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

In Progress

King County

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

Section 3—Model Development

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Prepared for:

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

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

Prepared by:

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

In conjunction with King County

Alternative formats available

206-263-6317   TTY Relay: 711

3. MODEL DEVELOPMENT

This section describes model development for the Green WQA and SWAMP study areas. Information specific to the sub-watersheds will be detailed in the subsequent calibration sections (Section 4 – XX). Much of the content in this section provides supporting documentation on HSPF model development for the study-areas, and data used as the basis for basin specific model development and calibration for the Green WQA and SWAMP programs. Whereas there are many general rules, methods, assumptions, etc. being described here, model development per subbasin may augment, modify, or even contradict this section. Therefore, sections covering the specific calibrations (Section 4 – XX) of subbasins, supercede any documentation in this section.

3.1 WATER QUANTITY

3.1.1 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. Fortunately, for this study a database appears to exist to support the application. Historical data collected by King and Snohomish counties, the University of Washington, federal agencies (e.g., NOAA, NWS), and various local jurisdictions, supplemented with ongoing data collection efforts of these same groups, appears to provide a sound basis for the watershed modeling effort. The purpose of this section is to identify the broad data needs for the various models and present findings of the availability and sources of these data. Ultimately, the findings in this section and subsequent calibration sections will determine the timeframe and constituents the data are capable of supporting for model simulations.

3.1.2 OVERVIEW OF DATA NEEDS

Within the modeling framework, the watershed model, HSPF, encompasses the largest spatial extent of the system, and will require the most encompassing dataset for model simulations. The data requirements for HSPF are extensive, in both spatial and temporal detail, especially for an application capable of assessing the potential environmental impact of such activities as land use development in the watershed based on GMA boundaries. Typical data requirements for an HSPF application can be categorized as input/execution data, watershed/channel characterization data, and calibration/validation data.

3.1.2.1 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 input to other HSPF models, CE-QUAL-W2, or CH3D-ICM for the Green River WQA and SWAMP study areas.

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.

3.1.2.1.1 Calibration Data

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

3.1.2.1.1.1 Precipitation

Precipitation data is variable spatially and temporarily. As such, calibration of the various subbasins will utilize local data wherever and whenever appropriate. Hence, precipitation data used for calibrations will be described specifically in each subbasin section.

3.1.2.1.1.2 Evaporation

The nearest evaporation data are available from Puyallup at the Washington State University Experimental Field Station. Puyallup lies approximately 40 to 60 miles to the south of the study areas, but because evaporation does not vary greatly in the Puget Sound lowlands this distance is not considered significant (Farnsworth, et al, 1982).

As shown in the subsequent specific subbasin calibration sections (Sections 4 through ##), the time period of the data is not a limiting factor for model simulations. The pan evaporation time series was developed from the available daily record for water years 1960 through 1997. For the most part, this station only measured pan evaporation during the growing season. Data for winter months were filled by King County staff (Hartley, 1999) using the Jensen-Haise equation. Data for water year 1960 were transposed without change to water years 1949 through 1959 and water years 1998 through 2002 (Hartley, 1999). The selection of a single year to represent years with missing data potentially introduces error in unusually wet or dry years. Accordingly, it may be worthwhile to instead use the Jensen-Haise equation for these years for which we do not have measured pan evaporation data. This will be investigated further.

Table 3.1-1 shows representative monthly evaporation volumes for water years 1981 through 2001. The volumes are relatively consistent from one year to the next. The average monthly values for water years 1960 through 1997 are summarized at the bottom of the table and have a mean annual total of 30.71 inches.

The evaporation data must be adjusted to convert to an estimate of potential evapotranspiration data that are used by the models. A pan evaporation coefficient is used to convert the pan evaporation data to PET data. For the study areas, the coefficient ranges from 0.75 to 0.85, 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). During calibration, adjustments may be made to the coefficient (Donigian, 2003).

Table 3.1-1 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

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)
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

3.1.2.1.1.3 Stream Flow

Like precipitation, stream flow data is specific to the stream segment and subbasin. Data available will be described in each calibration section.

3.1.2.2 OVERVIEW OF 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.

3.1.2.2.1 WATERSHED SEGMENTATION AND CHARACTERIZATION

Whenever HSPF, or any watershed model, is applied to an area of any significant size, the entire study area must undergo a process referred to as segmentation. The purpose of watershed segmentation is to divide the study area into individual land and channel segments, or pieces, which are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. This segmentation then provides the basis for assigning similar or identical parameter values or functions to where they can be applied logically to all portions of a land area or channel length contained within a segment. Since HSPF and most watershed models differentiate between land and channel portions of a watershed, and each is modeled separately, each undergoes a segmentation process to produce separate land and channel segments that are linked together to represent the entire watershed area.

The initial segmentation typically involves delineating areas (catchments) that have similar meterological conditions, topographical features, use practices for a given land, and/or are a region of interest (e.g., NPS loads need to be quantified). Once the catchments and channel segments have been defined, these catchments must then be further characterized to: 1) develop the model categories (i.e., PERLNDs / IMPLNDs) to represent; 2) define the physical parameters (e.g., elevation, slopes, channel length) for HSPF using available data; and 3) establish initial calibration parameters for HSPF based on past applications within the region and past experience with the model.

3.1.2.2.1.1 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 Little Bear 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 3.1-2 are representative values that have been provided by King County (Burkey, 2002). Other continuous simulation models use similar schemes to separate out impervious areas from pervious. These land use categories in Table 3.1-2 can also be used to differentiate different land covers and pollutant sources.

Table 3.1-2 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	25	0	0
Developed high	0	0	0	0	0	50	0
Bare ground/asphalt	0	0	0	0	0	50	0
Bare rock/concrete	0	0	0	0	0	0	50
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 3.1-3.

Table 3.1-3 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	75	0	0

King County Land Use Categories	Forest	Pasture	Forest Residential	Low Density Residential	High Density Residential	Commercial/ Industrial	Road
Developed high	0	0	0	0	0	50	0
Bare ground/asphalt	0	0	0	0	50	0	0
Bare rock/concrete	0	0	0	0	0	50	0
Shadow	50	50	0	0	0	0	0
INSIDE=100	0	0	0	0	0	14	0

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

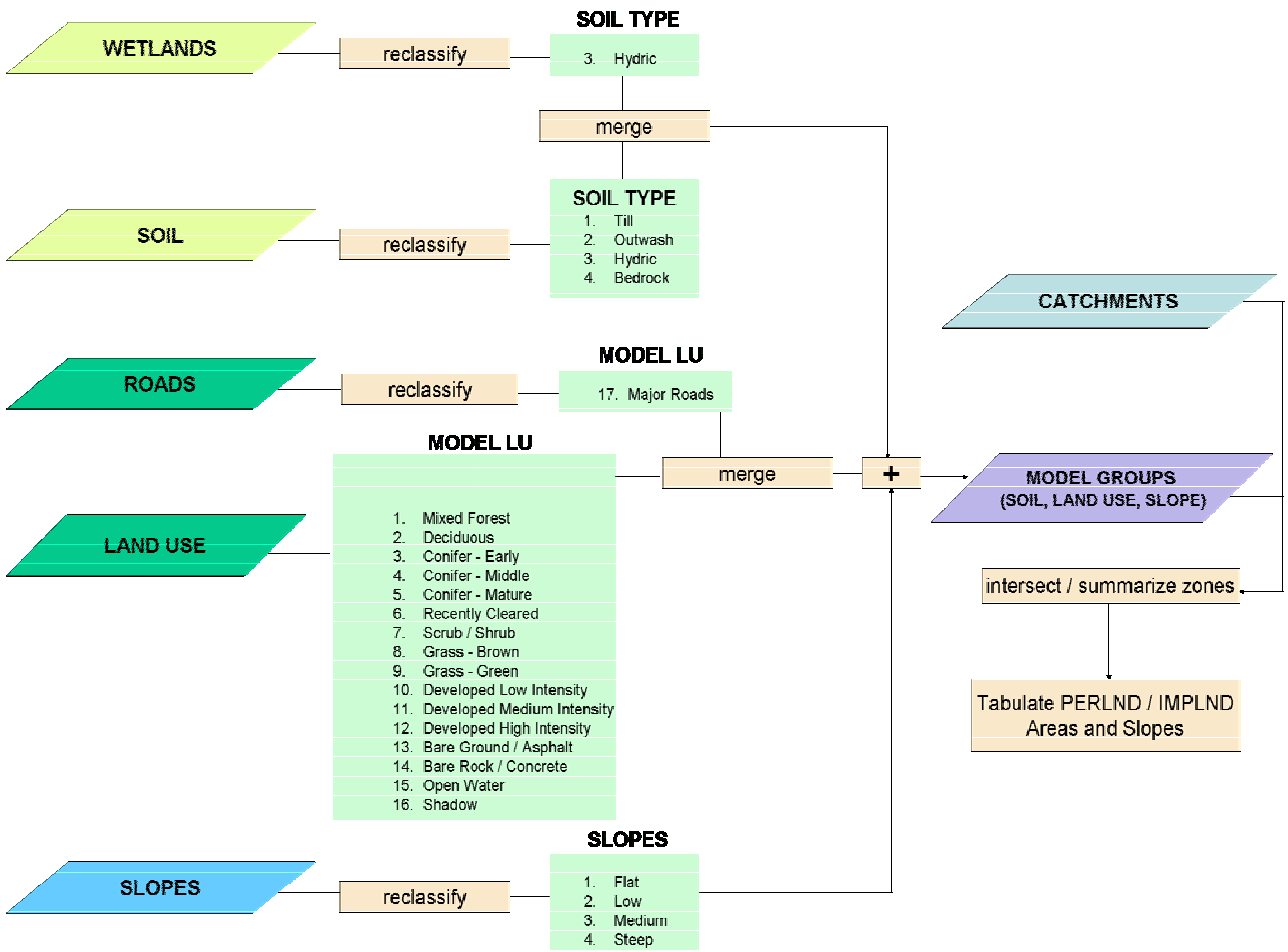
One of the objectives of the modeling is to have the capability to characterize pollutant loadings from road runoff. With the GIS data currently available, it was necessary to create a two-dimensional (i.e. polygon) data set representing roads from an existing one-dimensional (i.e. arc) road coverage. Given the extensive road network in King and parts of Snohomish County, it was necessary to develop an unsupervised[1] method to create the two-dimensional data. This method is based on a set of assumptions characterizing the width of roads based on its classification. Each classification is assumed to have typical number of lanes, with a typical lane width of 20 feet. Hence, using routine GIS operational capabilities, polygons were created from the arc coverage based on road classification. To prevent double counting impervious surfaces as previously defined, the newly created road coverage was intersected with the other GIS coverages, and supercedes previous classifications of the other GIS layers. Table 3.1-4 below summarizes the assumptions used in the methodology.

Table 3.1-4 Assigned Road Widths Creating INSIDE=100

Road Class	Description	Number of Lanes / Road Width
Freeway	Interstate travel routes (e.g. I-5, I-405, I-90)	8 / 160 ft
Highway	State Routes	5 / 100 ft
Major Arterials	Primary travel routes connecting greater population densities	4 / 80 ft
Major Roads	Main travel routs among city and rural roads	3 / 60 ft
Minor Roads	Typical city surface streets, and rural roads	2 / 40 ft

[1] An automated procedure requiring minimal human interaction.

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 3.1-1 displays a flow chart describing the methodology for spatially and quantitatively defining the PERLND / IMPLND categories. The catchment and soil coverages will be intersected in order to quantify the areas of various soil types within a given catchment. The resulting coverage will then be reclassified to group soils into till, outwash, saturated soils, and bedrock. Table 3.1-5 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 3.1-1 PERLND / IMPLND Development

Table 3.1-5 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 3.1-2 and accompanying discussion. Table 3.1-6 presents the final potential 72 PERLND / IMPLND categories; not all categories exist in Little Bear 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 3.1-6 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	
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	

TILL	OUTWASH	SATURATED	BEDROCK	EIA
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	

3.1.3 OVERVIEW OF MODEL CALIBRATION

The calibration of HSPF for the watersheds in the Green WQA and SWAMP study areas follow 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).

3.1.3.1 OVERVIEW OF HSPF CALIBRATION AND VALIDATION 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 in the subsequent sections.

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. This calibration report addresses only the hydrology calibration.

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.

3.1.3.2 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 (discussed further below).

The annual water balance specifies the ultimate destination of incoming precipitation and is indicated as:

Runoff = Precipitation - Actual Evapotranspiration - Deep Percolation

- ΔSoil Moisture

HSPF requires input precipitation and potential evapotranspiration (PET), which effectively drive the hydrology of the watershed; actual evapotranspiration (calculated by the model from the input potential); and ambient soil moisture conditions. Thus, both precipitation and evaporation inputs must be accurate and representative of the watershed conditions. It is often necessary to adjust the input data derived from neighboring stations that may be some distance away in order to reflect conditions on the watershed. HSPF allows the use of factors (referred to as MFACT) that uniformly adjust the input data to watershed conditions, based on local isohyetal and evaporation patterns. 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).

Thus, from the water balance equation, if precipitation is measured on the watershed, and if deep percolation to groundwater is small or negligible, actual evapotranspiration must be adjusted to cause a change in the long-term runoff component of the water balance. 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. In addition, on extremely small watersheds (less than 200 to 500 acres) that contribute runoff only during and immediately following storm events, the UZSN parameter can also affect annual runoff volumes because of its impact an individual storm events (described below). 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.

The focus of the next stage in calibration is the baseflow component. This portion of the flow is 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 adjusting INFILT, runoff can be shifted to either increase or decrease groundwater or baseflow conditions. 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.

As part of the calibration sections are the adjusted parameters as previously described in this section.

3.2 WATER QUALITY

3.2.1 Water Quality Constituents and Processes

Based on the considerations presented in the Little Bear Creek Simulation Plan, primarily the need to evaluate the impacts of siting the Regional Treatment Facility and the need to provide loads of specific constituents to the Sammamish River Model, the water quality constituents included in the model are:

- Water Temperature
- Sediment
- Dissolved Oxygen
- Ammonia (N)
- Nitrate (N)
- Orthophosphate (P)
- BOD/Organics comprised of:
  - BOD
  - Refractory Organic N
  - Refractory Organic P
  - Refractory Organic C
- Benthic Algae
- Alkalinity, TIC, and pH
- E-Coli
- Silica
- TDS*
- Metal*
- Organic toxicant*

(* Note: three constituents (TDS, metal, and organic toxicant) are not included in the current model because of limitations on the total number of constituents in the HSPF program. These constituents were selected for omission because they are of less importance in producing loads for the Sammamish River W2 model. The limitations of the program are being addressed and the constituents will be included in a subsequent iteration of the model.)

Water quality constituents are modeled by using the PERLND and IMPLND modules to generate loadings of sediment, heat, and pollutants (in addition to the water). These loads are transferred to the stream segments, which are modeled with the RCHRES module. Various submodules of PERLND, IMPLND, and RCHRES are used to represent the constituents and processes that produce the loadings. The hydrological and hydraulic results produced by the hydrology model are used by the water quality submodules to drive the generation and transport of sediment and constituent loads. Also, the nonpoint loading of several of the constituents are driven by the sediment erosion and delivery to the stream.

The primary water quality submodules in PERLND and IMPLND that are used to produce loadings of most constituents are PQUAL and IQUAL, respectively. These routines are “general” constituent routines that can simultaneously produce loadings of multiple user-defined constituents based on sediment erosion and water runoff from the land. They allow the user to specify for each constituent whether its loadings are primarily a function of sediment, surface runoff, subsurface (interflow and/or groundwater) runoff, or a combination. For the impervious land, only sediment loads and surface runoff are used to determine the loadings. All constituent loadings modeled by PQUAL and IQUAL, except E-Coli, (i.e., nutrients, BOD/organics, TDS, silica, metal, alkalinity, organic toxicant) are assigned units of pounds. The mass units for E-Coli are 10^9 CFUs (colony forming units or organisms). The following discussion describes the specific submodules, methods, and processes used in the Little Bear Creek model and other similar watersheds. Additional details about the processes and parameters can be obtained from the HSPF User’s Manual (Bicknell et al., 2000).

Water Temperature is modeled by performing an energy balance in each stream segment. Heat and energy inputs to the stream are determined from the temperature of nonpoint, point, and boundary inflows; and from meteorologic data (solar radiation, air temperature, dewpoint temperature, wind speed, and cloud cover). In the respective PERLND and IMPLND submodules PSTEMP/PWTGAS and IWTGAS, water temperature and heat content (in units of BTUs) of surface runoff and interflow are estimated from air temperature, using a simple regression equation; and groundwater runoff temperatures/heat are user-defined, based on local groundwater temperatures. All of the parameters for these processes are specified on a monthly basis to represent seasonal variability. In RCHRES, the HTRCH submodule performs the energy balance and estimates the stream water temperature. Radiational energy transfers at the water surface are estimated from solar radiation (shortwave) and cloud cover and temperature (longwave) data. Evaporative transfers are determined from wind, air temperature, and dewpoint temperature data. Conduction/convection transfers are determined from air temperature and wind. Finally, energy transfers between the underlying ground and the stream are estimated from ground temperature.

Sediment is simulated instream as three separate size fractions, referred to as sand, silt, and clay. The sediment loadings (in units of tons) are generated by the SEDMNT and SOLIDS submodules of PERLND and IMPLND using the surface storage and surface runoff results from the hydrologic simulation. In SEDMNT, empirical equations are used to predict the detachment and reattachment of sediment from the soil matrix and the subsequent erosion/transport of the detached sediment to the stream. In SOLIDS, an accumulation/removal method produces a storage of sediment available for transport, and another equation estimates the solids transport capacity, which is used to compute the washoff. The total nonpoint loading is divided into size fractions upon input to the stream using constant fractions based on local or representative soils and sediment erosion data and properties. Within the stream, the SEDTRN submodule is used to separately model deposition to a completely mixed bed, scour from the bed, and advection downstream. The deposition, scour, and advection processes are modeled differently for the noncohesive (sand) and the cohesive (silt and clay) fractions. Sand uses a simple power function of average stream velocity to estimate potential scour, and silt/clay uses channel shear stress and critical shear stress parameters and settling velocities in erosion and deposition equations to estimate the deposition and scour.

Dissolved Oxygen is simulated in the stream by defining the oxygen loads in nonpoint and point runoff, and representing reaeration and biological/chemical processes in the stream. The PWTGAS and IWTGAS submodules estimate oxygen content (in units of pounds) of surface runoff based on the temperature of the runoff and a standard oxygen saturation equation. Subsurface oxygen concentrations are user-defined, with monthly variation. In the stream, the OXRX submodule directs the simulation of dissolved oxygen, including the processes of reaeration and decay of BOD. Reaeration is simulated as a function of depth and velocity in the stream segment. Nitrification and algal growth/respiration also result in loss and/or gains of oxygen in the stream, and these processes are simulated in the NUTRX and PLANK submodules, respectively.

Ammonia-N is modeled by generating nonpoint loadings from the land using the PQUAL and IQUAL (general constituent) submodules described above. Ammonia loadings in this model are assumed to be determined by surface runoff, interflow, and groundwater. The surface runoff is determined by specifying accumulation/washoff parameters, and the subsurface (interflow and groundwater) components are modeled as user-defined concentrations, with monthly variation. In the stream, ammonia is modeled by the NUTRX submodule, and it takes part in several biochemical reactions (which are modeled in the OXRX and PLANK submodules). In this model, the processes ammonia undergoes are first-order, temperature-adjusted nitrification (resulting in conversion to nitrate), uptake by algae during growth, and release during algal respiration/death. It is also produced upon the degradation of dead organic material (BOD). Ammonia is assumed to be exclusively in dissolved form, and not associated with sediment.

Nitrate-N is modeled similarly to ammonia. PQUAL and IQUAL generate land loadings based on surface accumulation, washoff with surface runoff, and definition of monthly-varying interflow and groundwater concentrations. Its instream processes are modeled in NUTRX, and include production from nitrification, loss by denitrification under anoxic conditions, uptake by algae, and release upon the respiration/death of algae and decay of organic material. The algal uptake and release processes are modeled in the OXRX and PLANK submodules.

Orthophosphate-P is modeled similarly to ammonia with one major difference. Because of its propensity to be bound to solids, it is associated with sediment instead of surface runoff and is also associated with sediment in the stream. PQUAL and IQUAL generate land loadings based on surface accumulation, washoff in association with sediment that is transported to the stream, and definition of monthly-varying interflow and groundwater concentrations. Its instream processes are modeled in NUTRX, and include equilibrium adsorption/desorption from instream sediment, uptake by algae, and release upon the respiration/death of algae and decay of organic material.

BOD represents all nonliving, reactive (labile) organic material in the model, including BOD and detritus resulting from living material which comes from nonpoint loading of plant material and death of algae. Total land loadings of labile and nonreactive organic matter are estimated using the PQUAL and IQUAL submodules and are determined from surface runoff, interflow, and groundwater. The surface runoff is determined by specifying accumulation/washoff parameters, and the subsurface (interflow and groundwater) components are modeled as user-defined concentrations, with monthly variation. In the stream, the portion of the total organic matter land loadings that are assumed labile are input to the BOD constituent, which is modeled by the OXRX submodule in RCHRES. This constituent undergoes first-order, temperature adjusted decay (which consumes oxygen and releases inorganic nutrients in the water column) and settling out of the water column. BOD is also generated by death of algae. The nutrient composition of BOD is assumed the same as living material.

Refractory Organics (N, P, C) represent all nonliving, nonreactive organic material in the model including detritus resulting from living material which comes from nonpoint loading of plant material and death of algae. In contrast to BOD, they are represented as individual constituents instead of a single constituent (i.e., total organic matter) containing N, P, and C. For purposes of generating the land loadings, they are combined with the BOD as a single "organic matter" constituent (see BOD discussion for details of land loading), which is then fractionated into separate components upon input to the stream. Initial values of the factors used to convert the organic matter to these nutrient forms are determined from the standard stoichiometry of organic matter in HSPF; however, during calibration these factors are subject to adjustment based on calibration results and previous experience. These constituents are assigned the names ORN, ORP, and ORC in the stream, where they are simulated in the PLANK submodule of RCHRES. They undergo advection and settling, and are generated upon death of algae, again using the HSPF biomass stoichiometry.

Benthic Algae (or periphyton) is stationary, living organic matter that is modeled by the PLANK submodule of RCHRES. Its growth is modeled using the same Monod growth kinetics that are used to simulate phytoplankton. The material grows, respires, and dies in response to light and nutrient (N and P) availability and temperature. It takes up and releases nutrients and releases organic matter (detritus) during respiration, sloughing, and death. No data quantifying benthic algae or phytoplankton in these creeks have been located, and due to the small size of these watersheds and their relative quality, growth of this material is assumed to be having minor impacts on nutrient loads delivered to the outlets and instream water quality. The benthic algae in Little Bear Creek have been parameterized and calibrated to grow at subsistence levels.

Alkalinity, TIC, and pH are discussed together because they are necessary for the prediction of pH in the stream. Alkalinity loadings (pounds as $CaCO_3$) are generated by the PQUAL and IQUAL submodules, and are transferred to a general conservative constituent in the CONS submodule of RCHRES for advection in the stream and comparison with monitoring data. The resulting alkalinity concentrations are also used by the PHCARB submodule to estimate instream pH. Total inorganic carbon (TIC) nonpoint loadings are generated by the PWTGAS and IWTGAS submodules based on the saturation of CO_2 in runoff, which is estimated from the soil temperature and elevation (air pressure). These loadings are input to the TIC constituent in the stream (PHCARB submodule), where they are subject to adjustment by CO_2 invasion and loss at the water surface (and optionally by biochemical reactions in the PLANK submodule). pH is estimated from alkalinity, TIC, and water temperature based on the standard carbonic acid-bicarbonate-carbonate equilibrium equations.

E-Coli is simulated using the PQUAL and IQUAL submodule to generate nonpoint loadings in units of 10^9 CFUs (10^9 organisms). E-Coli loadings are assumed to be determined by the surface runoff, interflow, and groundwater. The surface runoff is determined by specifying accumulation/washoff parameters, and the subsurface (interflow and groundwater) components are modeled as user-defined concentrations, with monthly variation. In RCHRES, E-Coli is simulated in the general water quality constituent section GQUAL, and is assumed to undergo first-order decay. In GQUAL, it can optionally be associated with sediment, but the current model assumes it is dissolved because most prior simulations of coliform material with HSPF have been done this way, and thus provide tested parameter sets.

Silica is modeled using PQUAL and IQUAL to generate loadings in the same manner as ammonia, nitrate, and organics. In the RCHRES, it is modeled in the GQUAL submodule, which allows consideration of decay and/or adsorption to sediment if the need to do so is determined. However, it is currently assumed to be conservative and dissolved. No silica monitoring data have been located thus far, so the parameters have been set at initial values to attempt to produce typical instream concentrations.

3.2.2 DATA REQUIREMENTS AND AVAILABILITY

3.2.2.1 Additional Meteorological Data Required

HSPF requires additional climatic inputs for modeling water temperature, gas transport across the air-water interface (reaeration), and algal growth. Like evaporation, these quantities are less variable than rainfall and/or the overall model results are less sensitive to their values; thus, less spatial resolution is needed, and a single station can be used for the entire watershed. The required time series are:

- Air Temperature
- Cloud Cover
- Dewpoint Temperature
- Wind Speed
- Solar Radiation

3.2.3 Nonpoint Source Target Loading Rates

Generally, the water quality constituents measured at a monitoring station reflect the combined effects of nonpoint source contributions from multiple land uses, any point sources upstream from the station, and instream processes. Consequently, it is useful to develop target nonpoint source loading rates from regional data to help guide the model calibration effort and ensure that the simulated rates and fluxes for each land use category (i.e., nonpoint loads and instream processes) are reasonable and consistent with literature values. For each of the modeled nonpoint source constituents - including sediment, nutrients, and bacteria - target loading rates, by land use, should be compared to simulated values. This section presents a compilation of nonpoint loading rates, developed from a literature review for the constituents simulated, that are applicable to Puget Sound watersheds. Additional data, not specific to Puget Sound, are also presented to fill data gaps and to make comparisons with data provided by local studies.

While reviewing these target loading rates, it should be kept in mind that nonpoint loading rates are driven by the amount and intensity of precipitation and resulting runoff as well as the physiographic properties and anthropogenic activities of a particular land use. Climate, geology, and land use practices are highly variable spatially, and this level of detail can only be approximately represented in the model. Thus, the comparisons are somewhat subjective.

3.2.3.1 Sediment Loading Rates

Table 3.2-1 presents target loading rates (tons/acre-year) for sediment for 11 land use categories. These rates are a result of a watershed-scale sediment budget developed for the 56 square mile Issaquah Creek watershed (Nelson, 2002). The rates developed in this study are particularly useful because the watershed lies within the SWAMP/Green/Duwamish study area and includes various land use categories. However, these loading rates are site-specific to the conditions in the Issaquah Creek watershed and not necessarily representative of the rates occurring in nearby watersheds. For example, the forest loading rates presented in Table 3.2-1 represent the combined erosional processes of soil creep and land slides, which are clearly spatially variable processes. This study found that land slides accounted for approximately 50 percent of the overall sediment loading budget. Land slides are likely less prevalent in adjacent watersheds; therefore, it is to be expected that the loading rates in adjacent forested areas will be lower.

The loading rates for agriculture were developed using the Universal Soil Loss Equation (USLE). Comparison of the rates developed in this study to those reported at a national scale (Table 3.2-5), indicate that these Issaquah Creek rates are significantly lower. The authors state that the agricultural loadings are low, despite an unrealistically high assumed delivery ratio, because this land use occurs only on low-gradient valley bottoms. These rates are likely lower than rates seen at the national scale due to the USLE parameters selected to reflect the topography previously described and the low intensity agricultural within the Issaquah Creek watershed. This also helps to explain why the study lumped agriculture and grass, which typically have distinctly different erosional rates, into one land use category. If neighboring watersheds are found to have more intensive agricultural practices, they will be expected to have loading rates closer to those seen at a national scale and presented in Table 3.2-5.

Table 3.2-1 Sediment Target Loadings (tons/acre/year)

Land Use	Loading Rate
Undisturbed Forest *	0.146
Low-Density Residential	0.022
Med-Density Residential	0.142
High Density Residential	0.157
Commercial/Industrial	0.364
Urban Planned Development	0.143
Mining	0.892
Agriculture/Grass	0.041
Landfill	0.042
Construction	0.436
Roads	0.321

* Includes the erosional processes of soil creep and land slides. The loading rate for disturbed forest was calculated to be ~ 0.175 ton / ac-yr, which includes the additional erosional process of road surface erosion (Nelson, 2002).

Overall, these values appear reasonable when reviewing rates presented in similar studies and keeping in mind some of the aforementioned issues. The majority of other Puget Sound studies reviewed did not differentiate the load delivered from nonpoint sources and instream scour and bank erosion. Therefore, the results of these studies are not included herein.

3.2.3.2 Nutrient Loading Rates

Streamflow and surface-water quality data were monitored at 11 sites within the Puget Sound Basin by the USGS (Embrey and Fran, 2003) from November 1995 through April 1998 (see Table 3.2-2). Seven of these sites represented relatively homogenous land use and land cover watersheds. The remaining sites were integrators of mixed land use.

Table 3.2-2 USGS Monitoring Sites

Basin	Land Use	Area (Mi^2)
Upper Green River	Forest	16.5
North Fork Skokomish River	Forest	57.2
Skokomish River	Mixed Forestry	227.0
Upper Nooksack River	Mixed Forestry	589.0
Newaukum Creek	Agriculture	27.4
Fishtrap Creek	Agriculture	38.1
Lower Nooksack River	Mixed Agriculture	790.0
Thorton Creek	Urban	12.1
Springbrook Creek	Urban	20.0
Big Soos Creek	Urban	66.7
Duwamish River	Mixed Urban	461.0

Loading rates for total nitrogen (TN), dissolved orthophosphate (PO4), and total phosphorus (TP) were estimated by the rating-curve method using instantaneous concentration data and daily or unit streamflow data (Embrey and Fran, 2003). Table 3.2-3 presents the resulting average annual loading rates (lbs/acre/year) for the 6 land use categories included in the study. The rates developed in this study are particularly useful because the sampled watersheds are within or in close proximity to the SWAMP-Green-Duwamish study area. Unfortunately, the study does not provide insight into the fraction of TN that is inorganic versus organic. However, a statistical analysis of stream nutrient concentrations for 17 streams in the greater Seattle region showed that the organic nitrogen fraction accounted for only 19% of TN in the most forested Seattle area streams, and only a slightly higher fraction in the most urban streams (Brett et al., 2003). Nitrate was the dominant fraction at approximately 60 to 80%. This implies that the TN loadings presented in Table 3.2-3 could be distributed to ammonia, nitrite+nitrate, and organic nitrogen using the percentages of 10, 70, and 20, respectively for the purpose of approximating target loading rates for the nitrogen species.

Table 3.2-3 Nutrient Target Loadings (lbs/acre/year)

LAND USE	TN	PO_4	TP
Forest	1.91	0.19	0.63

Mixed Forestry	5.69	0.17	3.08
Agriculture	25.51	0.88	1.99
Mixed Agriculture	12.66	0.17	3.52
Urban	7.14	0.15	0.64
Mixed Urban	8.81	0.30	1.29

The TN loading rates for agriculture are above the mean, but within the range, observed at the national level, and are likely due to the more intensive agriculture (row crop, hobby farms, and dairy) occurring in the Newaukum and Fishtrap Creek watersheds. The PO_4 loading rates appear to be higher for forest and agriculture, yet lower for urban, when compared to those reported for orthophosphate at a national level. Overall, these values appear reasonable and tend to fall into ranges that have been reported at a national scale (Table 3.2-5).

3.2.3.3 Bacteria Loading Rates

Limited data were available in the literature to quantify bacterial loading rates typical of watersheds within the Puget Sound area. King County developed pollutant yield coefficients for fecal coliform (# Organisms/acre/year) for the 9 land use categories listed in Table 3.2-4 (King County, 1994). It is unclear exactly how these yield coefficients were estimated, since the reference cited simply states: ‘the yield coefficients are based on the best available data to simulate pollutant loadings in the study area (i.e., Eastern tributaries of the Lower Green River)’.

Table 3.2-4 Fecal Coliform Target Loading Rates (Organisms/acre/year)

Land Use	Fecal Coliform
Forest	4.856E+08
Grass	1.942E+09
Low Density - Forest	5.666E+08
Low Density - Grass	1.133E+09
High Density	1.821E+09
Multi-Family	2.550E+09
Commercial	6.880E+08
Impervious	2.550E+09
Wetland	0.000E+00

3.2.3.4 Summary of National Scale Nonpoint Loading Rates

Table 4.2-7 presents the mean and range of nonpoint loadings found during a “national scale” literature review for a particular scheme of aggregating the cited land use categories into more generalized categories. The table presents the annual loading rates for total suspended solids, ammonia-N, nitrite-N, nitrate-N, total N, phosphate-P, total P, copper, lead, and zinc. It is apparent that the ranges of some of the rates within the table are quite large, and even though the categories were grouped, there are still significant generalized land use and constituent combinations that lack information. This is due in part to the fact that certain combinations have not been considered to be significant sources of water quality impairment. For example, wetlands are often cited as a sink (i.e., negative load) for many of the constituents listed in Table 3.2-5. As previously mentioned, the table is provided to fill in data gaps and to provide comparisons with data available from local studies.

Table 3.2-5 National Scale Nonpoint Loading Rates

CONSTITUENT		GENERAL LAND USE AGRICULTURE		FOREST		OPEN/ PASTURE		URBAN		WETLANDS	
TSS (TONS/ACRE)	MEAN	0.624		0.044		0.253		0.352		0.010	
	RANGE	1.874	0.009	0.008	0.11 2	0.000	0.892	0.036	0.892	0.00	0.017
AMMONIA (LBS/ACRE)	MEAN	1.052		0.158		0.192		1.120		--	
	RANGE	0.500	2.534	0.15	0.165	0.027	0.350	0.368	1.834	--	--
NITRITE (LBS/ACRE)	MEAN	0.007		--		0.016		0.181		--	
	RANGE	0.007	0.007	--	--	0.006	0.027	0.083	0.384	--	--
NITRATE (LBS/ACRE)	MEAN	6.942		1.508		1.723		3.693		--	
	RANGE	0.390	15.44	1.50	1.515	0.809	3.800	2.302	5.505	--	--
TN (LBS/ACRE)	MEAN	13.667		2.570		4.414		7.172		3.850	
	RANGE	2.230	34.60	0.35	5.692	0.000	11.000	0.776	17.26	0.00	5.400
PO4 (LBS/ACRE)	MEAN	0.448		0.093		0.184		0.823		--	
	RANGE	0.188	0.714	0.09	0.095	0.168	0.200	0.418	1.142	--	--
TP (LBS/ACRE)	MEAN	1.766		0.203		0.609		1.741		0.353	
	RANGE	0.178	4.862	.012	0.900	0.000	4.600	0.10	9.010	0.00	0.880
BOD (LBS/ACRE)	MEAN	30.698		6.650		13.333		41.974		11.836	
	RANGE	4.100	106.3	2.60	15.00	1.600	46.020	4.46	91.530	6.70	16.13
COPPER (LBS/ACRE)	MEAN	0.104		--		0.008		0.057		--	
	RANGE	0.075	0.134	--	--	0.007	0.009	0.018	0.083	--	--
LEAD (LBS/ACRE)	MEAN	21.900		--		1.031		15.373		--	
	RANGE	0.020	43.78	--	--	0.001	2.061	0.009	159.39	--	--
ZINC (LBS/ACRE)	MEAN	0.200		--		0.016		1.066		--	
	RANGE	0.114	0.285	--	--	0.013	0.018	0.099	1.606	--	--

3.2.4 Additional Physical Data Needs for Water Quality Simulation

The primary additional physical data needed to characterize the watershed land areas specifically for water quality simulation are land segment elevations and groundwater temperatures. These are used to estimate soil temperatures (which are used to predict the temperature of runoff to streams) and concentrations of dissolved oxygen and carbon dioxide in the runoff. Average land elevations were obtained from the DEM and approximate groundwater temperatures were estimated from the mean annual temperature for the watershed, and were varied over the year. These monthly temperature values were adjusted slightly during calibration to improve the water temperature calibration.

Additional physical, geometric, and hydraulic data were developed to represent properties of the channels needed for water quality simulation. Since water temperature processes are primarily determined by energy transfers across the air-water interface, the surface area parameter in the FTABLE must be accurately determined so that these energy fluxes are representative. Related to the surface area, the initial value of the stream surface shading parameter (CFSAEX) must be estimated.

The sediment simulation requires information to: 1) divide the eroded loads and the existing sediment bed into sand, silt, and clay fractions, 2) determine physical properties of the sediments, and 3) estimate the width of the sediment bed.

The relationship between the channel surface area, depth, volume, and shading is also important for modeling the transfer of oxygen and other gases across the air-water interface, and for determination of light intensity for modeling growth of algae.

3.2.5 Overview of Water Quality Calibration Procedures and Concepts

3.2.5.1 Sediment Erosion Calibration

Sediment calibration follows the hydrologic calibration and must precede water quality calibration of other constituents that are affected by sediment erosion and transport. Calibration of watershed sediment erosion is more uncertain than hydrologic calibration due to less experience with sediment simulation in different regions of the country. The process is analogous, however; the major sediment parameters are modified to increase agreement between simulated and recorded monthly sediment loss and storm event sediment removal. However, observed monthly sediment loss is often not available, and the sediment calibration parameters are not as distinctly separated between those that affect monthly sediment and those that control storm sediment loss. In fact, annual sediment losses are often the result of only a few major storms during the year.

Sediment loadings to the stream channel are estimated by land use category from literature data, local Extension Service sources, or procedures like the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1972) and then adjusted for delivery to the stream with estimated sediment delivery ratios. Model parameters are then adjusted so that model calculated loadings are consistent with these estimated loading ranges. The loadings are further evaluated in conjunction with instream sediment transport calibration that extend to a point in the watershed where suspended sediment concentration data are available. The objective is to represent the overall sediment behavior of the watershed, with knowledge of the morphological characteristics of the stream (i.e., aggrading or degrading behavior), using sediment loading rates that are consistent with available values and providing a reasonable match with instream sediment data.

3.2.5.2 Instream Sediment Transport Calibration

Once the sediment loading rates are calibrated to provide the expected input to the stream channel, the sediment calibration then focuses on the channel processes of deposition, scour, and transport that determine both the total sediment load and the outflow sediment concentrations to be compared with observations. Although the sediment load from the land surface is calculated in HSPF as a total input, it is divided into sand, silt, and clay fractions for simulation of instream processes. Each sediment size fraction is simulated separately, and storages of each size are maintained for both the water column (i.e., suspended sediment) and the bed.

In HSPF, the transport of the sand (non-cohesive) fraction is commonly calculated as a power function of the average velocity in the channel reach in each timestep. This transport capacity is compared to the available inflow and storage of sand particles; the bed is scoured if there is excess capacity to be satisfied, and sand is deposited if the transport capacity is less than the available sand in the channel reach. For the silt and clay (i.e. non-cohesive) fractions, shear stress calculations are performed by the hydraulics (HYDR) submodule and are compared to user-defined critical, or threshold, values for deposition and scour for each size. When the shear stress in each timestep is greater than the critical value for scour, the bed is scoured at a user-defined erodibility rate; when the shear stress is less than the critical deposition value, the silt or clay fraction deposits at a settling rate input by the user for each size. If the calculated shear stress falls between the critical scour and deposition values, the suspended material is transported through the reach. After all scour and/or deposition fluxes have been determined, the bed and water column storages are updated and outflow concentrations and fluxes are calculated for each timestep. These simulations are performed by the SEDTRN submodule.

In HSPF, sediment transport calibration involves numerous steps in determining model parameters and appropriate adjustments needed to insure a reasonable simulation of the sediment transport and behavior of the channel system. These steps are usually as follows:

1. Divide input sediment loads into appropriate size fractions
2. Run HSPF to calculate shear stress in each reach to estimate critical scour and deposition values
3. Estimate initial parameter values and storages for all reaches
4. Adjust scour, deposition and transport parameters to impose scour and deposition conditions at appropriate times, e.g., scour at high flows, deposition at low flows
5. Analyze sediment bed behavior and transport in each channel reach
6. Compare simulated and observed sediment concentrations, bed depths, and particle size distributions, where available
7. Repeat steps 1 through 6 as needed

Rarely is there sufficient observed local data to accurately calibrate all parameters for each stream reach. Consequently, model users focus the calibration on sites with observed data and review simulations in all parts of the watershed to insure that the model results are consistent with field observations, historical reports, and expected behavior from past experience. Ideally comprehensive datasets available for storm runoff should include both tributary and mainstem sampling sites. Observed storm concentrations of TSS should be compared with model results, and the sediment loading rates by land use category should be compared with the expected targets and ranges, as noted above.

3.2.5.3 Nonpoint Source Loading and Water Quality Calibration

The essence of watershed water quality calibration is to obtain acceptable agreement of observed and simulated concentrations (i.e., within defined criteria or targets), while maintaining the instream water quality parameters within physically realistic bounds, and the nonpoint loading rates within the expected ranges from the literature.

The following steps are usually performed at each of the calibration stations, following the hydrologic calibration and validation, and after the completion of input development for point source and atmospheric contributions:

1. Estimate all model parameters, including land use specific accumulation and depletion/removal rates, washoff rates, and subsurface concentrations
2. Superimpose the hydrology and tabulate, analyze, and compare simulated nonpoint loadings with expected range of nonpoint loadings from each land use and adjust loading parameters when necessary to improve agreement and consistency
3. Calibrate instream water temperature
4. Compare simulated and observed instream concentrations at each of the calibration stations
5. Analyze the results of comparisons in steps 3 and 4 to determine appropriate instream and/or nonpoint parameter adjustments, and repeat those steps as needed until calibration targets are achieved. Watershed loadings are adjusted when the instream simulated and observed concentrations are not in full agreement, and instream parameters have been adjusted throughout the range determined reasonable.

Calibration procedures and parameters for simulation of nonpoint source pollutants will vary depending on whether constituents are modeled as sediment-associated or flow-associated. This refers to whether the loads are calculated as a function of sediment loadings or as a function of the overland flow rate.

Calibration of sediment-associated pollutants begins after a satisfactory calibration of sediment washoff has been completed. At this point, adjustments are performed in the contaminant potency factors, which are user-specified parameters for each contaminant. Potency factors are used primarily for highly sorptive contaminants that can be assumed to be transported with the sediment in the runoff. Generally, monthly and annual contaminant loss will not be available, so the potency factors will be adjusted by comparing simulated and recorded contaminant concentrations, or mass removal, for selected storm events. For nonpoint pollution, mass removal in terms of contaminant mass per unit time (e.g., gm/min) is often more indicative of the washoff and scour mechanisms than instantaneous observed contaminant concentrations.

Calibration procedures for simulation of contaminants associated with overland flow are focused on the adjustment of parameters relating to daily accumulation rates (lb/acre/day), accumulation limits (lb/acre), and washoff parameters (in/hr). As was the case for sediment-associated constituents, calibration is performed by comparing simulated and recorded contaminant concentrations, or mass removal, for selected storm events. In most cases, proper adjustment of corresponding parameters can be accomplished to provide a good representation of the washoff of flow-associated constituents.

In study areas where pollutant contributions are also associated with subsurface flows, contaminant concentration values are assigned for both interflow and active groundwater. The key parameters are simply the user-defined concentrations in interflow and groundwater/baseflow for each contaminant. HSPF includes the functionality to allow monthly values for all nonpoint loading parameters in order to better represent seasonal variations in the resulting loading rates.

Instream HSPF water quality calibration procedures are highly dependent on the specific constituents and processes represented, and in many ways, water quality calibration is equal parts art and science. As noted above, the goal is to obtain acceptable agreement of observed and simulated concentrations (i.e., within defined criteria or targets), while maintaining the instream water quality parameters within physically realistic bounds, and the nonpoint loading rates within the expected ranges from the literature. The specific model parameters to be adjusted depend on the model options selected and constituents being modeled, e.g. BOD decay rates, reaeration rates, settling rates, algal growth rates, temperature correction factors, coliform die-off rates, adsorption/desorption coefficients, etc. Part of the ‘art’ of water quality calibration, is assessing the interacting effects of modeled quantities, e.g., algal growth on nutrient uptake, and being able to analyze multiple timeseries plots jointly to determine needed parameter adjustments.

3.3 LINKAGE OF HSPF MODELS TO CE-QUAL-W2 MODEL

3.3.1 Material Linkage (Species and Units)

The 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 HSPF models 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 HSPF models developed do 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!

3.3.2 Spatial Linkage

All loadings to the River Model from HSPF models effectively enter the river at a single location, i.e., the mouth of the creek or may be distributed when land surface runoff has no defined channel routing schemes. Since the end of the most downstream reach of the watershed models 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, or directly from the Land Segments where channel routing is not used.

3.3.3 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.

3.3.4 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.