Appendix H
Model Configuration, Calibration and Validation

Basin: Willamette River

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Watershed Background

The Willamette River watershed comprises the Willamette and Sandy River watersheds in northwestern Oregon in EPA Region 10. The study area is bordered on the west by the Coast Range, where elevations exceed 4,000 ft, and on the east by the Cascade Range, with several peaks higher than 10,000 ft. The Willamette Valley, with elevations near sea level, lies between the two ranges (USGS 2001). Figure 1 shows the location of the Willamette River watershed.

Forested land dominates the foothills and mountains of the Coast and Cascade Ranges. Agricultural land, mostly cropland, comprises 22 percent of the study area and is located predominantly in the Willamette Valley. About one-third of the agricultural land is irrigated, and most of this is adjacent to the main stem Willamette River in the southern watershed or scattered throughout the northern valley. Urban land is located primarily in the valley along the main stem Willamette River. About 70 percent of Oregon's population lives in the Willamette watershed.

More than three-fourths of the water used in the Willamette watershed is surface water. The largest single use is for the irrigation of crops. Public water supply (serving cities, towns, mobile home parks, apartment complexes) is the second largest use. Public supply consists mostly of withdrawals from Cascade streams, including the Bull Run in the Sandy River watershed and the Clackamas, Santiam, and McKenzie Rivers. The small amount of groundwater used for public supply (~10% of the total) comes predominantly from alluvial aquifers located along Cascade streams or along the main stem Willamette River. Most commercial water use is by fish hatcheries, and most industrial use is by pulp-and-paper mills.

Water Body Characteristics

The Willamette River is the 13th largest river in the conterminous U.S. in terms of streamflow and produces more runoff per mi^2 than any of the larger rivers. The Sandy River watershed includes the Bull Run watershed, which is Portland's primary drinking water supply. The Willamette and Sandy Rivers are tributary to the Columbia River, which flows west to the Pacific Ocean along Oregon's northern border. The Willamette River flows through Portland, Oregon's largest metropolitan area, before entering the Columbia River.

Streamflow in the Willamette watershed reflects the seasonal distribution of precipitation, with 60-85 percent of runoff occurring from October through March, but less than 10 percent occurring during July and August. Releases from 13 tributary reservoirs are managed for water quality enhancement by maintaining a flow of 6,000 cubic feet per second (cfs) in the Willamette River at Salem during summer months.

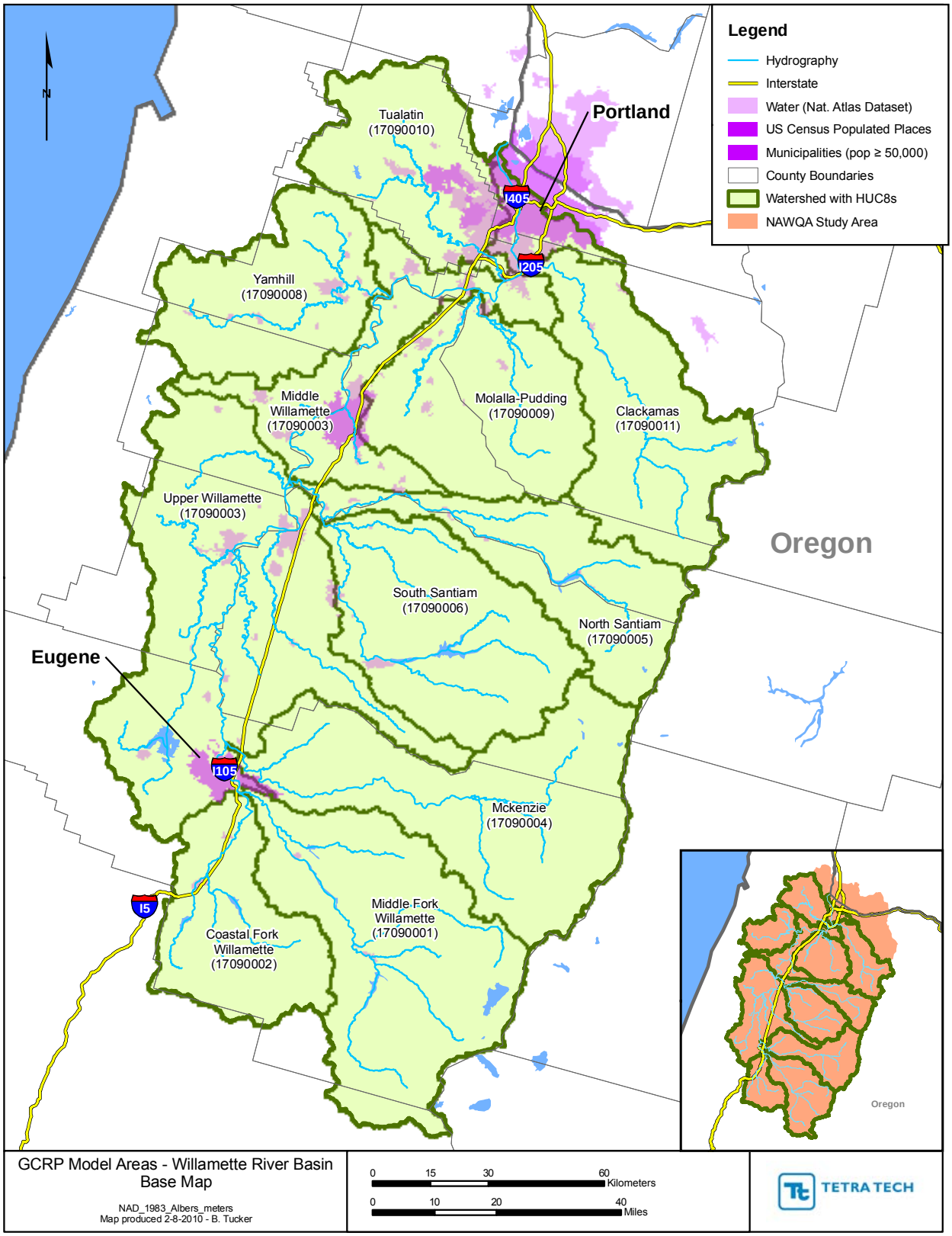

Figure 1. Location of the Willamette River watershed.

Soil Characteristics

One of the most important characteristics of soils for watershed modeling is their hydrologic soil group (HSG). The 20 Watershed study utilized STATSGO soil survey HSG information during model set-up. Soils are classified into four hydrologic groups (SCS 1986), separated by runoff potential, as follows:

- A Low runoff potential and high infiltration rates even when thoroughly wetted. Chiefly deep, well to excessively drained sands or gravels. High rate of water transmission (> 0.75 cm/hr).
- B Moderate infiltration rates when thoroughly wetted. Chiefly moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. Moderate rate of water transmission (0.40—0.75 cm/hr).
- C Low infiltration rates when thoroughly wetted. Chiefly soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. Low rate of water transmission (0.15—0.40 cm/hr).
- D High runoff potential. Very low infiltration rates when thoroughly wetted. Chiefly clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, or shallow soils over nearly impervious material. Very low rate of water transmission (0—0.15 cm/hr).

The Willamette River watershed contains all four HSGs, but consists of mostly B, C, and D soils with a dominance of C soils.

Land Use Representation

Land use/cover in the watershed is based on the 2001 National Land Cover Database (NLCD) coverage and is predominantly forest (Figure 2). Most of the developed areas of the watershed are found along the Willamette River with the major urban development near the mouth of the river at the city of Portland.

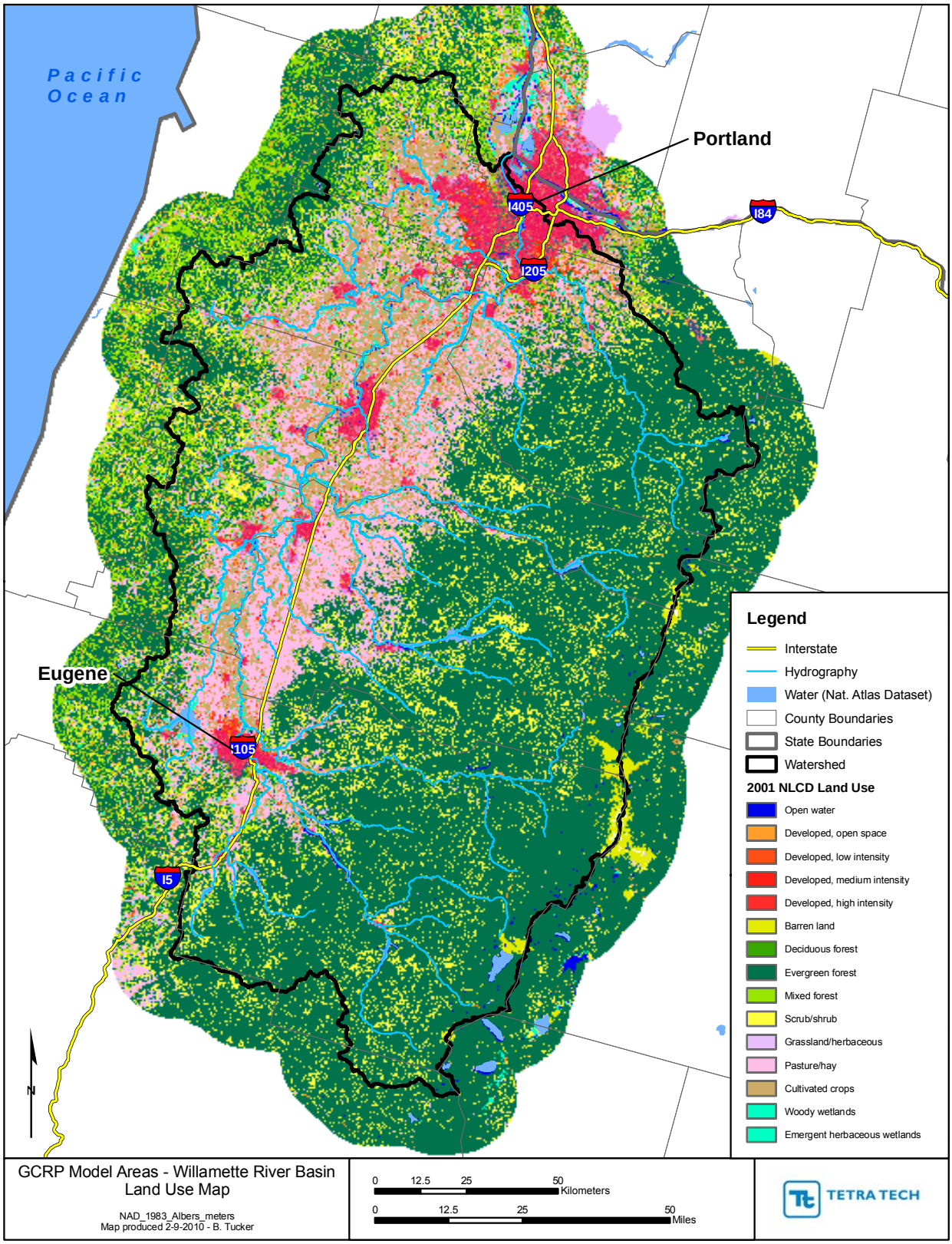

Figure 2. Land use in the Willamette River watershed.

NLCD land cover classes were aggregated according to the scheme shown in Table 1 for representation in the 20 Watershed model, and then overlain with the soils HSG grid. For HSPF, pervious and impervious lands are specified separately, so only one developed pervious class is used, along with an impervious class. HSPF simulates impervious land areas separately from pervious land. Impervious area distributions were determined from the NLCD Urban Impervious data coverage. Specifically, percent impervious area was calculated over the entire watershed for each of the four developed land use classes. These percentages were then used to separate out impervious land. NLCD impervious area data products are known to underestimate total imperviousness in rural areas; however, the model properly requires connected impervious area, not total impervious area, and the NLCD tabulation is assumed to provide a reasonable approximation of connected impervious area. In SWAT, different developed land classes are specified separately. In HSPF the WATER, BARREN, DEVPERV, and WETLAND classes are not subdivided by HSG; SWAT uses the built-in HRU overlay mechanism in the ArcSWAT interface.

Table 1. Aggregation of NLCD land cover classes

NLCD Class	Comments	SWAT class	HSPF (after processing)
11 Water	Water surface area usually accounted for as reach area	WATR	WATER
12 Perennial ice/snow		WATR	BARREN, Assume HSG D
21 Developed open space		URLD	DEVPERV; IMPERV
22 Dev. Low Intensity		URMD	
23 Dev. Med. Intensity		URHD	
24 Dev. High Intensity		UIDU	
31 Barren Land		SWRN	BARREN (D)
41 Forest	Deciduous	FRSD	FOREST (A,B,C,D)
42 Forest	Evergreen	FRSE	
43 Forest	Mixed	FRST	
51-52 Shrubland		RNGB	SHRUB (A,B,C,D)
71-74 Herbaceous Upland		RNGE	GRASS (A,B,C,D), BARREN (D)
81 Pasture/Hay		HAY	GRASS (A,B,C,D)
82 Cultivated		AGRR	AGRI (A,B,C,D)
91-97 Wetland	Emergent & woody wetlands	WETF, WETL, WETN	WETLAND, Assume HSG D
98-99 Wetland	Aquatic bed wetlands (not emergent)	WATR	WATER

The distribution of land use in the watershed is summarized in Table 2.

Table 2. Land use distribution for the Willamette River watershed (2001 NLCD mi^2)

HUC 8 watershed	Open water	Developed[a]				Barren land	Forest	Shrubland	Pasture/Hay	Cultivated	Wetland	Total
		Open space	Low density	Medium density	High density							
17090001	26.44	8.23	2.47	0.91	0.19	12.74	1,110.50	174.21	16.83	10.72	3.03	1,366.29
17090002	3.93	14.10	5.10	2.15	0.83	1.07	464.30	113.37	42.54	10.36	8.56	666.32
17090003	13.36	78.96	75.65	33.85	13.95	16.65	613.94	214.51	519.77	220.82	70.45	1,871.90
17090004	7.20	10.12	3.48	1.78	0.33	43.46	1,059.22	177.17	15.70	13.83	3.69	1,335.99
17090005	8.65	9.31	4.91	1.10	0.34	9.38	557.65	93.05	38.26	32.93	8.26	763.83
17090006	8.56	10.06	5.52	1.56	0.37	2.95	673.46	183.49	105.84	43.13	6.07	1,040.99
17090007	11.76	34.04	62.98	28.43	9.77	2.52	111.89	32.75	214.05	169.74	33.05	710.97
17090008	0.81	26.67	17.27	4.26	1.65	7.41	332.96	93.46	134.92	130.72	21.11	771.24
17090009	1.83	18.37	22.98	9.20	3.07	1.74	366.29	99.14	191.08	138.66	23.12	875.47
17090010	1.87	30.05	69.47	38.44	11.21	8.11	259.90	79.09	79.25	114.60	16.23	708.20
17090011	5.25	15.23	10.36	3.45	1.61	1.02	715.90	118.01	42.02	24.90	3.60	941.36
17090012	6.38	11.63	41.47	34.06	15.52	0.41	27.31	1.57	6.02	3.68	1.95	150.01
Total	96.04	266.77	321.66	159.19	58.84	107.46	6,293.32	1,379.81	1,406.28	914.10	199.11	11,202.58

[a]The percent imperviousness applied to each of the developed land uses is as follows: open space (9.56%), low density (32.31%), medium density (61.49%), and high density (88.94%).

The HSPF model is set up on a hydrologic response unit (HRU) basis. For HSPF, HRUs were formed from an intersection of land use and hydrologic soil group, and then further subdivided by precipitation gage. Average slopes (which tend to correlate with soils) were calculated for each HRU. The water land use area was adjusted to prevent double counting with area described in HSPF reaches. SWAT HRUs are formed from an intersection of land use and SSURGO major soils.

Point Sources

Facilities permitted under the National Pollutant Discharge Elimination System (NPDES) are, by definition, considered point sources. It was assumed that minor dischargers (below 1.0 MGD) were insignificant, therefore, not included in the model setup and simulation. Data were sought from the PCS database for the major dischargers in the Willamette River watershed (Table 3 and Figure 3). Facilities that were missing total nitrogen, total phosphorus, or total suspended solids (TSS) concentrations were filled with a typical pollutant concentration value from literature based on SIC classification (Tetra Tech 1999). Constant point source flows and concentrations were assumed for each major discharge facility in the watershed for the entire simulation period.

During the water quality calibration it was noticed that assumptions used for total phosphorus, at some facilities, were too high. An investigation into the point sources that had assumed values for total phosphorus was conducted. A new assumed value was supplied for these facilities. The modifications made to the total phosphorus values are described in the “Changes to the Base Data” section of this report. The new assumed value was also applied to the SWAT simulation. Both the HSPF and SWAT models used the same flows and concentrations for each of the major point sources included in the simulations for the Willamette River watershed.

Table 3. Major point source discharges in the Willamette River watershed

NPDES ID	Name	Design flow (MGD)	Observed flow (MGD) (1991-2006 average)
OR0026891	PORTLAND,	8.30	15.42
OR0026140	OAK LODGE	4.00	6.29
OR0026221	CLACKAMAS	2.66	19.82
OR0030589	SILTRONIC	--	0.88
OR0031259	TRI-CITY	0.00	17.85
OR0000566[a]	BLUE HERO	--	--
OR0000787[a]	WEST LINN	--	--
OR0020214	CANBY, CI	2.00	1.31
OR0028118[b]	CLEAN WAT	22.60	22.60
OR0029777[c]	CLEAN WAT	39.00	25.00
OR0023345[d]	CLEAN WAT	7.50	5.02
OR0020168[d]	CLEAN WAT	5.00	3.74
OR0020001	WOODBURN,	3.33	4.09
OR0022764	WILSONVIL	2.25	19.03
OR0032352	NEWBERG,	4.00	48.85
OR0000558[a]	VIRGINIA	--	--
OR0026409	SALEM, CI	35.00	51.60
OR0034002	MCMINNVIL	5.60	68.53
OR0020737	DALLAS, C	2.00	5.47
OR0020818	LEBANON,	3.00	3.93
OR0028801	ALBANY, C	8.70	7.28
OR0001112	TDY INDUS	--	2.50
OR0000442	WEYERHAEU	--	--
OR0020427	STAYTON,	1.90	3.47
OR0020346	SWEET HOM	1.38	3.69
OR0026361	CORVALLIS	9.70	13.57
OR0001716	OREGON ME	--	0.73
OR0033405[a]	FORT JAME	--	--
OR0001074[a]	CASCADE P	--	--
OR0000515[a]	WEYERHAEU	--	--
OR0031224	METROPOLI	49.00	36.77
OR0020559	COTTAGE G	1.20	2.78
OR0020656	SILVERTON	2.50	2.84

[a]Paper/pulp mills; discharge was ignored as their withdrawal and discharge are about the same
[b]Due to the upgrading of the treatment plant, total phosphorus concentration in the effluent value considered is 3.6 mg/L prior to 1992 and 0.07 mg/L for 1992 and onward.
[c]Due to the upgrading of the treatment plant, total phosphorus concentration in the effluent value considered is 2.1 mg/L prior to 1992 and 0.07 mg/L for 1992 and onward.
[d]Does not discharge to the river in summer

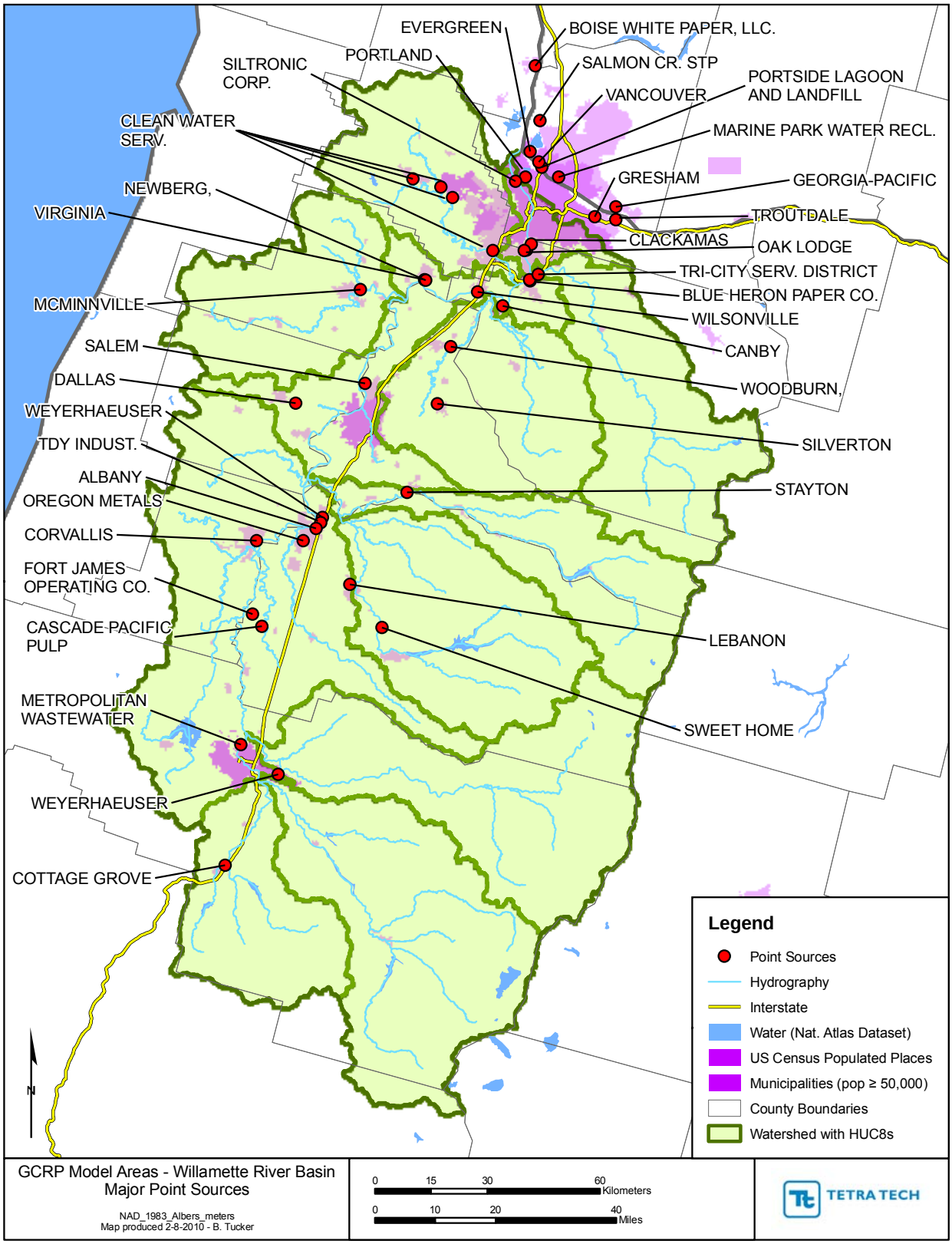

Figure 3. Major point sources in the Willamette River watershed.

Meteorological Data

The required meteorological data series for the 20 Watershed study are precipitation, air temperature, and potential evapotranspiration. The 20 Watershed model does not include water temperature or algal simulation and uses a degree-day method for snowmelt. These are drawn from the BASINS4 Meteorological Database (USEPA 2008), which provides a consistent, quality-assured set of nationwide data with gaps filled and records disaggregated. Scenario application will require simulation over 30 years, so the available stations are those with a common 30-year period of record (or one that can be filled from an approximately co-located station) that covers the year 2001. A total of 40 precipitation stations were identified for use in the Willamette River watershed model with a common period of record (Table 4 and Figure 4). Temperature records are sparser; where these are absent, temperature is taken from nearby stations with an elevation correction. For each weather station, Penman-Monteith reference evapotranspiration was calculated for use in HSPF using observed precipitation and temperature coupled with SWAT weather generator estimates of solar radiation, wind movement, cloud cover, and relative humidity.

For the 20 Watershed model applications, SWAT uses daily meteorological data, while HSPF requires hourly data. It is important to note that a majority of the meteorological stations available for the Willamette River watershed are Cooperative Summary of the Day stations that do not report sub-daily data. The BASINS4 dataset already has versions of the daily data that have been disaggregated to an hourly time step using template stations. For each daily station, this disaggregation was undertaken in reference to a single disaggregation template. Occasionally, this automated procedure provides undesirable results, particularly when the total rainfall for the day is very different between the subject station and the disaggregation template. This yields a small number of hourly precipitation intensity estimates that are unrealistically high (e.g., much greater than the 100-yr 1-hour event for the region). This has only a small impact on the watershed-scale hydrologic calibration as gages are influenced by rainfall from multiple weather stations, but can introduce significant problems for the prediction of erosion and sediment loads.

Table 4. Precipitation stations for the Willamette River watershed model

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
350595	OR350595	45.4548	-122.8200	Yes	269
350652	OR350652	44.2868	-122.0380	Yes	2,152
351222	OR351222	45.6864	-123.1910	No	157
351433	OR351433	44.3981	-122.4850	Yes	860
351735	OR351735	45.1701	-122.4330	No	679
351862	OR351862	44.6333	-123.1890	Yes	226
351877	OR351877	44.5087	-123.4580	Yes	591
351902	OR351902	43.7178	-123.0570	Yes	830
351914	OR351914	44.1331	-122.2500	No	384
352112	OR352112	44.9464	-123.2910	Yes	289
352292	OR352292	44.7243	-122.2540	Yes	1,220
352345	OR352345	43.7078	-122.7390	No	1,217
352374	OR352374	43.7823	-122.9630	Yes	820
352493	OR352493	45.2743	-122.2010	No	925
352693	OR352693	45.2690	-122.3180	Yes	449
352709	OR352709	44.1279	-123.2200	Yes	354
352805	OR352805	44.8578	-123.4300	Yes	420
352997	OR352997	45.5244	-123.1030	Yes	180
353047	OR353047	44.4139	-122.6720	Yes	551
353705	OR353705	45.3122	-123.3510	No	755
353971	OR353971	44.3525	-122.7840	No	610

COOP ID	Name	Latitude	Longitude	Temperature	Elevation (ft)
354606	OR354606	44.6254	-122.7180	Yes	518
354811	OR354811	44.1001	-122.6880	Yes	676
355050	OR355050	43.9145	-122.7600	Yes	712
355213	OR355213	44.1707	-122.8710	No	545
355221	OR355221	44.6125	-121.9480	Yes	2,474
355384	OR355384	45.2215	-123.1620	Yes	154
356151	OR356151	45.2818	-122.7510	Yes	151
356213	OR356213	43.7429	-122.4430	Yes	1,276
356334	OR356334	45.3553	-122.6050	Yes	167
356749	OR356749	45.5181	-122.6890	Yes	157
357127	OR357127	45.3037	-122.9140	No	515
357500	OR357500	44.9051	-123.0010	Yes	203
357631	OR357631	44.9469	-122.5240	Yes	2,316
357809	OR357809	44.8734	-122.6480	Yes	1,348
357823	OR357823	45.0051	-122.7730	Yes	407
358095	OR358095	44.7895	-122.8140	Yes	427
358466	OR358466	45.1250	-122.0720	Yes	1,119
359083	OR359083	44.5000	-122.8190	No	436
359372	OR359372	45.0832	-123.4890	No	384

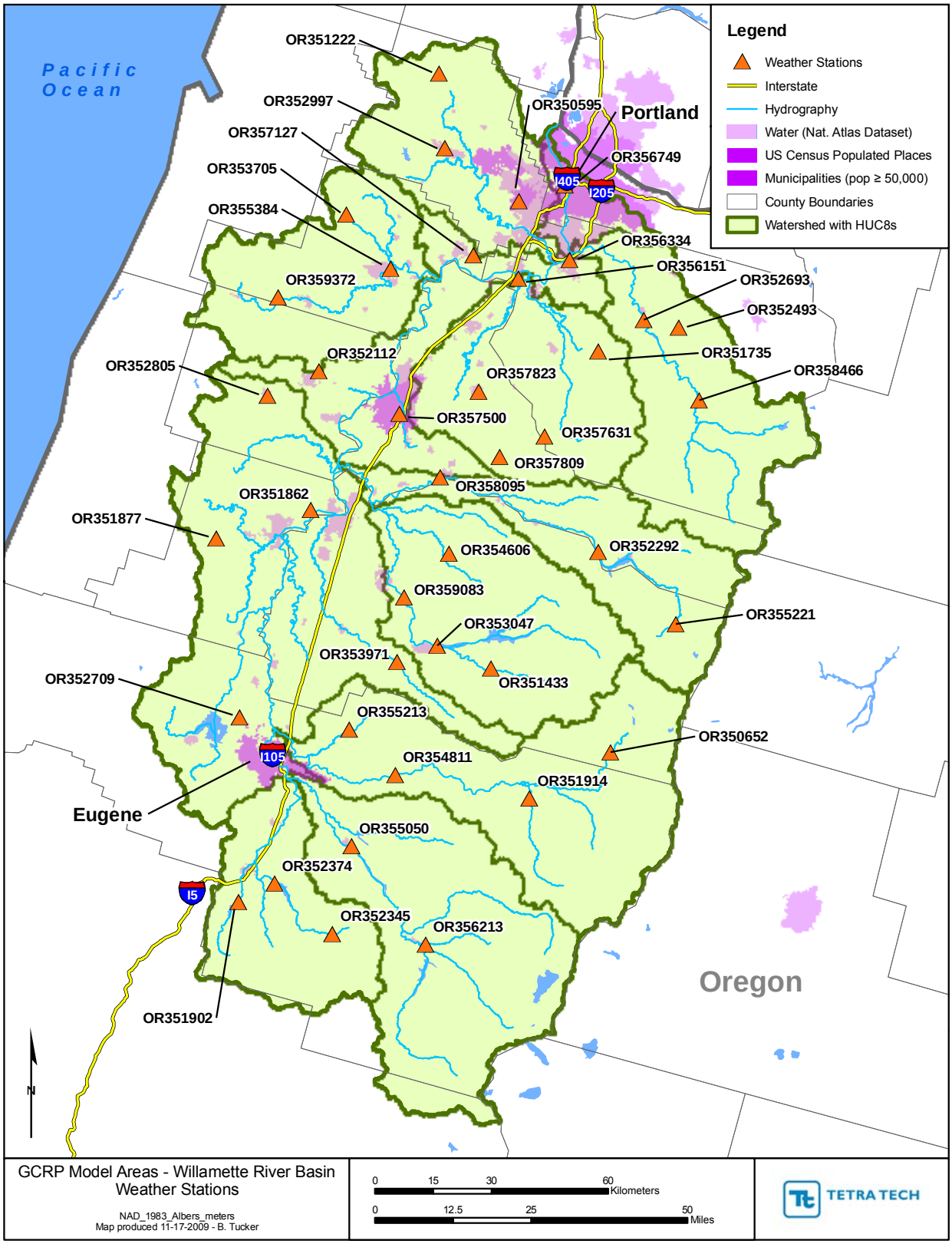

Figure 4. Weather stations for the Willamette River watershed model.

Watershed Segmentation

The Willamette River watershed was divided into 75 subwatersheds for the purposes of modeling (Figure 5). The initial calibration watershed (Tualatin HUC) is highlighted. Each of the subwatershed delineations represents roughly a HUC 10 scale watershed. Each of the major reservoirs in the Willamette watershed was delineated so that each dam outlet represents an individual watershed outlet. The delineations were done this way to ensure that any individual lake was contained in one watershed and that the watershed was only represented by one outlet. The Willamette 20 Watershed model is set for the complete Willamette watershed without any inflow from outside and thus does not require specification of any boundary conditions for application.

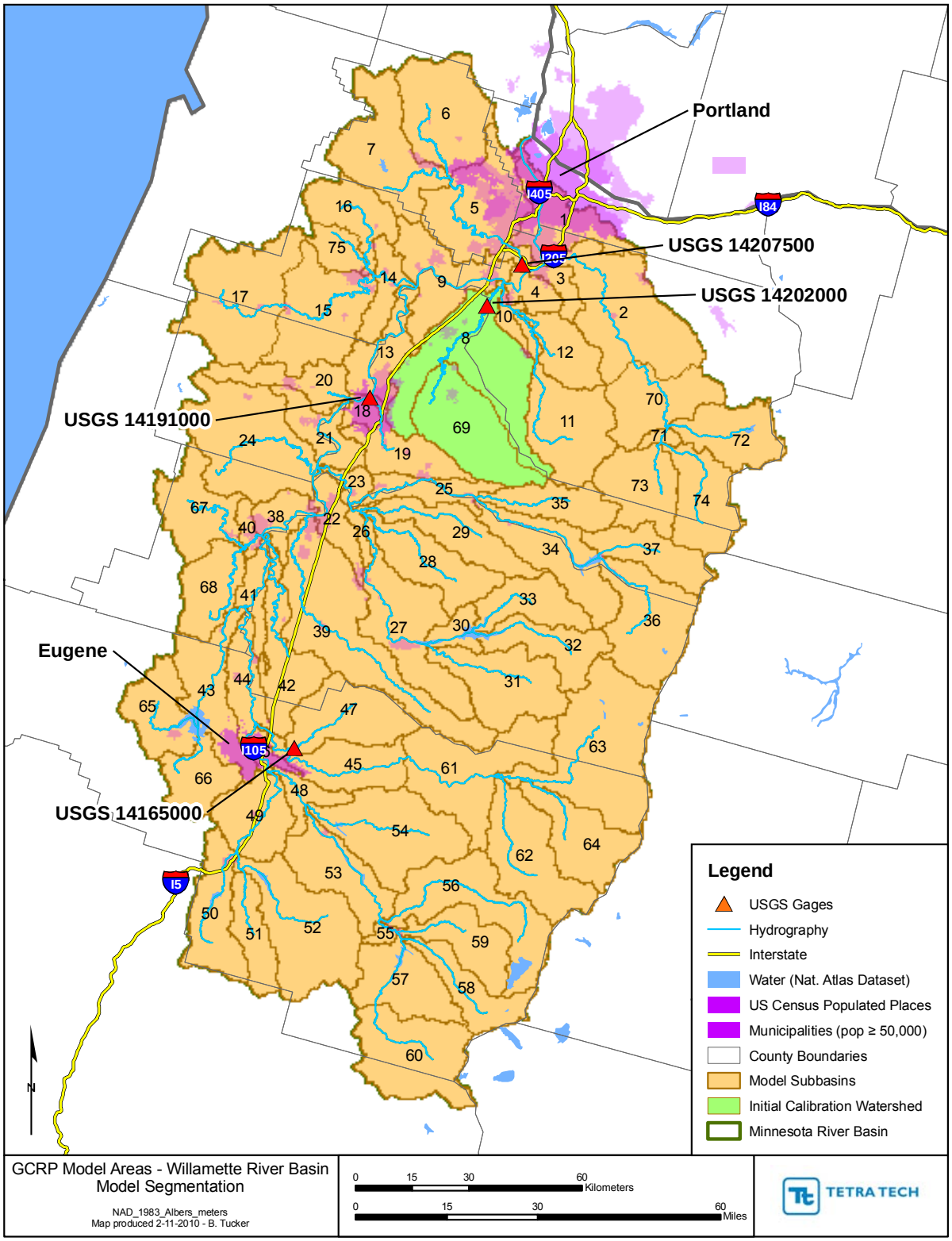

Figure 5. Model segmentation and USGS stations utilized for the Willamette River watershed. Note: SWAT subwatershed numbering is shown; the HSPF model for this watershed uses the same subwatershed boundaries with an alternative internal numbering scheme.

Calibration Data and Locations

Each of the twelve HUC8s in the watershed was considered as a candidate representative subwatershed for calibration. The objective was to find a HUC8 that resembled the overall characteristics of the Willamette watershed with respect to land use, precipitation and terrain. The USGS gages on the Tualatin River at West Linn, OR (USGS 14207500) and the Pudding River at Aurora, OR (USGS 14202000) were chosen as the primary hydrology and water quality calibration locations. Additional tributary hydrology calibration was performed on the South Yamhill River at McMinnville, OR (USGS 14194150) and the Mohawk (McKenzie) River near Springfield (USGS 14165000). A hydrology calibration check was performed at the USGS gage on the Willamette River at Salem, OR (USGS 14191000), which is the most downstream gage in the watershed that does not include tidal effects. At this location, 43 percent of the tributary area is controlled by the major dams. Therefore, calibration at this location would have been of limited use in developing model parameters. Table 5 presents the calibration and validation locations chosen for the Willamette River watershed.

Table 5. Calibration and validation locations in the Willamette River watershed

Station name	USGS ID	Drainage area (mi^2)	Hydrology calibration	Water quality calibration
Willamette River at Salem, Oregon	14191000	7280	X	
Pudding River at Aurora, Oregon	14202000	479	X	X
Tualatin River at West Linn, Oregon	14207500	706	X	X
Mohawk River near Springfield, Oregon	14165000	177	X	
South Yamhill River at McMinnville	14194150	528	X	

The model calibration period varied based on the availability of data. In general a calibration period of water years 1996 through 2005 was used and a period from water years 1986 through 1995 was used for validation. Water quality data were very limited and the period of coverage was not consistent between the two gages used for water quality calibration in this study. A calibration period of water years 1996 to 2002 and validation period of water years 1993 to 1995 were used for the Pudding gage; whereas, a calibration period of water years 1994-1995 and validation period of water years 1986 to 1993 were used for the Tualatin gage.

HSPF Modeling

Flows in the lower Willamette River watershed are dominated by the effects of 13 reservoirs and their associated dams operated by the U.S. Army Corps of Engineers for water supply, flood control, and navigation. These reservoirs control much of the runoff from the southern and eastern mountainous portions of the watershed where precipitation and snow fall are highest. Incorporation of the reservoirs in the model was a significant part of the model development effort. For the calibration model, the reservoirs were not modeled; the flow at the nearest USGS gage downstream of each reservoir was used as a boundary flow. One main stem gage was used as a hydrology calibration check; however, the flow at this gage was significantly affected by the boundary flows, particularly in the summer months when the boundary flows resulted in a significant overprediction of the observed flow. For the scenario model, the boundary conditions were removed, and the reservoirs were modeled by replacing the default HSPF FTABLEs with more realistic estimates of volume surface area, and spillway outflow rate. U.S. Army Corps of Engineer data were analyzed to develop seasonal storages and minimum flow time series which are specified as inputs to the model. During the simulation, each reservoir receives inflows from upstream areas, and the program computes outflows consisting of the minimum releases plus any water necessary to maintain the storage at or below the seasonal target storage.

Initial hydrologic parameterization for the Willamette calibration focus area came from the King County, Washington HSPF Modeling (Green River Water Quality Assessment and Sammamish-Washington Analysis and Modeling Program) (Bicknell et al. 2005). The King County hydrologic models have been under development for many years, and under the Green River/Sammamish-Washington project were extended to most of the watershed.

Calibrated parameters from the Tualatin River (USGS 14207500) and South Yamhill River (USGS 14194150) were applied to the eastern portions of the study area, while calibration adjustments for the Pudding River (USGS 14202000) were applied to the upper and western sections of the study area. Parameters from the Mohawk River (USGS 14165000) were applied to the southern and southwestern portions of the study area.

Once the hydrology calibration was complete for the entire Willamette watershed, the focus turned to sediment and water quality representation. The starting water quality parameters were again taken from the King County/Seattle HSPF models.

Changes Made to Base Data Provided

No changes were made to the meteorological or land use base data. However, one of the rainfall stations (OR357631) was not used because of unrealistic rainfall in 1996 that significantly skewed the water quality calibration results in the Pudding River subwatershed. A number of changes were made to the point sources. The flow from the six paper mills was changed to zero, since they draw water from the same rivers that they discharge to. These point sources are: OR0000442, OR0000515, OR0000558, OR0000566, OR0000787, and OR0001074. Also, several other point sources discharge to the calibration watersheds. Some of the parameters were determined to be erroneous, and since they caused obvious problems in the calibration in the Tualatin River and Pudding River sub-watersheds, were modified based on information obtained from other sources. Three point sources (OR0020001, OR0020168, and OR0023345) do not discharge to surface waters during the summer, so these three were modified to turn off the discharges between June and September. The discharges of three point sources (OR0028118, OR0029777, and OR0034002) were found to be overestimated by using the “Observed Flow”, and were changed to the “Design Flow”. The total phosphorus concentrations of two point sources were reduced as a result of the use of advanced treatment methods; these are OR0020168 and OR0029777. Summer loads of total phosphorus were substantially overpredicted with the higher values.

Assumptions

Reservoirs

There are 13 dams and 11 major reservoirs in the study area. Figure 6 shows the locations of the dams and the reservoirs in the watershed and Table 6 presents the 11 reservoirs that were included in the HSPF model. Two of the dams (Big Cliff and Dexter) are re-regulation dams that allow the Corps to adjust the downstream flow more smoothly than the releases from the upstream reservoir. The primary tributary calibration sites were chosen in order to avoid effects of these dams. The main stem calibration site on the Willamette at Salem, OR is affected by all of the major dams, so it was only used to check the calibration. The model used for calibration was modified from the original model to include specification of boundary inflows at the USGS gage downstream from each reservoir that provides flow to the Willamette main stem. The final model used for climate scenarios was modified by improving the hydraulic representation of each reservoir, and including a simplified representation of reservoir operation. Fortunately, all of the major reservoirs are operated by the U.S. Army Corps of Engineers, and they are operated in a relatively consistent manner. Seasonally varying target storages and minimum releases were programmed into the model using input time series. HSPF computes the reservoir outflows as the sum of the minimum releases and sufficient water to maintain the actual storage at or below the target storage. While one would assume the reservoirs influence the flow and water quality exiting the Willamette River at the outlet, for this model the impacts of these reservoirs are assumed to be implicitly represented through the modified FTABLES and the simplified operations, which should be applicable under future conditions.

Withdrawals

Because nobody knows what water withdrawals, by municipal and industrial facilities, will look like in the future they were not included in the 20 Watershed model application.

Irrigation

Irrigation is not being explicitly modeled in the Willamette River watershed.

Snow Simulation

The Willamette HPSF model includes snow simulation using the degree-day method for snowmelt. It is modeled in the subwatersheds that have a large area at high elevations, generally above 2,500 feet. The parameter values were extracted from other applications, and minor adjustments were made to ensure that the snow depths and duration were reasonable. No further calibration was performed for snow.

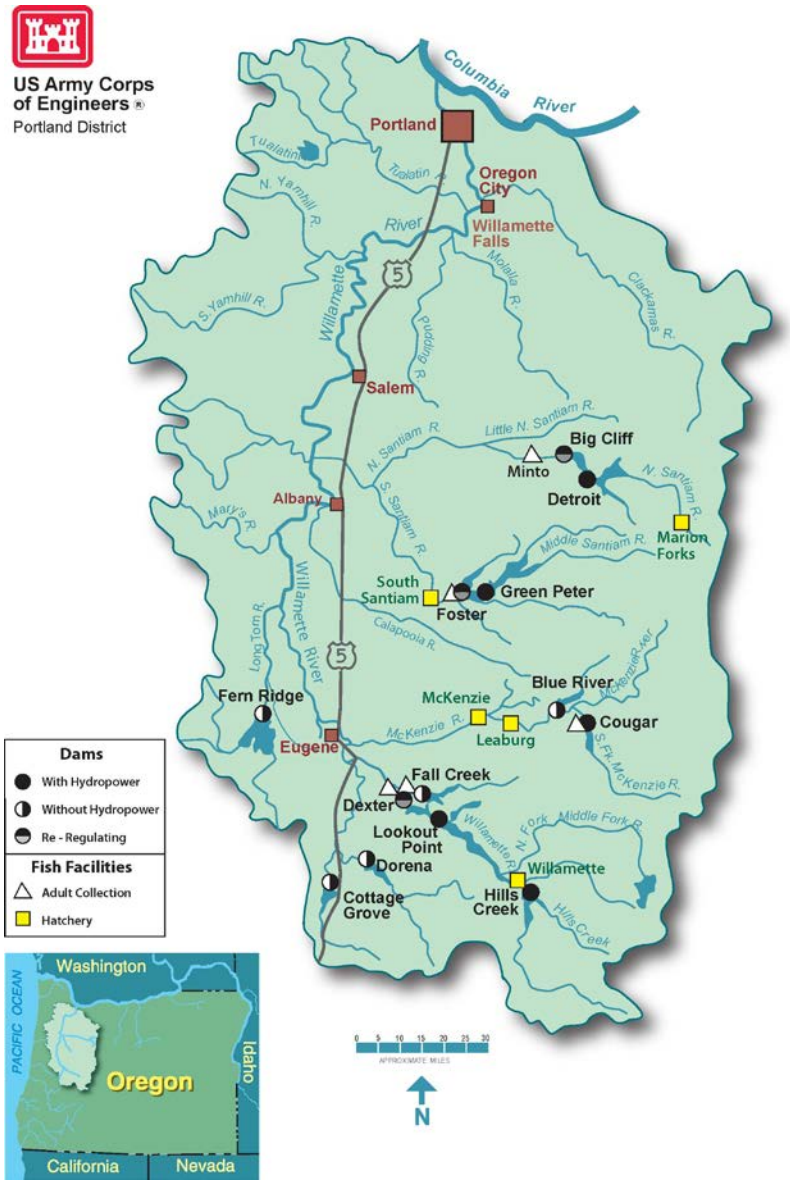

Figure 6. Dams and reservoirs in the Willamette River watershed (Source: USACE 2009).

Table 6. Reservoirs represented in the Willamette River watershed model

Dam Name	Other Name	River	Owner
Fall Creek	Fall Creek Lake	Fall Creek	USACE
Dorena	Dorena Lake	Row River	USACE
Lookout Point	Lookout Point Lake	Middle Fork-Willamette River	USACE
Green Peter	Green Peter	Middle Santiam River	USACE
Foster	Foster Lake	South Santiam River	USACE
Hills Creek	Hills Creek Lake	Middle Fork-Willamette River	USACE
Detroit	Detroit Lake	North Santiam River	USACE
Cottage Grove	Cottage Grove Lake	Coast Fork-Willamette River	USACE
Cougar	Cougar Lake	South Fork-McKenzie River	USACE
Blue River	Blue River Lake	Blue River-McKenzie River	USACE
Fern Ridge	Fern Ridge Lake	Long Tom River	USACE

Hydrology Calibration

As mentioned above, the starting parameters for this Willamette River HSPF model came from the King County, Washington HSPF models. After the starting parameters were inserted into the model input files, average annual potential evapotranspiration values were computed and compared to published values. Through this process it was determined the input potential evapotranspiration time series should be reduced by multipliers, since the computation of these time series produced more PET on an average annual basis than the published values indicate. The default multipliers used for PET were 0.80; however, some of the multipliers were adjusted slightly during the hydrology calibration. Calibration adjustments focused on the following parameters:

- LZSN (lower zone nominal storage): LZSN was reduced to shift flows to the wet period and reduce them in the summer. It was also used to increase total runoff.
- INFILT (index to mean soil infiltration rate): Infiltration was generally decreased from the initial values to increase storm peaks and reduce low flows.
- DEEPFR (fraction of groundwater inflow that will enter deep groundwater): small values of DEEPFR were used to attempt to reduce low flows and to reduce total flow volume.
- BASETP (ET by riparian vegetation): Slightly increasing the BASETP value provided some ET by riparian vegetation and improved the simulation of low flows.
- LZETP (lower zone E-T parameter): LZETP was generally increased to reduce flow, particularly the low flows, and to reduce total volumes.
- AGWRC (Groundwater recession rate)

Initial calibration was performed at the USGS gage on the Tualatin River at West Linn, OR (USGS 14207500), and is summarized in Figures 7 through 13 and Tables 7 and 8. The model fit is of good quality overall, but simulates slightly high on the storm flows as is indicated by the *Error in Storm Volumes* metric. The model calibration period was set to the 10 water years from 10/01/1995 to 09/30/2005.

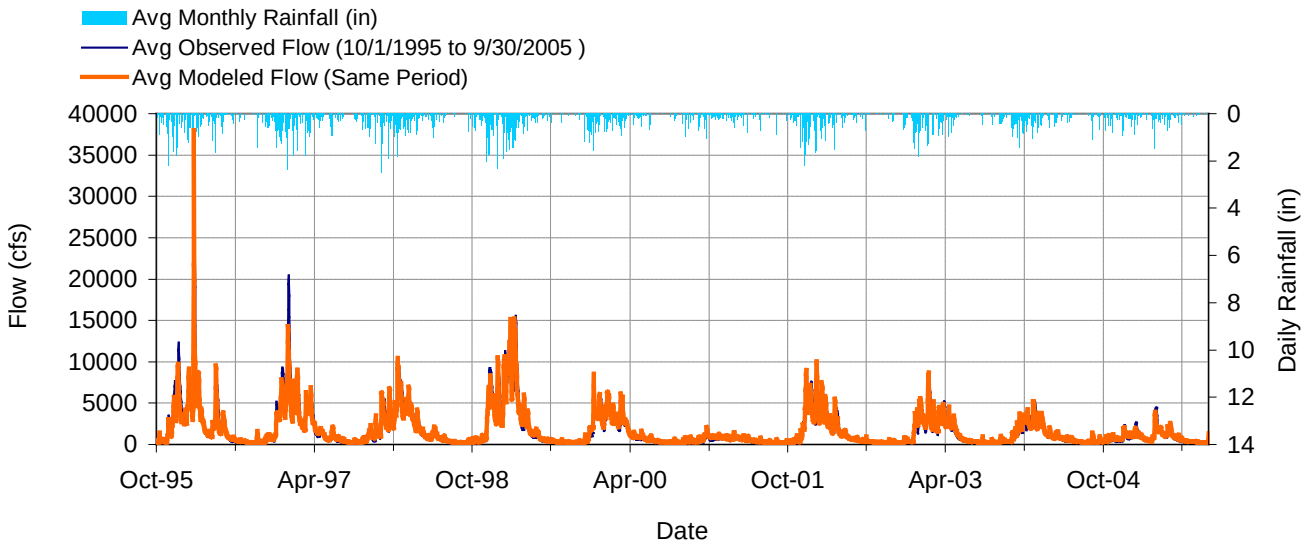

Figure 7. Mean daily flow at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF).

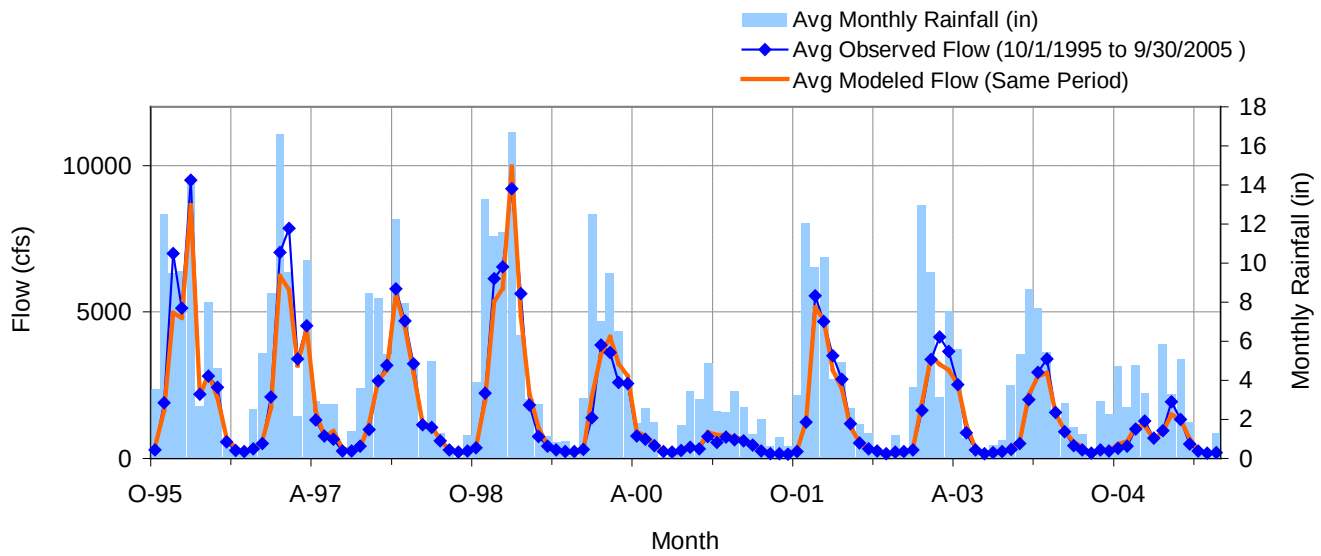

Figure 8. Mean monthly flow at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF).

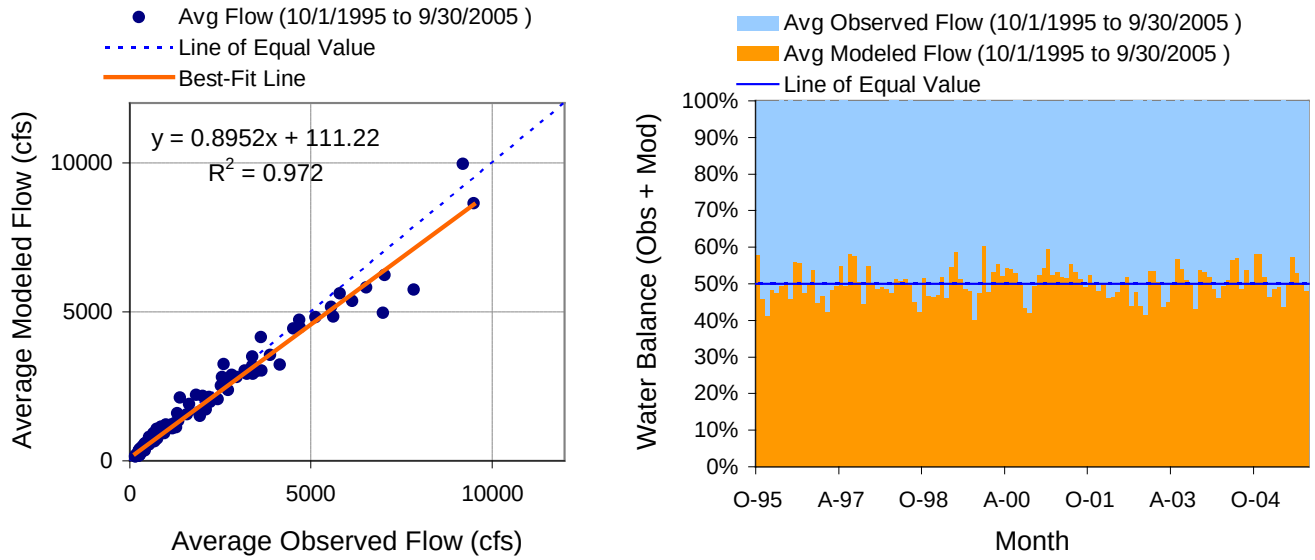

Figure 9. Monthly flow regression and temporal variation at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF).

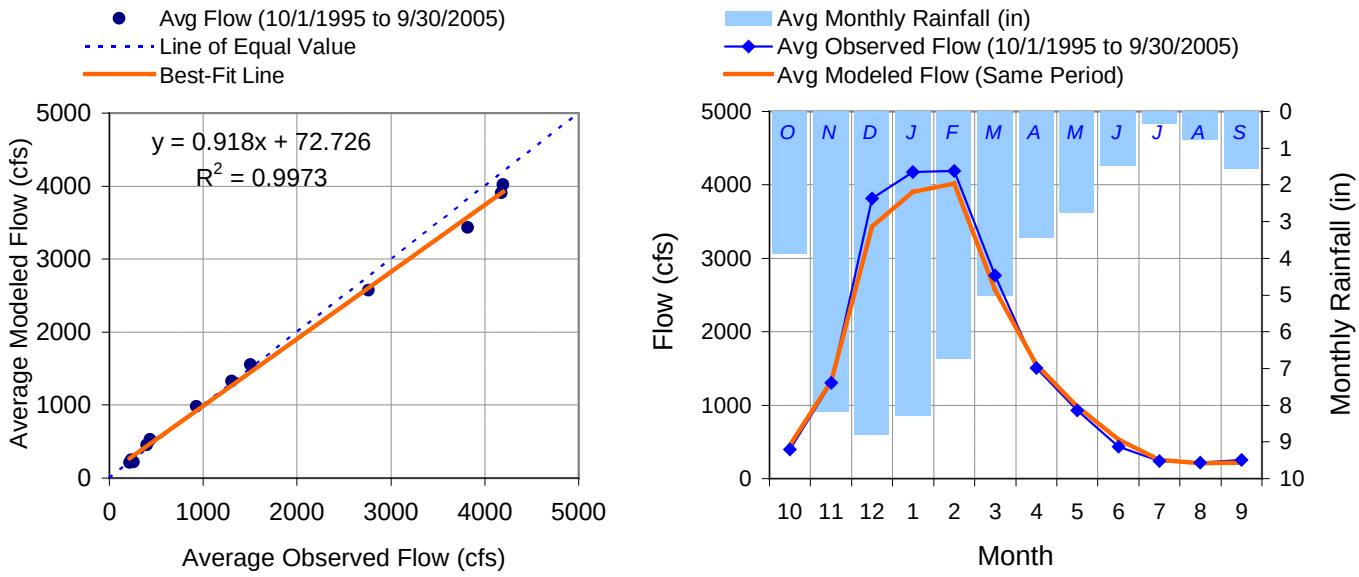

Figure 10. Seasonal regression and temporal aggregate at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF).

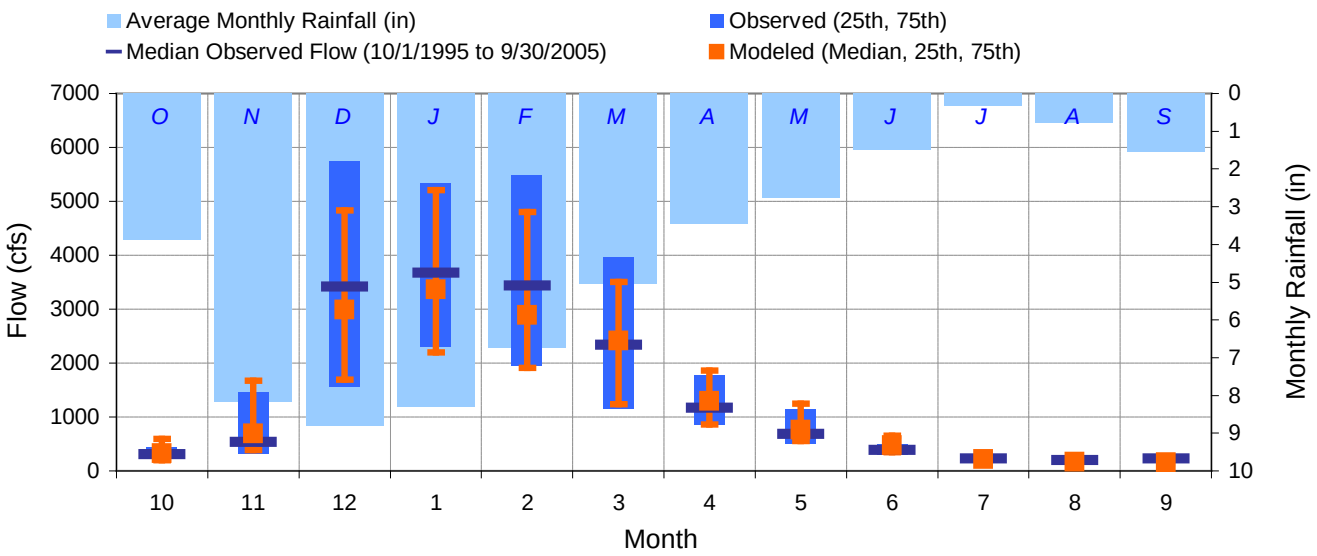

Figure 11. Seasonal medians and ranges at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF).

Table 7. Seasonal summary at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	399.00	309.00	234.00	436.75	454.72	329.52	193.65	592.38
Nov	1305.46	534.00	305.75	1460.00	1323.58	697.37	389.21	1674.78
Dec	3817.72	3420.00	1565.00	5747.50	3432.50	2985.78	1690.84	4827.79
Jan	4175.40	3675.00	2297.50	5340.00	3905.86	3369.21	2197.11	5211.28
Feb	4193.04	3440.00	1955.00	5485.00	4018.44	2892.20	1907.41	4798.64
Mar	2763.99	2340.00	1155.00	3962.50	2572.21	2415.34	1238.50	3501.83
Apr	1503.13	1165.00	855.00	1760.00	1551.10	1296.01	858.61	1860.24
May	929.54	681.00	497.25	1140.00	984.03	762.86	557.19	1243.80
Jun	434.30	385.50	295.00	485.00	529.68	479.68	342.37	655.71
Jul	236.99	227.00	187.00	275.50	251.49	222.59	182.91	294.57
Aug	215.16	197.50	171.25	233.75	207.51	170.68	149.20	208.77
Sep	258.55	232.00	197.75	286.25	215.52	156.46	135.63	203.93

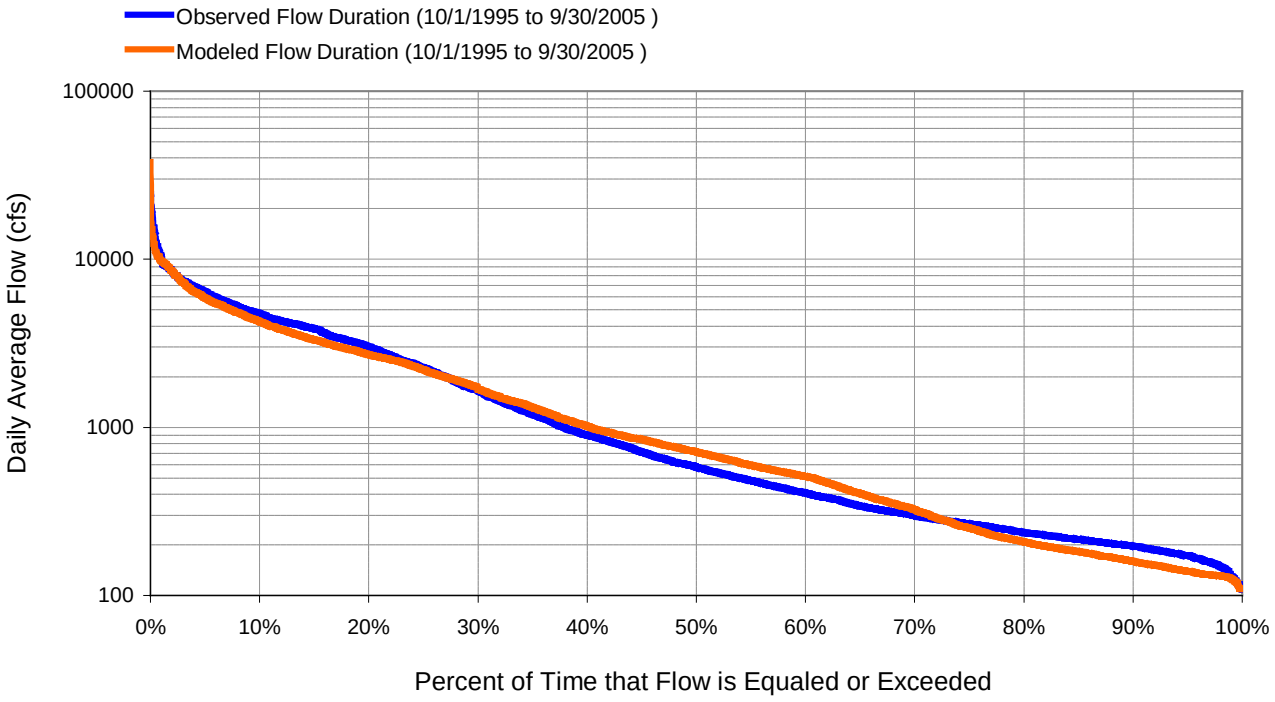

Figure 12. Flow exceedence at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF).

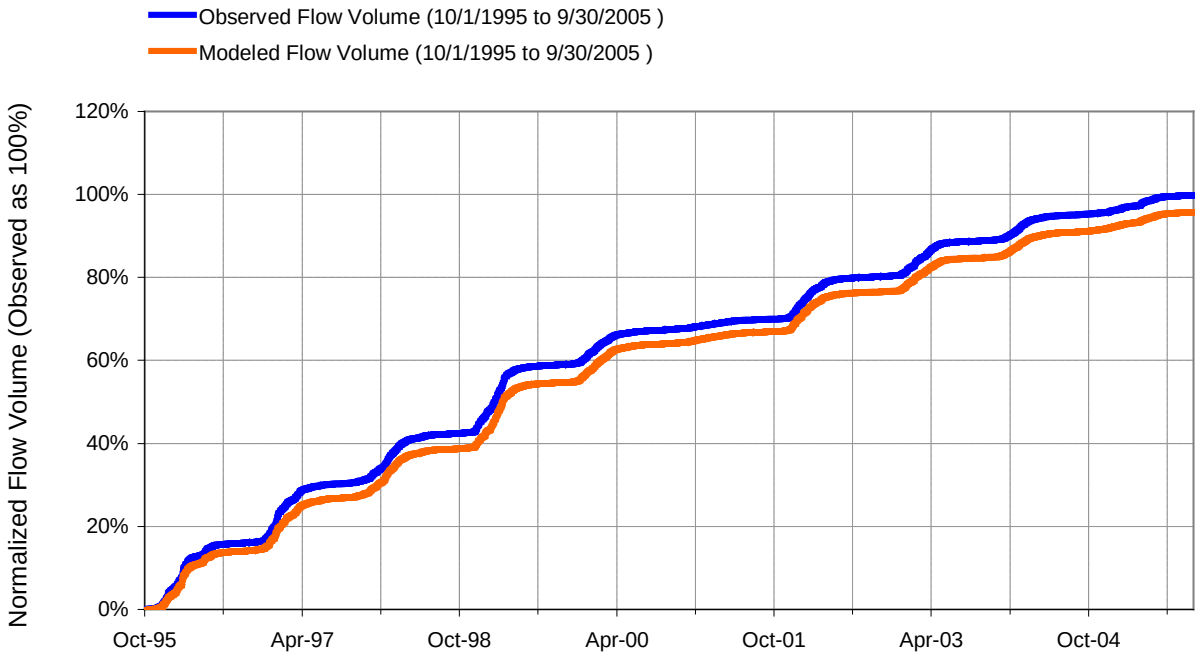

Figure 13. Flow accumulation at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF).

Table 8. Summary statistics at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 14 10-Year Analysis Period: 10/1/1995 - 9/30/2005 Flow volumes are (inches/year) for upstream drainage area		USGS 14207500 TUALATIN RIVER AT WEST LINN, OR Hydrologic Unit Code: 17090010 Latitude: 45.35067559 Longitude: -122.6762044 Drainage Area (sq-mi): 706	
Total Simulated In-stream Flow:	**30.99**	Total Observed In-stream Flow:	**32.25**
Total of simulated highest 10% flows:	**13.03**	Total of Observed highest 10% flows:	**13.96**
Total of Simulated lowest 50% flows:	**3.06**	Total of Observed Lowest 50% flows:	**2.85**
Simulated Summer Flow Volume (months 7-9):	**1.09**	Observed Summer Flow Volume (7-9):	**1.15**
Simulated Fall Flow Volume (months 10-12):	**8.44**	Observed Fall Flow Volume (10-12):	**8.95**
Simulated Winter Flow Volume (months 1-3):	**16.57**	Observed Winter Flow Volume (1-3):	**17.58**
Simulated Spring Flow Volume (months 4-6):	**4.89**	Observed Spring Flow Volume (4-6):	**4.58**
Total Simulated Storm Volume:	**7.59**	Total Observed Storm Volume:	**6.18**
Simulated Summer Storm Volume (7-9):	**0.20**	Observed Summer Storm Volume (7-9):	**0.16**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-3.92	10	
Error in 50% lowest flows:	7.28	10	
Error in 10% highest flows:	-6.64	15	
Seasonal volume error - Summer:	-4.95	30	
Seasonal volume error - Fall:	-5.69	30	
Seasonal volume error - Winter:	-5.76	30	
Seasonal volume error - Spring:	6.89	30	
Error in storm volumes:	**22.92**	**20**	
Error in summer storm volumes:	27.87	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.799	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.731	as E or E' approaches 1.0	

Hydrology Validation

Validation for the Willamette River watershed calibration focus area was performed at the same location (Tualatin River) but for water years 10/01/1985 to 09/30/1995. Results are presented in Figures 14 through 20 and Tables 9 and 10. Similar to the calibration years, the validation years' model fit is of good quality, although the validation shows oversimulation of low flows and summer seasonal flows, and undersimulation of the 10 percent highest flows. The rest of the metrics fall within the acceptable range set for the 20 Watershed study.

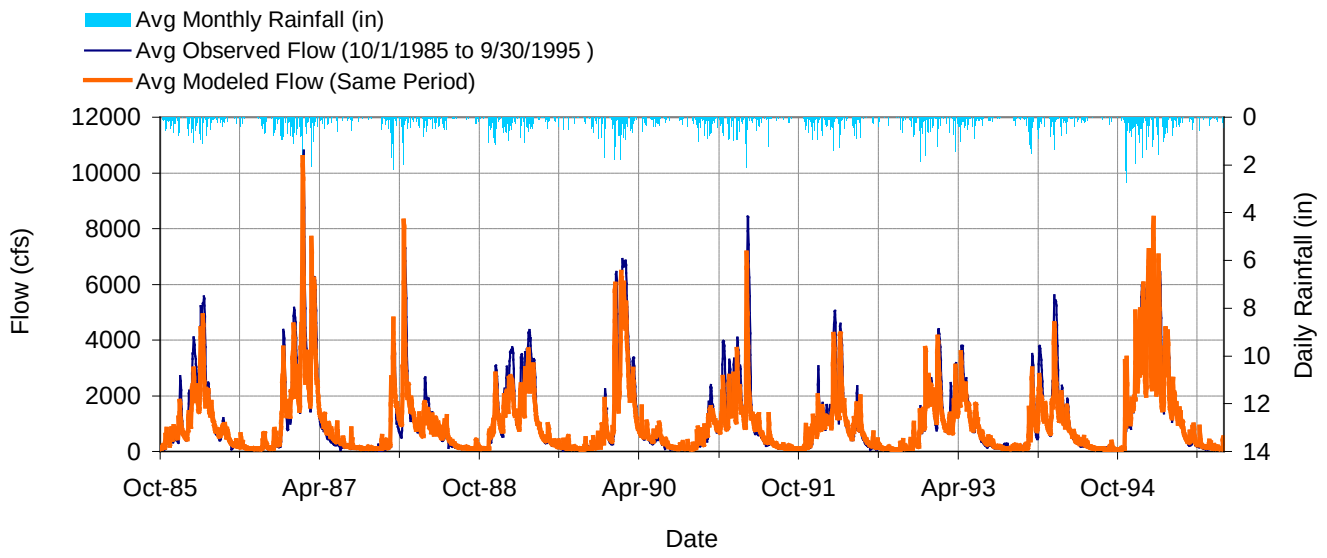

Figure 14. Mean daily flow at USGS 14207500 Tualatin River at West Linn, OR – validation period (HSPF).

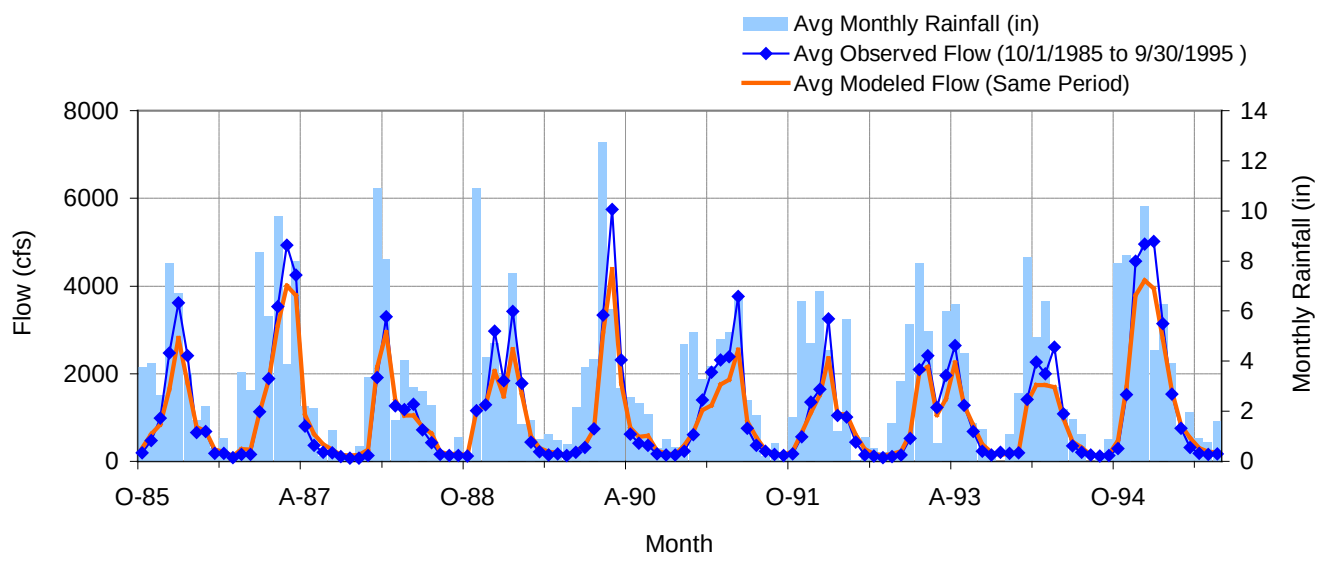

Figure 15. Mean monthly flow at USGS 14207500 Tualatin River at West Linn, OR – validation period (HSPF).

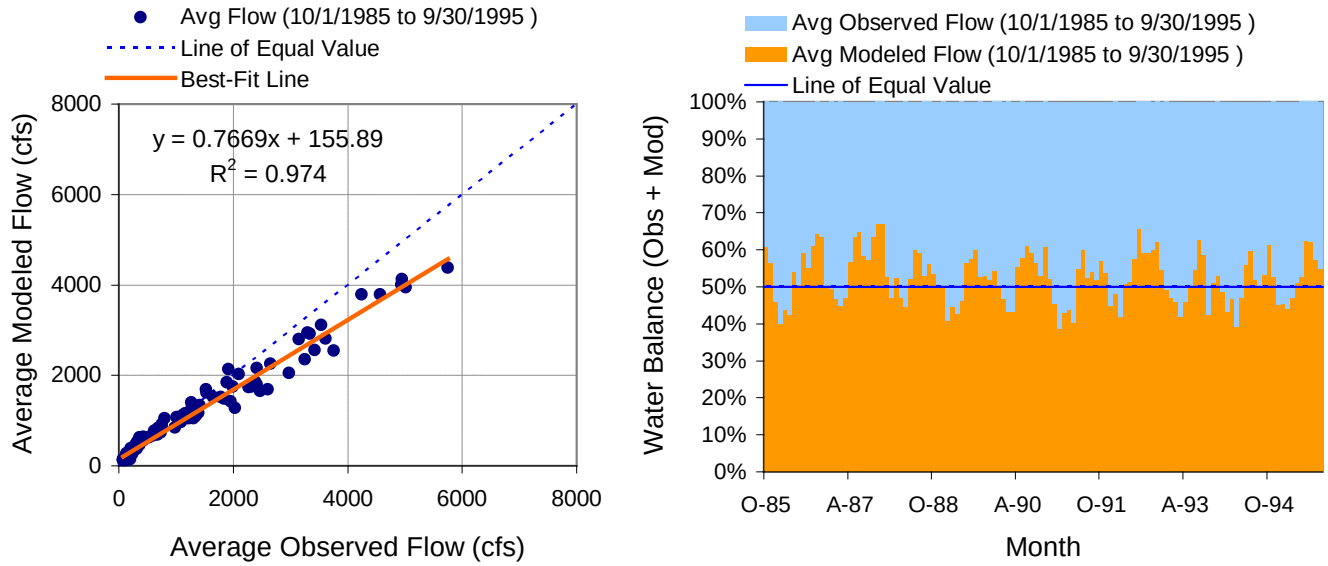

Figure 16. Monthly flow regression and temporal variation at USGS 14207500 Tualatin River at West Linn, OR – validation period (HSPF).

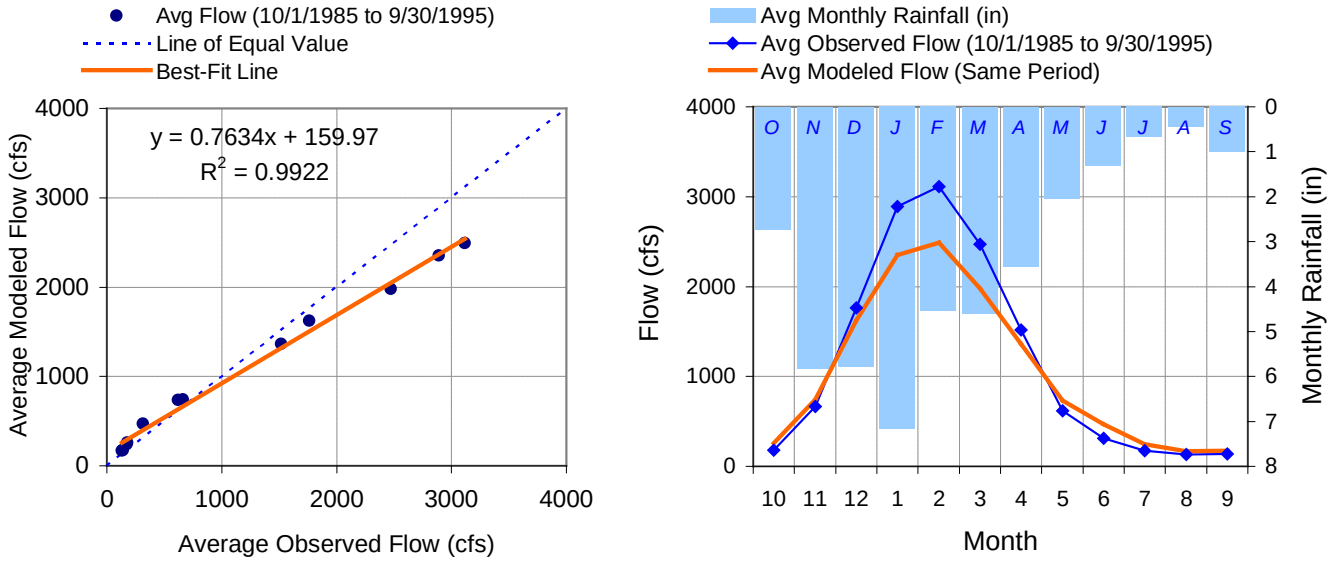

Figure 17. Seasonal regression and temporal aggregate at USGS 14207500 Tualatin River at West Linn, OR – validation period (HSPF).

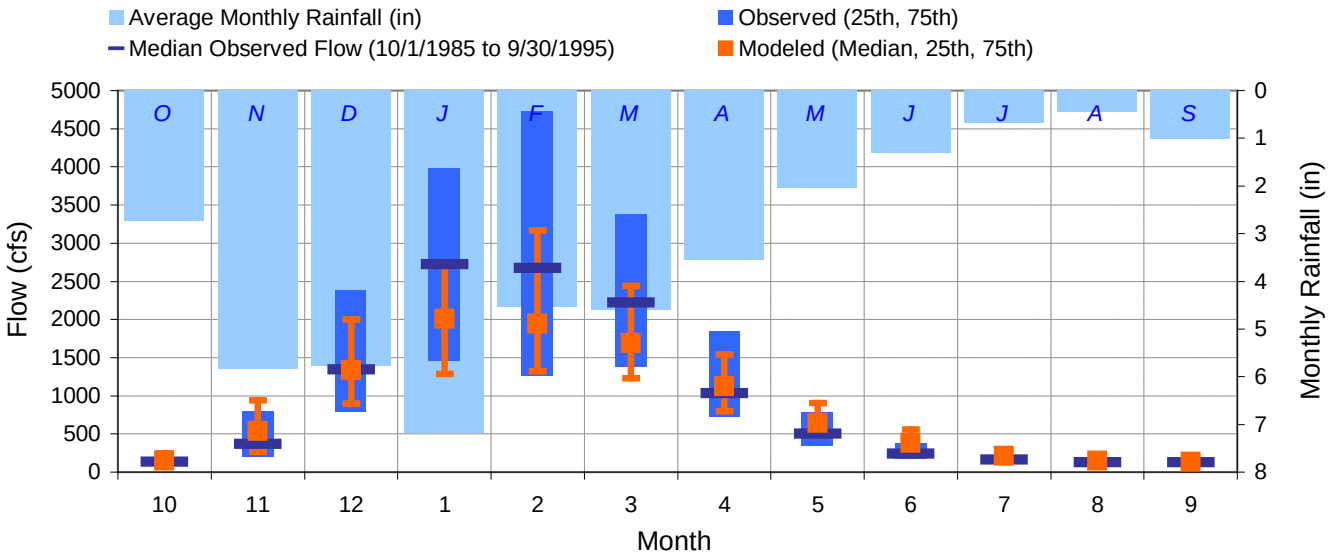

Figure 18. Seasonal medians and ranges at USGS 14207500 Tualatin River at West Linn, OR – validation period (HSPF).

Table 9. Seasonal summary at USGS 14207500 Tualatin River at West Linn – validation period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	178.35	132.00	100.00	193.50	257.87	148.30	134.63	250.42
Nov	663.27	369.00	198.00	792.00	742.01	539.33	271.12	940.92
Dec	1762.91	1345.00	786.50	2382.50	1625.28	1334.70	897.16	2002.84
Jan	2892.62	2725.00	1460.00	3985.00	2350.73	2010.52	1285.46	2745.93
Feb	3115.09	2670.00	1262.50	4737.50	2488.82	1947.93	1325.47	3171.78
Mar	2472.13	2220.00	1380.00	3377.50	1980.44	1691.04	1233.37	2442.64
Apr	1520.16	1035.00	731.25	1855.00	1363.78	1124.25	798.68	1542.90
May	618.69	505.50	343.75	788.25	733.54	644.97	488.42	903.26
Jun	313.98	242.00	182.75	382.50	468.21	380.64	293.42	555.62
Jul	173.94	164.50	127.25	211.75	244.29	210.25	169.95	296.58
Aug	131.78	126.50	102.50	158.00	166.56	150.77	131.70	182.07
Sep	140.05	126.50	107.75	162.25	173.33	137.78	127.92	167.28

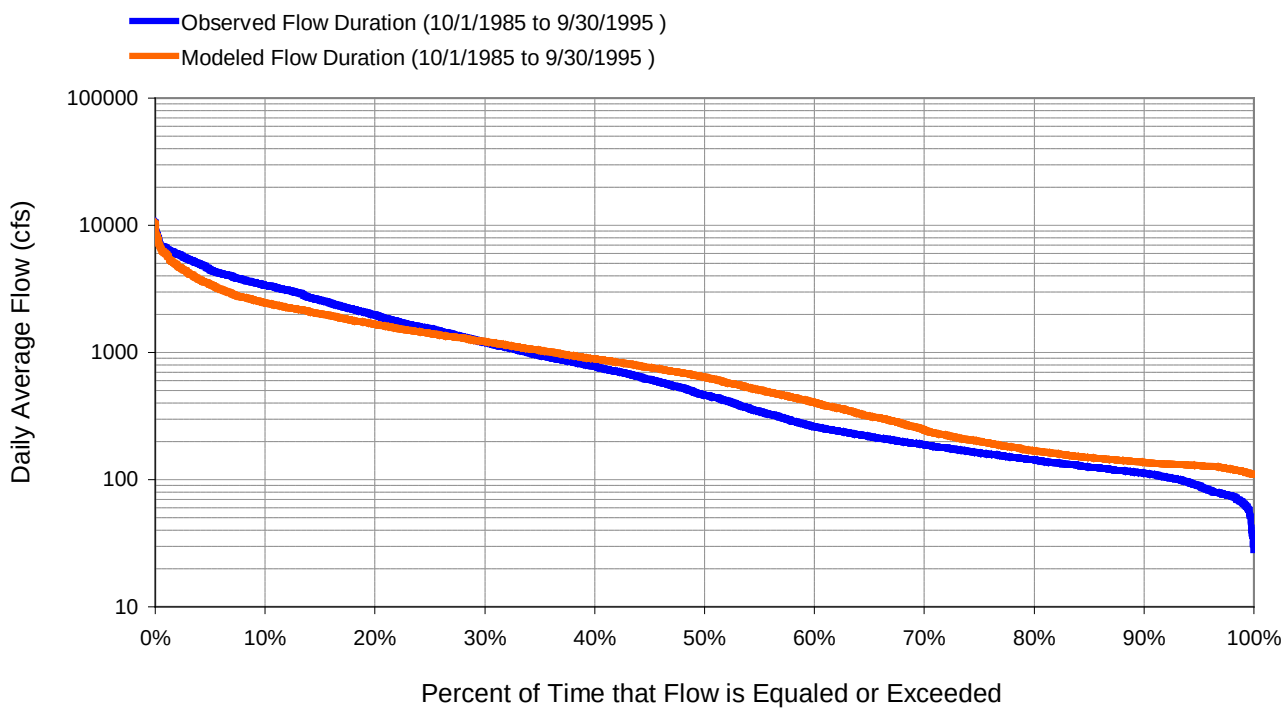

Figure 19. Flow exceedence at USGS 14207500 Tualatin River at West Linn, OR – validation period (HSPF).

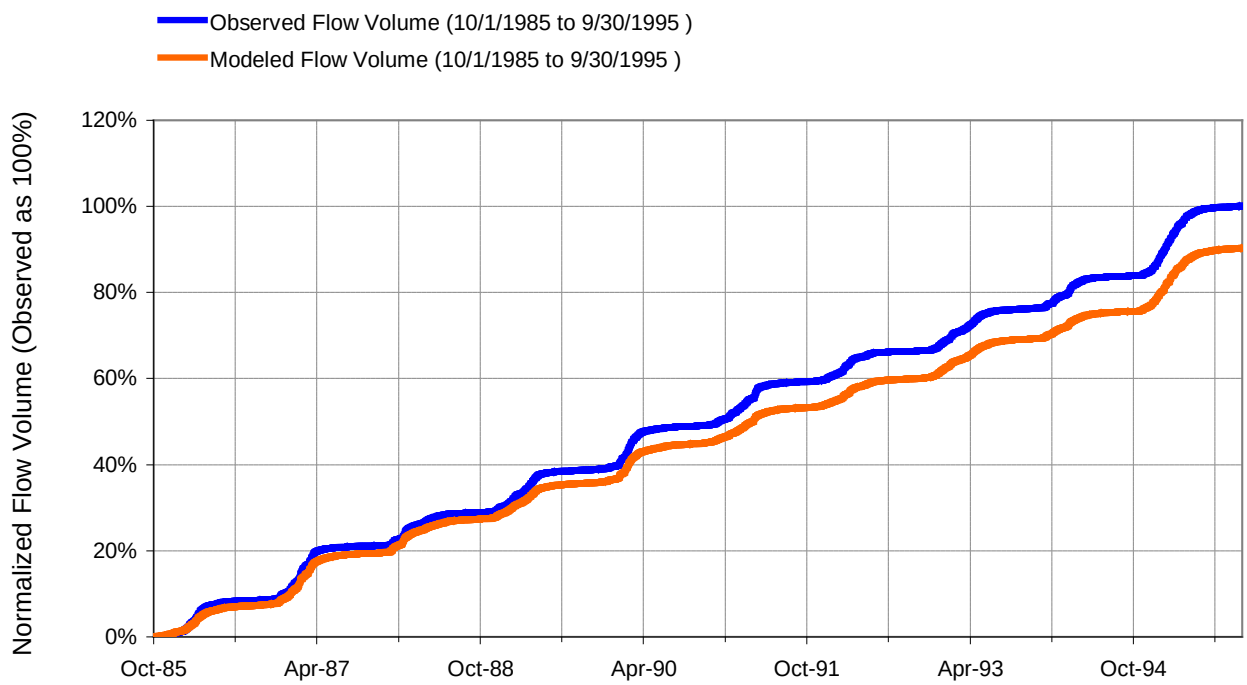

Figure 20. Flow accumulation at USGS 14207500 Tualatin River at West Linn, OR – validation period (HSPF).

Table 10. Summary statistics at USGS 14207500 Tualatin River at West Linn, OR – validation period (HSPF)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 14 10-Year Analysis Period: 10/1/1985 - 9/30/1995 Flow volumes are (inches/year) for upstream drainage area		USGS 14207500 TUALATIN RIVER AT WEST LINN, OR Hydrologic Unit Code: 17090010 Latitude: 45.35067559 Longitude: -122.6762044 Drainage Area (sq-mi): 706	
Total Simulated In-stream Flow:	**20.06**	Total Observed In-stream Flow:	**22.24**
Total of simulated highest 10% flows:	**7.44**	Total of Observed highest 10% flows:	**9.37**
Total of Simulated lowest 50% flows:	**2.53**	Total of Observed Lowest 50% flows:	**1.83**
Simulated Summer Flow Volume (months 7-9):	**0.94**	Observed Summer Flow Volume (7-9):	**0.72**
Simulated Fall Flow Volume (months 10-12):	**4.25**	Observed Fall Flow Volume (10-12):	**4.22**
Simulated Winter Flow Volume (months 1-3):	**10.77**	Observed Winter Flow Volume (1-3):	**13.39**
Simulated Spring Flow Volume (months 4-6):	**4.09**	Observed Spring Flow Volume (4-6):	**3.91**
Total Simulated Storm Volume:	**4.52**	Total Observed Storm Volume:	**4.60**
Simulated Summer Storm Volume (7-9):	**0.14**	Observed Summer Storm Volume (7-9):	**0.12**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	-9.80	10	
Error in 50% lowest flows:	**38.11**	**10**	
Error in 10% highest flows:	**-20.60**	**15**	
Seasonal volume error - Summer:	**31.12**	**30**	
Seasonal volume error - Fall:	0.70	30	
Seasonal volume error - Winter:	-19.56	30	
Seasonal volume error - Spring:	4.71	30	
Error in storm volumes:	-1.77	20	
Error in summer storm volumes:	22.38	50	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.811	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.702	as E or E' approaches 1.0	

Hydrology Results for Larger Watershed

Since the Tualatin River calibration location represents only a small portion of the drainage area for this project, results near the outlet of the entire watershed were examined at the Willamette River at Salem, OR (USGS 14191000). This gage is downstream of the large reservoirs in the Willamette River and more than 40 percent of the area at Salem is controlled by dams. Results are presented in Figures 21 through 27 and Tables 11 and 12. The results at the Salem gage look fairly good as well, but are being strongly determined by the input boundary inflows at the dams, particularly during the summer. The simulated output is quite high during the summer, which is manifested in overprediction of the metrics for 50 percent lowest flows, seasonal summer volume, and summer storm volumes. Summer storms are small in this region, and the summer storm volumes are also small; therefore, an error of 0.6 inches produces a large percent difference. The overall storm volumes are overpredicted, which results in exceedance of the metric by a small amount. The remainder of the metrics fall within the acceptable range set for the 20 Watershed study including a Nash-Sutcliffe of 0.88 at the Salem gage. Tables 13 and 14 show a summary of the hydrology calibration and validation results for all five locations. In general, the hydrology calibration results on the tributaries were quite good, largely as a result of the calibration efforts at each station. The calibrated parameters were transferred from the tributaries to other non-calibrated portions of the watershed based on location. Since the Salem mainstem gage is so heavily influenced by the reservoirs (as described above), the results at that location are reasonable, but not very useful in concluding that the calibrated parameters are transferrable to the entire watershed.

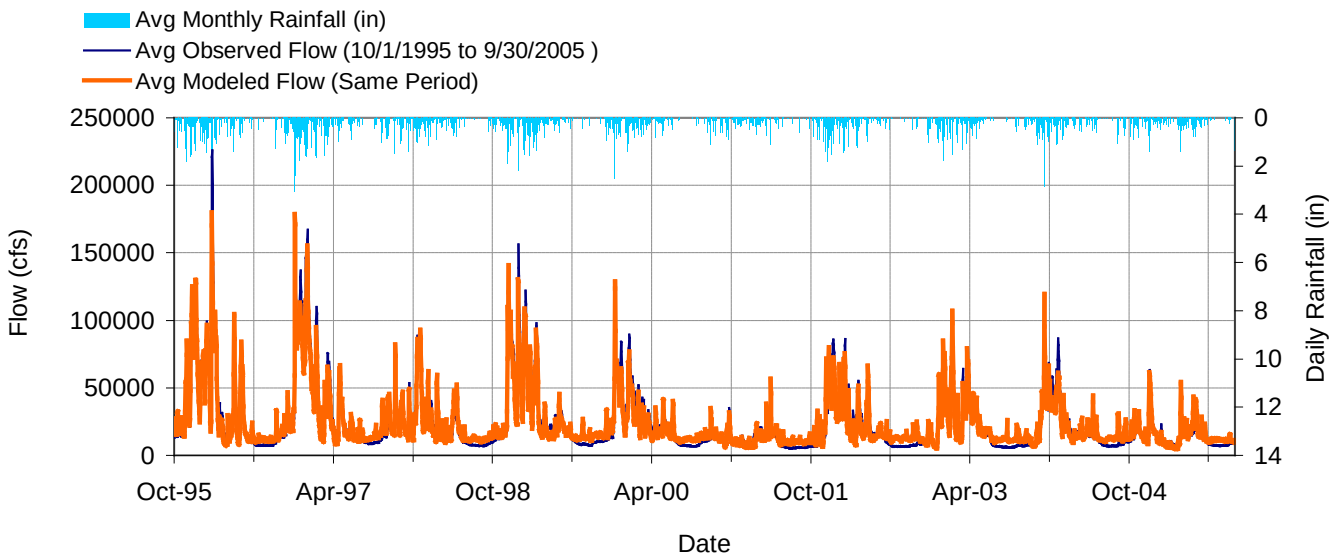

Figure 21. Mean daily flow at USGS 14191000 Willamette River at Salem, OR – calibration period (HSPF).

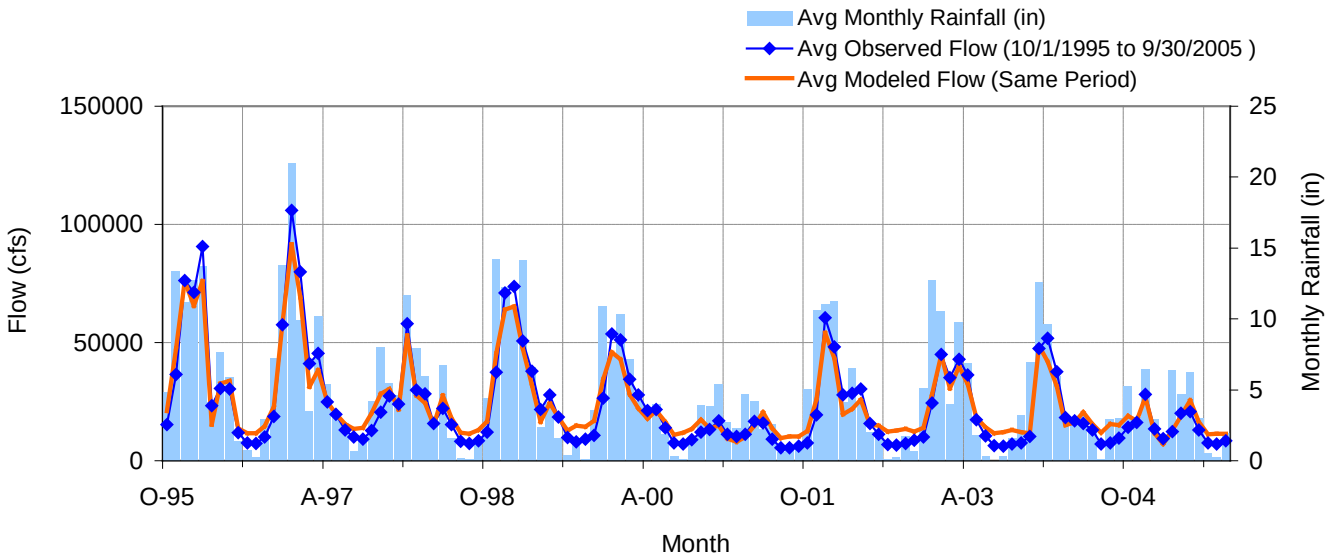

Figure 22. Mean monthly flow at USGS 14191000 Willamette River at Salem, OR – calibration period (HSPF).

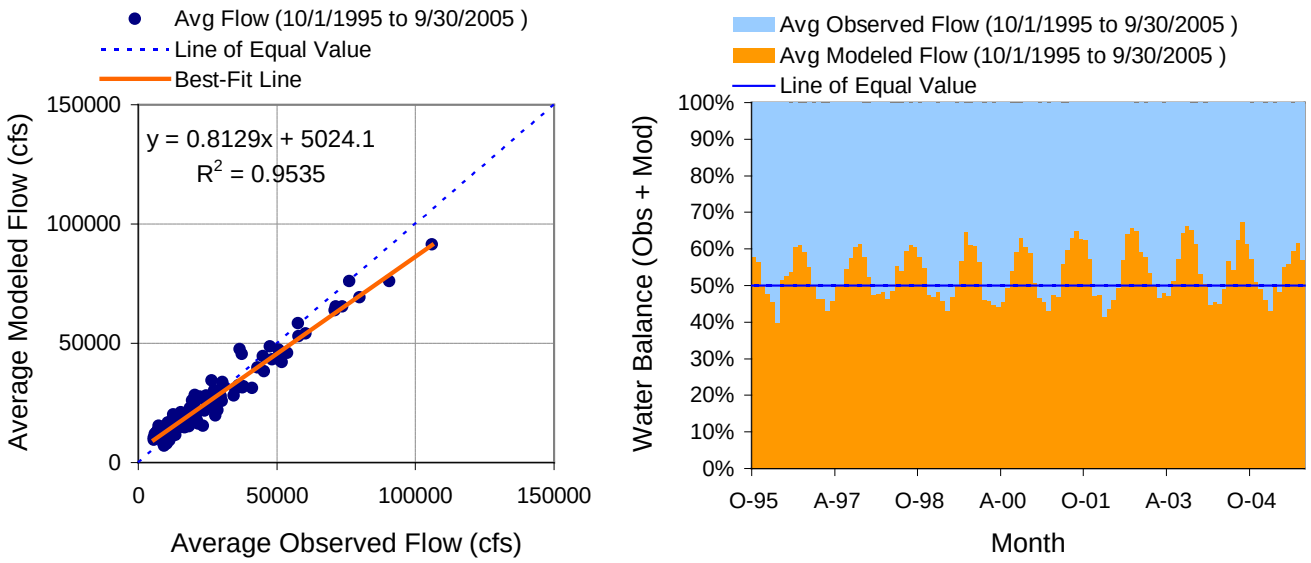

Figure 23. Monthly flow regression and temporal variation at USGS 14191000 Willamette River at Salem, OR – calibration period (HSPF).

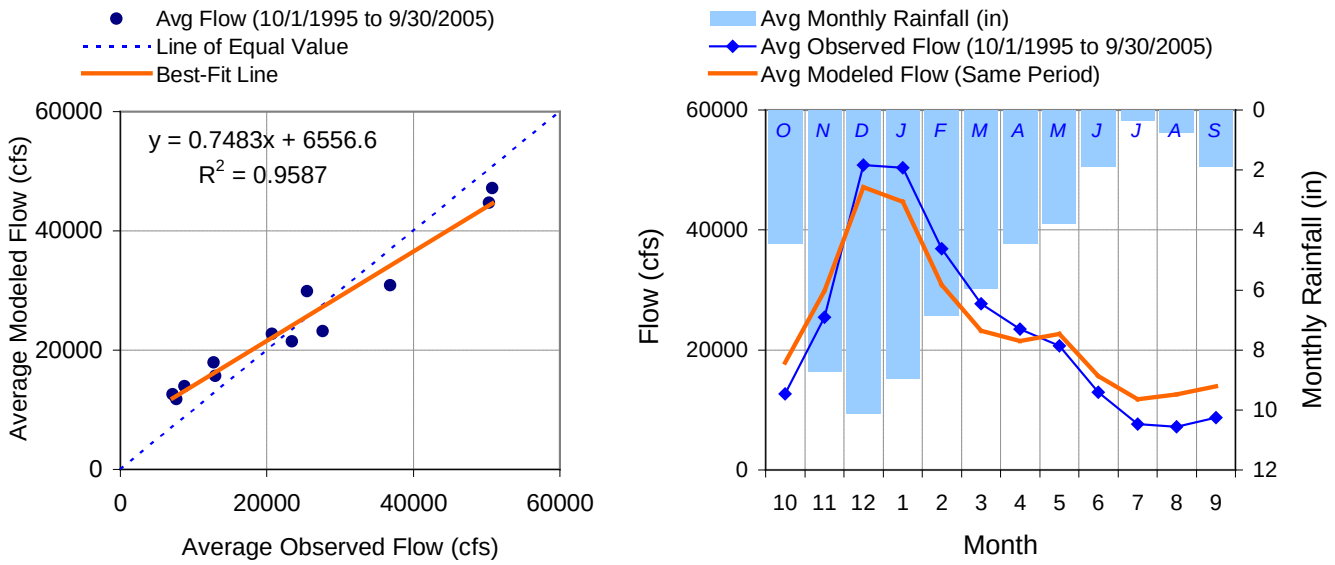

Figure 24. Seasonal regression and temporal aggregate at USGS 14191000 Willamette River at Salem, OR – calibration period (HSPF).

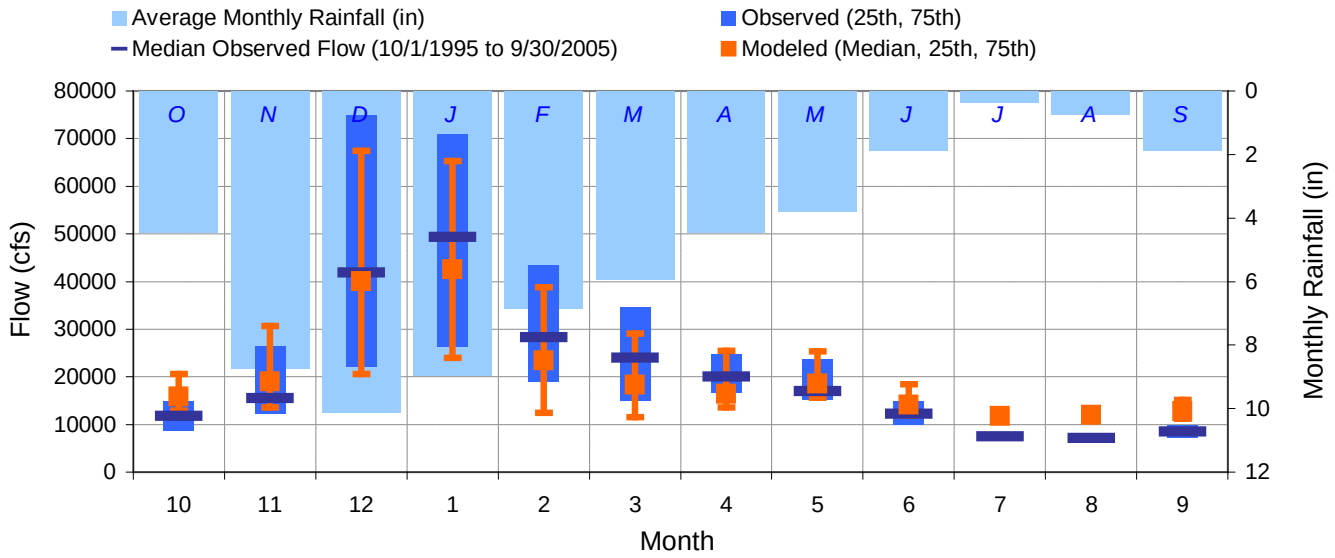

Figure 25. Seasonal medians and ranges at USGS 14191000 Willamette River at Salem, OR – calibration period (HSPF).

Table 11. Seasonal summary at USGS 14191000 Willamette River at Salem, OR – calibration period (HSPF)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	12717.87	11800.00	8752.50	14875.00	17880.47	15883.04	12873.57	20553.78
Nov	25500.23	15500.00	12375.00	26525.00	29822.48	19065.62	13575.24	30711.68
Dec	50807.87	41900.00	22175.00	74950.00	47121.03	40022.34	20587.66	67465.45
Jan	50369.00	49350.00	26325.00	70900.00	44675.55	42552.42	24029.88	65317.06
Feb	36872.79	28300.00	19050.00	43500.00	30886.30	23372.96	12456.04	38808.34
Mar	27664.39	23950.00	14950.00	34500.00	23206.99	18325.25	11562.67	29087.93
Apr	23458.33	20000.00	16600.00	24825.00	21472.71	16424.03	13542.39	25476.06
May	20733.55	16950.00	15100.00	23675.00	22704.18	18536.53	15626.60	25378.76
Jun	12950.87	12250.00	9807.50	14825.00	15686.14	14097.00	11904.53	18484.91
Jul	7675.19	7430.00	6780.00	8227.50	11749.44	11749.37	10807.98	12544.74
Aug	7159.26	7110.00	6602.50	7395.00	12563.64	12010.44	11030.47	12990.64
Sep	8761.37	8450.00	7210.00	9847.50	13918.00	12760.73	11221.73	15139.36

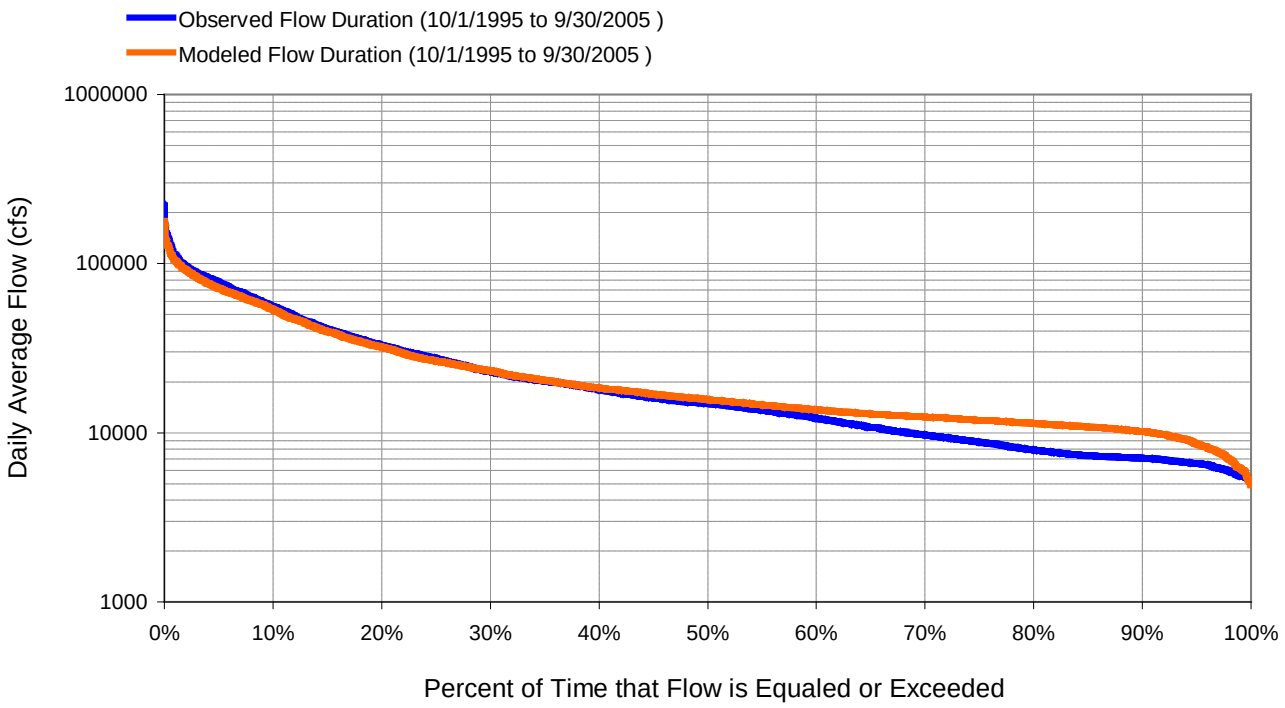

Figure 26. Flow exceedence at USGS 14191000 Willamette River at Salem, OR – calibration period (HSPF).

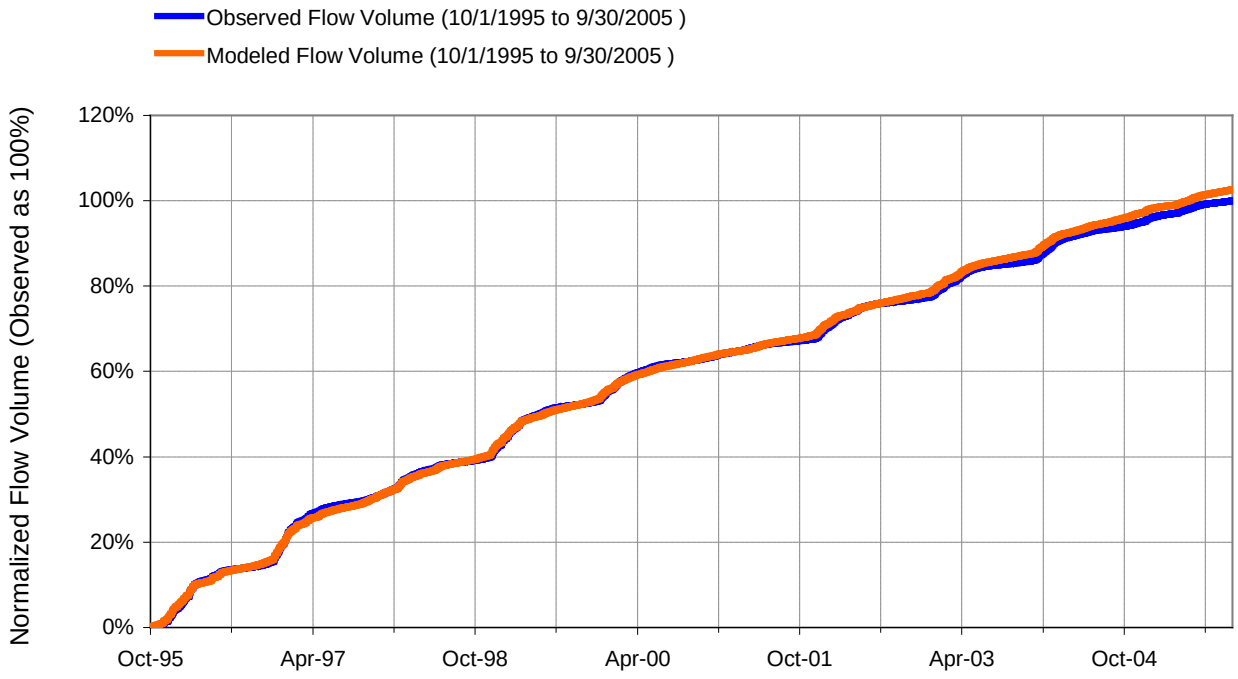

Figure 27. Flow accumulation at USGS 14191000 Willamette River at Salem, OR – calibration period (HSPF).

Table 12. Summary statistics at USGS 14191000 Willamette River at Salem, OR – calibration period (HSPF)

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 12 10-Year Analysis Period: 10/1/1995 - 9/30/2005 Flow volumes are (inches/year) for upstream drainage area		USGS 14191000 WILLAMETTE RIVER AT SALEM, OR Hydrologic Unit Code: 17090007 Latitude: 44.9442863 Longitude: -123.0428742 Drainage Area (sq-mi): 7280	
Total Simulated In-stream Flow:	**45.35**	Total Observed In-stream Flow:	**44.21**
Total of simulated highest 10% flows:	**14.60**	Total of Observed highest 10% flows:	**15.55**
Total of Simulated lowest 50% flows:	**11.01**	Total of Observed Lowest 50% flows:	**8.79**
Simulated Summer Flow Volume (months 7-9):	**5.98**	Observed Summer Flow Volume (7-9):	**3.69**
Simulated Fall Flow Volume (months 10-12):	**14.86**	Observed Fall Flow Volume (10-12):	**13.97**
Simulated Winter Flow Volume (months 1-3):	**15.21**	Observed Winter Flow Volume (1-3):	**17.69**
Simulated Spring Flow Volume (months 4-6):	**9.29**	Observed Spring Flow Volume (4-6):	**8.86**
Total Simulated Storm Volume:	**13.95**	Total Observed Storm Volume:	**11.48**
Simulated Summer Storm Volume (7-9):	**0.75**	Observed Summer Storm Volume (7-9):	**0.16**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	
Error in total volume:	2.58	10	
Error in 50% lowest flows:	**25.19**	**10**	
Error in 10% highest flows:	-6.12	15	
Seasonal volume error - Summer:	**62.06**	**30**	
Seasonal volume error - Fall:	6.42	30	
Seasonal volume error - Winter:	-13.98	30	
Seasonal volume error - Spring:	4.82	30	
Error in storm volumes:	**21.60**	**20**	
Error in summer storm volumes:	**364.63**	**50**	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.879	Model accuracy increases	
Baseline adjusted coefficient (Garrick), E':	0.662	as E or E' approaches 1.0	

Table 13. Summary statistics (percent error) for all stations – calibration period (HSPF)

Station	14191000 Salem	14207500 West Linn	14202000 Aurora	14194150 McMinnville	14165000 Springfield
Calibration Period:	WY 96-05	WY 96-05	WY 03-05	WY 00-05	WY 99-05
Error in total volume:	2.58	-3.92	6.08	-0.74	-6.41
Error in 50% lowest flows:	25.19	7.28	-13.76	-12.16	-11.20
Error in 10% highest flows:	-6.12	-6.64	2.42	3.88	2.78
Seasonal volume error - Summer:	62.06	-4.95	-2.94	1.19	9.35
Seasonal volume error - Fall:	6.42	-5.69	0.36	9.45	0.24
Seasonal volume error - Winter:	-13.98	-5.76	7.69	-4.63	-8.75
Seasonal volume error - Spring:	4.82	6.89	8.69	-7.70	-11.07
Error in storm volumes:	21.60	22.92	-7.94	6.83	33.01
Error in summer storm volumes:	364.63	27.87	-45.66	-41.57	-38.36
Nash-Sutcliffe Coefficient of Efficiency, E:	0.879	0.799	0.912	0.711	0.674
Baseline adjusted coefficient (Garrick), E':	0.662	0.731	0.766	0.658	0.621

Table 14. Summary statistics (percent error) for all stations – validation period (HSPF)

Station	14191000 Salem	14207500 West Linn	14202000 Aurora	14194150 McMinnville	14165000 Springfield
Calibration Period:	WY 86-95	WY 86-95	WY 94-97	WY 95-99	WY 88-97
Error in total volume:	5.04	-9.80	7.48	-4.52	-4.70
Error in 50% lowest flows:	27.56	38.11	12.54	-19.80	-4.88
Error in 10% highest flows:	-0.59	-20.60	8.10	-4.74	4.68
Seasonal volume error - Summer:	65.84	31.12	38.31	1.81	13.91
Seasonal volume error - Fall:	7.98	0.70	2.36	-2.46	18.51
Seasonal volume error - Winter:	-14.25	-19.56	10.21	-5.28	-14.93
Seasonal volume error - Spring:	7.81	4.71	6.68	-7.98	-13.54
Error in storm volumes:	24.68	-1.77	0.34	-3.10	39.72
Error in summer storm volumes:	298.14	22.38	3.37	-51.72	-39.06
Nash-Sutcliffe Coefficient of Efficiency, E:	0.835	0.811	0.886	0.720	0.467
Baseline adjusted coefficient (Garrick), E':	0.590	0.702	0.782	0.680	0.575

Water Quality Calibration and Validation

The 20 Watershed models are designed to provide water quality simulation for total suspended solids (TSS), total nitrogen, and total phosphorus. TSS is simulated with the standard HSPF approach (USEPA 2006). In contrast to sediment, total nitrogen and total phosphorus are simulated in this application in a simplistic fashion, as HSPF general quality constituents (GQUALs) subject to an exponential decay rate during transport.

The water quality calibration focuses on the replication of monthly loads, as specified in the project QAPP. Given the approach to water quality simulation in the 20 Watershed model, a close match to individual concentration observations cannot be expected. Comparison to monthly loads presents challenges, as monthly loads are not observed. Instead, monthly loads must be estimated from scattered concentration grab samples and continuous flow records. As a result, the monthly load calibration is inevitably based on the comparison of two uncertain numbers. Nonetheless, calibration is able to achieve a reasonable agreement. Further, the load comparisons were supported by detailed examinations of the relationships of flows to loads and concentrations and the distribution of concentration prediction errors versus flow, time, and season, as well as standard time series plots.

For application on a nationwide basis, the 20 Watershed protocols assume that sediment and total phosphorus loads will likely exhibit a strong positive correlation to flow (and associated erosive processes), while total nitrogen loads, which often have a dominant groundwater component, will not. Accordingly, TSS and total phosphorus loads were estimated from observations using a flow-stratified log-log regression approach, while total nitrogen loads were estimated using a flow-stratified averaging estimator, consistent with the findings of Preston et al. (1989).

Water quality calibration was done on the Tualatin River at West Linn, OR, comparing model results to data from USGS 14207500. Calibration and validation were performed for the period with available water quality data, which was 1986-1995. The 1991-1995 time period was used for calibration, and the 1986-1990 period was used for validation. TSS calibration was performed by adjusting the coefficients in the soil detachment (KRER) and soil washoff (KSER) equations along with changes to the seasonal vegetation COVER. Results of the TSS calibration are generally acceptable. The results are shown in Figures 28 through 31 and the statistics of TSS loads and concentrations are shown in Tables 15 and 16, respectively. Visually, the model is roughly simulating the trends contained in the observed data.

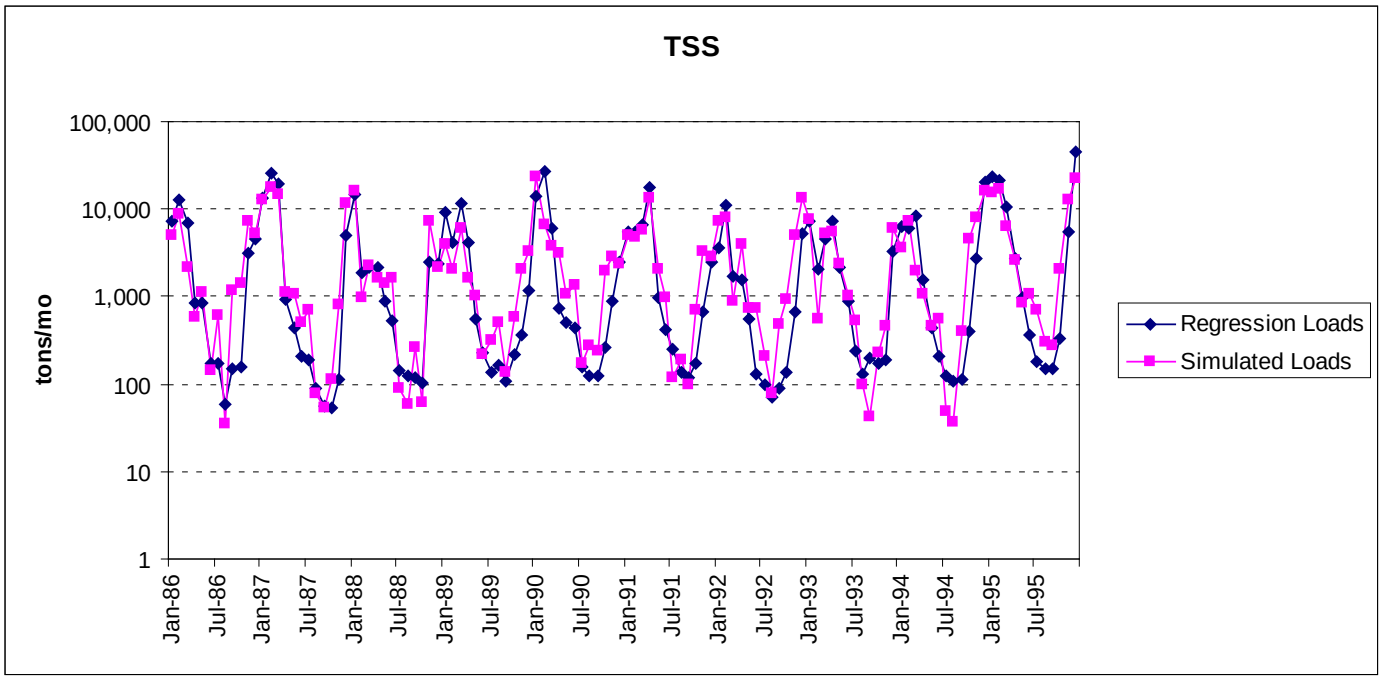

Figure 28. Fit for monthly load of TSS at USGS 14207500 Tualatin River at West Linn, OR (HSPF).

Table 15. Model fit statistics (observed minus predicted) for monthly sediment loads using stratified regression (HSPF)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Relative Percent Error	3%	5%
Relative Average Absolute Error	47%	53%
Relative Median Absolute Error	13.3%	15.9%

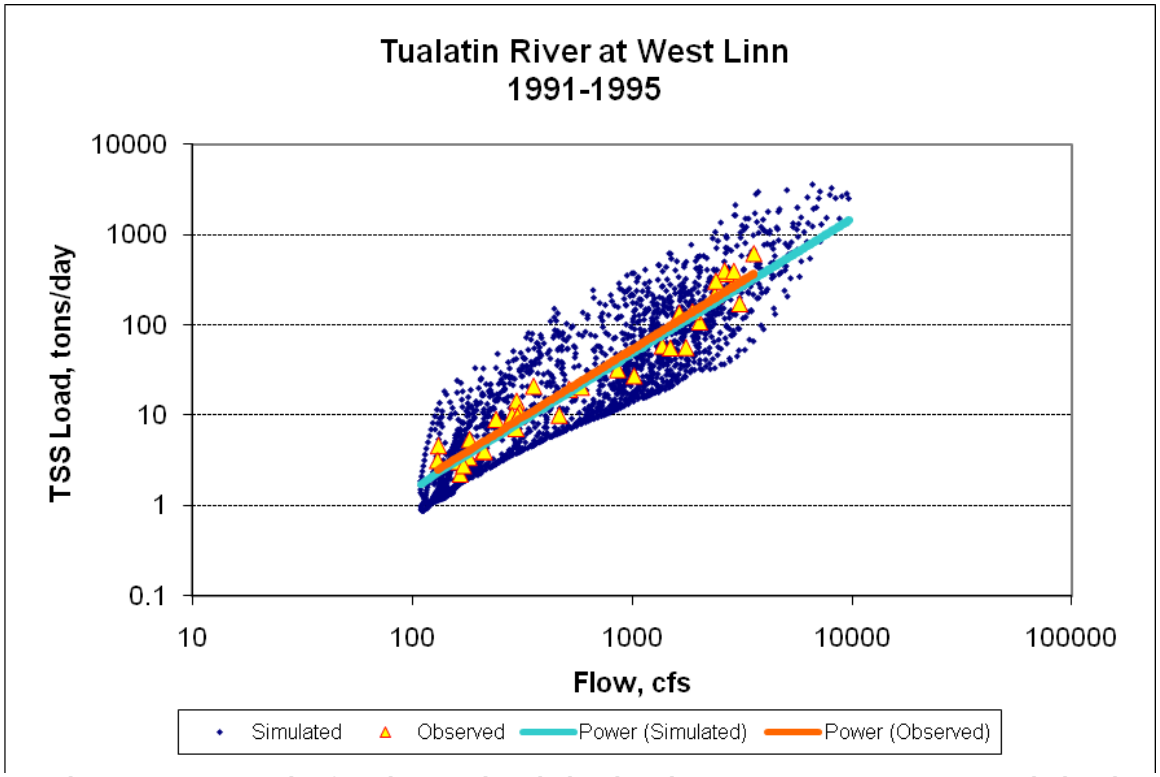

Figure 29. Power plot for observed and simulated TSS at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF).

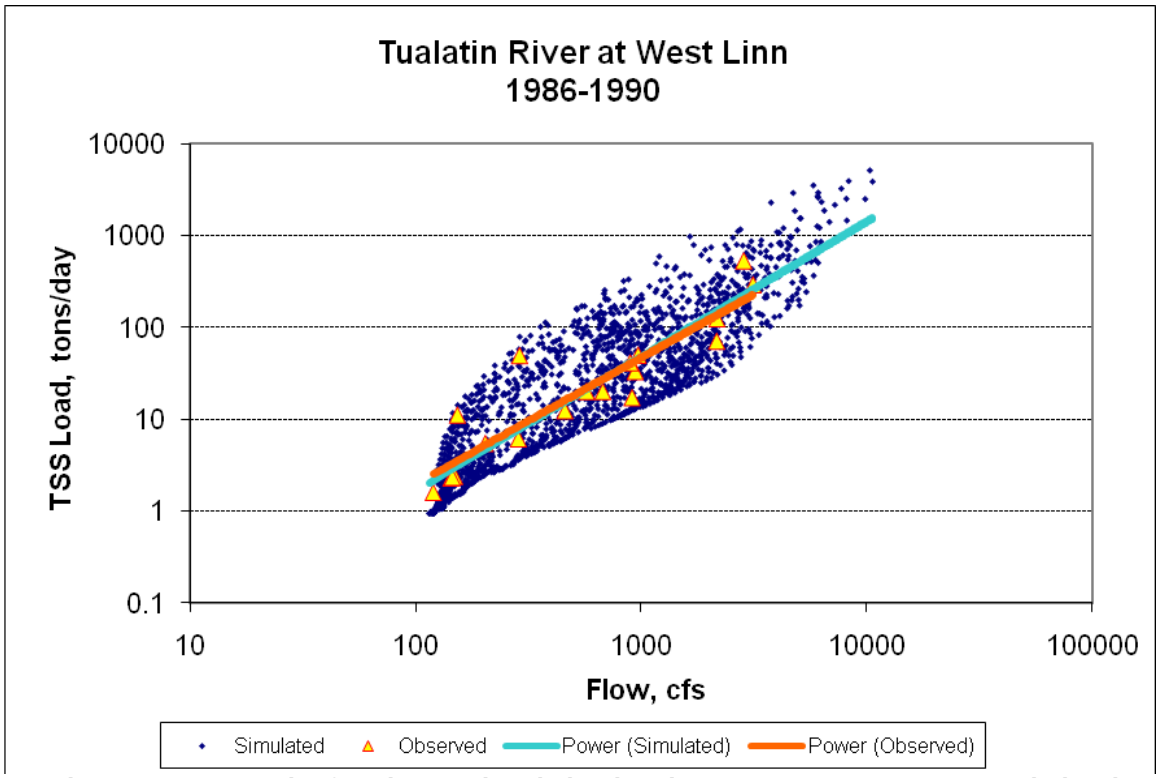

Figure 30. Power plot for observed and simulated TSS at USGS 14207500 Tualatin River at West Linn, OR – validation period (HSPF).

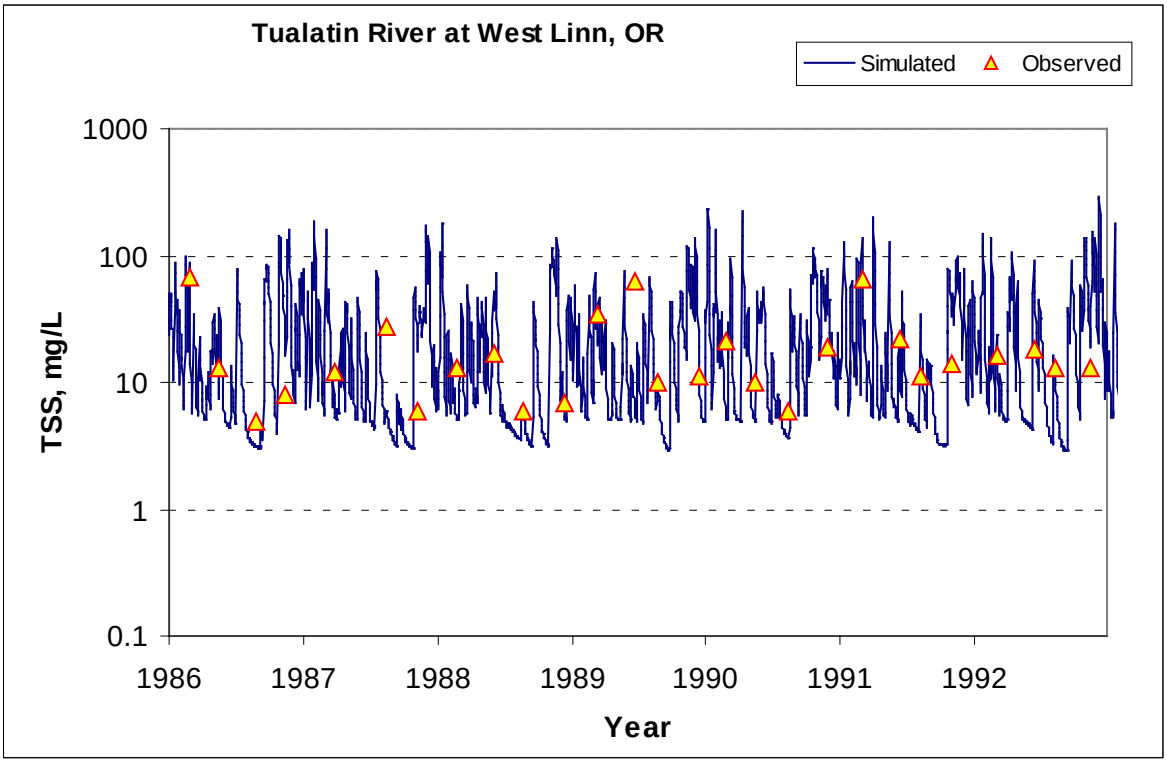

Figure 31. Time series plot of TSS concentration at USGS 14207500 Tualatin River at West Linn, OR – (HSPF).

Table 16. Relative errors (observed minus predicted), TSS concentration, at USGS 14207500 Tualatin River at West Linn, OR (HSPF)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Count	35	29
Concentration Average Error	-40.4%	21.9%
Concentration Median Error	-7.8%	10.0%

The total phosphorus calibration performed well at the Tualatin River location. Adjustments were made to the potency factors and the subsurface concentrations. In general, the observed and simulated total phosphorus loads attain an acceptable match for the simulation period (Figure 32 and Table 17). As with TSS, additional diagnostics for total phosphorus included flow-load power plots (Figures 33 and 34), a time series plot of concentrations (Figure 35), and statistics (Table 18). All show acceptable agreement.

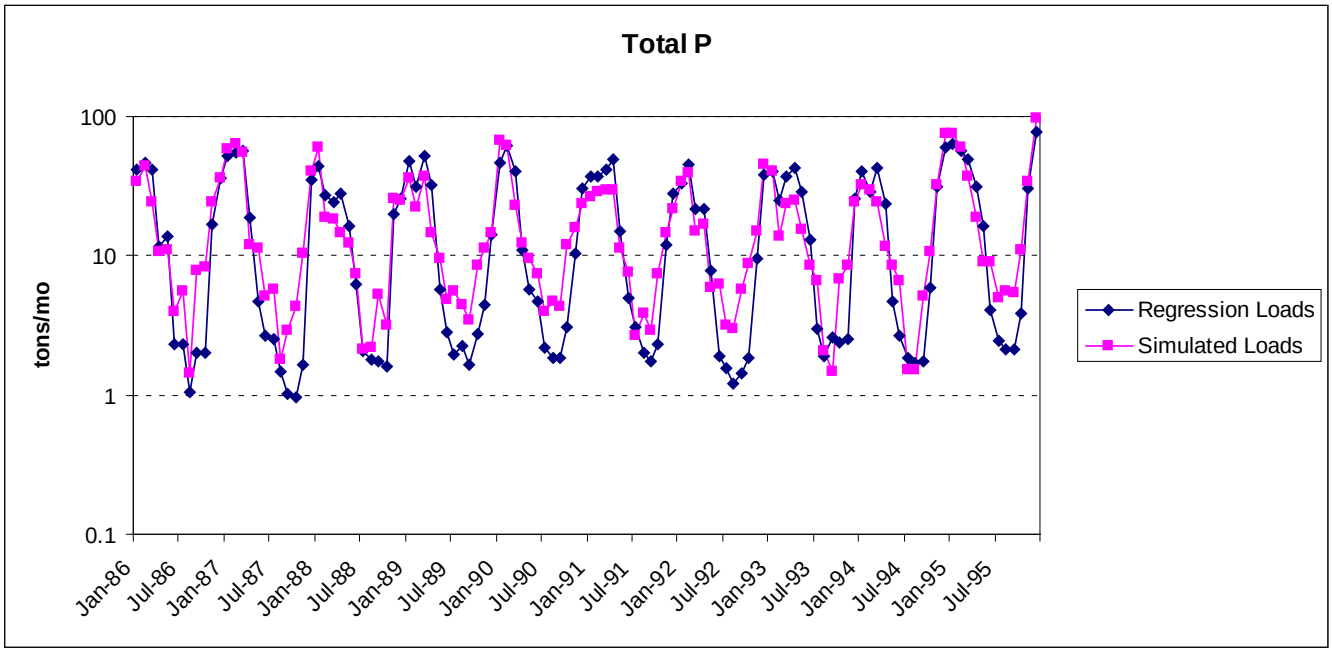

Figure 32. Fit for monthly load of total phosphorus at USGS 14207500 Tualatin River at West Linn, OR (HSPF).

Table 17. Model fit statistics (observed minus predicted) for monthly total phosphorus loads using stratified regression (HSPF)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Relative Percent Error	-1%	-9%
Average Absolute Error	31%	32%
Median Absolute Error	23.0%	21.8%

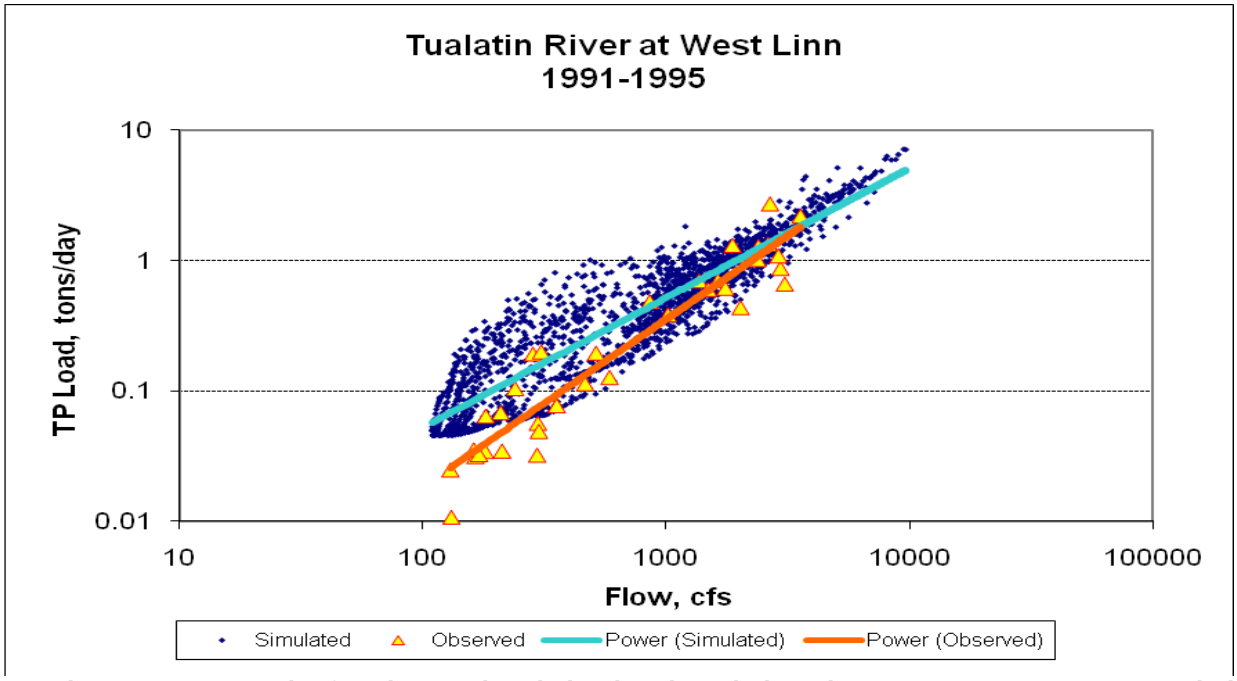

Figure 33. Power plot for observed and simulated total phosphorus at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF).

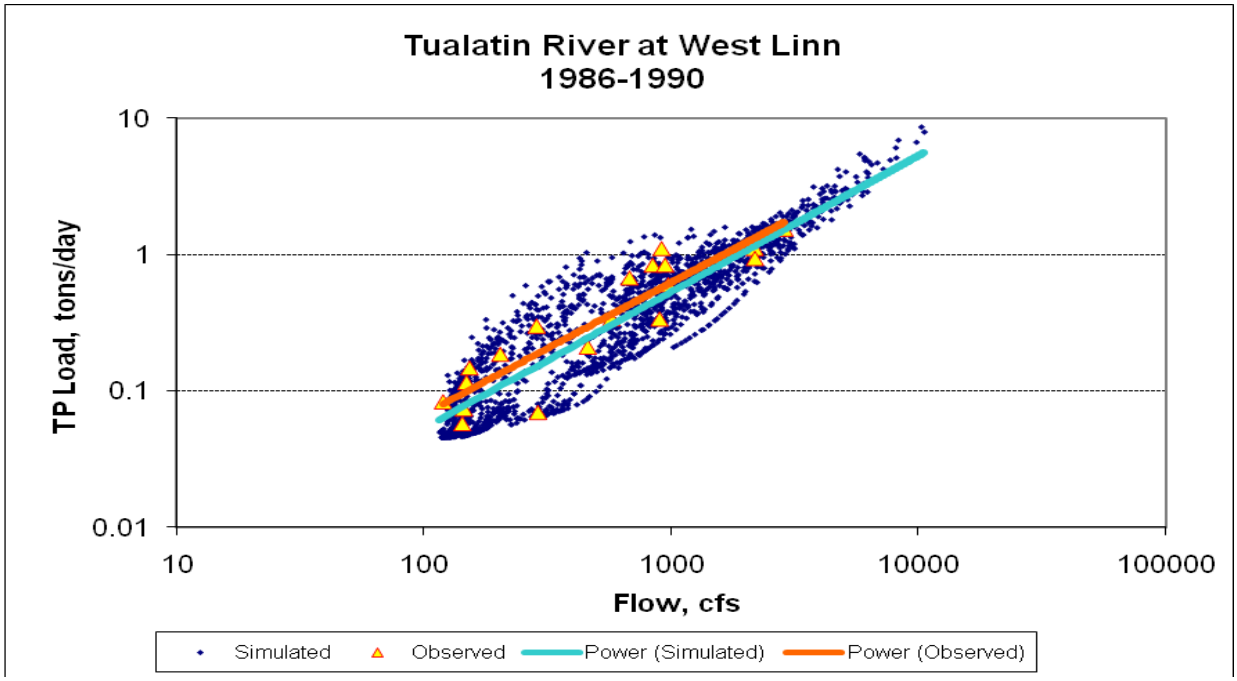

Figure 34. Power plot for observed and simulated total phosphorus at USGS 14207500 Tualatin River at West Linn, OR – validation period (HSPF).

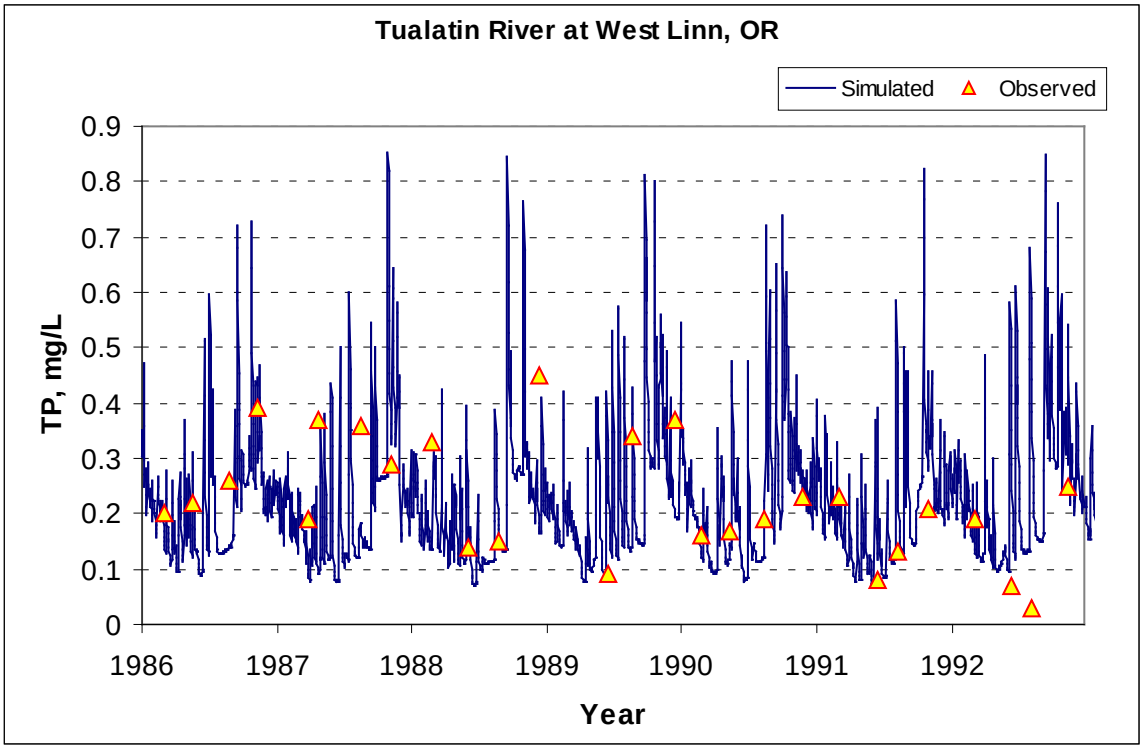

Figure 35. Time series plot of total phosphorus concentration at USGS 14207500 Tualatin River at West Linn, OR (HSPF).

Table 18. Relative errors (observed minus predicted), total phosphorus concentration at USGS 14207500 Tualatin River at West Linn, OR (HSPF)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Count	35	19
Concentration Average Error	-78.8%	26.3%
Concentration Median Error	-59.7%	26.5%

Nitrogen adjustments were made to the seasonally varying accumulation/washoff and subsurface concentrations. Results for total nitrogen are summarized in Figures 36 through 39 and Tables 19 and 20. The results are acceptable, and generally better than those for total phosphorus. This is because nitrogen is not sediment-associated, therefore, problems with sediment are not reflected in the calibration for total nitrogen. A summary of the water quality statistics at the two locations (Tualatin River and Pudding River) are shown in Table 21.

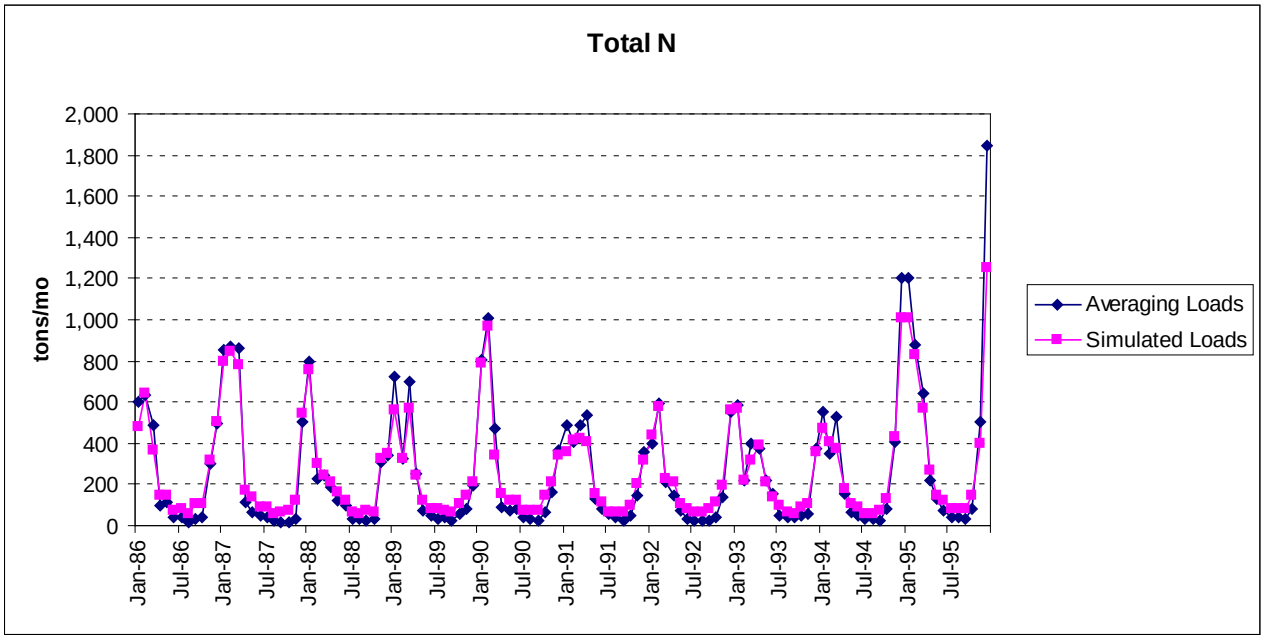

Figure 36. Fit for monthly load of total nitrogen at USGS 14207500 Tualatin River at West Linn, OR (HSPF).

Table 19. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator (HSPF)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Relative Percent Error	2%	-6%
Average Absolute Error	21%	20%
Median Absolute Error	15.5%	17.0%

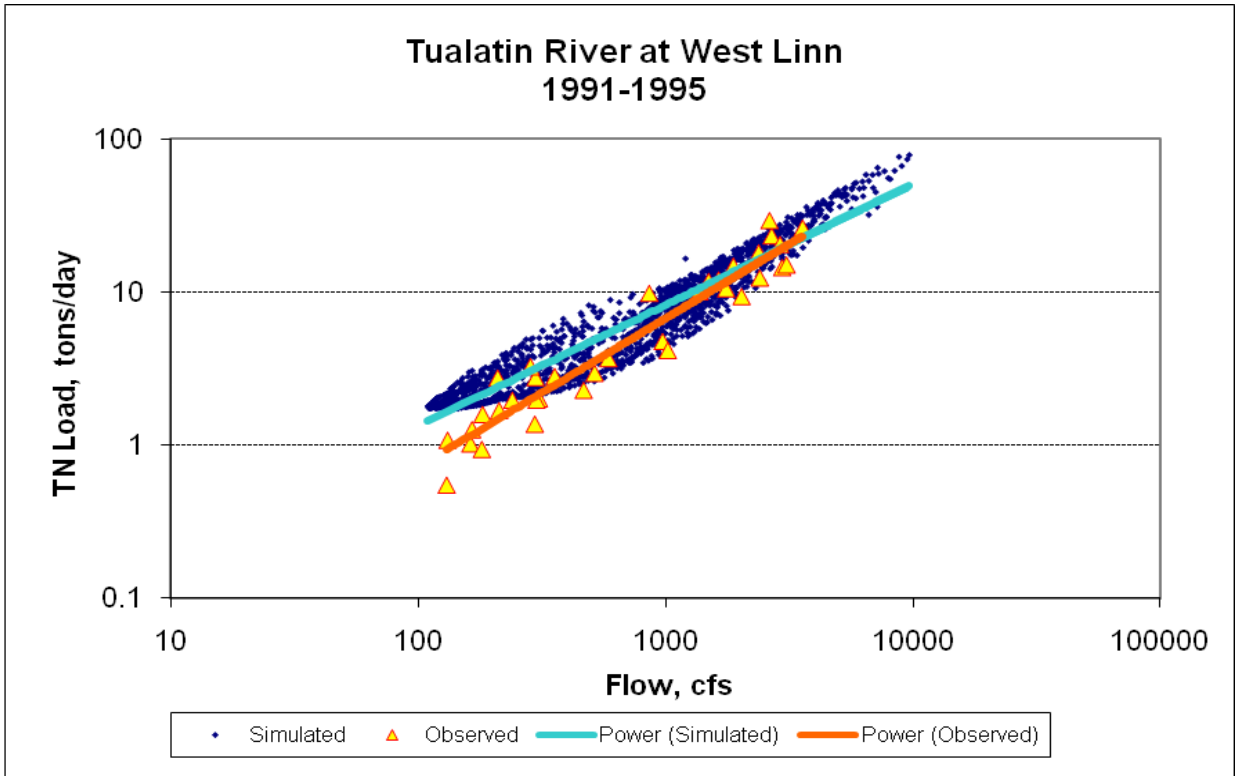

Figure 37. Power plot for observed and simulated total nitrogen at USGS 14207500 Tualatin River at West Linn, OR – calibration period (HSPF).

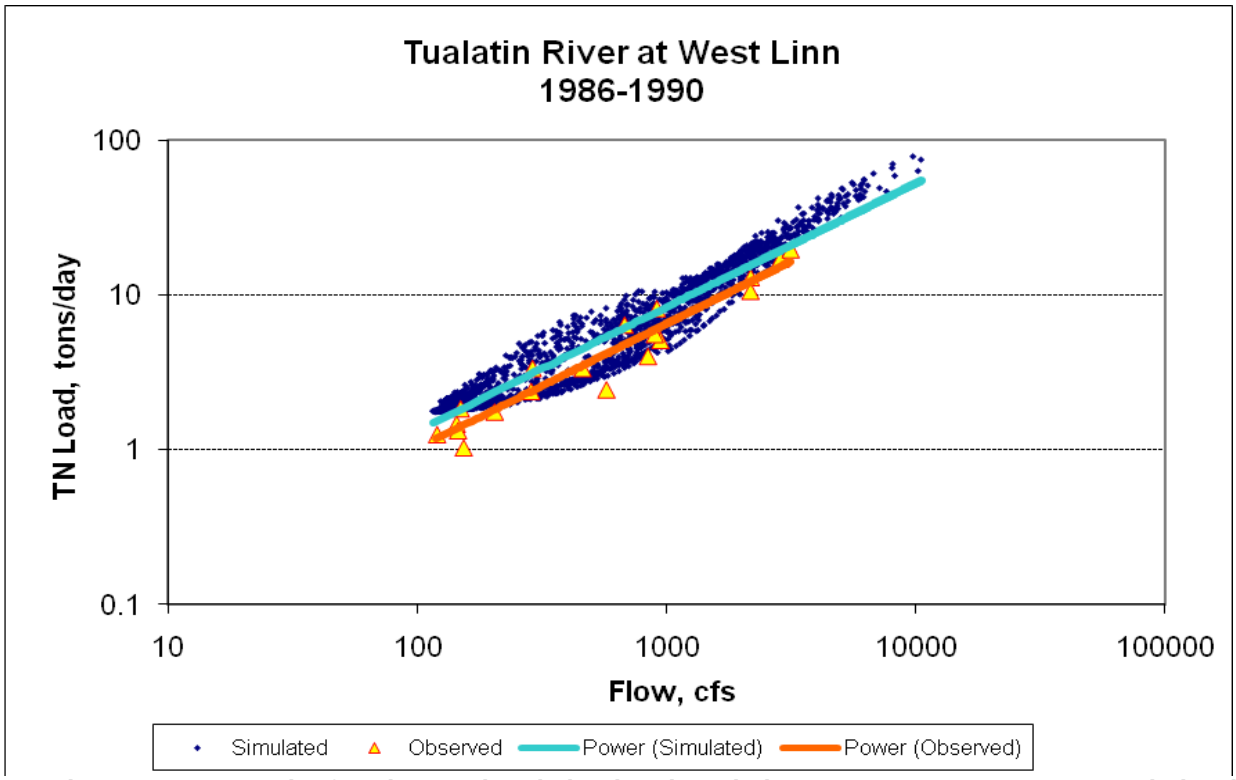

Figure 38. Power plot for observed and simulated total nitrogen at USGS 14207500 Tualatin River at West Linn, OR – validation period (HSPF).

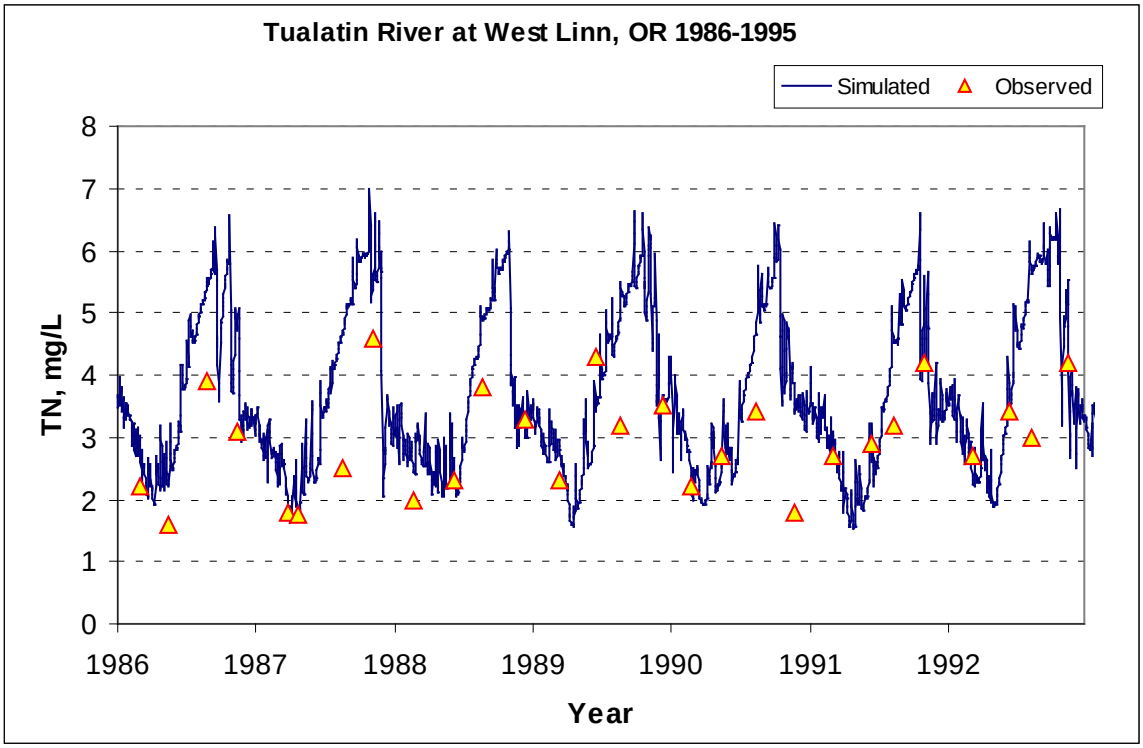

Figure 39. Time series plot of total nitrogen concentration at USGS 14207500 Tualatin River at West Linn, OR (HSPF).

Table 20. Relative errors (observed minus predicted), total nitrogen concentration, USGS 14207500 Tualatin River at West Linn, OR (HSPF)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Count	35	20
Concentration Average Error	-33.5%	-25.6%
Concentration Median Error	-16.8%	-19.2%

Water Quality Results for Larger Watershed

The Tualatin River water quality parameters were transferred to the Pudding River (Aurora) watershed, and further calibration was necessary in the Pudding. A combination of the parameters sets from the Tualatin and Pudding watersheds was transferred to the remaining portions of the watershed. Since there are no other water quality data available in the Willamette watershed, it was not possible to determine whether the parameter set was applicable to the entire watershed. However, the calibration at the two locations was fairly good with respect to the loads (Table 21). As expected, the concentration errors are larger.

Table 21. Summary statistics for water quality for all stations (observed minus predicted) (HSPF)

Station	14207500 West Linn Calibration	14207500 West Linn Validation	14202000 Aurora Calibration	14202000 Aurora Validation
Relative Percent Error TSS Load	3%	5%	1%	20%
TSS Concentration Median Percent Error	-7.8%	10.0%	22.1%	-10.3%
Relative Percent Error TP Load	-1%	-9%	4%	-28%
TP Concentration Median Percent Error	-59.7%	26.5%	-18.2%	38.3%
Relative Percent Error TN Load	2%	-6%	0%	11%
TN Concentration Median Percent Error	-16.8%	-19.2%	16.0%	-12.2%

SWAT Modeling

The USGS gages on the Tualatin River at West Linn, OR (USGS 14207500) and the Pudding River at Aurora, OR (USGS 14202000) were used as the primary hydrology and water quality calibration locations. Additional tributary hydrology calibration was performed on the South Yamhill River at McMinnville, OR (USGS 14194150) and the Mohawk (McKenzie) River near Springfield (USGS 14165000). A hydrology calibration check was performed at the USGS gage on the Willamette River at Salem, OR (USGS 14191000), which is the most downstream gage in the watershed that does not include tidal effects.

Changes Made to Base Data Provided

No changes were made to the input data provided for the SWAT model except for point sources. The flow from the six paper mills was changed to zero, since they draw water from the same rivers that they discharge to. These point sources are: OR0000442, OR0000515, OR0000558, OR0000566, OR0000787, and OR0001074. Several other point sources discharge to the calibration watersheds. Some of the parameters were determined to be erroneous, and since they caused obvious problems in the calibration in the Tualatin and Pudding subwatersheds, were modified based on information obtained from other sources. Three point sources (OR0020001, OR0020168, and OR0023345) do not discharge to surface waters during the summer, so these three were modified to turn off the discharges between June and September. The discharges of three point sources (OR0028118, OR0029777, and OR0034002) were found to be overestimated by using the “Observed Flow” and were changed to the “Design Flow”. The total phosphorus concentrations of two point sources were reduced as a result of the use of advanced treatment methods; these are OR0020168 and OR0029777. Summer loads of total phosphorus were substantially overpredicted with the higher values.

Assumptions

Reservoirs

Fall Creek Lake, Dorena Lake, Lookout Point Lake, Green Peter Lake, Foster Lake, Hills Creek Lake, Detroit Lake, Cottage Grove Lake, Cougar Lake, and Fern Ridge Lake (Table 6) were represented in the Willamette River watershed SWAT model. Pertinent reservoir information including surface area and storage at principal (normal) and emergency spillway levels for the reservoirs modeled were obtained from the National Inventory of dams (NID) database (USACE 1982). The SWAT model provides four options to simulate reservoir outflow: 1) measured daily outflow, 2) measured monthly outflow, 3) average annual release rate for uncontrolled reservoir, and 4) controlled outflow with target release. Keeping in view the 20 Watershed climate change impact evaluation application, it was assumed that the best representation of the reservoirs was to simulate them without supplying time series of outflow records. Therefore, a target release approach was used in the GCRP-SWAT model. The number of days to reach target storage was assumed to be 50 days and an average release rate of 50 m^3/s was assumed for all lakes.

Withdrawals

No withdrawals, either by municipal and industrial facilities, were included in the 20 Watershed model application.

Irrigation

Irrigation was not explicitly modeled in the Willamette River watershed.

Hydrology Calibration

The SWAT model setup for the Willamette River watershed 20 Watershed project was set up fresh, with no prior-existing SWAT model for the watershed.

Most of the calibration efforts were geared toward getting a closer match between simulated and observed flows at the outlet of the calibration focus area. Initially, the parameters set for this area were applied across the watershed and the model performance was verified at other stations. This resulted in model performance that was not the same as in the calibration focus area, mostly because of dominance of different land uses in different parts of the watershed. In response to the variations in spatial characteristics of the subwatersheds, a systematic adjustment of parameters, individually, by land use type was adopted and the same adjustment was applied throughout the watershed.

It can be acknowledged that a hydrologic/water quality model can be precisely calibrated, given the degree of freedom, resources, time, and data. Keeping in view the interests of this project, which are to study the land use change and climate change impacts on flow and water quality, a site-specific calibration was deliberately not attempted. To some extent, the limitation of this approach is that the local differences in soil, weather, management, and hydrology is not thoroughly accounted for. This approach will provide an idea of the model performance when it is not spatially-tightly calibrated and what to expect when transferring the parameters to other ungaged watersheds or to watersheds where detailed modeling is not practical due to limited resources.

While adjusting the hydrology and water quality parameters for calibration, crop yields were also checked. The crop yields for wheat, corn, and hay were found to be reasonably close to the reported yield values in the National Agricultural Statistics Service (NASS) database.

Land Use / Soil / Slope Definition

A 5/10/5 percent threshold was used for land use/soil/slope in the SWAT model while defining the HRUs. The cropland HRUs were simulated as 2-year winterwheat-corn-winterwheat rotation with every other year fallow during summer. The hay HRUs were simulated as hay every year with the fourth year being fallow. The urban (including current and future urban class types) classes were exempt from applying the thresholds.

The calibration focus area represents 3 subwatersheds, which together consist of 195 HRUs. The parameters were adjusted within the practical range to obtain a reasonable fit between the simulated and measured flows in terms of Nash-Sutcliffe modeling efficiency and the high flow and low flow components as well as the seasonal flows. The calibration focus area well-represented the general land use characteristics of the overall watershed. The predominantly forested subwatershed (Mohawk River near Springfield, OR; USGS 14165000) was chosen to set the parameters for forest, which were then applied across the entire watershed. There is essentially one set of parameters for a land use type for the entire watershed.

Once the hydrology calibration was complete for the entire Willamette watershed, the water quality calibration was pursued. Similar to hydrology, there is a single set of water quality parameters for the entire Willamette River watershed.

Hydrology calibration adjustments focused on the following parameters:

- Curve numbers (varied systematically by land use)
- ESCO (soil evaporation compensation factor)
- SURLAG (surface runoff lag coefficient)
- Baseflow factor
- GW_DELAY (groundwater delay time)
- Sol_AWC (available water capacity of the soil layer, mm water/mm of soil)

Initial hydrology calibrations were performed for the Tualatin River at West Linn, OR (USGS 14207500) and are summarized in Figures 40 through 46 and Tables 22 and 23. The model calibration period was set to the 10 water years from 10/01/1995 to 09/30/2005. As evidenced through the time series plot, the model performed well in simulating the timing at various seasons. The model overpredicted seasonal spring, summer, and overall storm volumes indicated by the *Error in Storm Volumes* metric.

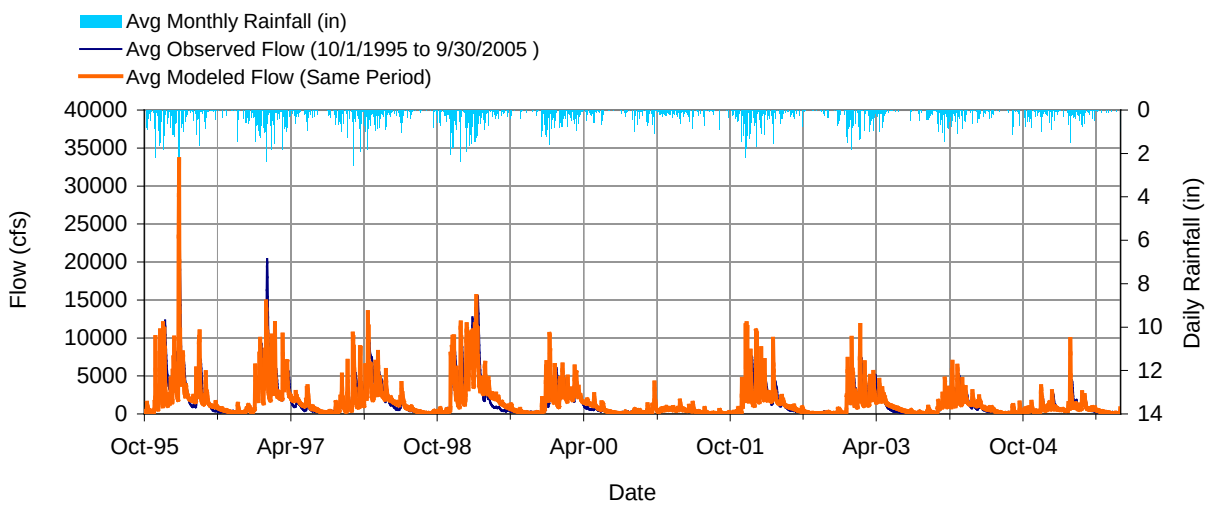

Figure 40. Mean daily flow at USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT).

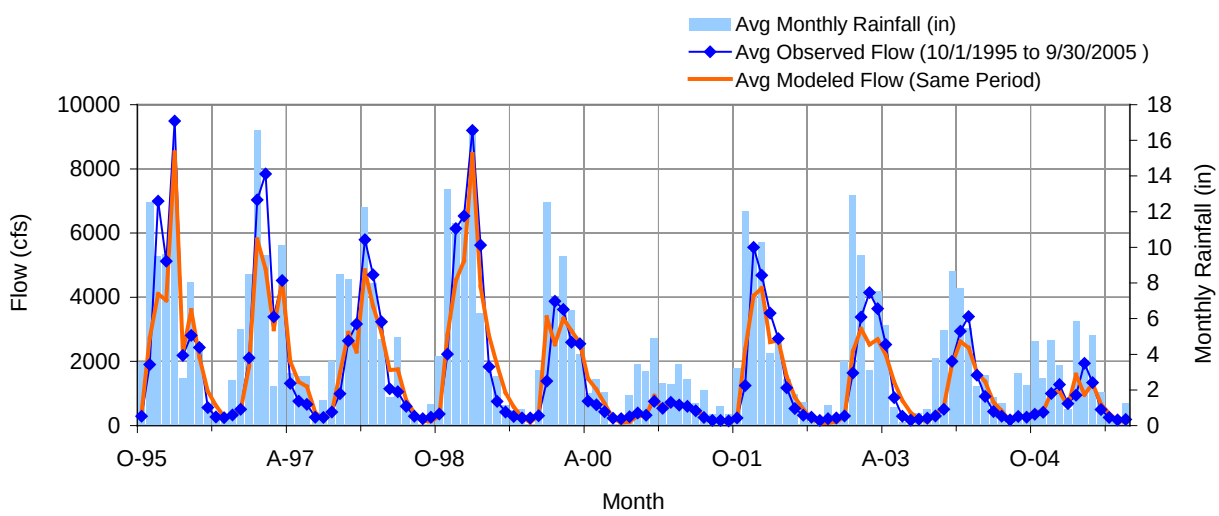

Figure 41. Mean monthly flow at USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT).

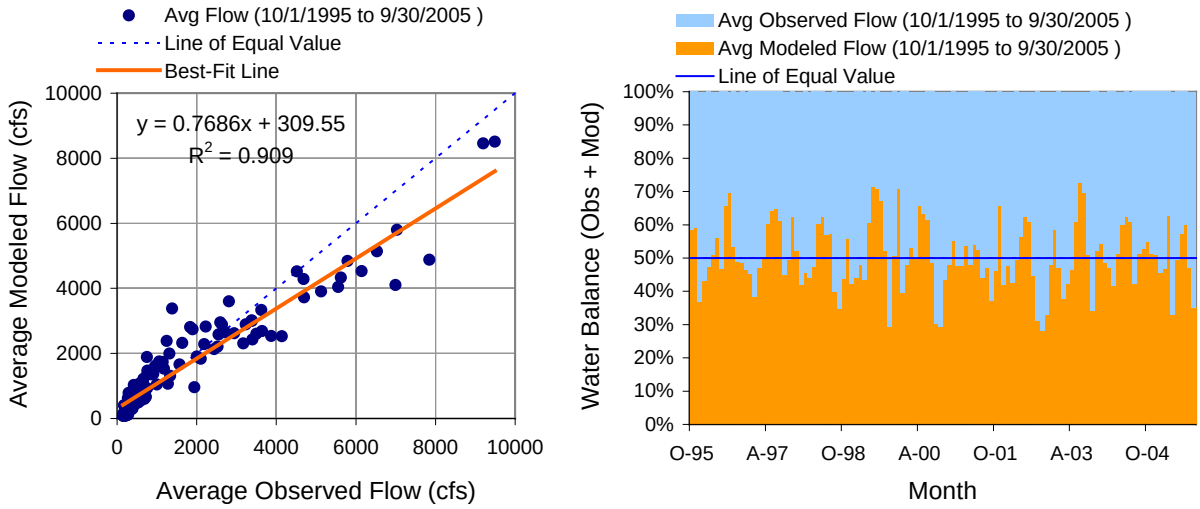

Figure 42. Monthly flow regression and temporal variation at USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT).

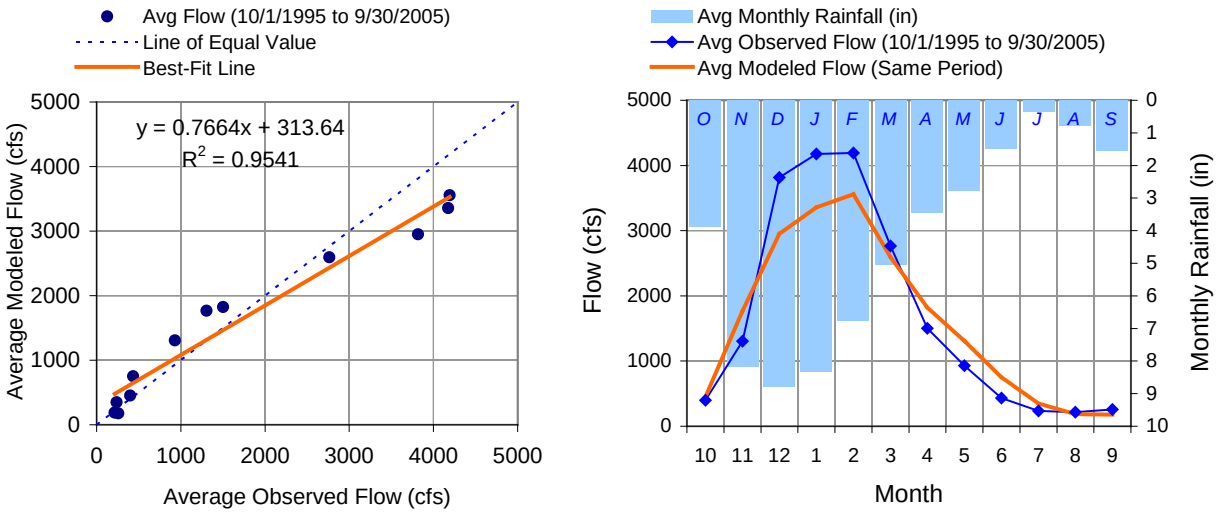

Figure 43. Seasonal regression and temporal aggregate at USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT).

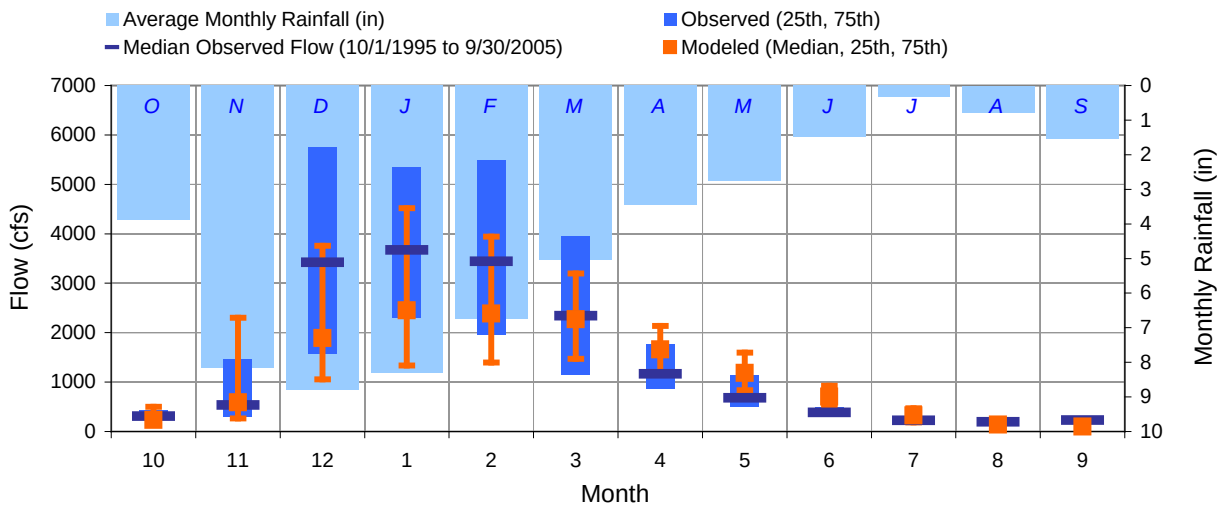

Figure 44. Seasonal medians and ranges at USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT).

Table 22. Seasonal summary at USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	399.00	309.00	234.00	436.75	451.80	233.45	133.30	502.09
Nov	1305.46	534.00	305.75	1460.00	1766.52	591.34	265.80	2302.69
Dec	3817.72	3420.00	1565.00	5747.50	2950.48	1891.63	1053.44	3756.60
Jan	4175.40	3675.00	2297.50	5340.00	3356.79	2452.25	1333.92	4517.63
Feb	4193.04	3440.00	1955.00	5485.00	3557.28	2384.45	1397.75	3944.65
Mar	2763.99	2340.00	1155.00	3962.50	2594.23	2270.38	1469.18	3195.54
Apr	1503.13	1165.00	855.00	1760.00	1822.10	1663.14	1182.51	2135.92
May	929.54	681.00	497.25	1140.00	1307.67	1187.81	835.28	1596.66
Jun	434.30	385.50	295.00	485.00	749.55	705.59	519.57	927.19
Jul	236.99	227.00	187.00	275.50	347.93	325.30	183.15	468.27
Aug	215.16	197.50	171.25	233.75	186.90	138.33	85.99	222.95
Sep	258.55	232.00	197.75	286.25	177.81	98.44	78.28	155.79

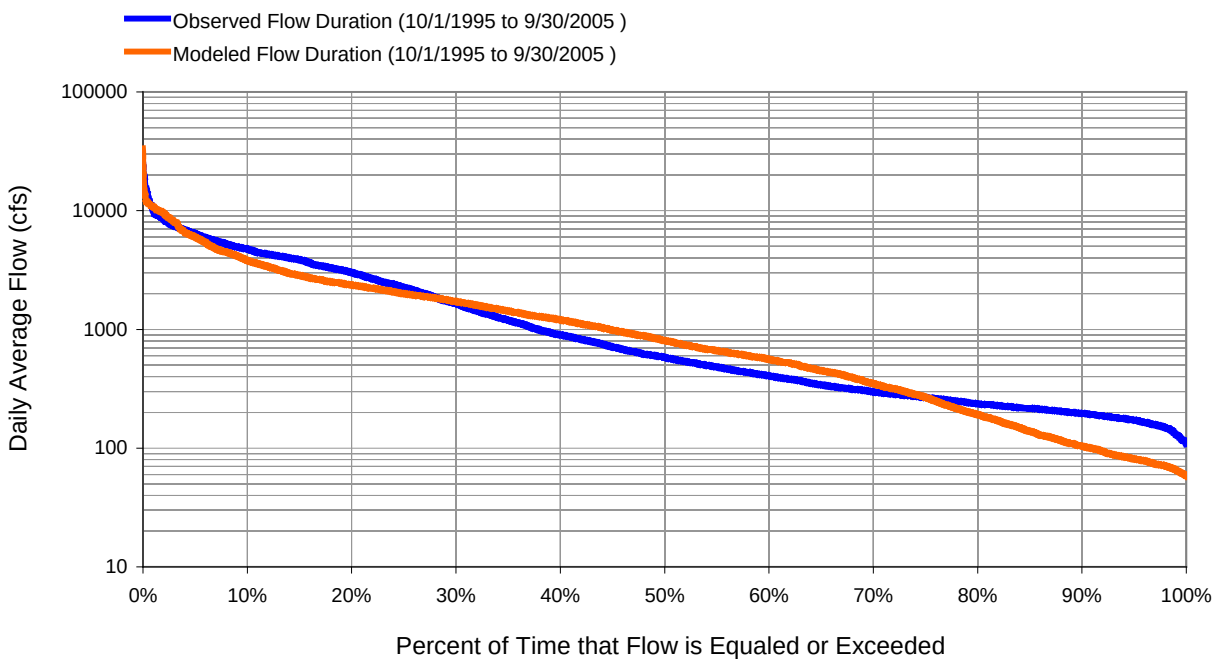

Figure 45. Flow exceedence at USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT).

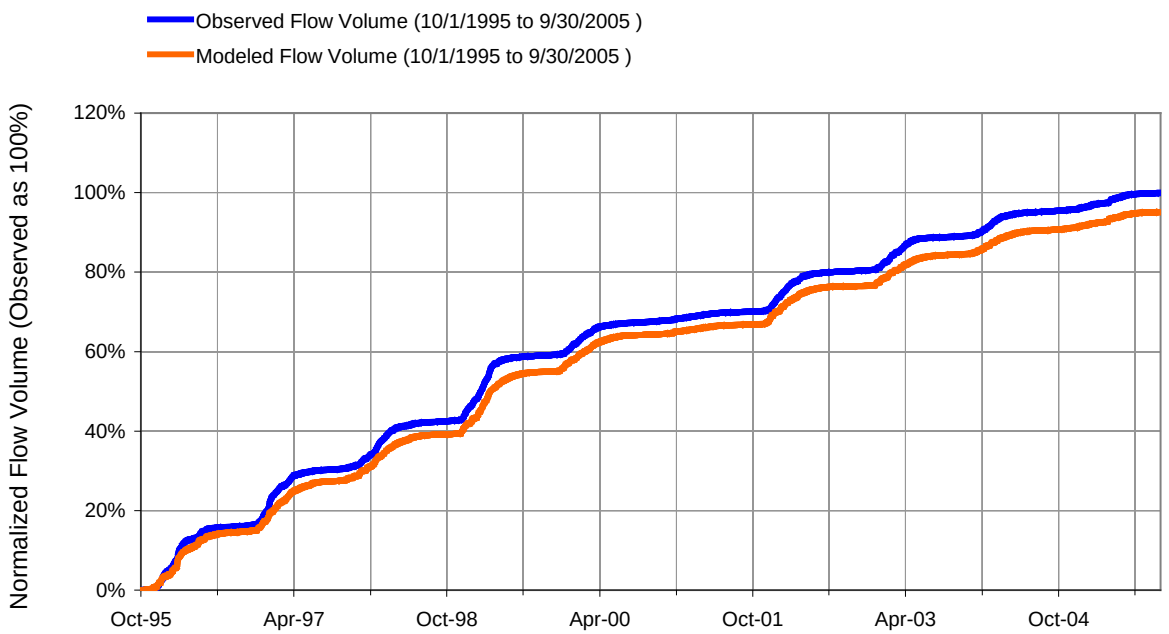

Figure 46. Flow accumulation at USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT).

Table 23. Summary statistics: USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT)

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 5 10-Year Analysis Period: 10/1/1995 - 9/30/2005 Flow volumes are (inches/year) for upstream drainage area		USGS 14207500 TUALATIN RIVER AT WEST LINN, OR Hydrologic Unit Code: 17090010 Latitude: 45.35067559 Longitude: -122.6762044 Drainage Area (sq-mi): 706	
Total Simulated In-stream Flow:	**30.72**	Total Observed In-stream Flow:	**32.25**
Total of simulated highest 10% flows:	**13.40**	Total of Observed highest 10% flows:	**13.96**
Total of Simulated lowest 50% flows:	**3.11**	Total of Observed Lowest 50% flows:	**2.85**
Simulated Summer Flow Volume (months 7-9):	**1.15**	Observed Summer Flow Volume (7-9):	**1.15**
Simulated Fall Flow Volume (months 10-12):	**8.35**	Observed Fall Flow Volume (10-12):	**8.95**
Simulated Winter Flow Volume (months 1-3):	**15.02**	Observed Winter Flow Volume (1-3):	**17.58**
Simulated Spring Flow Volume (months 4-6):	**6.20**	Observed Spring Flow Volume (4-6):	**4.58**
Total Simulated Storm Volume:	**10.56**	Total Observed Storm Volume:	**6.18**
Simulated Summer Storm Volume (7-9):	**0.24**	Observed Summer Storm Volume (7-9):	**0.16**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*Run (n-1)*	*Run (n-2)*
Error in total volume:	-4.76	10	-4.76	
Error in 50% lowest flows:	9.00	10	11.08	
Error in 10% highest flows:	-4.03	15	-4.19	
Seasonal volume error - Summer:	0.65	30	6.04	
Seasonal volume error - Fall:	-6.72	30	-6.91	
Seasonal volume error - Winter:	-14.57	30	-14.74	
Seasonal volume error - Spring:	**35.37**	**30**	**35.01**	
Error in storm volumes:	**71.00**	**20**	**71.50**	
Error in summer storm volumes:	**52.22**	**50**	**52.98**	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.489	Model accuracy increases	0.489	
Baseline adjusted coefficient (Garrick), E':	0.505	as E or E' approaches 1.0	0.505	

Hydrology Validation

Consistent with HSPF modeling efforts, validation for the Tualatin River calibration focus area was performed at the same location but for the water years from 10/01/1985 to 09/30/1995. Results are presented in Figures 47 through 53 and Tables 24 and 25. Although, the Nash-Sutcliffe modeling efficiency is not as good as it was for the calibration period, the model performance was adequate for the validation period. The model underestimates total flow volumes while it overestimates low flows and storm volumes. The rest of the metrics fall within the acceptable range set for the 20 Watershed study.

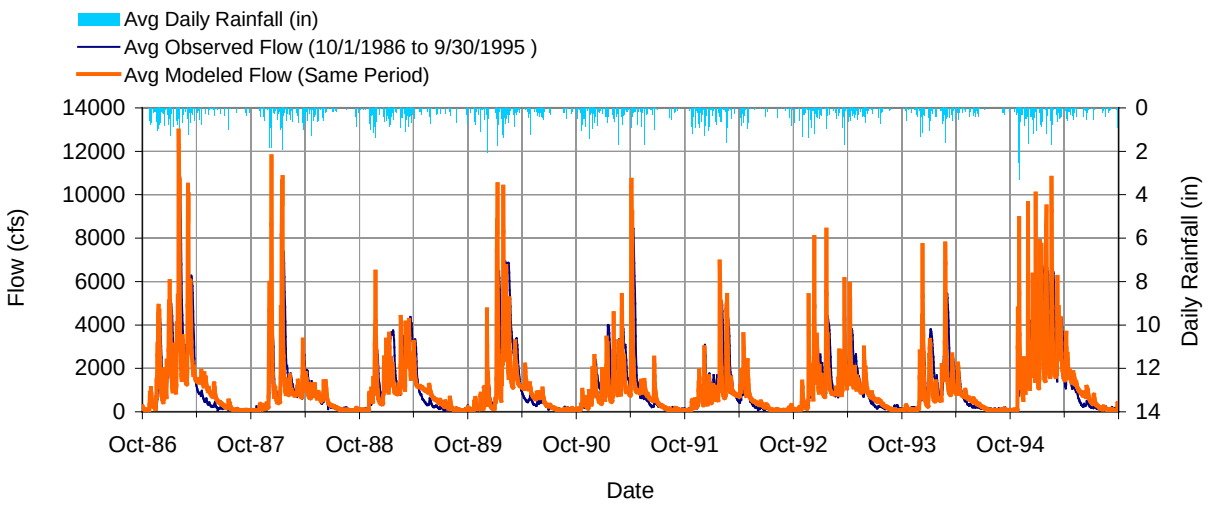

Figure 47. Mean daily flow at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT).

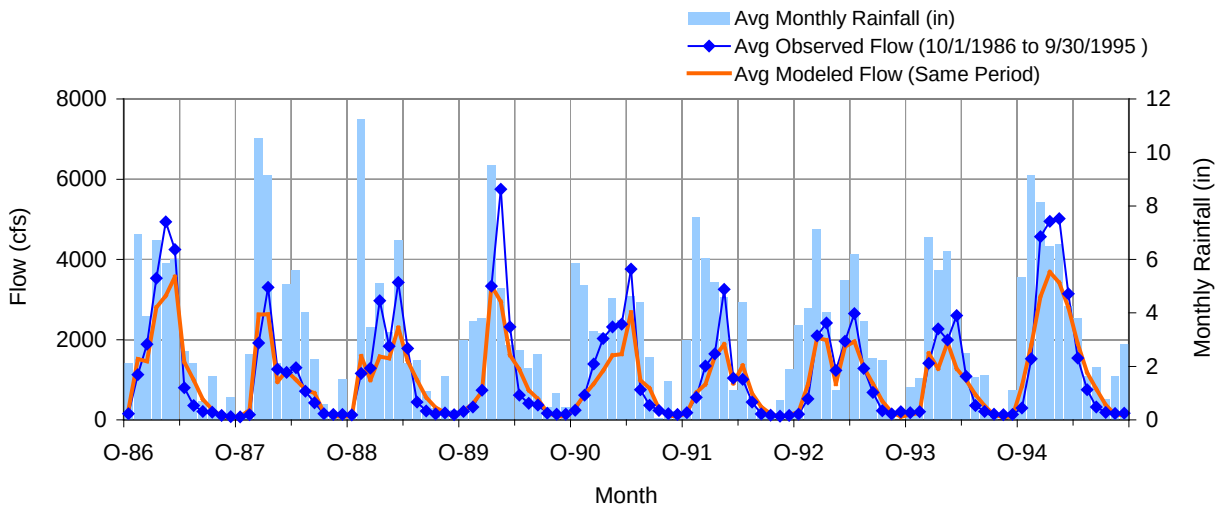

Figure 48. Mean monthly flow at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT).

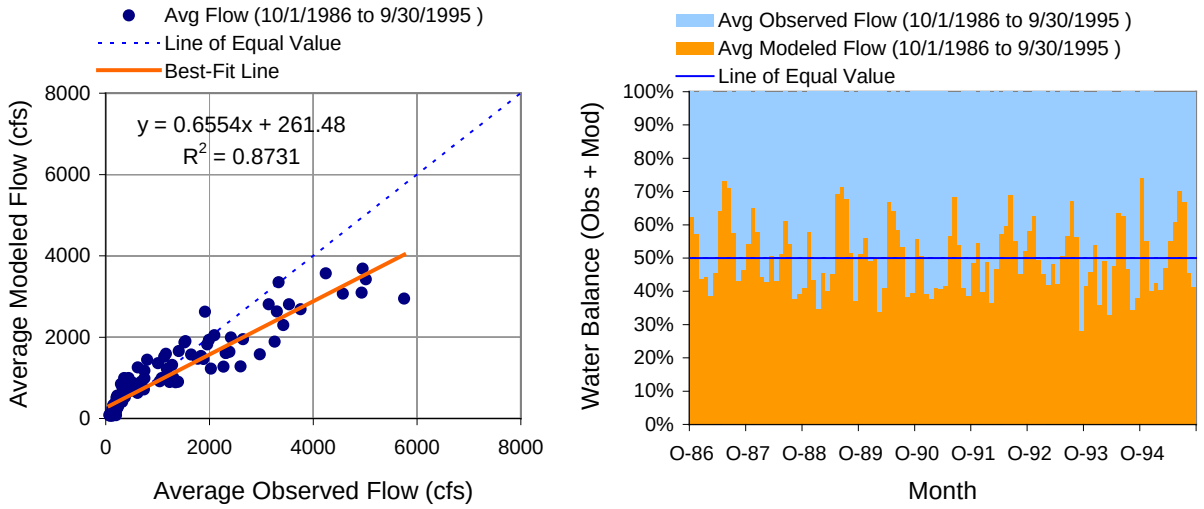

Figure 49. Monthly flow regression and temporal variation at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT).

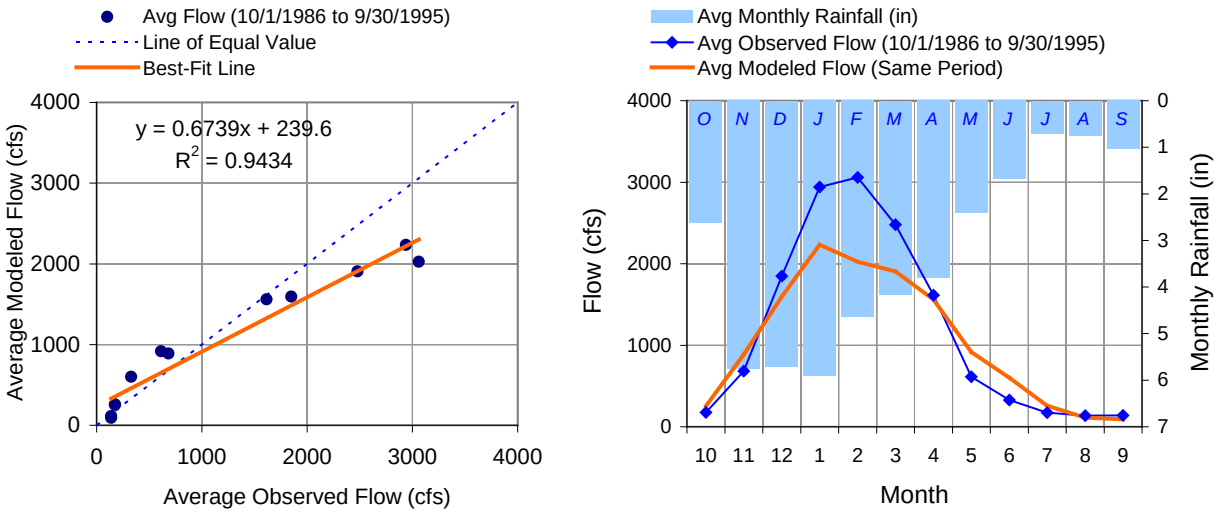

Figure 50. Seasonal regression and temporal aggregate at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT).

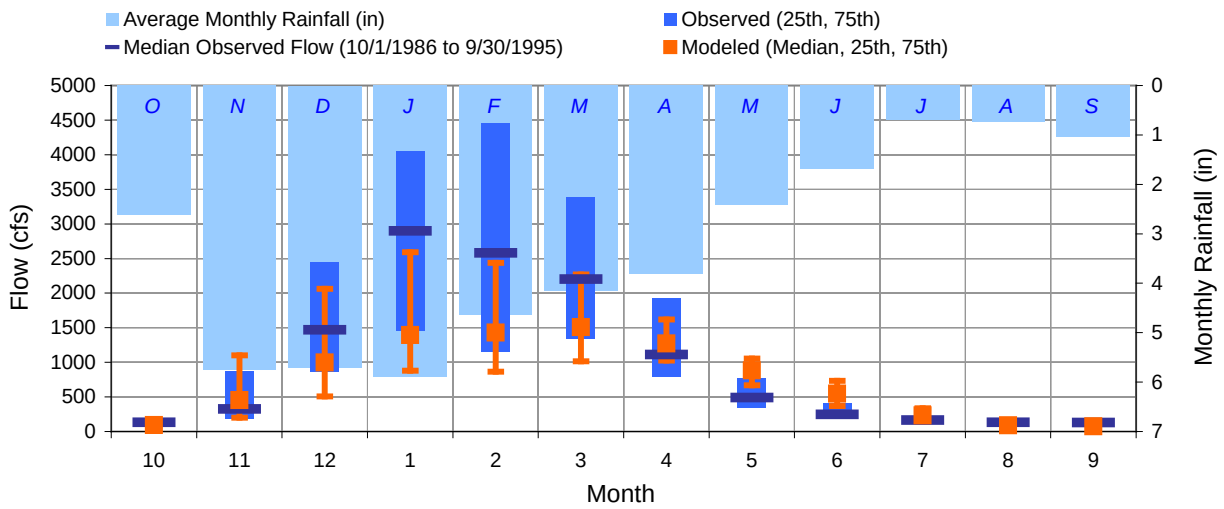

Figure 51. Seasonal medians and ranges at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT).

Table 24. Seasonal summary at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	176.23	133.00	103.00	187.50	253.63	92.74	83.59	157.15
Nov	684.20	324.00	193.00	875.00	887.67	455.03	200.88	1100.85
Dec	1849.41	1470.00	873.00	2450.00	1595.11	996.23	507.82	2060.43
Jan	2939.52	2900.00	1460.00	4055.00	2234.76	1393.87	880.57	2590.33
Feb	3060.41	2580.00	1150.00	4450.00	2025.35	1429.89	865.74	2438.83
Mar	2478.49	2200.00	1335.00	3380.00	1906.07	1506.88	1014.94	2270.91
Apr	1615.37	1110.00	791.00	1917.50	1560.53	1272.74	1025.63	1620.06
May	612.33	491.00	339.50	770.50	915.70	882.87	667.62	1053.08
Jun	328.74	248.00	199.00	410.25	599.41	547.55	367.63	731.63
Jul	173.48	165.00	130.50	211.50	258.61	233.54	149.65	336.11
Aug	137.55	132.00	112.00	159.50	112.11	89.66	72.13	125.44
Sep	138.14	127.00	111.00	158.00	90.80	74.92	66.13	97.54

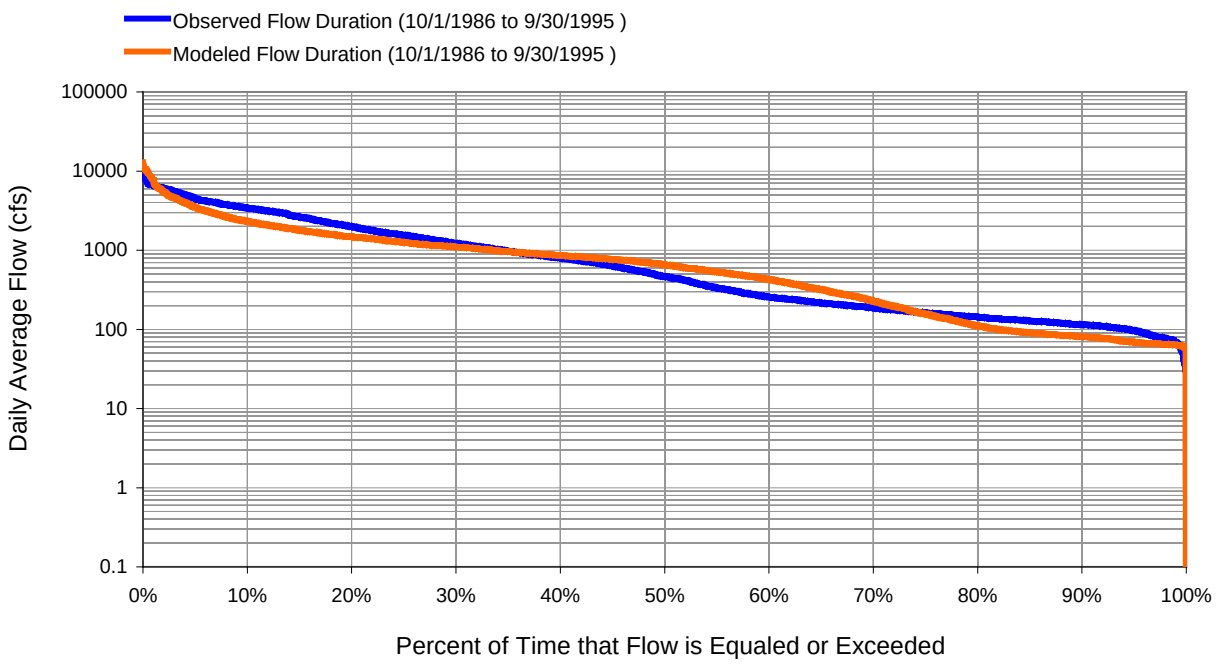

Figure 52. Flow exceedence at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT).

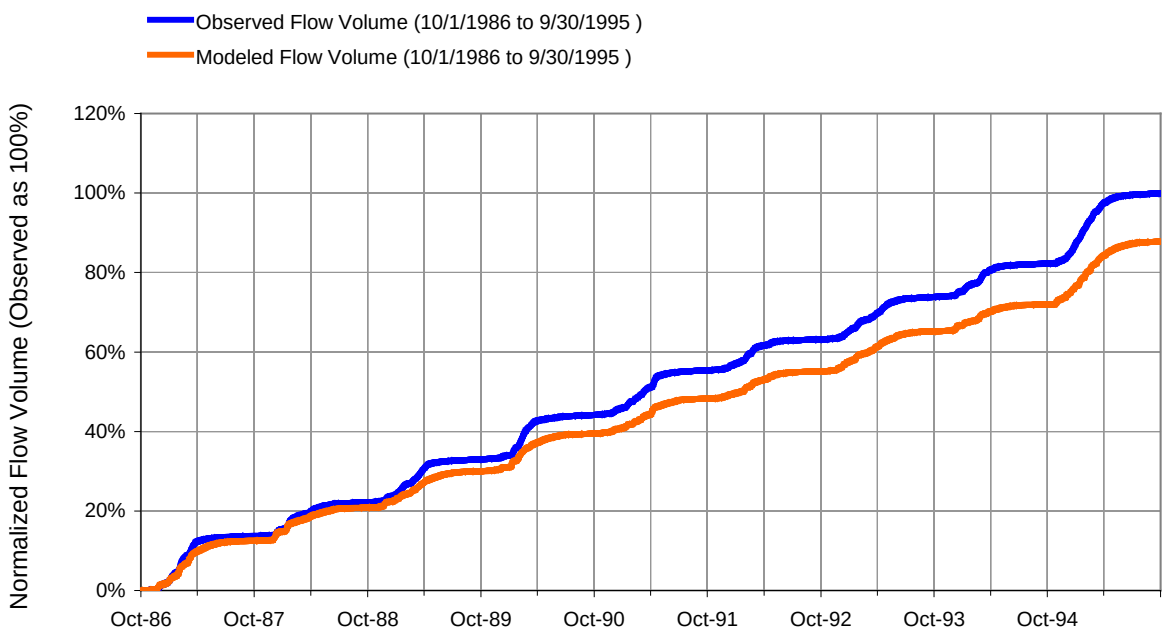

Figure 53. Flow accumulation at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT).

Table 25. Summary statistics at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT)

SWAT Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM OUTLET 5 9-Year Analysis Period: 10/1/1986 - 9/30/1995 Flow volumes are (inches/year) for upstream drainage area		USGS 14207500 TUALATIN RIVER AT WEST LINN, OR Hydrologic Unit Code: 17090010 Latitude: 45.35067559 Longitude: -122.6762044 Drainage Area (sq-mi): 706	
Total Simulated In-stream Flow:	**19.85**	Total Observed In-stream Flow:	**22.59**
Total of simulated highest 10% flows:	**8.29**	Total of Observed highest 10% flows:	**9.50**
Total of Simulated lowest 50% flows:	**2.28**	Total of Observed Lowest 50% flows:	**1.83**
Simulated Summer Flow Volume (months 7-9):	**0.75**	Observed Summer Flow Volume (7-9):	**0.73**
Simulated Fall Flow Volume (months 10-12):	**4.42**	Observed Fall Flow Volume (10-12):	**4.39**
Simulated Winter Flow Volume (months 1-3):	**9.77**	Observed Winter Flow Volume (1-3):	**13.40**
Simulated Spring Flow Volume (months 4-6):	**4.91**	Observed Spring Flow Volume (4-6):	**4.07**
Total Simulated Storm Volume:	**6.95**	Total Observed Storm Volume:	**4.72**
Simulated Summer Storm Volume (7-9):	**0.12**	Observed Summer Storm Volume (7-9):	**0.11**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*Run (n-1)*	*Run (n-2)*
Error in total volume:	**-12.10**	**10**	**-11.90**	
Error in 50% lowest flows:	**24.62**	**10**	**28.58**	
Error in 10% highest flows:	-12.81	15	-12.92	
Seasonal volume error - Summer:	3.12	30	11.74	
Seasonal volume error - Fall:	0.74	30	0.75	
Seasonal volume error - Winter:	-27.05	30	-27.19	
Seasonal volume error - Spring:	20.54	30	20.56	
Error in storm volumes:	**47.27**	**20**	**47.08**	
Error in summer storm volumes:	4.49	50	3.21	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.394	Model accuracy increases	0.394	
Baseline adjusted coefficient (Garrick), E':	0.459	as E or E' approaches 1.0	0.459	

Hydrology Results for Larger Watershed

Since the Tualatin River calibration location represents only a small portion of the entire Willamette River watershed, the results near the outlet of the entire watershed were examined at the Willamette River at Salem, OR (USGS 14191000). This gage is downstream of the large reservoirs in the Willamette River watershed. Greater than 40 percent of the area at Salem is controlled by dams. The results are presented in Figures 54 through 60 and Tables 26 and 27. Summer storms are small in this region, and the summer storm volumes are also small; therefore, an error of 0.2 inches produces a large percent difference. Underestimation of low flow is manifested in underestimation of seasonal summer volumes. The remainder of the metrics fall within the acceptable range set for the 20 Watershed study including a Nash-Sutcliffe of 0.67 at the Salem gage. Tables 28 and 29 show a summary of the hydrology calibration and validation results for all five locations, respectively.

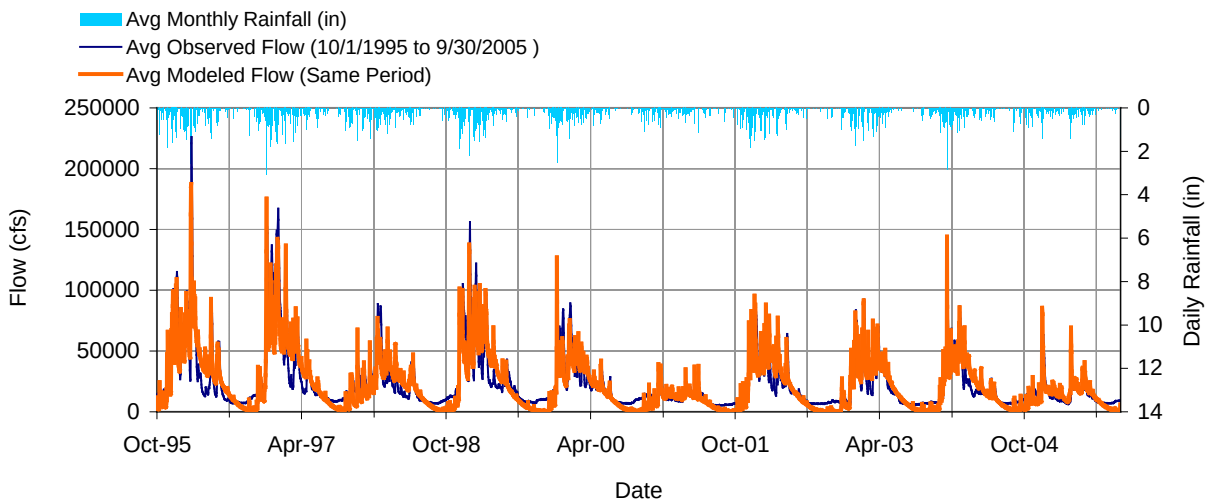

Figure 54. Mean daily flow at USGS 14191000 Willamette River at Salem, OR – calibration period (SWAT).

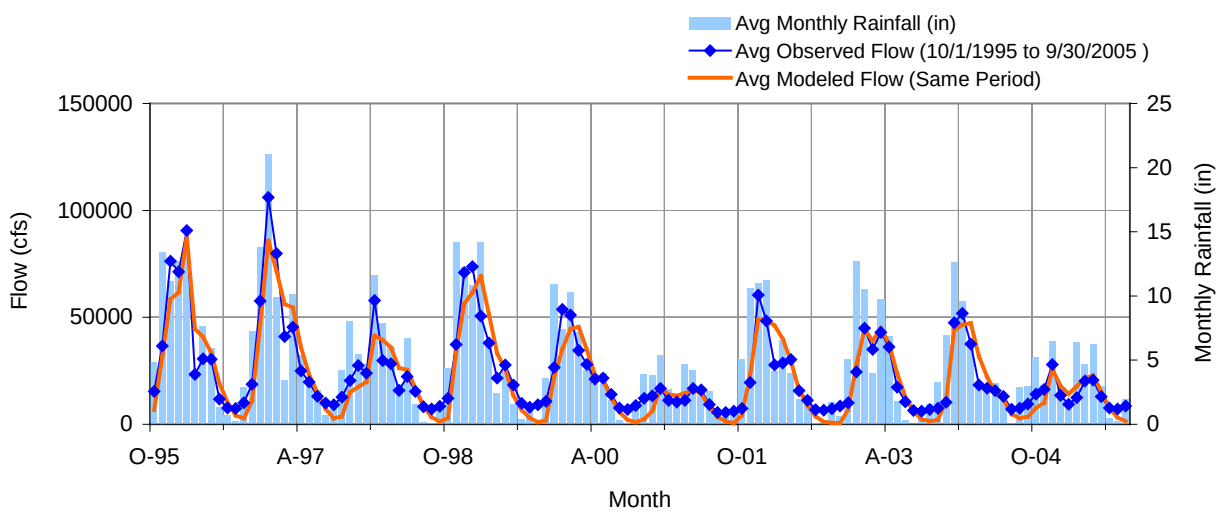

Figure 55. Mean monthly flow at USGS 14191000 Willamette River at Salem, OR – calibration period (SWAT).

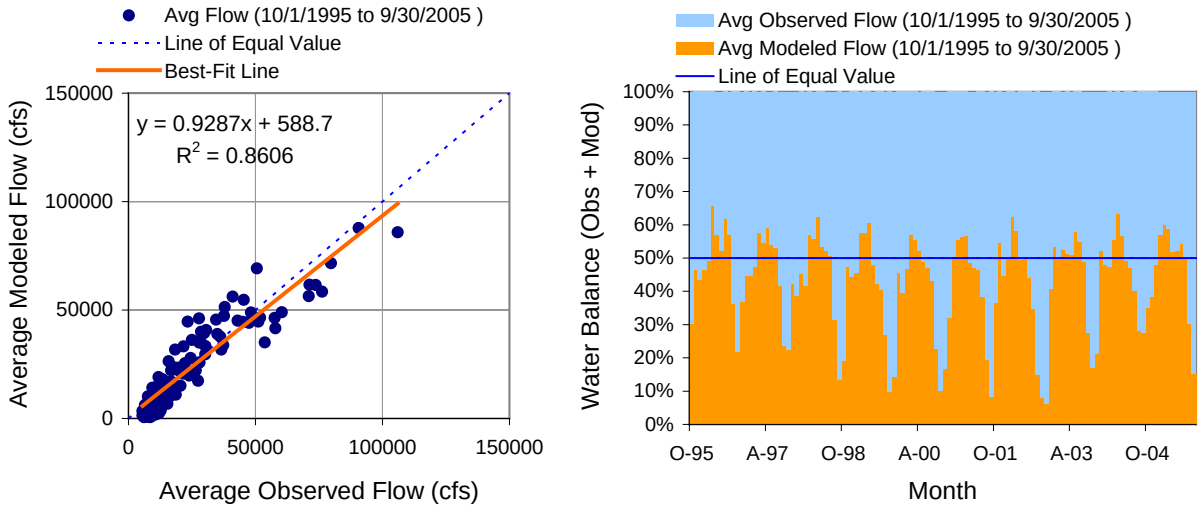

Figure 56. Monthly flow regression and temporal variation at USGS 14191000 Willamette River at Salem, OR – calibration period (SWAT).

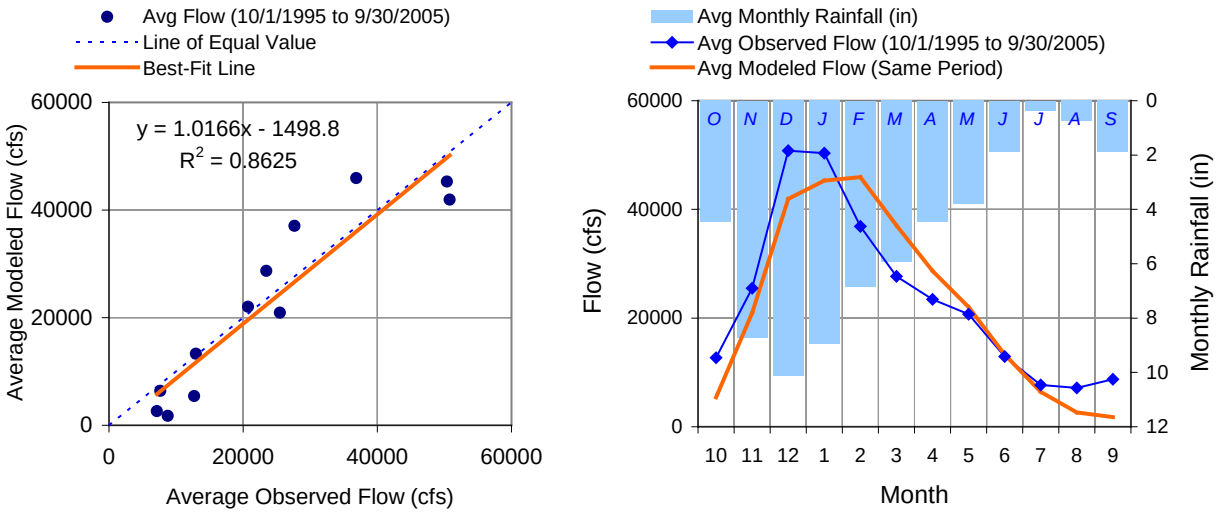

Figure 57. Seasonal regression and temporal aggregate at USGS 14191000 Willamette River at Salem, OR – calibration period (SWAT).

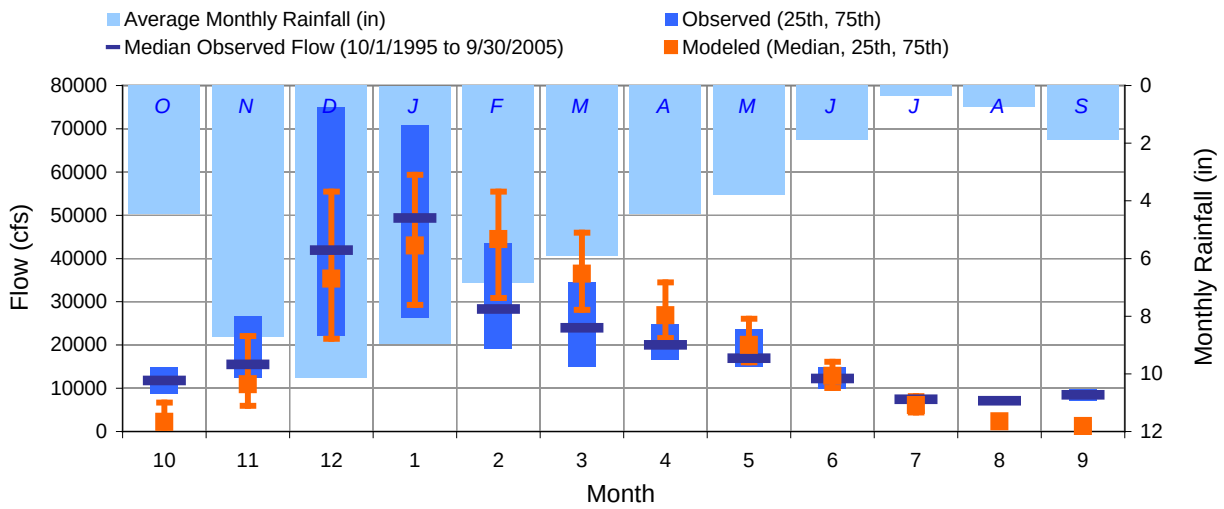

Figure 58. Seasonal medians and ranges at USGS 14191000 Willamette River at Salem, OR – calibration period (SWAT).

Table 26. Seasonal summary at USGS 14191000 Willamette River at Salem, OR – calibration period (SWAT)

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	12717.87	11800.00	8752.50	14875.00	5439.92	2240.19	905.47	6665.64
Nov	25500.23	15500.00	12375.00	26525.00	20933.37	10921.06	5974.36	22100.80
Dec	50807.87	41900.00	22175.00	74950.00	41930.27	35365.87	21415.70	55488.17
Jan	50369.00	49350.00	26325.00	70900.00	45283.04	42977.95	29260.85	59355.13
Feb	36872.79	28300.00	19050.00	43500.00	45938.63	44496.48	30854.42	55461.68
Mar	27664.39	23950.00	14950.00	34500.00	37075.54	36462.39	28114.89	45953.21
Apr	23458.33	20000.00	16600.00	24825.00	28696.06	26883.29	21591.39	34482.12
May	20733.55	16950.00	15100.00	23675.00	22035.69	20011.06	15987.83	26090.48
Jun	12950.87	12250.00	9807.50	14825.00	13294.29	12840.41	10054.09	16113.20
Jul	7675.19	7430.00	6780.00	8227.50	6400.42	6098.84	4428.46	8161.22
Aug	7159.26	7110.00	6602.50	7395.00	2621.14	2353.02	1650.52	3287.97
Sep	8761.37	8450.00	7210.00	9847.50	1757.98	1243.78	715.39	1834.86

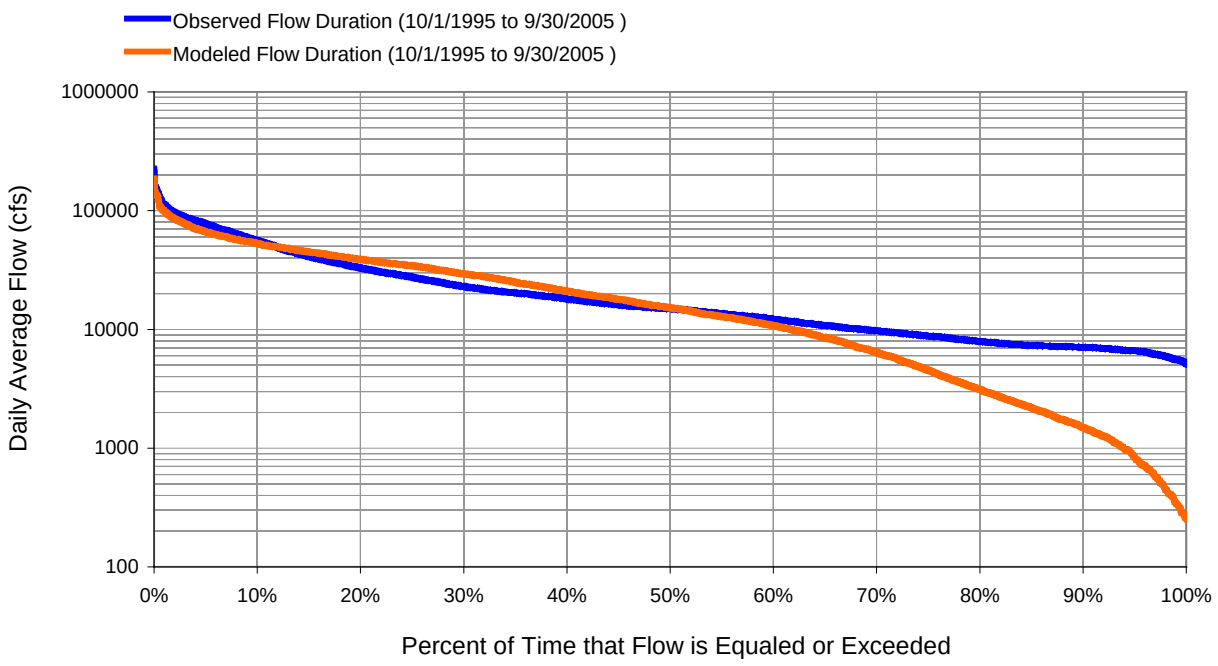

Figure 59. Flow exceedence at USGS 14191000 Willamette River at Salem, OR – calibration period (SWAT).

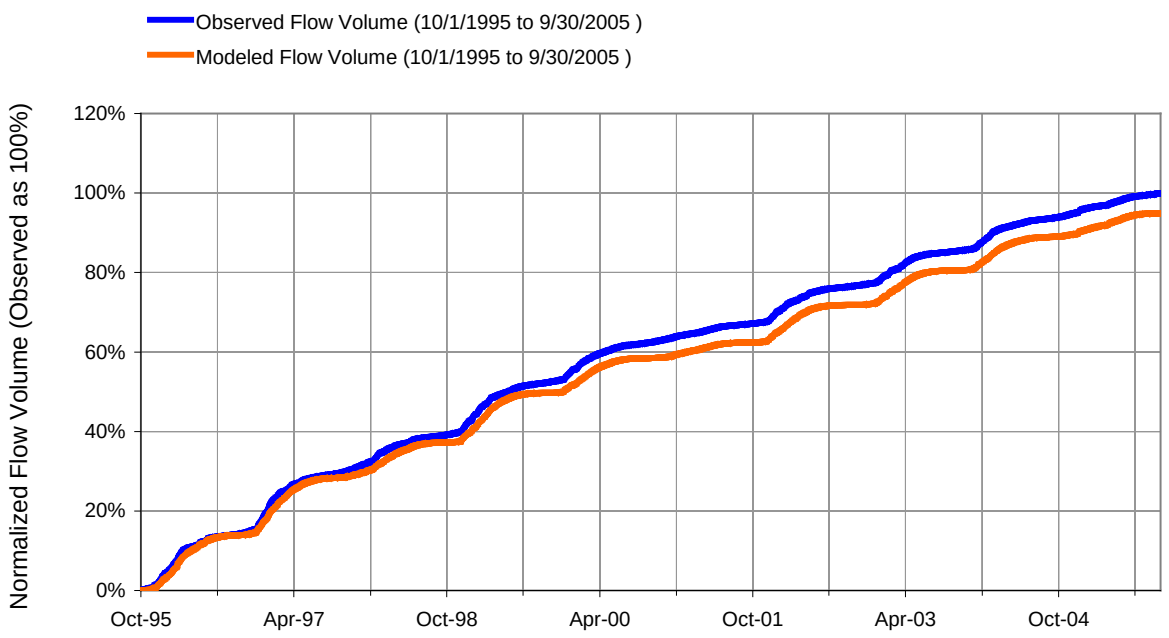

Figure 60. Flow accumulation at USGS 14191000 Willamette River at Salem, OR – calibration period (SWAT).

Table 27. Summary statistics at USGS 14191000 Willamette River at Salem, OR – calibration period (SWAT)

SWAT Simulated Flow		Observed Flow Gage		
REACH OUTFLOW FROM OUTLET 18 10-Year Analysis Period: 10/1/1995 - 9/30/2005 Flow volumes are (inches/year) for upstream drainage area		USGS 14191000 WILLAMETTE RIVER AT SALEM, OR Hydrologic Unit Code: 17090007 Latitude: 44.9442863 Longitude: -123.0428742 Drainage Area (sq-mi): 7280		
Total Simulated In-stream Flow:	**42.01**	Total Observed In-stream Flow:		**44.21**
Total of simulated highest 10% flows:	**13.73**	Total of Observed highest 10% flows:		**15.55**
Total of Simulated lowest 50% flows:	**5.44**	Total of Observed Lowest 50% flows:		**8.79**
Simulated Summer Flow Volume (months 7-9):	**1.70**	Observed Summer Flow Volume (7-9):		**3.69**
Simulated Fall Flow Volume (months 10-12):	**10.71**	Observed Fall Flow Volume (10-12):		**13.97**
Simulated Winter Flow Volume (months 1-3):	**19.68**	Observed Winter Flow Volume (1-3):		**17.69**
Simulated Spring Flow Volume (months 4-6):	**9.92**	Observed Spring Flow Volume (4-6):		**8.86**
Total Simulated Storm Volume:	**10.96**	Total Observed Storm Volume:		**11.48**
Simulated Summer Storm Volume (7-9):	**0.34**	Observed Summer Storm Volume (7-9):		**0.16**
Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*	*Run (n-1)*	*Run (n-2)*
Error in total volume:	-4.96	10	-4.84	
Error in 50% lowest flows:	**-38.08**	**10**	**-37.67**	
Error in 10% highest flows:	-11.71	15	-11.67	
Seasonal volume error - Summer:	**-54.01**	**30**	**-53.28**	
Seasonal volume error - Fall:	-23.33	30	-23.13	
Seasonal volume error - Winter:	11.28	30	11.37	
Seasonal volume error - Spring:	11.98	30	11.82	
Error in storm volumes:	-4.51	20	-3.37	
Error in summer storm volumes:	**109.03**	**50**	**109.39**	
Nash-Sutcliffe Coefficient of Efficiency, E:	0.669	Model accuracy increases	0.670	
Baseline adjusted coefficient (Garrick), E':	0.449	as E or E' approaches 1.0	0.450	

Table 28. Summary statistics (percent error) for all stations – calibration period (SWAT)

Station	14191000 Salem	14207500 West Linn	14202000 Aurora	14194150 McMinnville	14165000 Springfield
Calibration Period:	WY 96-05	WY 96-05	WY 03-05	WY 00-05	WY 99-05
Error in total volume:	-4.96	-4.76	-1.06	-31.37	-18.37
Error in 50% lowest flows:	-38.08	9.00	31.57	-17.54	-34.33
Error in 10% highest flows:	-11.71	-4.03	-14.73	-38.63	-15.69
Seasonal volume error - Summer:	-54.01	0.65	71.04	-9.98	-60.43
Seasonal volume error - Fall:	-23.33	-6.72	3.75	-39.84	0.45
Seasonal volume error - Winter:	11.28	-14.57	-12.99	-35.67	-23.92
Seasonal volume error - Spring:	11.98	35.37	11.82	-0.70	-23.90
Error in storm volumes:	-4.51	71.00	5.57	-35.70	-0.30
Error in summer storm volumes:	109.03	52.22	49.05	5.47	2.75
Nash-Sutcliffe Coefficient of Efficiency, E:	0.669	0.489	0.691	0.448	0.663
Baseline adjusted coefficient (Garrick), E':	0.449	0.505	0.577	0.499	0.595

Table 29. Summary statistics (percent error) for all stations – validation period (SWAT)

Station	14191000 Salem	14207500 West Linn	14202000 Aurora	14194150 McMinnville	14165000 Springfield
Calibration Period:	WY 86-95	WY 86-95	WY 94-97	WY 95-99	WY 88-97
Error in total volume:	-5.67	-12.10	1.56	-30.25	-19.42
Error in 50% lowest flows:	-37.51	24.62	63.52	18.59	-30.89
Error in 10% highest flows:	-7.99	-12.81	-10.57	-39.11	-16.44
Seasonal volume error - Summer:	-51.91	3.12	144.28	64.02	-57.17
Seasonal volume error - Fall:	-24.97	0.74	-11.14	-43.35	10.29
Seasonal volume error - Winter:	12.23	-27.05	-7.96	-32.93	-30.79
Seasonal volume error - Spring:	8.57	20.54	48.39	15.41	-29.57
Error in storm volumes:	-5.50	47.27	9.52	-37.44	2.05
Error in summer storm volumes:	79.12	4.49	180.98	25.45	3.44
Nash-Sutcliffe Coefficient of Efficiency, E:	0.534	0.394	0.699	0.451	0.486
Baseline adjusted coefficient (Garrick), E':	0.361	0.459	0.566	0.488	0.544

Water Quality Calibration

Initial water quality calibration and validation was performed for the Tualatin River at Linn, OR (USGS14207500) using water years 1991-1995 for calibration and water years 1986-1990 for validation. As with hydrology, water quality calibration was performed on the later period as this better reflects the land use included in the model. The start of the validation period is constrained by data availability.

Calibration adjustments for TSS focused on the following parameter:

- RSDCO (Residue decomposition coefficient)

Time series of simulated and estimated TSS loads at the Tualatin River gage for both the calibration and validation periods are shown in Figure 61. Statistics for the two periods are provided separately in Table 30. The key statistic in Table 30 is the relative percent error, which shows the error in the prediction of monthly load normalized to the estimated load. Table 30 also shows the relative average absolute error, which is the average of the relative magnitude of errors in individual monthly load predictions. This number is inflated by outlier months in which the simulated and estimated loads differ by large amounts (which may be as easily due to uncertainty in the estimated load due to limited data as to problems with the model) and the third statistic, the relative median absolute error, is likely more relevant and shows good agreement. Additional diagnostics for TSS included flow-load power plots (Figures 62 and 63), a time series plot of concentrations (Figure 64), and statistics (Table 31).

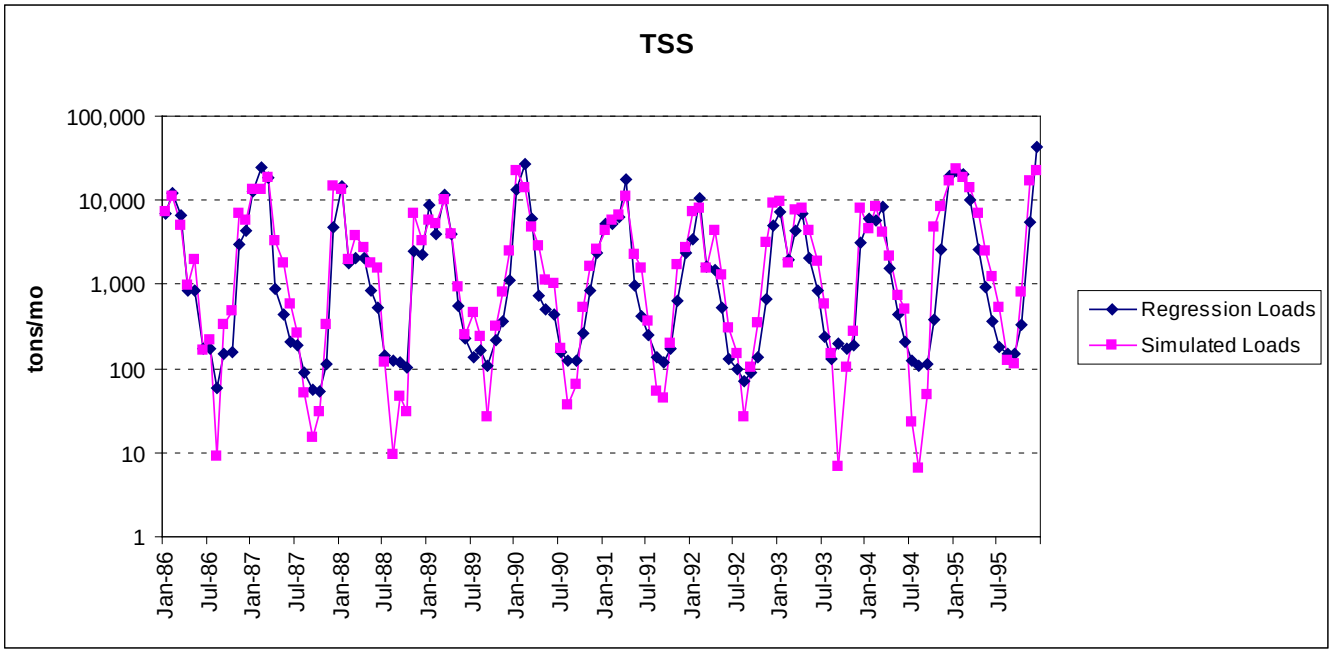

Figure 61. Fit for monthly load of TSS at USGS 14207500 Tualatin River at West Linn, OR (SWAT).

Table 30. Model fit statistics (observed minus predicted) for monthly TSS loads using stratified regression (SWAT)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Relative Percent Error	-12	-7
Relative Average Absolute Error	47	40
Relative Median Absolute Error	17.2	10.5

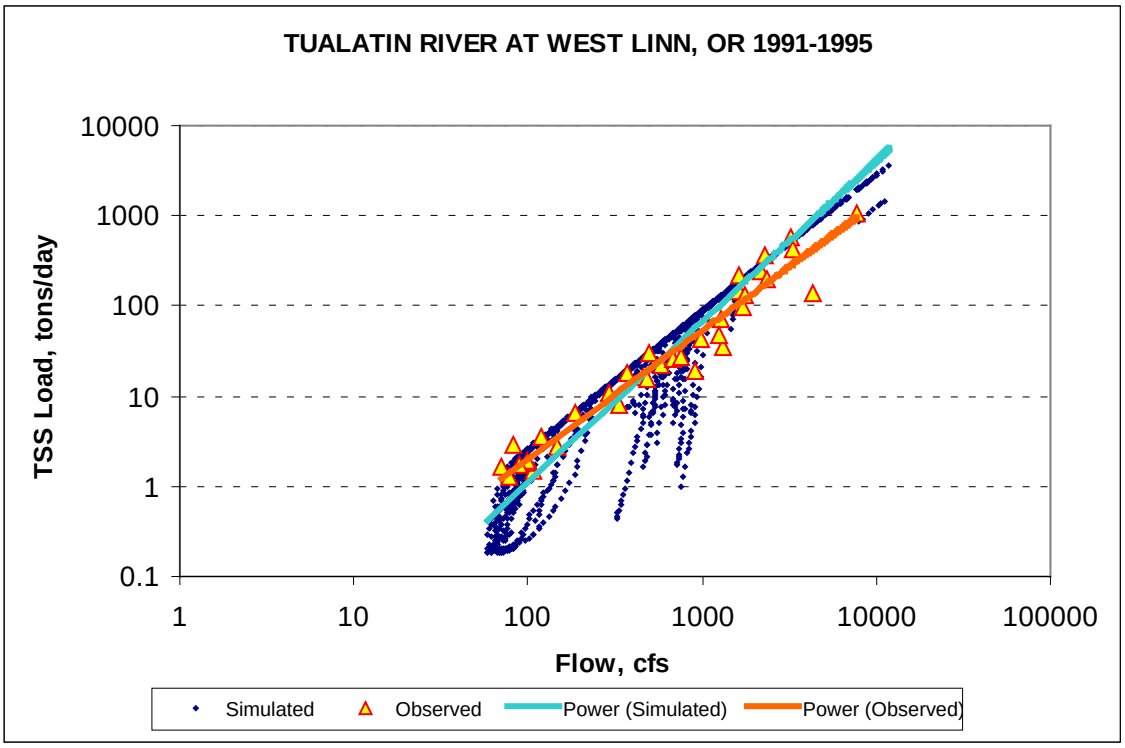

Figure 62. Power plot for observed and simulated TSS at USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT).

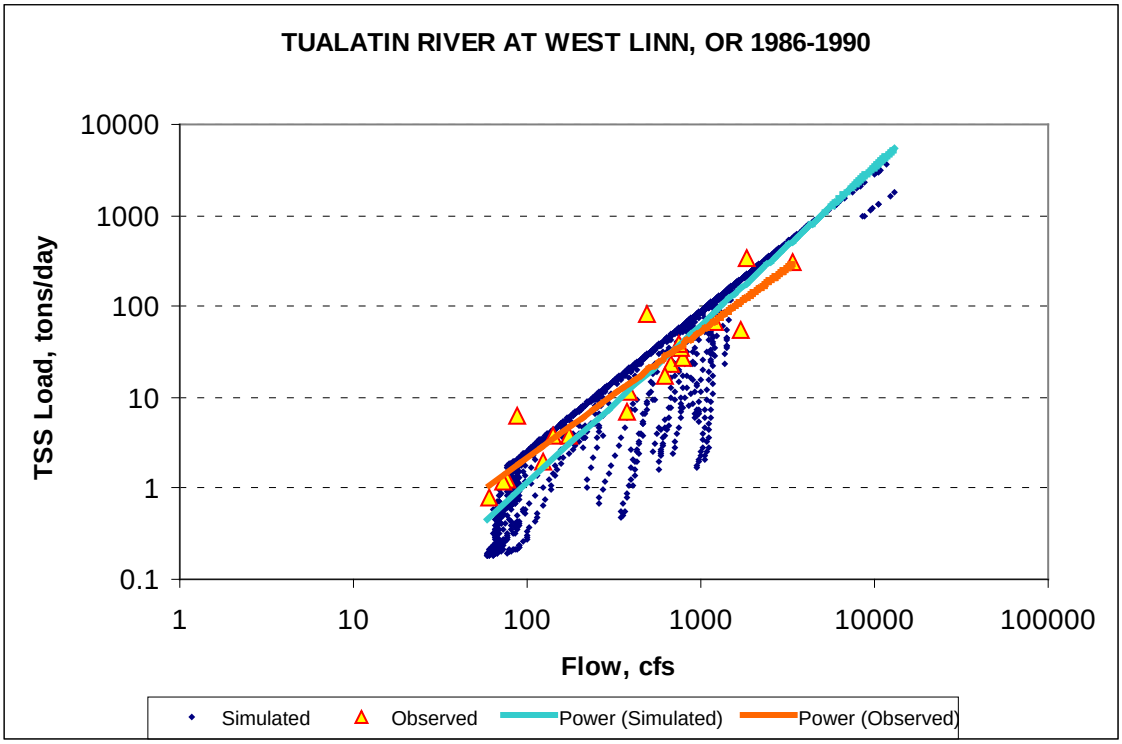

Figure 63. Power plot for observed and simulated TSS at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT).

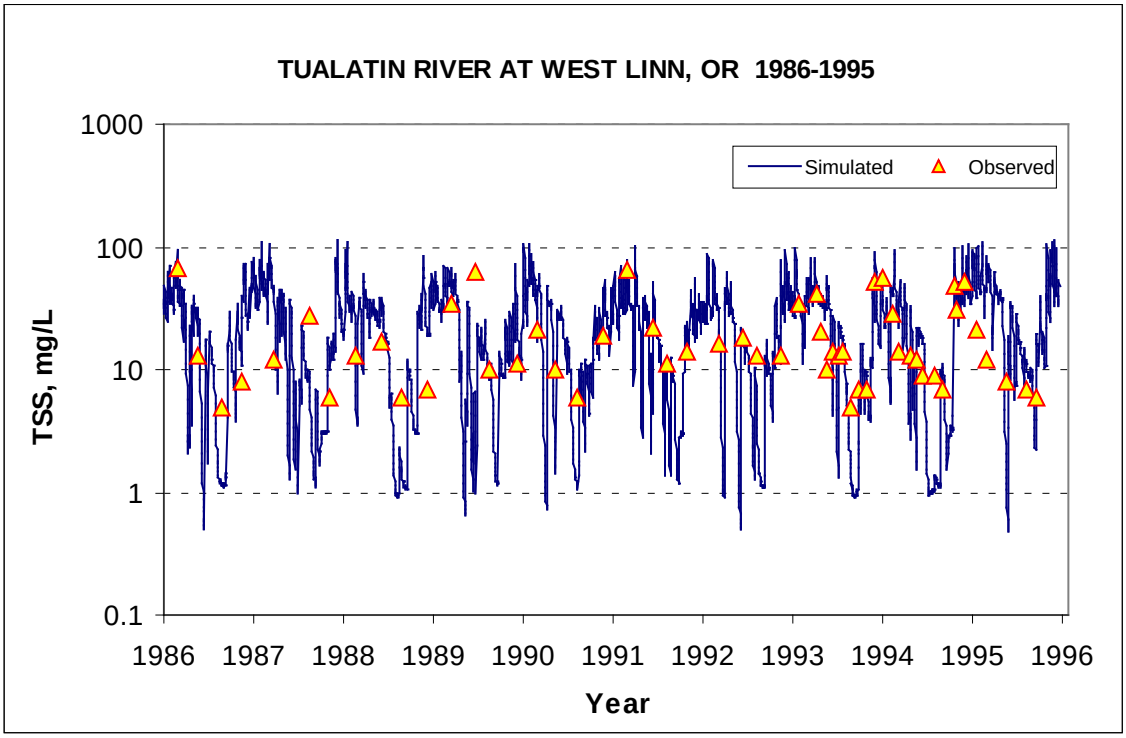

Figure 64. Time series plot of TSS concentration at USGS 14207500 Tualatin River at West Linn, OR (SWAT).

Table 31. Relative errors (observed minus predicted), TSS concentration, at USGS 14207500 Tualatin River at West Linn, OR (SWAT)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Count	35	19
Concentration Average Error	-30.3%	0.06%
Concentration Median Error	10.13%	-22.31%

Calibration adjustments for total phosphorus and total nitrogen focused on the following parameters:

- PPERCO (phosphorus percolation coefficient)
- NPERCO (nitrogen percolation coefficient)
- PHOSKD (phosphorus soil partitioning coefficient)
- HLIFE_NGW (half life of nitrate in the shallow aquifer)
- SOL_CBN1 (organic carbon in the first soil layer)
- QUAL2E parameters such as algal, organic nitrogen, and organic phosphorus settling rate in the reach, benthic source arte for dissolved phosphorus and NH4-N in the reach, fraction of algal biomass that is nitrogen and phosphorus, Michaelis-Menton half-saturation constant for nitrogen and phosphorus

The time series of observed and simulated total phosphorus loads is shown in Figure 65 (monthly loads) and Table 32 (load statistics). As with TSS, additional diagnostics for total phosphorus included flow-load power plots (Figures 66 and 67), a time series plot of concentrations (Figure 68), and statistics (Table 33). In general, total phosphorus for the Willamette River watershed was overestimated by the SWAT model.

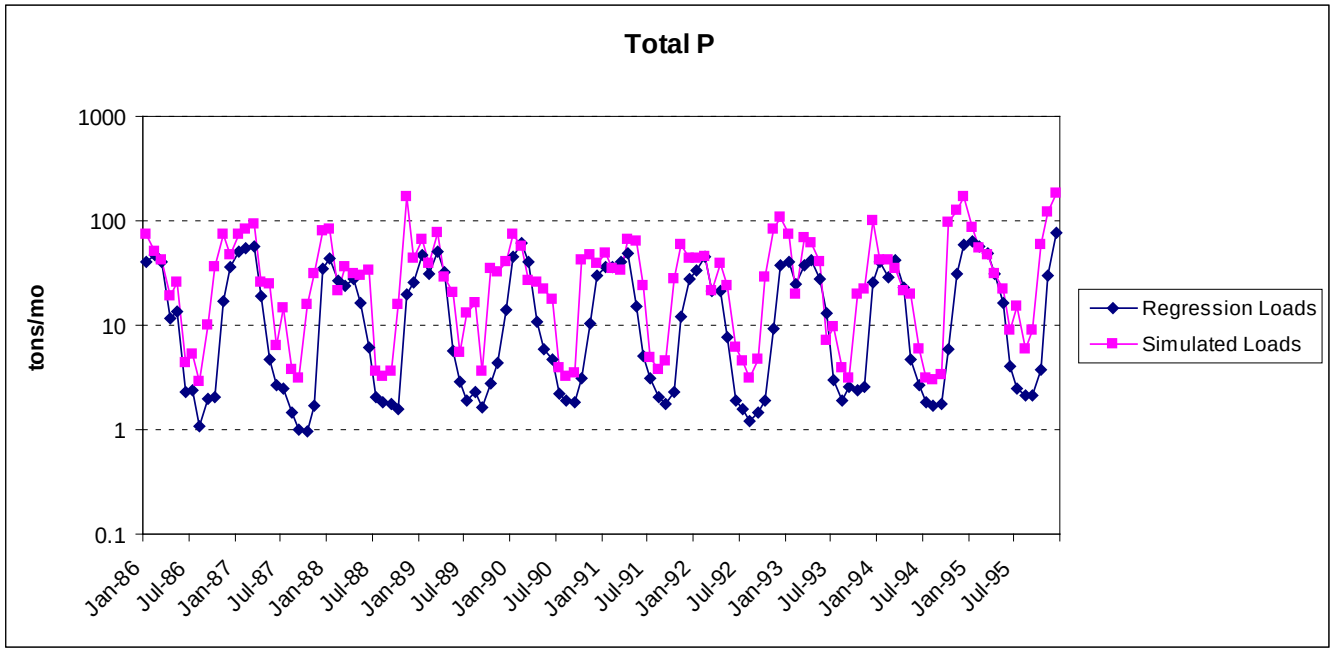

Figure 65. Fit for monthly load of total phosphorus at USGS 14207500 Tualatin River at West Linn, OR (SWAT).

Table 32. Model fit statistics (observed minus predicted) for monthly total phosphorus loads using stratified regression (SWAT)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Relative Percent Error	-114%	-105%
Average Absolute Error	118%	109%
Median Absolute Error	51.7%	79.7%

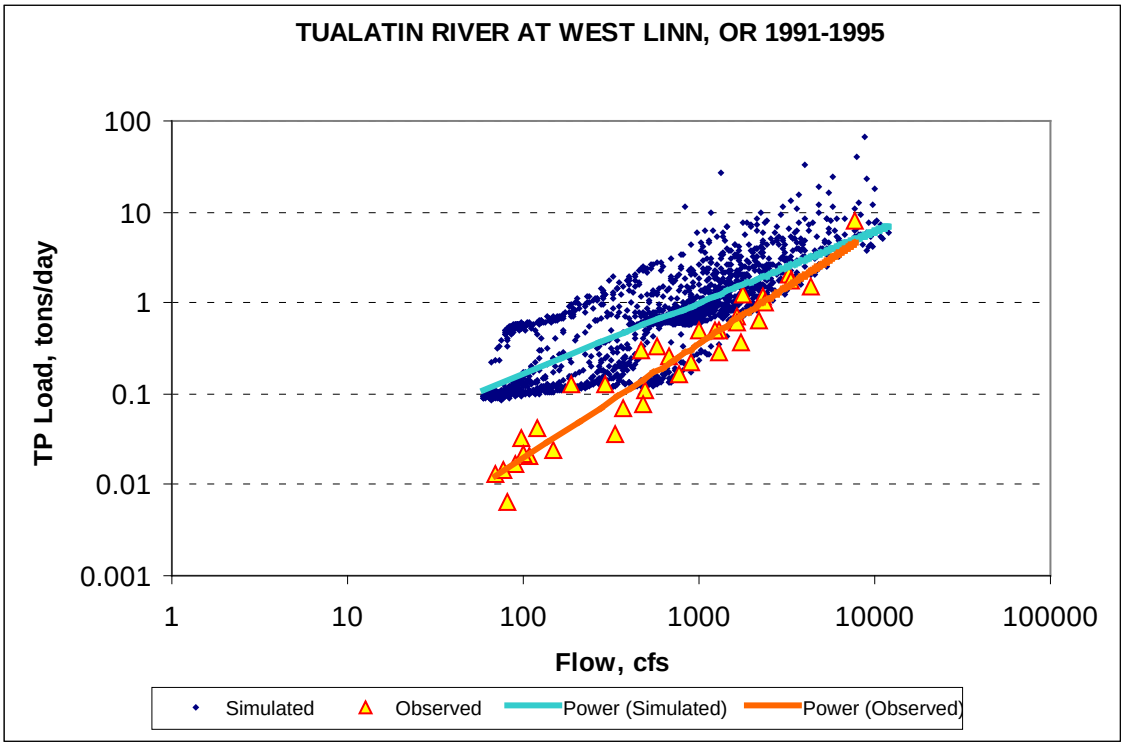

Figure 66. Power plot for observed and simulated total phosphorus at USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT).

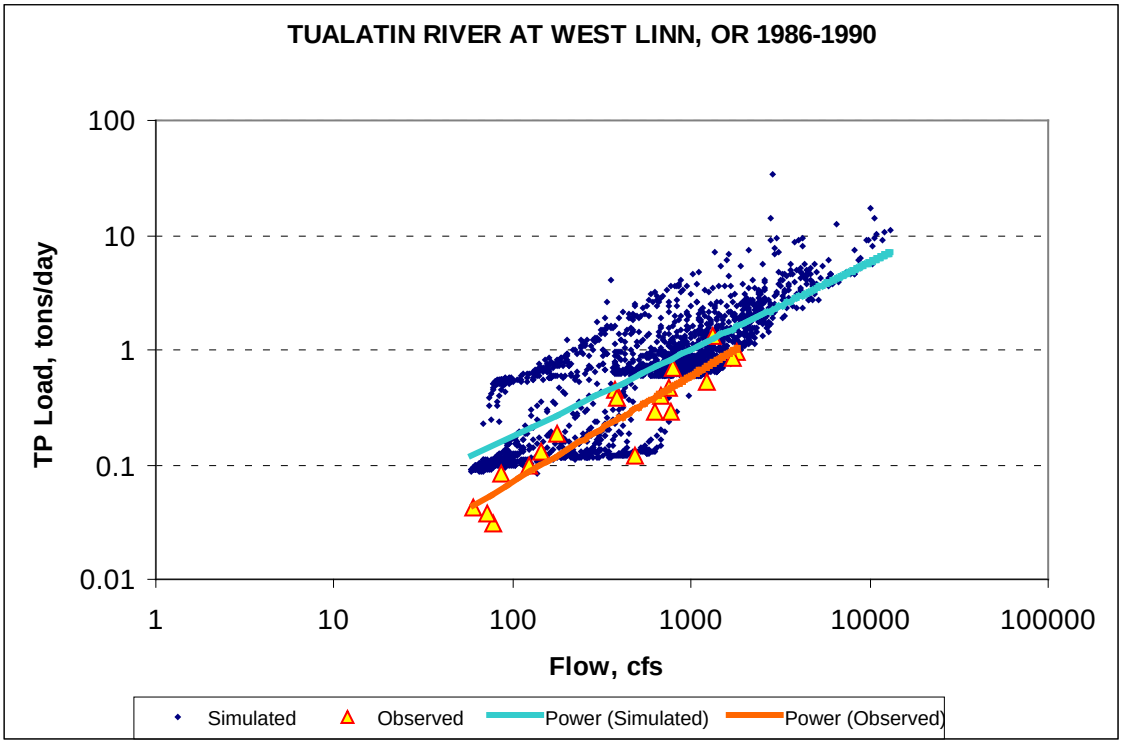

Figure 67. Power plot for observed and simulated total phosphorus at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT).

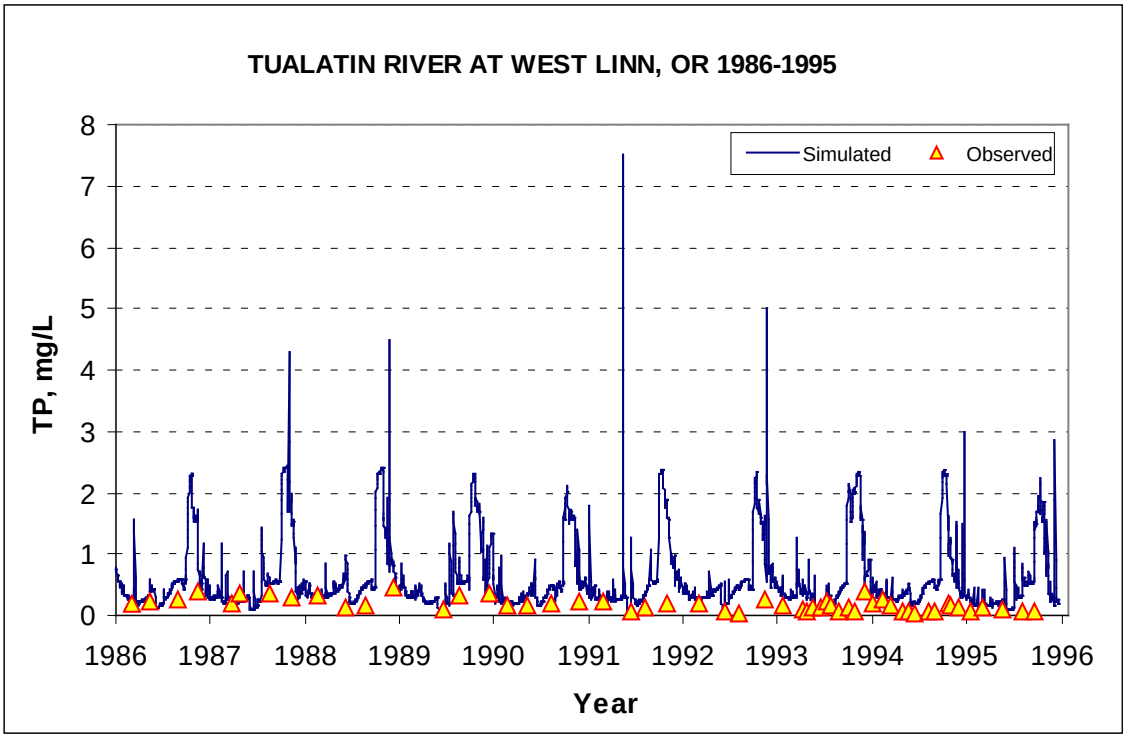

Figure 68. Time series plot of total phosphorus concentration at USGS 14207500 Tualatin River at West Linn, OR (SWAT).

Table 33. Relative errors (observed minus predicted), total phosphorus concentration, at USGS 14207500 Tualatin River at West Linn, OR (SWAT)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Count	35	19
Concentration Average Error	-312.95%	-127.9%
Concentration Median Error	-163.58%	-109.9%

Results for total nitrogen are summarized in Figures 69 through 72 and Tables 34 and 35. Again, total nitrogen loads are overestimated, but are generally better than those for total phosphorus. A summary of the water quality statistics at the two locations (Tualatin River and Pudding River) are shown in Table 36.

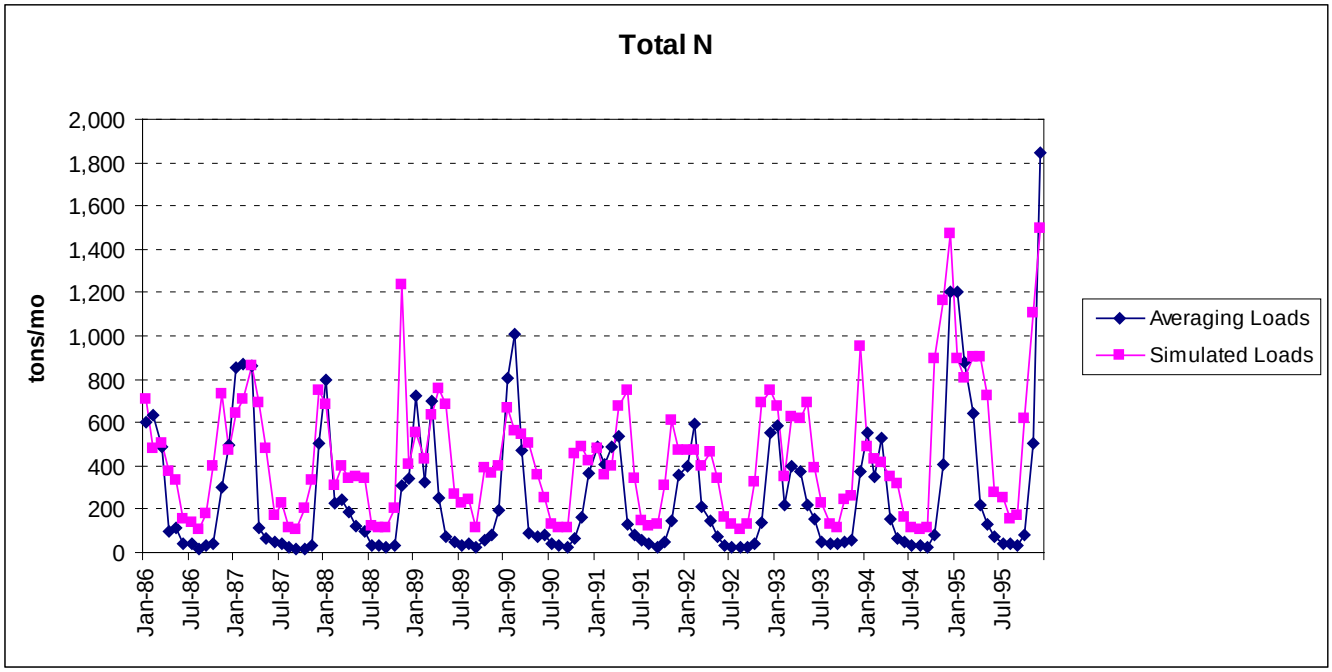

Figure 69. Fit for monthly load of total nitrogen at USGS 14207500 Tualatin River at West Linn, OR (SWAT).

Table 34. Model fit statistics (observed minus predicted) for monthly total nitrogen loads using averaging estimator (SWAT)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Relative Percent Error	-72%	-66%
Average Absolute Error	86%	86%
Median Absolute Error	68.2%	66.3%

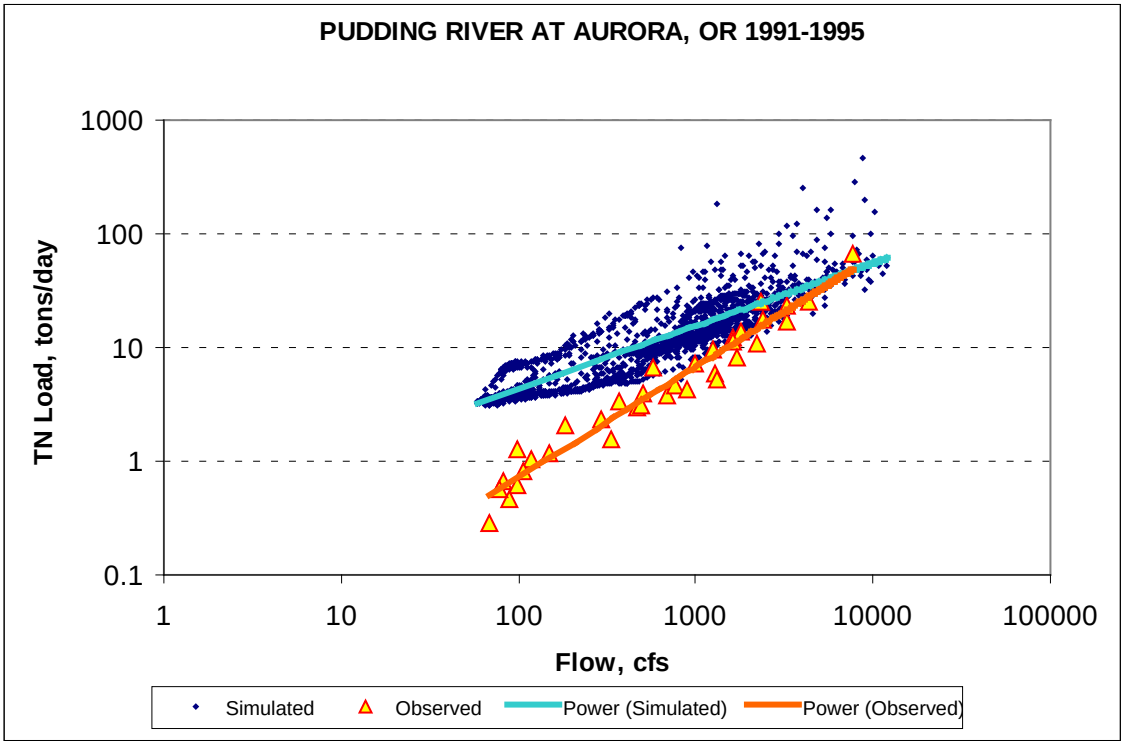

Figure 70. Power plot for observed and simulated total nitrogen at USGS 14207500 Tualatin River at West Linn, OR – calibration period (SWAT).

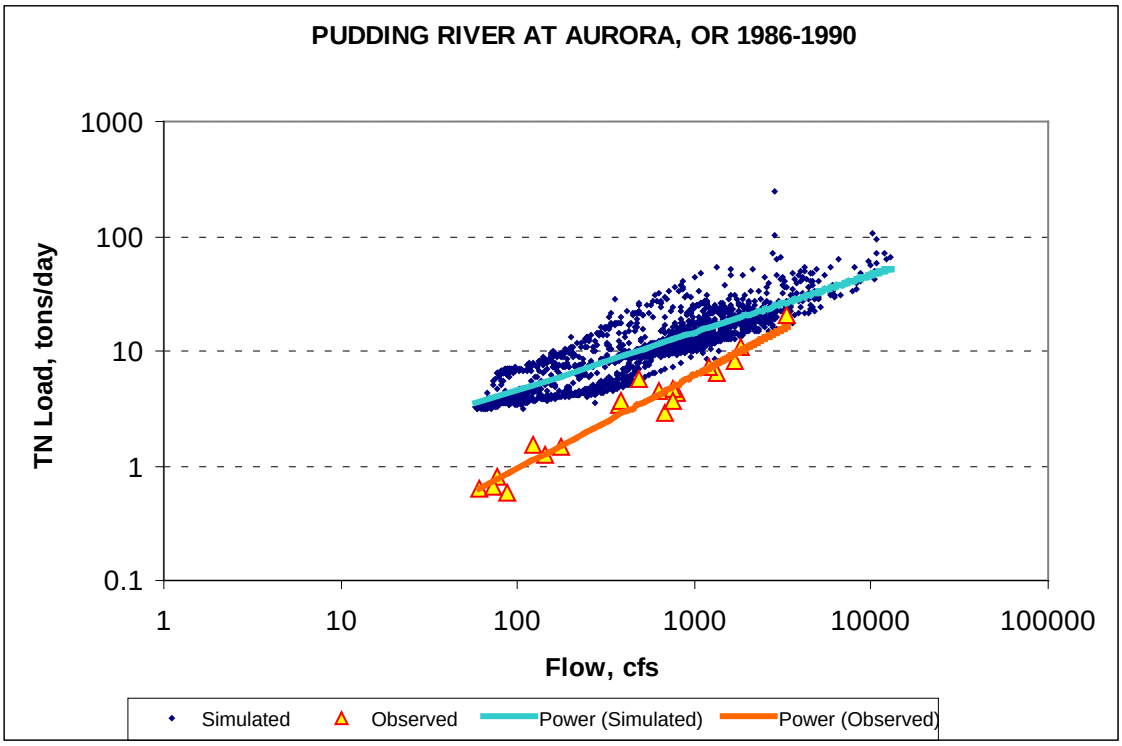

Figure 71. Power plot for observed and simulated total nitrogen at USGS 14207500 Tualatin River at West Linn, OR – validation period (SWAT).

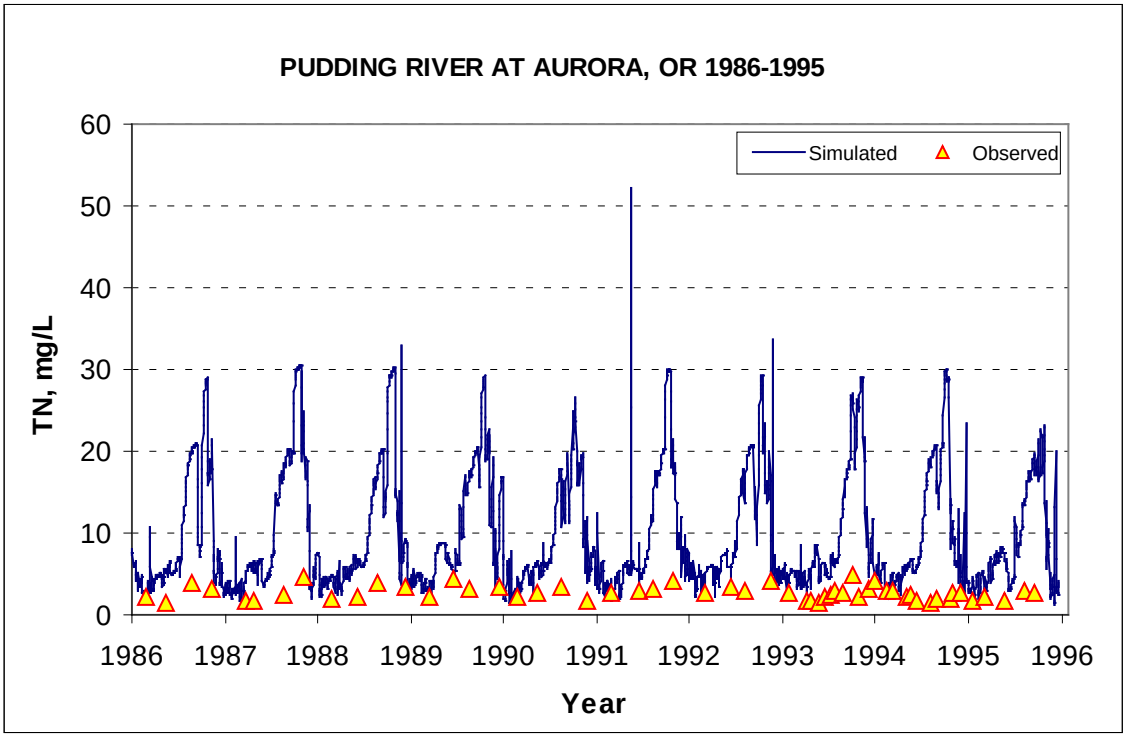

Figure 72. Time series plot of total nitrogen concentration at USGS 14207500 Tualatin River at West Linn, OR (SWAT).

Table 35. Relative errors (observed minus predicted), total nitrogen concentration, at USGS 14207500 Tualatin River at West Linn, OR (SWAT)

Statistic	Calibration period (1991-1995)	Validation period (1986-1990)
Count	35	20
Concentration Average Error	-251.26%	-265.41%
Concentration Median Error	-137.89%	-160.42%

Water Quality Results for Larger Watershed

As with hydrology, the Tualatin River watershed parameters for water quality were directly transferred to other portions of the watershed. This approach resulted in relatively large errors in predicting loads and concentrations at some stations. Summary statistics for the water quality calibration and validation at other stations in the watershed are provided in Table 36.

Table 36. Summary statistics for water quality: all stations (observed minus predicted) (SWAT)

Station	14207500 West Linn Calibration	14207500 West Linn Validation	14202000 Aurora Calibration	14202000 Aurora Validation
Relative Percent Error TSS Load	-12%	-7%	30%	-100%
TSS Concentration Median Percent Error	-10.13%	-22.31%	-13.27%	-43.55%
Relative Percent Error TP Load	-114%	-105%	-30%	-373%
TP Concentration Median Percent Error	-163%	-109.9%	-106.01%	-94.96%
Relative Percent Error TN Load	-72%	-66%	-11%	-218%
TN Concentration Median Percent Error	-137.89%	-160.42%	-42.13%	-165.16%

References

Bicknell, B.R., J.J. Burkey, and R.A. Dusenbury. 2005. Modeling Water Quality in Urban Northwest Watersheds. Presented at ASCE Watershed Management 2005, Williamsburg, VA..

Preston, S.D., V.J. Bierman, Jr., and S.E. Silliman. 1989. An evaluation of methods for the estimation of tributary mass loads. *Water Resources Research*, 25(6): 1379-1389.

Tetra Tech. 1999. Improving Point Source Loadings Data for Reporting National Water QualityIndicators. Final Technical Report prepared for U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC, by Tetra Tech, Inc., Fairfax, VA.

USACE (U.S. Army Corps of Engineers). 1982. National inventory of dams data base in card format, available from National Technical Information Service, Springfield, VA 22162, #ADA 118670

USACE (U.S. Army Corps of Engineers). 2009. http://www.nwp.usace.army.mil/op/v/wvmap.asp

USEPA (United States Environmental Protection Agency). 2008. Using the BASINS Meteorological Database (Version 2006). BASINS Technical Note 10. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

USEPA (United States Environmental Protection Agency). 2006. Sediment Parameter and Calibration Guidance for HSPF. BASINS Technical Note 8. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

USGS (United States Geological Survey). 2001. National Water Quality Assessment (NAWQA) Program: Willamette Basin Study Unit. http://or.water.usgs.gov/projs_dir/pn366/nawqa.html Accessed June 2009.