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

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Section 8—Newaukum Creek

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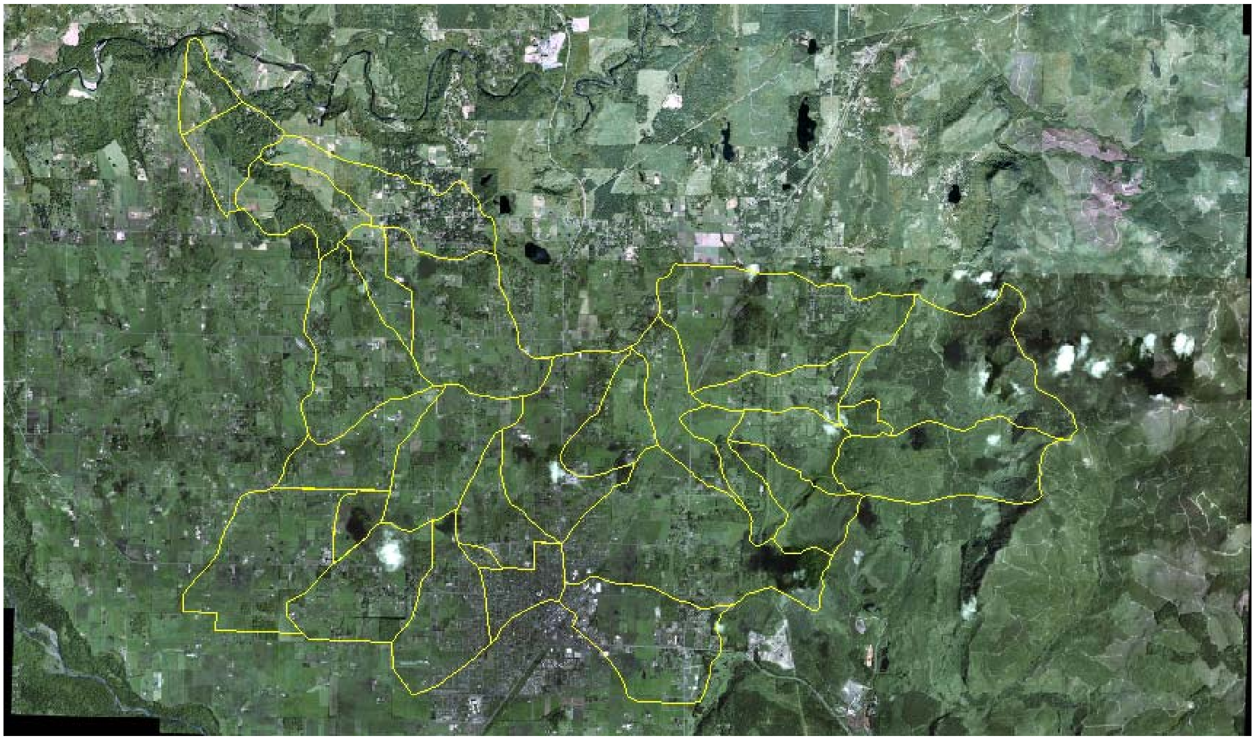
8 NEWAUKUM CREEK MODEL DEVELOPMENT



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8.1 NEWAUKUM CREEK WATERSHED DOMAIN

The physical domain of the HSPF model for this study is the entire Newaukum Creek watershed above the confluence with the Green River, an area of approximately 26 square miles.

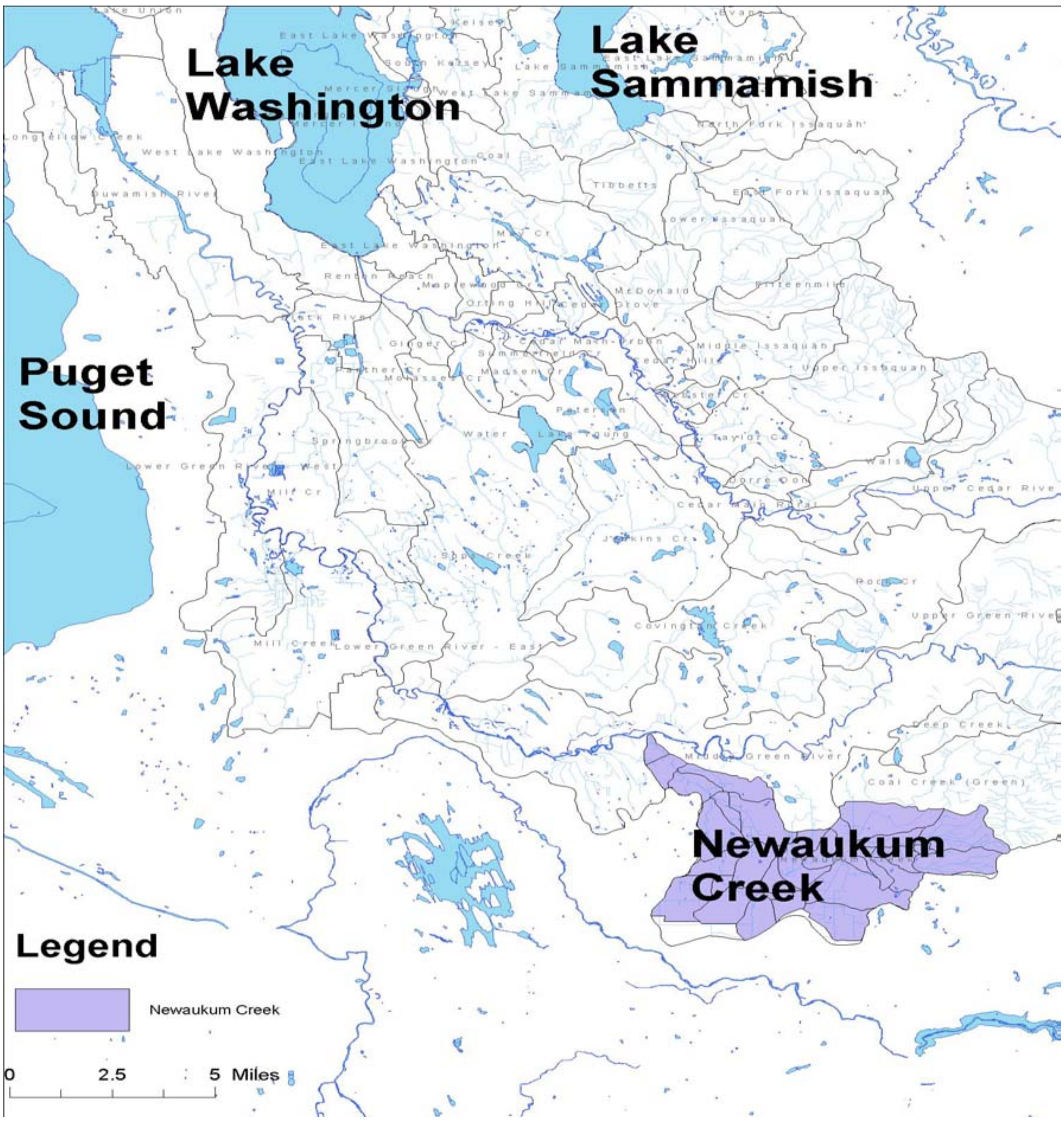


Figure 8.1-1 Newaukum Creek Subbasin

8.2 DATA REQUIREMENTS AND AVAILABILITY

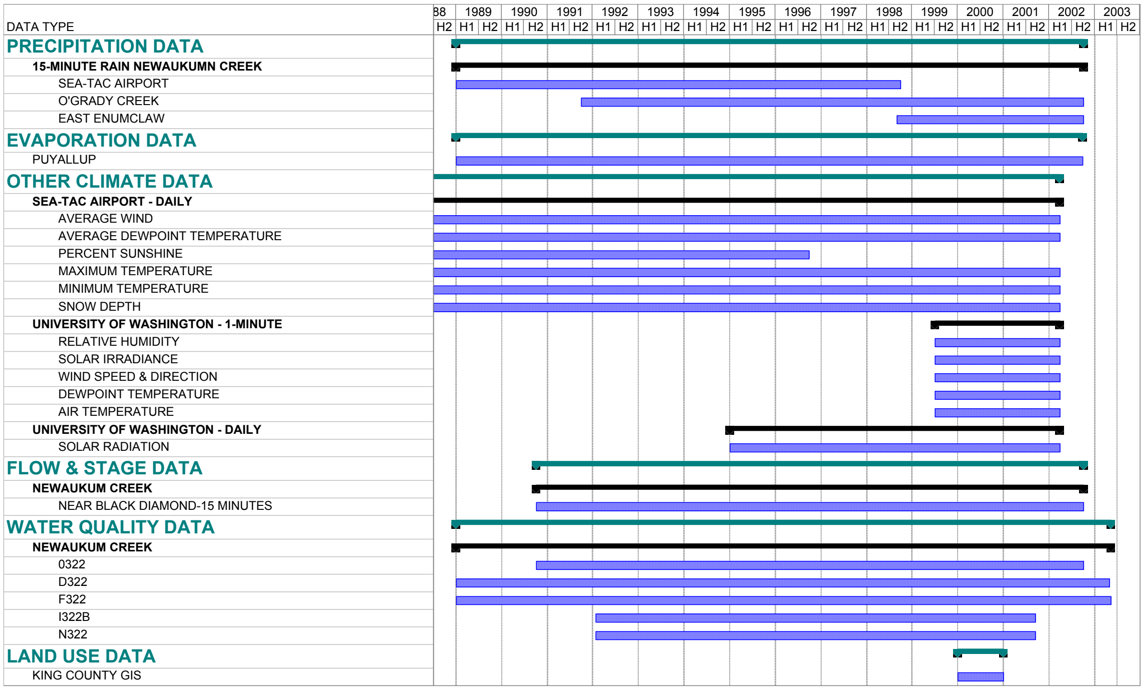
Database development is a major portion of the total modeling effort, requiring acquisition of data from a variety of sources, developing estimation procedures when needed data are not available, applying available techniques to fill-in missing data, and ensuring consistency and accuracy of the information obtained. The purpose of this section is to identify the data needs for the various models and present findings of the availability and sources of these data. Ultimately, the findings in this section determine the timeframe and constituents the data are capable of supporting for model simulations. Typical data requirements for an HSPF application can be categorized as input/execution data, watershed/channel characterization data, and calibration/validation data.

8.2.1 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 Green River CE-QUAL-W2 segments receiving Newaukum Creek inflows.

Table 8.2-1 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 8.2-1 include published reports (AQUA TERRA and King County, 2002b), USGS data, NOAA/NCDC data, and the King County Hydrologic Information Center http://dnr.metrokc.gov/hydrodat/index.htm, along with other personal communications and miscellaneous sources.

Table 8.2-1 Data Availability for Model Simulations



8.2.1.1 Calibration Data

Table 8.2-2 provides a summary of the types of data that will be used for the Newaukum Creek hydrology calibration and the time periods over which they are available. Evaporation and precipitation are stored in the file MetData.wdm, while flow is stored in OutputWQ.wdm. References to these time series can be found in the EXT SOURCES block of the UCI file.

Table 8.2-2 Data Availability for Model Calibration

Location	Data Type	Time Step	Starting Date	Ending Date	DSN
Puyallup	Evaporation	Daily	1948/10/01	2002/09/30	1002
O'Grady Creek (King County Gage 40U)	Precipitation	15-Minute	1991/10/01	2002/09/30	1010
East Enumclaw (King County Gage 44U)	Precipitation	15-Minute	1998/10/01	2002/09/30	1011
Newaukum Creek nr Black Diamond (USGS Gage 12108500)	Streamflow	15-Minute	1990/10/01	2002/09/30	30

8.2.1.1.1 Precipitation

Precipitation data are available at a 15-minute interval from two King County gages for the time intervals shown in Table 8.2-2. The East Enumclaw rain gage (44U), is located in the south-central of the watershed, and the O' Grady Creek (Middle Green) rain gage (40U) is located just outside of the watershed about two miles from the western watershed's boundary. The locations of the respective King County gages can be seen in Figure 8.2-1 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 rain gages to the Newaukum Creek watershed. Ultimately, the limited period of record at East Enumclaw rain gage (44U) led to the calibration period being restricted to water years 1999-2002.

As shown in
Table 8.2-3, the two rain gage's records were compared based on annual total volumes to determine how these records used to represent the Newaukum 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 8.2-1. No single precipitation record was found to accurately represent the entire Newaukum Creek watershed for the calibration period of water years (WY) 1999 through 2002. Nor did the calibration period average annual precipitation at the two gages match well with the PRISM isohyets values. The PRISM isohyets show a much smaller annual precipitation volume than the average precipitation records of gage 44U (53 vs. 60 inches) from WY1999 to WY2002, and a comparable volume with the records of gage 40U (45 vs. 44 inches). As such, the isohyets were used 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 historical precipitation record was scaled to represent the entire Newaukum Creek watershed.

Based on the location of the two King County precipitation gages, the pattern of the PRISM isohyets, and the fact that annual rainfall volume increases from west to east, the Newaukum Creek watershed is subdivided into two precipitation zones. The catchments located on the east of 50" isohyets (catchments 131 and lower) are grouped in Zone A. The records of gage 44U represent rainfall time series in these catchments. The record will multiply by a factor of

0.9160 to scale up the average precipitation to the zone average. Likewise, catchments 141 and higher are grouped in Zone B and their rainfall time series are represented by the records of gage 40U. The MFACT for Zone B is 1.0762.

Table 8.2-3 Comparison of Precipitation Annual Volumes

Water Year	King Co 40U O'Grady Creek DSN 40	King Co 44U East Enumclaw DSN 44	Watershed Average
1992	30.23		
1993	37.72		
1994	29.05		
1995	39.79		
1996	49.24		
1997	54.77		
1998	32.71		
1999	46.72	68.99	
2000	47.27	65.63	
2001	36.67	46.27	
2002	46.86	59.12	
Average			
Period of Record	41.00	60.00	
1999-2002	44.38	60.00	
PRISM at gage	45	53	49.24
Fraction of watershed	0.47	0.53	1.00

The precipitaton records (DSN 40 and DSN 44) were used for the calibration period of October 1998 through September 2002 (water years 1999-2002).

The period of the water quality calibration was extended (from that used in the hydrology calibration, i.e., 10/1/98-3/20/03) to 8/1/91-7/31/03 in order to take advantage of water quality data collected by King County over that longer time span. In order to cover the earlier period, the precipitation data at Enumclaw (44U) had to be extended back in time, since its period of record is only 2/12/98-present. The missing period for gage 44U was filled with weighted values from gage 40U, which is at a lower elevation and receives less rain.

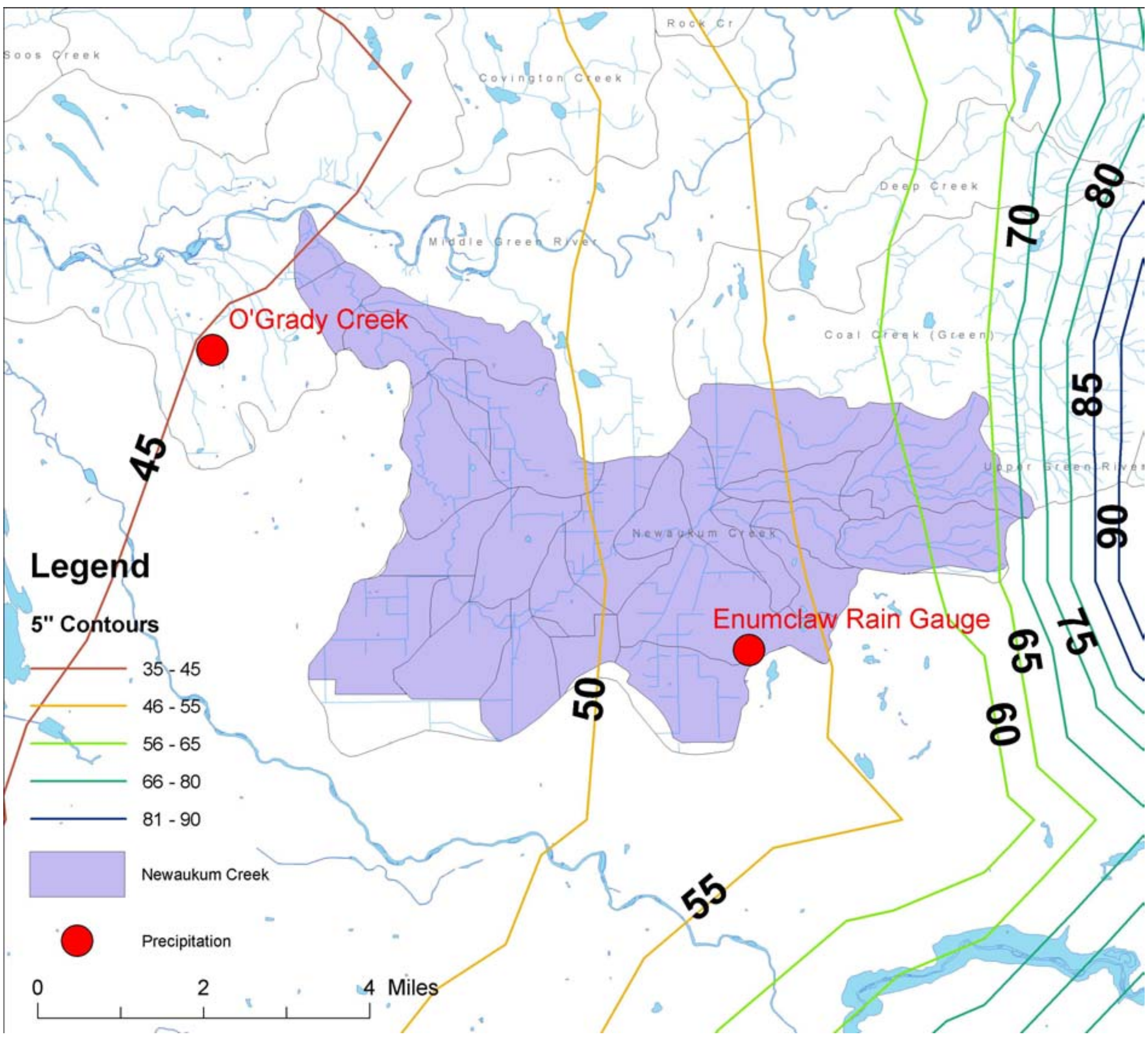


Figure 8.2-1 Nearby Precipitation Stations

8.2.1.1.2 Evaporation

Puyallup lies approximately 15 miles to the west of the Newaukum 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 2002 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 Newaukum Creek watershed coefficient was set to 0.78 and not adjusted during calibration.

Table 8.2-4 Evaporation Monthly Volumes

Water Year	Oct (in)	Nov (in)	Dec (in)	Jan (in)	Feb (in)	Mar (in)	Apr (in)	May (in)	Jun (in)	Jul (in)	Aug (in)	Sep (in)	Total (in)
1981	1.11	0.72	0.65	0.90	0.84	1.74	2.64	2.86	3.24	4.88	4.86	2.98	27.42
1982	1.10	0.74	0.65	0.91	0.84	1.74	3.67	4.61	5.18	5.21	4.75	2.83	32.23
1983	1.73	0.74	0.65	0.90	0.84	1.74	3.04	4.11	4.47	4.02	4.93	2.71	29.88
1984	1.26	0.72	0.65	0.90	0.87	1.74	2.42	4.01	4.42	6.43	5.27	3.13	31.82
1985	1.40	0.91	0.28	0.35	0.67	1.99	2.37	4.13	4.93	7.56	5.41	2.72	32.72
1986	1.71	0.37	0.23	0.87	1.13	3.35	2.08	3.24	5.81	4.59	5.87	2.88	32.13
1987	0.95	0.44	0.40	0.41	0.80	1.13	2.39	4.25	5.67	4.88	5.44	3.64	30.40
1988	1.63	0.63	0.35	0.84	0.87	1.90	2.36	3.50	4.92	5.74	5.20	3.61	31.55
1989	1.24	0.69	0.61	0.84	0.83	1.77	3.32	5.84	5.33	6.20	5.13	3.95	35.75
1990	1.58	0.69	0.61	0.84	0.83	1.77	2.53	4.48	5.40	6.76	5.45	2.88	33.82
1991	1.31	0.69	0.61	0.84	0.83	1.77	2.53	3.79	3.92	6.40	6.20	3.63	32.52
1992	1.31	0.69	0.61	0.84	0.87	1.77	2.53	5.29	2.53	5.35	6.01	4.20	32.00
1993	2.57	1.19	0.87	0.34	0.46	0.42	0.51	4.17	1.96	5.34	6.33	4.37	28.53
1994	1.28	0.69	0.61	0.84	0.86	1.79	2.58	3.68	4.12	6.63	5.86	3.58	32.52
1995	1.28	0.69	0.61	0.84	0.84	1.77	2.53	5.29	2.53	5.35	6.01	4.20	31.94
1996	2.57	1.19	0.87	0.34	0.47	0.43	0.51	4.33	1.84	5.44	6.38	4.30	28.67
1997	2.57	1.19	0.87	0.34	0.46	0.42	0.51	4.17	1.96	5.34	6.33	4.37	28.53
1998	1.27	0.72	0.65	0.90	0.84	1.74	2.49	3.94	4.59	5.67	4.68	2.82	30.31
1999	1.27	0.72	0.65	0.90	0.84	1.74	2.49	3.94	4.59	5.67	4.68	2.82	30.31
2000	1.27	0.72	0.65	0.90	0.90	1.76	2.53	3.96	4.62	5.64	4.62	2.77	30.34
2001	1.25	0.72	0.66	0.90	0.87	1.76	2.53	3.96	4.62	5.64	4.62	2.77	30.30
Average (60-97)	1.41	0.73	0.63	0.82	0.82	1.68	2.39	4.07	4.37	5.66	5.06	3.08	30.71
Average (99-01)	1.26	0.72	0.65	0.90	0.87	1.75	2.52	3.95	4.61	5.65	4.64	2.79	30.32

8.2.1.1.3 Water Quality Required Meteorological Data

The period of hydrology calibration is 10/1/1998-9/30/2002. This period was extended to 8/1/1991-7/31/2003 for the water quality calibration in order to take advantage of water quality data collected by King County over that longer span. The evaporation data used in the hydrology calibration had adequate coverage, but the precipitation data had to be extended. The O'Grady Creek (40U) and Enumclaw (44U) gages operated by King County are the precipitation data sources. The period of record for 40U is 7/24/1991-present, while that for 44U is 2/12/1998-present. The missing period for gage 44U was filled with weighted values from gage 40U, which is at a lower elevation and receives less rainfall.

The HSPF water quality simulation runs require five meteorological data sets in addition to the precipitation and evaporation data sets required for the hydrologic runs. These additional data are:

- Temperature
- Dew Point
- Cloud Cover
- Wind
- Solar Radiation

AQUA TERRA identified the King County gage 44U as the best source for temperature data. As mentioned above, this gage came online in February, 1998. The period of 8/1/1991-2/12/1998 was filled with weighted values from NCDC station Palmer 3 ESE. Seattle-Tacoma International Airport (SEATAC) was determined to be the best source of data for the remaining four quantities. Table 8.2-5 contains selected descriptive attributes of these stations. The map in Figure 8.2-2 shows the spatial relation of these stations to the Newaukum Creek watershed.

Table 8.2-5 Additional Meteorologic Data Stations for Newaukum Creek

StationID	STATION NAME	COUNTY	LAT (dec^o)	LONG (dec^o)	ELEV (m)	START	END
40U	O'GRADY CREEK	KING	47.2607	-122.0919	520	7/24/91	7/31/01
44U	ENUMCLAW	KING	47.2074	-121.9557	830	2/12/98	7/31/01
456295	PALMER 3 ESE	KING	47.300	-121.850	920	1/1/31	12/31/01
457473	SEATTLE-TACOMA AP	KING	47.467	-122.317	400	1/1/48	7/31/03

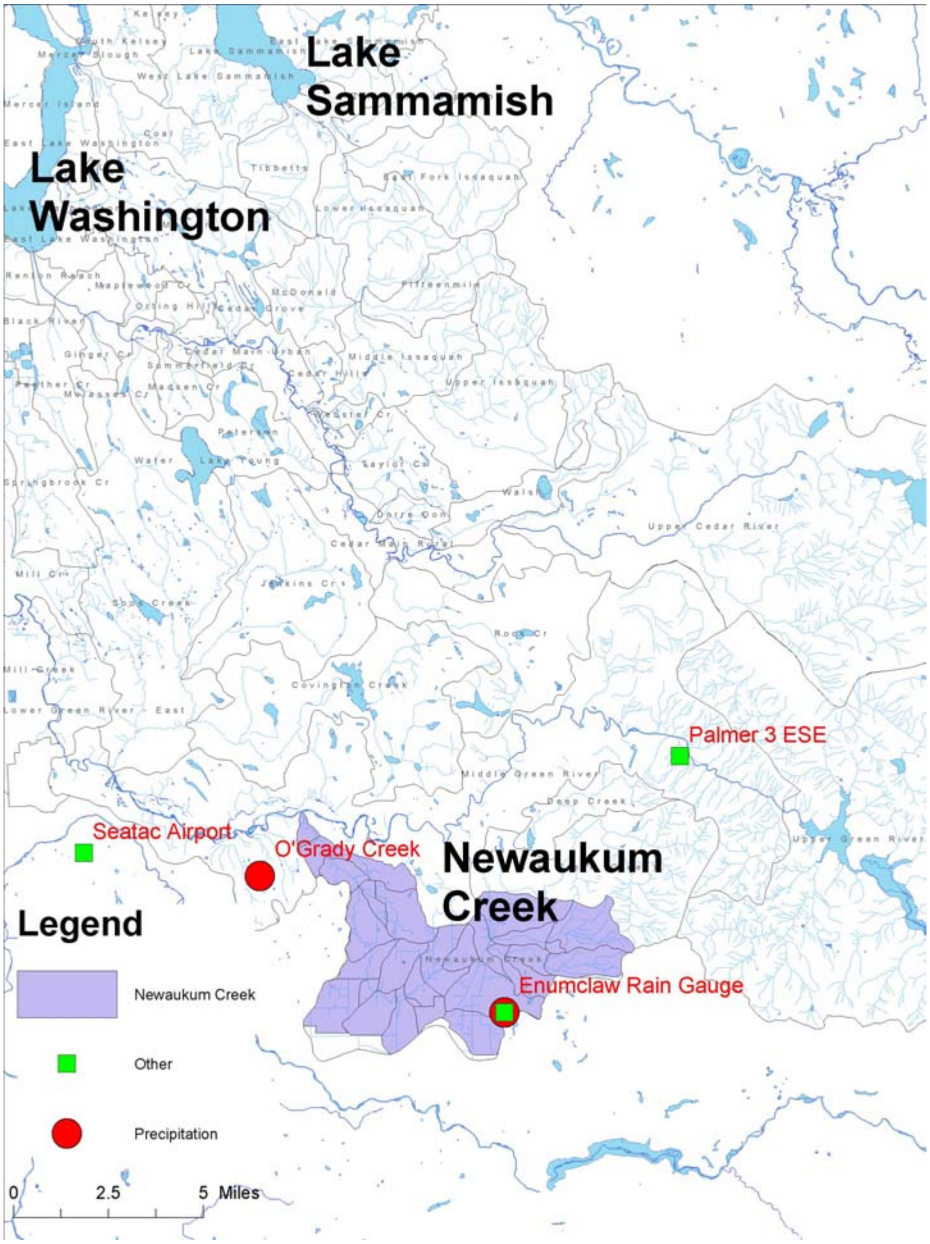


Figure 8.2-2 Map of Meteorological Data Stations Used for Newaukum Creek

Data from the Seattle Tacoma 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). Since the data 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 (8 hours or less); whereas, for cloud cover and wind, values were interpolated if there were 24 or fewer consecutive missing values (1 day or less). 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 2 feet, representing the standard height for wind data used in the model.

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 shown in Table 8.2-6.

Table 8.2-6 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.

The SEATAC solar radiation dataset was developed by aggregating data from 3 different collection methods. For the period of 1/1/91-9/30/96, daily sky cover data were converted to total daily solar radiation using the solar radiation computation model implemented within the ‘Compute’ tool in WDMUtil. The total daily values were then disaggregated to hourly using the average daily distribution from 1960-1990, which was available at the National Solar Radiation Data Base (NSRDB) at http://rredc.nrel.gov/solar/old_data/nsrdb/. For the period of 10/1/96-7/31/99, an average annual time series was calculated as the average hourly value for that day of the year over the 30 years for which there are actual observations at SEATAC in the NSRDB. Directly observed solar radiation data were used for the final period (8/1/99-7/31/03).

8.2.1.1.4 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 neither NPDES point sources nor diversions identified in Newaukum Creek. Therefore, these quantities are not considered in the water quality budget of Newaukum Creek. Time series of nitrate and ammonia concentrations in rainfall (wet atmospheric deposition) were incorporated into the model using the standard methodology for specifying atmospheric deposition in HSPF. The concentrations from the two closest National Atmospheric Deposition Program (NADP) monitoring stations were averaged and combined with the rainfall data to produce loadings of nitrate and ammonia to the surface storages on land segments. The two NADP stations are LaGrande (Pierce County) and North Cascades National Park (Skagit County).

8.2.1.2 Water Quantity Calibration Data

8.2.1.2.1 Stream Flow

Recorded streamflow data are used to check the simulated streamflow results and evaluate the accuracy of the calibration. There are four streamflow stations along the Newaukum Creek that have collected data. One of these gages (one operated by USGS and three by King County) have been in operation long enough to develop an accurate rating curve.

The USGS gage is the USGS 12108500 Newaukum Creek near Black Diamond. This gage has been collecting data since July of 1944.

The King County gages are Clovercrest Outfall at Enumclaw (44F), Newaukum Tributary near Black Diamond (44G), and North Fork Newaukum Creek near Enumclaw (44H). None of the three gages have collected streamflow data longer than two water years. They were not used for hydrological model calibrations because of the short time period, but they're shown for reference.

Recorded streamflow data are available from the USGS station for the model calibration period of October 1998 through September 2002. The period of record is complete. Maximum flow events for each water year are shown in Table 8.2-7. The maximum flood event during this period occurred in different time of the year in response to large rainfall events.

Table 8.2-7 Newaukum Creek Maximum Streamflows at USGS Gage 12108500

Water Year	Maximum Flow (cfs)	Date of Event
1999	985	1998/11/26
2000	477	1999/11/13
2001	183	2001/06/12
2002	488	2002/03/20

For this same period of record low flows at the USGS gage were in the range of 12 to 20 cfs.

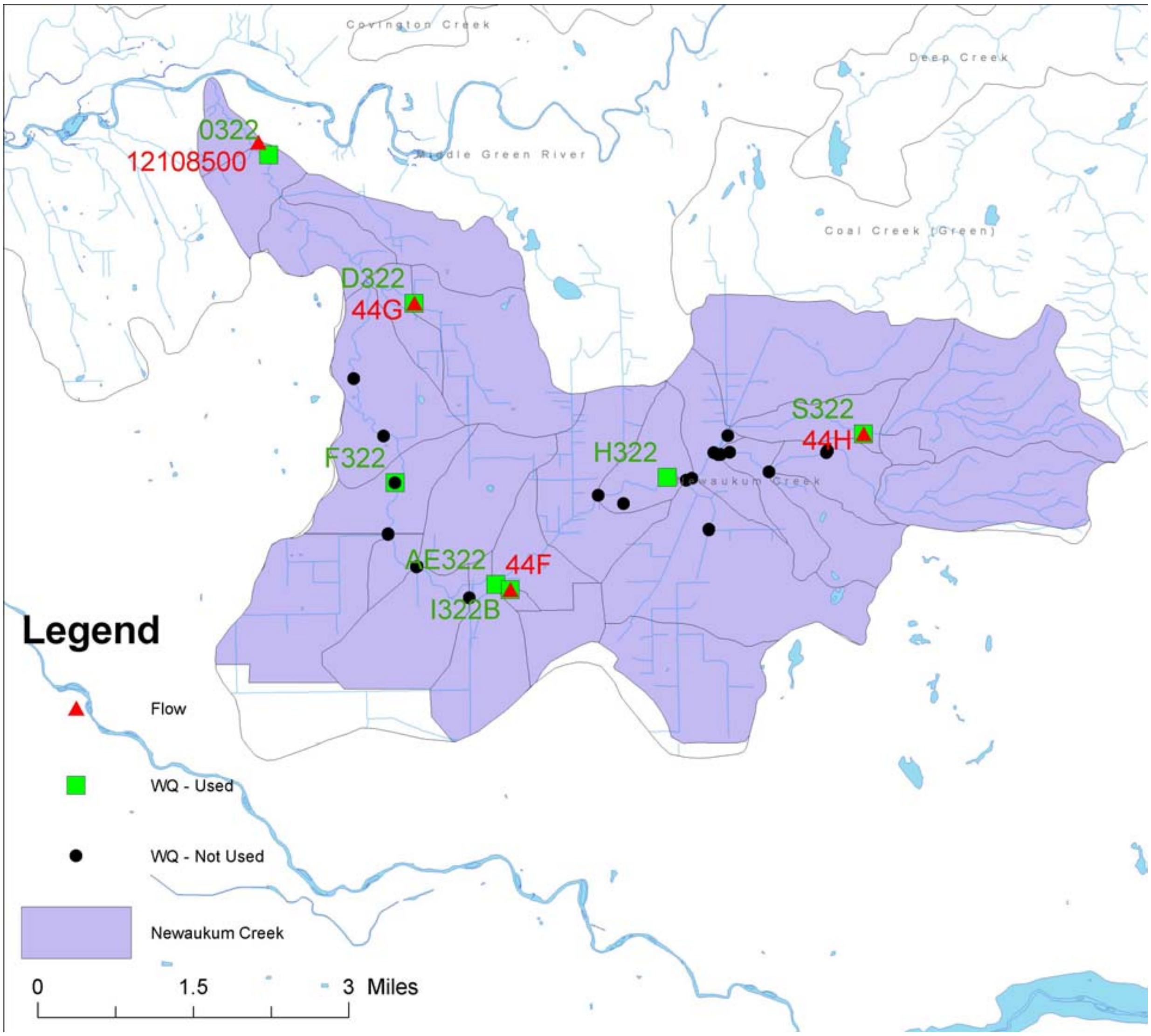


Figure 8.2-2 Flow and Water Quality Gages

8.2.1.3 Water Quality Calibration Data

King County maintains a large number of water quality sampling sites in the Newaukum watershed. In total there are 23 distinct currently operational or historical stations. Due to time and budget considerations, 7 stations were used as the basis for calibration. The stations were selected because the land parcels draining to 3 of them represent distinct land uses, 3 others are located progressively along the main stem, and the final station is at the watershed outlet. The primary calibration points are S322 (forest), I322B (residential), D322 (agricultural), H322, AE322, F322, and 0322 (basin outlet). Stations 0322 and I322B contain some data points that are the result of continuous sampling by an autosampler over the course of many hours. In such cases, the middle point in the span was taken as the time of sampling. The data for the sampling stations were all provided by King County.

Figure 8.2-3 shows the location of the stations in the study area. H322, AE322, F322, and 0322 are located on Newaukum Creek while the other three stations are on tributaries to the creek.

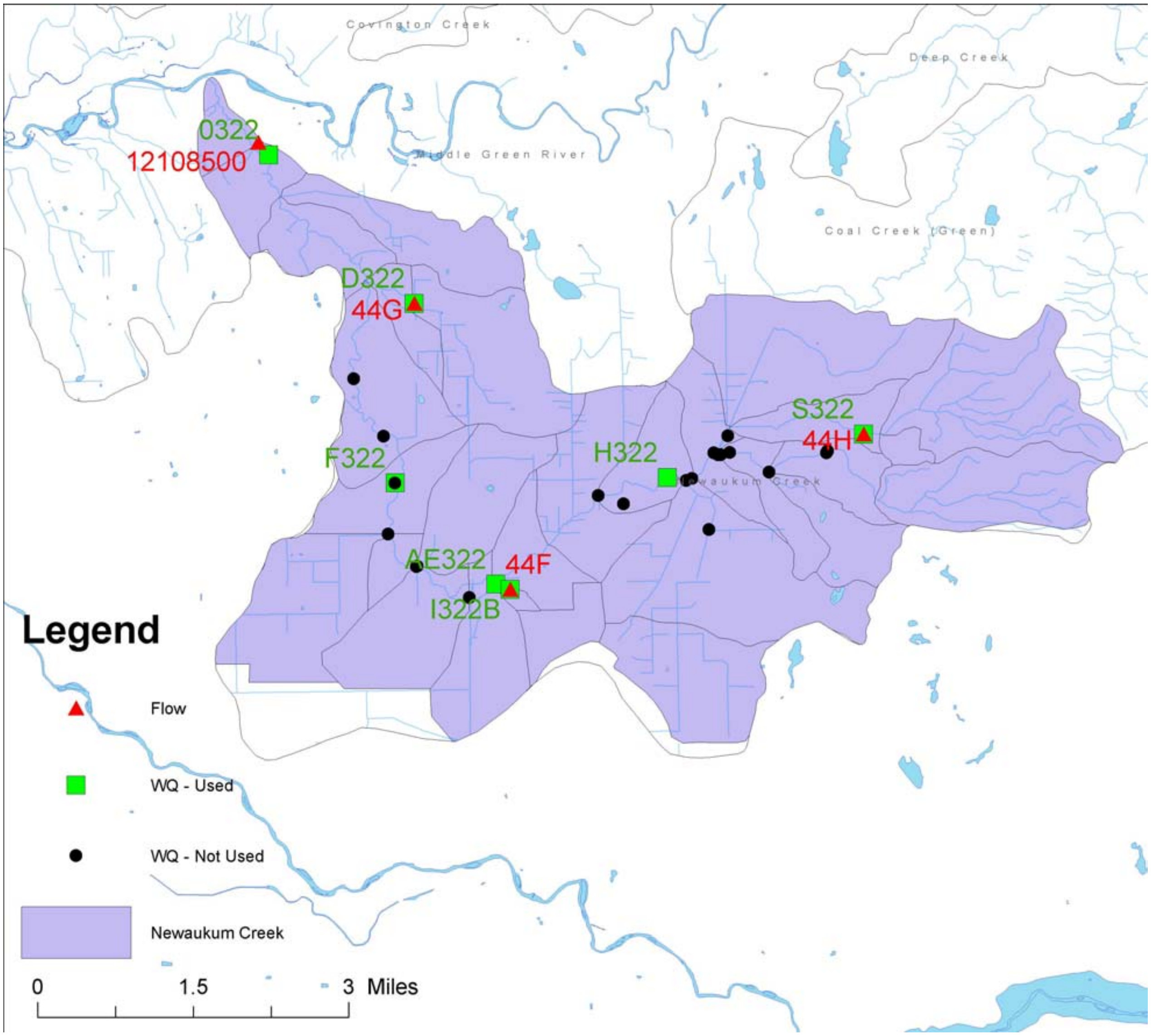


Figure 8.2-3 Map of Water Quality Data Stations Used for Newaukum Creek

When comparing simulated and observed values, the data observed at a particular sampling station are compared to simulated results 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; an example of the latter situation is provided by station S322 and Reach 11. Using this reasoning, the following stations are compared against the corresponding reaches:

Table 8.2-8 Linkage of Sampling Station to Reach Number

Station	Reach
King County Gage 0322	281
King County Gage F322	221
King County Gage 44G/D322	241
King County Gage 44F/I322B	151
King County Gage AE322	141
King County Gage H322	121
King County Gage 44H/S322	11

D322, H322, AE322, F322, and 0322 have historically been sampled approximately on a monthly interval with multiple samples collected during some storm events. The periods of record for all of these stations except AE322 span the majority or all of the calibration period, although D322 was dormant from approximately 1/1999-10/2001 and sampling for some constituents began around 10/2001. Sampling at AE322 only spans the period 1/1999-9/2001. Sampling at S322 and I322B began on approximately 10/2002 and 10/2001, respectively, and is ongoing. Table 8.2-9 summarizes the period of record for the various constituents at each station.

Table 8.2-9 Constituents and Periods of Record for Water Quality Monitoring Stations

	Stations						
Constituent	0322	D322	F322	I322B	AE322	H322	S322
Water Temperature	8/20/91-6/11/03	8/20/91-6/9/03	8/20/91-6/11/03	3/18/01-1/4/03	1/20/99-9/11/01	8/9/94-9/11/01	10/22/02-4/28/03
Dissolved Oxygen	8/20/91-6/11/03	8/20/91-6/9/03	8/20/91-6/11/03	3/18/01-1/4/03	1/20/99-9/11/01	8/9/94-9/11/01	10/22/02-4/28/03
BOD	6/29/02-1/22/03	3/9/03-3/9/03					
Suspended Sand							
Suspended Silt							
Suspended Clay							
TSS	8/20/91-6/11/03	8/20/91-6/9/03	8/20/91-6/11/03	1/24/02-6/8/03	1/20/99-9/11/01	8/9/94-9/11/01	10/22/02-6/9/03
Ammonia / Ammonium	8/20/91-5/13/03	8/20/91-6/9/03	8/20/91-4/14/03	11/13/01-6/8/03	1/20/99-9/11/01	8/9/94-9/11/01	10/22/02-6/9/03
Nitrite / Nitrate	8/20/91-6/11/03	8/20/91-6/9/03	8/20/91-6/11/03	11/13/01-6/8/03	1/20/99-9/11/01	8/9/94-9/11/01	10/22/02-6/9/03
Organic Nitrogen							
Total Nitrogen	4/13/93-6/11/03	4/13/93-6/9/03	4/13/93-6/11/03	11/13/01-6/8/03	1/20/99-9/11/01	1/20/99-9/11/01	10/22/02-6/9/03
Phosphate	8/20/91-6/11/03	8/20/91-6/9/03	8/20/91-6/11/03	11/13/01-6/8/03	1/20/99-9/11/01	8/9/94-9/11/01	10/22/02-6/9/03
Organic Phosphorus							
Total Phosphorus	8/20/91-6/11/03	8/20/91-6/9/03	8/20/91-6/11/03	11/13/01-6/8/03	1/20/99-9/11/01	8/9/94-9/11/01	10/22/02-6/9/03
Total Organic Carbon	11/28/01-6/11/03	11/28/01-6/9/03		11/28/01-6/8/03			10/22/02-6/9/03
Total Inorganic Carbon							
Alkalinity	12/13/95-7/13/03	11/13/01-6/9/03	2/13/02-7/13/03	11/13/01-6/8/03			10/22/02-6/9/03
pH	8/20/91-6/11/03	10/14/92-7/12/01	1/20/99-6/11/03	3/18/01-1/4/03	1/20/99-9/11/01	1/20/99-8/14/01	
Silica	5/14/02-10/14/02						
E-Coli	1/20/99-6/11/03	3/18/01-6/9/03	2/17/99-5/13/03	3/18/01-6/8/03	2/17/99-9/11/01	2/17/99-9/11/01	10/22/02-6/9/03
Fecal Coli	1/20/99-6/11/03	3/18/01-6/9/03	8/20/91-5/13/03	3/18/01-6/8/03	1/20/99-9/11/01	9/20/94-9/11/01	10/22/02-6/9/03
Benthic Algae							
Total Copper	4/29/92-6/8/03	3/18/01-6/9/03		3/18/01-6/8/03			10/22/02-6/9/03

8.2.2 WATERSHED / CONVEYANCE SYSTEM CHARACTERIZATION DATA

Table 8.2-10 documents the 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 8.2.3.1.

Table 8.2-10 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	
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	Newaukum Creek and major tributaries
Stream and Meteorological Gages	King County	Locations of nearby King County gages
Culverts/Bridges	King County	Specific hydraulic analysis was not performed
Cross-sections	King County	Field survey

8.2.3 WATERSHED SEGMENTATION AND CHARACTERIZATION

8.2.3.1 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 29 catchments ranging in size from 36 to 1460 acres (0.06 to 2.28 square miles) (Table 8.2-11). The catchments are shown in Figure 8.2-4; the schematic in Figure 8.2-5.

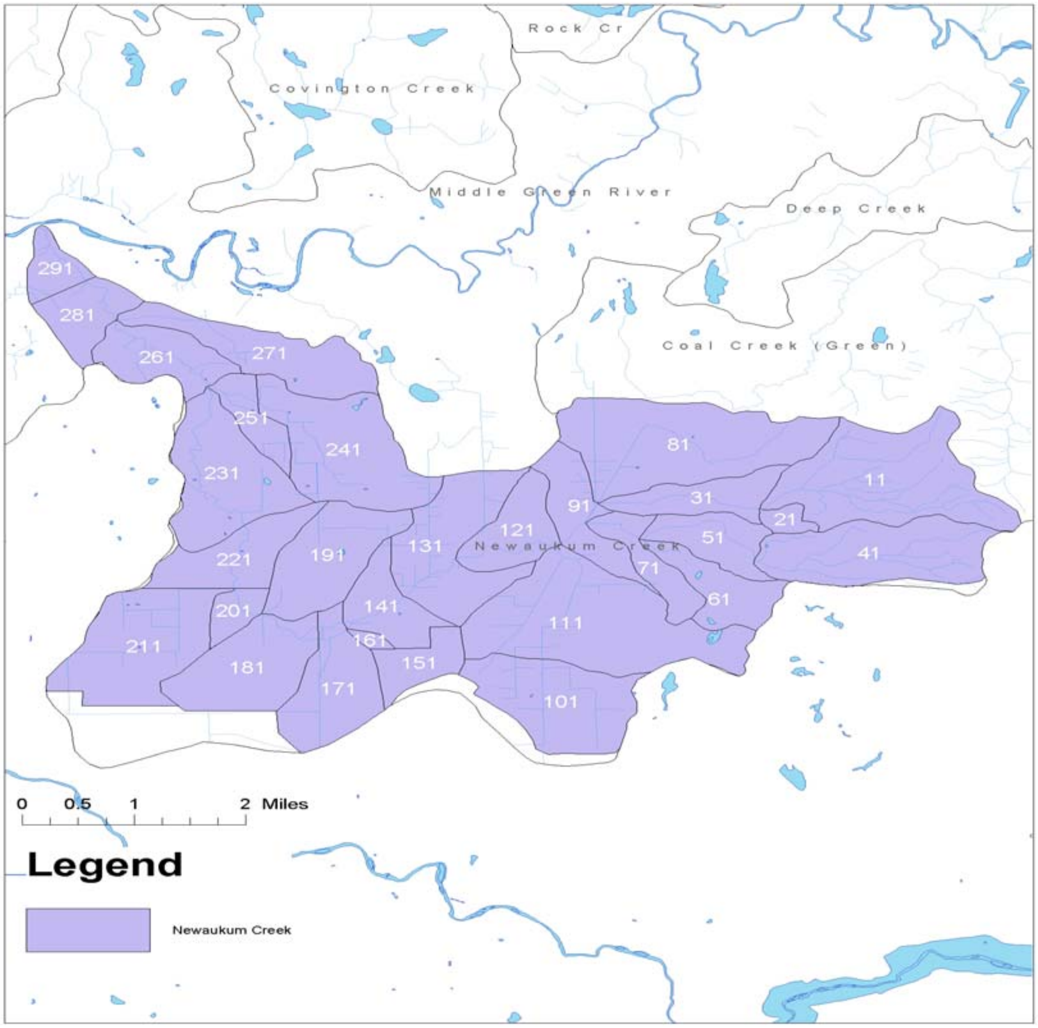


Figure 8.2-4 Newaukum Creek Catchments

Table 8.2-11 Catchment Areas

Catchment No.	Catchment Area (acres)	Stream Reach No.
11	1229	11
21	83	21
31	367	31
41	891	41

Catchment No.	Catchment Area (acres)	Stream Reach No.
51	352	51
61	381	61
71	287	71
81	1291	81
91	414	91
101	828	101
111	1460	111
121	400	121
131	836	131
141	349	141
151	268	151
161	36	161
171	624	171
181	708	181
191	671	191
201	153	201
211	947	211
221	491	221
231	854	231
241	969	241
251	237	251
261	445	261
271	658	271
281	341	281
291	195	291

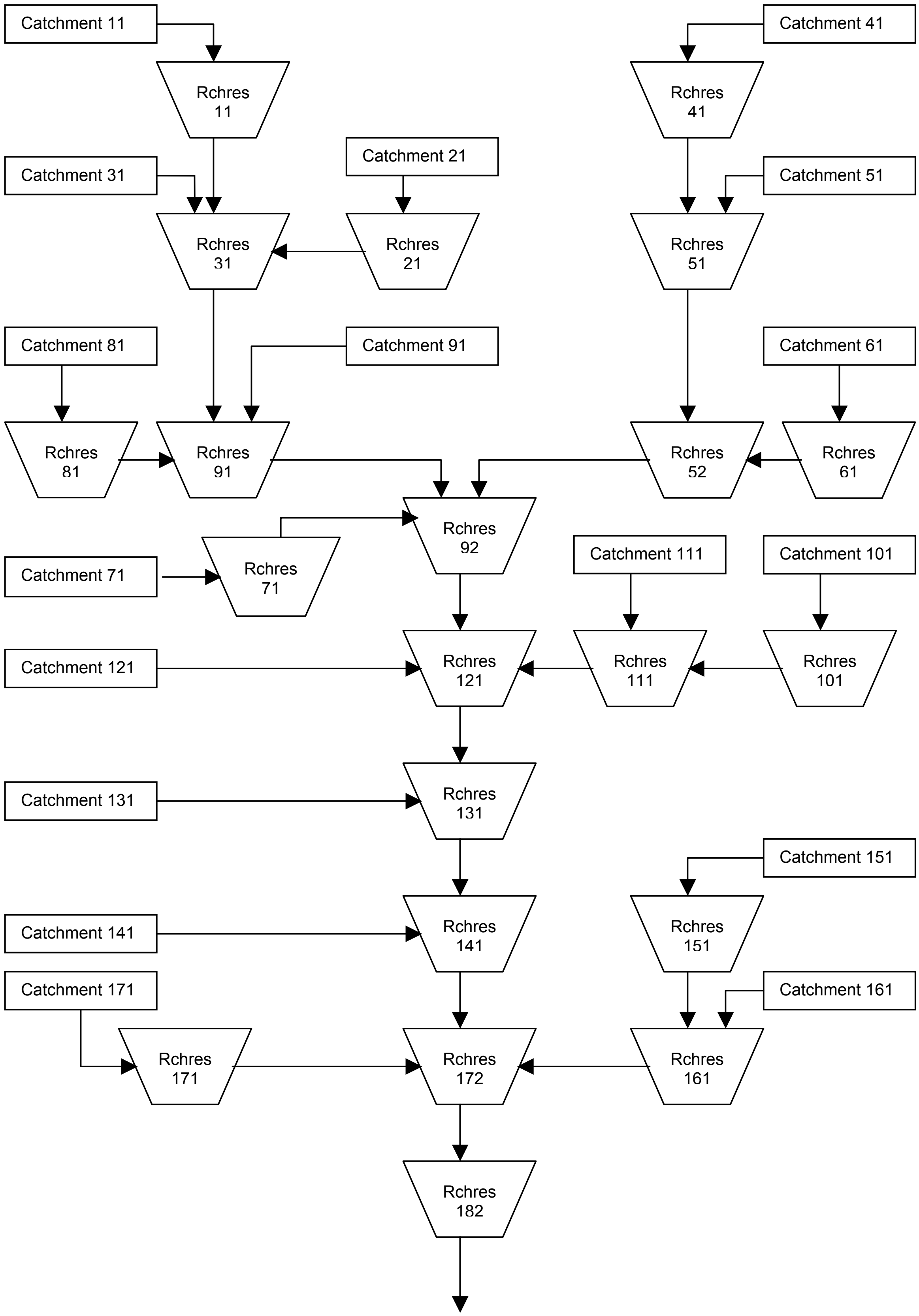
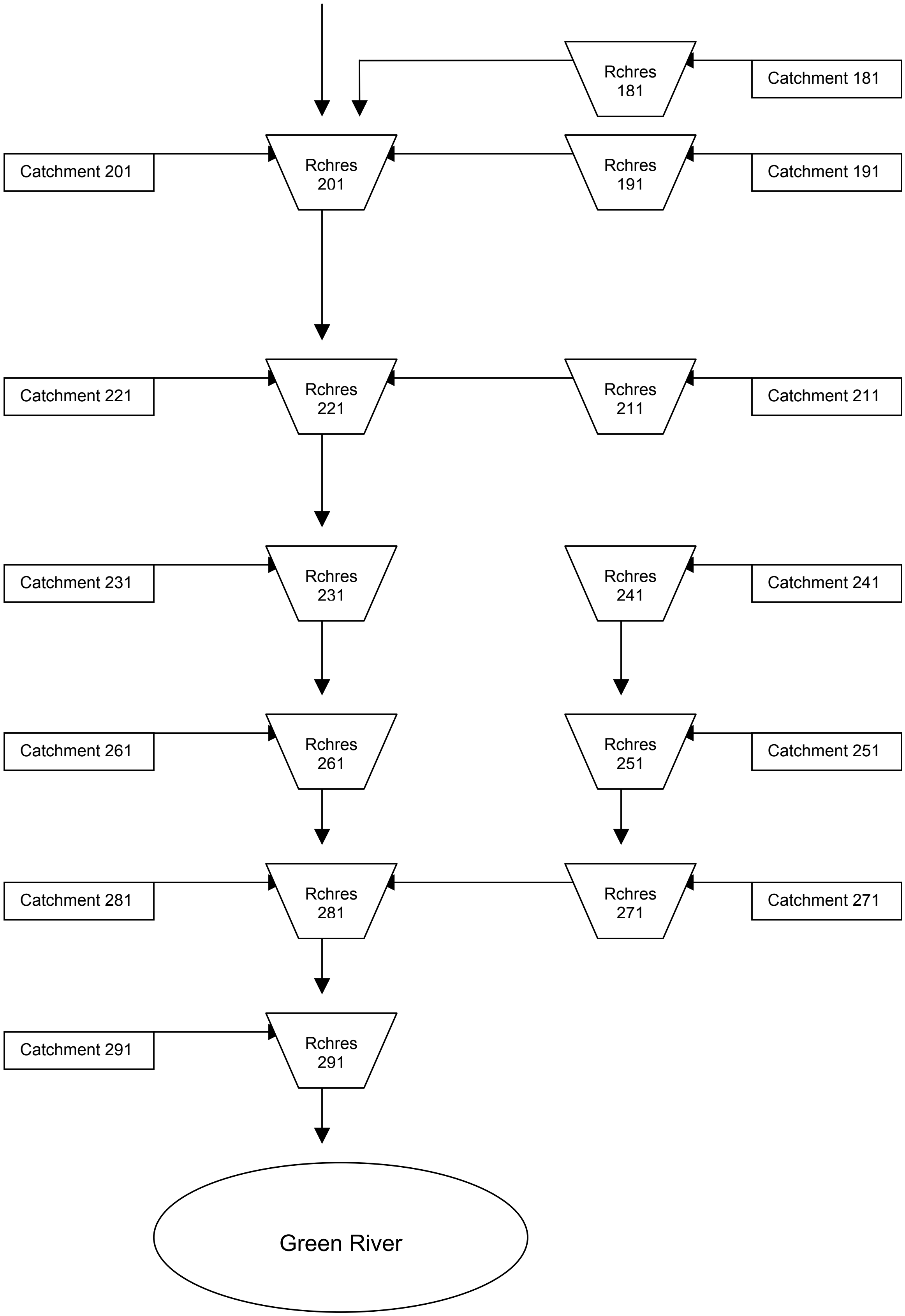


Figure 8.2-5 Newaukum Catchment Schematic


Rchres 181
Catchment 181
Catchment 201
Rchres 201
Rchres 191
Catchment 191
Catchment 221
Rchres 221
Rchres 211
Catchment 211
Catchment 231
Rchres 231
Rchres 241
Catchment 241
Catchment 261
Rchres 261
Rchres 251
Catchment 251
Catchment 281
Rchres 281
Rchres 271
Catchment 271
Catchment 291
Rchres 291
Green River

8.2.3.2 PERLND and IMPLND Categories

After the catchment delineation was finalized, the areas of the respective PERLND (pervious land) and IMPLND (impervious land) categories were determined on a catchment-by-catchment basis. Land categories are selected so that a given set of parameters represents the hydrologic and water quality response from that land category.

For an application involving water quality simulation, such as the Newaukum Creek application, it is also necessary to consider how the use practices for various land uses impact the nonpoint source loadings. For this application, this involves increasing the number of vegetation/land use categories that are represented by the model. The PERLND / IMPLND categories were developed based on the following revised scheme.

1. soils: till, outwash, saturated, bedrock
2. vegetation/land use: forest, pasture/agricultural, cropland, forest residential, low density residential landscaping, high density residential landscaping, commercial/industrial landscaping
3. land slope: flat (0-5%), low (5-10%), medium (10-15%), steep (>15%)

It was determined that outwash and saturated soils could be grouped for all land slope categories (i.e., flat, low, medium, and steep); the slopes for these soils are not expected to vary significantly. Thus, the hydrologic and water quality responses from these areas are not expected to be greatly impacted by slope differences.

For modeling purposes a distinction is made between total impervious area and effective impervious area. Total impervious area includes all surfaces that do not infiltrate runoff. Roofs, paved streets, sidewalks, driveways, and parking lots are all part of the total impervious area. Effective impervious area (EIA) is defined as the area where there is no opportunity for surface runoff from an impervious site to infiltrate into the soil before it reaches a conveyance system (pipe, ditch, stream, etc.). Because it is extremely expensive and time consuming to look at every impervious surface in a watershed to determine whether or not it is an effective impervious area, average EIA values are used instead. Each average EIA value is based on the land use (forest, low density residential, high density residential, commercial, etc.) and previous experience in other Puget Sound lowland watersheds. For example, the following EIA percentages in Table 8.2-12 are representative values that have been provided by King County (Burkey, 2004). Other continuous simulation models use similar schemes to separate out impervious areas from pervious. These land use categories in Table 8.2-12 can also be used to differentiate different land covers and pollutant sources.

Table 8.2-12 HSPF EIA Values

King County Land Use Categories	Forest	Pasture	Forest Residential	Low Density Residential	High Density Residential	Commercial/ Industrial	Road
	%	%	%	%	%	%	%
Forest	0	0	0	0	0	0	0
Recently cleared	0	0	0	0	0	0	0
Scrub/shrub	0	0	0	0	0	0	0
Grass – brown	0	0	0	0	0	0	0
Grass – green	0	0	0	0	0	0	0
Developed low	0	0	0	5	0	0	0
Developed med	0	0	0	0	40	0	0
Developed high	0	0	0	0	0	86	0
Bare ground/asphalt	0	0	0	0	0	50	0
Bare rock/concrete	0	0	0	0	0	0	86
Shadow	0	0	0	0	0	0	0
INSIDE=100	0	0	0	0	0	0	86

Corresponding pervious land divisions are shown below in Table 8.2-13.

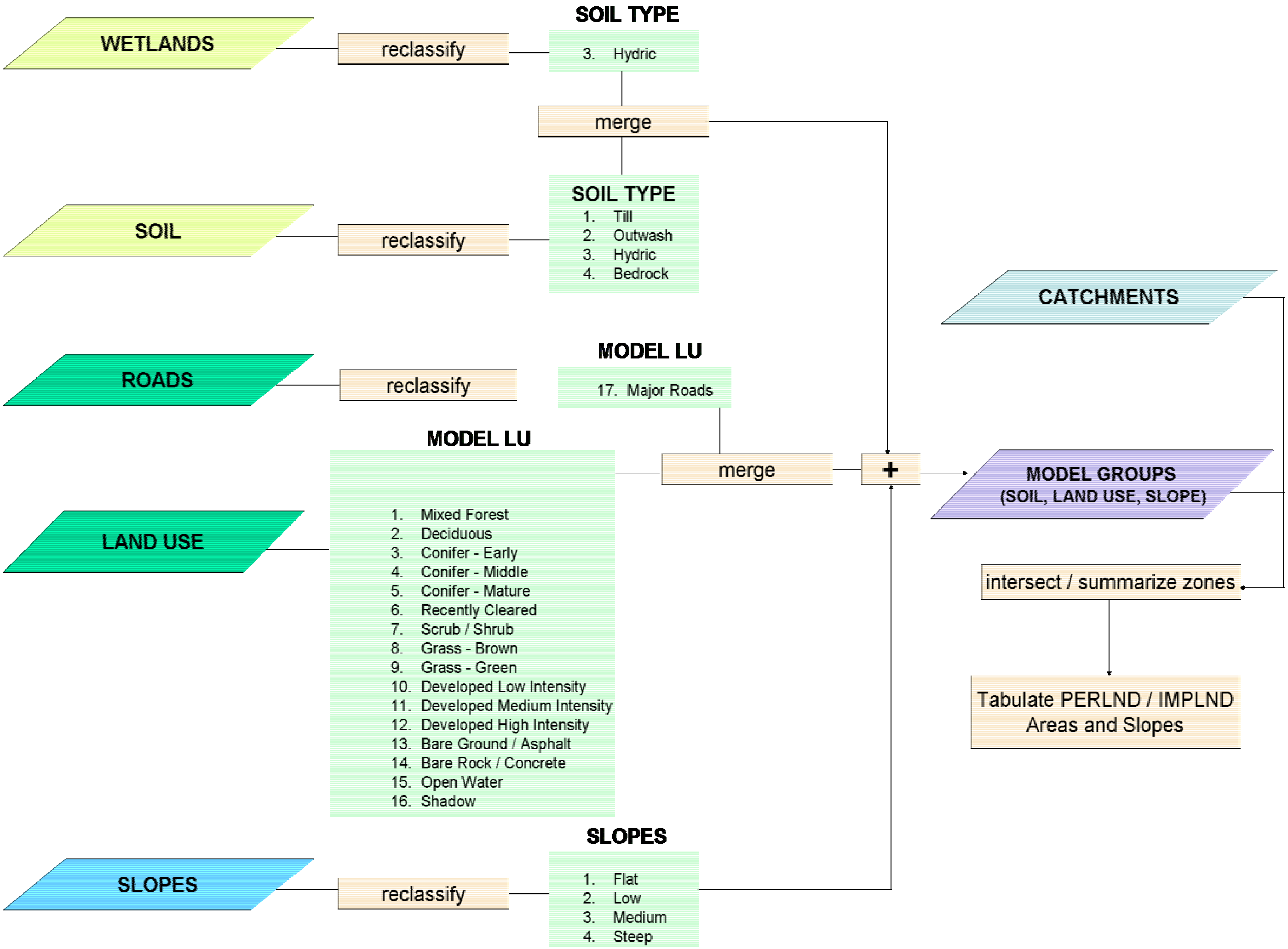
Table 8.2-13 HSPF Pervious Land Divisions

King County Land Use Categories	Forest	Pasture	Forest Residential	Low Density Residential	High Density Residential	Commercial/ Industrial	Road
	%	%	%	%	%	%	%
Forest	100	0	0	0	0	0	0
Recently cleared	0	100	0	0	0	0	0
Scrub/shrub	F*	100-F	0	0	0	0	0
Grass – brown	0	100	0	0	0	0	0
Grass – green	0	0	0	100	0	0	0
Developed low	0	0	35	60	0	0	0
Developed med	0	0	0	0	60	0	0
Developed high	0	0	0	0	14	0	0
Bare ground/asphalt	0	0	0	0	50	0	0
Bare rock/concrete	0	0	0	0	14	0	0
Shadow	50	50	0	0	0	0	0
INSIDE=100	0	0	0	0	14	0	0

* The percent F (forest) is based on the percentage of forest in the catchment compared to pasture.

For the purpose of the Newaukum 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.

Determining the areas of the PERLNDs / IMPLNDs within the catchments is readily handled within the framework of a GIS system (ArcView) with some additional processing using Microsoft Access. Figure 8.2-6 displays a flow chart describing the methodology for spatially and quantitatively defining the PERLND / IMPLND categories. The catchment and soil coverages were intersected in order to quantify the areas of various soil types within a given catchment. The resulting coverage were then reclassified to group soils into till, outwash, saturated soils, and bedrock. Table 8.2-14 displays the relationship between the King County attribute geologic code to the four reclassified soil types. The land use coverage was reclassified into the vegetative/land use categories previously discussed and intersected with the modified soils coverage; creating regions with the desired combinations of soil type and vegetation characteristics (e.g., TF – Till, Forest).



Legend: **Soil Type** –Till; Outwash; Hydric; Bedrock

LU – Mixed Forest; Decidious; Conifer Early; Conifer Middle; Conifer Mature; Recently Clear; Scrub/Shrub; Grass Brown; Grass Green; Developed Low; Developed Medium; Developed High; Bare Ground Asphalt; Bare Ground Concrete; Open Water; Shadow

Slope – Flat (0 – 5%); Low (5-10%); Medium (10-15%); Steep (>15%)

Figure 8.2-6 PERLND / IMPLND Development

Table 8.2-14 King County Geologic Code to Four Soil Types

SOIL TYPE			
Till	**Outwash**	**Saturated**	**Bedrock**
Qmw	Qb	Qls	Tb
Qoal	Qal	Qw	Tdg
Qob	Qag		Teg
Qpf	Qf		Tf
Qt	Qva		Ti
Qtb	Qvi		Tmp
Qtu	Qvr		To
Qu	Qyal		Tp
Qvb			Tpr
Qvp			Tpt
Qvt			Ts
Qvu			Tsc
M			Tsg
Qom			Tv

Using the 10-meter resolution DEM, percent slopes were developed for the watershed at the same resolution. The zones established by the desired combinations of soil type and vegetation were then summarized using this slope grid (i.e., the weighted average slope for each polygon was assigned). These slopes were reclassified into flat, low, medium, and steep classifications based on the ranges discussed earlier (e.g., TFF – Till, Forest, Flat)

The final processing occurred outside the GIS within Microsoft Access. At this point, the multiple slope classes for outwash and saturated soils and the vegetation classes with an impervious component were combined into one slope class. In addition, the EIA was broken out from these vegetation classes to create four IMPLND categories (i.e., residential, commercial, industrial, and major road pollution) using the values and method previously presented in Table 8.2-12 and accompanying discussion. Table 8.2-15 presents the final potential 72 PERLND /

IMPLND categories; not all categories exist in Newaukum Creek watershed. GIS processing identified the specific categories needed.

The final processing produced a spreadsheet with the number of acres for each PERLND and IMPLND in each catchment. Within each catchment the relative size of the PERLND was checked. If the PERLND consisted of less than 5 percent of the catchment area then it was aggregated to an adjacent larger PERLND according to rules developed by AQUA TERRA Consultants. The purpose of the aggregation was to minimize the number of PERLNDs per catchment for water quality simulation linkages. Physically this also means that very small PERLNDs probably do not have a direct connection to the catchment's stream reach (RCHRES), but drain through an adjacent, larger PERLND. IMPLND areas were not changed.

Table 8.2-15 Final PERLND/IMPLND Categories

TILL	OUTWASH	SATURATED	BEDROCK	EIA
TFF: till, forest, flat	OF: outwash, forest, all slopes	SF: saturated, forest, all slopes	BFF: bedrock, forest, flat	ELDR: EIA Low Density Residential
TFL: till, forest, low	OP: outwash, pasture, all slopes	SP: saturated, pasture, all slopes	BFL: bedrock, forest, low	EHDR: EIA High Density Residential
TFM: till, forest, medium	OC: outwash, cropland, all slopes	SC: saturated, cropland, all slopes	BFM: bedrock, forest, medium	ECI: EIA Commercial / Industrial
TFS: till, forest, steep	OFR: outwash, forest residential, all slopes	SFR: saturated, forest residential, all slopes	BFS: bedrock, forest, steep	ER: EIA Road
TPF: till, pasture, flat	OLDR: outwash, low density residential, all slopes	SLDR: saturated, low density residential, all slopes	BPF: bedrock, pasture, flat	
TPL: till, pasture, low	OHDR: outwash, high density residential, all slopes	SHDR: saturated, high density residential, all slopes	BPL: bedrock, pasture, low	
TPM: till, pasture, medium	OCI: outwash, commercial/ industrial, all slopes	SCI: saturated, commercial/ industrial, all slopes	BPM: bedrock, pasture, medium	
TPS: till, pasture, steep	OR: outwash, major road, all slopes	SR: saturated, major road, all slopes	BPS: bedrock, pasture, steep	
TCF: till, cropland, flat			BCF: bedrock, cropland, flat	
TCL: till, cropland, low			BCL: bedrock, cropland, low	
TCM: till, cropland, medium			BCM: bedrock, cropland, medium	
TCS: till, cropland, steep			BCS: bedrock, cropland, steep	
TFRF: till, forest residential, flat			BFRF: bedrock, forest residential, flat	

TILL	OUTWASH	SATURATED	BEDROCK	EIA
TFRL: till, forest residential, low			BFRL: bedrock, forest residential, low	
TFRM: till, forest residential, medium			BFRM: bedrock, forest residential, medium	
TFRS: till, forest residential, steep			BFRS: bedrock, forest residential, steep	
TLDF: till, low density residential, flat			BLDF: bedrock, low density residential, flat	
TLDL: till, low density residential, low			BLDL: bedrock, low density residential, low	
TLDM: till, low density residential, medium			BLDM: bedrock, low density residential, medium	
TLDS: till, low density residential, steep			BLDS: bedrock, low density residential, steep	
THDF: till, high density residential, flat			BHDF: bedrock, high density residential, flat	
THDL: till, high density residential, low			BHDL: bedrock, high density residential, low	
THDM: till, high density residential, medium			BHDM: bedrock, high density residential, medium	
THDS: till, high density residential, steep			BHDS: bedrock, high density residential, steep	
TCIF: till, commercial/ industrial, flat			BCIF: bedrock, commercial/ industrial, flat	
TCIL: till, commercial/ industrial, low			BCIL: bedrock, commercial/ industrial, low	
TCIM: till, commercial/ industrial, medium			BCIM: bedrock, commercial/ industrial, medium	
TCIS: till, commercial/ industrial, steep			BCIS: bedrock, commercial/ industrial, steep	

8.2.3.3 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.

8.2.3.4 Physical Parameters

The Newaukum Creek watershed PERLND soil type and land use areas and IMPLND land use areas used in the HSPF model are summarized in Table 8.2-16. They are based on the GIS coverage and the delineation methodology described in Section 8.2.3.2.

Table 8.2-16 Newaukum Creek Watershed PERLND/IMPLND Areas

Land Use	Till (acres)	Outwash (acres)	Saturated (acres)	Bedrock (acre)	EIA (acre)	Total (acre)
Forest	3303	2269	293	1129	0	6994
Pasture/Ag	2554	366	0	0	0	2920
Forest Residential	371	113	0	35	0	519
Low Density Residential	3615	1199	384	42	152	5392
High Density Residential	281	0	0	0	364	645
Commercial/Industrial	0	0	0	0	105	105
Roads	0	0	0	0	217	217
Total	**10124**	**3947**	**677**	**1206**	**838**	**16792**

Table 8.2-16 Newaukum Creek Watershed PERLND/IMPLND Areas (cont'd)

Land Use	Till	Outwash	Saturated	Bedrock	EIA	Total
Forest	19.67%	13.51%	1.74%	6.72%	0.00%	41.65%
Pasture/Ag	15.21%	2.18%	0.00%	0.00%	0.00%	17.39%
Forest Residential	2.21%	0.67%	0.00%	0.21%	0.00%	3.09%
Low Density Residential	21.53%	7.14%	2.29%	0.25%	0.90%	32.11%
High Density Residential	1.68%	0.00%	0.00%	0.00%	2.17%	3.84%
Commercial/Industrial	0.00%	0.00%	0.00%	0.00%	0.63%	0.63%
Roads	0.00%	0.00%	0.00%	0.00%	1.29%	1.29%
Total	**60.29%**	**23.51%**	**4.03%**	**7.18%**	**4.99%**	**100.00%**

8.2.3.5 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.

8.2.3.6 HSPF Reach Network

The current network includes 30 reaches totaling approximately 12.75 miles in length; with the individual reaches ranging from approximately 0.10 to 2.25 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. Additional field survey work was conducted by King County staff to provide additional cross-section and hydraulic property information. However, no culvert data were collected to assist with the FTABLE development.

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. Table 8.2-17 shows the data used to construct the FTABLEs for Newaukum Creek.

Table 8.2-17 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
11	**12.75**	**2.25**	**2600**	**1000**	**1600**	**13.5%**	**0.050**	**0.1**	**channel**
21	0.40	0.40	1420	1000	420	19.9%	0.050	0.1	culvert
31	**10.50**	**1.50**	**1000**	**730**	**270**	**3.4%**	**0.050**	**0.1**	**culvert**
41	4.40	2.10	2920	1040	1880	17.0%	0.050	0.1	channel
51	2.30	1.75	1040	780	260	2.8%	0.050	0.1	culvert
52	0.55	0.55	780	718	62	2.1%	0.050	0.1	culvert
61	1.50	1.50	1220	780	440	5.6%	0.050	0.1	channel
71	1.40	1.40	840	730	110	1.5%	0.050	0.1	channel
81	2.50	2.50	940	730	210	1.6%	0.050	0.1	channel
91	**9.00**	**0.50**	**730**	**718**	**12**	**0.5%**	**0.050**	**0.1**	**culvert**
92	**8.50**	**0.30**	**718**	**710**	**8**	**0.5%**	**0.050**	**0.1**	**culvert**
101	2.55	1.20	840	770	70	1.1%	0.050	0.1	channel
111	1.35	1.35	770	710	60	0.8%	0.050	0.1	channel
121	**8.20**	**1.00**	**710**	**680**	**30**	**0.6%**	**0.050**	**0.1**	**bridge**
131	**7.20**	**0.60**	**680**	**670**	**10**	**0.3%**	**0.050**	**0.1**	**bridge**
141	**6.60**	**0.65**	**670**	**665**	**5**	**0.2%**	**0.050**	**0.1**	**bridge**
151	0.90	0.55	750	730	20	0.7%	0.050	0.1	culvert
161	0.35	0.35	730	665	65	3.5%	0.050	0.1	channel
171	1.00	1.00	750	665	85	1.6%	0.050	0.1	culvert
172	**5.95**	**0.10**	**665**	**650**	**15**	**2.8%**	**0.050**	**0.1**	**channel**
181	1.25	1.25	700	638	62	0.9%	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
182	**5.85**	**0.60**	**650**	**638**	**12**	**0.4%**	**0.050**	**0.1**	**channel**
191	1.60	1.60	680	638	42	0.5%	0.050	0.1	weir
201	**5.25**	**0.40**	**638**	**630**	**8**	**0.4%**	**0.050**	**0.1**	**channel**
211	2.00	2.00	640	630	10	0.1%	0.050	0.1	culvert
221	**4.85**	**0.75**	**630**	**600**	**30**	**0.8%**	**0.050**	**0.1**	**channel**
231	**4.10**	**1.75**	**600**	**500**	**100**	**1.1%**	**0.050**	**0.1**	**bridge**
241	2.40	1.50	820	640	180	2.3%	0.050	0.1	culvert
251	0.90	0.90	640	500	140	3.0%	0.050	0.1	channel
261	**2.35**	**1.10**	**500**	**300**	**200**	**3.4%**	**0.050**	**0.1**	**channel**
271	2.25	2.25	540	300	240	2.0%	0.050	0.1	channel
281	**1.25**	**0.50**	**300**	**240**	**60**	**2.3%**	**0.050**	**0.1**	**channel**
291	**0.75**	**0.75**	**240**	**180**	**60**	**1.5%**	**0.050**	**0.1**	**channel**

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

8.3 MODEL CALIBRATION

The calibration of HSPF to the Newaukum 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).

8.3.1 WATER QUANTITY

8.3.1.1 OVERVIEW OF HSPF CALIBRATION PROCEDURES

For HSPF, calibration is an iterative procedure of parameter evaluation and refinement, as a result of comparing simulated and observed values of interest. This approach is required for parameters that cannot be deterministically, and uniquely, evaluated from topographic, climatic, edaphic, or physical/chemical characteristics of the watershed and compounds of interest. Fortunately, the large majority of HSPF parameters do not fall in this category. Calibration is based on several years of simulation to evaluate parameters under a variety of climatic, soil moisture, and water quality conditions. Calibration results in parameter values that produce the best overall agreement between simulated and observed values throughout the calibration period. Any biases in the calibration data may affect the quality of the calibration and will be noted.

Calibration includes the comparison of both monthly and annual values, and individual storm events, whenever sufficient data are available for these comparisons. All of these comparisons are performed for a proper calibration of hydrology parameters. In addition, when a continuous observed record is available, such as for streamflow, simulated and observed values are analyzed on a frequency basis and their resulting cumulative distributions (e.g., flow duration curves) compared to assess the model behavior and agreement over the full range of observations.

A weight of evidence approach, as described above, 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.

Calibration is a hierarchical process beginning within hydrology calibration of both runoff and streamflow, followed by sediment erosion and sediment transport calibration, and finally calibration of water quality constituents, including water temperature.

When modeling land surface processes, hydrologic calibration must precede sediment and water quality calibration since runoff is the transport mechanism by which nonpoint pollution occurs. Likewise, adjustments to the instream hydraulics simulation must be completed before instream sediment and water quality transport and processes are calibrated. Each of these steps is discussed below with the emphasis on the key calibration parameters.

8.3.1.2 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 Newaukum watershed. The final values were selected through the calibration process and a comparison of the simulated and recorded streamflow. Table 8.3-1 through Table 8.3-5 present the final PERLND and IMPLND parameter values selected for the Newaukum Creek watershed.

8.3.1.3 Hydrologic Calibration and Key Calibration Parameters

Hydrologic simulation combines the physical characteristics of the watershed and the observed meteorologic data series to produce the simulated hydrologic response. All watersheds have similar hydrologic components, but they are generally present in different combinations; thus different hydrologic responses occur on individual watersheds. HSPF simulates runoff from four components: surface runoff from impervious areas directly connected to the channel network, surface runoff from pervious areas, interflow from pervious areas, and groundwater flow. Because the historic streamflow is not divided into these four units, the relative relationship among these components must be inferred from the examination of many events over several years of continuous simulation.

A complete hydrologic calibration involves a successive examination of the following four characteristics of the watershed hydrology, in the order shown: (1) annual water balance, (2) seasonal and monthly flow volumes, (3) baseflow, and (4) storm events. Simulated and observed values for reach characteristic are examined and critical parameters are adjusted to attain acceptable levels of agreement.

In addition to the input meteorologic data series, the critical parameters that govern the annual water balance are as follows:

LZSN -	lower zone soil moisture storage (inches).
LZETP -	vegetation evapotranspiration index (dimensionless).
INFILT -	infiltration index for division of surface and subsurface flow (inches/hour).
UZSN -	upper zone soil moisture storage (inches).
DEEPFR-	fraction of groundwater inflow to deep recharge (dimensionless).

Changes in LZSN and LZETP affect the actual evapotranspiration by making more or less moisture available to evaporate or transpire. Both LZSN and INFILT also have a major impact on percolation and are important in obtaining an annual water balance. Whenever there are losses to deep groundwater, such as recharge, or subsurface flow not measured at the flow gage, DEEPFR is used to represent this loss from the annual water balance.

For the Newaukum watershed LZSN values were generally increased for till soils (the predominate soil type in the watershed) from 4.5 (part of the Puget Sound lowland regional values developed by the USGS) to a range from 3.6 to 6.3 inches, dependent on slope (steeper slopes, lower LZSN values – see Table 8.3-1). Outwash LZSN values were raised from 5.0 to 8.0 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 residential landscaping values) and by season (winter low; summer high – see Table 8.3-4). For till and outwash soils, the monthly LZETP values are relatively constant and vary from 0.60 in January to 0.70 in August. Saturated soil monthly values vary from 0.50 to 0.80. Rock varies from 0.30 to 0.70, except for landscaping which ranges from 0.15 to 0.25. CEPS values were also adjusted monthly using the MON-INTERCEP Block in HSPF. Values are seasonal (winter low; summer high – see Table 8.3-5). For all soil types, forest varies from 0.20-0.45, pasture from 0.15-0.35, and landscaping from 0.10-0.20. UZSN values were increased by 27.5 percent (see Table 8.3-3) from their initial values to be consistent with the increase in LZSN values. DEEPFR was changed from its initial value of zero to 0.02 for till soils and outwash soils (see Table 8.3-2). DEEPFR represents the fraction of groundwater that bypasses the stream gage and recharges the underlying aquifer or flows directly to the Green River. BASETP was reduced from 0.02 to 0.01 for till and outwash soils, while remaining at zero for saturated soils. BASETP represents the fraction of remaining potential evapotranspiration that can be satisfied from baseflow (groundwater outflow), if enough is available.

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 for 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, land use, and soil type. The till forest INFILT values varied from 0.176 to 0.143 (steeper slope, lower INFILT – see Table 8.3-1), till pasture from 0.099 to 0.11, and till urban landscaping from 0.088 to 0.11. Outwash INFILT varied from 0.115 to 0.242, saturated from 1.5 to 2.2, and rock from 0.08 to 0.10 for the Newaukum 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 Newaukum watershed the AGWRC value was increased from the USGS regional value of 0.996 to 0.997 for till forest land use (see Table 8.3-1) and was kept at 0.996 for till pasture. AGWRC was lowered to 0.995 for till urban landscaping and all outwash soils, while all saturated soils were set at 0.997. KVARY was found to differ slightly from the regional value of

0.50 for till and was set to 0.405. Correspondingly, KVARY for outwash was lowered 10% from its regional value of 0.30 to 0.27. KVARY for rock was set at 0.45.

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.

Regional values for INTFW were adopted and they varied from 2.00 to 2.85 for till forest (see Table 8.3-3). Lower values were used for steeper slopes to increase surface runoff and decrease interflow. For till pasture the values ranged from 2.26 to 2.42, and till landscaping had values between 2.39 and 2.57. Rock INTFW values ranged from 1.25 to 2.5, while outwash was set to 0.5 (relatively little interflow is produced by outwash soils) and saturated soils to 4.5.

IRC was set to 0.70 for forest and pasture on till and outwash soils to produce relatively slow interflow runoff, with no change for slope variability (see Table 8.3-3). The landscaping IRC value was lower at 0.5. Outwash IRC has only a small impact on the simulation because there is little outwash interflow, as noted above. IRC for rock ranged from a value of 0.7 for all flat land uses down to 0.2 for all steep uses.

To provide sufficient surface runoff for measured loadings in the water quality calibration, the INFEXP regional value of 2.0 was increased to 3.0 for all till and rock PERLNDs. The regional value of INFEXP for outwash was kept at 2.0, while saturated was lowered slightly from 10.0 to 9.0.

8.3.1.4 Final Calibration Parameter List

Table 8.3-1A Final PERLND/IMPLND Parameter Values (Part 1) for Watershed in Zone A

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
11	Till Forest Flat	6.3	0.176	350	0.028	0.405	0.997
12	Till Forest Low	5.4	0.165	300	0.072	0.405	0.997
13	Till Forest Med	4.5	0.154	250	0.116	0.405	0.997
14	Till Forest Steep	3.6	0.143	200	0.195	0.405	0.997
21	Till Pasture Flat	4.5	0.11	350	0.026	0.405	0.996
22	Till Pasture Low	4.5	0.099	300	0.070	0.405	0.996
31	Till Forest Residential Flat	6.3	0.176	350	0.028	0.405	0.997
32	Till Forest Residential Low	5.4	0.154	300	0.072	0.405	0.997
41	Till Low Density Residential Flat	4.5	0.11	350	0.028	0.405	0.995
42	Till Low Density Residential Low	4.5	0.099	300	0.070	0.405	0.995
51	Till High Density Residential Flat	3.6	0.088	350	0.028	0.405	0.995
71	Outwash Forest	8.0	0.242	300	0.089	0.27	0.995
72	Outwash Pasture	8.0	0.115	300	0.060	0.27	0.995
73	Outwash Forest Residential	8.0	0.242	300	0.089	0.27	0.995
74	Outwash Low Density Res	8.0	0.165	300	0.077	0.27	0.995
81	Saturated Forest	3.6	2.2	150	0.048	0.45	0.997
84	Saturated Low Density Res	3.6	1.5	150	0.043	0.45	0.997

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 8.3-1B Final PERLND/IMPLND Parameter Values (Part 1) for Watershed in Zone B

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
211	Till Forest Flat	6.3	0.176	350	0.028	0.405	0.997
212	Till Forest Low	5.4	0.165	300	0.072	0.405	0.997
213	Till Forest Med	4.5	0.154	250	0.116	0.405	0.997
214	Till Forest Steep	3.6	0.143	200	0.195	0.405	0.997
221	Till Pasture Flat	4.5	0.11	350	0.026	0.405	0.996
231	Till Forest Residential Flat	6.3	0.176	350	0.028	0.405	0.997
241	Till Low Density Residential Flat	4.5	0.11	350	0.028	0.405	0.995
251	Till High Density Residential Flat	3.6	0.088	350	0.028	0.405	0.995
271	Outwash Forest	8.0	0.242	300	0.089	0.27	0.995
272	Outwash Pasture	8.0	0.115	300	0.060	0.27	0.995
273	Outwash Forest Residential	8.0	0.242	300	0.089	0.27	0.995
274	Outwash Low Density Res	8.0	0.165	300	0.077	0.27	0.995
281	Saturated Forest	3.6	2.2	150	0.048	0.45	0.997
284	Saturated Low Density Res	3.6	1.5	150	0.043	0.45	0.997
313	Rock Forest Med	3.6	0.12	400	0.100	0.45	0.991
314	Rock Forest Steep	3.6	0.08	400	0.200	0.45	0.991
331	Rock Forest Residential Flat	3.6	0.2	400	0.100	0.45	0.991
344	Rock Low Density Residential Steep	3.6	0.06	400	0.200	0.45	0.991

Table 8.3-2A Final PERLND/IMPLND Parameter Values (Part 2) for Watershed in Zone A

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
11	Till Forest Flat	3.0	2.0	0.05	0.02	0.0
12	Till Forest Low	3.0	2.0	0.05	0.02	0.0
13	Till Forest Med	3.0	2.0	0.02	0.01	0.0

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
14	Till Forest Steep	3.0	2.0	0.02	0.01	0.0
21	Till Pasture Flat	3.0	2.0	0.02	0.01	0.0
22	Till Pasture Low	3.0	2.0	0.02	0.01	0.0
31	Till Forest Residential Flat	3.0	2.0	0.02	0.01	0.0
32	Till Forest Residential Low	3.0	2.0	0.02	0.01	0.0
41	Till Low Density Residential Flat	3.0	2.0	0.02	0.01	0.0
42	Till Low Density Residential Low	3.0	2.0	0.02	0.01	0.0
51	Till High Density Residential Flat	3.0	2.0	0.02	0.01	0.0
71	Outwash Forest	2.0	2.0	0.02	0.01	0.0
72	Outwash Pasture	2.0	2.0	0.02	0.01	0.0
73	Outwash Forest Residential	2.0	2.0	0.02	0.01	0.0
74	Outwash Low Density Res	2.0	2.0	0.02	0.01	0.0
81	Saturated Forest	9.0	2.0	0.02	0.00	0.7
84	Saturated Low Density Res	9.0	2.0	0.02	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 8.3-2B. Final PERLND/IMPLND Parameter Values (Part 2) for Watershed in Zone B

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
211	Till Forest Flat	3.0	2.0	0.05	0.02	0.0
212	Till Forest Low	3.0	2.0	0.05	0.02	0.0
213	Till Forest Med	3.0	2.0	0.02	0.01	0.0
214	Till Forest Steep	3.0	2.0	0.02	0.01	0.0
221	Till Pasture Flat	3.0	2.0	0.02	0.01	0.0
231	Till Forest Residential Flat	3.0	2.0	0.02	0.01	0.0
241	Till Low Density Residential Flat	3.0	2.0	0.02	0.01	0.0
251	Till High Density Residential Flat	3.0	2.0	0.02	0.01	0.0
271	Outwash Forest	2.0	2.0	0.02	0.01	0.0
272	Outwash Pasture	2.0	2.0	0.02	0.01	0.0
273	Outwash Forest Residential	2.0	2.0	0.02	0.01	0.0
274	Outwash Low Density Res	2.0	2.0	0.02	0.01	0.0
281	Saturated Forest	9.0	2.0	0.02	0.00	0.7
284	Saturated Low Density Res	9.0	2.0	0.02	0.00	0.7
313	Rock Forest Med	3.0	2.0	0.00	0.00	0.0
314	Rock Forest Steep	3.0	2.0	0.00	0.00	0.0
331	Rock Forest Residential Flat	3.0	2.0	0.00	0.00	0.0
344	Rock Low Density Residential Steep	3.0	2.0	0.00	0.00	0.0

Table 8.3-3A Final PERLND/IMPLND Parameter Values (Part 3) for Watershed in Zone A

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
11	Till Forest Flat	Monthly	1.28	0.35	2.85	0.70	Monthly
12	Till Forest Low	Monthly	0.85	0.35	2.66	0.70	Monthly
13	Till Forest Med	Monthly	0.51	0.35	2.38	0.70	Monthly

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
14	Till Forest Steep	Monthly	0.38	0.35	2.00	0.70	Monthly
21	Till Pasture Flat	Monthly	0.77	0.30	2.42	0.70	Monthly
22	Till Pasture Low	Monthly	0.51	0.30	2.26	0.70	Monthly
31	Till Forest Residential Flat	Monthly	1.28	0.35	2.85	0.50	Monthly
32	Till Forest Residential Low	Monthly	0.85	0.35	2.66	0.50	Monthly
41	Till Low Density Residential Flat	Monthly	0.64	0.25	2.57	0.50	Monthly
42	Till Low Density Residential Low	Monthly	0.38	0.25	2.39	0.50	Monthly
51	Till High Density Residential Flat	Monthly	0.64	0.25	2.42	0.50	Monthly
71	Outwash Forest	Monthly	0.64	0.35	0.5	0.70	Monthly
72	Outwash Pasture	Monthly	0.64	0.30	0.5	0.70	Monthly
73	Outwash Forest Residential	Monthly	0.64	0.25	0.5	0.70	Monthly
74	Outwash Low Density Res	Monthly	0.64	0.25	0.5	0.50	Monthly
81	Saturated Forest	Monthly	2.55	0.50	4.5	0.70	Monthly
84	Saturated Low Density Res	Monthly	2.55	0.50	4.5	0.50	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 Tables 4.3-4A and 4.3-4B for monthly values)

Table 8.3-3B. Final PERLND/IMPLND Parameter Values (Part 3) for Watershed in Zone B

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
211	Till Forest Flat	Monthly	1.28	0.35	2.85	0.70	Monthly
212	Till Forest Low	Monthly	0.85	0.35	2.66	0.70	Monthly

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
213	Till Forest Med	Monthly	0.51	0.35	2.38	0.70	Monthly
214	Till Forest Steep	Monthly	0.38	0.35	2.00	0.70	Monthly
221	Till Pasture Flat	Monthly	0.77	0.30	2.42	0.70	Monthly
231	Till Forest Residential Flat	Monthly	1.28	0.35	2.85	0.50	Monthly
241	Till Low Density Residential Flat	Monthly	0.64	0.25	2.57	0.50	Monthly
251	Till High Density Residential Flat	Monthly	0.64	0.25	2.42	0.50	Monthly
271	Outwash Forest	Monthly	0.64	0.35	0.5	0.70	Monthly
272	Outwash Pasture	Monthly	0.64	0.30	0.5	0.70	Monthly
273	Outwash Forest Residential	Monthly	0.64	0.25	0.5	0.70	Monthly
274	Outwash Low Density Res	Monthly	0.64	0.25	0.5	0.50	Monthly
281	Saturated Forest	Monthly	2.55	0.50	4.5	0.70	Monthly
284	Saturated Low Density Res	Monthly	2.55	0.50	4.5	0.50	Monthly
313	Rock Forest Med	Monthly	0.26	0.35	1.75	0.30	Monthly
314	Rock Forest Steep	Monthly	0.17	0.35	1.25	0.20	Monthly
331	Rock Forest Residential Flat	Monthly	0.43	0.35	2.5	0.70	Monthly
344	Rock Low Density Residential Steep	Monthly	0.043	0.25	1.25	0.20	Monthly

Table 8.3-4A Final PERLND/IMPLND Parameter Values (Part 4): Monthly LZETP Values for Zone A Watershed

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
74-76	Outwash Development	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
81-86	Saturated	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
111-114	Rock Forest	0.30	0.30	0.30	0.40	0.50	0.60	0.70	0.70	0.70	0.50	0.30	0.30
121-124	Rock Pasture	0.20	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.20	0.20
131-134	Rock Forest Residential	0.30	0.30	0.30	0.40	0.50	0.60	0.70	0.70	0.70	0.50	0.30	0.30
141-164	Rock Development	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15

Table 8.3-4B. Final PERLND/IMPLND Parameter Values (Part 4): Monthly LZETP Values for Zone B Watershed.

No.	PERLND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
211-214	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
221-224	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
231-234	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
241-244	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

No.	PERLND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
251-254	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
261-264	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
271	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
272	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
273	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
274-276	Outwash Development	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
281-286	Saturated	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
311-314	Rock Forest	0.30	0.30	0.30	0.40	0.50	0.60	0.70	0.70	0.70	0.50	0.30	0.30
321-324	Rock Pasture	0.20	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.20	0.20
331-334	Rock Forest Residential	0.30	0.30	0.30	0.40	0.50	0.60	0.70	0.70	0.70	0.50	0.30	0.30
341-364	Rock Development	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15

Table 8.3-5A Final PERLND/IMPLND Parameter Values (Part 5): Monthly CEPS Values for Zone A Watershed.

No.	PERLND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
11-14	Till Forest	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
21-24	Till Pasture	.15	.15	.20	.25	.30	.35	.35	.35	.30	.25	.20	.15
31-34	Till Forest Residential	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
41-64	Till Development	.10	.10	.12	.14	.17	.20	.20	.20	.18	.14	.12	.10
71	Outwash Forest	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
72	Outwash Pasture	.15	.15	.20	.25	.30	.35	.35	.35	.30	.25	.20	.15
73	Outwash Forest Residential	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
74-76	Outwash Development	.10	.10	.12	.14	.17	.20	.20	.20	.18	.14	.12	.10
81	Saturated Forest	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
82	Saturated Pasture	.15	.15	.20	.25	.30	.35	.35	.35	.30	.25	.20	.15

No.	PERLND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
83	Saturated Forest Residential	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
84-86	Saturated Development	.10	.10	.12	.14	.17	.20	.20	.20	.18	.14	.12	.10

Table 8.3-5B. Final PERLND/IMPLND Parameter Values (Part 5): Monthly CEPS Values for Zone B Watershed.

No.	PERLND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
211-214	Till Forest	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
221-224	Till Pasture	.15	.15	.20	.25	.30	.35	.35	.35	.30	.25	.20	.15
231-234	Till Forest Residential	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
241-244	Till Low Density Residential	.10	.10	.12	.14	.17	.20	.20	.20	.18	.14	.12	.10
251-254	Till High Density Residential	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
261-264	Till Commercial/ Industrial	.15	.15	.20	.25	.30	.35	.35	.35	.30	.25	.20	.15
271	Outwash Forest	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
272	Outwash Pasture	.10	.10	.12	.14	.17	.20	.20	.20	.18	.14	.12	.10
273	Outwash Forest Residential	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
274-276	Outwash Development	.15	.15	.20	.25	.30	.35	.35	.35	.30	.25	.20	.15
281	Saturated Forest	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
282	Saturated Pasture	.10	.10	.12	.14	.17	.20	.20	.20	.18	.14	.12	.10
283	Saturated Forest Residential	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
284-286	Saturated Development	.15	.15	.20	.25	.30	.35	.35	.35	.30	.25	.20	.15
311-314	Rock Forest	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
321-324	Rock Pasture	.10	.10	.12	.14	.17	.20	.20	.20	.18	.14	.12	.10
331-334	Rock Forest Residential	.20	.20	.25	.30	.38	.45	.45	.45	.38	.30	.25	.20
341-364	Rock Development	.15	.15	.20	.25	.30	.35	.35	.35	.30	.25	.20	.15

Table 8.3-6 Final PERLND/IMPLND Parameter Values (Part 5)

No.	IMPLND	LSUR	SLSUR	NSUR	RETSC
Zone A					
91	Low Density Residential	500	0.01	0.10	0.10
92	High Density Residential	500	0.01	0.10	0.10
93	Commercial/Industrial	500	0.01	0.10	0.10
94	Road	500	0.01	0.10	0.10
Zone B					
291	Low Density Residential	500	0.01	0.10	0.10
292	High Density Residential	500	0.01	0.10	0.10
293	Commercial/Industrial	500	0.01	0.10	0.10
294	Road	500	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 watershed GIS layers provided by King County.

8.3.1.5 COMPARISONS PERFORMED

The hydrologic calibration was performed for the time period of water year 1999 through water year 2002. The available flow data used the continuous flow records at the USGS 12108500 gage on Newaukum Creek near Black Diamond. 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 12108500 for water years 1999 through 2002 are shown in Table 8.3-7 and Table 8.3-8. The average daily flows and annual volumes show that the simulated results match well with the observed values, differing by 0.6 percent. The correlation coefficient is 0.94 and the model fit efficiency is 0.88. These values show an excellent calibration at this location.

Table 8.3-7 Daily Flow Statistics at USGS Gage 12108500 (Oct 1999 – Sep 2002)

	Sim (cfs)	Obs (cfs)	Diff (cfs)	Diff (%)
Mean	54.77	55.12	-0.34	-0.6 %
Geometric Mean	38.08	39.20	-1.12	-2.9 %
Standard Deviation	56.48	56.08		
Correlation Coefficient	0.94			
Coefficient of Determination	0.88			
Mean Error	-0.35			
Mean Absolute Error	9.87			
RMS Error	19.82			
Nash Sutcliffe	0.12			
Model Fit Efficiency	0.88			
Skill Score	0.65			

The skill score is computed as 1 – (Root Mean Square Error/Standard Deviation of the observed flow).

A comparison of the annual volumes by water year in Table 8.3-8 shows some variability from water year to water year, with 1999-2000 being a little low and 2001 being high, but overall an excellent match.

Table 8.3-8 Annual Volumes at USGS Gage 12108500 (Oct 1999 – Sep 2002)

Water Year	Precip (in)	Sim (in)	Obs (in)	Difference (in)	Difference (%)
1999	46.72	32.09	34.14	-2.05	-6.0%
2000	47.27	31.23	32.50	-1.26	-3.9%
2001	36.67	20.16	17.71	2.45	13.8%
2002	46.86	31.61	31.41	0.20	0.6%
Average	44.38	28.77	28.94	-0.16	-0.6

Mean monthly volumes for Gage 12108500 are shown in Table 8.3-9. The mean monthly simulated values are close to the observed values with the greatest differences occurring in the July. The flows in July are usually low flows; accordingly, the actual flow differences in these months are very small. Rounding to the second decimal place may cause the listed value for difference between flows to vary by 0.01 from the apparent difference.

Table 8.3-9 Mean Monthly Flow Statistics at USGS Gage 12108500

Month	Sim (in)	Obs (in)	Diff (in)	Diff (%)
Jan	3.94	4.04	-0.11	-2.61%
Feb	3.69	3.45	0.24	6.90%
Mar	3.92	3.72	0.20	5.45%
Apr	2.63	2.70	-0.06	-2.41%
May	1.98	2.10	-0.13	-5.98%
Jun	1.66	1.67	-0.02	-1.15%
Jul	0.94	1.14	-0.21	-17.96%
Aug	0.80	0.82	-0.03	-3.10%
Sep	0.67	0.66	0.00	0.49%
Oct	0.82	0.76	0.07	8.70%
Nov	3.46	3.59	-0.13	-3.58%
Dec	4.15	4.18	-0.02	-0.52%
Total	28.65	28.84	0.00	-0.65

Table 8.3-10 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 shown in Table 8.3-9, 11 of the criteria are met; average summer storm volume was exceeded 91.7%. The storm peaks and volume calculations were based on a total of 18 winter, 9 Sping, 1 Summer, and 8 Fall storm events during the four-year calibration period.

The calibration tends to over estimate the peak flows during the Spring and Summer, which may be due to an overestimation of the effective impervious area. 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 8.3-10 Expert System Statistics at USGS Gage 12108500 (Oct 1998 – Sep 2002)

	Sim	Obs	Diff	Diff (%)	Criteria (%)	Meets Criteria
Total (in)	28.69	28.87	-0.183	-0.6%	10%	Excellent
10% high (in)	9.86	9.66	0.196	2.0%	10%	Excellent
25% high (in)	16.95	6.53	0.422	2.6%	15%	Excellent
50% low (in)	5.26	5.66	-0.395	-7.0%	15%	Good
25% low (in)	1.99	1.99	0.002	0.1%	15%	Excellent
10% low (in)	0.69	0.67	0.024	3.6%	15%	Excellent
storm volume (in)	8.87	9.00	-0.127	-1.4%	20%	Excellent
average storm peak (cfs)	246.9	282.0	-35.07	-12.4%	15%	Fair
summer volume (in)	3.39	3.64	-0.249	-6.9%	15%	Good
winter volume (in)	11.82	11.70	0.114	1.0%	10%	Excellent
summer storms (in)	0.28	0.15	0.135	91.7%	10%	Poor
winter storms (in)	2.99	2.86	0.136	4.8%	15%	Excellent

Figure 8.3-1 shows the daily simulated and observed streamflow at USGS Gage 12108500 for the period of October 1998 through September 2002. Figure 8.3-2 to Figure 8.3-4 show the daily simulated and observed streamflow at King County gages, 44F, 44G, and 44H, respectively for the periods which data were collected. The negative flow values shown in Figure 8.3-3 are data gaps in the records of gage 44G, where the missing data were filled with a value of '-9.0.'
Figure 8.3-5 shows the Gage 12108500 flow duration for the same period and demonstrates a good match.

Figure 8.3-6 and Figure 8.3-7 compare the Gage 12108500 hourly simulated and observed streamflow values for the winter flow periods of November 1999 and November-December 2001, respectively.

Monthly simulated and observed flow volumes are shown in Figure 8.3-8. A scatter plot of the simulated and observed daily values are presented in Figure 8.3-9. The scatter plot shows a correlation coefficient of 0.938.

Figure 8.3-10 shows the residual plot of the difference between the simulated and observed mean daily flows at USGS gage 12108500.

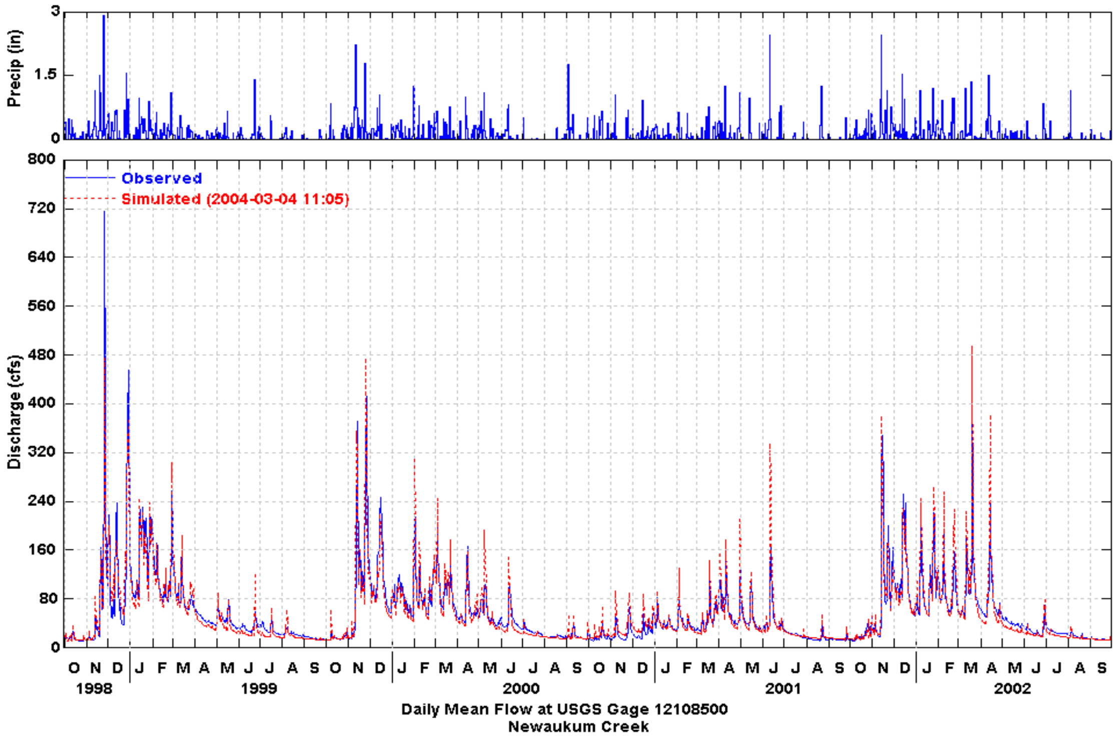


Figure 8.3-1 Observed and Simulated Daily Flow at USGS Gage 12108500

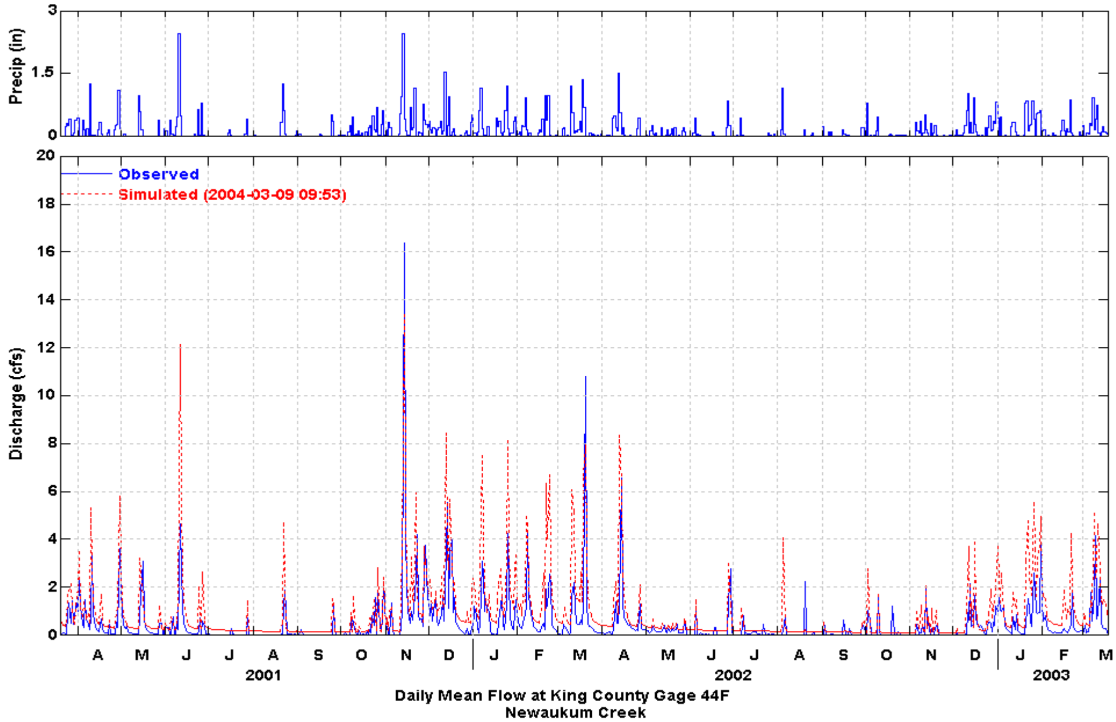


Figure 8.3-2 Observed and Simulated Daily Flow at King County Gage 44F.

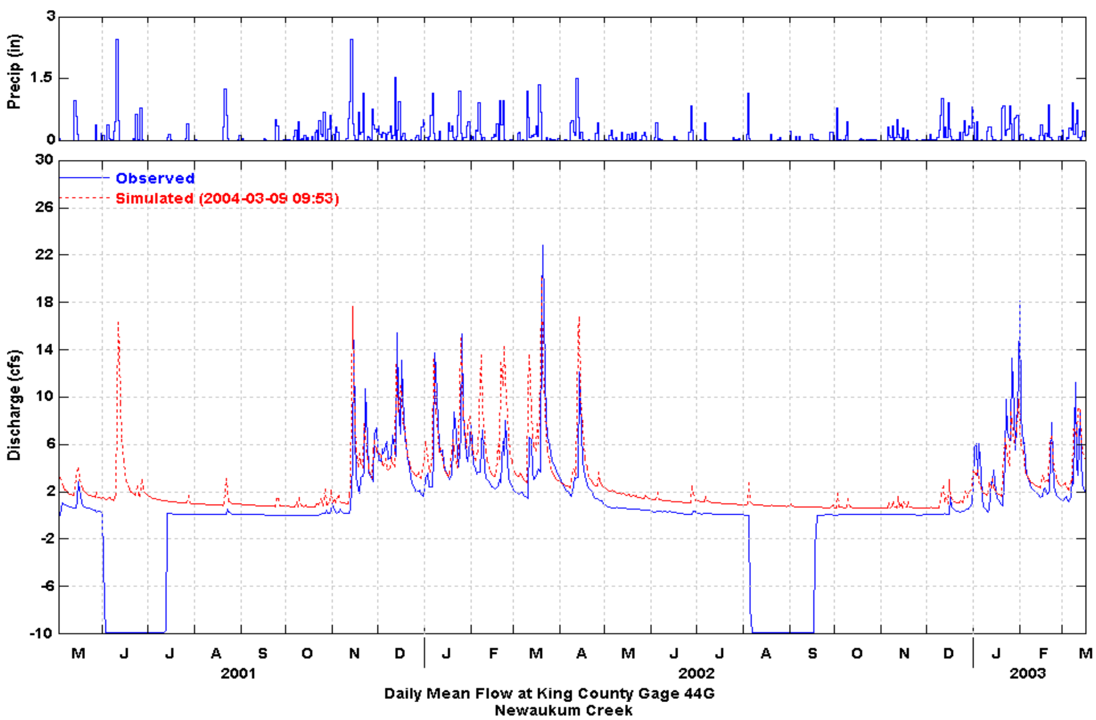


Figure 8.3-3 Observed and Simulated Daily Flow at King County Gage 44G.

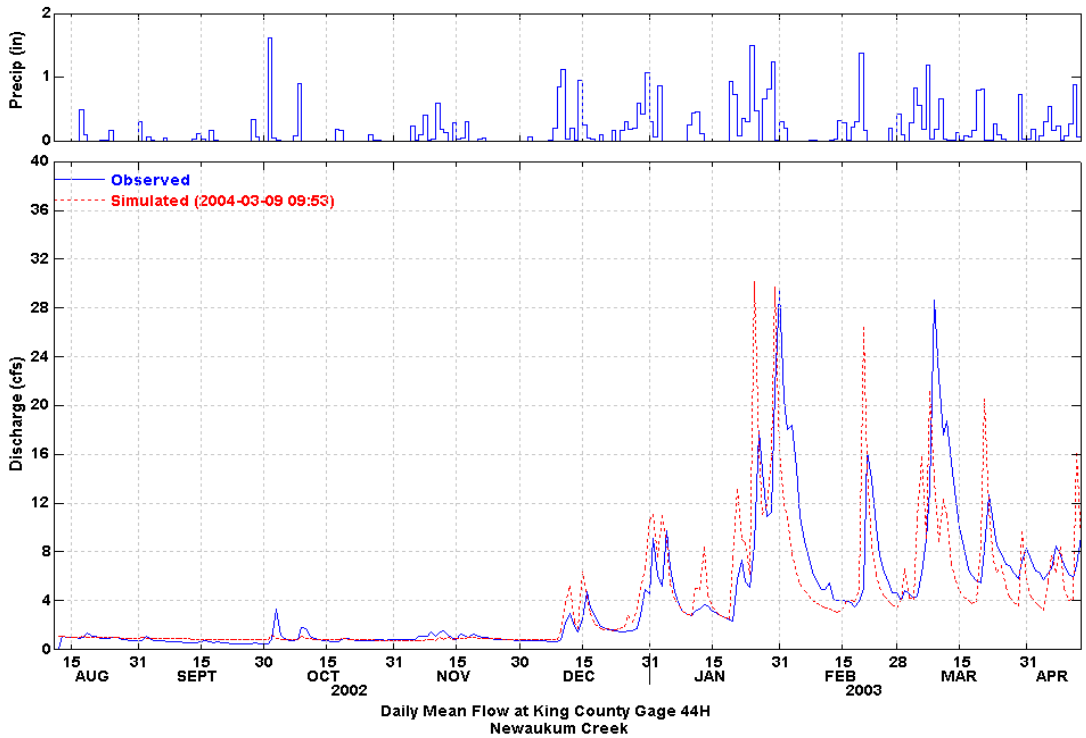


Figure 8.3-4 Observed and Simulated Daily Flow at King County Gage 44H.

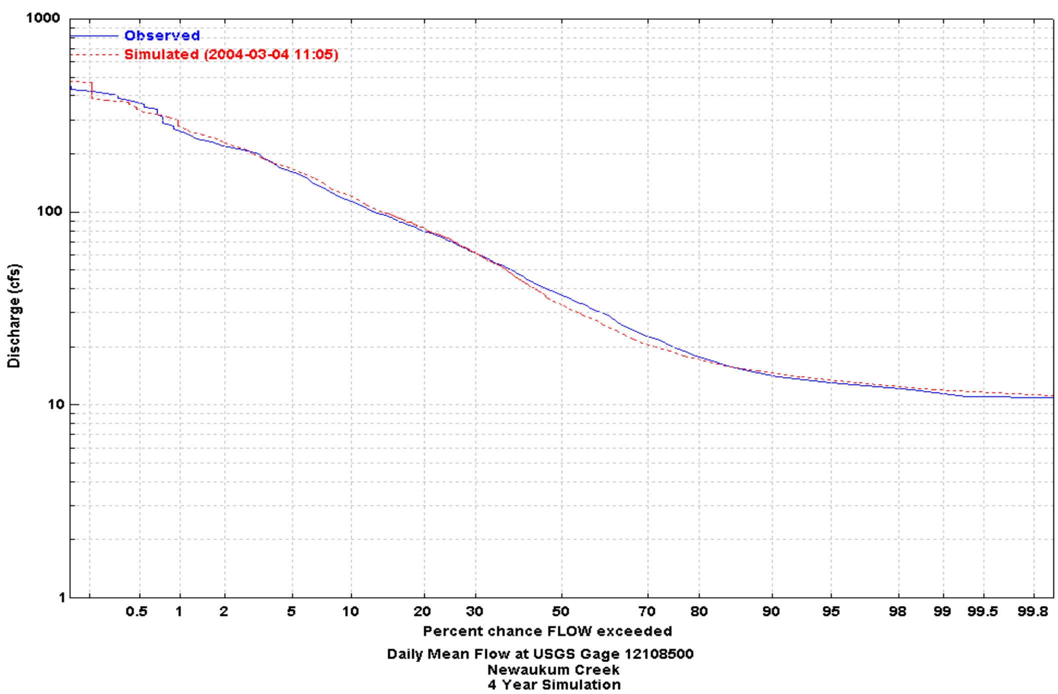


Figure 8.3-5 Observed and Simulated Flow Duration at USGS Gage 12108500

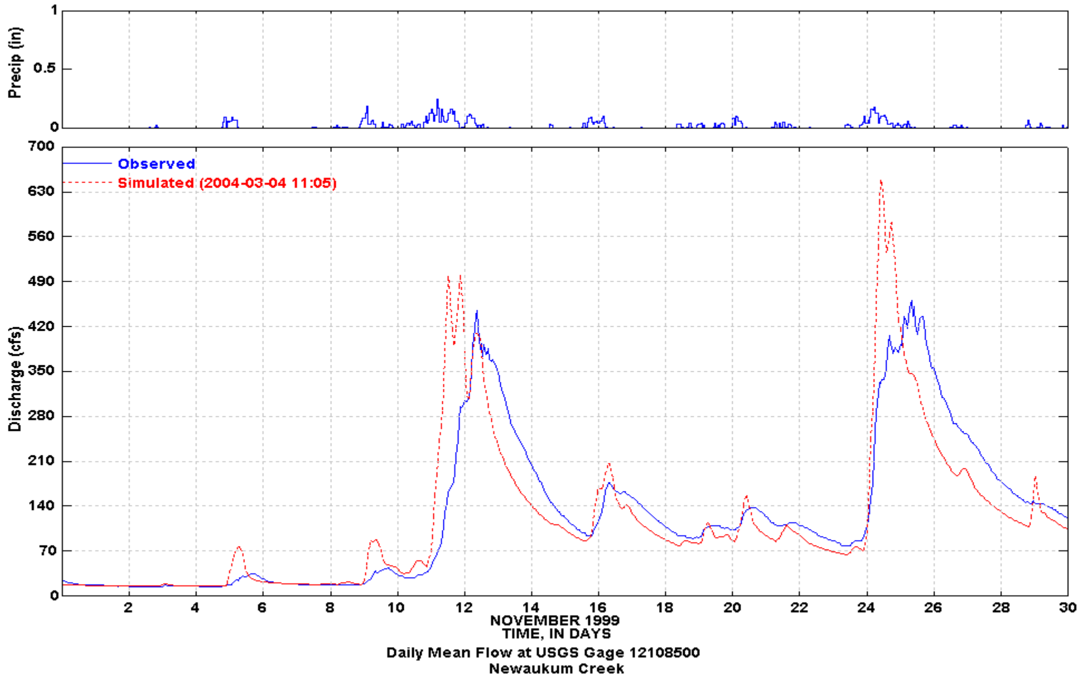


Figure 8.3-6 Observed and Simulated November 1999 Hourly Flow at USGS Gage 12108500

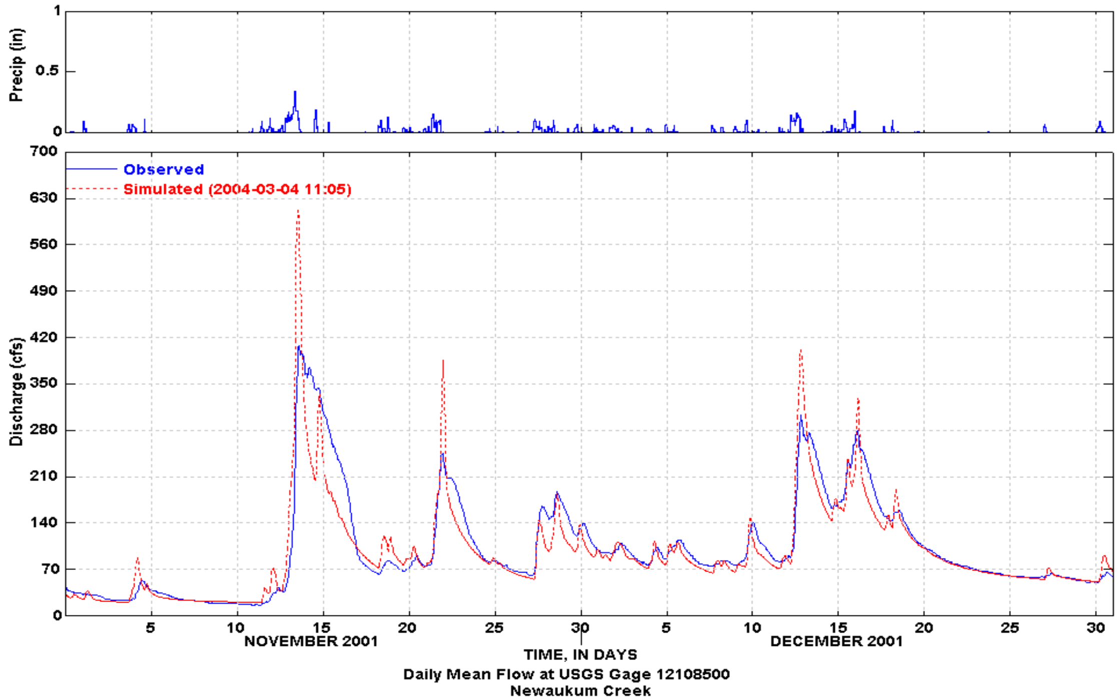


Figure 8.3-7 Observed and Simulated November-December 2001 Hourly Flow at USGS Gage 12108500

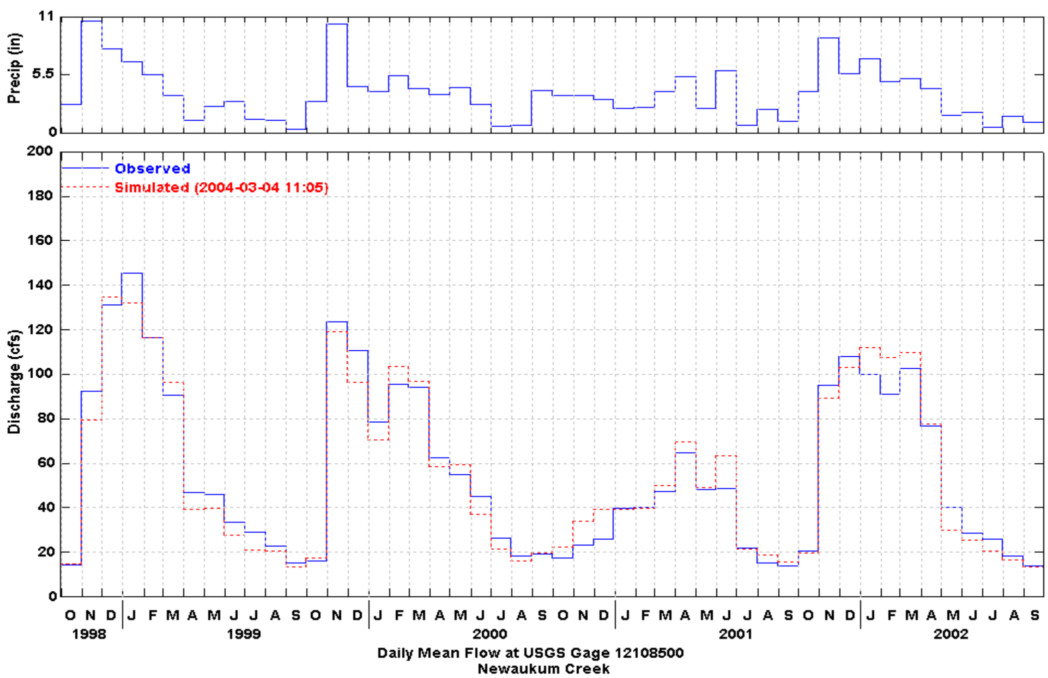


Figure 8.3-8 Observed and Simulated Monthly Flow at USGS Gage 12108500

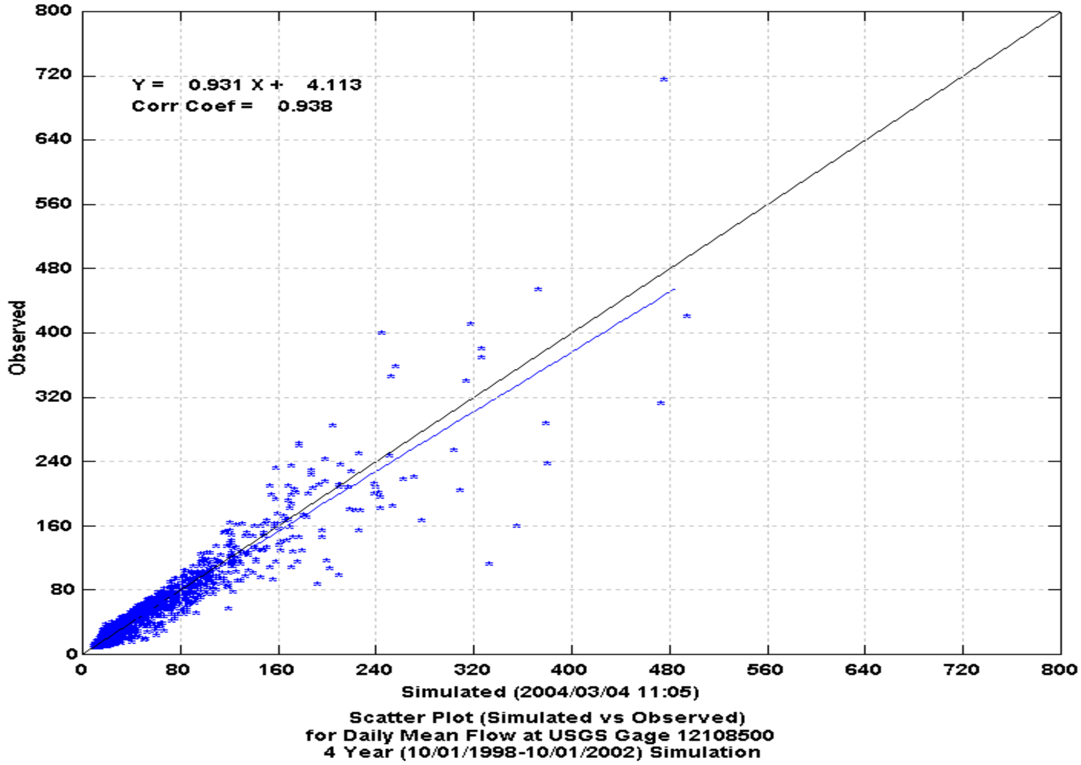


Figure 8.3-9 USGS Gage 12108500 Scatter Plot

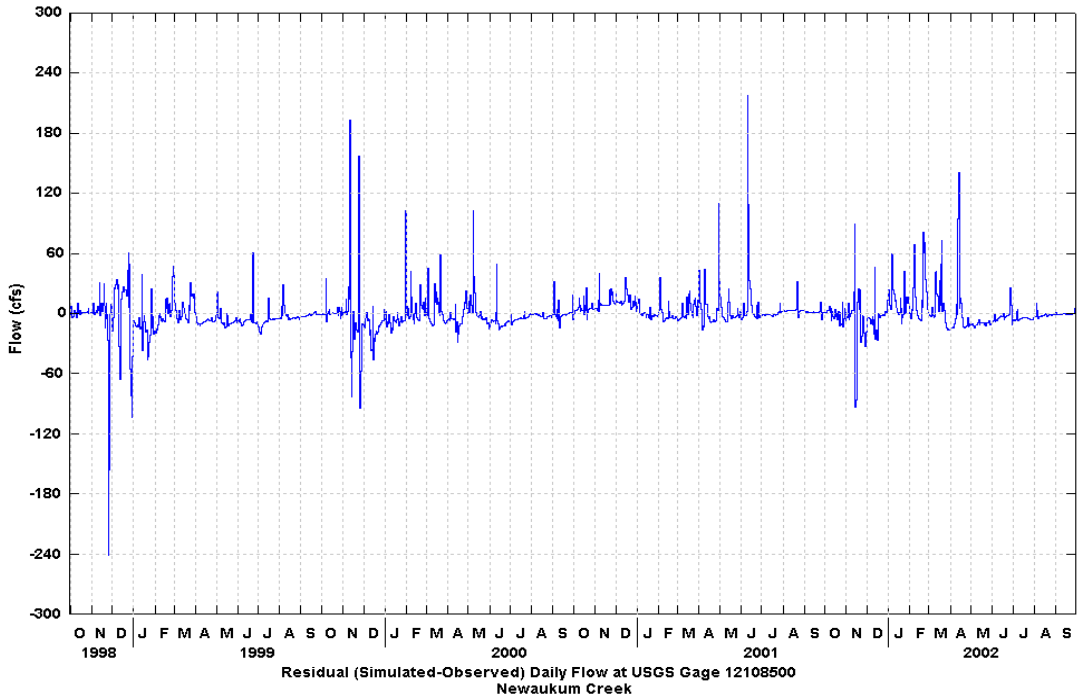


Figure 8.3-10 USGS Gage 12108500 Residual Mean Daily Flow, (Simulated – Observed)

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

Groundwater Inflow

Deep

Active

Total Actual Evapotranspiration (ET) (sum of following components)

Interception ET
Upper zone ET
Lower zone ET
Active groundwater ET
Baseflow ET

Although observed values are not 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 Newaukum Creek watershed.

The water balance components for the entire Newaukum Creek watershed are shown in Table 8.3-11. These values are weighed based on the contributing area of each Newaukum Creek PERLND for the period of record (water years 1999 through 2002). For this time period the mean annual precipitation was 51.62 inches, the total runoff was 28.16 inches, the groundwater flow to the stream was 15.64 inches, the potential evaporation was 23.65 inches, and the actual evaporation was 22.34 inches. These values are all close to or in the range of the expected values, as presented by Dinicola (1990).

Table 8.3-11 Newaukum Creek Mean Annual Water Balance (Oct 1998 – Sep 2002)

PERLND:	Till (in)	Outwash (in)	Saturated (in)	Bedrock (in)	EIA (in)	Watershed Average (in)	Expected (Dinicola, 1990) (in)
Influx							
Rainfall	50.50	53.52	50.18	54.96	52.44	51.62	35-50

PERLND:	Till (in)	Outwash (in)	Saturated (in)	Bedrock (in)	EIA (in)	Watershed Average (in)	Expected (Dinicola, 1990) (in)
Runoff							
Surface	0.80	0.03	7.60	1.82	43.69	3.11	
Interflow	14.94	0.11	3.73	23.77	0.00	10.89	
Baseflow	11.07	27.05	13.61	8.09	0.00	14.16	
Total	26.81	27.20	24.95	33.68	43.69	28.16	15-20
GW Inflow							
Deep	0.62	1.48	0.00	0.03	0.00	0.72	
Active	11.76	28.09	16.83	7.60	0.00	14.92	
Total	12.38	29.57	16.83	7.63	0.00	15.64	
Evaporation							
Potential	23.65	23.65	23.65	23.65	23.65	23.65	25
Interception Storage	10.11	10.78	10.00	11.84	9.65	10.36	
Upper Zone	5.07	1.80	9.44	2.71	0.00	4.05	
Lower Zone	7.39	10.06	1.26	7.42	0.00	7.40	
Ground Water	0.00	0.00	2.95	0.00	0.00	0.12	
Baseflow	0.47	0.47	0.00	0.02	0.00	0.40	
Total	23.04	23.11	23.64	21.98	9.65	22.34	18-20
Area (ac)	10,132	3,946	677	1,207	838	16,792	
Area (%)	60.29	23.50	4.03	7.19	4.99	100	

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.

8.3.1.6 CALIBRATION SUMMARY

Newaukum Creek Model was calibrated against the flow records at USGS Gage 12108500. Statistics and plots were produced to demonstrate the accuracy of the calibration.

Annual volumes matched well, with an error of 0.6% at the USGS gage 12108500.

The hydrology calibration is sufficiently accurate to proceed to the next step in the calibration process for Newaukum Creek, which is the calibration of the water quality model with the available data.

8.3.2 WATER QUALITY

8.3.2.1 Initial Water Quality Parameter Set

Initial water quality parameters for Newaukum Creek were obtained from the previously completed calibration on North and Swamp Creeks. 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 Newaukum Creek. The final calibrated values are provided in the Newaukum Creek UCI file, in Appendix A.

8.3.2.2 Water Quality Calibration

The primary time period of the water quality calibration is August 1991 – July 2003. However, observations of several constituents exhibited a significant change over this period. Since land use changes have been significant during this period, and we could not definitely attribute the trend to another reason, it was decided that calibration of these constituents should be refined by focusing on the most recent five year period when observed data are available, i.e., 8/1998 – 7/2003. Both the primary and secondary calibration periods include the hydrology calibration time period (10/1998 – 9/2002), and the calibration utilizes additional water quality data (and meteorological data) that are available at the water quality monitoring stations beginning in 1992 and 1993.

The calibration of Newaukum Creek was performed simarly to the calibration of North and Swamp Creeks. Subsequent to development of the initial parameter set using the previously calibrated watersheds, specifically Swamp and North Creeks, detailed adjustments were made to the pollutant loading parameters to fine-tune the calibration. The calibration of some constituents, such as temperature, sediment, DO, and copper, required instream parameter adjustments. However, similar to the other watersheds, the impacts of instream processes on pollutant concentrations are considered minimal for these small dynamic watersheds. Therefore, the main emphasis of the calibration and parameter adjustments was the nonpoint loading values, primarily the subsurface (interflow and baseflow) concentrations, and the surface loading associated with surface runoff and sediment.

In Newaukum Creek, three subwatersheds with significant observed data are available where the land use is dominated by a single major category. As documented earlier, these subwatersheds and their respective water quality monitoring stations are: 1) an agricultural subbasin in the northwest part of Newaukum Creek (station D322), a residential/urban subbasin in the city of Enumclaw (station I322B), and a forest subbasin in the eastern part of Newaukum Creek (station S322). This allowed the calibration of more reliable land use-specific parameters for these categories. In future watershed calibrations in this region, the parameters from this basin will be used as the starting values, and efforts will be made to maintain consistency, to the extent possible, with the Newaukum values.

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 significantly with soils properties (i.e., till, outwash, saturated, rock) or with the four slope classes. Therefore, 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.

8.3.2.3 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 values are presented in Section 8.3.2.4 of this document when discussing and comparing the simulated loading rates.

For most of the constituents, the calibration procedure involved an iterative series of simulations in which the following information was reviewed:

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 reviews 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, with initial focus on the land use-specific subwatersheds in order to obtain the most benefit from these watersheds. 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 station at the outlet of Newaukum Creek (over the upstream stations), since this model will be used primarily to evaluate impacts of total loads delivered to the Green 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.

8.3.2.4 Calibration Discussion and Results

The results of the calibration are presented on the following pages. Table 8.3-12 shows the average annual (over the nine year simulation period) loading rates in pounds/acre/year for nitrogen species and compares them with the target rates. **Error! Reference source not found.** shows the same information for phosphorus species and sediment. Table 8.3-14 presents the mean simulated and observed concentrations on sampling dates for the various constituents, and the ratio of the means. **Error! Reference source not found.** shows the average (and range) of simulated/observed concentration ratios for all Newaukum Creek Stations. Finally, **Error! Reference source not found.** through **Error! Reference source not found.** show the time series plots of simulated daily and observed water quality constituent concentrations for the primary (outlet) station in Newaukum Creek (Station 0322). Similar plots for the other six calibration stations are shown in Appendix B. The following discussion is focused by constituent.

Water temperature calibration is done first, so that the various instream processes that are dependent on temperature are modeled with reasonable temperature conditions. Temperature adjustments were made as follows:

- Stream shading is generally checked with any available information, and then adjusted to improve the agreement with observations; no information was available for Newaukum Creek, so shading was utilized as a calibration parameter (as noted below).
- The parameters that determine the temperature of runoff from pervious and impervious land areas were adjusted seasonally.
- Since these are shallow streams, the temperature of the ground beneath the stream was adjusted seasonally to increase the effect of heat transfers via this pathway. Generally, the average daily water temperature is well calibrated in Newaukum Creek as evidenced in **Error! Reference source not found.** and the statistical information presented below (Tables 4.3-14 and 4.3-15), with occasional summertime oversimulations in the comparisons of daily average data apparent at all seven of the monitoring stations (shown in Figure 4.3-11 and Appendix B).
- The statistical analysis of water temperature revealed an undersimulation at the downstream end of the creek between RCHRES 221/241 and RCHRES 281. While higher temperatures are expected because of the rapid decrease in elevation in this area, the model was still too low. In order to match the higher observed temperatures, the shade factor for the four most downstream reaches was reduced significantly (to 0 for three of the reaches).

Sediment - Target sediment loadings to the stream channel were estimated for each land use category from the available literature data. Table 8.3-13 lists target loading rates that were developed for calibrating the nonpoint sediment loadings within the Newaukum 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 govern 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 Newaukum 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 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 Newaukum 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 all seven stations, with the primary focus on Station 0322, located near the outlet of the watershed. 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.

Based on the loading results and the statistical summaries in Table 8.3-14 and given the limited data available (particularly the scarcity of peak flow data) and the difficulty in modeling sediment, we concluded that the model reasonably represents the behavior of sediment concentrations and loads in Newaukum Creek. We note however, that the model probably oversimulates the peak concentrations during the 1995-96 and 1996-97 wet seasons.

Nitrogen Species – In general, nitrogen species are higher in Newaukum Creek than previously calibrated basins as a result of the large amount of agricultural land use and practices. Calibration of nitrate and ammonia was largely done by adjusting the interflow and groundwater concentrations (and ammonia surface loading factors) by land use, until the errors were minimized at the seven stations. While the agreement was fairly good for nitrate at the urban, forest, and outlet stations, this was achieved by undersimulating nitrate in the agricultural subbasin (D322) when compared over the full 12-year simulation. However, when the calibration period was limited to the most recent five years, agreement at the agricultural subbasin was improved. Further attempts to improve the agricultural subbasin agreement caused the nitrate at the other mainstem stations to be significantly oversimulated. Ammonia concentrations were calibrated using the most recent five years of data because of the difficulty in achieving a calibration over the longer period. During the period 1979 to 1998, the percentage of land in Newaukum basin that is categorized as agricultural changed from 56% to 17%. Since we do not know how much of this change occurred between 1991 and 1998, we could not rule out the impact of land use changes on the calibration difficulty over the longer period. Therefore, it was decided to use the period more closely corresponding to the approximate period of the land use data. The resulting statistical agreement was good at the outlet and agricultural stations, and improved at the other mainstem stations. The agreement at the urban and forest subbasin stations was good. Minor adjustments were made to the overall organics loading to improve the total nitrogen agreement at the outlets. These adjustments, plus the fact that total nitrogen concentrations are largely determined by nitrate, resulted in good agreement for total nitrogen, both statistically and graphically. Algal growth and other biological processes have a relatively small impact on the nitrogen behavior in the model.

Phosphorus Species – Phosphorus is relatively high in Newaukum Creek because of agricultural activity. Orthophosphate concentrations were calibrated by adjusting the land use-specific interflow and groundwater concentrations and the surface parameters (potency factors) seasonally to achieve a fit. For the forest and urban subbasins, this was done in such a way to reproduce the observed seasonal pattern, which is apparently determined primarily by the SRP in groundwater, and the dilution of this SRP by the higher rainfall-driven flows (interflow) in the winter. However, the agricultural areas exhibit a different pattern, with higher levels in the wet period caused primarily by runoff from pasture during storms. The large amount of agricultural areas causes this pattern and higher levels to dominate at the outlet. The graphical and statistical measures indicate it is fairly well calibrated. Note that storms produce spikes of PO4, which is primarily from the surface-generated particulate P.

Total organic carbon – Total organic carbon data were available at the outlet and the three land use-specific stations in Newaukum Creek for 2002-2003. In previous watershed calibrations, the organics (N and P) were adjusted by adjusting BOD loading and N and P were adjusted differentially by changing multiplication factors in the MASS-LINK block, which changes the ratio between BOD loading and N or P. Organic carbon loads are determined similarly. They are a function of the actual BOD inputs to the stream (degradable fraction) and the loading of refractory (non-degradable fraction) organic carbon, both of which are based on the same BOD loading rates and separate multiplication factors. In this case, the primary adjustment was made to the multiplication factors rather than the BOD rates, so that the organic N and P would not be negatively affected. Considering the limited data, the statistical results for TOC shown in Tables 4.3-14 and 4.3-15 suggest fairly good agreement. While the peaks appear to be over-simulated at the outlet station and the agricultural subbasin (Figure 4.3-19 and B.9-1), the graphical results for the urban and forest subbasins in Figures B.9-2 and B.9-3 (Appendix B) support the statistical information.

Dissolved oxygen - The initial simulations produced fairly good agreement with the observed DO, because in relatively low impact streams and watersheds such as Newaukum 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 various Newaukum Creek stations.

Alkalinity was calibrated primarily by adjusting subsurface (interflow and groundwater) concentrations to obtain the seasonal variation exhibited at the outlet station while maintaining appropriate differences between land uses. The agreement at the outlet was favored over that at the agricultural subbasin, where the summer was undersimulated. Overall, the statistical agreement at the other stations was also good (e.g., average ratio of simulated to observed concentrations = 1.07) except for the urban subbasin.

pH was calibrated to data at all seven stations on Newaukum Creek. The calibration focused on attaining reasonable values and seasonal variation, based on experience and the monitoring data. The pH was sensitive to alkalinity, and was also sensitive to total inorganic carbon (TIC) concentration. TIC modeling was handled the same as in the previous watersheds. Based on the 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 CO2 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 Puget Sound watersheds. Considering the difficulty in modeling pH, the modeling results shown in Tables 4.3-14 and 4.3-15 and Figures 4.3-21 and B.11-1 - B.11-6 (Appendix B) are acceptable. The model predicts pH values in the same range (approximately 7-8) and with the same seasonal trends as the observed data.

E-Coli and fecal coliforms are extremely variable and difficult to predict. One reason for this is that many of the larger loadings of bacterial material probably occur not only during storms, but also during somewhat random but “catastrophic” events, such as failure of human (and agricultural) waste disposal facilities, which can produce large, unpredictable concentrations. Therefore, efforts were made to attain general agreement between the simulated concentrations of both species by adjusting loading rates, both surface and subsurface runoff-associated by land use. Because of the difficulty in matching actual observed values, the calibration focused primarily on agreement between the means (primarily the geometric mean, since the arithmetic mean can be strongly biased by a few extreme values) and the standard deviation. The EColi and fecal coliform levels in Newaukum Creek are higher than previously calibrated watersheds, because of the relatively high agricultural loadings. The results, which are shown in Table 8.3-14 and Figures 4.3-22, 4.3-23, and B.12-1 – B.13-6 exhibit higher levels in the agricultural subbasin, the downstream mainstem stations, and the outlet (reflecting impacts of downstream agricultural areas), whereas the forest and urban subbasins and the most upstream mainstem station show relatively low levels.

Total and dissolved copper concentrations were calibrated by adjusting the land use-specific interflow and groundwater concentrations and the surface parameters (potency factors) to achieve a statistical fit with the available data. Copper is sediment-associated, so all surface loading was modeled in the sorbed phase, and most of the data supports the association of high copper levels with storms. The instream adsorption/desorption rates and adsorption equilibrium coefficients were adjusted to achieve reasonable behavior and a good match between the dissolved and total forms of copper. Adsorption rates for suspended sediment are 5 orders of magnitude higher than bed sediments, reflecting greater mixing and turbulence in the water column, and the lack of exposure of particles in the bed to the water column. This also helps to avoid large seasonal fluctuations in the baseline concentration caused by rapid sorption to the bed during periods of high concentration (storms) and slow desorption during periods of lower concentration. The calibrated adsorption equilibrium coefficients are the same for suspended and bed sediments.

Table 8.3-12 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	4.3	0.2	0.07	0.4	3.7	2.0	8.1
Pasture/Ag	9.0	40.	1.3	1.0	2.5	6.0	13.	47.
Forest Residential	4.2	5.2	0.6	0.06	1.2	2.2	6.0	7.4

Residential								
Low Density Residential	4.9	9.5	0.7	0.2	1.4	1.3	7.0	11.
High Density Residential	6.3	23.	0.9	0.3	1.8	2.0	9.0	25.
Commercial/ Industrial	4.9	N/A	0.7	N/A	1.4	N/A	7.0	N/A

Table 8.3-13 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	0.12	0.07	0.21	0.12	0.33	0.04	0.03
Pasture/Ag	0.6	3.6	0.7	0.35	1.3	3.9	0.08	0.08
Forest Residential	0.09	0.16	0.16	0.13	0.25	0.29	0.06	0.02
Low Density Residential	0.2	0.22	0.3	0.08	0.5	0.3	0.14	0.04
High Density Residential	0.35	0.22	0.45	0.11	0.7	0.33	0.16	0.014
Commercial/ Industrial	0.5	N/A	0.9	N/A	1.4	N/A	0.36	N/A

Table 8.3-14 Mean Simulated vs. Observed Concentrations on Sample Dates

	Newaukum Creek at Outlet - Station 0322			Newaukum Creek at Station F322			Newaukum Creek at Station AE322			Newaukum Creek at Station H322			Newaukum Creek at Station D322 (Agric)			Newaukum Creek at Station I322B (Resid)			Newaukum Creek at Station S322 (Forest)		
Constituent	Sim.	Obs.	Mean Daily Ratio *	Sim.	Obs.	Mean Daily Ratio *	Sim.	Obs.	Mean Daily Ratio *	Sim.	Obs.	Mean Daily Ratio *	Sim.	Obs.	Mean Daily Ratio *	Sim.	Obs.	Mean Daily Ratio *	Sim.	Obs.	Mean Daily Ratio *
Water Temperature (C)	9.26	9.43	1.04 (225)	9.22	9.18	1.05 (136)	8.81	8.78	0.98 (31)	9.14	9.12	0.99 (80)	9.72	9.77	1.12 (106)	9.73	9.30	1.03 (14)			
Suspended Sediment	11.6	12.0	1.22 (236)	4.5	4.7	0.82 (134)	6.4	4.7	1.04 (31)	6.7	6.6	1.10 (82)	9.0	8.8	1.53 (115)	13.7	13.8	2.14 (14)	16.2	16.6	1.05 (20)
Dissolved Oxygen	11.4	11.3	1.01 (215)	10.6	10.6	1.01 (135)	10.9	10.9	1.01 (29)	10.8	10.4	1.05 (80)	9.6	9.6	1.04 (105)	10.8	10.4	1.06 (14)			
Nitrate-Nitrite as N	2.04	2.03	1.02 (236)	2.00	1.83	1.11 (134)	1.69	1.63	1.04 (31)	1.64	1.46	1.14 (82)	2.43	4.08	0.70 (120)	2.20	2.17	1.15 (27)	0.84	0.88	1.75 (22)
Ammonia as N	0.053	0.053	1.59 (78)	0.031	0.073	1.05 (40)	0.035	0.046	1.22 (22)	0.029	0.044	1.16 (34)	0.054	0.046	1.22 (38)	0.023	0.027	1.06 (22)	0.017	0.017	1.08 (13)
Total Nitrogen	2.66	2.58	1.14 (182)	2.37	2.28	1.07 (81)	2.21	1.99	1.11 (31)	2.12	1.75	1.23 (31)	2.94	5.87	0.69 (67)	2.50	2.51	1.05 (27)	1.21	1.11	1.40 (22)
Orthophosphate as P	0.093	0.097	1.13 (101)	0.084	0.072	1.48 (53)	0.095	0.042	2.69 (31)	0.085	0.050	1.96 (36)	0.136	0.106	1.54 (39)	0.028	0.024	1.21 (27)	0.023	0.019	1.29 (22)
Total Phosphorus	0.135	0.157	1.03 (236)	0.111	0.127	1.24 (136)	0.144	0.073	2.33 (31)	0.118	0.096	1.82 (82)	0.132	0.197	0.94 (122)	0.056	0.055	1.13 (27)	0.058	0.037	1.52 (22)
Alkalinity as $CaCO_3$	46.7	47.3	0.99 (117)	48.8	47.8	1.01 (17)							50.0	53.9	0.98 (35)	35.0	28.0	1.69 (27)	37.0	39.5	0.96 (23)
pH	7.62	7.61	1.00(193)	7.24	7.31	0.99(40)	7.24	7.28	1.00(24)	7.37	7.34	1.01(23)	6.77	7.21	0.94 (17)	6.99	7.19	0.97(14)			
EColi (CFUs/100 ml)	1531	1540	8.03 (97)	722	1227	10.9 (45)	933	996	3.0 (29)	844	1139	6.3 (29)	1295	1333	1.8 (38)	754	977	1.7 (30)	103	100	2.1 (23)
Fec. Coli. (CFUs/100 ml)	1621	1688	6.1 (233)	974	1514	5.3 (130)	1110	1012	3.3 (30)	1288	1348	4.8 (78)	1084	1371	1.8 (120)	725	896	1.3 (30)	116	110	2.4 (19)
Copper (dissolved -)	2.77	2.11	1.41 (51)										1.13	2.62	0.47 (38)	2.41	2.40	1.00 (34)	0.84	0.70	1.12 (22)
Copper (total -)	4.02	3.98	1.10 (68)										2.46	3.34	0.61 (38)	3.57	3.55	1.05 (34)	1.35	1.36	0.86 (21)
Organic Carbon	7.86	8.54	0.97 (42)										11.3	10.3	1.10 (34)	6.13	6.07	1.07 (24)	7.43	6.47	0.99 (23)

* Mean Daily Ratio - mean of Simulated:Observed ratios on sampling dates; sample size in parentheses

Table 8.3-15 Average and Range of Simulated/Observed Concentration Ratios for all Newaukum Creek Stations

Constituent	Average	Range
Water Temperature (deg C)	1.05	0.50 – 8.3
Suspended Sediment	1.18	0.01 – 34.8
Dissolved Oxygen	1.02	0.74 – 3.2
Nitrite-Nitrate as N	1.03	0.14 – 9.9
Ammonia as N (5-year run)	1.28	0.11 – 18.2
Total Nitrogen	1.07	0.09 – 9.0
Orthophosphate as P (5-year run)	1.51	0.23 – 10.0
Total Phosphorus	1.24	0.09 – 19.4
Alkalinity as $CaCO_3$	1.07	0.38 – 5.4
pH	0.99	0.88 – 1.12
EColi	5.87	0.01 – 251
Fecal Coliform	4.56	0.004 – 224
Copper (dissolved)	1.02	0.10 – 5.9
Copper (total)	0.94	0.19 – 4.8
Total Organic Carbon	1.03	0.33 – 2.4

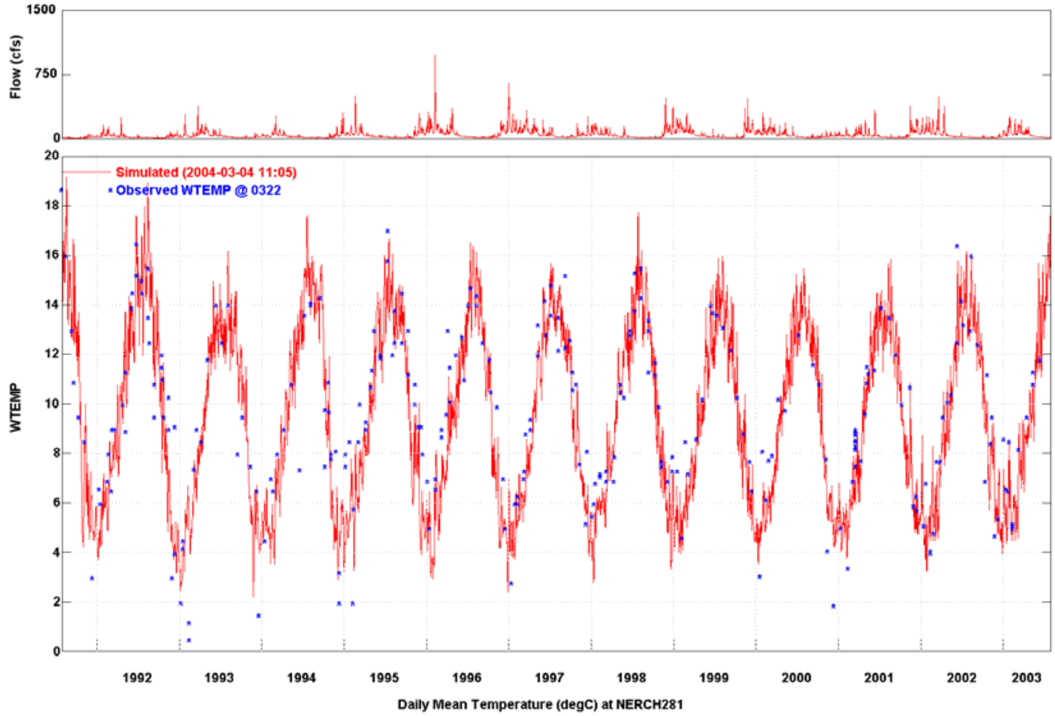


Figure 8.3-11 Observed and Simulated Daily Water Temperature for Newaukum Creek at Station 0322

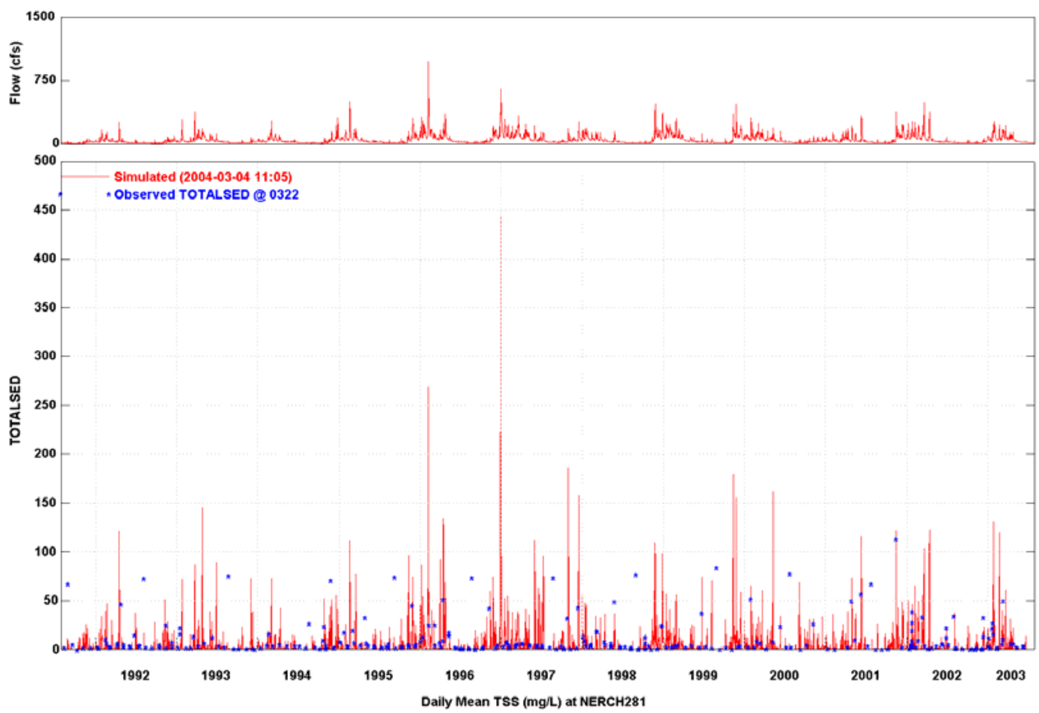


Figure 8.3-12 Observed and Simulated Daily Suspended Sediment Concentrations for Newaukum Creek at Station 0322

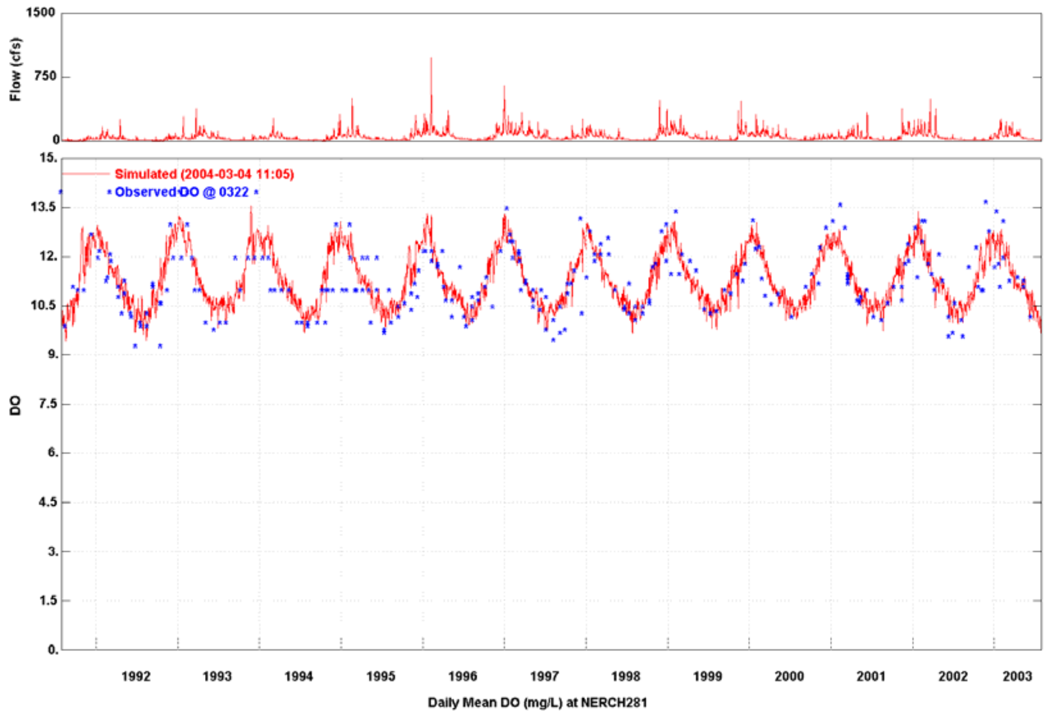


Figure 8.3-13 Observed and Simulated Daily Dissolved Oxygen Concentrations for Newaukum Creek at Station 0322

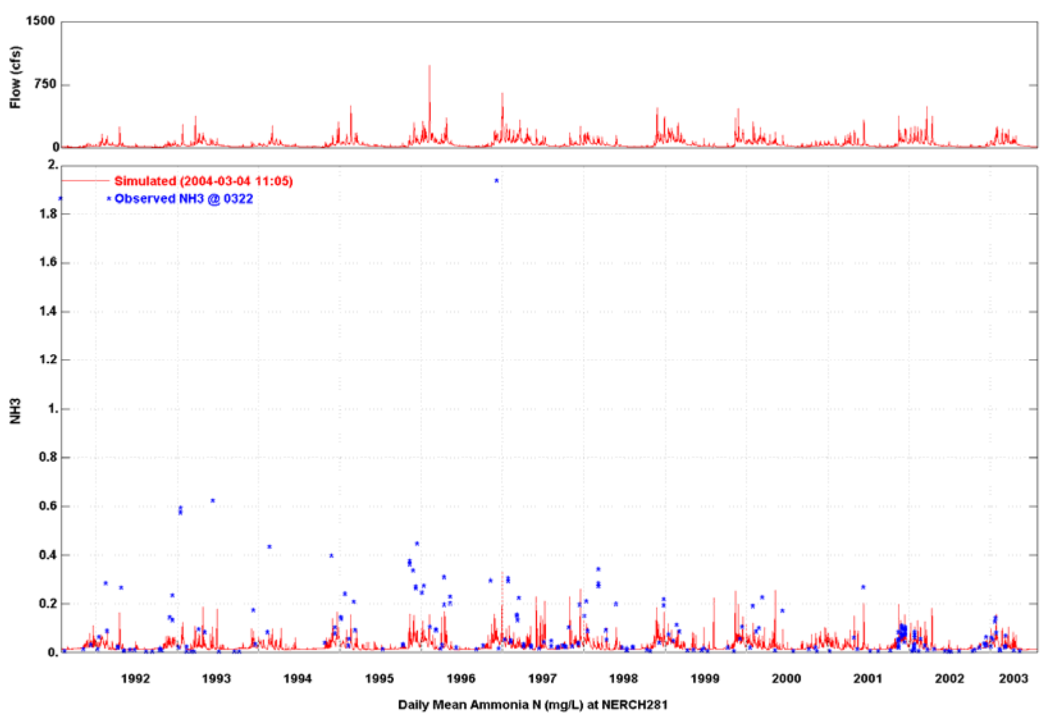


Figure 8.3-14 Observed and Simulated Daily Ammonia Concentrations for Newaukum Creek at Station 0322

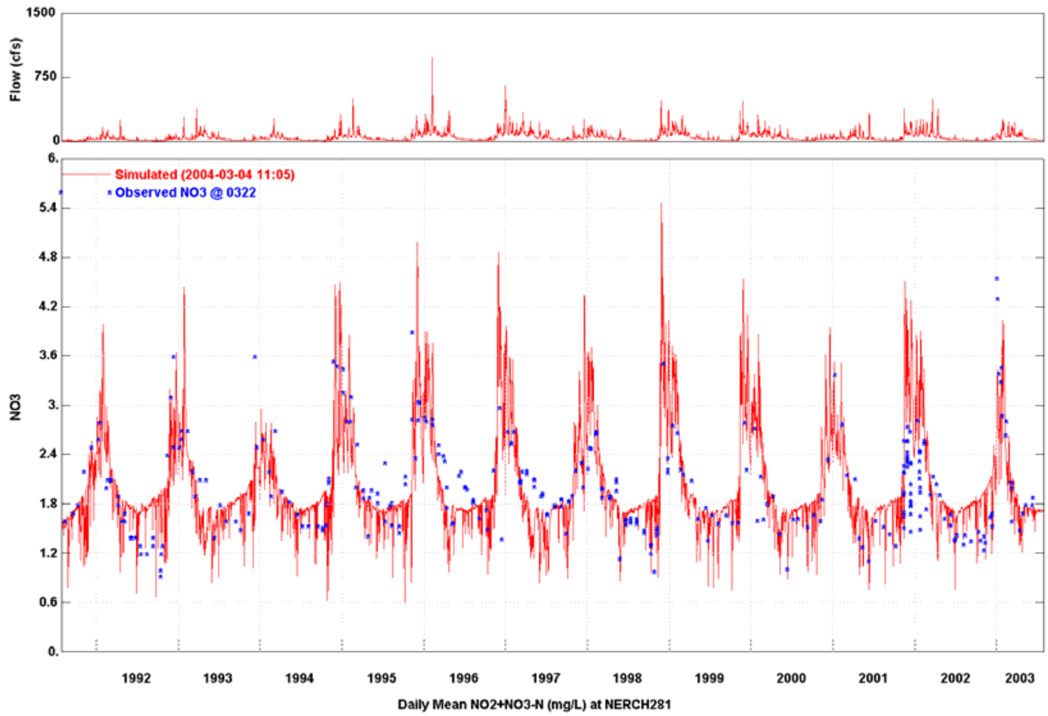


Figure 8.3-15 Observed and Simulated Daily Nitrate Concentrations for Newaukum Creek at Station 0322

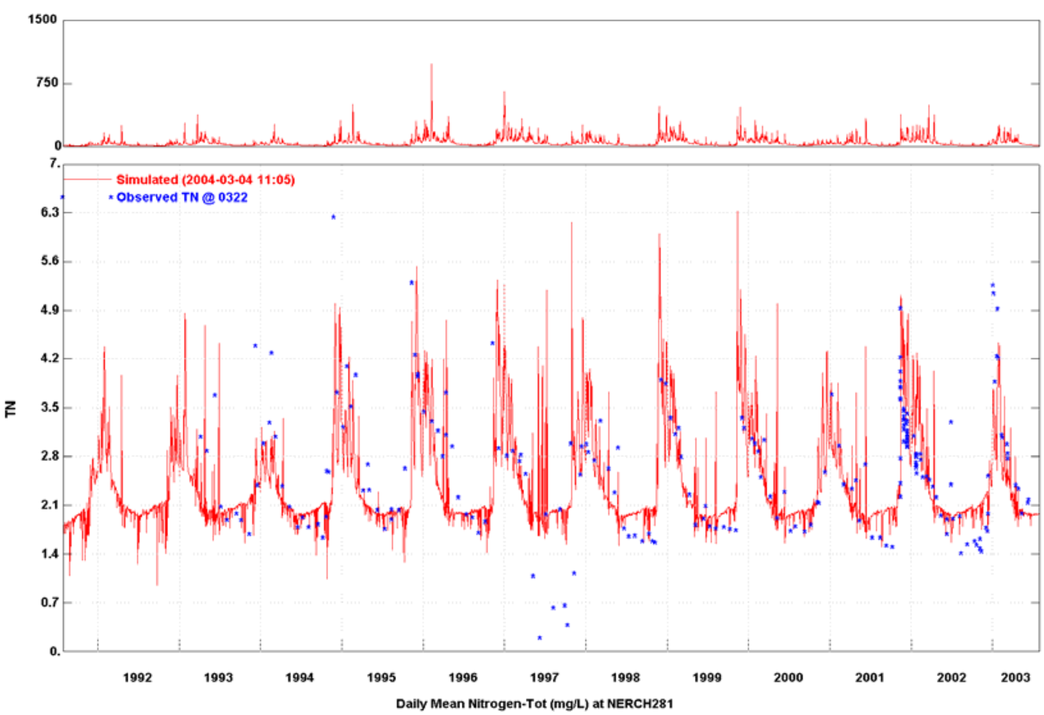


Figure 8.3-16 Observed and Simulated Daily Total Nitrogen Concentrations for Newaukum Creek at Station 0322

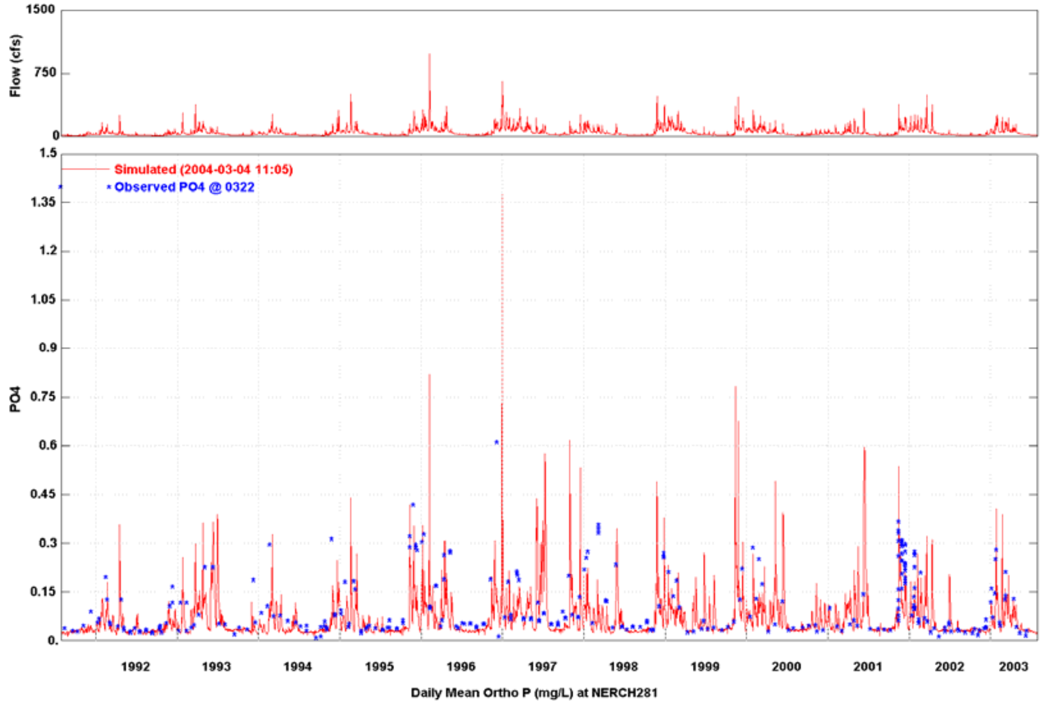


Figure 8.3-17 Observed and Simulated Daily Orthophosphate Concentrations for Newaukum Creek at Station 0322

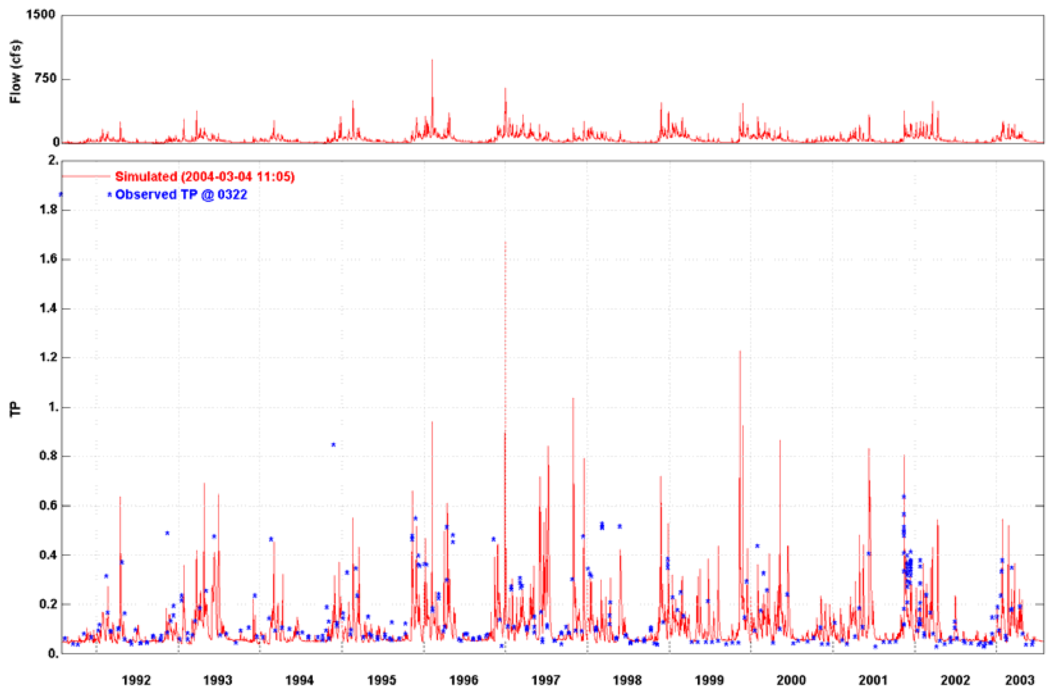


Figure 8.3-18 Observed and Simulated Daily Total Phosphorus Concentrations for Newaukum Creek at Station 0322

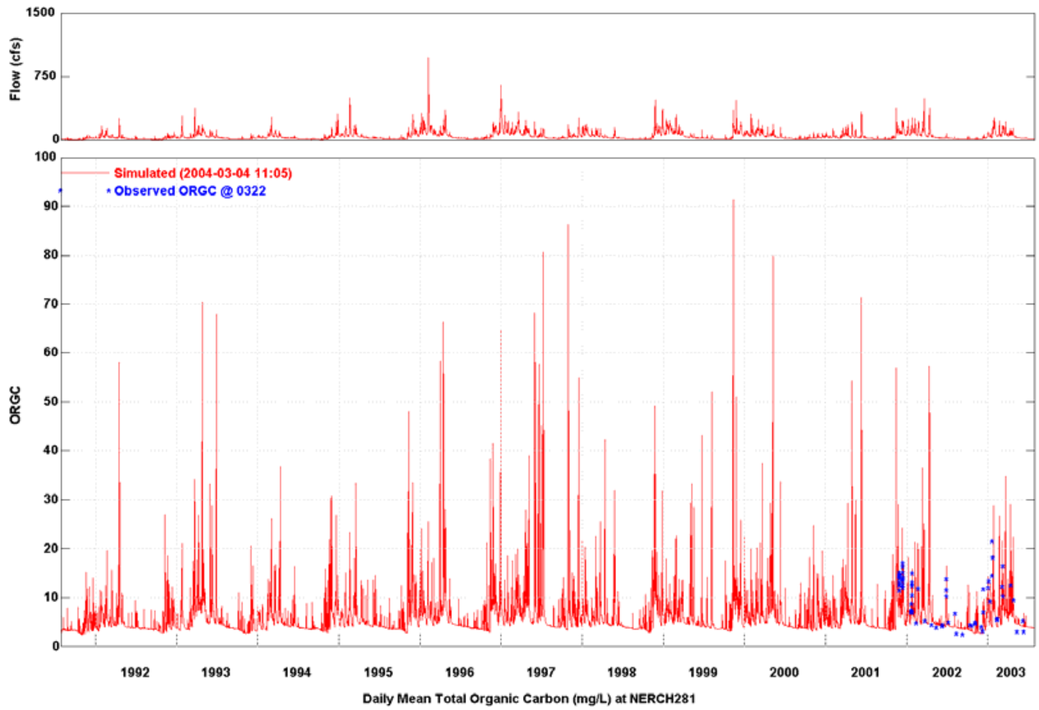


Figure 8.3-19 Observed and Simulated Total Organic Carbon Concentrations for Newaukum Creek at Station 0322

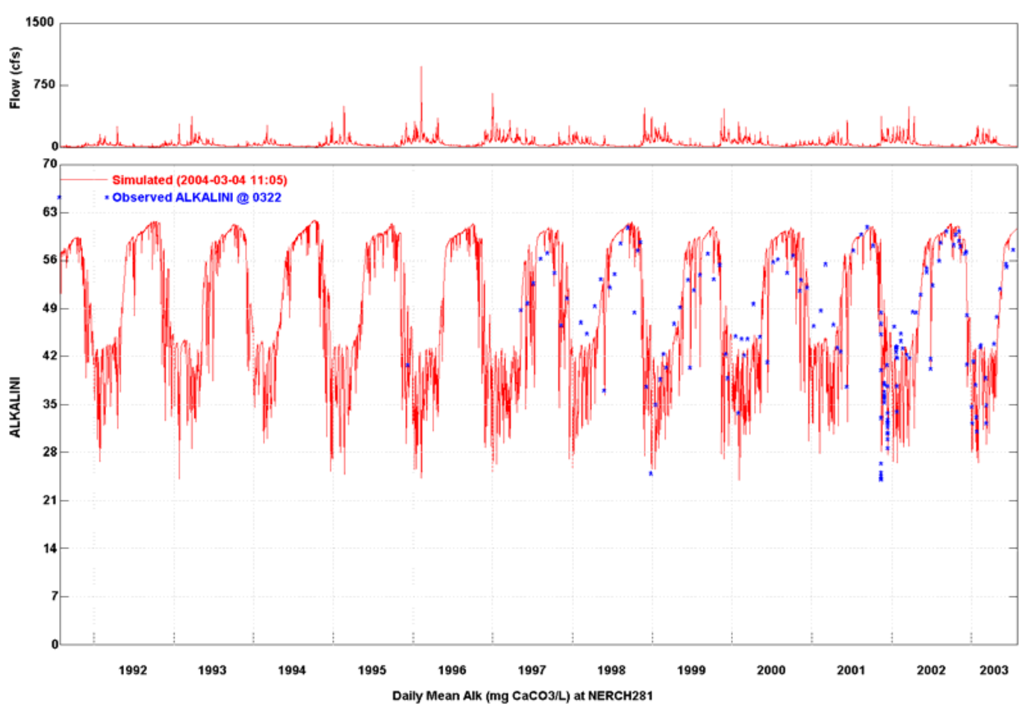


Figure 8.3-20 Observed and Simulated Daily Alkalinity Concentrations for Newaukum Creek at Station 0322

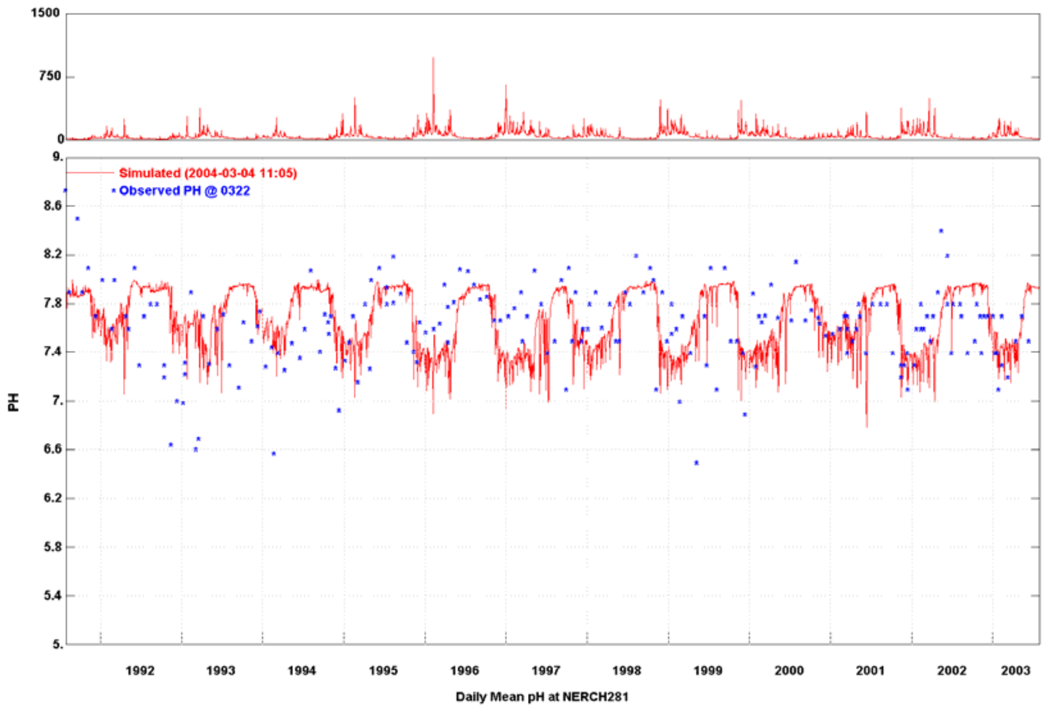


Figure 8.3-21 Observed and Simulated Daily pH Values for Newaukum Creek at Station 0322

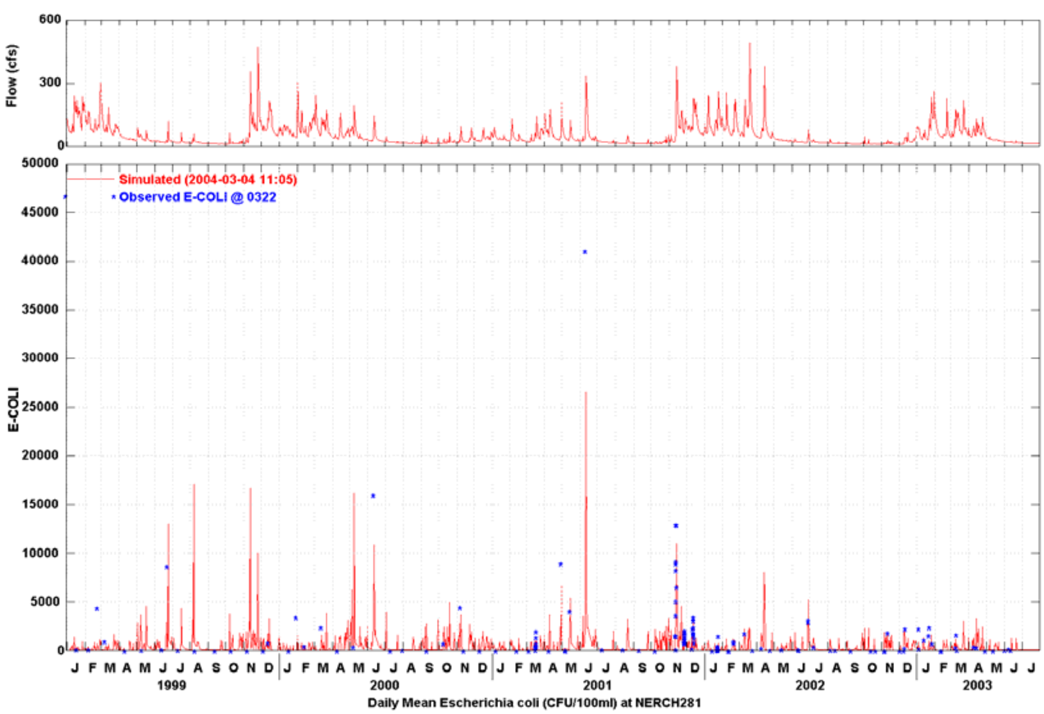


Figure 8.3-22 Observed and Simulated Daily EColi Concentrations for Newaukum Creek at Station 0322

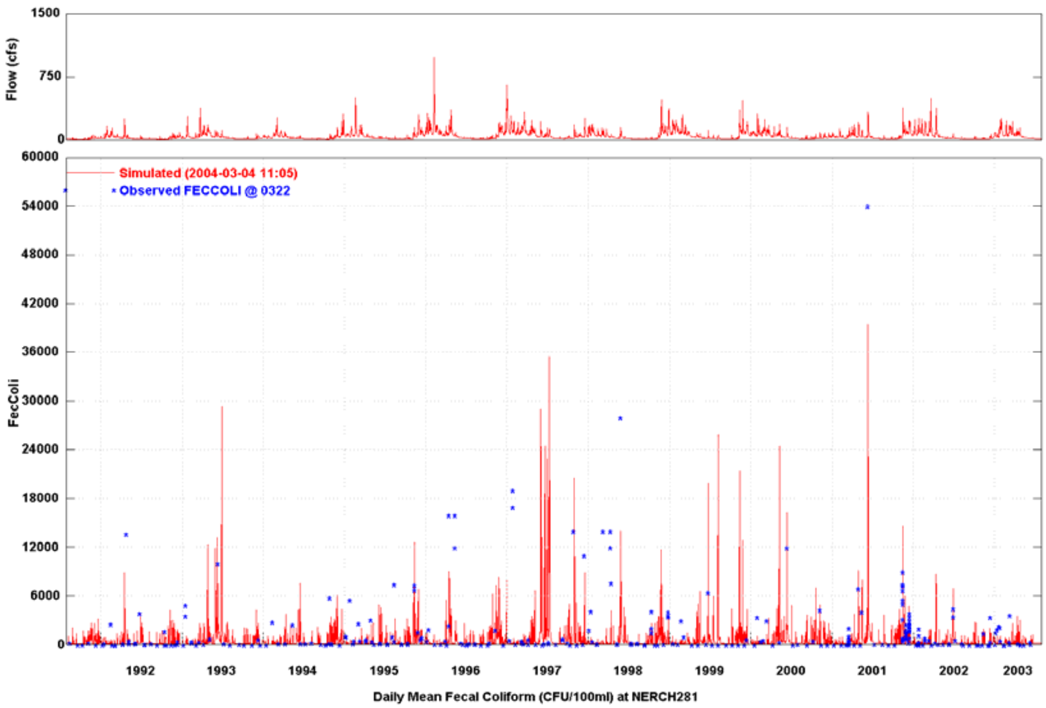


Figure 8.3-23 Observed and Simulated Daily Fecal Coliform Concentrations for Newaukum Creek at Station 0322

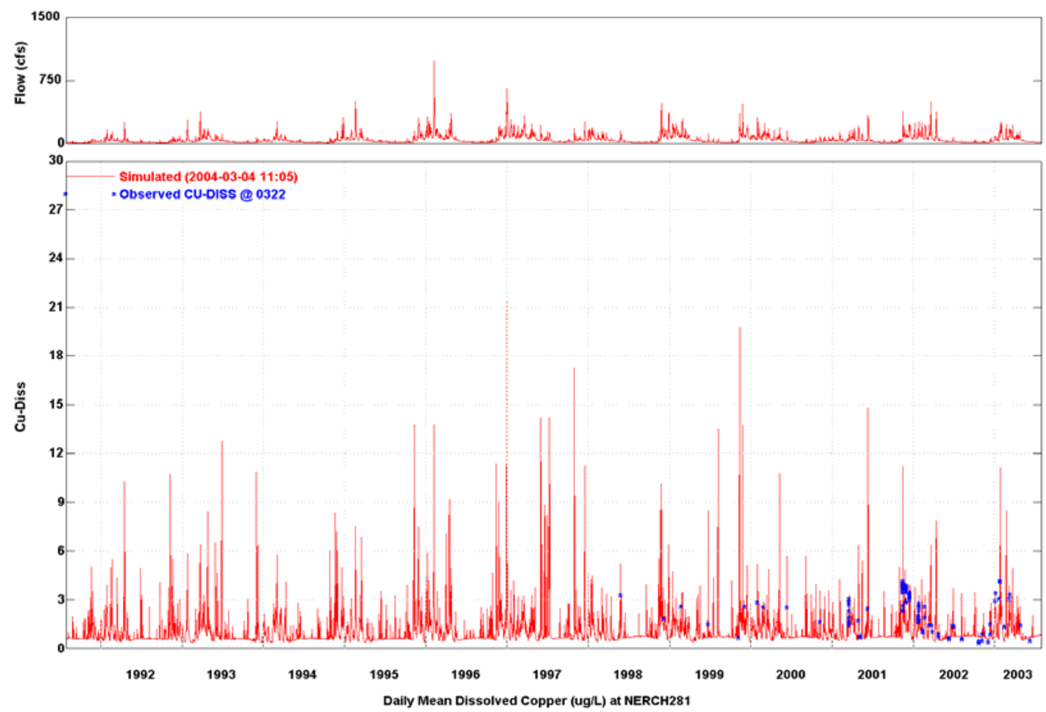


Figure 8.3-24 Observed and Simulated Daily Dissolved Copper Concentrations for Newaukum Creek at Station 0322

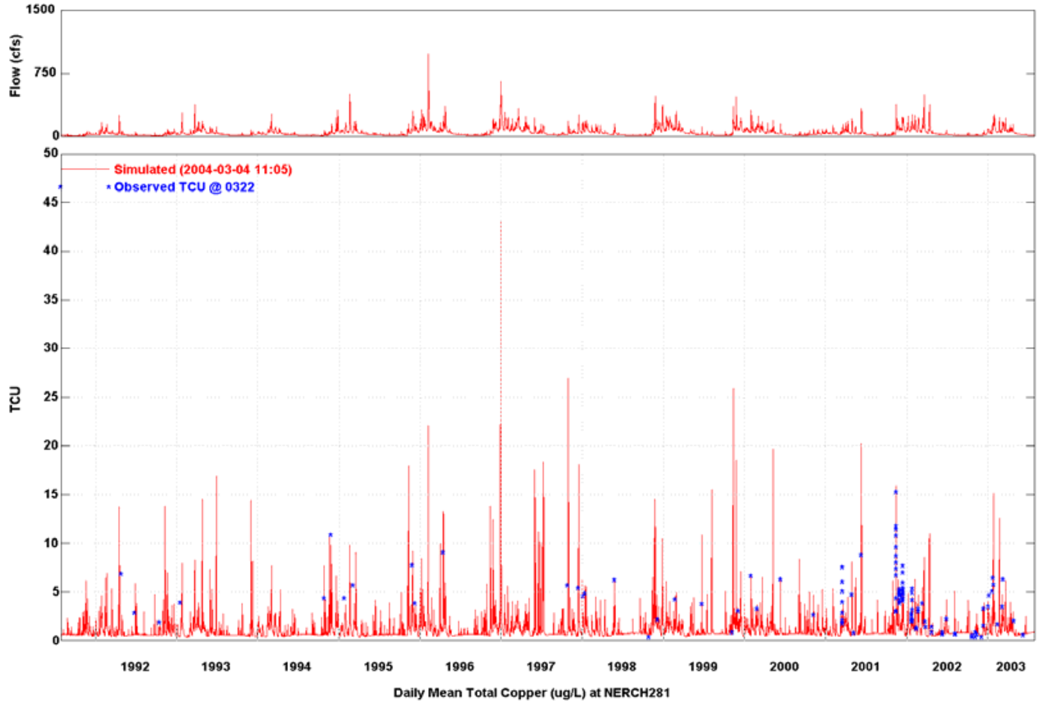


Figure 8.3-25 Observed and Simulated Daily Total Copper Concentrations for Newaukum Creek at Station 0322

8.3.2.5 Unresolved Calibration Issues

At the current time, several issues related to this model are not complete or should at the least be considered further. One of these issues is addressed below, and others should be noted in reviews by County staff.

- 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 scarcity of organics (e.g., BOD, TOC) or other monitoring data which indicates their impact 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 watersheds.

8.4 MODEL LINKAGES

The Lower Green River River Model (to be based on 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 Newaukum 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 Newaukum 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 needs further investigation.

8.4.1 Spatial Linkage

All loadings to the Green River from Newaukum Creek effectively enter the river at a single location, i.e., the mouth of the creek near Black Diamond, WA. Since the end of the most downstream reach (RCHRES 291) of the Newaukum 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.

8.4.2 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 is one hour. Therefore, the data (flows, temperatures, concentrations) will be one-hour averages.

8.4.3 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.

8.5 REFERENCES

8.5.1 Water Quality

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.

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.

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.