HSPF model explicitly simulates (or can simulate) all of these except for the four organic matter quantities: LDOM, RDOM, LPOM, RPOM. (Note: at the current time the Little Bear Creek model does not include the TDS constituent, and the Silica constituent is not calibrated due to a lack of monitoring data.) The correspondence between HSPF constituents (refractory organic N, P, & C) and the W2 organic matter constituents is unresolved!

4.4.1 Spatial Linkage

All loadings to the Sammamish River from Little Bear Creek effectively enter the river at a single location, i.e., the mouth of the creek. Since the end of the most downstream reach of the Little Bear Creek watershed model corresponds to this location, time series results from HSPF (for all of the required constituents) which represent the downstream outflow from this reach will provide the necessary boundary condition data to be input to CE-QUAL-W2.

4.4.2 Temporal Linkage

HSPF can generate results at any time step which is a multiple of the simulation timestep (i.e., 15 minutes). According to C. DeGasperi (Personal communication, 5/2003), the appropriate time step for the CE-QUAL-W2 model of the Sammamish River is one hour. Therefore, the data (flows, temperatures, concentrations) will be one-hour averages.

4.4.3 Linkage Formats

The model linkage output from HSPF will be generated in PLTGEN format, which is easy to to generate and understand. Each PLTGEN file can contain up to 20 time series, so all of the results produced at a boundary location (e.g., a tributary stream model) contributing to CE-QUAL-W2 can be stored in a single file. It is also easy to control the time step, aggregation, and units of the data. Flow will be in units of m^3/s, temperature will be in degrees C, and all WQ constituents will be generated in the form of concentrations (g/m^3) with the possible exception of the indicator bacteria.

4.5 REFERENCES

4.5.1 Water Quality

AQUA TERRA Consultants and HydroQual, Inc. 2001. Modeling Nutrient Loads to Long Island Sound from Connecticut Watersheds, and Impacts of Future Buildout and Management Scenarios. Prepared for Connecticut Department of Environmental Protection, Hartford, CT.

Booth, D.B., J.R.Karr, S. Schauman, C.P.Conrad, S.A. Morley, M.G. Larson, P.C. Henshaw, E.J. Nelson, and S.J. Burges. 2001. Urban Stream Rehabilitation in the Pacific Northwest, Final Report of EPA Grant No. R82-5284-010, University of Washington, Seattle, WA.

Brett, M.T., S.E. Stanley, G.B. Arhonditsis, D.M. Hartley, J.D. Frodge, and D.E. Funke. 2002. Non Point Source Nutrient Impacts on Stream Nutrient Concentrations Along a Forest to Urban Gradient, University of Washington and King County Water and Land Resources, Seattle, WA.

Embrey, S.S., and L.M. Fran. 2003. Surface-Water Quality of the Skokomish, Nooksack, and Green-Duwamish Rivers and Thorton Creek, Puget Sound Basin, Washington, 1995-98: U.S. Geological Survey Water-Resources Investigations Report 02-4190, 199 p.

Fevold, K., C.W. May, H. Berge, and E. Ostergaard. 2001. Habitat Inventory and Assessment of Three Sammamish River Tributaries: North, Swamp, and Little Bear Creeks, King County Department of Natural Resources, Water and Land Resources Division, Seattle, WA.

King County. 1994. Enhanced Reconnaisance of the Eastern Tributaries of the Lower Green River Basin: Data, Analyses, and Management Recommendations, King County Basin Planning Program, Department of Public Works, Seattle, WA.

Nelson, E.J., D.B. Booth, 2002. Sediment Sources in an Urbanizing Mixed Land-Use Watershed. Journal of Hydrology 264: 51-68.

Prych, E. A., and R. N. Brenner. 1983. Effects of Land Use on Discharge and Water Quality in Newaukum Creek Basin, King County, Washington. August 1983, U.S. Geological Survey, and Municipality of Metropolitan Seattle, Seattle WA.

4.5.2 Water Quantity

AQUA TERRA and King County. 2002a. Little Bear Creek Simulation Plan. King County Watershed Modeling Services Work Order #6. Prepared for King County Department of Natural Resources, Water and Land Division, Seattle, WA.

AQUA TERRA and King County. 2002b. Watershed Modeling Needs Assessment, Modeling Strategy, and Model Recommendations for SWAMP and Green WQA Projects. King County Watershed Modeling Services Work Order #2. Prepared for King County Department of Natural Resources, Water and Land Division, Seattle, WA.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle Jr., T.H. Jobes, and A.S. Donigian, Jr. 2000. Hydrological Simulation Program - FORTRAN. User's Manual for Release 12. FINAL DRAFT. U.S. EPA Ecosystem Research Division, Athens, GA. & U. S. Geological Survey, Office of Surface Water, Reston, VA.

Burkey, J. 2002. Personal Communication. King County Department of Natural Resources, Water and Land Resources Division. Seattle, WA.

Chandler, R. D. 1993. Modeling and Nonpoint Source Pollution Loading Estimates in Surface Water Management. M.S. Engr. thesis submitted for Department of Civil Engineering, University of Washington.

Crawford, N.H. and R.K. Linsley. 1966. Digital Simulation on Hydrology: Stanford Watershed Model IV. Stanford University Technical Report No. 39, Stanford University, Palo Alto, CA.

Dinicola, R.S. 1990. Characterization and Simulation of Rainfall-Runoff Relations for Headwater Basins in Western King and Snohomish Counties, Washington, U.S. Geological Survey, Water-Resources Investigations Report 89-4052, Tacoma, WA.

Donigian, A.S., Jr., J.C. Imhoff, B.R. Bicknell and J.L. Kittle, Jr. 1984. Application Guide for the Hydrological Simulation Program - FORTRAN EPA 600/3-84-066, Environmental Research Laboratory, U.S. EPA, Athens, GA. 30613.

Donigian, A.S. Jr., B.R. Bicknell, A.S. Patwardhan, L.C. Linker, C.H. Chang, and R. Reynolds. 1994. Chesapeake Bay Program - Watershed Model Application to Calculate Bay Nutrient Loadings: Final Findings and Recommendations (FINAL REPORT). Prepared for U.S. EPA Chesapeake Bay Program, Annapolis, Maryland. 283 p.

Donigian, A.S. Jr. 2002a. Bibliography for HSPF and Related References. AQUA TERRA Consultants, Inc. Mountain View, CA.

Donigian, A.S. Jr. 2002b. Watershed Model Calibration and Validation: The HSPF Experience. Presented at National TMDL Science and Policy 2002 Conference. November 13-16, 2002, Phoenix, AZ. CD conference proceedings prepared by Water Environment Federation, Washington, DC.

Donigian, A.S. Jr. 2003. Personal Communication. AQUA TERRA Consultants, Inc. Mountain View, CA.

Farnsworth, R.K., E.S. Thompson, and E.L. Peck. 1982. Evaporation Atlas for the Contiguous 48 United States. NOAA Technical Report NWS 33. U. S. Department of Commerce, NOAA. Washington, DC. 26 p.

Hartley, D. 1999. Personal Communication. King County Department of Natural Resources, Water and Land Resources Division. Seattle, WA.