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 6—North Creek

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6 NORTH CREEK MODEL DEVELOPMENT

6.1 NORTH CREEK WATERSHED DOMAIN

The physical domain of the HSPF model for this study is the entire North Creek watershed above the confluence with the Sammamish River, an area of approximately 28 square miles.

Figure 6-1 North Creek Subbasin

6.2 DATA REQUIREMENTS AND AVAILABILITY

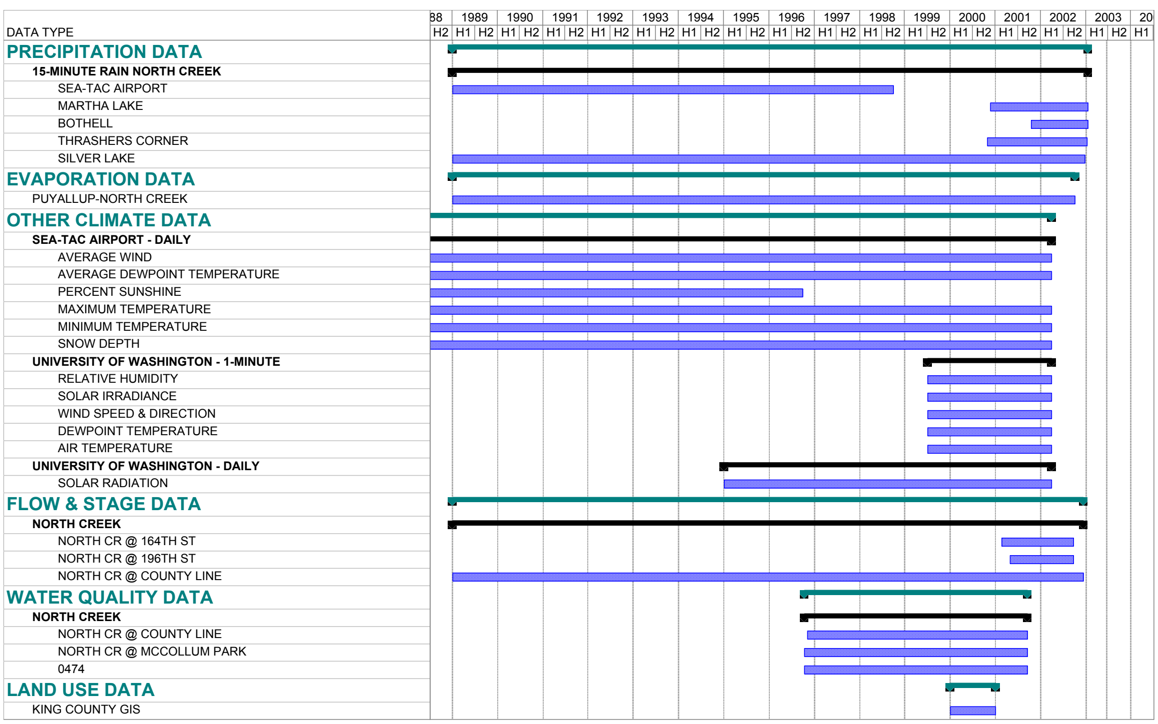
This section will describes the timeframe and constituents the data are capable of supporting for North Creek model simulations.

6.2.1 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 atmospheric data. The output from HSPF will provide the input to CE-QUAL-W2.

The selection of the calibration and simulation periods requires an evaluation of what field data are available and a determination as to what additional data collection is needed to fully support the modeling effort. Table 6.2-1 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 6.2-1 include published reports (AQUA TERRA and King County, 2002b), USGS data, NOAA/NCDC data, the King County Hydrologic Information Center http://dnr.metrokc.gov/hydrodat/index.htm, and the Snohomish County Surface Water Management site http://www.co.snohomish.wa.us /publicwk/swm/, along with other personal communications and miscellaneous sources.

Table 6.2-1 Data Availability for Model Simulations



6.2.1.1 Calibration Data

Precipitation is the primary driving force in any watershed modeling effort. Evaporation is the other important climatic data required for hydrologic simulation.

Table 6.2-2 provides a summary of the types of data that will be used for the North Creek hydrology calibration and the time periods over which they are available.

Table 6.2-2 Data Availability for Model Calibration

Location	Data Type	Time Step	Starting Date	Ending Date	DSN
Puyallup	Evaporation	Daily	1948/10/01	2002/09/30	1
SeaTac Airport	Precipitation	15-Minute	1948/10/01	1998/09/30	8
Martha Lake	Precipitation	15-Minute	2000/11/21	2003/01/15	101
Bothell	Precipitation	15-Minute	2001/10/17	2003/01/15	103
Thrashers Corner	Precipitation	15-Minute	2000/10/25	2003/01/07	105
Silver Lake	Precipitation	15-Minute	1948/10/01	2002/12/23	112
Alderwood	Precipitation	15-Minute	1948/10/01	2002/12/23	113
North Creek	Streamflow	15-Minute	2001/02/17	2002/09/18	164
North Creek	Streamflow	15-Minute	2001/04/25	2002/09/18	196
North Creek	Streamflow	15-Minute	1988/05/22	2002/12/06	240

6.2.1.1.1 Precipitation

Precipitation data are available at a 15-minute interval from three King County gages and one Snohomish County gage for the time intervals shown in Table 6.2-2. The three King County gages (Martha Lake, Bothell, and Thrashers Corner) are located in Snohomish County and are part of King County's I&I data collection effort. Only the Thrashers Corner and Bothell gages are located in the North Creek watershed, the Martha Lake gage is just west of the watershed. The Snohomish County gage (Silver Lake) is located in the northern portion of the watershed. The Snohomish County Alderwood gage is located west of the North Creek watershed. The locations of the King County gages and the two Snohomish County gages can be seen in Figure 6-3.

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

Only one long-term precipitation station is located in the North Creek watershed. The specific location of the North Creek precipitation station is at the Silver Lake Water District yard near the intersection of 132nd Street SE and 25th Avenue SE. The gage record has been extended using disaggregated Everett NWS gage data.

As shown in Table 6.2-3 and Figure 6-3, the other nearby precipitation stations' records were compared based on annual total volumes to determine which record was most representative of the North 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 6-3. No single precipitation record was found to accurately represent the entire North Creek watershed for the calibration period of water years 1999 through 2002. The PRISM isohyets show increasing annual precipitation from west to east across the watershed, which is generally supported by the gage records. Because all of the North Creek precipitation records are for very short periods, except the Silver Lake gage, the isohyets were used as the primary reference in the determination of an appropriate multiplication factor (MFACT) by which the composite record was scaled to represent the entire North Creek watershed.

The composite precipitation record was based on the two gages (Silver Lake and Thrashers Corner) for the period starting 25 Oct 2000 (the start of the Thrashers Corner record). The Silver Lake record provided 40% of the total and the Thrashers Corner record the remaining 60% (prior to Oct 2000 only the Silver Lake record was used). The averaged record was then multiplied by a factor of 1.13 (MFACT) to scale up the average precipitation to the watershed average.

The Alderwood gage was used as the precipitation source for the external groundwater that enters North Creek downstream of 196th Street SE. The MFACT for this gage was 1.11.

Table 6.2-3 Comparison of Precipitation Annual Volumes

Month	King Co Martha Lake DSN 101	King Co Bothel DSN 103	King Co Thrashers DSN 105	Snohomish Co Silver Lake DSN 112	Snohomish Co Alderwood DSN 113	Watershed Average
2000/10	No Data	No Data	No Data	3.41	3.11	
2000/11	No Data	No Data	3.24	3.18	3.07	
2000/12	2.86	No Data	2.96	2.78	2.70	
2001/01	No Data	No Data	3.70	2.99	2.94	
2001/02	No Data	No Data	2.52	2.07	1.62	
2001/03	2.23	No Data	3.34	2.99	2.69	
2001/04	2.21	No Data	2.85	2.40	2.33	
2001/05	2.03	No Data	1.96	2.01	2.15	
2001/06	3.67	No Data	4.33	3.75	3.71	
2001/07	No Data	No Data	2.67	2.28	1.96	
2001/08	No Data	No Data	2.22	1.65	1.87	
2001/09	No Data	No Data	0.53	1.06	0.79	
2001/10	4.37	No Data	4.86	5.02	4.62	
2001/11	7.71	10.73	9.63	8.58	8.25	
2001/12	5.19	7.01	6.23	6.16	6.15	
2002/01	5.93	7.22	6.49	6.74	6.00	
2002/02	3.77	4.86	4.50	4.10	4.35	
2002/03	4.21	3.74	4.45	4.55	3.86	
2002/04	2.44	2.77	3.04	2.68	2.41	
2002/05	2.39	1.73	2.06	2.44	2.22	
2002/06	2.36	1.15	2.08	1.65	1.56	
2002/07	1.41	1.39	1.37	1.59	1.42	

Month	King Co Martha Lake DSN 101	King Co Bothel DSN 103	King Co Thrashers DSN 105	Snohomish Co Silver Lake DSN 112	Snohomish Co Alderwood DSN 113	Watershed Average
2002/08	0.04	0.22	0.22	0.04	0.01	
2002/09	0.85	0.94	1.03	0.85	0.95	
2002/10	0.77	0.76	0.85	0.98	0.78	
2002/11	2.36	2.8	3.02	2.93	2.80	
2002/12	5.20	5.94	5.75	No Data	No Data	
WY 2002	40.67	No Data	45.96	44.40	41.80	
PRISM at gage	41	39	41	43	39.5	42
Fraction of watershed	0	0	0.6	0.4	0	1.0

The weighted-average precipitation record (DSN 119) was used for the calibration period of October 1998 through September 2002 (water years 1999-2002).

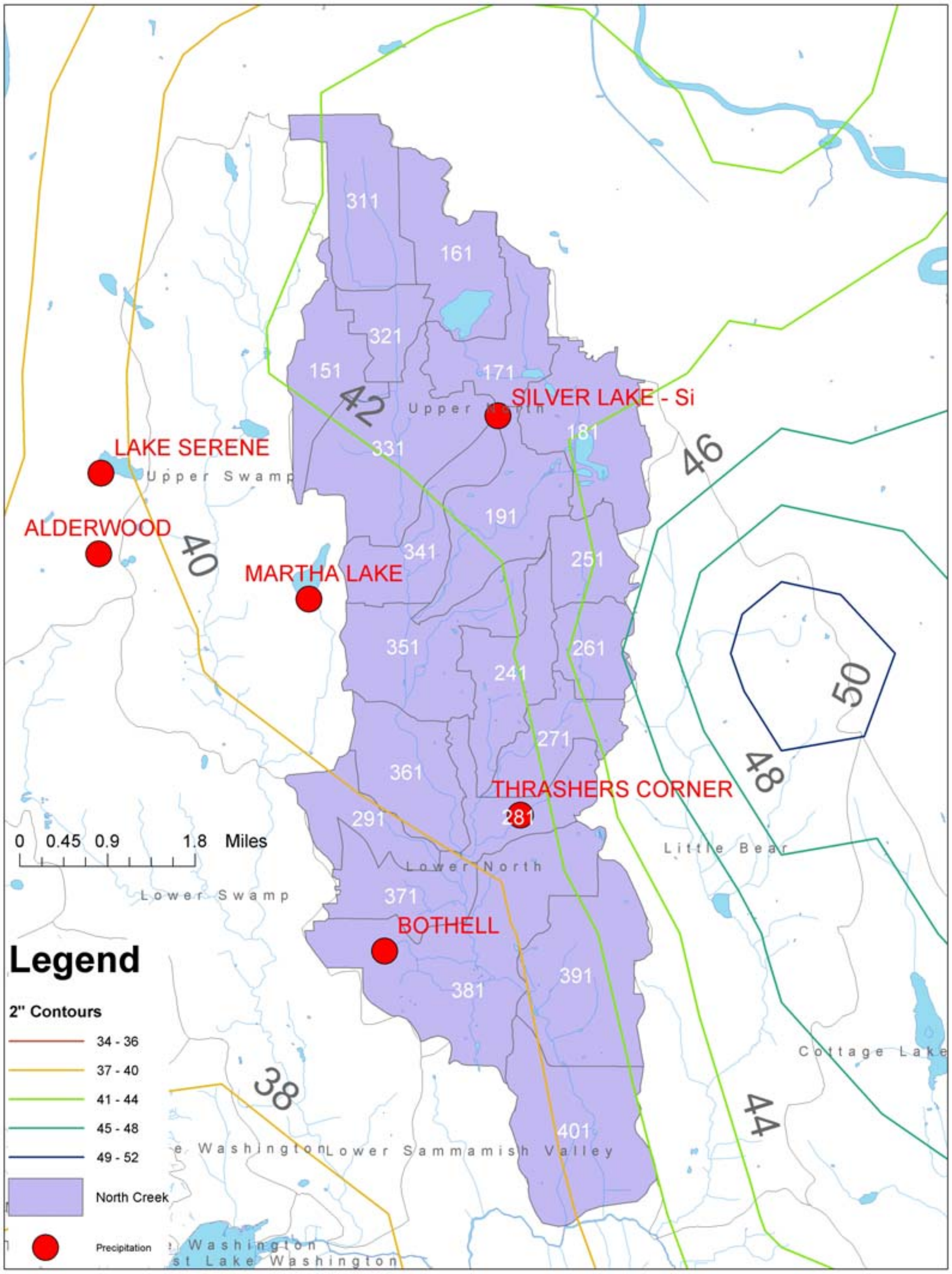


Figure 6-3 Nearby Precipitation Stations

6.2.1.1.2 Evaporation

The nearest evaporation data are available from Puyallup at the Washington State University Experimental Field Station. Puyallup lies approximately 60 miles to the south of the North 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 the North Creek watershed this coefficient was set to 0.79, based on the pan evaporation coefficient values shown on Map 4 of the NOAA Technical Report NWS 33, *Evaporation Atlas for the Contiguous 48 United States* (Farnsworth, et al, 1982). The pan evaporation coefficient is often adjusted in the calibration process (Donigian, 2003), but there was no need to do so in the North Creek calibration.

6.2.1.1.3 Water Quality Required Meteorological Data

AQUA TERRA identified the station at Everett Snohomish County Airport (Paine Field) as the best source of data for the first four of these quantities, and Seattle Sand Point Weather Station Forecast Office as the best source for solar radiation data. Table 6.2-4 contains selected descriptive attributes of these stations. The map in Figure 6.2-5 shows the spatial relation of these stations to the North Creek watershed.

Table 6.2-4 Additional Meteorologic Data Stations for North Creek

StationID	STATION NAME	COUNTY	LAT (dec°)	LONG (dec°)	ELEV (m)	START	END
452670	EVERETT AIRPORT	SNOHOMISH	47.900	-122.283	94.7	6/1/48	12/31/01
457470	SEATTLE SAND PT WSFO	KING	47.683	-122.250	18.3	3/21/95	12/31/02

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

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

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

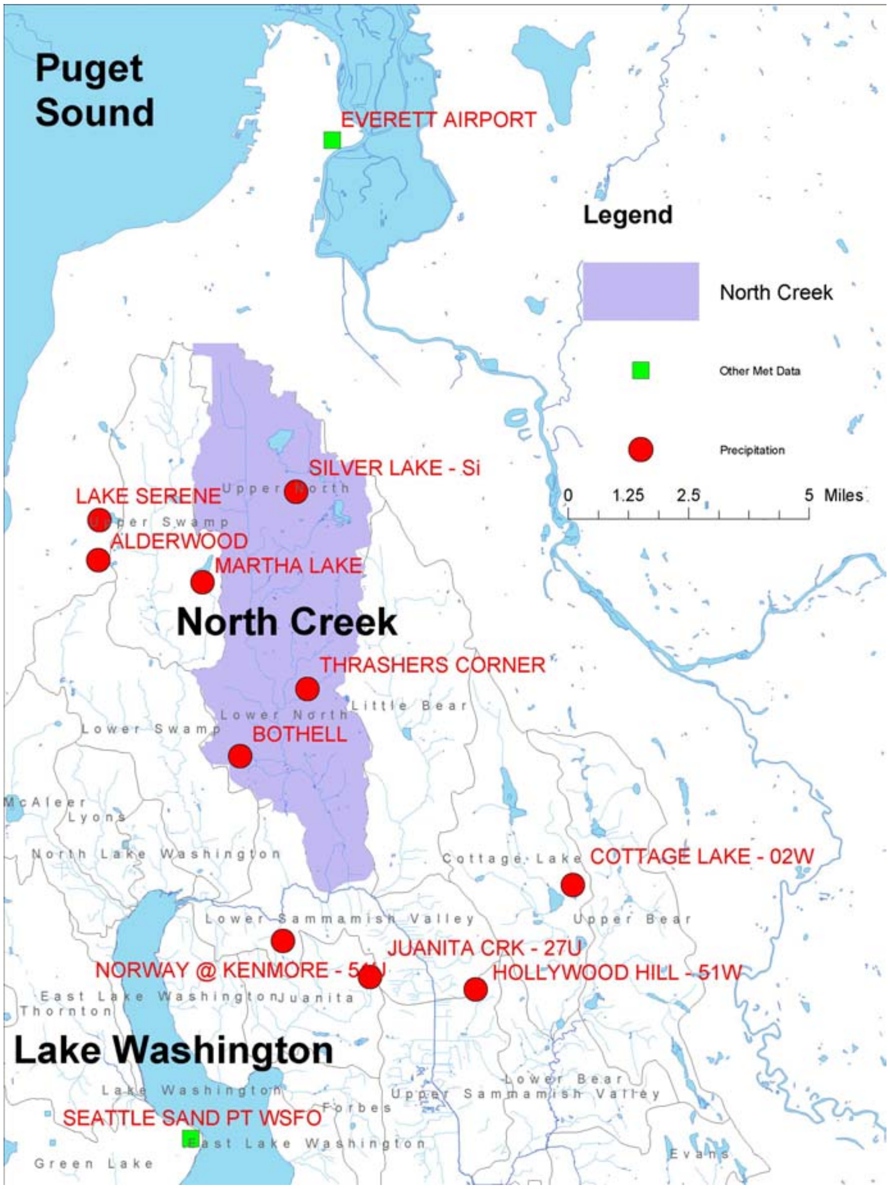


Figure 6.2-5 Map of Meteorologic Data Stations Used for North Creek

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

Table 6.2-5 ASOS Terms

Term	Description	Equivalent in Octas	Avg Decimal Equivalent

CLR	Clear	0/8	0.0
FEW	Few	1/8 to 2/8	0.1875
SCT	Scattered	3/8 to 4/8	0.4375
BKN	Broken	5/8 to 7/8	0.75
OVC	Overcast	8/8	1.0

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

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

6.2.1.1.3.1 Additional Water Quality Source Data

In addition to nonpoint loadings, other sources and losses of water quality constituents that must be represented in a model of this type are point sources, imports, diversions, and atmospheric deposition. There were no point sources or diversions identified in North Creek. Therefore, neither of these quantities are considered in the water quality budget of North Creek. Time series of nitrate and ammonia concentrations in rainfall (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).

6.2.2 WATERSHED / CONVEYANCE SYSTEM CHARACTERIZATION DATA

Information describing the characteristics of the watershed, including topography, drainage patterns, meteorological variability, soils conditions, and the land use distribution are required for segmenting the watershed into individual land segments that demonstrate a similar hydrologic and water quality response. A wealth of GIS data is available from King County to describe the aforementioned characteristics of the watershed. In addition, the region has been modeled extensively using HSPF for hydrology applications which have resulted in a database of HSPF calibration parameters as they relate to watershed characteristics.

In an analogous fashion, information describing the channels, floodplain morphology, culverts, and other hydraulic features within the watershed allows for the segmentation of the conveyance system (both natural and artificial) into discrete sections with similar hydraulic and water quality behavior. Locations of dams/reservoirs, point source discharges, gages/data collectors, culverts, and diversions provides information to develop a segmentation scheme that supports modeling localized conditions within the watershed.

Table 6.2-6 documents the various information, along with the respective sources, that was used in characterizing the watershed and conveyance system. The use of this information will be discussed in detail in Section 6.2.3.3.

Table 6.2-6 Data and GIS Coverages used for Characterization of the Watershed and Conveyance System.

Data / GIS Coverage	Source	Comment
Digital Elevation Model (DEM)	USGS	Required 4 individual 10 meter resolution DEMs to be mosaiced together
Slopes	AQUA TERRA Consultants	Developed using DEM and ArcView Spatial Analyst functionality
Land Use	King County	1995 Classification
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	North Creek and major tributaries
Stream and Meteorological Gages	King County, Snohomish County, NOAA	Locations of King and Snohomish County and nearby NOAA gages
Culverts	Snohomish County	Locations and attributes of culverts within the North Creek watershed; supplemented by field survey*
Cross-sections	Snohomish County	Field survey*

* Information provided from the Snohomish County Drainage Needs Report hydraulic modeling.

6.2.3 CALIBRATION / VALIDATION DATA

The hydrologic calibration and subsequent validation of a watershed model requires observed flow. Table 6.2-1 and the following sub-sections reflect knowledge of known monitoring that has been performed in North Creek. The stations discussed in the following sections are displayed in Figure 6-6.

6.2.3.1 Streamflow

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

Of the three gages the one in longest operation is the North Creek gage at 240th Street SE, near the county line. This gage has a rating curve, is located near the outlet of the North Creek watershed, and has been collecting data since May 1988. The hydrology calibration focus on the period of October 1998 through September 2002, as earlier years have either missing or questionable data (Collins, 2002).

Recorded streamflow data are complete at this station for the period of October 1998 through September 2002. Maximum flow events for each water year are shown in Table 6.2-7. Each maximum flood event occurred in the autumn (November-December) in response to large rainfall events.

Table 6.2-7 North Creek Maximum Streamflows at 240th Street Gage

Water Year	Maximum Flow (cfs)	Date of Event
1999	759	1999/01/24
2000	664	1999/11/12
2001	224	2000/10/20
2002	996	2001/12/17

For this same period of record low flows at the Snohomish County gage at 204th Street SE were in the range of 14 to 18 cfs.

The next upstream Snohomish County gage is located at the 196th Street SE bridge over North Creek. It has a shorter period of record than the 240th Street gage. It started operation on 25 April 2001. Due to its short period of record this gage was used as a check on the calibration, but with less emphasis than the longer 240th Street gage. At this gage observed flows ranged from 4 to 200 cfs.

The farthest upstream Snohomish County gage is located at the 164th Street SE bridge over North Creek. As with the 196th Street gage, it has a shorter period of record than the 240th Street gage. It started operation on 17 February 2001. Due to its short period of record this gage was used as a check on the calibration, but with less emphasis than the longer 240th Street gage. At this gage observed flows ranged from 2 to 150 cfs.

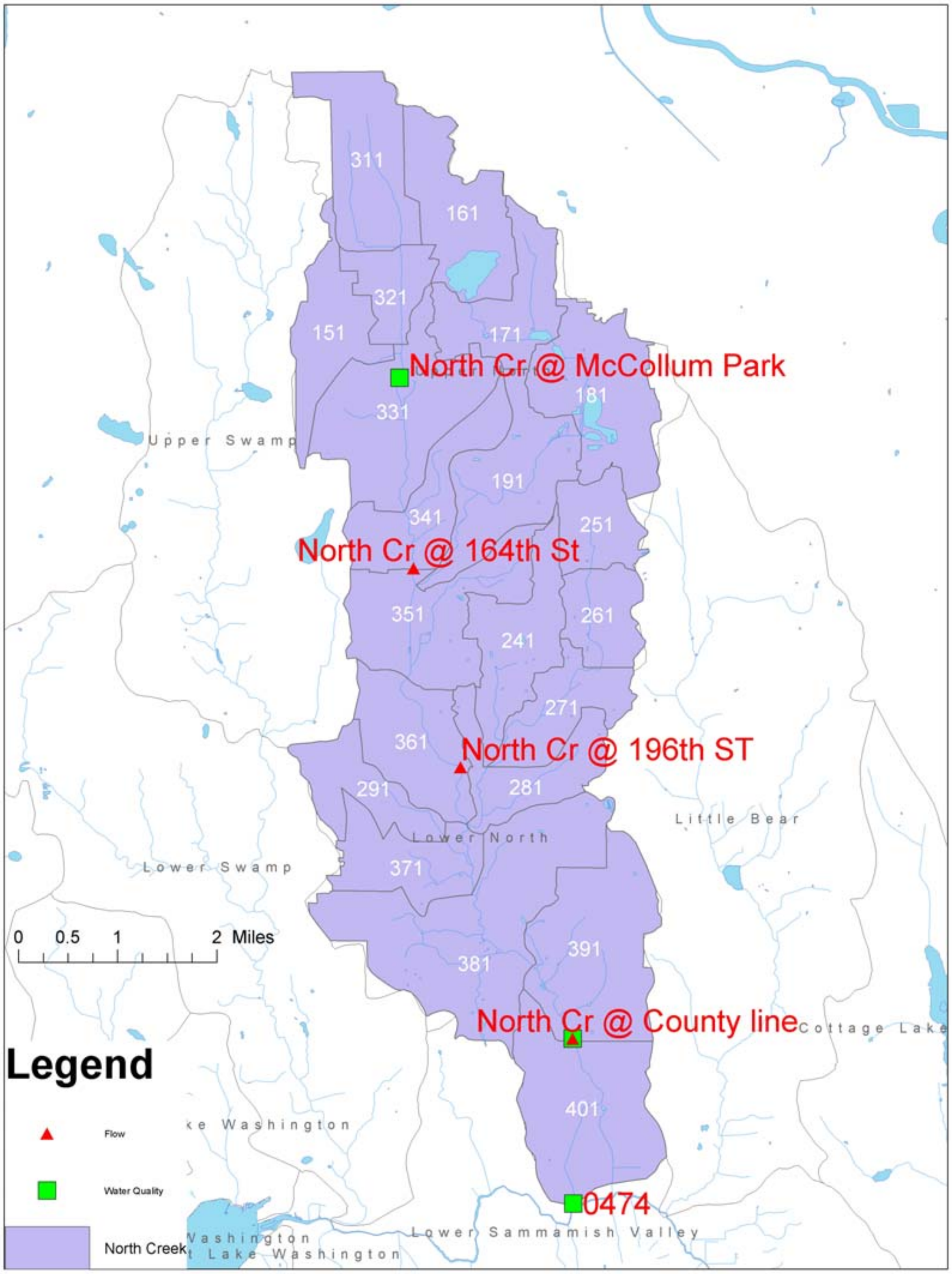


Figure 6-6 Flow and Water Quality Gages

6.2.3.2 Water Quality Calibration Data

Four long-term water quality sampling sites were identified within the North watershed. The first is sampled by King County, and data for that station were provided directly from the County. Snohomish County samples at three other stations, and data for these were obtained from the Snohomish County Surface Water Management (SWM) online data application at http://198.238.192.103/spw_swhydro/geo-search.asp. One of these three stations (Ruggs Lake) was not used for calibration because there were no data collected at this station during the calibration period.

The map in Figure 6.2-8 shows the spatial relation of the stations to the study area. All stations are located on North Creek.

The outlet station in King County (0474 – near Bothell, WA and Highway I-405) has data for many of the constituents of interest, and is the primary calibration station for the watershed. The two Snohomish County stations have data for only total phosphorus, nitrate, dissolved oxygen, TSS, temperature, and pH. Since there are few or no direct measurements of organic material (BOD, total organic carbon, dissolved organic matter, etc), the calibration of organics was based on the apparent organic N and P values inferred from measured total N, total P, and the inorganic nutrient forms (i.e., nitrate, ammonia, and orthophosphate).

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

Table 6.2-8 Linkage of Sampling Station to Reach Number

Station	Reach
North Cr @ McCollum Park (NCLU)	331
North Cr @ County Line (NCLD)	391
North Cr @ Station 0474	401

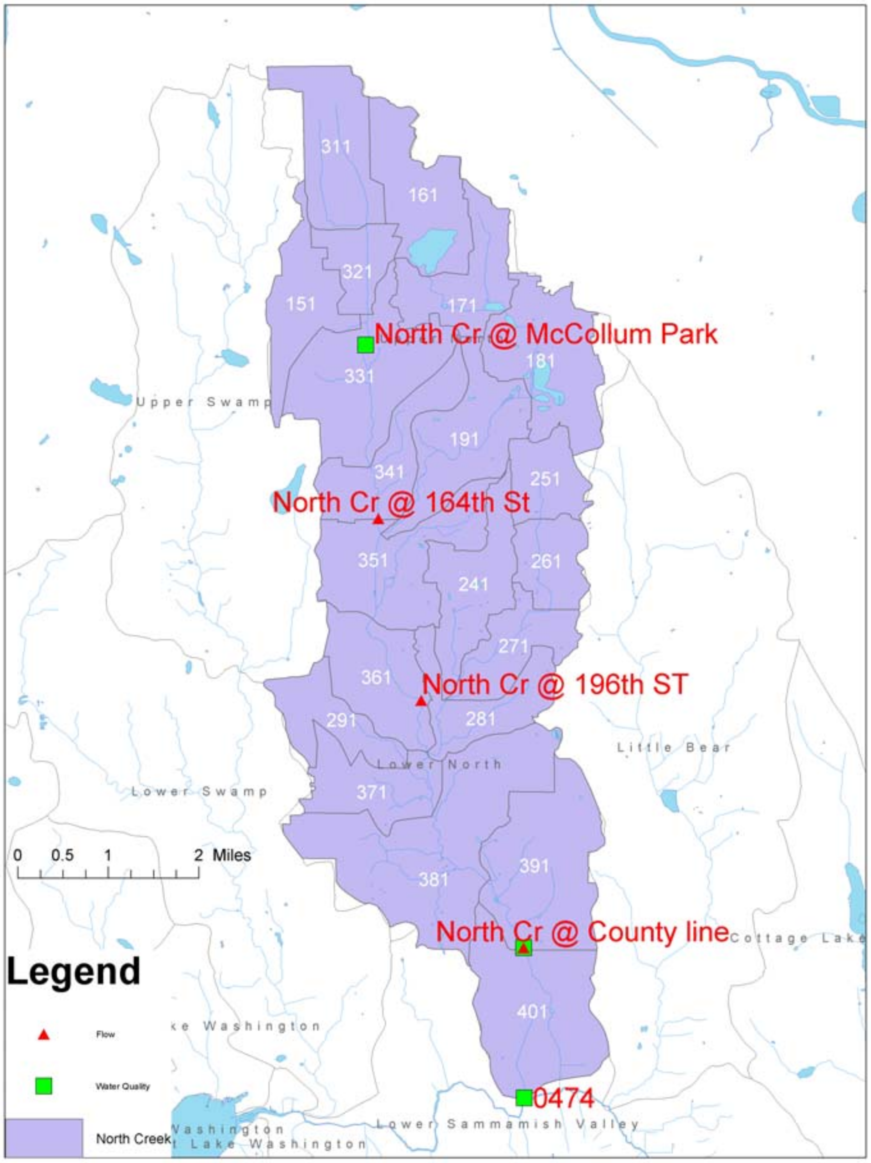


Figure 6.2-8 Map of Water Quality Data Stations Used for North Creek

All three stations are typically sampled on a monthly interval. Table 6.2-9 summarizes the period of record for the various constituents sampled at each station.

Table 6.2-9 Constituents and Periods of Record for Water Quality Monitoring Stations on North Creek

Stations

Constituent	McCollum Park (NCLU)	County Line (NCLD)	Station 0474
Water Temperature	10/13/96-9/10/01	10/13/96-9/10/01	1/11/93-9/10/01
Dissolved Oxygen	4/13/00-9/6/01	9/8/93-9/6/01	1/11/93-9/6/01
BOD			
Suspended Sand			
Suspended Silt			
Suspended Clay			
Total Suspended Sediment	10/13/96-9/10/01	10/13/96-9/10/01	1/11/93-9/10/01
Ammonia / Ammonium			1/11/93-9/10/01
Nitrite / Nitrate	10/13/96-9/10/01	10/13/96-9/10/01	1/11/93-9/10/01
Organic Nitrogen			
Total Nitrogen			4/12/93-9/10/01
Phosphate			1/11/93-9/10/01
Organic Phosphorus			
Total Phosphorus	10/13/96-9/10/01	10/13/96-9/10/01	1/11/93-9/10/01
Total Organic Carbon			1/11/93-9/10/01
Total Inorganic Carbon			
Alkalinity			5/12/97-9/10/01
pH	10/13/96-9/10/01	10/13/96-9/10/01	
Silica			
E-Coli			10/21/98-9/10/01
Benthic Algae			

6.2.3.3 WATERSHED SEGMENTATION AND CHARACTERIZATION

6.2.3.3.1 Catchment Delineation

The initial catchment delineation was performed as part of the Snohomish County Drainage Needs Report study (CH2M Hill, 2002). It was revised by AQUA TERRA Consultants to consolidate numerous small catchment areas into 21 catchments ranging in size from 0.60 to 3.20 square miles (Table 6.2-10). The catchments are shown in Figure 6-9; the schematic in .

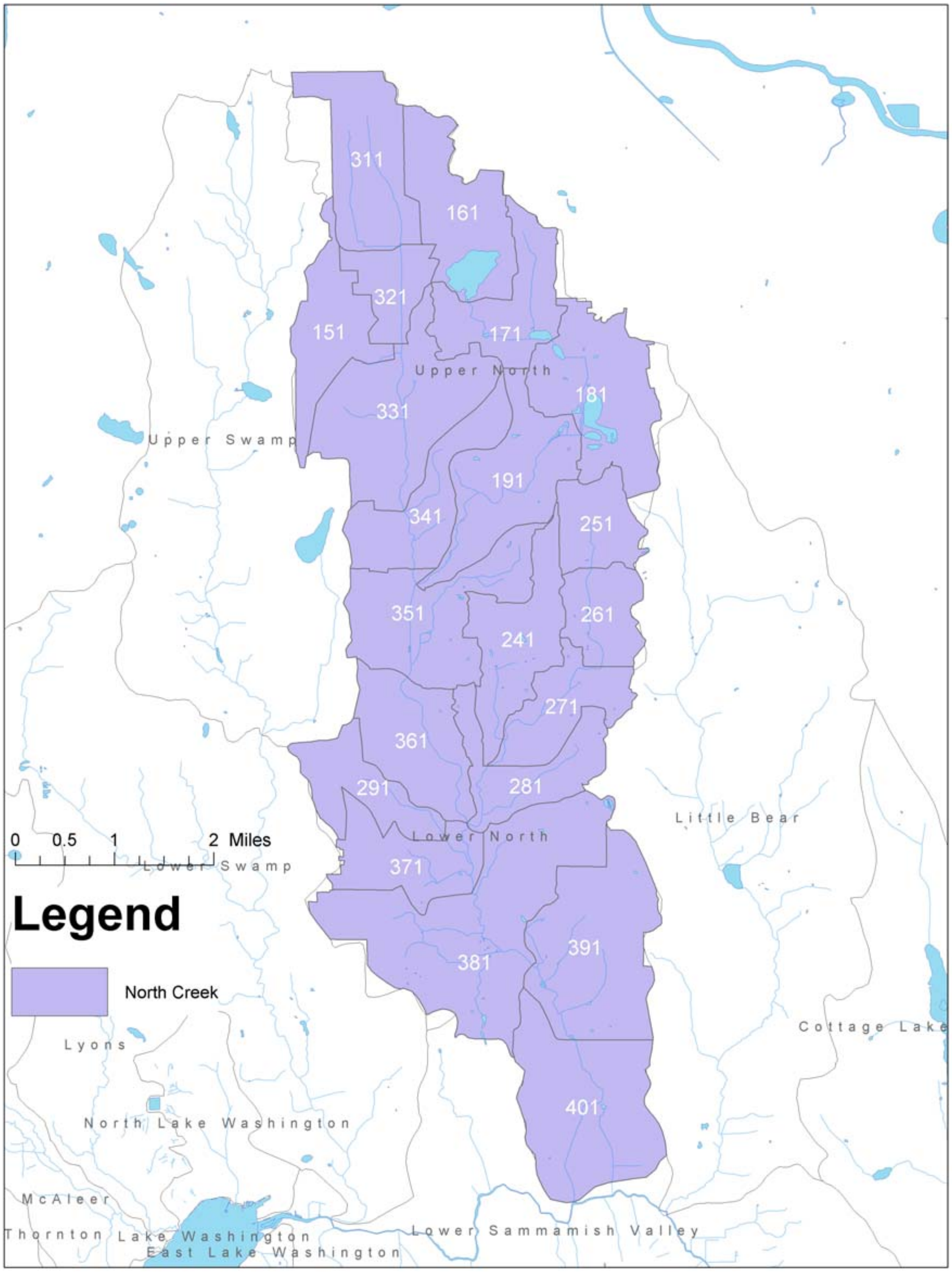
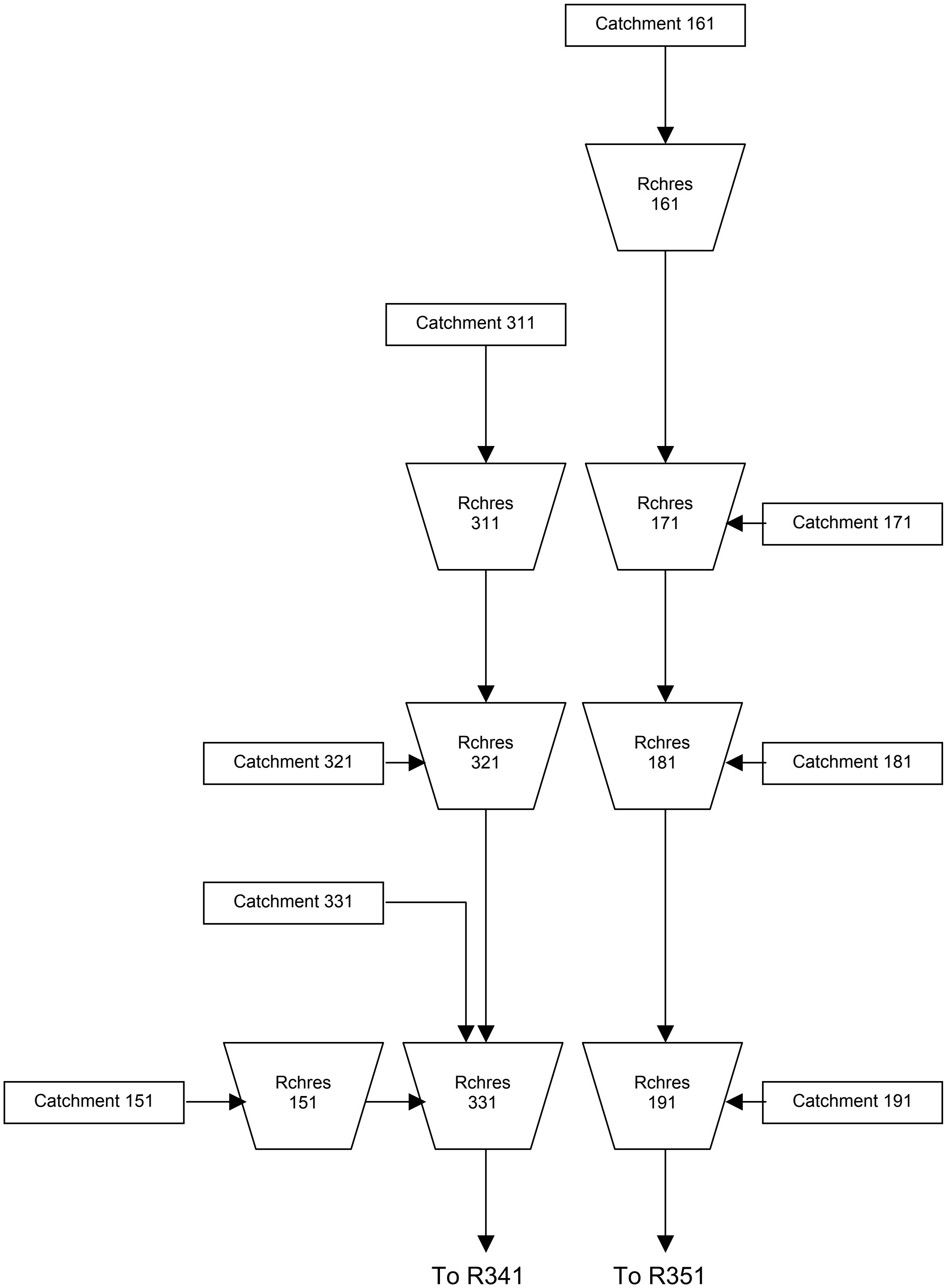


Figure 6-9 North Creek Catchments

Table 6.2-10 Catchment Areas

Catchment No.	Catchment Area (acres)	Stream Reach No.
151	662	151
161	767	161
171	712	171
181	1059	181
191	929	191
241	775	241
251	453	251
261	456	261
271	563	271
281	599	281
291	535	291
311	842	311
321	385	321
331	1310	331
341	722	341
351	1088	351
361	802	361
371	642	371
381	2050	381
391	1340	391
401	1339	401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Rchres 161
Catchment 311
Rchres 311
Rchres 171
Catchment 171
Rchres 321
Rchres 181
Catchment 321
Catchment 181
Catchment 331
Catchment 151
Rchres 151
Rchres 331
Rchres 191
Catchment 191
To R341
To R351

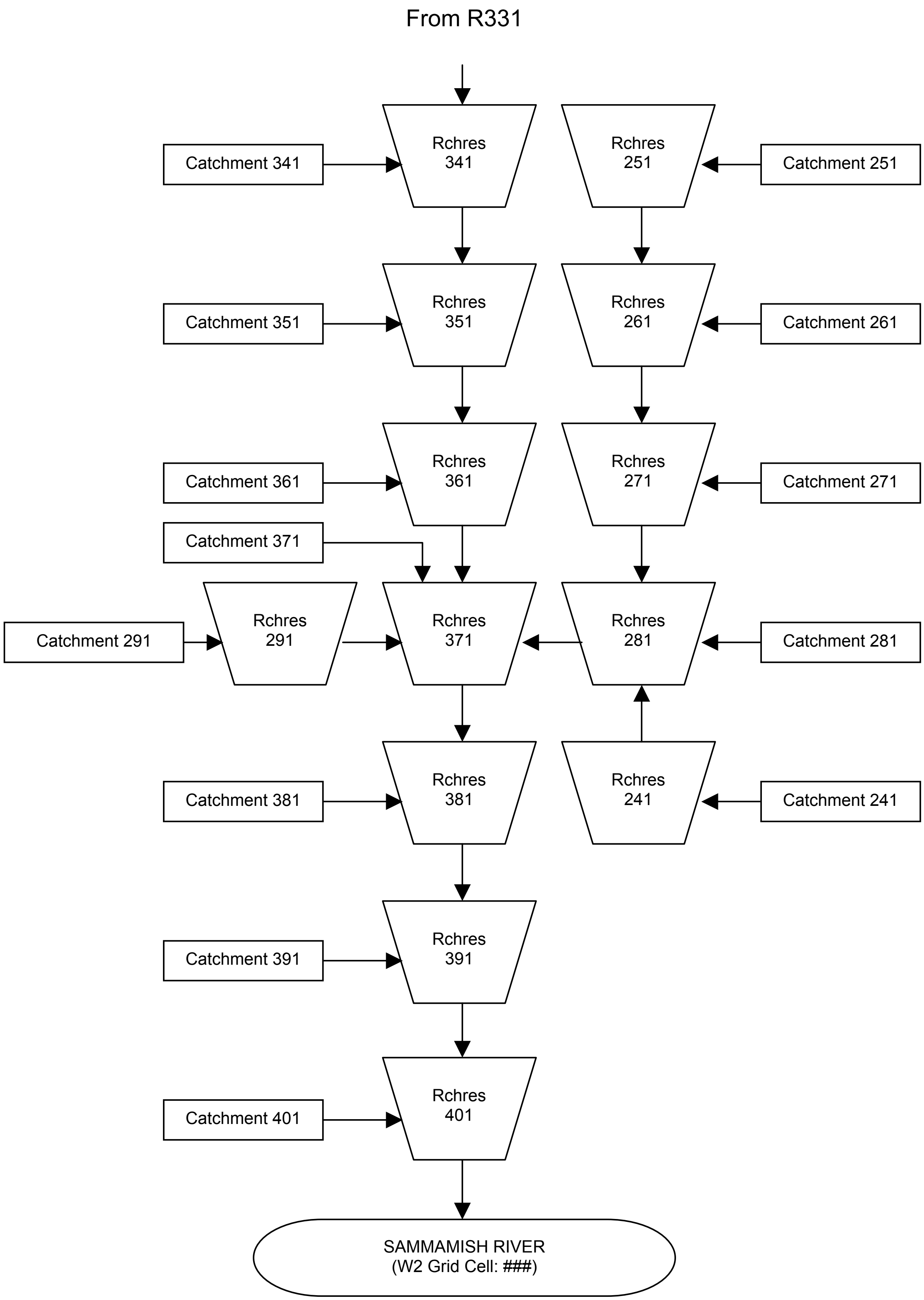


Figure 6-11 North Creek Schematic

6.2.3.3.2 PERLND and IMPLND Categories

For the purpose of the North 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. Detail on land segment creations can be found in section 3.1.2.2.

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. Note that there are no cropland or bedrock categories in the North Creek watershed.

6.2.3.3.3 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.

6.2.3.3.3.1 Physical Parameters

The North Creek watershed PERLND soil type and land use areas and IMPLND land use areas used in the HSPF model are summarized in Table 6.2-11. They are based on the GIS coverage and the delineation methodology described in Section 6.2.3.3.2.

Table 6.2-11 North Creek Watershed PERLND/IMPLND Areas

Land Use	Till (acres)	Outwash (acres)	Saturated (acres)	EIA (acres)	Total (acres)
Forest	1676	1423	812	0	3911
Pasture/Ag	450	306	83	0	838
Forest Residential	1383	467	100	0	1949
Low Density Residential	2894	2074	246	300	5514
High Density Residential	2315	1118	0	1612	5045
Commercial/Industrial	106	28	38	236	409
Roads	0	0	0	364	364
Total	**8824**	**5416**	**1279**	**2513**	**18031**

Table 6.2-11 North Creek Watershed PERLND/IMPLND Areas (cont'd)

Land Use	Till (%)	Outwash (%)	Saturated (%)	EIA (%)	Total (%)

Land Use	Till (%)	Outwash (%)	Saturated (%)	EIA (%)	Total (%)
Forest	9%	8%	5%	0%	22%
Pasture/Ag	2%	2%	<1%	0%	5%
Forest Residential	8%	3%	1%	0%	11%
Low Density Residential	16%	12%	1%	2%	31%
High Density Residential	13%	6%	0%	9%	28%
Commercial/ Industrial	1%	<1%	<1%	1%	2%
Roads	0%	0%	0%	2%	2%
Total	**49%**	**30%**	**7%**	**14%**	**100%**

6.2.3.3.3.2 Additional Physical Data Needs for Water Quality Simulation

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

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

6.2.3.3.3.3 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 North Creek watershed. The final values were selected through the calibration process and a comparison of the simulated and recorded streamflow. Table 6.2-12 through Table 6.2-16 present the final PERLND and IMPLND parameter values selected for the North Creek watershed.

Table 6.2-12 Final PERLND/IMPLND Parameter Values (Part 1)

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
11	Till Forest Flat	4.0	0.080	350	0.024	0.45	0.996
12	Till Forest Low	3.5	0.070	300	0.075	0.45	0.996
13	Till Forest Med	3.0	0.060	250	0.124	0.45	0.996

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
14	Till Forest Steep	2.5	0.050	200	0.203	0.45	0.996
21	Till Pasture Flat	4.0	0.070	350	0.025	0.45	0.996
22	Till Pasture Low	3.5	0.060	300	0.068	0.45	0.996
23	Till Pasture Med	3.0	0.050	250	0.116	0.45	0.996
24	Till Past Steep	2.5	0.040	200	0.184	0.45	0.996
31	Till Forest Residential Flat	4.0	0.080	350	0.024	0.45	0.996
32	Till Forest Residential Low	3.5	0.070	300	0.075	0.45	0.996
33	Till Forest Residential Med	3.0	0.060	250	0.124	0.45	0.996
34	Till Forest Res Steep	2.5	0.050	200	0.203	0.45	0.996
41	Till Low Density Residential Flat	4.0	0.040	350	0.024	0.45	0.996
42	Till Low Density Residential Low	3.5	0.030	300	0.070	0.45	0.996
43	Till Low Density Residential Med	3.0	0.025	250	0.119	0.45	0.996
44	Till Low Density Res Steep	2.5	0.020	200	0.180	0.45	0.996
51	Till High Density Residential Flat	4.0	0.040	350	0.023	0.45	0.996
52	Till High Density Residential Low	3.5	0.030	300	0.068	0.45	0.996
53	Till High Density Residential Med	3.0	0.025	250	0.116	0.45	0.996
54	Till High Density Res Steep	2.5	0.020	200	0.181	0.45	0.996
61	Till Commercial/ Industrial Flat	4.0	0.040	350	0.024	0.45	0.996
62	Till Commercial/ Industrial Low	3.5	0.030	300	0.068	0.45	0.996
63	Till Commercial/ Industrial Med	3.0	0.025	250	0.120	0.45	0.996
64	Till Commercial/ Industrial Steep	2.5	0.020	200	0.186	0.45	0.996
71	Outwash Forest	5.0	1.0	300	0.082	0.30	0.996
72	Outwash Pasture	5.0	0.7	300	0.046	0.30	0.996
73	Outwash Forest Residential	5.0	1.0	300	0.082	0.30	0.996
74	Outwash Low Density Res	5.0	0.4	300	0.059	0.30	0.996
75	Outwash High Density Res	5.0	0.4	300	0.049	0.30	0.996

No.	PERLND	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
76	Outwash Commercial/Ind	5.0	0.4	300	0.040	0.30	0.996
81	Saturated Forest	4.0	2.0	150	0.048	0.50	0.996
82	Saturated Pasture	4.0	1.8	150	0.022	0.50	0.996
83	Saturated Forest Residential	4.0	2.0	150	0.048	0.50	0.996
84	Saturated Low Density Res	4.0	1.0	150	0.026	0.50	0.996
85	Saturated High Density Res	4.0	1.0	150	0.040	0.50	0.996
86	Saturated Commercial/Ind	4.0	1.0	150	0.032	0.50	0.996
950	External GW	4.5	0.6	400	0.100	0.50	0.999

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 6.2-13 Final PERLND/IMPLND Parameter Values (Part 2)

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
11	Till Forest Flat	2.0	2.0	0.07	0.02	0.0
12	Till Forest Low	2.0	2.0	0.07	0.02	0.0
13	Till Forest Med	2.0	2.0	0.07	0.03	0.0
14	Till Forest Steep	2.0	2.0	0.07	0.03	0.0
21	Till Pasture Flat	2.0	2.0	0.07	0.03	0.0
22	Till Pasture Low	2.0	2.0	0.07	0.03	0.0
23	Till Pasture Med	2.0	2.0	0.07	0.03	0.0
24	Till Past Steep	2.0	2.0	0.07	0.03	0.0
31	Till Forest Residential Flat	2.0	2.0	0.07	0.03	0.0
32	Till Forest Residential Low	2.0	2.0	0.07	0.03	0.0
33	Till Forest Residential Med	2.0	2.0	0.07	0.03	0.0
34	Till Forest Res Steep	2.0	2.0	0.07	0.03	0.0
41	Till Low Density Residential Flat	2.0	2.0	0.07	0.03	0.0

No.	PERLND	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
42	Till Low Density Residential Low	2.0	2.0	0.07	0.03	0.0
43	Till Low Density Residential Med	2.0	2.0	0.07	0.03	0.0
44	Till Low Density Res Steep	2.0	2.0	0.07	0.03	0.0
51	Till High Density Residential Flat	2.0	2.0	0.07	0.03	0.0
52	Till High Density Residential Low	2.0	2.0	0.07	0.03	0.0
53	Till High Density Residential Med	2.0	2.0	0.07	0.03	0.0
54	Till High Density Res Steep	2.0	2.0	0.07	0.03	0.0
61	Till Commercial/ Industrial Flat	2.0	2.0	0.07	0.03	0.0
62	Till Commercial/ Industrial Low	2.0	2.0	0.07	0.03	0.0
63	Till Commercial/ Industrial Med	2.0	2.0	0.07	0.03	0.0
64	Till Commercial/ Industrial Steep	2.0	2.0	0.07	0.03	0.0
71	Outwash Forest	2.0	2.0	0.06	0.03	0.0
72	Outwash Pasture	2.0	2.0	0.06	0.03	0.0
73	Outwash Forest Residential	2.0	2.0	0.07	0.03	0.0
74	Outwash Low Density Res	2.0	2.0	0.06	0.03	0.0
75	Outwash High Density Res	2.0	2.0	0.06	0.03	0.0
76	Outwash Commercial/Ind	2.0	2.0	0.06	0.03	0.0
81	Saturated Forest	10.0	2.0	0.00	0.03	0.7
82	Saturated Pasture	10.0	2.0	0.00	0.03	0.7
83	Saturated Forest Residential	10.0	2.0	0.00	0.03	0.7
84	Saturated Low Density Res	10.0	2.0	0.00	0.03	0.7
85	Saturated High Density Res	10.0	2.0	0.00	0.03	0.7
86	Saturated Commercial/Ind	10.0	2.0	0.00	0.03	0.7
950	External GW	2.0	2.0	0.0	0.00	0.0

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 6.2-14 Final PERLND/IMPLND Parameter Values (Part 3)

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
11	Till Forest Flat	0.20	1.50	0.35	1.00	0.50	Monthly
12	Till Forest Low	0.20	1.00	0.35	0.90	0.40	Monthly
13	Till Forest Med	0.20	0.60	0.35	0.80	0.30	Monthly
14	Till Forest Steep	0.20	0.45	0.35	0.70	0.20	Monthly
21	Till Pasture Flat	0.15	0.90	0.30	0.90	0.50	Monthly
22	Till Pasture Low	0.15	0.60	0.30	0.80	0.40	Monthly
23	Till Pasture Med	0.15	0.45	0.30	0.70	0.30	Monthly
24	Till Past Steep	0.15	0.30	0.30	0.60	0.20	Monthly
31	Till Forest Residential Flat	0.20	1.50	0.35	1.00	0.50	Monthly
32	Till Forest Residential Low	0.20	1.00	0.35	0.90	0.40	Monthly
33	Till Forest Residential Med	0.20	0.60	0.35	0.80	0.30	Monthly
34	Till Forest Res Steep	0.20	0.45	0.35	0.70	0.20	Monthly
41	Till Low Density Residential Flat	0.10	0.75	0.25	0.80	0.40	Monthly
42	Till Low Density Residential Low	0.10	0.45	0.25	0.70	0.30	Monthly
43	Till Low Density Residential Med	0.10	0.30	0.25	0.60	0.25	Monthly
44	Till Low Density Res Steep	0.10	0.20	0.25	0.50	0.20	Monthly
51	Till High Density Residential Flat	0.10	0.75	0.25	0.80	0.40	Monthly
52	Till High Density Residential Low	0.10	0.45	0.25	0.70	0.30	Monthly
53	Till High Density Residential Med	0.10	0.30	0.25	0.60	0.25	Monthly
54	Till High Density Res Steep	0.10	0.20	0.25	0.50	0.20	Monthly
61	Till Commercial/ Industrial Flat	0.10	0.75	0.25	0.80	0.40	Monthly
62	Till Commercial/ Industrial Low	0.10	0.45	0.25	0.70	0.30	Monthly
63	Till Commercial/ Industrial Med	0.10	0.30	0.25	0.60	0.25	Monthly
64	Till Commercial/ Industrial Steep	0.10	0.20	0.25	0.50	0.20	Monthly
71	Outwash Forest	0.20	0.75	0.35	0.0	0.70	Monthly
72	Outwash Pasture	0.15	0.75	0.30	0.0	0.70	Monthly

No.	PERLND	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
73	Outwash Forest Residential	0.20	0.75	0.25	0.0	0.70	Monthly
74	Outwash Low Density Res	0.10	0.75	0.25	0.0	0.70	Monthly
75	Outwash High Density Res	0.10	0.75	0.25	0.0	0.70	Monthly
76	Outwash Commercial/Ind	0.10	0.75	0.25	0.0	0.70	Monthly
81	Saturated Forest	0.20	3.00	0.50	1.0	0.50	Monthly
82	Saturated Pasture	0.15	3.00	0.50	1.0	0.50	Monthly
83	Saturated Forest Residential	0.20	3.00	0.50	1.0	0.50	Monthly
84	Saturated Low Density Res	0.10	3.00	0.50	1.0	0.50	Monthly
85	Saturated High Density Res	0.10	3.00	0.50	1.0	0.50	Monthly
86	Saturated Commercial/Ind	0.10	3.00	0.50	1.0	0.50	Monthly
950	External GW	0.15	0.30	0.30	6.0	0.5	Monthly

CEPSC: Interception storage (inches)
UZSN: Upper Zone Storage Nominal (inches)
NSUR: Surface roughness (Manning’s n)
INTFW: Interflow index
IRC: Interflow Recession Constant (per day)
LZETP: Lower Zone Evapotranspiration fraction (see Table 6.2-15 for monthly values)

Table 6.2-15 Final PERLND/IMPLND Parameter Values (Part 4): Monthly LZETP Values

No.	PERLND	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
11-14	Till Forest	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60
21-24	Till Pasture	0.20	0.20	0.20	0.25	0.30	0.35	0.40	0.40	0.40	0.35	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	0.35	0.30	0.20
73	Outwash Forest Residential	0.60	0.60	0.60	0.60	0.70	0.70	0.70	0.70	0.70	0.60	0.60	0.60
74	Outwash Low Density Res	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
75	Outwash High Density Res	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
76	Outwash Commercial/Ind	0.15	0.15	0.20	0.20	0.25	0.25	0.25	0.25	0.25	0.20	0.20	0.15
81	Saturated Forest	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
82	Saturated Pasture	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
83	Saturated Forest Residential	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
84	Saturated Low Density Res	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
85	Saturated High Density Res	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
86	Saturated Commercial/Ind	0.50	0.50	0.50	0.60	0.70	0.75	0.80	0.80	0.75	0.70	0.60	0.50
950	External GW	0.20	0.20	0.20	0.25	0.30	0.35	0.40	0.40	0.40	0.35	0.30	0.20

Table 6.2-16 Final PERLND/IMPLND Parameter Values (Part 5)

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

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

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

PERLND 950 is an external groundwater PERLND added to the HSPF model to represent groundwater entering the North Creek watershed. It has pasture PERLND parameter values.

6.2.3.3.4 CONVEYANCE SYSTEM SEGMENTATION AND CHARACTERIZATION

The current segmentation scheme is primarily the result of the catchment delineation. The modeling scheme incorporates a single HSPF reach per catchment.

6.2.3.3.4.1 HSPF Reach Network

The current network includes 21 reaches totaling approximately 25 miles in length; with the individual reaches ranging from approximately 0.4 to 2.8 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.

Snohomish County has provided FTABLEs from the Snohomish County Drainage Needs Report study. AQUA TERRA staff reviewed and aggregated these FTABLEs, where needed, to match the model's reach lengths.

Table 6.2-17 shows the data used to construct the FTABLEs for North Creek.

Table 6.2-17 Stream Reach Data

RCHRES	RCHRES Length (mi)	Upstream Elev (ft)	Downstream Elev (ft)	Change in Elev (ft)	Slope (%)	DNR RCHRES

RCHRES	RCHRES Length (mi)	Upstream Elev (ft)	Downstream Elev (ft)	Change in Elev (ft)	Slope (%)	DNR RCHRES
151	0.37	440	394	46	2.3%	825,830,845
161	0.57	443	430	13	0.4%	685
171	1.47	430	400	30	0.4%	665,660,670
181	1.24	400	397	3	0.1%	630,635,650
191	2.84	397	243	154	1.0%	605,610,615
241	1.07	308	174	134	2.4%	525,535
251	0.52	394	377	17	0.6%	580,590
261	1.09	377	351	26	0.5%	560,570
271	1.87	351	174	177	1.8%	510,515
281	0.81	174	121	52	1.2%	500,503
291	1.20	358	148	210	3.3%	410,415,425, 430,435
311	**1.40**	**518**	**456**	**62**	**0.8%**	**230,240**
321	**1.00**	**456**	**394**	**62**	**1.2%**	**210,220**
331	**1.85**	**394**	**295**	**98**	**1.0%**	**200**
341	**0.66**	**295**	**259**	**36**	**1.0%**	**195**
351	**1.14**	**259**	**203**	**56**	**0.9%**	**190**
361	**1.89**	**203**	**148**	**55**	**0.6%**	**170,180**
371	**1.18**	**148**	**108**	**40**	**0.6%**	**140,150,160**
381	**1.21**	**108**	**62**	**46**	**0.7%**	**120**
391	**1.01**	**62**	**39**	**23**	**0.4%**	**110**
401	**1.95**	**39**	**20**	**20**	**0.2%**	**100**

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

6.3 MODEL CALIBRATION

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

6.3.1 WATER QUANTITY

General procedures on HSPF water quantity calibration can be found in Section 3.1.3

6.3.1.1 HYDROLOGIC CALIBRATION AND KEY CALIBRATION PARAMETERS

For the North watershed LZSN values were decreased for till soils (the predominate soil type in the watershed) from 4.5 to a range from 4.0 to 2.5 inches, dependent on slope (steeper slopes, lower LZSN values – see Table 6.2-12). Outwash and saturated LZSN values were set to regional values of 5.0 and 4.0 inches, respectively. LZETP values were adjusted monthly using the MON-LZETPARM Block in HSPF. LZETP monthly values varied by PERLND vegetation types (with forest values higher than pasture values, which in turn, are higher than residential landscaping values) and by season (winter low; summer high – see Table 6.2-15). For forest PERLNDs the monthly LZETP values are relatively constant and varied from 0.60 in January to 0.70 in August; pasture monthly values varied from 0.20 to 0.40. UZSN values were increased by 50 percent (Table 6.2-14) from the regional values. DEEPFR was changed from its initial value of zero to 0.07 for till soils and 0.06 for outwash soils (Table 6.2-13). DEEPFR represents the fraction of groundwater that bypasses the stream gage and recharges the underlying aquifer or flows directly to the Sammamish River.

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

The USGS regional values for till PERLNDs were used as a starting point and then varied by slope and land use. The forest INFILT value varied from 0.08 to 0.50 (steeper slope, lower INFILT – see Table 6.2-12). The pasture INFILT ranged from 0.07 to 0.04. The urban landscaping INFILT varied from 0.04 to 0.02 for the North 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.

AGWRC is calculated as the rate of baseflow (i.e., groundwater discharge to the stream) on one day divided by the baseflow on the previous day; thus AGWRC is the parameter that controls the rate of outflow from the groundwater storage. Using hydrograph separation techniques, values of AGWRC are often calculated as the slope of the receding baseflow portion of the hydrograph; these initial values are then adjusted as needed through calibration. The KVARY index allows users to impose a nonlinear recession that so that the slope can be adjusted as a function of the groundwater gradient. KVARY is usually set to zero unless the observed flow record shows a definite change in the recession rate (i.e., slope) as a function of wet and dry seasons.

For the North watershed the AGWRC value was set to the USGS regional value of 0.996 for all soils (Table 6.2-12). KVARY was found to differ slightly from the regional value of 0.50 for till and was set to 0.45. KVARY for outwash and saturated did not change from their regional values of 0.30 and 0.50, respectively.

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

INTFW - Interflow inflow parameter (dimensionless).

IRC - Interflow recession rate (per day).

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

INTFW was varied from 1.00 to 0.70 for till forest (see Table 6.2-14). Lower values were used for steeper slopes to increase surface runoff and decrease interflow. For till pasture the values ranged from 0.90 to 0.60; till landscaping had values between 0.80 and 0.50. The reason for the low till INTFW values was because in the water quality calibration it was found that there was insufficient surface runoff to provide the measured loadings. Decreasing the till INTFW values produced more surface runoff (and less interflow) without significantly changing the hydrology calibration. Outwash INTFW values were set to the regional value of 0.0 (only surface runoff and groundwater are produced by outwash soils), as were saturated INTFW values (1.0).

IRC varied from 0.50 to 0.20 to produce relatively slow interflow runoff for forest and pasture on till soils, with lower values at higher slopes (Table 6.2-14). The till landscaping IRC values were lower (0.40 to 0.20). Outwash IRC values are set to 0.70 (regional values), but have no impact on the simulation because there is no outwash interflow, as noted above. Saturated IRC values were also set to regional values (0.50).

As part of the calibration process it was found that additional groundwater from a source outside of the North Creek watershed enters North Creek as base flow downstream of the 196th Street gage but upstream of the 240th Street gage. This phenomenon was also observed in the Snohomish County Drainage Needs Report for North Creek. The measured base flow at 196th Street is approximately 6 cfs. At 240th Street (approximately 3.4 miles downstream) the measured base flow increases to 16 cfs. The increase in base flow between these two gages cannot be fully explained by the intervening contributing area. Swamp Creek, west of North Creek, loses most of its groundwater. It is assumed that some of the Swamp Creek groundwater drains to North Creek downstream of 196th Street. This has been represented in the North Creek HSPF model by the addition of 4000 acres of simulated till pasture groundwater between stream reaches 361 (196th Street) and 391 (240th Street). This external groundwater source uses the Alderwood precipitation record and a precipitation multiplier of 1.11 and results in a good match of base flow at the 240th Street gage.

6.3.1.2 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 Snohomish County gage on North Creek at 240th Street SE. The streamflow recorded at 164th Street SE and 196th Street SE were too short to provide significant calibration statistics.

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 240th Street for water years 1999 through 2002 are shown in Table 6.3-1. The average daily flows and annual volumes show that the simulated results match well with the observed values, only differing by 0.6 percent. The correlation coefficient is 0.94 and the model fit efficiency is 0.84. These values show an excellent calibration at this location.

Table 6.3-1 Flow Statistics at Snohomish County Gage at 240th (Oct 1998 – Sep 2002)

	Sim (cfs)	Obs (cfs)	Diff (cfs)	Diff (%)
Mean	58.90	58.52	0.38	0.6%
Geometric Mean	41.77	40.75	1.02	2.5%
Correlation Coefficient	0.94			
Coefficient of Determination	0.88			
Mean Error	-0.374			
Mean Absolute Error	10.789			
RMS Error	22.24			
Nash Sutcliffe	0.16			
Model Fit Efficiency	0.84			

	Sim (cfs)	Obs (cfs)	Diff (cfs)	Diff (%)
Skill Score				

A comparison of the annual volumes by water year in Table 6.3-2 shows some variability from water year to water year, with 2002 being low and 2000 being high, but in general an excellent match.

Table 6.3-2 Annual Volumes at Snohomish County Gage at 240th (Oct 1998 – Sep 2002)

Water Year	Precip (in)	Sim (in)	Obs (in)	Difference (in)	Difference (%)
1999	57.21	37.80	38.68	-0.88	-2.3%
2000	47.67	30.63	28.34	2.29	8.1%
2001	36.74	19.03	17.91	1.12	6.3%
2002	51.23	35.23	36.98	-1.75	-4.7%
Average	48.21	30.67	30.48	0.20	0.6%

Mean monthly volumes for the Snohomish County gage at 240th are shown in Table 6.3-3. The mean monthly simulated values are close to the observed values with the greatest differences occurring in the months of April and October. The flows in these transition months shows that the simulated flow changes from dry to wet (September to October) and wet to dry (April to May) are delayed compared to the observed data. This is a timing problem that does not affect the overall calibration volume accuracy.

Table 6.3-3 Mean Monthly Flow Statistics at Snohomish County Gage at 240th

Month	Sim (in)	Obs (in)	Diff (in)	Diff (%)
Jan	4.46	4.20	0.26	6.2%
Feb	4.32	4.03	0.28	7.0%
Mar	3.76	3.38	0.38	11.3%
Apr	2.55	2.16	0.39	18.2%
May	1.61	1.50	0.11	7.5%
Jun	1.45	1.39	0.07	4.8%
Jul	1.16	1.14	0.02	1.5%
Aug	0.88	0.84	0.04	4.7%
Sep	0.71	0.70	0.01	2.0%

Month	Sim (in)	Obs (in)	Diff (in)	Diff (%)
Oct	1.40	1.82	-0.42	-23.3%
Nov	3.75	4.49	-0.74	-16.5%
Dec	4.64	4.85	-0.21	-4.3%
Total	30.67	30.48	0.20	0.6%

Table 6.3-3 uses the HSPF Expert System statistics to evaluate the accuracy of the calibration. The simulated and observed flow values were divided into a number of categories and then evaluated according to defined criteria that allow the user to target specific flow ranges and events, such as the highest 10% of the flows, 50% low flows, summer storm volumes, etc. The criteria values range from 10 percent error to 20 percent error, depending on the type of flow range. Of the 12 criteria show in Table 6.3-3, all are met with either excellent or good comparisons. The storm peaks and volume calculations were based on a total of 27 winter storm events and 10 summer storms during the four-year calibration period.

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

Table 6.3-3 Expert System Statistics at Snohomish Co Gage at 240th (Oct 1998 – Sep 2002)

	Sim (cfs)	Obs (cfs)	Diff (cfs)	Diff (%)	Criteria (%)	Meets Criteria
Total (in)	30.67	30.48	0.19	0.6%	10%	Excellent
10% high (in)	10.47	11.07	-0.60	-5.4%	10%	Good
25% high (in)	18.06	18.15	-0.09	-0.5%	15%	Excellent
50% low (in)	5.56	5.75	-0.19	-3.3%	15%	Excellent
25% low (in)	2.12	2.02	0.10	5.0%	15%	Excellent
10% low (in)	0.74	0.71	0.03	4.2%	15%	Excellent
Storm volume (in)	14.05	14.95	-0.90	-6.0%	20%	Excellent
Average storm peak (cfs)	333.54	322.84	10.70	3.3%	15%	Excellent
Summer volume (in)	4.20	4.06	0.14	3.4%	15%	Excellent
Winter volume (in)	22.31	22.76	-0.45	-2.0%	10%	Excellent
Summer storms (in)	0.78	0.77	0.01	1.3%	10%	Excellent
Winter storms (in)	12.74	13.42	-0.68	-5.1%	15%	Good

Figure 6-13 shows the daily simulated and observed streamflow at the Snohomish County at 240th for the period of October 1998 through September 2002. Figure 6-15 shows the flow duration for the same period and demonstrates a good match.

Figure 6-17 and Figure 6-19 compare the 240th Street gage hourly simulated and observed streamflow values for the winter flow periods of December 1998 and December 1999, respectively.

Monthly simulated and observed flow volumes are shown in Figure 6-21. A scatter plot of the simulated and observed daily values are presented in Figure 6-23. The scatter plot shows a correlation coefficient of 0.94.

Because of the short period of record for the Snohomish County stream gages at 196th Street SE and 164th Street SE fewer plots of simulated and observed flows were produced at these two locations.

Figure 6-13 Snohomish Co Gage at 240th Daily Flow Time Series

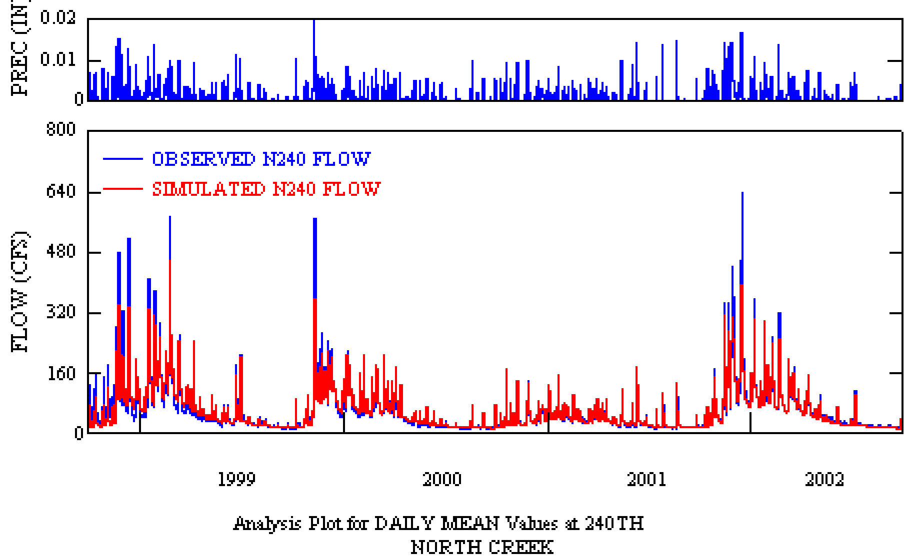


Figure 6-15 Snohomish Co Gage at 240th Flow Duration

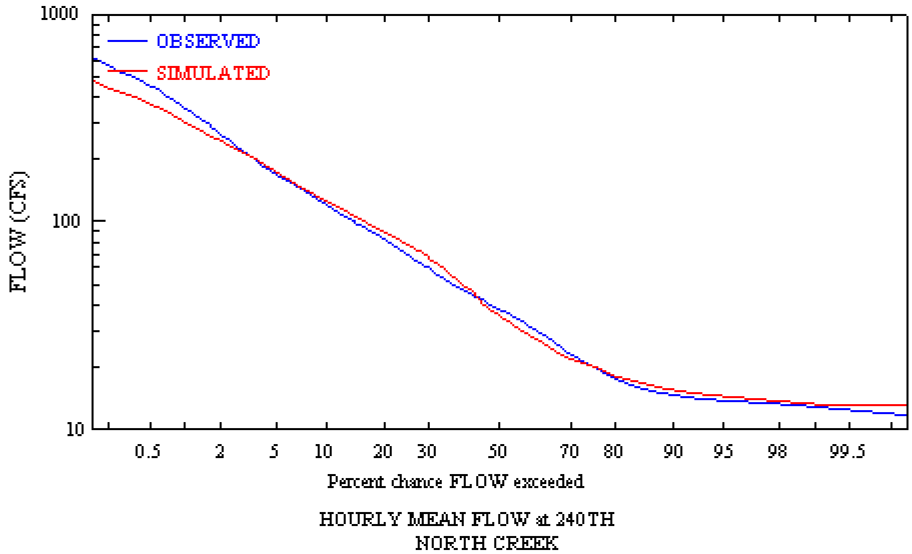


Figure 6-17 Snohomish Co Gage at 240th December 1998 Hourly Flow Time Series

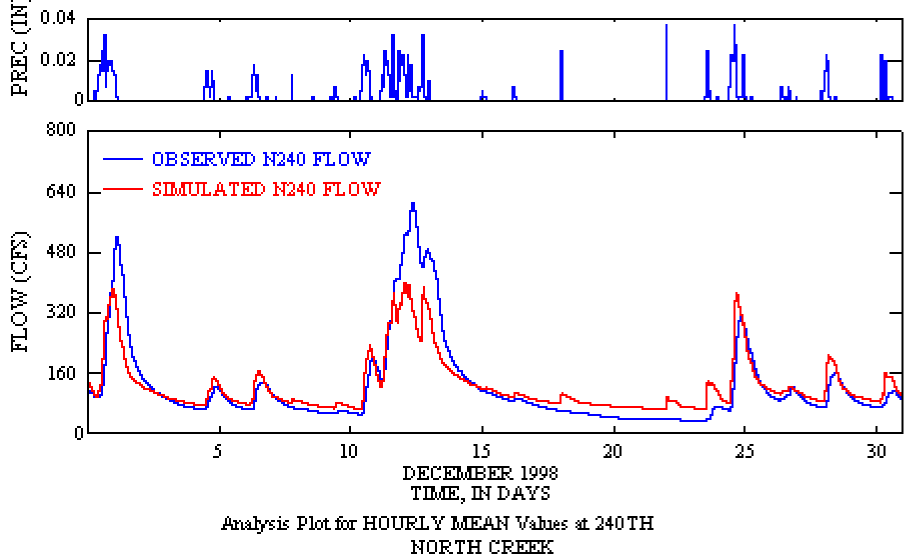


Figure 6-19 Snohomish Co Gage at 240th December 1999 Hourly Flow Time Series

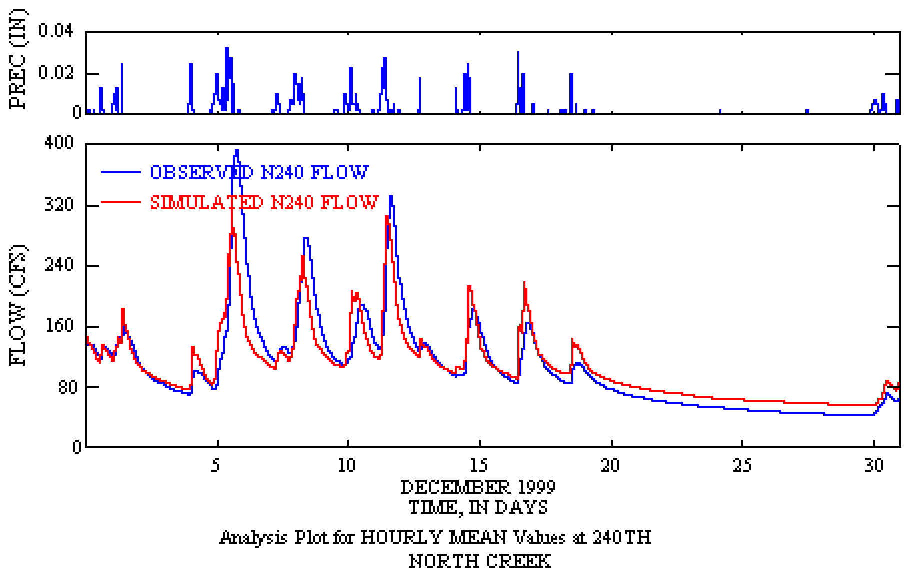


Figure 6-21 Snohomish Co Gage at 240th Monthly Flow Time Series

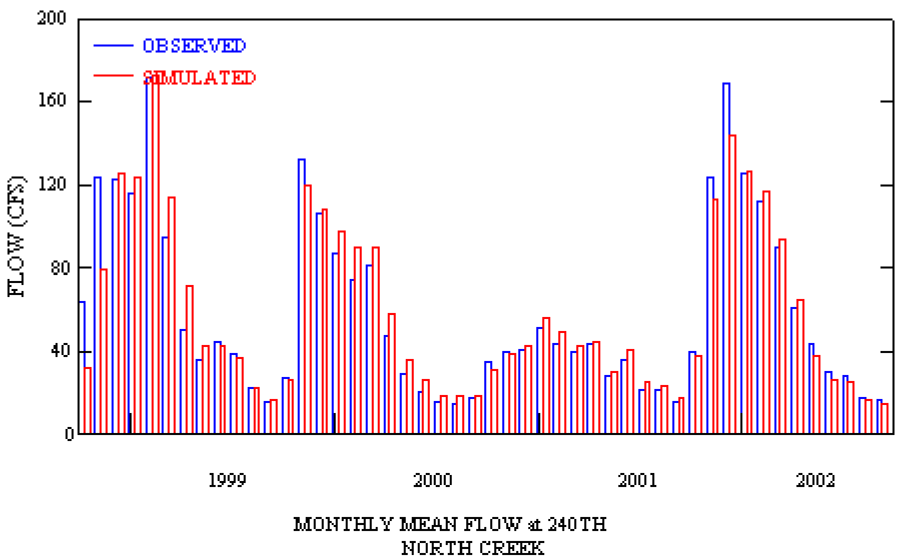
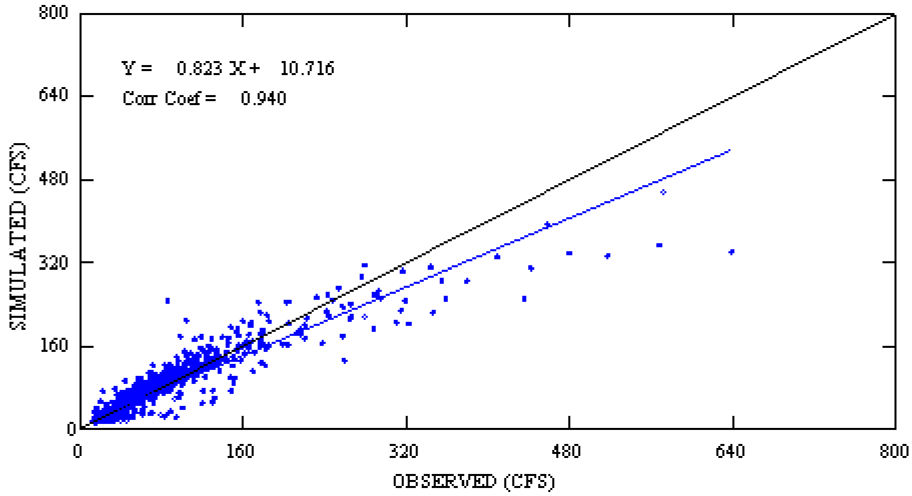


Figure 6-23 Snohomish Co Gage at 240th Scatter Plot



Scatter Plot (OBSERVED vs SIMULATED)
for MEAN DAILY FLOW at 240TH
NORTH CREEK

Figure 6.3-7 Snohomish Co Gage at 240th Residual Plot

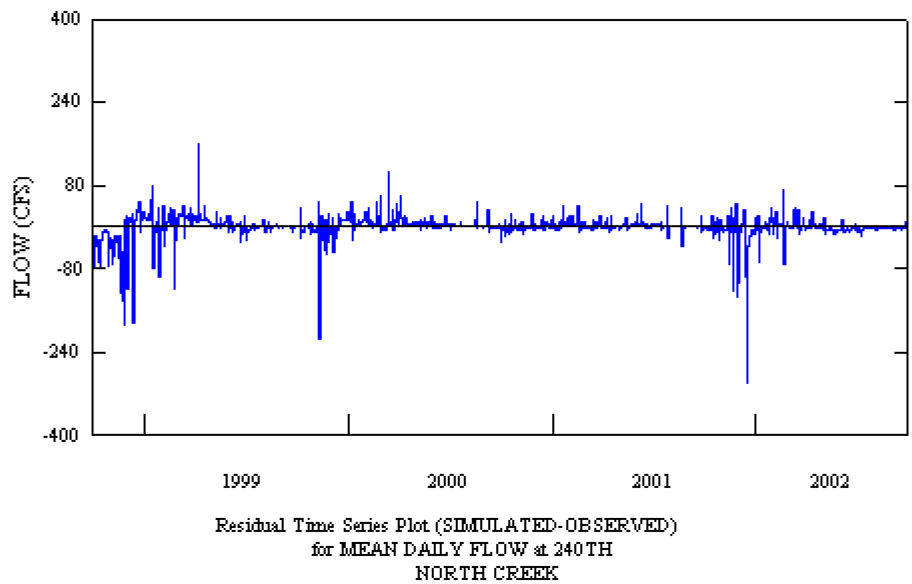


Figure 6.3-8 Snohomish Co Gage at 196th Hourly Flow Time Series

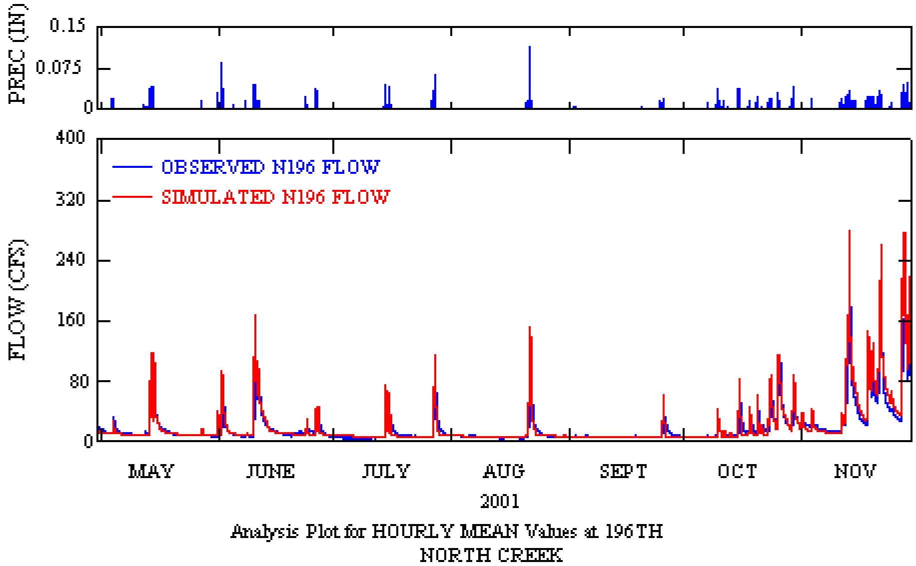
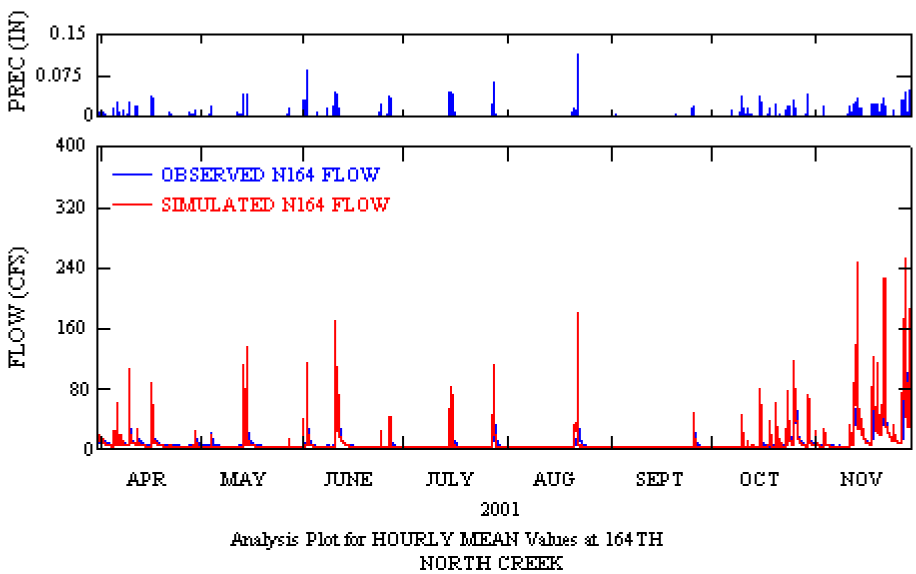


Figure 6.3-9 Snohomish Co Gage at 164th Hourly Flow Time Series



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

- Precipitation
- Total Runoff (sum of following components)
  - Surface Runoff/Overland Flow
  - Interflow
  - Groundwater/Baseflow
- Total Actual Evapotranspiration (ET) (sum of following components)
  - Interception ET
  - Upper zone ET
  - Lower zone ET
  - Baseflow ET
  - Active groundwater ET
- Deep Groundwater Recharge/Losses

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

The water balance components for the entire North Creek watershed are shown in Table 6.3-4. These values are weighed based on the contributing area of each North Creek PERLND for the period of record (water years 1999 through 2002). For this time period the mean annual precipitation was 48.21 inches, the total runoff was 27.86 inches, the groundwater flow to the stream was 15.78 inches, the potential evaporation was 23.95 inches, and the actual evaporation was 19.39 inches. These values are all close to or in the range of the expected values, as presented by Dinicola (1990), except for total runoff.

Table 6.3-4 North Creek Mean Annual Water Balance (Oct 1998 – Sep 2002)

PERLND:	Till (in)	Out-wash (in)	Saturated (in)	EIA (in)	Watershed Average (in)	Expected (Dinicola, 1990) (in)
Influx						
Rainfall	48.22	48.22	48.22	48.21	48.21	35-50
Runoff						
Surface	4.12	0.29	7.44	38.85	8.04	
Interflow	9.19	0.00	4.55	0.00	4.82	
Baseflow	12.79	26.15	12.42	0.00	15.00*	
Total	26.10	26.44	24.41	38.85	27.86	15-20
GW Inflow						
Deep	1.02	1.71	0.00	0.00	1.01	
Active	13.50	26.80	15.77	0.00	15.78	
Total	14.52	28.51	15.77	0.00	16.79	
Evaporation						
Potential	23.95	23.95	23.95	23.95	23.95	25
Interception Storage	9.96	9.97	10.73	9.35	9.93	
Upper Zone	6.12	3.09	8.67	0.00	4.54	
Lower Zone	4.34	6.35	1.15	0.00	4.11	
Ground Water	0.00	0.00	2.68	0.00	0.19	
Baseflow	0.72	0.72	0.72	0.00	0.62	
Total	21.14	20.13	23.95	9.35	19.39	18-20
Area (ac)	**8,823**	**5,415**	**1,279.33**	**2,512.77**	**18,031.20**	
Area (%)	**48.94%**	**30.03%**	**7.10%**	**13.94%**	**100.00%**	

* An additional 2.40 inches (3600 acre-feet) per year of baseflow enters North Creek from outside of the watershed. This external source of groundwater is approximately 14% of the total baseflow and increases the total runoff to 30.26 inches per year.

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.

6.3.1.3 CALIBRATION SUMMARY

North Creek was calibrated at one location: Snohomish County gage at 240th Street SE in Bothell. Statistics and plots were produced for to demonstrate the accuracy of the calibration.

Annual volumes matched well, with error of 0.6% at the Snohomish County gage at 240th Street SE.

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

6.3.2 WATER QUALITY

6.3.2.1 Initial Water Quality Parameter Set

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

6.3.2.2 Water Quality Calibration

The time period of the water quality calibration is October 1992 – September 2001. This period includes the hydrology calibration time period (10/1996 – 9/2001) and utilizes additional water quality data (and meteorological data) that are available at the outlet gage (Station 0474) beginning in 1993.

The initial calibration of North Creek was performed simultaneously and in concert with the calibration of North and Swamp Creeks in order to develop general land use-specific water quality parameter sets for use in other parts of the SWAMP and Green-Duwamish Basins. However, subsequent to development of an initial parameter set using all three watersheds, small adjustments were made to the pollutant loading parameters in each watershed to fine-tune the calibration. Similarly to the Little Bear Creek watershed, it was assumed that significant impacts of instream processes on pollutant concentrations are unlikely. Therefore, the main emphasis of the calibration and parameter adjustments was the nonpoint loading, primarily via the subsurface (interflow and baseflow) concentrations, but also surface loading associated with surface runoff and sediment. However, the instream parameters were reviewed and adjusted as needed to ensure reasonable values for the specific stream reaches in these watersheds.

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

6.3.2.3 Summary of Calibration Procedures

As noted earlier, the main goal of water quality calibration is to obtain acceptable agreement of observed and simulated concentrations, while maintaining the instream water quality parameters and processes within physically realistic bounds, and the nonpoint loading rates within the expected ranges from the literature or based on local experience and guidelines. The use of target nonpoint source loading rates is useful because the water quality concentrations measured at a particular location reflect the combined effects of contributions from multiple land uses, point sources, and instream processes. The target loading rates help to guide the calibration effort and ensure that simulated rates and fluxes from each land use category are reasonable and consistent with literature values and/or local knowledge. These nonpoint loading rates (also known as export coefficients) are highly variable with values ranging up to an order of magnitude, depending on local conditions. Therefore, AQUA TERRA compiled a set of targets with as much applicability to Puget Sound watersheds as possible. Additional data, not specific to Puget Sound were included where necessary to fill data gaps and compare with the locally derived information. These target data are presented in Section 4.3.2.4 of this document.

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

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

Based on a review of this information, the monthly variable loading rate parameters for a constituent were adjusted by land use to improve the seasonal agreement for all watersheds and stations. The adjustments were made to try to improve the agreement of concentrations (statistically and graphically) while maintaining reasonable loading rates and reasonable/expected variation among the land use categories. When conflicts arose in the direction of adjustments, priority was given to agreement: 1) at the monitoring stations at the outlets of the three watersheds, since these models will be used primarily to evaluate impacts of total loads delivered to the Sammamish River; and 2) to agreement of concentrations/statistics over target loading rates; and 3) to maintenance of reasonable differences between land use categories. In some cases, if knowledge of local stream conditions was sufficient, instream processes were adjusted to try to improve agreement. For example, algal growth and settling of organics was encouraged in some stream segments to represent the effects of wetland stream channels where lowered nutrient concentrations were observed at nearby downstream monitoring stations. This involved increasing the growth parameter, increasing the availability of light in the channel, reducing the respiration rate of algae, and increasing the settling rates of organics species.

6.3.2.4 Calibration Discussion and Results

The results of the calibration are presented on the following pages. Table 6.3-5 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. Table 6.3-6 shows the same information for phosphorus species and sediment. Table 6.3-7 presents the mean simulated and observed concentrations on sampling dates for the various constituents, and the ratio of the means. Table 6.3-8 shows the average (and range) of simulated/observed concentration ratios for all North Creek Stations. Finally, Figure 6.3-25 through Figure 6.3-34 show the time series plots of simulated daily and observed water quality constituent concentrations for the primary (outlet) station in North Creek, Station 0474, near Bothell. The following discussion is focused by constituent.

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

- Stream shading was checked with any available information; and adjusted to improve the agreement.
- The parameters that determine the temperature of runoff from pervious and impervious land areas were adjusted seasonally.
- Since these are shallow streams, the temperature of the ground beneath the stream was adjusted seasonally to increase the effect of heat transfers via this pathway. Generally, the water temperature is very well calibrated in North Creek as evidenced in Figure 6.3-25 and the statistical information shown below, with some remaining summertime differences apparent in the comparisons of daily average data at the McCollum Park (Snohomish County) monitoring station (shown in Appendix B).

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

KRER and KSER are the primary sediment erosion calibration parameters in HSPF. They governing detachment of soil particles by raindrop impact on the land surface and the subsequent transport of these particles by overland flow, respectively. KRER is usually estimated as equal to the erodibility factor, K, in the USLE, and then adjusted in calibration, while KSER is primarily evaluated through calibration and past experience. During the calibration of the North Creek watershed model, KRER was set to reflect the variability of the soil types while KSER was adjusted to achieve the expected range of loading rates amongst the land use categories. The loading rates by slope class were primarily dictated by the overland flow rates generated by the respective class. The parameters for vegetal cover (COVER) and atmospheric fallout (NVSI) were not adjusted during the calibration process, but assumed to be constant, based on the type of land use.

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

1. Divided the nonpoint sediment loads into sand, silt, and clay fractions. For the North 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 Station 0474, located near the outlet of the watershed and operated by King County, along with the Snohomish County gages located at McCollum Park and the County Line. The Snohomish County sites served primarily as consistency checks of the overall sediment budgets and loading rates. The frequency and overall number of data points did not support any rigorous statistical tests. Therefore, the comparisons primarily consisted of graphical plots and simple statistics (e.g., comparison of means, geometric means, ratio of simulated vs. observed). The primary parameters for scour, deposition and transport were further adjusted to achieve agreement between simulated and observed concentrations, while maintaining the desired bed behavior and a reasonable distribution of sand, silt, and clay within the beds and water column.

Nitrogen Species - Calibration of nitrate and ammonia was largely done by adjusting the interflow and groundwater concentrations (and ammonia surface loading factors) by land use based on the relative amounts of land in each of the three watersheds (Little Bear, North, Swamp), until the errors were minimized at the three outlet stations. Based on this initial calibration, the agreement was fairly good for nitrate at the two downstream stations in North Creek, where local effects of significant groundwater transfers are minimized. The nitrate levels at the McCollum Park station (NCLU) were consistently oversimulated (particularly in summer);

however, these discrepancies were corrected using additional minor land use adjustments to the loading rates in North Creek. The ammonia showed reasonably good statistical agreement over the three watersheds, after adjustment of loading parameters by land use. Adjustments were made to the overall organics loading to improve the total nitrogen agreement. These adjustments, plus the fact that total nitrogen loads are largely determined by nitrate loads, 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.

Phosphorus Species - 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. This was done in such a way to reproduce the 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. 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. The oversimulation of TP at the McCollum Park station is partially caused by the method used in the hydrology calibration to remove the groundwater contributions in sub-basins 151 and 311, which make up a significant portion of the contributing area to the McCollum Park station.

Dissolved oxygen - The initial simulations produced fairly good agreement with the observed DO, because in relatively low impact streams and watersheds such as North 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 North Creek stations. The time series plot for the McCollum Park station shown in Appendix B shows mixed results. It is assumed that the differences exhibited for this station during the summer are partly caused by the methodology used to reduce the baseflow in the upstream portion of the watershed.

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. Initial values and the land use variation were based on the monitoring data and very limited land use-specific sampling from Newaukum Creek presented by Prych and Brenner (1983). The graphical and statistical agreement in North Creek was good (e.g., average ratio of simulated to observed concentrations = 1.02). One difficulty noticed in the initial calibration runs was the effect of storms that resulted in both sharp upward spikes (increases) and sharp downward spikes (dilutions) in close proximity to each other in time. Since pH is very sensitive to alkalinity, large variations in predicted pH resulted from this behavior. However, the observed pH data (and alkalinity data) in some streams suggest that there can be significant variation over relatively short periods. Furthermore, the sensitivity of pH to alkalinity provided a more accurate indicator of error in the alkalinity calibration, and therby facilitated an improved calibration over that provided solely by alkalinity comparisons.

pH was calibrated to data at the two Snohomish County stations on North Creek because there were no monitoring data at the outlet station (0474). The calibration focused on attaining reasonable values and seasonal variation, based on experience and the monitoring data in both North and Swamp Creeks. The pH was sensitive to alkalinity as was noted above. It was also sensitive to total inorganic carbon (TIC) concentration. Initial simulated TIC concentrations from runoff (< 1 mg/L) resulted in unreasonably high values of predicted pH (~11). Based on fundamental chemical equilibrium equations relating pH, alkalinity, and TIC, it was determined that the observed alkalinity and pH levels would necessitate concentrations of TIC in the range of 16-19 mg/L, which are unattainable with the existing formulation in HSPF. Therefore, the existing algorithm was used as an indicator or index to the TIC loading, but the actual values were adjusted upwards by a constant factor of 40 to attain the necessary TIC to compute pH values that are in line with the observations in Swamp and North Creeks. The statistical and graphical evidence shown in Tables 4.3-3 and 4.3-4 and Appendix B suggests a good representation of pH in North Creek.

E-Coli is notoriously variable and difficult to predict. One reason for this is that many of the larger loadings of bacterial material probably occur during somewhat random but "catastrophic" events, such as CSO events or failure of human waste disposal facilities, which can produce large, unpredictable concentrations. Examination of the observed E-Coli data suggests relatively little quantitative correlation with the storms and little seasonal variation. Therefore, efforts were made to attain general agreement between the simulated concentrations and the bulk of the observed values, which are on the order of 200 CFUs/100 mL as opposed to the arithmetic mean (~500), which is strongly biased by the several extreme values in the data record. Initial attempts to calibrate to these extremes in the observed data, e.g., by large increases in the surface runoff of E-Coli, produced unreasonably large loadings.

Table 6.3-5 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	2.8	0.2	0.06	0.4	1.5	2.0	4.4
Pasture/Ag	9.0	35.	1.3	0.44	2.5	12.	13.	47.
Forest Residential	4.2	3.1	0.6	0.07	1.2	1.6	6.0	4.7
Low Density Residential	4.9	4.7	0.7	0.24	1.4	2.0	7.0	6.9
High Density Residential	6.3	4.8	0.9	0.4	1.8	2.2	9.0	7.4
Commercial/ Industrial	4.9	8.1	0.7	0.6	1.4	2.7	7.0	11.

Table 6.3-6 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	0.03	0.07	0.09	0.12	0.12	0.04	0.03

	Constituents (pounds/acre/year loadings)							
	Orthophosphate-P		Organic P		Total P		Sediment (tons)	
Land Category	Target	Simulated	Target	Simulated	Target	Simulated	Target	Simulated
Pasture/Ag	0.6	4.2	0.7	0.7	1.3	4.9	0.08	0.09
Forest Residential	0.09	0.05	0.16	0.09	0.25	0.14	0.06	0.06
Low Density Residential	0.2	0.15	0.3	0.11	0.5	0.26	0.14	0.13
High Density Residential	0.35	0.20	0.45	0.13	0.7	0.32	0.16	0.17
Commercial/ Industrial	0.5	1.2	0.9	0.15	1.4	1.3	0.36	0.33

Table 6.3-7 Mean Simulated vs. Observed Concentrations on Sample Dates

Constituent	North Creek at Station 0474			North Creek at County Line			North Creek at McCollum Park		
	Simulated	Observed	* Mean Daily Ratio	Simulated	Observed	* Mean Daily Ratio	Simulated	Observed	* Mean Daily Ratio
Water Temperature (C)	9.55	9.83	1.05 (134)	9.9	10.6	0.97 (104)	10.7	9.7	1.15 (104)
Suspended Sediment	9.9	10.7	0.83 (134)	9.2	9.7	1.16 (97)	6.7	6.6	0.95 (84)
Dissolved Oxygen	11.2	10.7	1.05 (133)	11.1	10.7	1.06 (103)	9.7	9.4	1.12 (104)
Nitrate-Nitrite as N	0.80	0.87	0.99 (134)	0.75	0.84	1.14 (104)	0.49	0.53	1.46 (104)
Ammonia as N	0.034	0.038	1.10 (102)						
Total Nitrogen	1.11	1.28	0.89 (129)						
Orthophosphate as P	0.040	0.042	1.11 (134)						
Total Phosphorus	0.069	0.089	0.86 (156)	0.066	0.067	1.33 (104)	0.043	0.035	1.79 (104)
Alkalinity as $CaCO_3$	58.3	58.7	1.02 (61)						
pH				7.4	7.4	1.00 (103)	7.0	7.1	0.99 (103)
EColi (CFUs/100 ml)	215	194	4.05 (40)						

Table 6.3-8 Average and Range of Simulated/Observed Concentration Ratios for all North Creek Stations

Constituent	Average	Range
Water Temperature (deg C)	1.06	0.5 – 6.0
Suspended Sediment	0.96	0.02 – 20.8
Dissolved Oxygen	1.07	0.63 – 2.58
Nitrite-Nitrate as N	1.18	0.19 – 22.9
Ammonia as N	1.10	0.27 – 6.2
Total Nitrogen	0.89	0.41 - 1.46
Orthophosphate as P	1.11	0.11 – 4.23
Total Phosphorus	1.26	0.18 – 19.4
Alkalinity as $CaCO_3$	1.02	0.83 – 1.85
EColi	4.05	0.17 – 55.0
pH	1.00	0.84 – 1.69

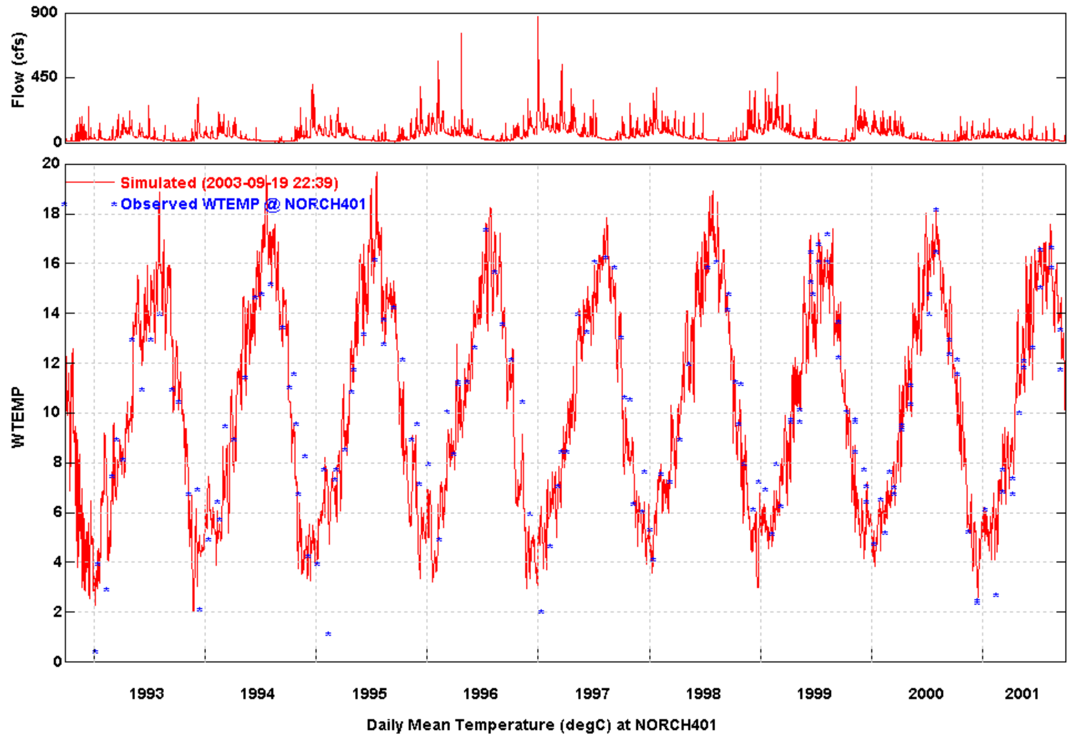


Figure 6.3-25 Observed and Simulated Daily Water Temperature for North Creek at Station 0474

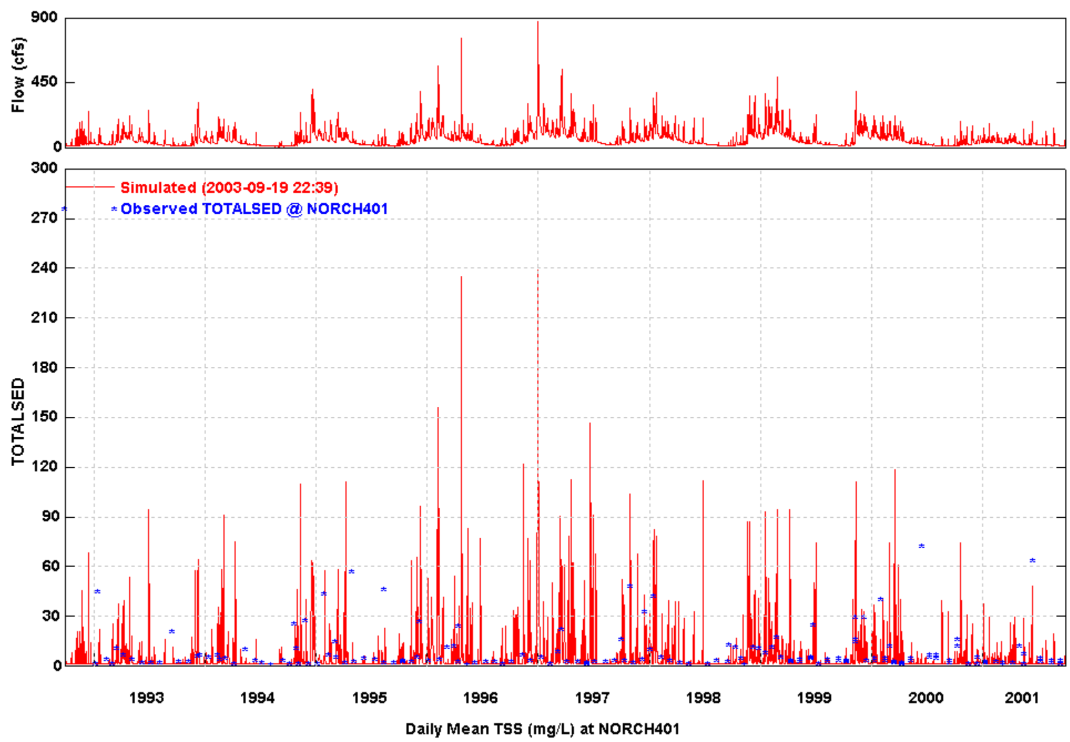


Figure 6.3-14 Observed and Simulated Daily Suspended Sediment Concentrations for North Creek at Station 0474

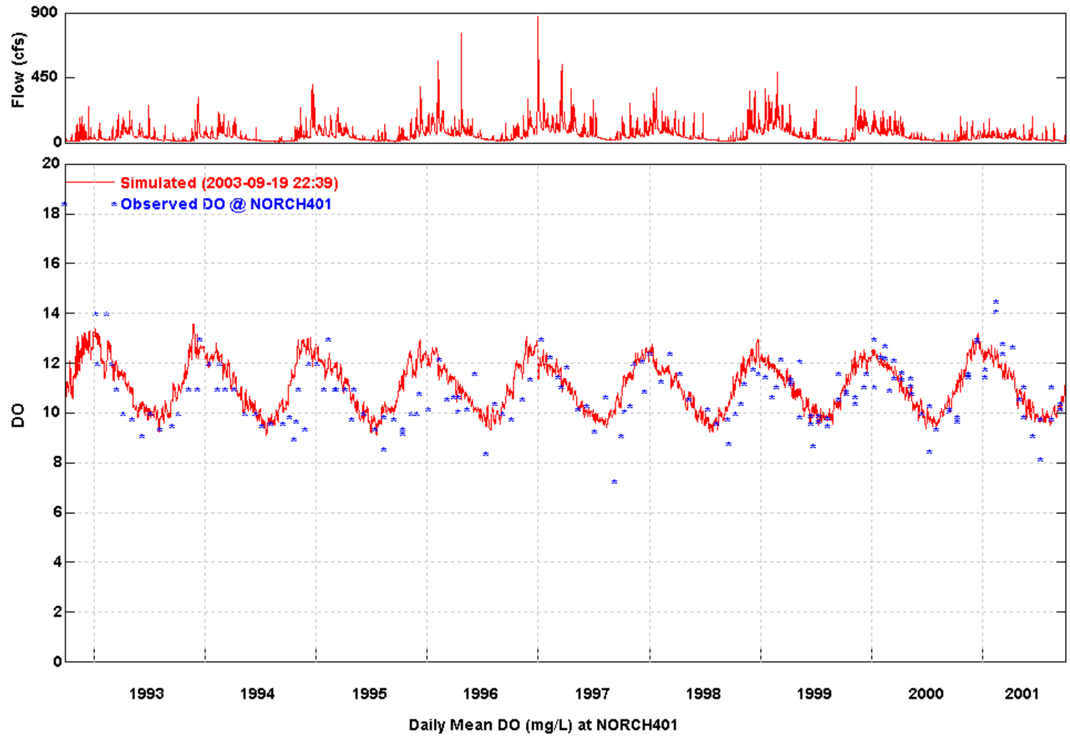


Figure 6.3-15 Observed and Simulated Daily Dissolved Oxygen Concentrations for North Creek at Station 0474

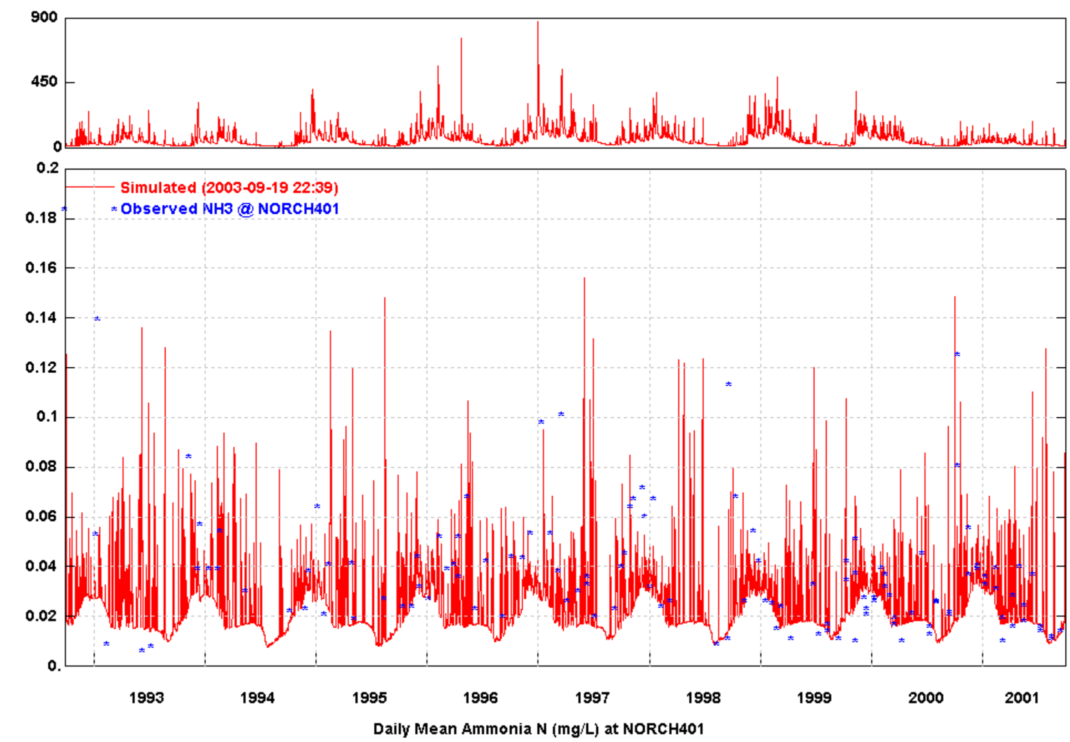


Figure 6.3-16 Observed and Simulated Daily Ammonia Concentrations for North Creek at Station 0474

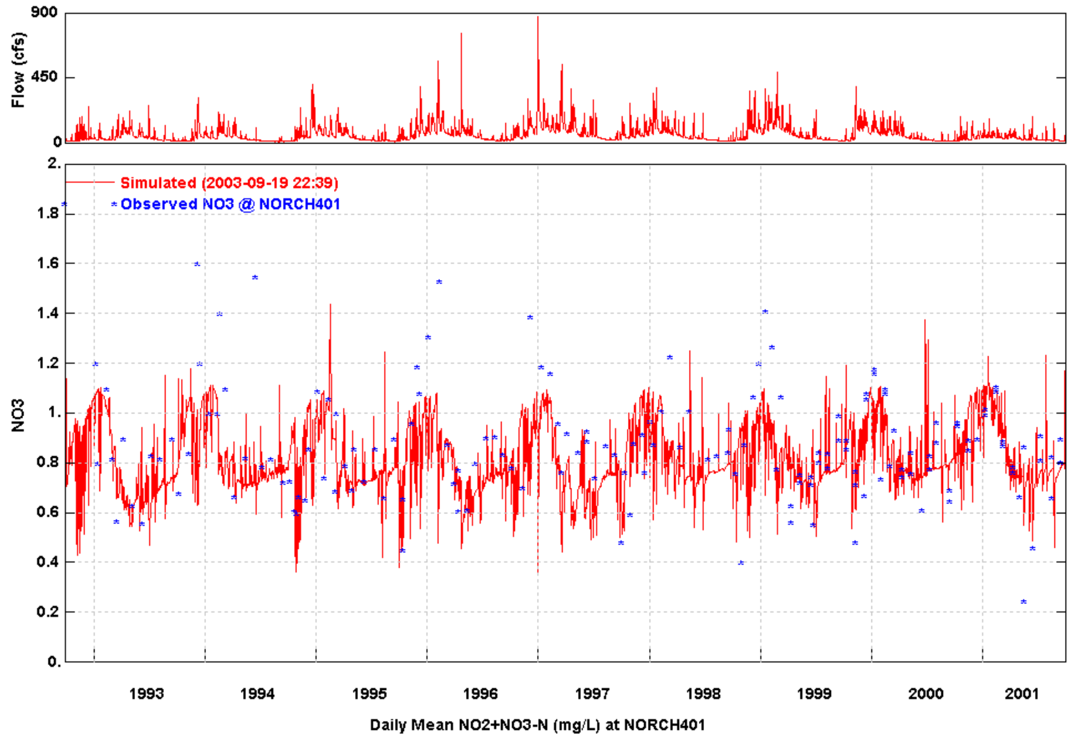


Figure 6.3-17 Observed and Simulated Daily Nitrate Concentrations for North Creek at Station 0474

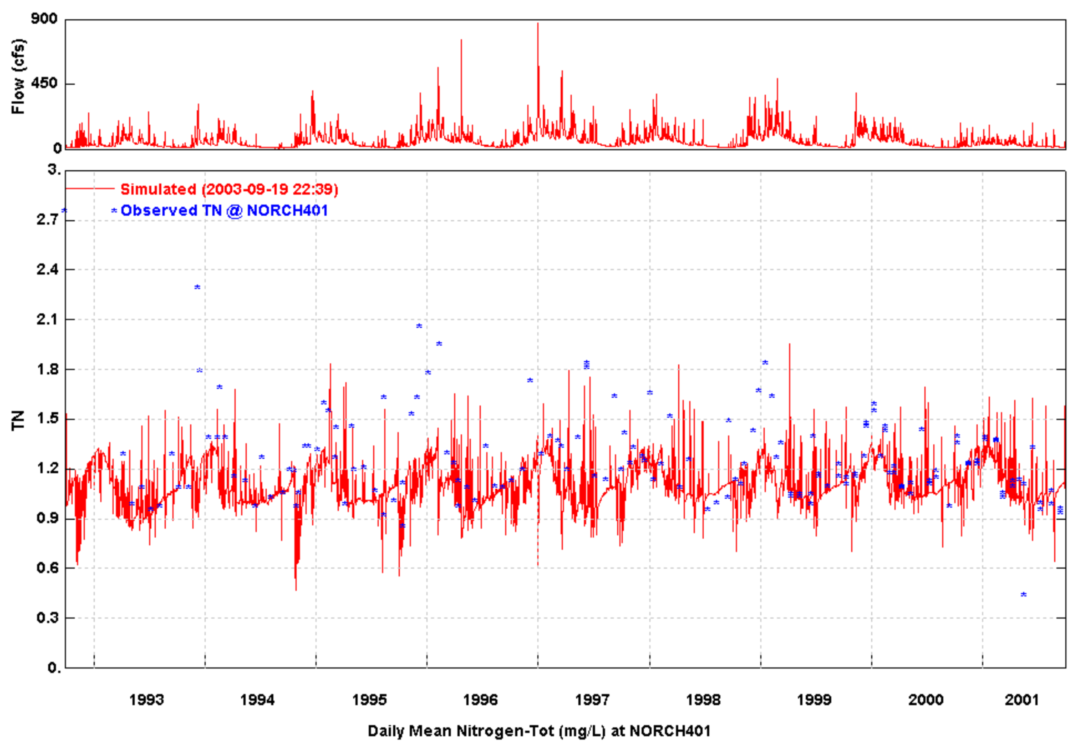


Figure 6.3-18 Observed and Simulated Daily Total Nitrogen Concentrations for North Creek at Station 0474

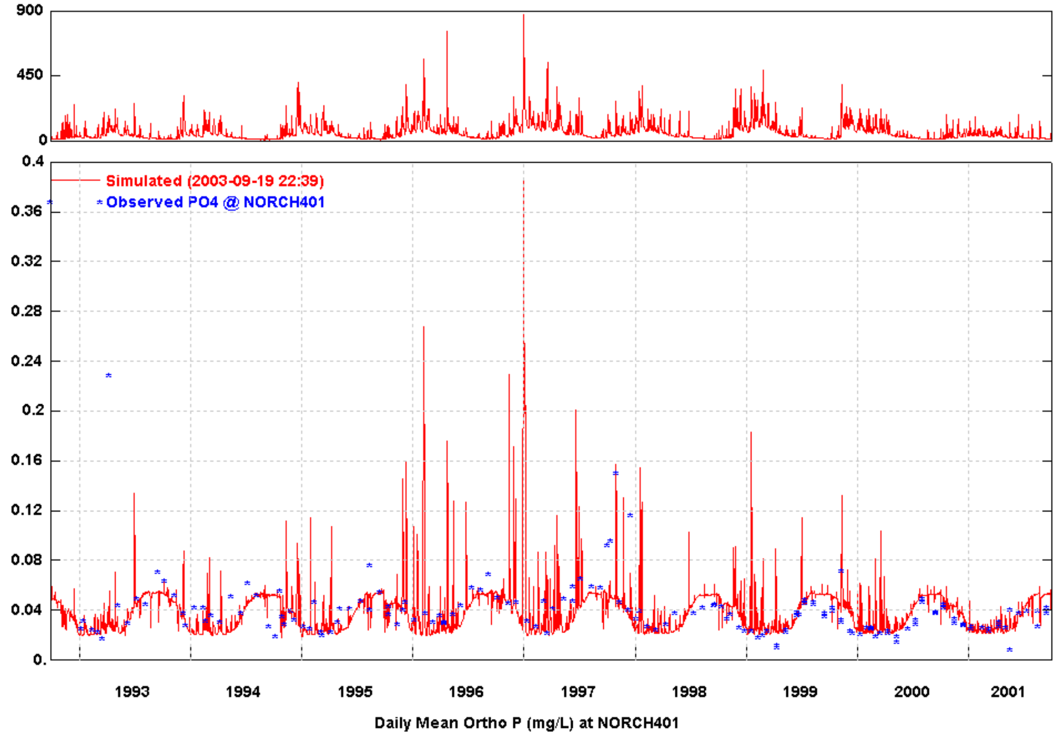


Figure 6.3-19 Observed and Simulated Daily Orthophosphate Concentrations for North Creek at Station 0474

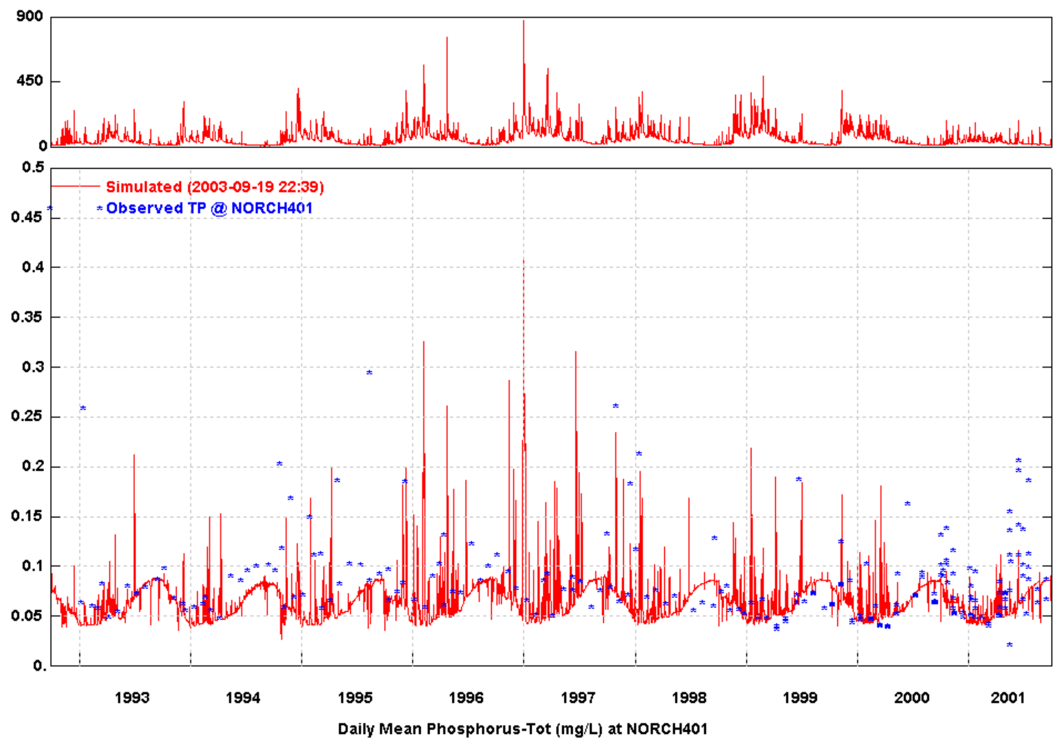


Figure 6.3-20 Observed and Simulated Daily Total Phosphorus Concentrations for North Creek at Station 0474

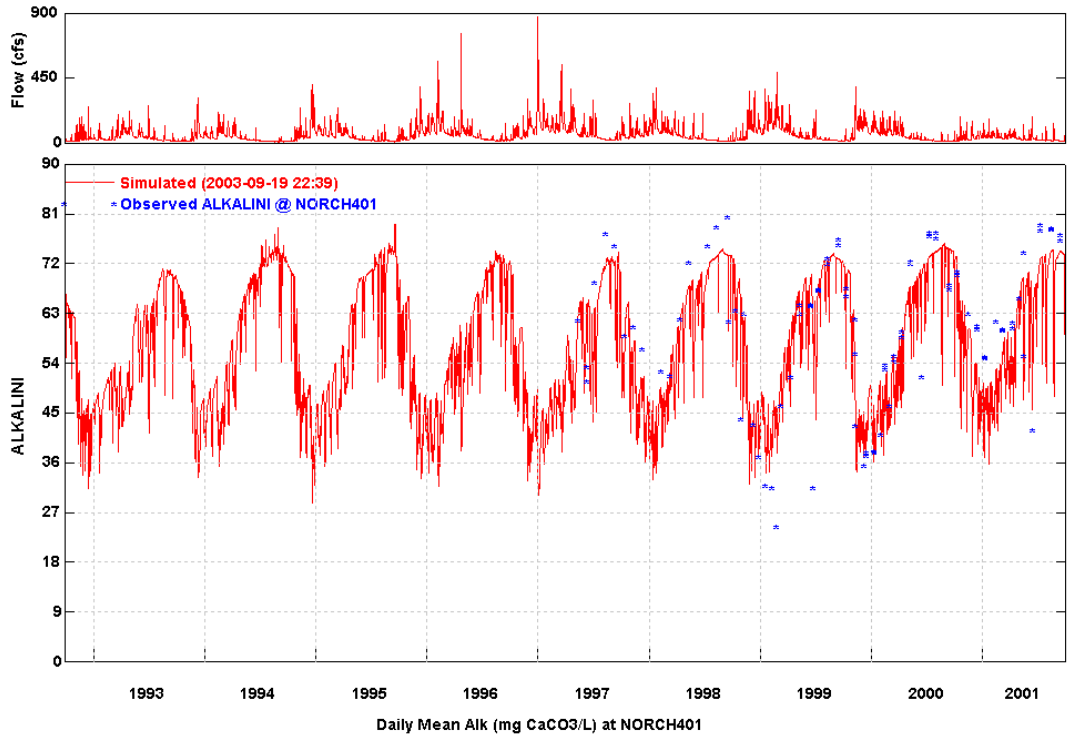


Figure 6.3-21 Observed and Simulated Daily Alkalinity Concentrations for North Creek at Station 0474

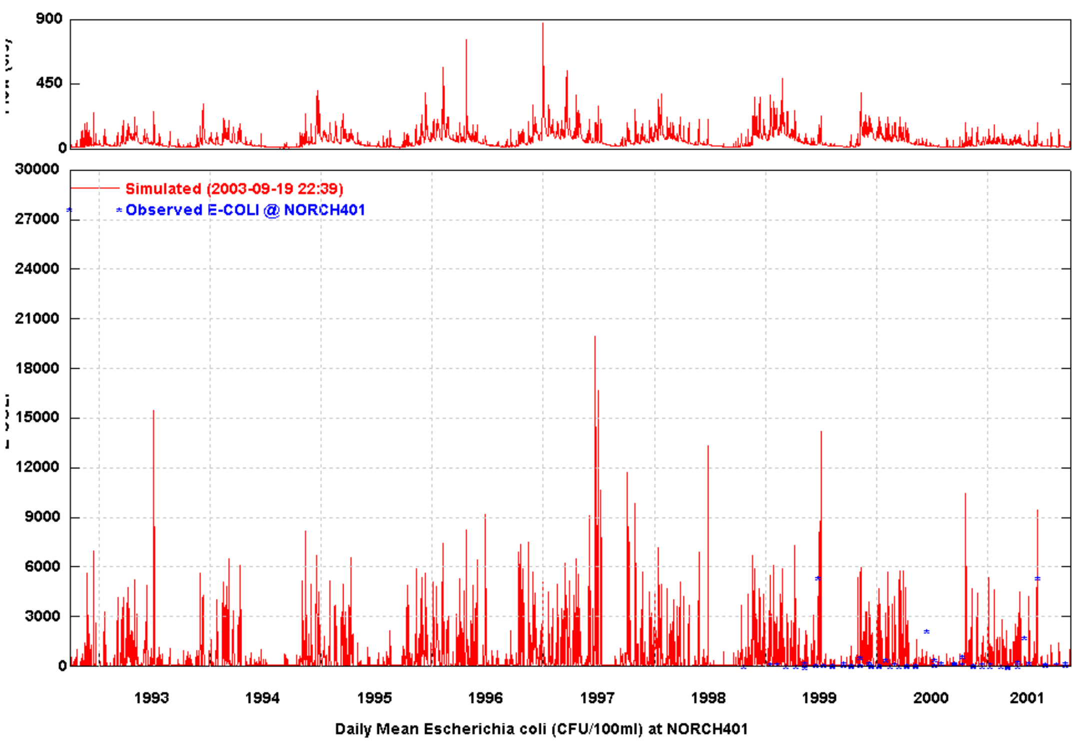


Figure 6.3-34 Observed and Simulated Daily EColi Concentrations for North Creek at Station 0474

6.3.2.5 Unresolved Calibration Issues

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

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

6.4 MODEL LINKAGES

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

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

The North 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 North Creek model does not include the TDS constituent, and the Silica constituent is not calibrated due to a lack of monitoring data.) The correspondence between HSPF constituents (refractory organic N, P, & C) and the W2 organic matter constituents is unresolved.

6.4.1 Spatial Linkage

All loadings to the Sammamish River from North Creek effectively enter the river at a single location, i.e., the mouth of the creek near Bothell, WA. Since the end of the most downstream reach (RCHRES 401) of the North 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.

6.4.2 Temporal Linkage

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

6.4.3 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.

6.5 REFERENCES

6.5.1 Water Quality

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