# FINAL
# Model Report for Lake Whatcom Watershed TMDL Model Project

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Prepared By:


**The Cadmus Group, Inc.**

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CDM

11811 NE 1st Street, Suite 201
Bellevue, Washington 98005



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# Section 1
# Introduction

## 1.1 Watershed Description

The Lake Whatcom watershed is located in Whatcom and Skagit Counties in western Washington State. Most of the watershed is in Whatcom County. This TMDL modeling effort covers the entire watershed contributing to Lake Whatcom, an area covering approximately 49 square miles. **Figure 1-1** shows the physical features of the watershed and the perennial streams within its boundaries.

The watershed rises to approximately 3400 feet (1000 meters) mean sea level in the northeastern portion of the watershed and descends to approximately 300 feet (90 meters) mean sea level in the northwest portion of the lake. Excluding the lake, land use in the watershed is primarily forest comprising approximately 88% of the area, 7% of the watershed is residential, while 3% is shrub and grassland areas. Commercial, industrial, and agricultural uses only comprise 1% of the watershed Several small communities are located within the watershed, and the outlet of Lake Whatcom to Whatcom Creek is located within urbanized areas of the City of Bellingham.

Lake Whatcom is included on the Washington State 303(d) list of waterbodies not attaining water quality criteria for dissolved oxygen (DO). The Lake has natural bathymetric features (glacial sills) that subdivide the lake waterbody into three basins. Monitoring efforts in the 1980s and 1990s found DO depletion rates significantly increased in the hypolimnion for Basins 1 and 2 during the summer months. This has been found in previous studies to be caused, in part, by loading of phosphorous from the watershed tributaries.

## 1.2 Purpose of Preliminary Lake Whatcom Watershed TMDL Modeling Project

The purpose of the Lake Whatcom TMDL modeling project was to develop a numerical hydrologic, hydraulic, and water quality model to support current and future TMDL efforts by the state of Washington Department of Ecology in the Lake Whatcom Watershed. The objectives for the model are to:

- Predict tributary phosphorus concentrations and loads from all of the sub-watersheds of Lake Whatcom,

- Determine monthly average and maximum storm event loads of phosphorus at the mouths of the tributaries along the lake. The model should also have the capability to allow for the determination of loads on a daily basis by estimation or other means,

- Estimate loadings of sediment and nutrients from a variety of point sources (diversions into Anderson Creek) and land use practices, e.g. agriculture practices, forest practices, livestock watering/pasturing, and highway and residential stormwater runoff. The model should also have the capability to incorporate some spatial variations from non-point source best management practice implementation as well as identification of jurisdictional responsibilities,

- Characterize and account for spatial, seasonal, and temporal variability in nutrient pollutant loads, transport, and fate in the watershed and support development of Margins of Safety factors to account for analytical uncertainties and calculation of daily loads, and
- Serve as a readily useable tool by client/stakeholder technical staff to evaluate potential load allocations and wasteload allocation scenarios for use in developing TMDLs and allocations.

## 1.3 Report Overview

This report provides a summary of the Lake Whatcom Watershed TMDL model construction, calibration, model parameter sensitivity, and recommendations for filling data gaps and future model supported management scenarios. It contains the following:

Section 2: TMDL Model Construction – provides details on the selected Hydrological Simulation Program—Fortran (HSPF) model inputs.

Section 3: HSPF Calibration – provides model parameters in the HSPF software, which were modified for the hydrology and water quality calibration. Also includes a summary of the HSPF parameter sensitivity analysis.

Section 4: Model Recommendations and Future Scenarios – provides a discussion regarding data gaps, additional calibration efforts, and future scenarios to address water quality effects of non-point source and point source loadings in the watershed.

Section 5: References – provides a list of references used in the report.

Project deliverables leading up to HSPF model construction are included as appendices to this report. These include:

Appendix A – Data Bibliography for the Lake Whatcom Watershed

Appendix B – Modeling Approach for Lake Whatcom Watershed TMDL Project

Appendix C – Modeling Quality Assurance Plan for Lake Whatcom Watershed

Appendix D – Includes a working copy of the Draft HSPF model for Lake Whatcom Watershed TMDL Project with a complete set of water quality data and current calibrated input parameters.

# Section 2
# Lake Whatcom Watershed TMDL Model Construction

## 2.1 HFAM to HSPF Conversion

The City of Bellingham calibrated HFAM model developed by HydroLogic Services Company was manually converted to an HSPF model for TMDL modeling of the Lake Whatcom Watershed. Many input parameters are common between the two models, but the objectives of the models and the distribution of parameters are different. The HFAM model is a water supply model intended to simulate in detail the snowpack hydrology in the nearby Nooksack Watershed as well as the Lake Whatcom Watershed. As such, the model hydrology is distributed across elevation bands of up to over 10,000 feet. For TMDL modeling in the Lake Whatcom watershed (elevation range 300 to 3,000 feet), the hydrologic parameters are distributed across land use and soil types in the watershed. Snow hydrology is not considered in the HSPF model, as it is a minor element of the Lake Whatcom Watershed hydrology.

The HFAM subwatershed delineation was used to develop the HSPF model, which allows for comparisons across models and future collaborations, as shown in **Figure 2-1**. **Table 2-1** provides a crosswalk for HFAM to HSPF model IDs and shows subwatershed acreages and relative fractions of the Lake Whatcom Watershed.

The HFAM hydraulic representation of the tributary streams to the lake was generated by 'burning in' streams using a Digital Elevation Model (DEM). These reaches consist of trapezoidal channels with side slopes extending outward to represent floodplains. The geometry and slopes of these channels were used with Manning's equation for flow to generate hydraulic function tables in HSPF, which define the relationships between depth, volume, surface area, and outflow (FTABLES, described in detail in Section 2.1.4).

The converted HSPF model runs on an hourly timestep for water years 1998 to 2005 (October 1997 through September 2005), with an eight month antecedent initialization period.

## 2.2 HSPF Model

### 2.2.1 Overview of HSPF Operation

This section describes in general terms the HSPF model developed by CDM as well as general procedures used to model impervious areas, pervious areas, in-stream hydraulic, and water quality.

### 2.2.2 IMPLND Module for Impervious Tributary Area

The IMPLND module of HSPF accounts for surface runoff from impervious land areas (e.g., parking lots, roads,). Overall, a large fraction of rainfall onto impervious surface will be converted to surface runoff. However, a small fraction (typically 5 to 15%) may be lost through ponding in depressions on the impervious surface and subsequent evaporation of the ponded water.

### 2.2.3 PERLND Module for Pervious Tributary Area

The PERLND module of HSPF accounts for surface runoff, interflow and groundwater flow (baseflow) from pervious land areas.

HSPF uses the Stanford Watershed Model methodology as the basis for hydrologic calculations. This methodology calculates soil moisture and flow of water between a number of different storages, including surface storage, interflow storage, upper soil storage zone, a lower soil storage zone, an active groundwater zone, and deep storage. Rain that is not converted to surface runoff or interflow infiltrates into the soil storage zones. The infiltrated water is lost by evapotranspiration, discharged as baseflow, or lost by deep percolation (e.g., deep aquifer recharge).

Several of the key parameters of the PERLND module include the following:

***LZSN (lower zone nominal storage)*** - LZSN is the key parameter in establishing an annual water balance. Increasing the value of LZSN increases the amount of infiltrated water that is lost by evapotranspiration, and therefore decreases the annual streamflow volume.

***LZETP (lower zone evapotranspiration parameter)*** – LZETP affects the amount of potential evapotranspiration that can be satisfied by lower zone storage, and is another key factor in the annual water balance.

***INFILT (infiltration)*** - INFILT can also affect the annual water balance. Increasing the value of INFILT decreases surface runoff and interflow, and increase the flow of water to the lower soil storage and groundwater, and results in greater evapotranspiration.

***UZSN (upper zone nominal storage)*** - Reducing the value of UZSN increases the percentage of flow that is associated with surface runoff as opposed to groundwater flow. This would be appropriate for areas where receiving water inflows are highly responsive to rainfall events. Increasing UZSN can also affect the annual water balance by resulting in greater overall evapotranspiration.

### 2.2.4 RCHRES Module for Stream/Reservoir Routing

The RCHRES module of HSPF is designed to accept and convey flows from the PERLND and IMPLND modules and to route flows based on a rating curve supplied by the modeler (HFAM DEM data as described in Section 2.1). Within each subwatershed of the Lake Whatcom HSPF model, a RCHRES element was developed which defines the stage-area-volume relationship for the modeled water body.

### 2.2.5 PQUAL and IQUAL Modules of Build up and Washoff of Conservative Constituents.

HSPF PERLND elements simulate the fluxes and storages of conservative constituents (Total Phosphorus) in both surface and subsurface flows using the PQUAL module. For this application, simple build up and washoff of Total Phosphorus (TP) is simulated, although HSPF is able to simulate more complex dynamics. Varying monthly concentrations of TP are applied to the baseflow and groundwater of the subwatersheds. For impervious surfaces, build up and washoff occurs via the IQUAL module, which routes the mass of TP washoff directly to the reaches.

## 2.3 HSPF Model Inputs

### 2.3.1 Land Use and Soils

Eighteen land cover classifications (2001 National Land Cover Data) were aggregated to seven land use categories for use in HSPF modeling, shown in **Table 2-2**. Actual study area impervious cover was calculated and area weighted to derive a 21.3% impervious cover value for the single developed land use class used in the model.

Land use distribution per subwatershed is shown in **Table 2-3**. Land use distribution is shown on **Figure 2-2**. The watershed is dominated by the three forest classes shown (88% of study area), with minimal agriculture land use, and 7.5% developed land uses, found primarily in northwest area of Lake Whatcom.

Hydrologic soils groups for the watershed are shown on **Figure 2-3**. Generally there is a gradient from B to C in a northwest to southeast direction, with some A and D soils present on northwest side of lake. Group A soils have high infiltration rates and low runoff potential, even when thoroughly wetted; Group B soils have moderate infiltration rates; Group C soils have low infiltration rates; and Group D soils have very low infiltration rates and very high runoff potential.

### 2.3.2 Rainfall, Evapotranspiration, and Streamflow Data

Three City of Bellingham hourly precipitation gauges were distributed to the HSPF model as shown in **Table 2-4** and on **Figure 2-4**. The HFAM model distributes the rainfall across elevation bands, with hourly measured precipitation depths increasing via lapse rates. The lapse rates were area weighted by elevation band in the HFAM model; in HSPF, a single coefficient, gamma ($\gamma$) is applied to the base hourly rainfall data for each subwatershed, shown in **Table 2-4**.

Hourly calculated potential evapotranspiration data from the Smith Creek station is used for all subwatersheds in the model. During the simulation period, the average annual potential evapotranspiration at the Smith Creek station ranged from 23.8 to 26.1 inches per year.

Four locations with flow data in the watershed coinciding with HFAM calibration locations were chosen for hydrologic calibration, as shown in **Figure 2-4**. Graphical plots of the observed flow data are presented with model simulation results in **Section 3.2**.

### 2.3.3 Observed Water Quality

For the four hydrology calibration stations, monthly Total Phosphorus grab sample data are also available for use in calibration. **Table 2-5** provides summary statistics for these datasets. The Final Model CD (**Appendix D**) includes copies of these datasets. Graphical plots of the observed TP data are presented with model simulation results in **Section 3.3**. It is noted that average TP concentration for the more developed Mill Wheel Creek subwatershed (27% developed) is higher than for the less developed subwatersheds (reference **Table 2-5** to **Figure 2-2**). Maximum concentrations, however, are not higher for the Mill Wheel Creek subwatershed.

### 2.3.4 Anderson Creek / COB Diversion

The Middle Fork Diversion, which augments Lake Whatcom for the City of Bellingham's water supply, is routed to Mirror Lake, which flows into Anderson Creek. **Figure 2-5** shows the time series data of the diversion flows into Mirror Lake provided by HydroLogic Services Company (light blue – bottom graph). **Figure 2-5** also shows TP loads calculated for the Middle Fork Nooksack at the diversion point using a statistical regression model (black – top graph)[1]. Finally, **Figure 2-5** shows two plots that compare TP contribution from the diversion simulated using a statistical regression model (red; center graph) and estimated from arithmetic means (blue; center graph)[2]. The Lake Whatcom HSPF model utilized the latter estimated diversion loads as a model input.

The comparison graph shows that the diversion loads used in the HSPF model are more constant and generally higher than those simulated using the regression model. However, when diversion flows are continuous, the regression model simulates an

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[1] The Statistical Regression Model was developed by Paul Pickett at Washington State Department of Ecology (WDOE) for water years 1999-2003. Using the regression formulas and updated USGS flow data at the Middle Fork Nooksack Diversion, CDM extended model simulation through the 2005 water year.

[2] CDM used the WDOE regression model formulas on the diversion flows into Mirror Lake for the regression simulation.

increasing TP load that exceeds HSPF simulation results. A closer examination of this is provided in an enlarged segment of the simulation period and shown on **Figure 2-5b**. Between mid-May 2002 and the end of July 2002, there is a nearly continuous diversion period. The increasing TP concentration estimated from the regression model during this time is an exponential curve that continues to increase despite a diversion flow drop at the end of June 2002. It is unclear at this point why the regression formulas produce this during continuous and constant discharge, but it may represent diminished TP attenuation of Mirror Lake over long-term and continuous diversion events.

For the HSPF simulation, TP loads associated with the diversion inflow are approximated by applying the average concentration of 0.0259 mg/L from TP data collected by the City of Bellingham at outfall of Mirror Lake during October 17, 2006 to May 1, 2007[3]. This results in simulated TP loads with a trend that parallels the constant rate of the diversion flows. The total average annual TP load estimated by the regression model for the simulation period was 478.2 pounds (lbs), while the HSPF model input an average annual load of 862.7 lbs. The results of the regression model suggest that the value of 0.0259 mg/l may be skewed to the higher side due to a limited dataset. Additional data should be evaluated in subsequent versions of the Lake Whatcom HSPF model to assess whether this average TP concentration applied to the diversion is appropriate or needs to be revised.

Mirror Lake is approximately 6 acres and some attenuation of the end-of-pipe TP load from the actual diversion is expected to occur. Modeling this attenuation in HSPF would require acquisition of lake bathymetry and modeling in stream kinetics, and suitable calibration data is not available for this effort. Therefore the constant TP concentration applied to the diversion flow to generate an approximation of TP mass entering Anderson Creek was found to be suitable for this modeling effort.

CDM compared total TP loading for the Anderson Creek Watershed to those estimated for the Brannian Creek Watershed, a closely matched watershed in terms of geography and land cover. Average annual TP load estimated for Anderson Creek with the diversion contribution is 1,279 lbs. For Brannian, the simulated TP load equals 587 lbs. In theory, if both watersheds were exactly the same, the additional phosphorus load for Anderson would be attributed to the diversion contribution into the watershed. This is shown mathematically as follows:

1,279 lbs (Anderson Crk) – 587 lbs (Brannian) = 692 lbs (Diversion TP input)

This compares closely to the TP load from the diversion as input to the HSPF model, which is 863 lbs, or 11% of the total loading to Lake Whatcom. Because more

[3] This average TP data used for the HSPF input does not coincide with the simulation run time and should be considered approximate until additional diversion flow data is collected simultaneous with observed data and calibrated.

development of input data and investigation of Mirror lake attenuation are necessary, the best estimate from the currently calibrated HSPF model is likely within the range of 9 to 11% of the total simulated loading into Lake Whatcom.

### 2.3.5 Subwatershed and Stream Segment Parameters

Translation of the HFAM model into HSPF provided the initial parameterization of the model. HSPF and HFAM results for stream flow at the four calibration gages compared well initially. **Table 2-6** shows the hydrologic parameters for the initialized model. **Table 2-7** shows the initial water quality parameters set in the model.

# Section 3
# Lake Whatcom Watershed TMDL Model Calibration

## 3.1 HSPF Model Calibration Overview

Calibration involves minimization of deviation between measured field conditions and model output by adjusting parameters of the model. Data required for this step are a set of known input values along with corresponding field observation results. Once the model is calibrated properly, the model predictions should be acceptably close to representative field observations. However, the capability of any model to accurately depict water quality conditions is directly related to the accuracy of input data and the accuracy and completeness of observed data available for comparison. A calibrated watershed model will be a useful planning tool for developing and addressing TMDLs in the Lake Whatcom watershed. The model will be able to assess the impacts of changing land use, develop load allocations to fairly meet TMDL numeric targets, and test the water quality benefits of BMPs.

The Lake Whatcom HSPF watershed model was calibrated based on available existing data as discussed throughout the remainder of this section. For the hydrology calibration, simulated average daily flows were compared to historical average daily flows. Select model parameters were adjusted within expected ranges until the simulation results showed a close match between observed and predicted flows. For the water quality calibration, observed total phosphorus concentrations were compared to simulated results. Select model parameters were adjusted accordingly to achieve an acceptable match between observed and predicted concentrations.

## 3.2 Hydrology Calibration

The purpose of the hydrology calibration is to develop a model that predicts runoff and baseflow similar to historical data in the watershed during a variety of climactic conditions. Hydrologic calibration is essential prior to initiation of water quality loading simulation. The simulation period for calibration with observed hydrology includes the water years of 1998 through 2005 (October 1997 to September 2005). This period includes a variety of climatic conditions, as shown by annual rainfall ranging from 35–40 inches in 2000 to 45-60 inches in 2003 from three nearby meteorological stations, described in more detail in Section 2 of this report.

### 3.2.1 Hydrology Calibration Locations

There are five existing flow gauging stations on Lake Whatcom tributaries. The gauged waterbodies selected for this hydrologic calibration include:

- Anderson Creek
- Austin Creek

- Euclid Creek
- Mill Creek
- Olsen Creek
- Smith Creek

Hydrology for the remaining Lake Whatcom subwatersheds was simulated by applying final parameters from one of the five calibrated subwatersheds with the most similar characteristics as shown in **Table 3-1**. The selection of calibrated parameters to use as surrogates in uncalibrated subwatersheds was based on a review of land use, soil hydrologic group, and geographic proximity.

**Figure 2-4** shows the stream flow gage location for the five streams listed above and also shows other gauging stations within the Lake Whatcom watershed that were not used in the calibration of this HSPF model. The selection of the five gauges to be used in calibration was based on the robustness of the data record and to provide spatial diversity and different predominant land uses in calibration locations. The period of record for each gage is detailed in **Appendix A**.

### 3.2.2 Hydrology Calibration Parameters

Provided below is a discussion of the HSPF model parameters that were modified to improve hydrologic simulation results so that modeled stream flow matched observed stream flow. Changes to parameters were made so that the final values would fall within expected ranges, reported in the *EPA BASINS Technical Note 6; Estimating Hydrology and Hydraulics Parameters for HSPF*. Parameters related to soil characteristics used in the calibration of the Lake Whatcom HSPF model include:

- *Lower Zone Nominal Storage* (LZSN) – the inches of water that can be stored within the lower soil horizon. Greater volumes of available soil moisture storage will result in reduced total runoff volume.

- *Upper Zone Nominal Storage* (UZSN) – the inches of water that can be stored within the upper soil horizon. Greater volumes of available soil moisture storage will result in reduced total runoff volume, and attenuate peak flow rates

- *Mean Soil Infiltration Rate* (INFILT) – the rate of infiltration from the surface into the subsurface. This parameter controls the division of runoff between overland flow and subsurface flow, with higher INFILT values resulting in more subsurface flow and attenuated peaks.

- *Groundwater Recession Rate* (AGWRC) – the ratio of groundwater discharge at the current timestep to 24 hours prior.

- *Groundwater Recession Flow Parameter* (KVARY) – a multiplier used to skew groundwater recession rates based on the antecedent moisture condition

- *Interflow rate* (INTFW) – Coefficient that determines the amount of infiltrated water that becomes interflow or percolates to the lower soil layer. Assigning a greater portion of infiltrated runoff to interflow would result in higher peak flows.

- *Interflow Recession Coefficient* (IRC) – the ratio of interflow at the current timestep to 24 hours prior. This parameters determines the the shape of the falling limb of a storm event hydrograph.

- *Deep Percolation* (DEEPFR) – the fraction of infiltrating water that is lost to deep aquifers. This parameter was not varied by subwatershed and was calibrated so that the total deep aquifer recharge was simulated to be approximately 2 inches per year (Pitz, 2005).

In addition to the parameters that are related to the hydrologic response of pervious land areas, a rainfall multiplier was used as a calibration parameter to account for differences in storm events at varying elevations and at greater distances from individual points of measurement. The initial HFAM parameters and final calibrated HSPF parameters are included in **Table 3-2**[4].

### 3.2.3 Hydrology Calibration Results

In order to assess the hydrology calibration efforts, calculations were completed for each calibration location. These calculations included basic statistics and several different error measures, including relative error (RE), root mean square error (RMSE), and two measures of fit (Nash, 1970; McMahon, 1994), referred to as NS and MH, respectively. The following equations show how the different error measures use the simulated (x) and observed (c) daily flow values, and the average values (x bar and c bar) to assess the accuracy of the calibration for (n) observations:

$$RE = \frac{\sum (x - c)}{n}$$

$$RMSE = \sqrt{\frac{\sum (x - c)^2}{n}}$$

$$NS = 1 - \left( \frac{\sum (x - c)^2}{\sum (c - \bar{c})^2} \right)$$

[4] Several parameters that were global in the HFAM model were used for sub-watershed specific calibration

$$MH = 1 - \left( \frac{\sum \left( \sqrt{x} - \sqrt{c} \right)^2}{\sum (\sqrt{c} - \sqrt{\bar{c}})^2} \right)$$

**Table 3-3** present summary statistics from each calibrated subwatershed including mean daily flow, maximum daily flow, and distribution of runoff volume by season and weather condition, and error measures including RE, RMSE, NS, and MH to portray the accuracy of the hydrologic calibration.

Results of the simulated and observed flow for each of the calibration subwatersheds are presented in the form of time series plots, correlations, and cumulative runoff curves. **Figure 3-1** shows cumulative flow volume curves of simulated and observed flow. This portrayal of the calibration results shows that model adequately estimates long-term flow volumes in each subwatershed, given multiple years with varying climactic conditions. **Figure 3-2** includes annual time series plots of simulated and observed daily flow for each year between 1999 and 2005. The final calibration showed a good correlation between average daily observed flow and average daily calibrated flow (top graph in each figure). **Figure 3-3** shows scatter plots of the calibrated flow versus the observed flow data. The $R^2$ ranges from 0.73 to 0.88, indicating that the model produces good predictions of high flow and low flow periods.

# 3.3 Water Quality Calibration

## 3.3.1 Water Quality Calibration Parameters

Several parameters were used to modify the simulation of TP in five Lake Whatcom subwatersheds. The Lake Whatcom HSPF watershed model utilized a generalized water quality approach, in the form of a pollutant "buildup" and "washoff" model. Parameters that were modified to improve the match of simulated and measured TP concentration during low flow conditions were the assumed groundwater and interflow soil water concentrations. Monthly soil water values were modified to show seasonal trends in low flow TP.

During wet weather, pollutant buildup and washoff parameters were modified so that increased TP would be close to values measured during wet weather. Parameters included the accumulation rate, maximum pollutant buildup, and initial TP accumulation. For this analysis, it was assumed that 90% of accumulated pollutant would be washed off the land surface following the first ½ inch of rain in a given event. This pollutant washoff assumption has been used in many water quality modeling applications (Kuo et al, 1988).

Butcher (2003) developed a relationship between observed EMCs and pollutant accumulation and washoff rates, and the limit of maximum pollutant buildup. Initial estimates for pollutant accumulation and limit of maximum buildup were developed from land cover specific event mean concentrations extracted from previous studies (Smullen et al, 1999; Harper, H. H., 1998). For impervious surfaces in the developed land cover type, a different approach was used to estimate pollutant buildup parameters. Several studies have used street sweeping to estimate the mass of sediment that will accumulate on impervious surfaces (Pitt and Amy, 1973; APWA, 1969). These studies as well as more recent guidance provided by the US EPA for HSPF model development (http://www.epa.gov/waterscience/ftp/basins/training/b4lec11.pdf) also provide particulates analysis, including measurements of TP per unit mass of accumulated sediment. These potency estimates were applied to the per acre sediment buildup findings to develop initial parameter estimates for TP accumulation rate and limit of maximum buildup on impervious surfaces.

Initial pollutant accumulation rate and limit of maximum buildup parameters were modified in the water quality calibration to improve the goodness of fit with available observed water quality concentrations.

### 3.3.2 Water Quality Calibration Results

**Figure 3-4** show time series plots of simulated water quality with observed values overlaid as individual observations for TP. Generally, the simulated TP concentrations match well with observed values. However, there was an under prediction of total phosphorus concentrations during 2002. Observed TP concentrations during this period were much higher than values after 2002 in the water quality monitoring dataset.

To compare the results of the water quality calibration for different hydrologic conditions, a sliding interval baseflow separation data analysis tool was employed. **Figure 3-5** shows an example of this baseflow separation. **Figure 3-6** shows the TP simulation results for all days in the simulation period compared to observed values in box and whisker plots.

In order to evaluate TP loads from the watershed into Lake Whatcom, the contribution from uncalibrated subwatersheds was evaluated. The dominant land use, soil hydrologic group, size, and geographic location for each of the uncalibrated subwatersheds were compared to the ten calibrated subwatersheds. Likeness ratings were developed based on the two most dominant land cover types and hydrologic soil groups, overall size of the watershed, and its location with respect to calibrated subwatersheds. These ratings are shown in **Table 3-1**. Based on this comparison, parameters from the most similar calibrated subwatersheds were used in the uncalibrated subwatersheds to simulate both hydrology and TP loading to Lake Whatcom (**Figure 3-7)**.

In the Lake Whatcom watershed area, TP loads are driven predominantly by non-point source areas. The Lake Whatcom HSPF TP loading simulation results were extracted for each land cover type to assess the sources of TP from the watershed area to the lake (**Figure 3-8**). The simulated TP loading for each land cover type, when normalized for area and time, fell within ranges of measured TP export coefficients (lbs/acre/day) from numerous studies throughout the world, including some in the Pacific Northwest region (Reckhow et al, 1980; Rast and Lee, 1978). The simulation showed that the greatest load is generated from the landscaped or pervious areas in the developed, primarily residential, land cover classification. This loading is greater than from forested land cover types even though forested lands account for a disproportionately larger land area in most of the Lake Whatcom subwatersheds. Previous field studies of pollutant transport in developed watersheds have also shown that landscaped areas contributed more TP loads than impervious surfaces during storm events, and can account for close to the entire load from developed lands following the first 0.25 inches of rainfall (Pitt, 1994).

Average annual simulated TP loads from each inflow to Lake Whatcom and for each individual subwatershed are shown in **Figure 3-8**. The lake inflow with the largest TP load is Anderson Creek, in which the Middle Fork diversion is responsible for an estimated two-thirds of the load from Anderson Creek and 11% of the total TP load to Lake Whatcom. Other inflows with relatively high TP loads to the lake include Olsen Creek, Silver Beach Creek, Austin Creek, and the several lakeside subwatersheds in the northwestern side of the lake. These subwatersheds have a higher percentage of developed land and are larger, thus discharging a greater runoff volume to the lake.

## 3.4 Calibration Summary

Accurate input data and field measurements are important to model calibration. There is uncertainty in both of these items and it is not possible to achieve a close match at all locations at all times. Of the 22 subwatersheds included in the Lake Whatcom HSPF model, only 10 were calibrated to approximate reality using measured hydrologic and water quality data. The remaining subwatersheds were parameterized by comparing subwatersheds with similar characteristics.

In the Lake Whatcom watershed area, rainfall estimates vary widely over a small geographic area. Also, subwatersheds are very distinct, with different topography, soil characteristics, and land use patterns. These diverse watershed characteristics were investigated to develop reasonable ranges for parameter values during calibration. Initial estimates that were used are those included in the HFAM model, developed by the City of Bellingham. The Lake Whatcom HSPF model improved the goodness of fit of simulated flow from the initial HFAM simulation results (**Figure 3-9**) and provided water quality loading results that fall within expected ranges.

**Figures 3-10a, b, and c** show time series plots of HSPF simulated TP results (Green) and observed TP data (Red Points) for Austin, Euclid, Mill, Olsen, and Smith Creeks. This is plotted with WDOE's regression model TP simulation (Black) and high/low confidence bands (Blue Band) for the same creeks during the 2002 to 2003 tributary statistical loading study. These figures indicate:

- HSPF modeled TP simulations are slightly less, but within general agreement to WDOE's tributary statistical loading and confidence bands for 2002-2003.

- HSPF simulated TP concentrations, which tend to increase sharply during storm events, are more variable, with highs and lows ranging a full order of magnitude (0.01 – 0.1) greater, than those simulated in the regression model.

The current Lake Whatcom HSPF watershed model should be considered a work in progress; however the model is adequately set up to evaluate potential scenarios within the watershed. Further data collection efforts, refinement of calibration in the Smith, Mill, Olsen, Anderson, Euclid and Austin Creek subwatersheds, and incorporation of calibration data for other Lake Whatcom tributaries that were not calibrated in this study is needed in the near future. These subwatersheds are included in the model, but are given parameters from calibrated subwatersheds with similar land use, soil hydrology, and geographic location.

## 3.5 HSPF Parameter Sensitivity Summary

The impact of changes to different parameters upon the accuracy of the calibration can be determined by performing a model sensitivity analysis. There are many different approaches to conducting a sensitivity analysis of wide ranging complexity. For the Lake Whatcom HSPF watershed model, a qualitative sensitivity analysis was performed by evaluating changes in mean daily flow, maximum daily flow, and goodness of fit measures to different parameter sets.

The sensitivity analysis showed that the most sensitive parameters were those that controlled the total volume of flow. The precipitation weighting factor was one of the most sensitive parameters within the model. This parameter was not modified significantly from initial estimates, determined by a spatial averaging of three rainfall gauges, considering different rainfall conditions due to topography. Other parameters that impacted the total volume of flow, are those related to storage of water in pervious land segments. These parameters included the storage capacity of the lower (LZSN) and upper (UZSN) soil layers.

Hydrograph shape, and to some extent, event runoff volume was very sensitive to changes in other parameters used to simulate hydrologic processes in the pervious land segment. These parameters included the means infiltration rate (INFILT), interflow rate (INTFW) and interflow recession coefficient (IRC). These parameters control the movement of flow between three potential pathways; overland flow, subsurface stormflow (interflow), or lower zone groundwater outflow.

When the infiltration rate or interflow rate is decreased, less runoff is infiltrated into the subsurface, and more flow is conveyed as overland flow, thus increasing event peaks and the flashiness of the hydrograph. The interflow recession coefficient impacts only the shape of the falling limb of the hydrograph. A higher value will result in a more attenuated recession.

Simulation results were less sensitive to changes in other soil hydrology parameters that were included in the calibration set, such as the fraction of groundwater lost to deep percolation (DEEPFR), groundwater recession rate (AGWRC), and groundwater recession coefficient (KVARY). These parameters, when modified within expected ranges, had a relatively smaller impact upon simulation results. Since these parameters play a role in the simulated baseflow rate, they were more sensitive to the McMahon 1994 goodness-of-fit evaluation criteria.

It was found that relatively small changes in the pollutant accumulation rate (ACQOP) or maximum pollutant buildup capacity (SQOLIM) had a significant impact upon simulated in-stream TP concentration. The initial mass of pollutant (SQO) did not impact the simulation result due to a sufficient period of start up time incorporated into the calibration.

# Section 4
# Lake Whatcom TMDL Model Recommendations and Future Scenarios

This section discusses data gaps in the model and provides recommendations for collecting information to refine the HSPF model for future TMDL management scenarios.

## 4.1 Data Gaps/Model Refinements

A preliminary model for determining the loading and delivery of phosphorus from tributaries to Lake Whatcom was developed and calibrated. By addressing the following data gaps, the client/stakeholder group will be able to further improve the functionality of the TMDL model. Data gaps and potential model refinements include:

- Additional hydrology and water quality calibration for subwatersheds where observed data is available for the simulation period;
- Phosphorous loading from the diversion to Anderson Creek was incorporated into the model by averaging TP measurements from 2006 and assuming this average concentration for the Anderson Creek subwatershed simulation period of 2000 through 2005. The model could be updated through 2006 to utilize actual TP monitoring data for the diversion inflow load time series;
- Inclusion of additional rainfall data from gages in the hillsides west of Lake Whatcom could potentially be used to refine rainfall inputs.
- Future land use coverages can be prepared using local Land Use Plans or zoning maps to apply the model to estimate the impacts potential future urbanization in the watershed.

## 4.2 Model Maintenance

The following model maintenance and updates are recommended:

- Keep model current by extending the period of simulation with updated input climate and diversion data;
- Increase water quality monitoring frequency in areas where potential for high TP concentrations is predicted and update model calibration with new data;
- Apply the model to test alternatives for effective TMDL development and for evaluation of BMP implementation scenarios;
- Develop linkages with the Lake Whatcom lake model to assess watershed impact on in lake water quality.

## 4.3 Future Scenarios

The Lake Whatcom HSPF watershed model may be used to assess future land use or diversion scenarios to estimate TP loading and the spatial distribution of source areas. Three scenarios to evaluate may include:

- Changing land use and impacts of urbanization on watershed hydrology and water quality
- Improvements in watershed runoff resulting from implementation of various BMP and other management measures
- Impacts of the timing and volume of varying Middle Fork diversion discharges to Anderson Creek drainage area

# Section 5
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# Distribution

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# Tables

## Table 2-1
### HFAM and HSPF Subwatershed Key

| HFAM ID | HSPF ID | Name | Subbasin Total Acres | Subbasin % Study Area |
|---|---|---|---|---|
| 3000 | 1 | Mirror Lake | 133 | 0.4% |
| 3005 | 5 | Anderson Creek Gage | 2,579 | 8.3% |
| 3006 | 6 | Northeast Lake Whatcom Inflow | 663 | 2.1% |
| 3010 | 10 | Northeast Lake Whatcom Inflow | 3,241 | 10.4% |
| 3015 | 15 | Smith Creek Gage | 3,262 | 10.5% |
| 3018 | 18 | Smith Creek Outlet | 40 | 0.1% |
| 3020 | 20 | Olsen Creek Gage | 2,448 | 7.9% |
| 3025 | 25 | Carpenter Creek Gage | 766 | 2.5% |
| 3030 | 30 | North Lake Whatcom Inflow | 1,156 | 3.7% |
| 3035 | 35 | Silver Beach Creek Gage | 712 | 2.3% |
| 3040 | 40 | North West Lake Whatcom Inflow | 3,717 | 11.9% |
| 3045 | 45 | Brannian Creek Gage | 2,297 | 7.4% |
| 3050 | 50 | Brannian Creek Outlet | 70 | 0.2% |
| 3055 | 55 | South Lake Whatcom Inflow | 2,307 | 7.4% |
| 3060 | 60 | Upper Austin Creek | 1,759 | 5.6% |
| 3065 | 65 | Beaver Cr trib Austin Cr | 3,036 | 9.7% |
| 3070 | 70 | Austin Creek at Gage | 118 | 0.4% |
| 3072 | 72 | Austin Creek Outlet | 433 | 1.4% |
| 3075 | 75 | Southwest2 Lake Whatcom Inflow | 950 | 3.0% |
| 3080 | 80 | Southwest Lake Whatcom Inflow | 582 | 1.9% |
| 3085 | 85 | Euclid Creek Gauge | 340 | 1.1% |
| 3090 | 90 | Mill Wheel Cr Gage | 574 | 1.8% |
| | | **Total** | **31,184** | **100.0%** |

## Table 2-2
### Lake Whatcom Land Cover and HSPF Aggregated Land Use

| 2001 Utah State University update of 1992 NLCD Land Cover | Acres | % of Study Area | Imperv. Acres | % Imperv. | Aggregate to HSPF Land Use Category |
|---|---|---|---|---|---|
| Open Water | 149 | 0.5% | | | Water/Wetlands |
| Low Intensity Residential | 2,086 | 7% | 428 | 20.5% | Developed |
| High Intensity Residential | 59 | 0.2% | 24 | 41.2% | Developed |
| Commercial/Industrial/Transportation | 206 | 0.7% | 48 | 23.3% | Developed |
| Bare Rock/Sand/Clay | 34 | 0.1% | | | Open |
| Quarries/Strip Mines/Gravel Pits | 2 | 0.005% | | | Open |
| Transitional | 577 | 1.9% | | | Open |
| Deciduous Forest | 6,264 | 20% | | | Deciduous Forest |
| Evergreen Forest | 10,843 | 35% | | | Evergreen Forest |
| Mixed Forest | 10,288 | 33% | | | Mixed Forest |
| Shrubland | 229 | 0.7% | | | Open |
| Orchards/Vineyards/Other | 8 | 0.03% | | | Agriculture |
| Grasslands/Herbaceous | 219 | 0.7% | | | Open |
| Pasture/Hay | 192 | 0.6% | | | Agriculture |
| Row Crops | 6 | 0.02% | | | Agriculture |
| Small Grains | 6 | 0.018% | | | Agriculture |
| Urban/Recreational Grasses | 1 | 0.002% | | | Open |
| Woody Wetlands | 15 | 0.049% | | | Water/Wetlands |
| **Total Acres** | 31,184 | | | | |
| **Total Developed Acres** | 2,351 | | | | |
| **Total % of Study Area** | | 7.5% | | | |
| **Total Imperv. Acres** | | | 500 | | |
| **Weighted % Imperv.**[1] | | | | 21.3% | |

1. Weighted Average % Impervious applied to all developed land use in HSPF model.

**Table 2-3**

**Lake Whatcom Land Use Distribution per Subwatershed**

**Total Acres per Subwatershed**

| HFAM ID | HSPF ID | Name | HSPF Land Use Category | | | | | | | Subbasin |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Agriculture | Deciduous Forest | Developed | Evergreen Forest | Mixed Forest | Open | Water/Wetlands | Total Acres |
| 3000 | 1 | Mirror Lake | | 54 | | 8 | 33 | 25 | 13 | 133 |
| 3005 | 5 | Anderson Creek Gage | 77 | 591 | 7 | 1,015 | 756 | 126 | 6 | 2,579 |
| 3006 | 6 | Northeast Lake Whatcom Inflow | 11 | 152 | 3 | 329 | 161 | 4 | 2 | 663 |
| 3010 | 10 | Northeast Lake Whatcom Inflow | 2 | 453 | 19 | 1,436 | 1,106 | 201 | 24 | 3,241 |
| 3015 | 15 | Smith Creek Gage | | 498 | | 1,486 | 1,174 | 105 | | 3,262 |
| 3018 | 18 | Smith Creek Outlet | | 12 | 2 | 4 | 18 | 4 | 0.1 | 40 |
| 3020 | 20 | Olsen Creek Gage | | 375 | 13 | 1,220 | 824 | 16 | 0.2 | 2,448 |
| 3025 | 25 | Carpenter Creek Gage | 4 | 147 | 45 | 186 | 347 | 37 | 1 | 766 |
| 3030 | 30 | North Lake Whatcom Inflow | 1 | 254 | 112 | 187 | 484 | 104 | 14 | 1,156 |
| 3035 | 35 | Silver Beach Creek Gage | 0.2 | 104 | 222 | 88 | 272 | 27 | 0.0 | 712 |
| 3040 | 40 | North West Lake Whatcom Inflow | 114 | 1,355 | 661 | 224 | 1,223 | 116 | 24 | 3,717 |
| 3045 | 45 | Brannian Creek Gage | | 493 | 1 | 1,070 | 634 | 96 | 2 | 2,297 |
| 3050 | 50 | Brannian Creek Outlet | | 17 | 13 | 11 | 28 | 2 | 1 | 70 |
| 3055 | 55 | South Lake Whatcom Inflow | 0.4 | 698 | 133 | 489 | 805 | 153 | 28 | 2,307 |
| 3060 | 60 | Upper Austin Creek | 1 | 100 | 7 | 1,306 | 340 | 5 | | 1,759 |
| 3065 | 65 | Beaver Cr trib Austin Cr | 0.2 | 598 | 126 | 1,134 | 1,168 | 8 | 1 | 3,036 |
| 3070 | 70 | Austin Creek at Gage | | 9 | 16 | 62 | 32 | 0.5 | | 118 |
| 3072 | 72 | Austin Creek Outlet | | 26 | 152 | 110 | 109 | 8 | 28 | 433 |
| 3075 | 75 | Southwest2 Lake Whatcom Inflow | 0.4 | 130 | 250 | 258 | 287 | 9 | 15 | 950 |
| 3080 | 80 | Southwest Lake Whatcom Inflow | | 69 | 328 | 51 | 122 | 11 | 1 | 582 |
| 3085 | 85 | Euclid Creek Gauge | | 55 | 84 | 66 | 133 | 2 | | 340 |
| 3090 | 90 | Mill Wheel Cr Gage | | 75 | 156 | 104 | 231 | 3 | 4 | 574 |
| | | **Total** | 212 | 6,264 | 2,351 | 10,843 | 10,288 | 1,062 | 164 | 31,184 |
| | | **Percent** | 1% | 20% | 7.5% | 35% | 33% | 3% | 1% | 100% |

**Percentages per Subwatershed**[1]

| HFAM ID | HSPF ID | Name | HSPF Land Use Category | | | | | | | Subbasin % |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Agriculture | Deciduous Forest | Developed | Evergreen Forest | Mixed Forest | Open | Water/Wetlands | Study Area |
| 3000 | 1 | Mirror Lake | 0.00% | 41% | 0.00% | 5.8% | 25% | 19% | 10% | 0.4% |
| 3005 | 5 | Anderson Creek Gage | 3.0% | 23% | 0.3% | 39% | 29% | 4.9% | 0.2% | 8% |
| 3006 | 6 | Northeast Lake Whatcom Inflow | 1.7% | 23% | 0.5% | 50% | 24% | 0.6% | 0.3% | 2% |
| 3010 | 10 | Northeast Lake Whatcom Inflow | 0.1% | 14% | 0.6% | 44% | 34% | 6.2% | 0.7% | 10% |
| 3015 | 15 | Smith Creek Gage | 0.00% | 15% | 0.00% | 46% | 36% | 3.2% | 0.00% | 10% |
| 3018 | 18 | Smith Creek Outlet | 0.00% | 31% | 4.5% | 9% | 45% | 10% | 0.3% | 0.1% |
| 3020 | 20 | Olsen Creek Gage | 0.00% | 15% | 0.5% | 50% | 34% | 0.6% | 0.01% | 8% |
| 3025 | 25 | Carpenter Creek Gage | 0.5% | 19% | 5.8% | 24% | 45% | 4.8% | 0.1% | 2% |
| 3030 | 30 | North Lake Whatcom Inflow | 0.1% | 22% | 10% | 16% | 42% | 9.0% | 1.2% | 4% |
| 3035 | 35 | Silver Beach Creek Gage | 0.03% | 15% | 31% | 12% | 38% | 3.7% | 0.00% | 2% |
| 3040 | 40 | North West Lake Whatcom Inflow | 3.1% | 36% | 18% | 6.0% | 33% | 3.1% | 0.7% | 12% |
| 3045 | 45 | Brannian Creek Gage | 0.00% | 21% | 0.1% | 47% | 28% | 4.2% | 0.1% | 7% |
| 3050 | 50 | Brannian Creek Outlet | 0.00% | 24% | 18% | 15% | 40% | 2.2% | 0.9% | 0.2% |
| 3055 | 55 | South Lake Whatcom Inflow | 0.02% | 30% | 5.8% | 21% | 35% | 6.6% | 1.2% | 7% |
| 3060 | 60 | Upper Austin Creek | 0.1% | 5.7% | 0.4% | 74% | 19% | 0.3% | 0.00% | 6% |
| 3065 | 65 | Beaver Cr trib Austin Cr | 0.01% | 20% | 4.1% | 37% | 38% | 0.3% | 0.04% | 10% |
| 3070 | 70 | Austin Creek at Gage | 0.00% | 7.4% | 13% | 52% | 27% | 0.4% | 0.00% | 0.4% |
| 3072 | 72 | Austin Creek Outlet | 0.00% | 6.0% | 35% | 25% | 25% | 2.0% | 6.4% | 1% |
| 3075 | 75 | Southwest2 Lake Whatcom Inflow | 0.05% | 14% | 26% | 27% | 30% | 0.9% | 1.6% | 3% |
| 3080 | 80 | Southwest Lake Whatcom Inflow | 0.00% | 12% | 56% | 8.8% | 21% | 1.9% | 0.2% | 2% |
| 3085 | 85 | Euclid Creek Gauge | 0.00% | 16% | 25% | 19% | 39% | 0.7% | 0.00% | 1% |
| 3090 | 90 | Mill Wheel Cr Gage | 0.00% | 13% | 27% | 18% | 40% | 0.5% | 0.7% | 2% |
| | | | | | | | | | | 100.0% |

1. Percentages > 10% in Blue

7/18/2007

# Table 2-4
## Rainfall Station Distribution

***Rainfall Stations***

| Name | Elevation (ft) | Mean Precipitation (in) |
|---|---|---|
| Geneva Intake | 324 | 38.8 |
| Brannian Creek | 308 | 51.2 |
| Smith Creek | 377 | 41.7 |

***Rainfall Station Distribution***

| HFAM ID | HSPF ID | Name | Precipitaion Gauge Assigned | Mean Elevation (ft) | $\gamma$ |
|---|---|---|---|---|---|
| 3000 | 1 | Mirror Lake | Brannian Creek | 548 | 0.92 |
| 3005 | 5 | Anderson Creek Gage | Brannian Creek | 1191 | 1.06 |
| 3006 | 6 | Northeast Lake Whatcom Inflow | Brannian Creek | 1356 | 1.09 |
| 3010 | 10 | Northeast Lake Whatcom Inflow | Brannian Creek | 1465 | 1.11 |
| 3015 | 15 | Smith Creek Gage | Smith Creek | 1808 | 1.10 |
| 3018 | 18 | Smith Creek Outlet | Brannian Creek | 438 | 0.76 |
| 3020 | 20 | Olsen Creek Gage | Geneva Intake | 1780 | 1.41 |
| 3025 | 25 | Carpenter Creek Gage | Geneva Intake | 856 | 1.20 |
| 3030 | 30 | North Lake Whatcom Inflow | Geneva Intake | 740 | 1.14 |
| 3035 | 35 | Silver Beach Creek Gage | Geneva Intake | 806 | 1.01 |
| 3040 | 40 | North West Lake Whatcom Inflow | Geneva Intake | 645 | 0.98 |
| 3045 | 45 | Brannian Creek Gage | Brannian Creek | 1164 | 1.01 |
| 3050 | 50 | Brannian Creek Outlet | Brannian Creek | 374 | 0.93 |
| 3055 | 55 | South Lake Whatcom Inflow | Smith Creek | 772 | 1.07 |
| 3060 | 60 | Upper Austin Creek | Smith Creek | 1618 | 1.18 |
| 3065 | 65 | Beaver Cr trib Austin Cr | Smith Creek | 967 | 1.08 |
| 3070 | 70 | Austin Creek at Gage | Smith Creek | 538 | 1.04 |
| 3072 | 72 | Austin Creek Outlet | Brannian Creek | 462 | 0.78 |
| 3075 | 75 | Southwest2 Lake Whatcom Inflow | Brannian Creek | 500 | 0.98 |
| 3080 | 80 | Southwest Lake Whatcom Inflow | Geneva Intake | 541 | 0.95 |
| 3085 | 85 | Euclid Creek Gauge | Geneva Intake | 771 | 0.93 |
| 3090 | 90 | Mill Wheel Cr Gage | Geneva Intake | 722 | 0.94 |

## Table 2-5
**Statistics for Water Quality Calibration Stations**

| *Statistics* | *Anderson Creek* | | *Austin Creek* | | *Euclid Creek* | | *Mill Creek* | | *Olsen Creek* | | *Smith Creek* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Wet* | *Dry* | *Wet* | *Dry* | *Wet* | *Dry* | *Wet* | *Dry* | *Wet* | *Dry* | *Wet* | *Dry* |
| Count | 21 | 20 | 10 | 31 | 19 | 17 | 11 | 9 | 14 | 28 | 21 | 20 |
| Minimum | 0.008 | 0.008 | 0.005 | 0.006 | 0.010 | 0.000 | 0.006 | 0.015 | 0.004 | 0.005 | 0.003 | 0.003 |
| Maximum | 0.076 | 0.073 | 0.033 | 0.094 | 0.065 | 0.037 | 0.198 | 0.061 | 0.114 | 0.041 | 0.052 | 0.020 |
| Mean | 0.024 | 0.025 | 0.017 | 0.017 | 0.027 | 0.019 | 0.057 | 0.032 | 0.027 | 0.015 | 0.014 | 0.009 |
| Standard Deviation | 0.016 | 0.020 | 0.009 | 0.016 | 0.014 | 0.010 | 0.052 | 0.015 | 0.029 | 0.009 | 0.011 | 0.005 |
| Standard Error | 0.003 | 0.004 | 0.003 | 0.003 | 0.003 | 0.002 | 0.016 | 0.005 | 0.008 | 0.002 | 0.002 | 0.001 |
| Sample Variance | 0.0003 | 0.0004 | 0.0001 | 0.0002 | 0.0002 | 0.0001 | 0.0027 | 0.0002 | 0.0009 | 0.0001 | 0.0001 | 0.0000 |
| Range | 0.067 | 0.065 | 0.027 | 0.088 | 0.055 | 0.037 | 0.192 | 0.046 | 0.110 | 0.036 | 0.049 | 0.017 |
| First Quartile | 0.013 | 0.012 | 0.012 | 0.010 | 0.018 | 0.014 | 0.028 | 0.022 | 0.012 | 0.010 | 0.009 | 0.005 |
| Second Quartile (media | 0.021 | 0.017 | 0.017 | 0.013 | 0.024 | 0.017 | 0.051 | 0.027 | 0.019 | 0.013 | 0.011 | 0.007 |
| Third Quartile | 0.027 | 0.029 | 0.024 | 0.021 | 0.032 | 0.025 | 0.060 | 0.042 | 0.024 | 0.020 | 0.018 | 0.012 |
| Fourth Quartile | 0.076 | 0.073 | 0.033 | 0.094 | 0.065 | 0.037 | 0.198 | 0.061 | 0.114 | 0.041 | 0.052 | 0.020 |

## Table 2-6
### Lake Whatcom HSPF Model HFAM Parameters

**Global HFAM Parameters**

| Parameter | Description | Units | Value |
|---|---|---|---|
| LZSN | lower zone nominal storage | Inches | 5.0 |
| INFILT | index to the infiltration capacity of the soil | Dimensionless | 0.080 |
| AGWETP | fraction of remaining potential E-T which can be satisfied from active groundwater storage if enough is available | Dimensionless | 0 |
| BASETP | fraction of remaining potential E-T which can be satisfied from baseflow (groundwater outflow), if enough is available | Dimensionless | 0.1 |
| CEPSC | interception storage capacity | Inches | 0.35 |
| DEEPFR | fraction of groundwater inflow which will enter deep (inactive) groundwater, and, thus, be lost from the system as it is defined in HSPF | Dimensionless | 0 |
| IRC | ratio of today's interflow outflow rate to yesterday's rate | Dimensionless | 0.65 |
| LSUR | length of the assumed overland flow plane | Feet | 250 |
| LZETP | index to the density of deep-rooted vegetation | Dimensionless | 0.8 |
| NSUR | Manning's n for the overland flow plane | Dimensionless | 0.35 |
| PETMAX | air temperature below which E-T will arbitrarily be reduced below the value obtained from the input time series | Deg F | 44 |
| PETMIN | temperature below which E-T will be zero regardless of the value in the input time series | Deg F | 36.5 |

**Varying HFAM Parameters**

| RCHRES | UZSN | INTFW | AGWRC | SLSUR |
|---|---|---|---|---|
| | upper zone nominal storage | interflow inflow parameter | ratio of current groundwater discharge to groundwater discharge 24-hr | slope of the overland flow plane |
| Units | Inches | Dimensionless | Dimensionless | ft/ft |
| 3000 | 1.50 | 2.50 | 0.98 | 0.2492 |
| 3005 | 1.30 | 2.50 | 0.98 | 0.3247 |
| 3006 | 1.32 | 2.50 | 0.98 | 0.3329 |
| 3010 | 1.26 | 2.50 | 0.97 | 0.4594 |
| 3015 | 1.20 | 2.50 | 0.97 | 0.4671 |
| 3018 | 1.58 | 2.50 | 0.99 | 0.1807 |
| 3020 | 1.23 | 2.50 | 0.97 | 0.3432 |
| 3025 | 1.20 | 2.50 | 0.97 | 0.1806 |
| 3030 | 1.39 | 2.50 | 0.98 | 0.2200 |
| 3035 | 1.37 | 2.50 | 0.98 | 0.1260 |
| 3040 | 1.47 | 2.50 | 0.98 | 0.1331 |
| 3045 | 1.20 | 2.50 | 0.97 | 0.2454 |
| 3050 | 1.60 | 2.50 | 0.99 | 0.0683 |
| 3055 | 1.43 | 2.50 | 0.98 | 0.2882 |
| 3060 | 1.20 | 2.50 | 0.97 | 0.4079 |
| 3065 | 1.20 | 2.50 | 0.97 | 0.2225 |
| 3070 | 1.51 | 2.50 | 0.98 | 0.2183 |
| 3072 | 1.55 | 2.50 | 0.98 | 0.1784 |
| 3075 | 1.55 | 2.50 | 0.98 | 0.2042 |
| 3080 | 1.50 | 2.50 | 0.98 | 0.1428 |
| 3085 | 1.33 | 2.50 | 0.98 | 0.1483 |
| 3090 | 1.39 | 2.50 | 0.98 | 0.1279 |

# Table 2-7
## Lake Whatcom HSPF Model, Initial Water Quality Parameters

**PERLND Initial WQ Parameters**

| Param | Description | Value | Units |
|---|---|---|---|
| SQO | Initial storage on the land surface | 0.006 | lbs |
| ACQOP | Rate of accumulation | 0.006 | lbs/ac/d |
| SQOLIM | Maximum storage | 0.018 | lbs |
| WSQOP | Rate of surface runoff which will remove 90 percent of stored constituent per | 0.5 | In/hr |
| IOQC | Concentration of the constituent in interflow outflow | 0 | mg/l |
| AOQC | Concentration of the constituent in active groundwater outflow; | 0 | mg/l |

*** Monthly interflow and groundwater concentrations
(table MON-IFLW-CONC and MON-GRND-CONC) set to 0.05

**IMPLND Initial WQ Parameters**

| Param | Description | Value | Units |
|---|---|---|---|
| SQO | Initial storage on the land surface | 0.03 | lbs |
| ACQOP | Rate of accumulation | 0.03 | lbs/ac/d |
| SQOLIM | Maximum storage | 0.09 | lbs |
| WSQOP | Rate of surface runoff which will remove 90 percent of stored constituent per | 0.5 | In/hr |

**Table 3-1**
**Distribution of Parameters from Calibrated Subwatersheds to Uncalibrated Subwatershed**

| Reach Number | ID | Reach Name | Nearest | Primary HSG | Secondary HSG | Primary Land Cover | Secondary Land Cover | Reach Acres | Related Calibrated Subwatershed |
|---|---|---|---|---|---|---|---|---|---|
| 3000 | 1 | Mirror Lake | Anderson | C | D | Deciduous Forest | Mixed Forest | 136 | Anderson |
| 3005 | 5 | Anderson Creek Gage | Anderson | C | B | Evergreen Forest | Mixed Forest | 2589 | Anderson |
| 3006 | 10 | Northeast Lake Whatcom Inflow | Anderson | C | B | Evergreen Forest | Mixed Forest | 664 | Anderson |
| 3010 | 6 | Northeast Lake Whatcom Inflow | Smith | C | B | Evergreen Forest | Mixed Forest | 3241 | Smith |
| 3015 | 15 | Smith Creek Gage | Smith | C | B | Evergreen Forest | Mixed Forest | 3262 | Smith |
| 3018 | 18 | Smith Creek Outlet | Smith | C | B | Mixed Forest | Deciduous Forest | 40 | Smith |
| 3020 | 20 | Olsen Creek Gage | Olsen | C | B | Evergreen Forest | Mixed Forest | 2448 | Olsen |
| 3025 | 25 | Carpenter Creek Gage | Olsen | B | A | Mixed Forest | Developed | 766 | Olsen |
| 3030 | 30 | North Lake Whatcom Inflow | Smith/ Olsen | B | C | Mixed Forest | Deciduous Forest | 1156 | Smith |
| 3035 | 35 | Silver Beach Creek Gage | Mill | B | C | Mixed Forest | Developed | 712 | Mill |
| 3040 | 40 | North West Lake Whatcom Inflow | Olsen/ Euclid | B | C | Deciduous Forest | Mixed Forest | 3717 | Olsen |
| 3045 | 45 | Brannian Creek Gage | Anderson | C | B | Evergreen Forest | Mixed Forest | 2309 | Anderson |
| 3050 | 50 | Brannian Creek Outlet | Anderson | C | B | Mixed Forest | Deciduous Forest | 70 | Anderson |
| 3055 | 55 | South Lake Whatcom Inflow | Austin/ Anderson | C | B | Mixed Forest | Deciduous Forest | 2314 | Anderson |
| 3060 | 60 | Upper Austin Creek | Austin | C | B | Evergreen Forest | Mixed Forest | 1766 | Austin |
| 3065 | 65 | Beaver Cr trib Austin Cr | Austin | B | C | Mixed Forest | Evergreen Forest | 3041 | Austin |
| 3070 | 70 | Austin Creek at Gage | Austin | B | C | Evergreen Forest | Mixed Forest | 118 | Austin |
| 3072 | 72 | Austin Creek Outlet | Austin | B | C | Developed | Evergreen Forest | 433 | Austin |
| 3075 | 75 | Southwest2 Lake Whatcom Inflow | Austin | C | B | Mixed Forest | Evergreen Forest | 950 | Austin |
| 3080 | 80 | Southwest Lake Whatcom Inflow | Euclid | B | C | Developed | Mixed Forest | 582 | Euclid |
| 3085 | 85 | Euclid Creek Gauge | Euclid | B | B | Mixed Forest | Developed | 340 | Euclid |
| 3090 | 90 | Mill Wheel Cr Gage | Mill | C | B | Mixed Forest | Developed | 574 | Mill |

## Table 3-2
### Lake Whatcom HSPF Model Calibration Parameters

| Parameter | Anderson Creek | | Austin Creek | | Euclid Creek | | Mill Wheel Creek | | Olsen Creek | | Smith Creek | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial | Calibrated | Initial | Calibrated | Initial | Calibrated | Initial | Calibrated | Initial | Calibrated | Initial | Calibrated |
| ***Hydrology*** | | | | | | | | | | | | |
| Precip Factor | 0.92 - 1.06 | 0.96 - 1.11 | 1.04 - 1.18 | 1.08 | 0.93 | 0.87 | 0.94 | 0.85 | 1.41 | 1.39 | 1.10 | 1.19 |
| LZSN | 5.0 | 4.0 | 5.0 | 2.0 | 5.0 | 11.7 | 5.0 | 7.3 | 5.0 | 2.5 | 5.0 | 2.2 |
| INFILT | 0.08 | 0.03 - 0.07 | 0.08 | 0.03 - 0.07 | 0.08 | 0.06 - 0.10 | 0.08 | 0.03 - 0.07 | 0.08 | 0.02 - 0.06 | 0.08 | 0.03 - 0.07 |
| CEPSC | 0.35 | 0.15 - 0.20 | 0.35 | 0.10 - 0.25 | 0.35 | 0.05 - 0.25 | 0.35 | 0.17 - 0.35 | 0.35 | 0.10 - 0.25 | 0.35 | 0.10 - 0.25 |
| DEEPFR | 0.0 | 0.14 | 0.0 | 0.14 | 0.0 | 0.14 | 0.0 | 0.14 | 0.0 | 0.14 | 0.0 | 0.14 |
| IRC | 0.65 | 0.80 | 0.65 | 0.65 | 0.65 | 0.15 | 0.65 | 0.55 | 0.65 | 0.25 | 0.65 | 0.60 |
| LSUR | 250 | 150 | 250 | 100 | 250 | 100 | 250 | 250 | 250 | 100 | 250 | 100 |
| AGWRC | 0.98 | 0.99 | 0.98 | 0.99 | 0.98 | 0.98 | 0.98 | 0.97 | 0.97 | 0.99 | 0.97 | 0.99 |
| INTFW | 2.5 | 4.5 | 2.5 | 5.5 | 2.5 | 5.5 | 2.5 | 2.5 | 2.5 | 5.4 | 2.5 | 4.0 |
| UZSN | 1.40 | 0.06 - 0.30 | 1.30 | 0.01 - 0.06 | 1.33 | 0.11 - 0.22 | 1.39 | 0.08 - 0.95 | 1.23 | 0.02 - 0.30 | 1.20 | 0.03 - 0.27 |
| ***Water Quality*** | | | | | | | | | | | | |
| SQO | 0.006 | 0.009 - 0.100 | 0.006 | 0.009 - 0.100 | 0.006 | 0.009 - 0.100 | 0.006 | 0.009 - 0.100 | 0.006 | 0.009 - 0.100 | 0.006 | 0.009 - 0.100 |
| ACQOP | 0.006 | 0.002 - 0.023 | 0.006 | 0.002 - 0.013 | 0.006 | 0.003 - 0.032 | 0.006 | 0.002 - 0.020 | 0.006 | 0.004 - 0.023 | 0.006 | 0.002 - 0.023 |
| SQOLIM | 0.018 | 0.025 - 0.19 | 0.018 | 0.010 - 0.110 | 0.018 | 0.030 - 0.225 | 0.018 | 0.012 - 0.160 | 0.018 | 0.030 - 0.190 | 0.018 | 0.030 - 0.190 |

## Table 3-3
### Summary Statistics for Calibrated Hydrology for Subwatersheds

#### Anderson Creek

| Evaluation Criteria | Simulated | Observed |
|---|---|---|
| Mean Daily Flow (cfs) | 27 | 26 |
| November to April | 23 | 25 |
| April to October | 17 | 17 |
| Maximum Day Flow (cfs) | 120 | 214 |
| Absolute Error | 5.14 | |
| Relative Error | 0.06 | |
| RMSE Error | 9.56 | |
| Nash-Sutcliff 1970 Criteria | 89% | |
| McMahon 1994 Criteria | 91% | |

#### Austin Creek

| Evaluation Criteria | Simulated | Observed |
|---|---|---|
| Mean Daily Flow (cfs) | 15 | 15 |
| November to April | 24 | 24 |
| April to October | 5 | 5 |
| Maximum Day Flow (cfs) | 259 | 412 |
| Absolute Error | 4.25 | |
| Relative Error | 0.02 | |
| RMSE Error | 11.85 | |
| Nash-Sutcliff 1970 Criteria | 82% | |
| McMahon 1994 Criteria | 90% | |

#### Euclid Creek

| Evaluation Criteria | Simulated | Observed |
|---|---|---|
| Mean Daily Flow (cfs) | 0.6 | 0.5 |
| November to April | 0.5 | 0.5 |
| April to October | 0.2 | 0.1 |
| Maximum Day Flow (cfs) | 9 | 40 |
| Absolute Error | 0.28 | |
| Relative Error | 0.05 | |
| RMSE Error | 1.20 | |
| Nash-Sutcliff 1970 Criteria | 44% | |
| McMahon 1994 Criteria | 74% | |

#### Mill Creek

| Evaluation Criteria | Simulated | Observed |
|---|---|---|
| Mean Daily Flow (cfs) | 0.8 | 0.8 |
| November to April | 1.6 | 1.6 |
| April to October | 0.3 | 0.3 |
| Maximum Day Flow (cfs) | 10.8 | 14.0 |
| Absolute Error | 0.32 | |
| Relative Error | -0.02 | |
| RMSE Error | 0.62 | |
| Nash-Sutcliff 1970 Criteria | 80% | |
| McMahon 1994 Criteria | 83% | |

#### Olsen Creek

| Evaluation Criteria | Simulated | Observed |
|---|---|---|
| Mean Daily Flow (cfs) | 10 | 10 |
| November to April | 16 | 13 |
| April to October | 5 | 5 |
| Maximum Day Flow (cfs) | 236 | 951 |
| Absolute Error | 6.35 | |
| Relative Error | 0.08 | |
| RMSE Error | 35.53 | |
| Nash-Sutcliff 1970 Criteria | 42% | |
| McMahon 1994 Criteria | 65% | |

#### Smith Creek

| Evaluation Criteria | Simulated | Observed |
|---|---|---|
| Mean Daily Flow (cfs) | 10 | 10 |
| November to April | 16 | 16 |
| April to October | 4 | 5 |
| Maximum Day Flow (cfs) | 175 | 402 |
| Absolute Error | 3.45 | |
| Relative Error | 0.07 | |
| RMSE Error | 8.50 | |
| Nash-Sutcliff 1970 Criteria | 75% | |
| McMahon 1994 Criteria | 83% | |

# Figures

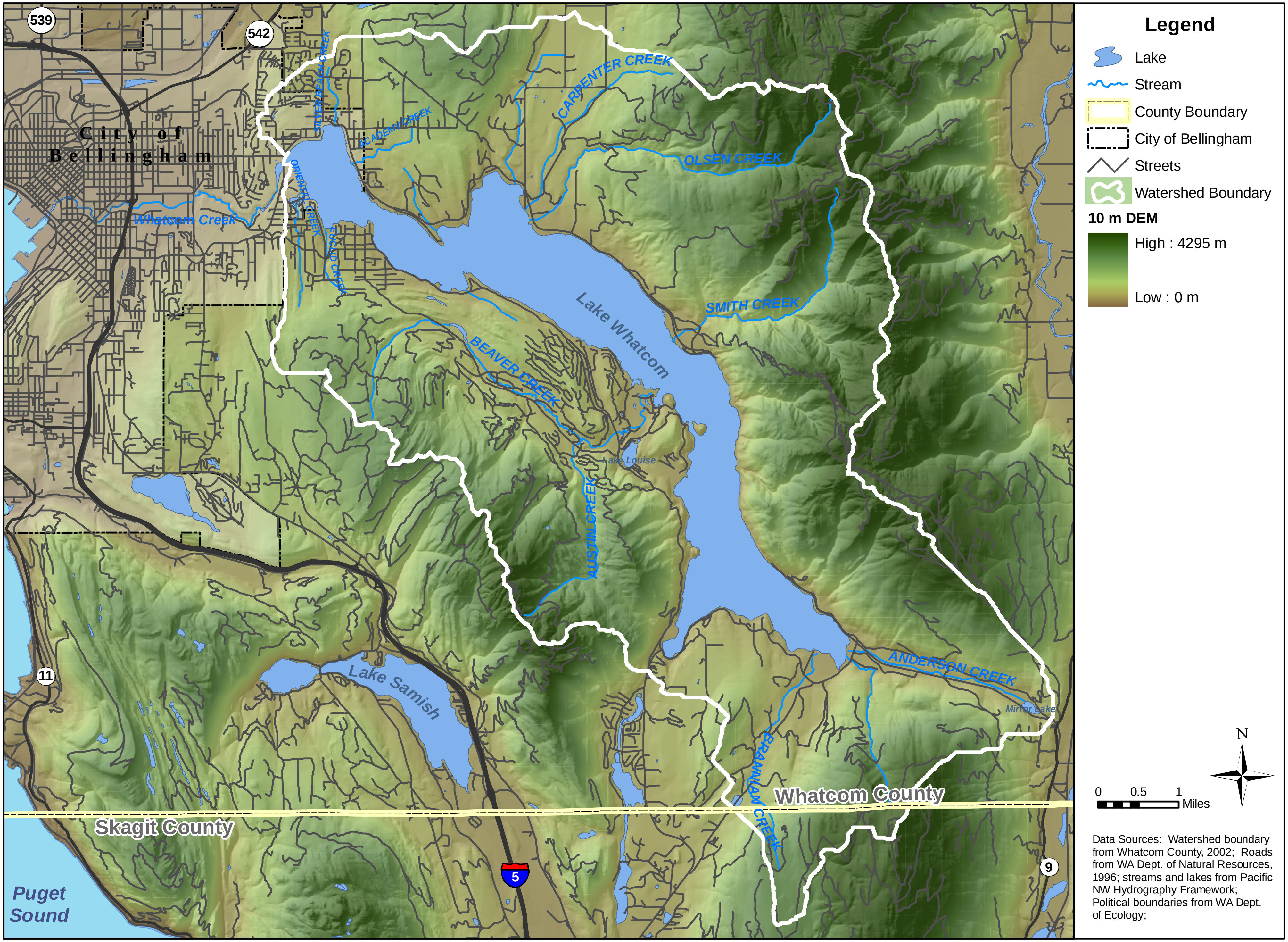


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**Figure 1-1**
Lake Whatcom Watershed

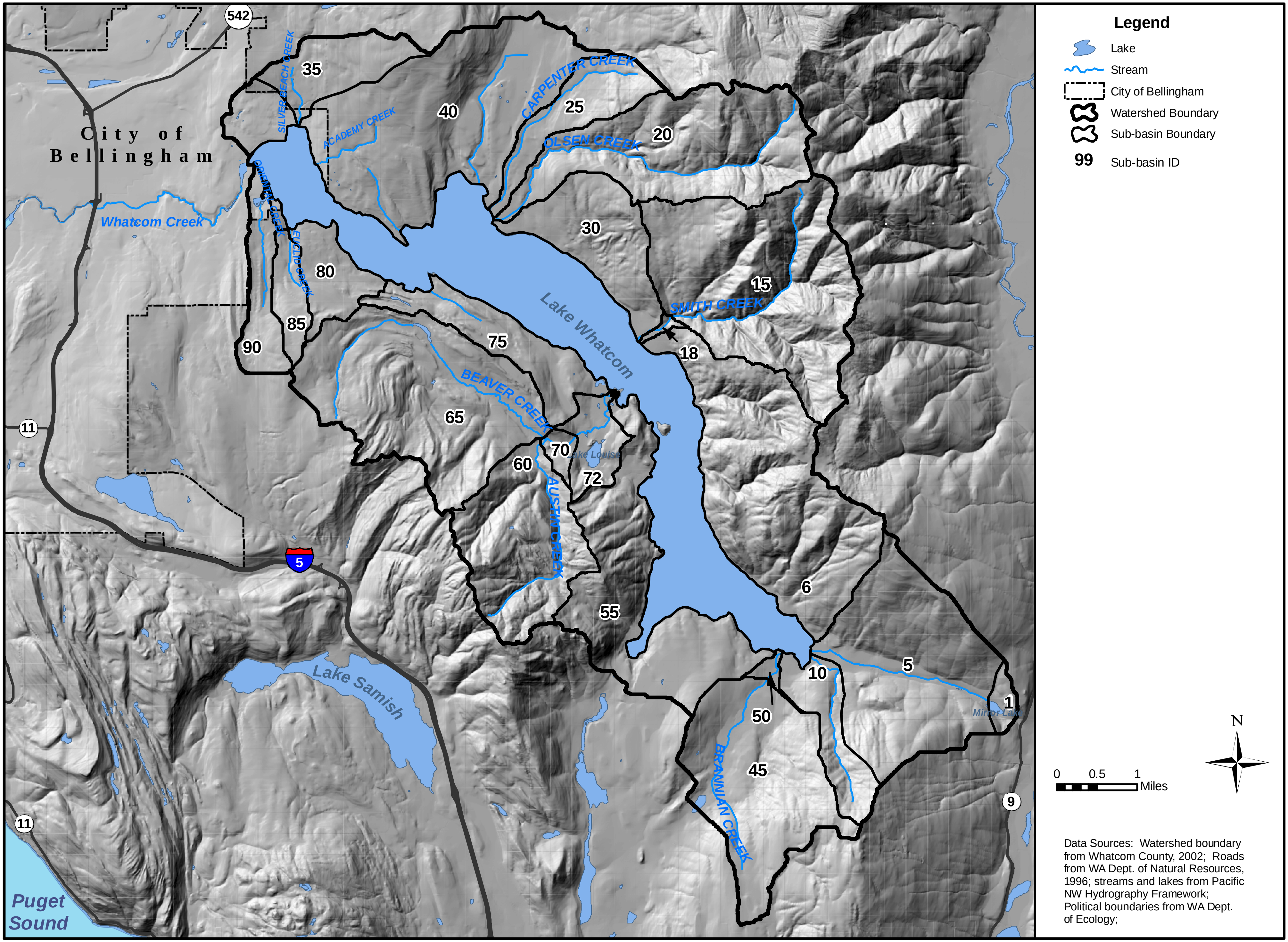


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**Figure 2-1**
Watershed Subwatersheds

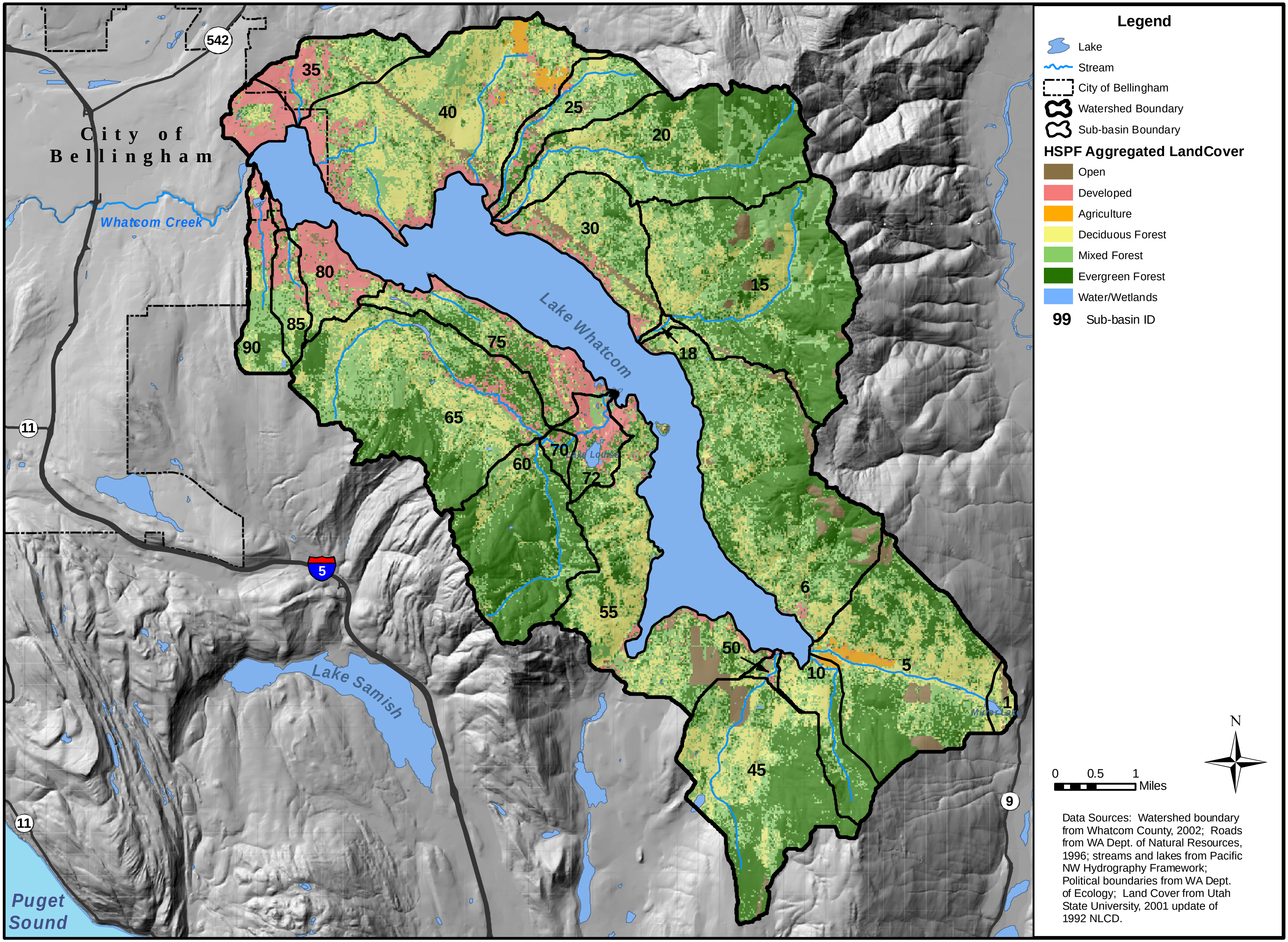


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**Figure 2-2**
Land Cover

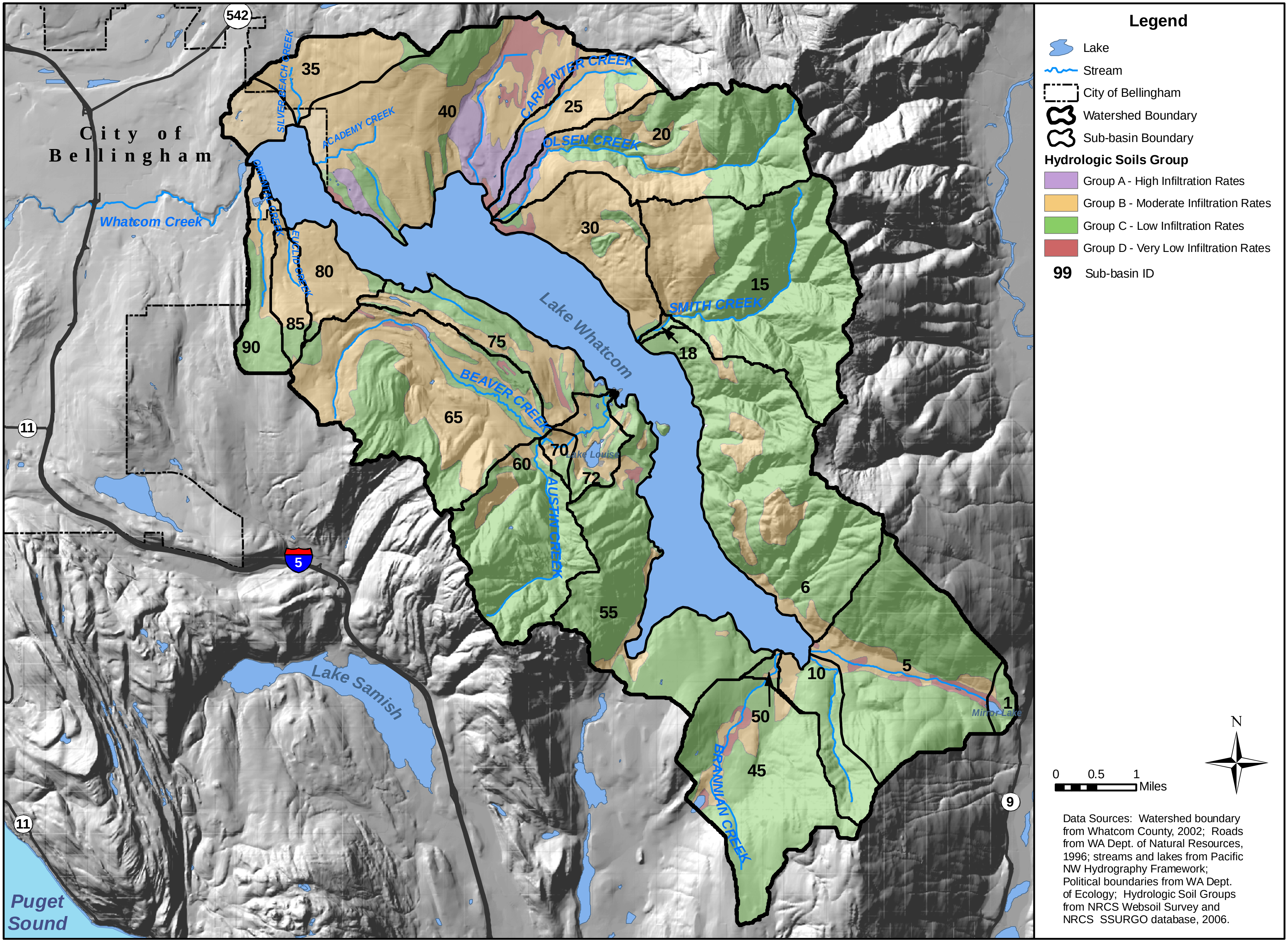


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**Figure 2-3**
Hydrologic Soil Groups

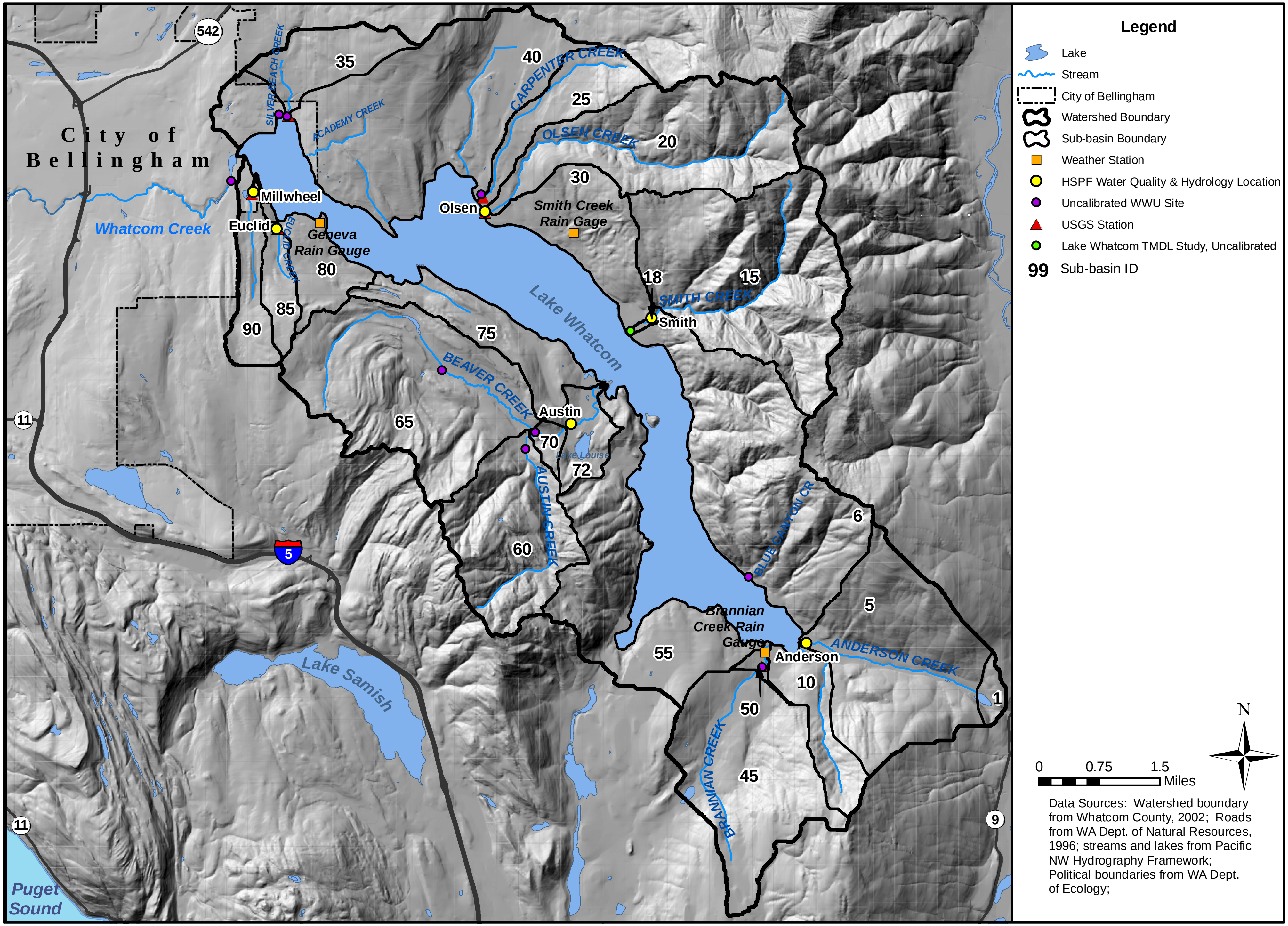


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**Figure 2-4**
Hydrology, Water Quality, and Weather Stations

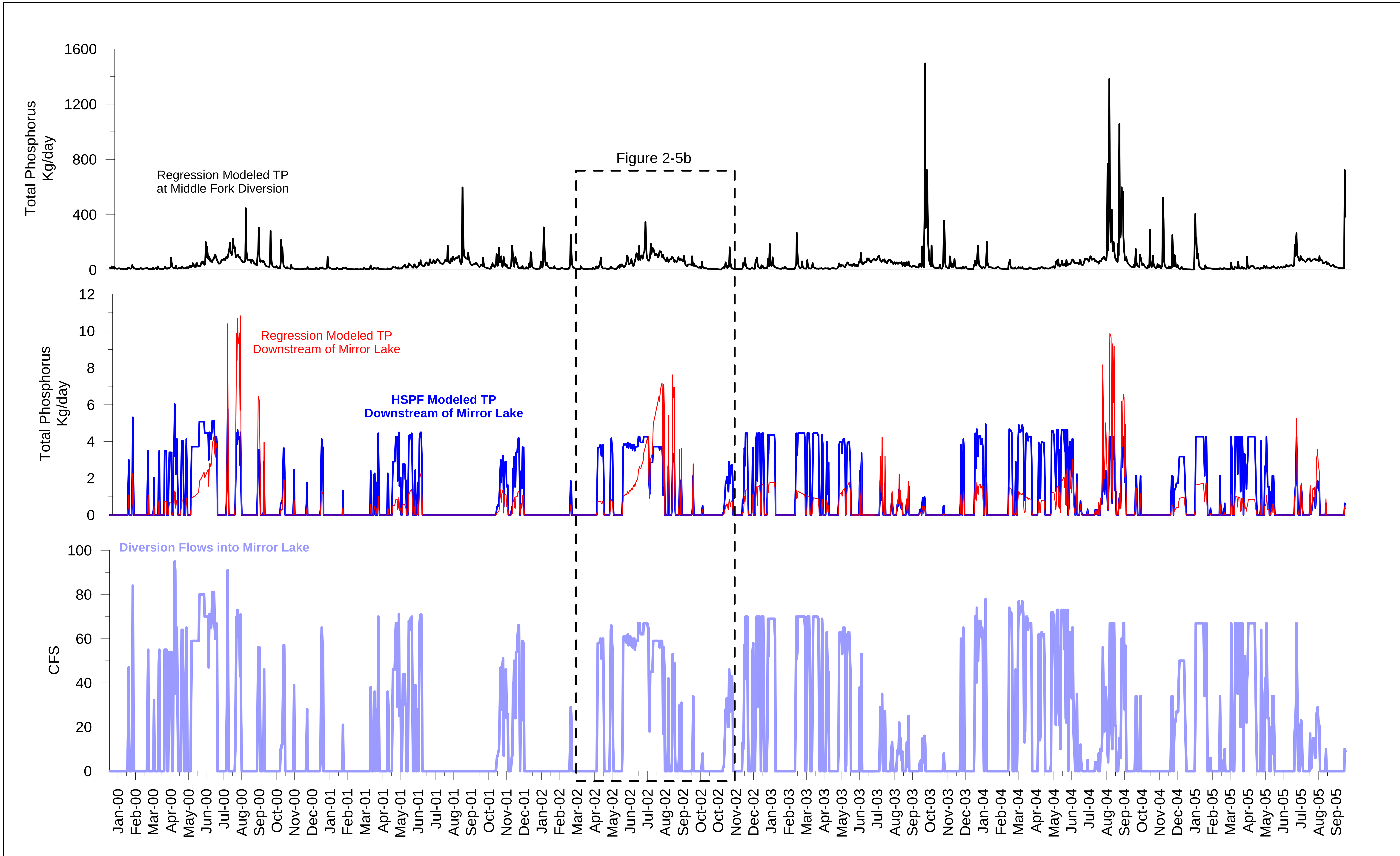




**Figure 2-5**
Middle Fork Nooksack Diversion
Comparison of WDOE Regression Model and HSPF Results

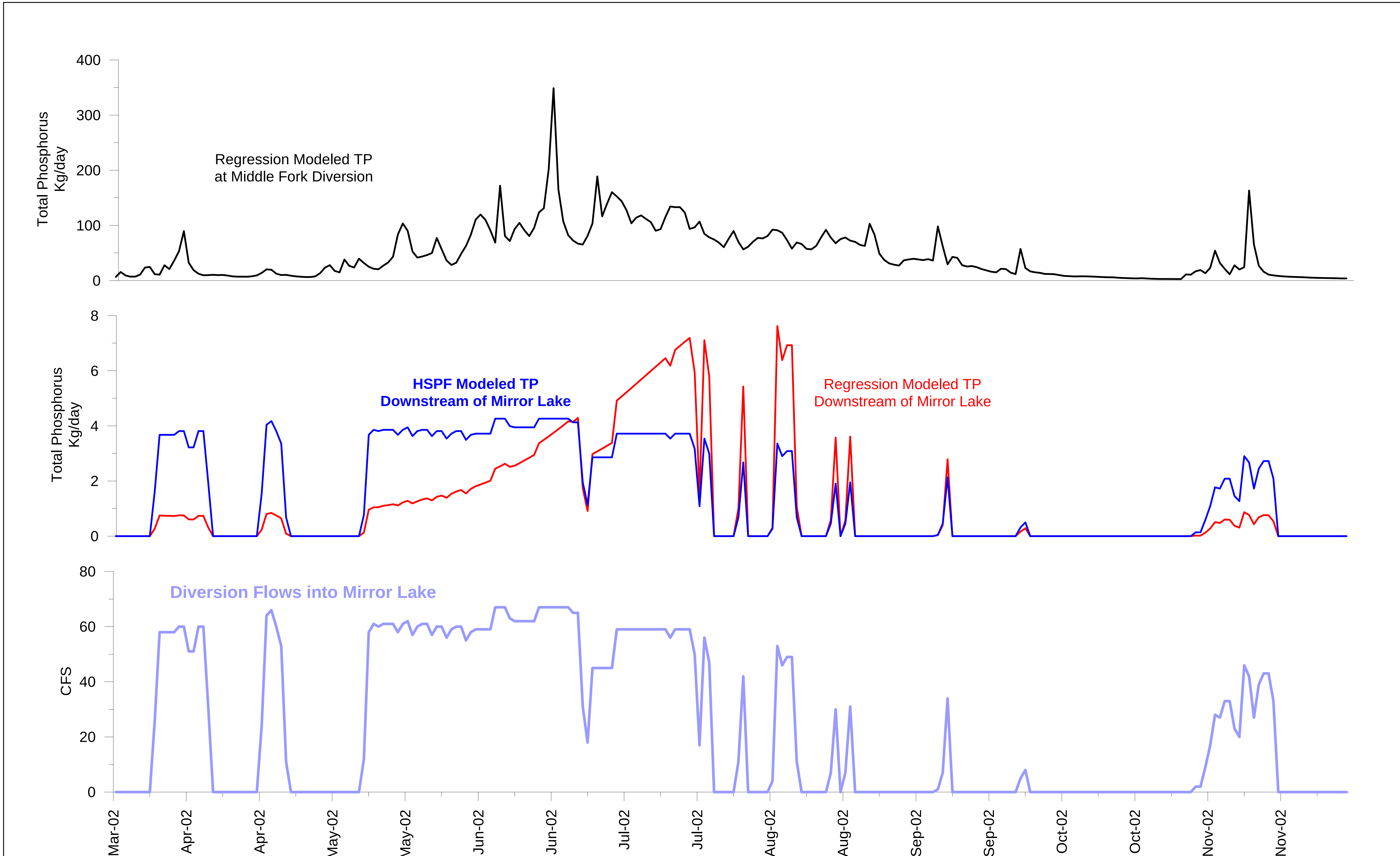


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**Figure 2-5b**
Middle Fork Nooksack Diversion
Comparison of WDOE Regression Model and HSPF Results

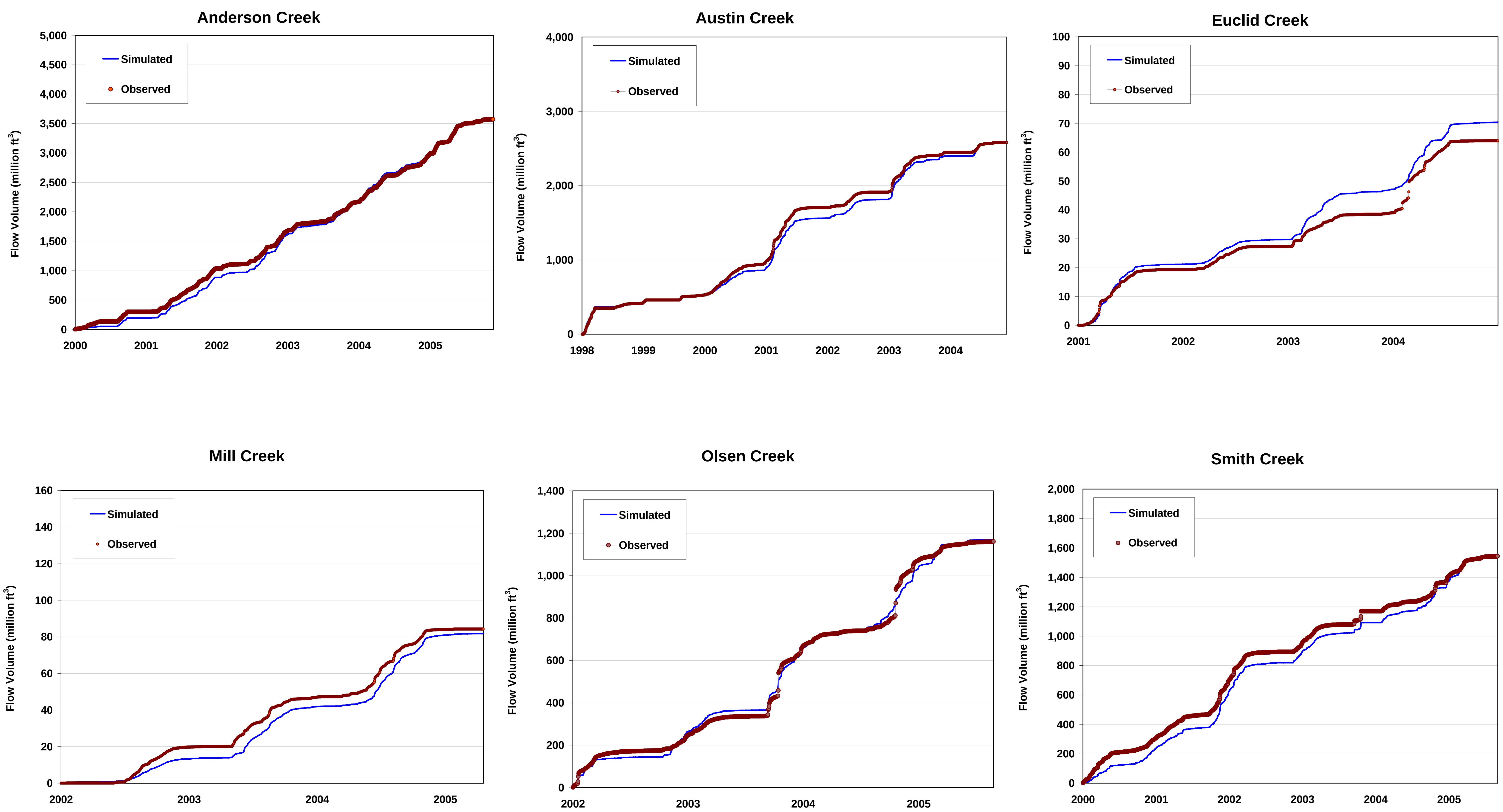




**Figure 3-1**
Cumulative Runoff Volume Plots
Simulated and Observed

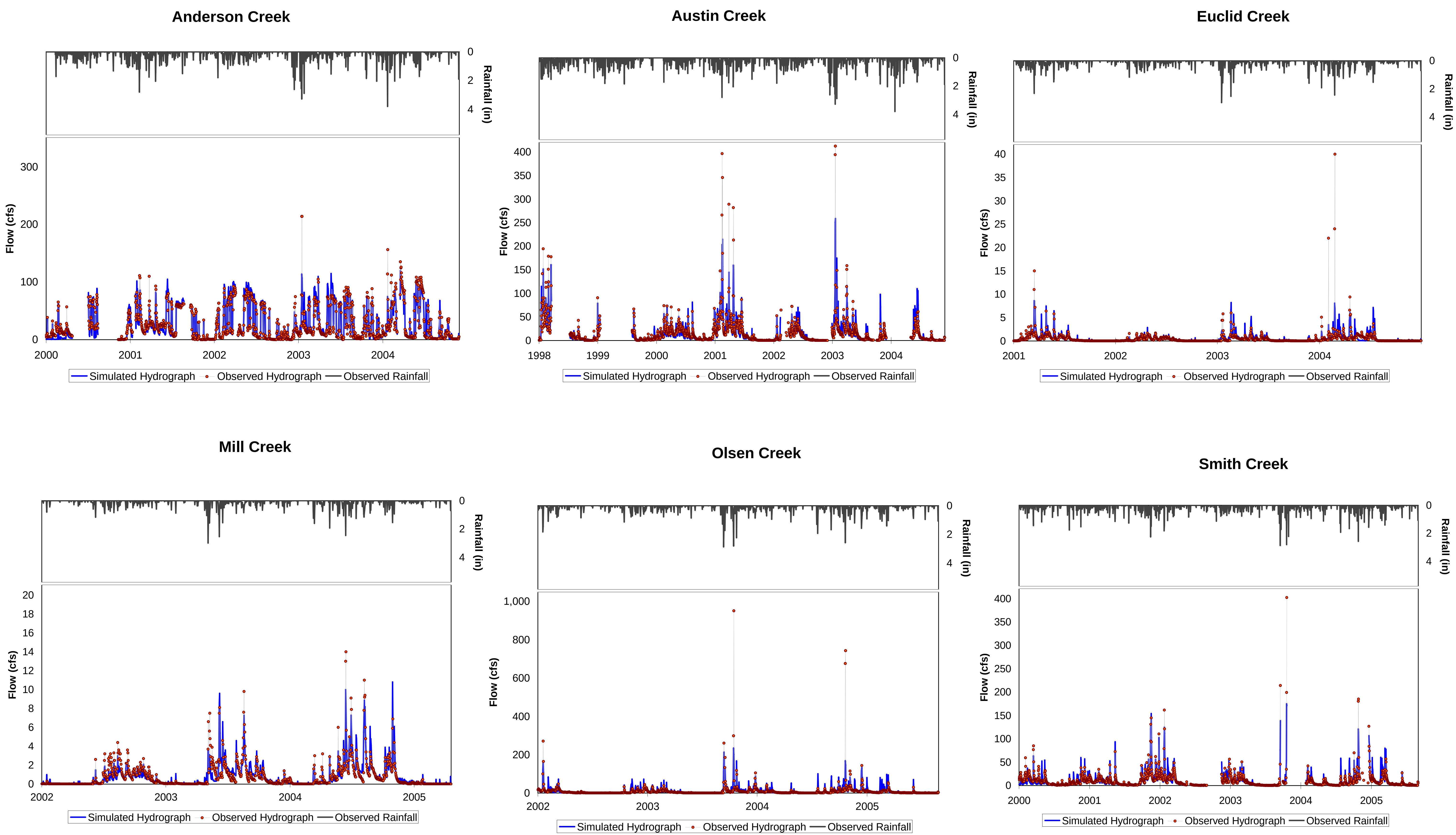


**Figure 3-2**
Hydrographs
Simulated and Observed

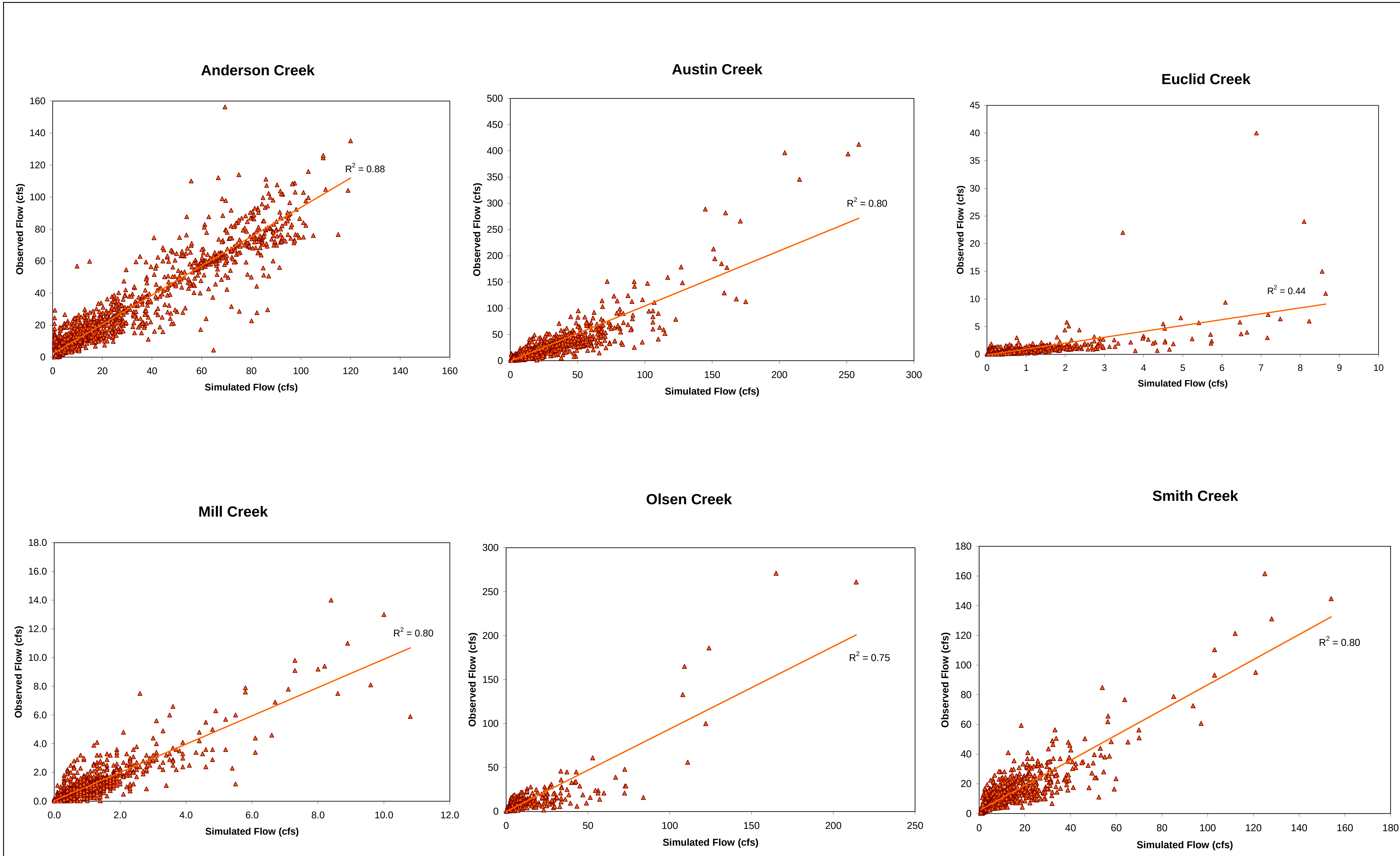




**Figure 3-3**
HSPF Hydrology Calibration Scatter Plots
Simulated versus Observed

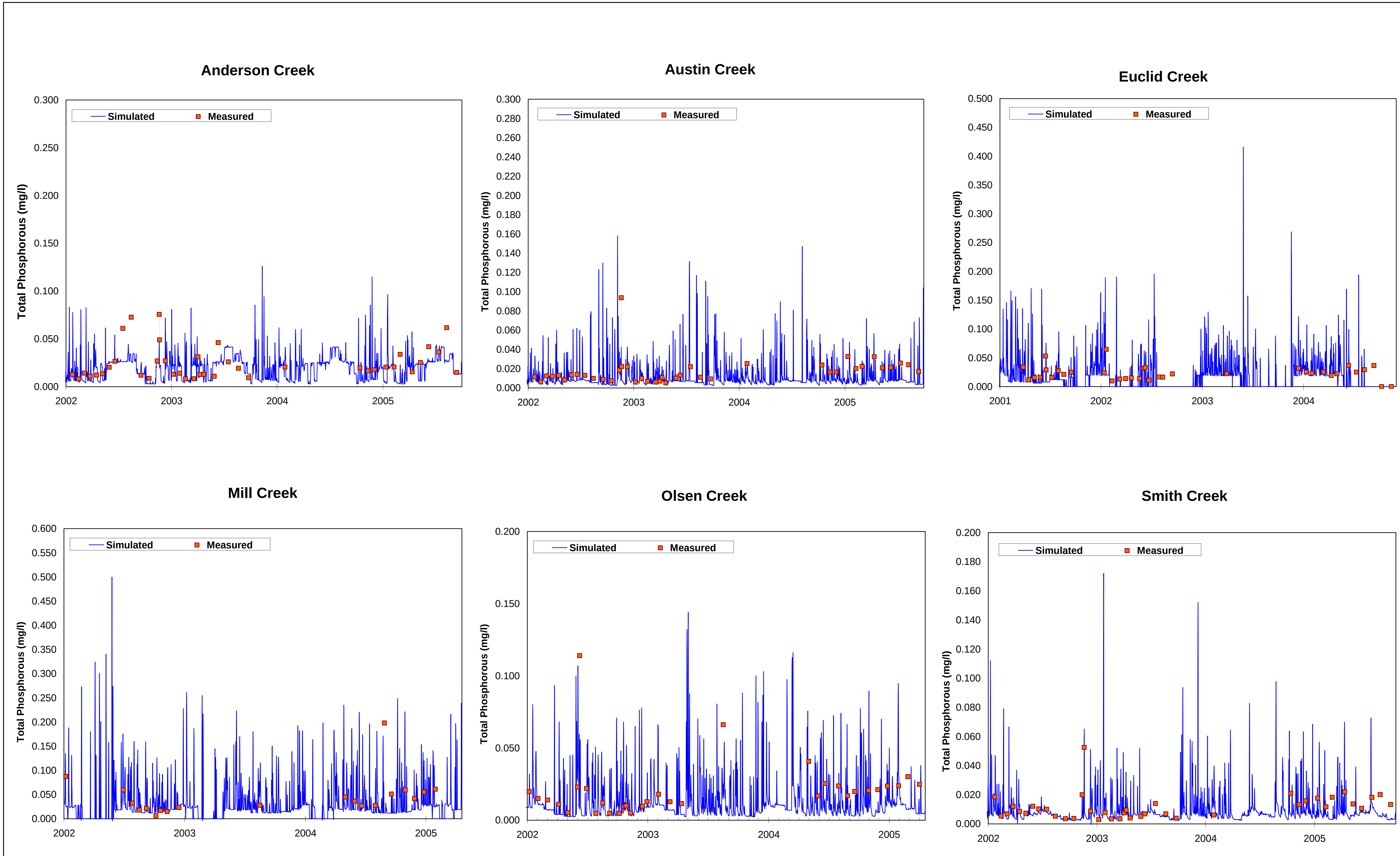




**Figure 3-4**
Total Phosphorus Water Quality Data
Simulated and Observed

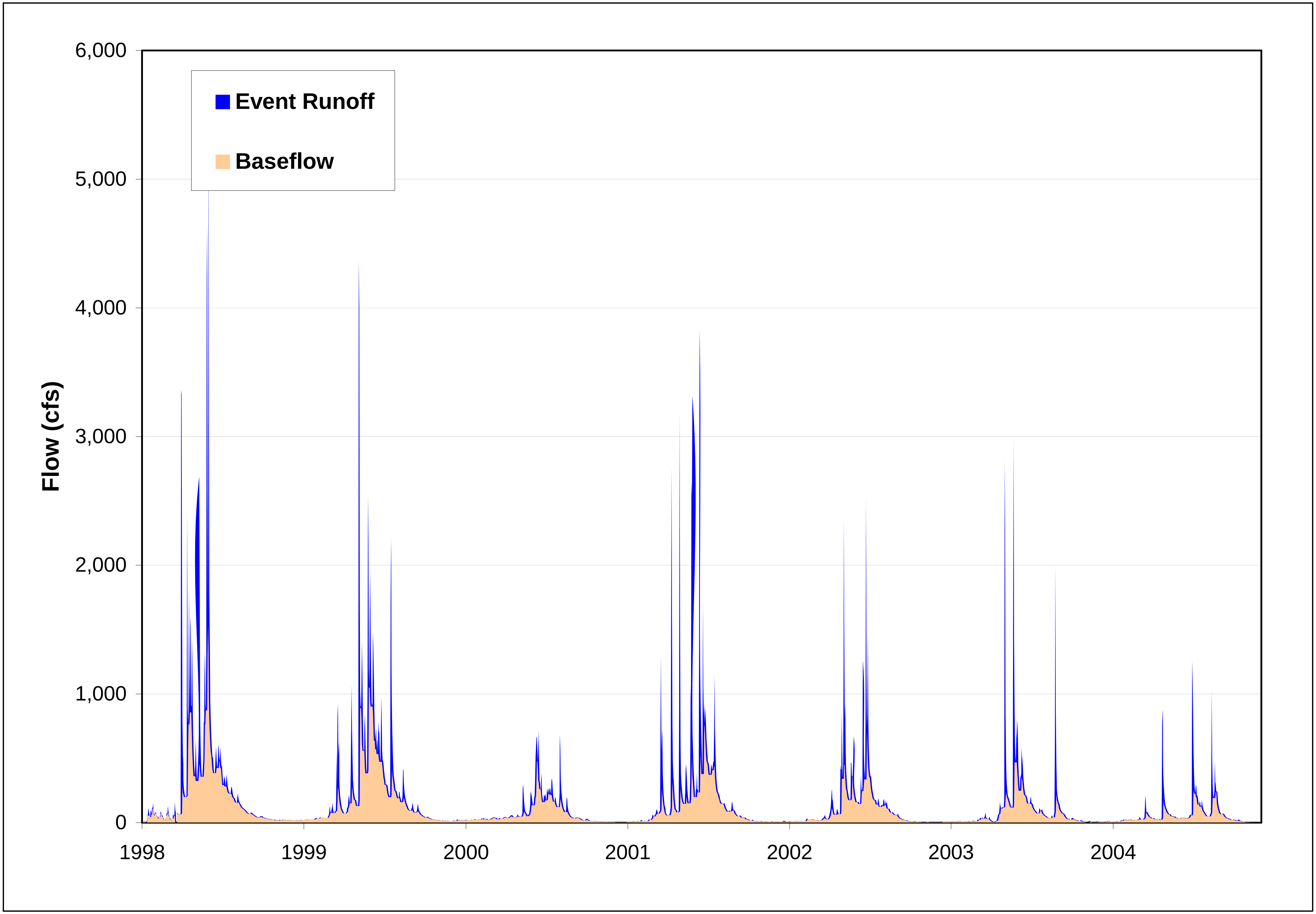


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**Figure 3-5**
Sliding Interval Baseflow Separation
Data Analysis Tool

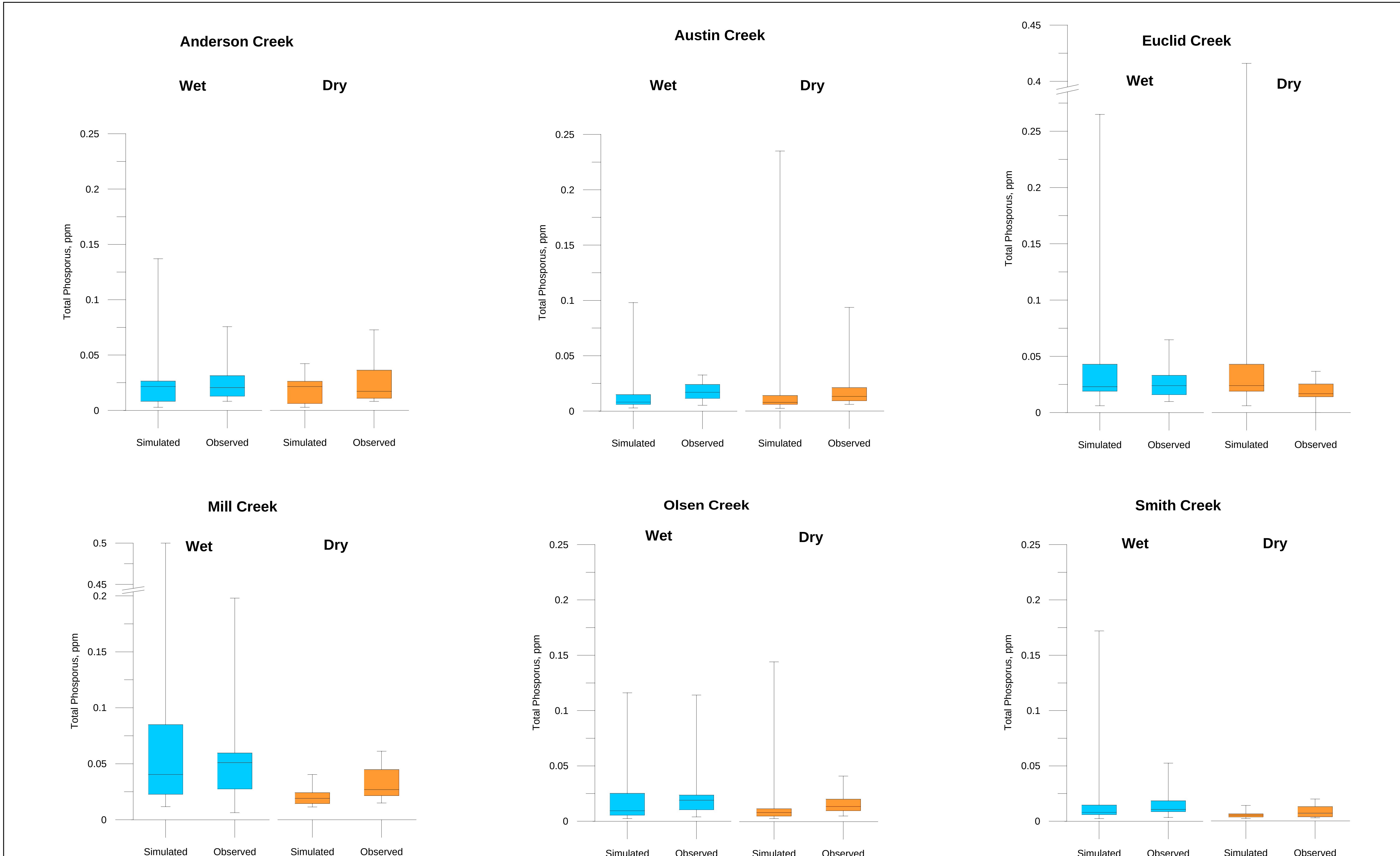
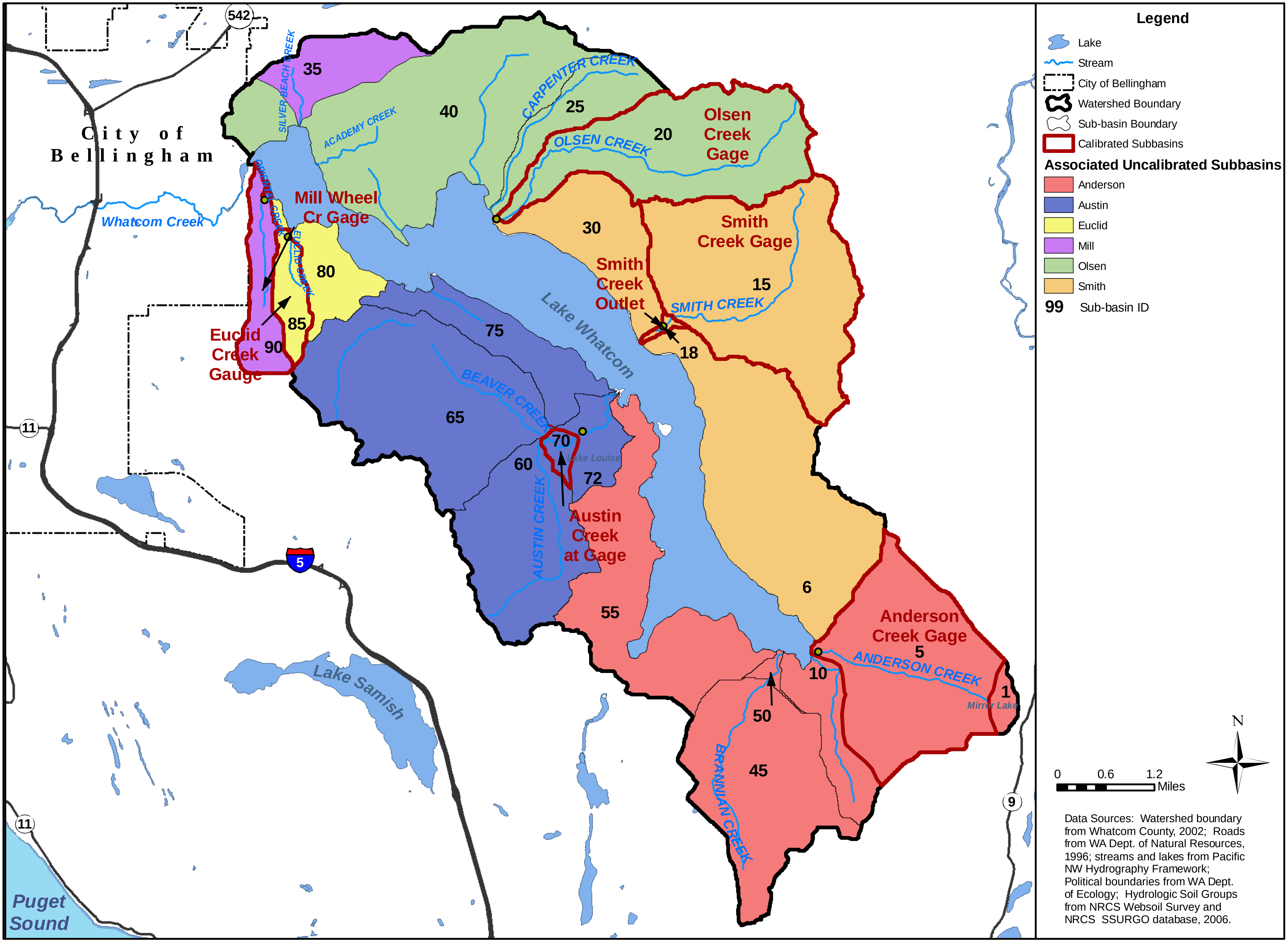



**Figure 3-6**
Box and Whisker Plots of Total Phosphorus Data for Dry and Wet Conditions
Simulated and Observed

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FINAL MODEL REPORT

**Figure 3-7**
Application of Calibrated Subwatershed Parameters

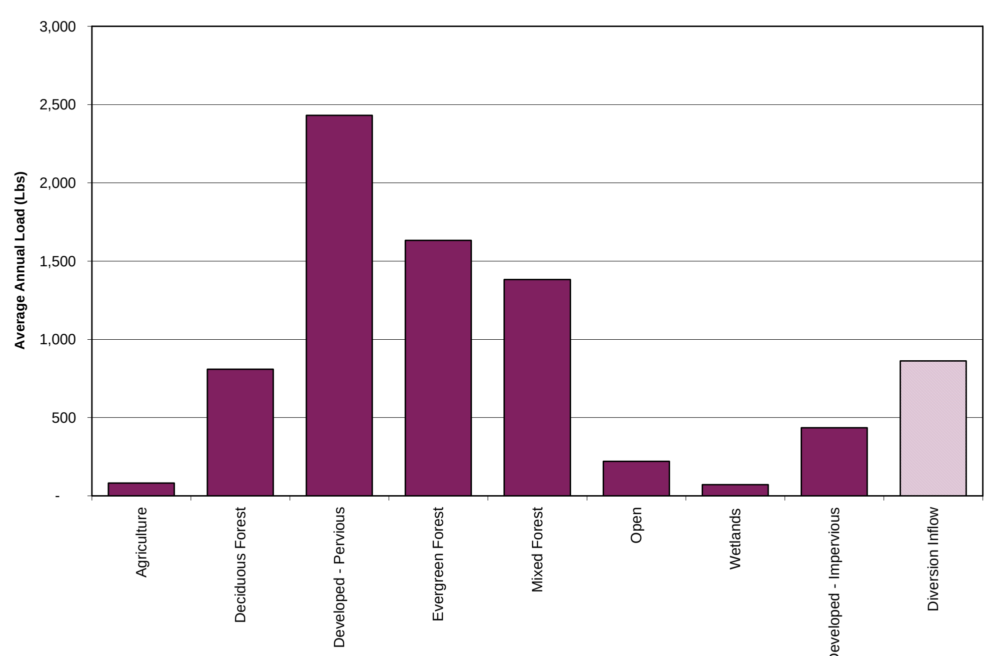
## Total Phosphorus Loading in Pounds per a Year for Each Land Cover Type in Lake Whatcom Watershed Area

| Land Cover Type | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|
| | *Year* | | | | | | |
| Agriculture | 41 | 50 | 111 | 63 | 117 | 113 | **83** |
| Deciduous Forest | 410 | 545 | 1,078 | 640 | 1,121 | 1,065 | **810** |
| Developed Pervious | 1,403 | 2,070 | 3,048 | 1,963 | 3,130 | 2,976 | **2,432** |
| Evergreen Forest | 851 | 1,086 | 2,182 | 1,319 | 2,259 | 2,095 | **1,632** |
| Mixed Forest | 695 | 950 | 1,843 | 1,086 | 1,907 | 1,813 | **1,382** |
| Open | 116 | 144 | 295 | 182 | 305 | 287 | **221** |
| Wetlands | 35 | 39 | 96 | 60 | 103 | 94 | **71** |
| Developed Impervious | 412 | 158 | 521 | 467 | 532 | 523 | **435** |
| Diversion Inflow | | 900 | 512 | 911 | 859 | 1,131 | **863** |
| **Total Annual Load** | 3,963 | 5,043 | 9,173 | 5,780 | 9,474 | 8,966 | **7,067** |

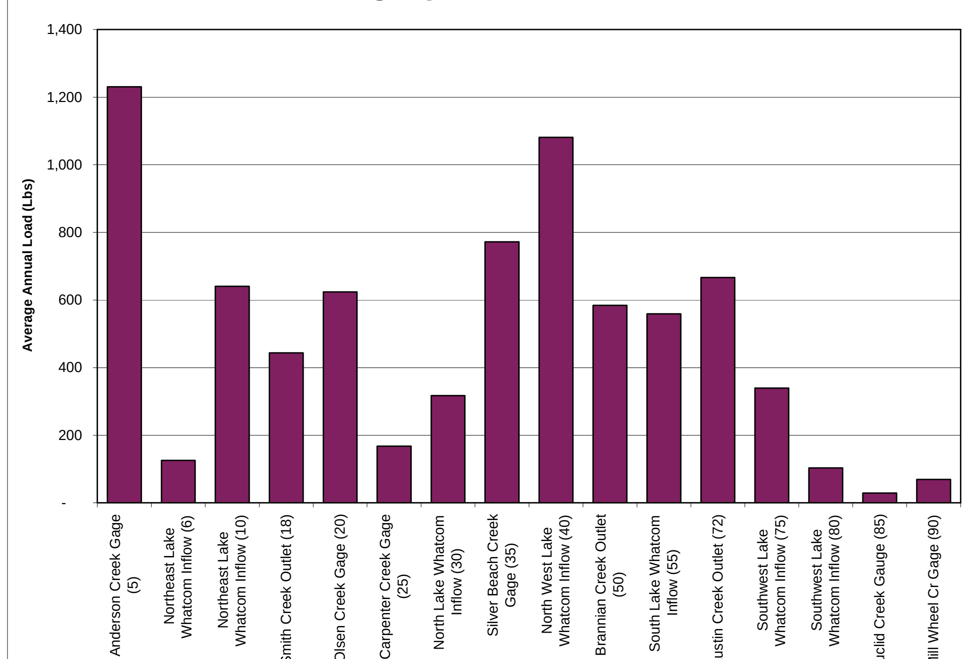
## Total Phosphorus Loading in Pounds per a Year for Each Subwatershed in Lake Whatcom Watershed Area

| Reach | Name | Average Annual Simulated TP Load (Lbs) | | |
|---|---|---|---|---|
| | | *By Lake Inflows* | *By Subwatershed* | |
| 1 | Diversion | | 863 | |
| 1 | Mirror Lake (1) | | 31 | |
| 5 | Anderson Creek Gage (5) | 1,231 | 385 | |
| 6 | Northeast Lake Whatcom Inflow (6) | 125 | 127 | |
| 10 | Northeast Lake Whatcom Inflow (10) | 640 | 642 | |
| 15 | Smith Creek Gage (15) | | 433 | |
| 18 | Smith Creek Outlet (18) | 444 | 3 | |
| 20 | Olsen Creek Gage (20) | 624 | 621 | |
| 25 | Carpenter Creek Gage (25) | 168 | 166 | |
| 30 | North Lake Whatcom Inflow (30) | 317 | 315 | |
| 35 | Silver Beach Creek Gage (35) | 772 | 764 | |
| 40 | North West Lake Whatcom Inflow (40) | 1,081 | 1068 | |
| 45 | Brannian Creek Gage (45) | | 565 | |
| 50 | Brannian Creek Outlet (50) | 584 | 22 | |
| 55 | South Lake Whatcom Inflow (55) | 559 | 560 | |
| 60 | Upper Austin Creek (60) | | 216 | |
| 65 | Beaver Cr trib Austin Cr (65) | | 320 | |
| 70 | Austin Creek at Gage (70) | | 29 | |
| 72 | Austin Creek Outlet (72) | 666 | 112 | |
| 75 | Southwest Lake Whatcom Inflow (75) | 340 | 334 | |
| 80 | Southwest Lake Whatcom Inflow (80) | 190 | 177 | |
| 85 | Euclid Creek Gauge (85) | 54 | 51 | |
| 90 | Mill Wheel Cr Gage (90) | 129 | 125 | |
| | **TOTAL** | 7,925 | 7,929 | Total Annual TP Load (Lbs) |
| | | 31,360 | 31,360 | Total Watershed Area |
| | | 0.25 | 0.25 | Lbs/acre/year |

## Loading by Land Cover




## Loading by Lake Inflows




## Loading by Subwatershed

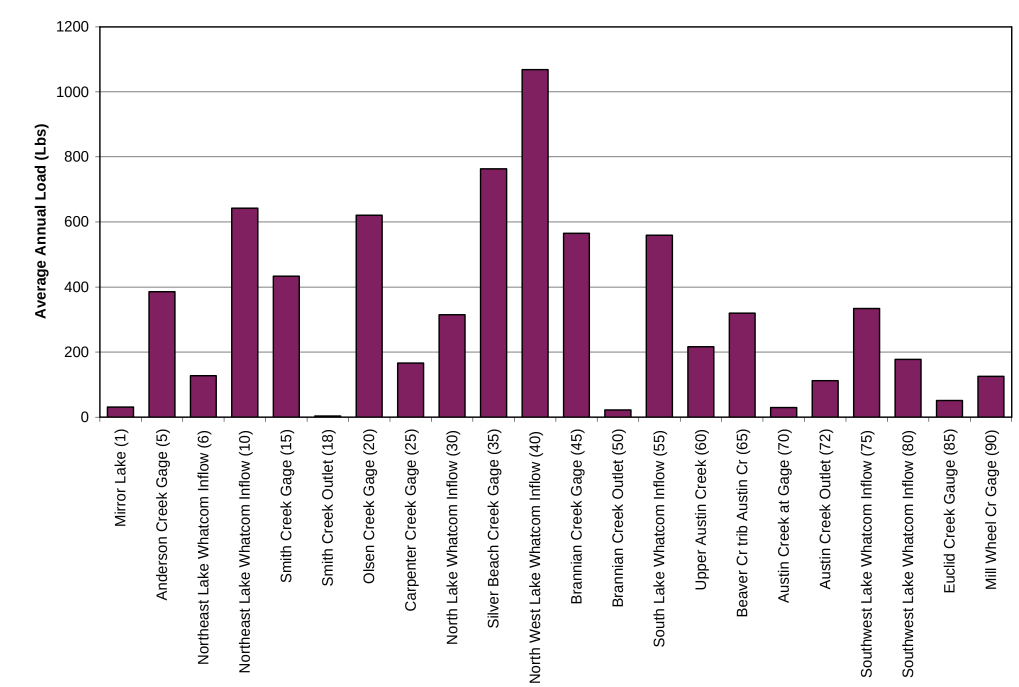





**Figure 3-8**
Total Phosphorus Loading Results by Land Cover, Lake Inflows, and Subwatershed

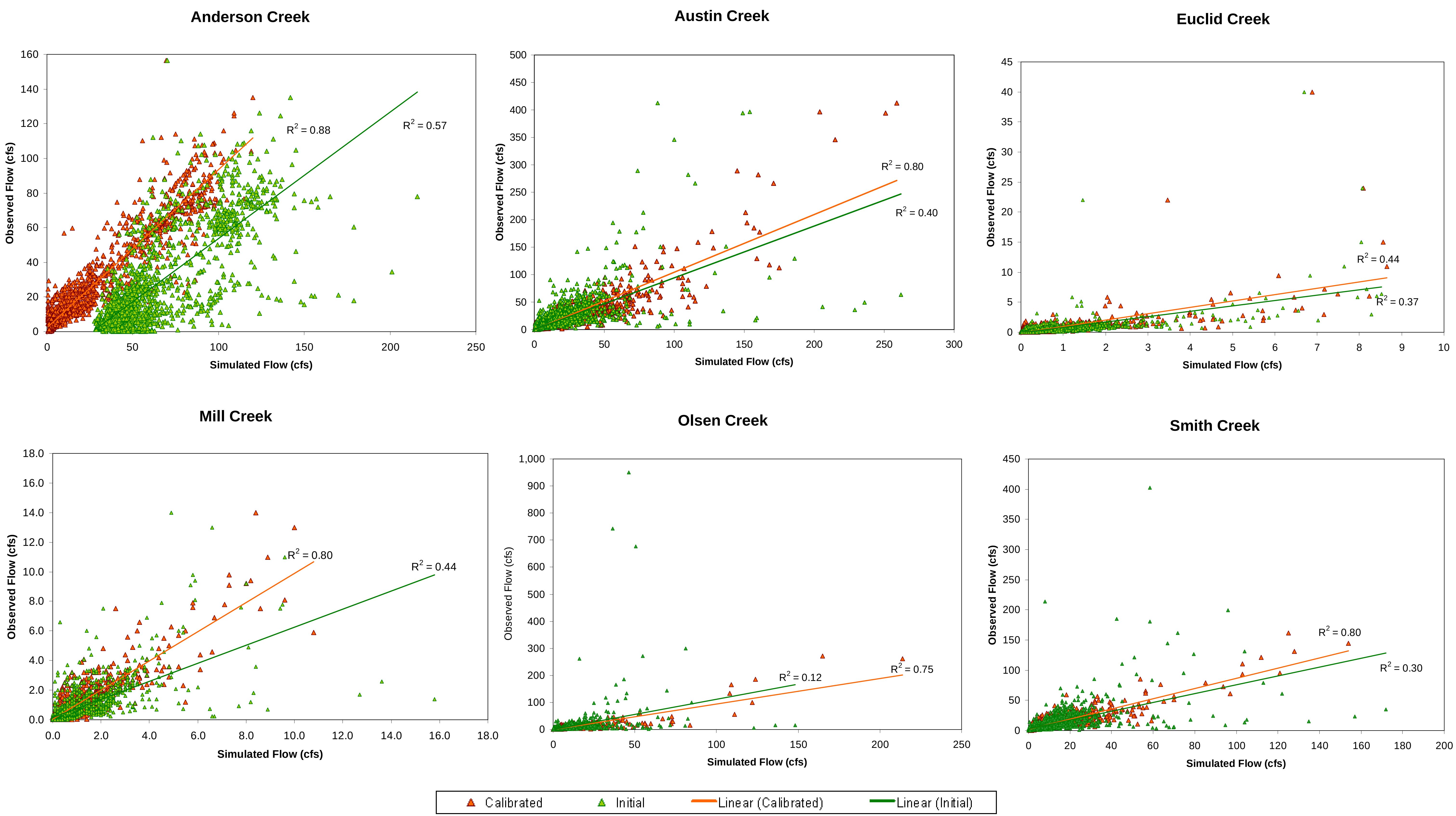





**Figure 3-9**
Comparison of HFAM and HSPF
Simulated Hydrology Results after Calibration

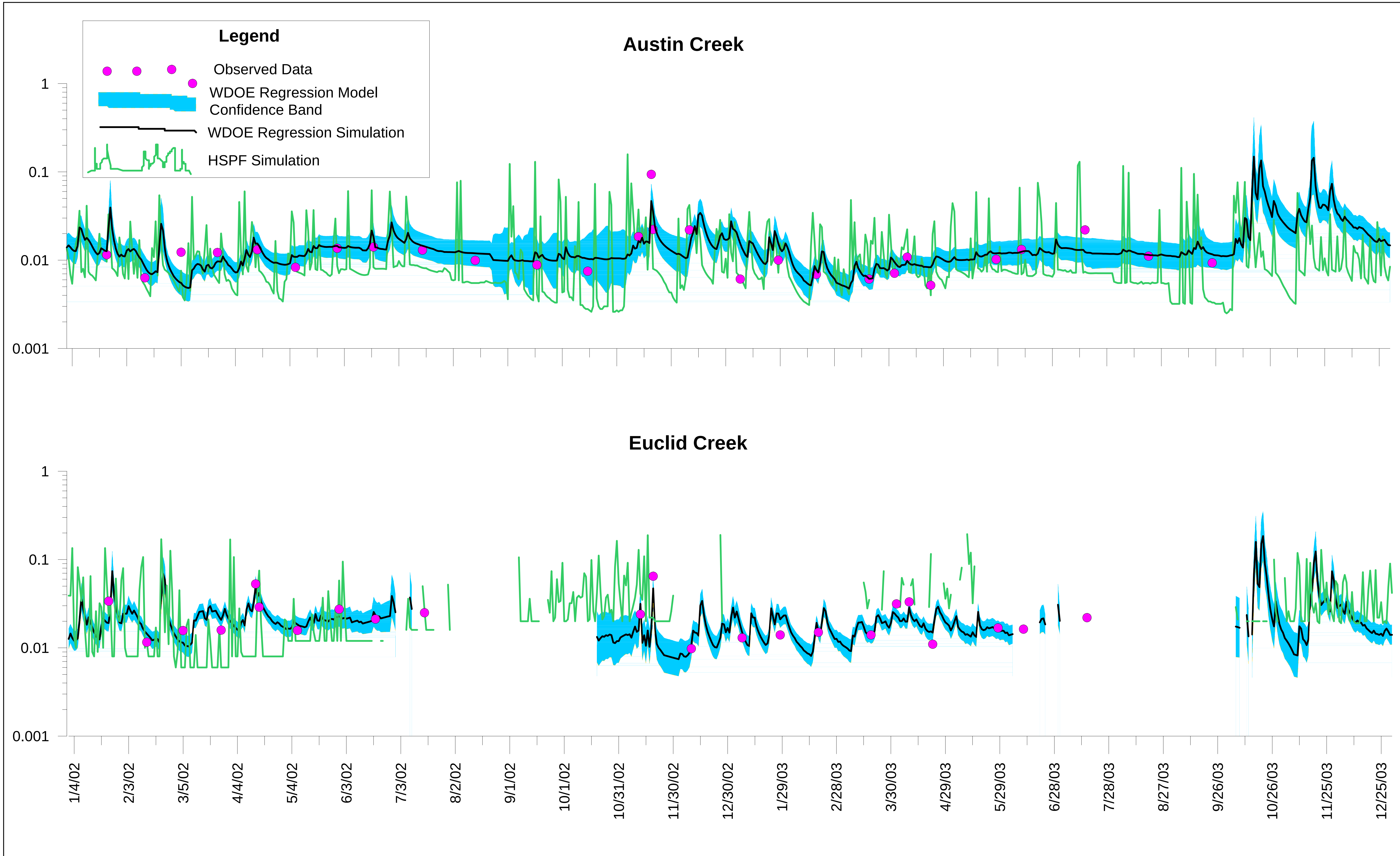





**Figure 3-10a**
Comparison of WDOE Regression Model and HSPF Results
Total Phosphorus (mg/L)

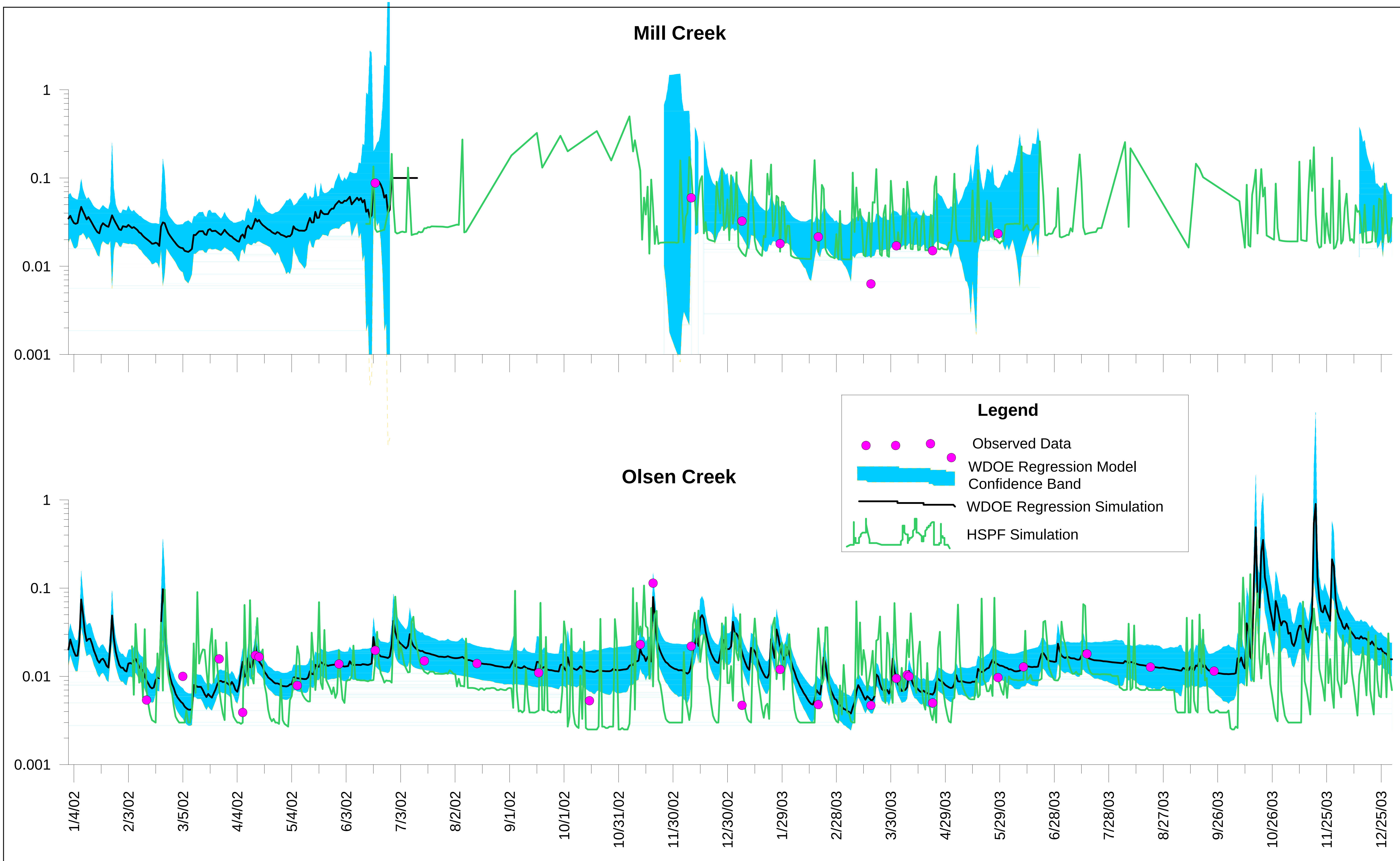





**Figure 3-10b**
Comparison of WDOE Regression Model and HSPF Results
Total Phosphorus (mg/L)

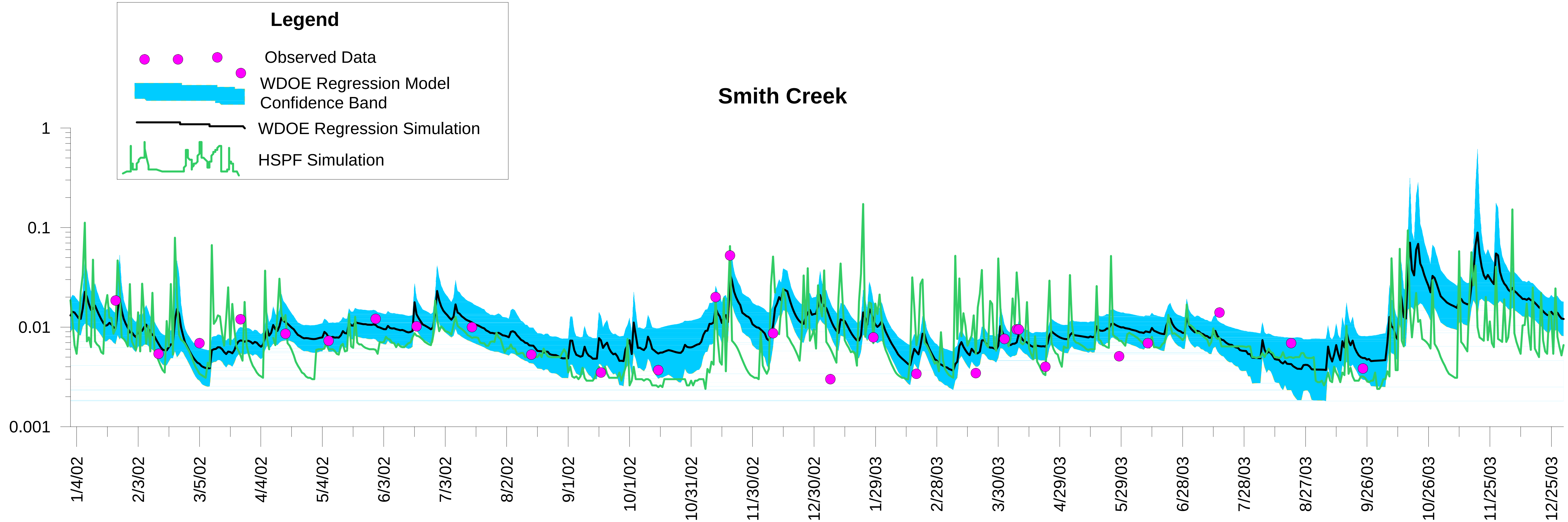





**Figure 3-10c**
Comparison of WDOE Regression Model and HSPF Results
Total Phosphorus (mg/L)

# Appendix A
## Data Bibliography

# Appendix B

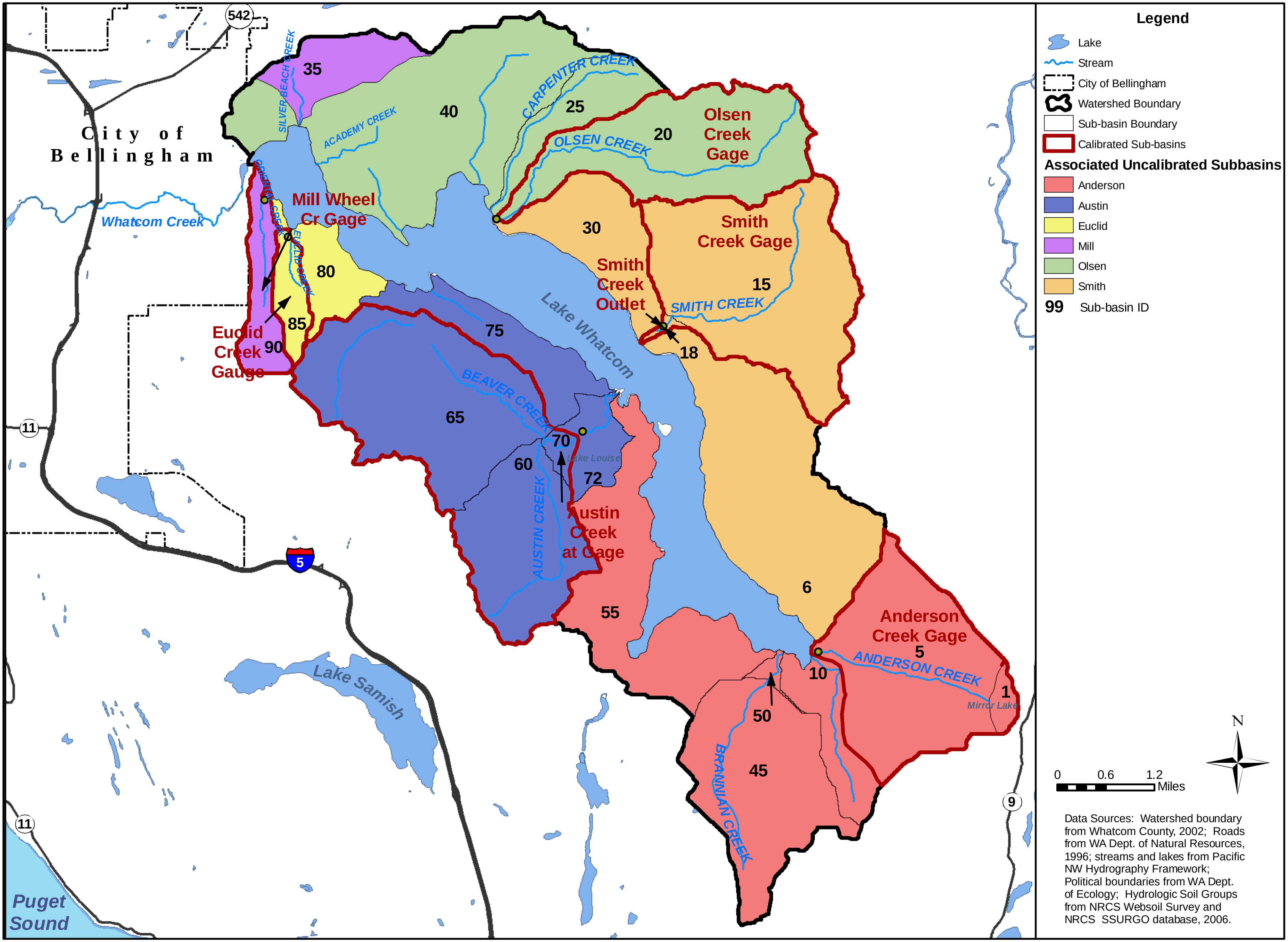
## Technical Memorandum – Modeling Approach

# Appendix C

## Modeling Quality Assurance Project Plan

# Appendix D

## Lake Whatcom HSPF Model CD and Datasets

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FINAL MODEL REPORT

**Figure 3-7**
Application of Calibrated Subwatershed Parameters

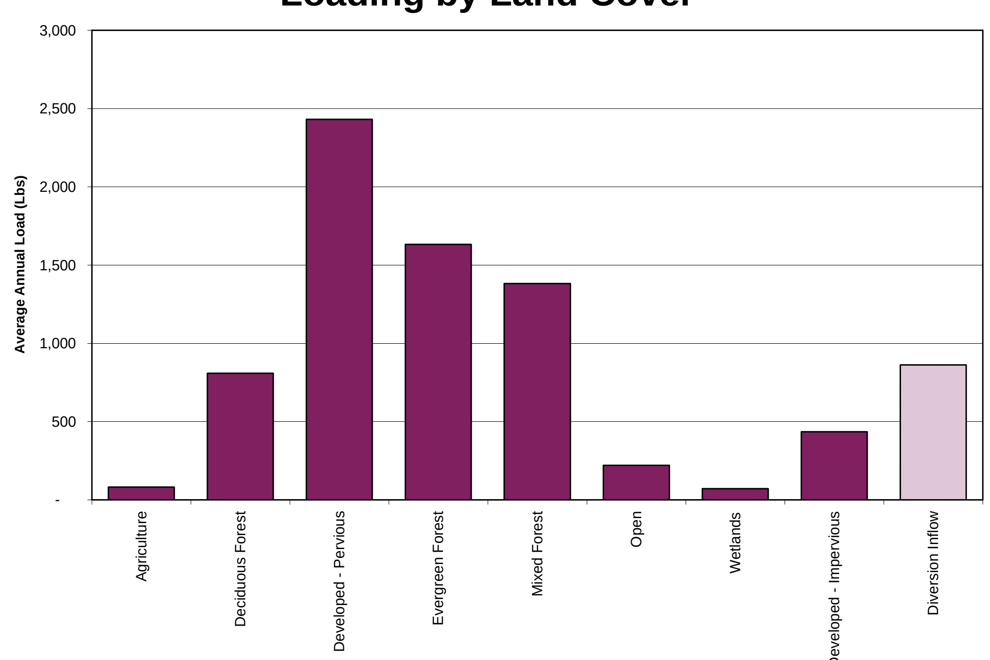
### Total Phosphorus Loading in Pounds per a Year for Each Land Cover Type in Lake Whatcom Watershed Area

| Land Cover Type | Year 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | Average |
|---|---|---|---|---|---|---|---|
| Agriculture | 41 | 50 | 111 | 63 | 117 | 113 | **83** |
| Deciduous Forest | 410 | 545 | 1,078 | 640 | 1,121 | 1,065 | **810** |
| Developed Pervious | 1,403 | 2,070 | 3,048 | 1,963 | 3,130 | 2,976 | **2,432** |
| Evergreen Forest | 851 | 1,086 | 2,182 | 1,319 | 2,259 | 2,095 | **1,632** |
| Mixed Forest | 695 | 950 | 1,843 | 1,086 | 1,907 | 1,813 | **1,382** |
| Open | 116 | 144 | 295 | 182 | 305 | 287 | **221** |
| Wetlands | 35 | 39 | 96 | 60 | 103 | 94 | **71** |
| Developed Impervious | 412 | 158 | 521 | 467 | 532 | 523 | **435** |
| Diversion Inflow | | 900 | 512 | 911 | 859 | 1,131 | **863** |
| Total Annual Load | 3,963 | 5,043 | 9,173 | 5,780 | 9,474 | 8,966 | **7,929** |

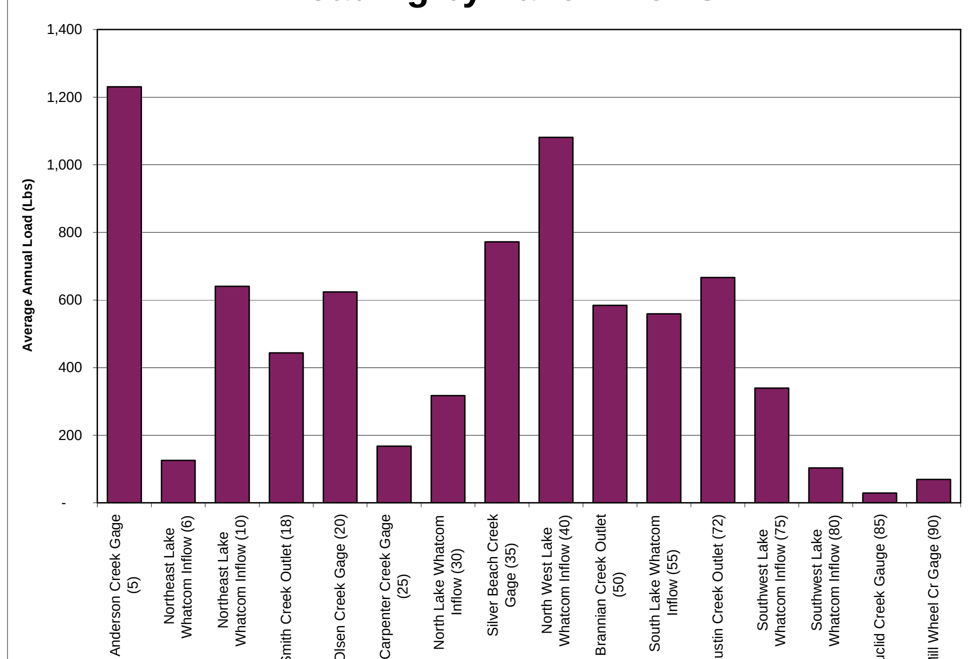
### Total Phosphorus Loading in Pounds per a Year for Each Subwatershed in Lake Whatcom Watershed Area

| Reach | Name | Average Annual Simulated TP Load (Lbs) *By Lake Inflows* | *By Subwatershed* | Ecology TMDL Lake Model Tributary Input Loads (Lbs) |
|---|---|---|---|---|
| 1 | Diversion | | 863 | |
| 1 | Mirror Lake (1) | | 31 | |
| 5 | Anderson Creek Gage (5) | 1,231 | 385 | |
| 6 | Northeast Lake Whatcom Inflow (6) | 125 | 127 | |
| 10 | Northeast Lake Whatcom Inflow (10) | 640 | 642 | |
| 15 | Smith Creek Gage (15) | | 433 | |
| 18 | Smith Creek Outlet (18) | 444 | 3 | 541 |
| 20 | Olsen Creek Gage (20) | 624 | 621 | 3,940 |
| 25 | Carpenter Creek Gage (25) | 168 | 166 | 74 |
| 30 | North Lake Whatcom Inflow (30) | 317 | 315 | |
| 35 | Silver Beach Creek Gage (35) | 772 | 764 | 214 |
| 40 | North West Lake Whatcom Inflow (40) | 1,081 | 1068 | |
| 45 | Brannian Creek Gage (45) | | 565 | |
| 50 | Brannian Creek Outlet (50) | 584 | 22 | 786 |
| 55 | South Lake Whatcom Inflow (55) | 559 | 560 | |
| 60 | Upper Austin Creek (60) | | 216 | |
| 65 | Beaver Cr trib Austin Cr (65) | | 320 | |
| 70 | Austin Creek at Gage (70) | | 29 | 1,268 |
| 72 | Austin Creek Outlet (72) | 666 | 112 | |
| 75 | Southwest Lake Whatcom Inflow (75) | 340 | 334 | |
| 80 | Southwest Lake Whatcom Inflow (80) | 190 | 177 | |
| 85 | Euclid Creek Gauge (85) | 54 | 51 | 43 |
| 90 | Mill Wheel Cr Gage (90) | 129 | 125 | 100 |
| | **TOTAL** | 7,925 | 7,929 | Total Annual TP Load (Lbs) |
| | | 31,360 | 31,360 | Total Watershed Area |
| | | 0.25 | 0.25 | Lbs/acre/year |

### Loading by Land Cover




### Loading by Lake Inflows




### Loading by Subwatershed

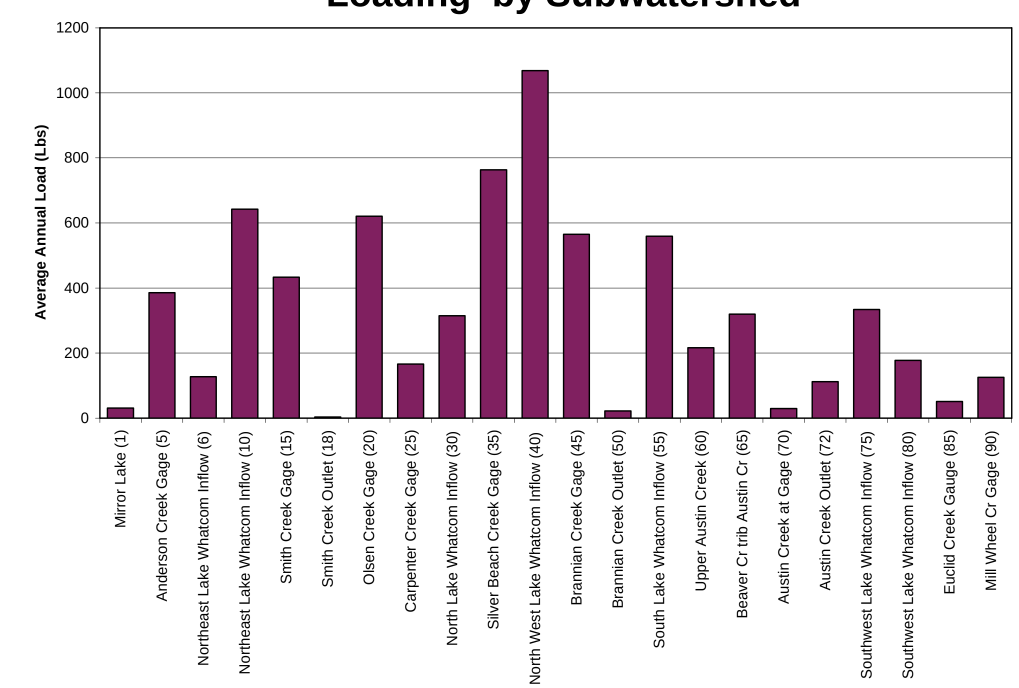





**Figure 3-8**
Total Phosphorus Loading Results by Land Cover, Lake Inflows, and Subwatershed

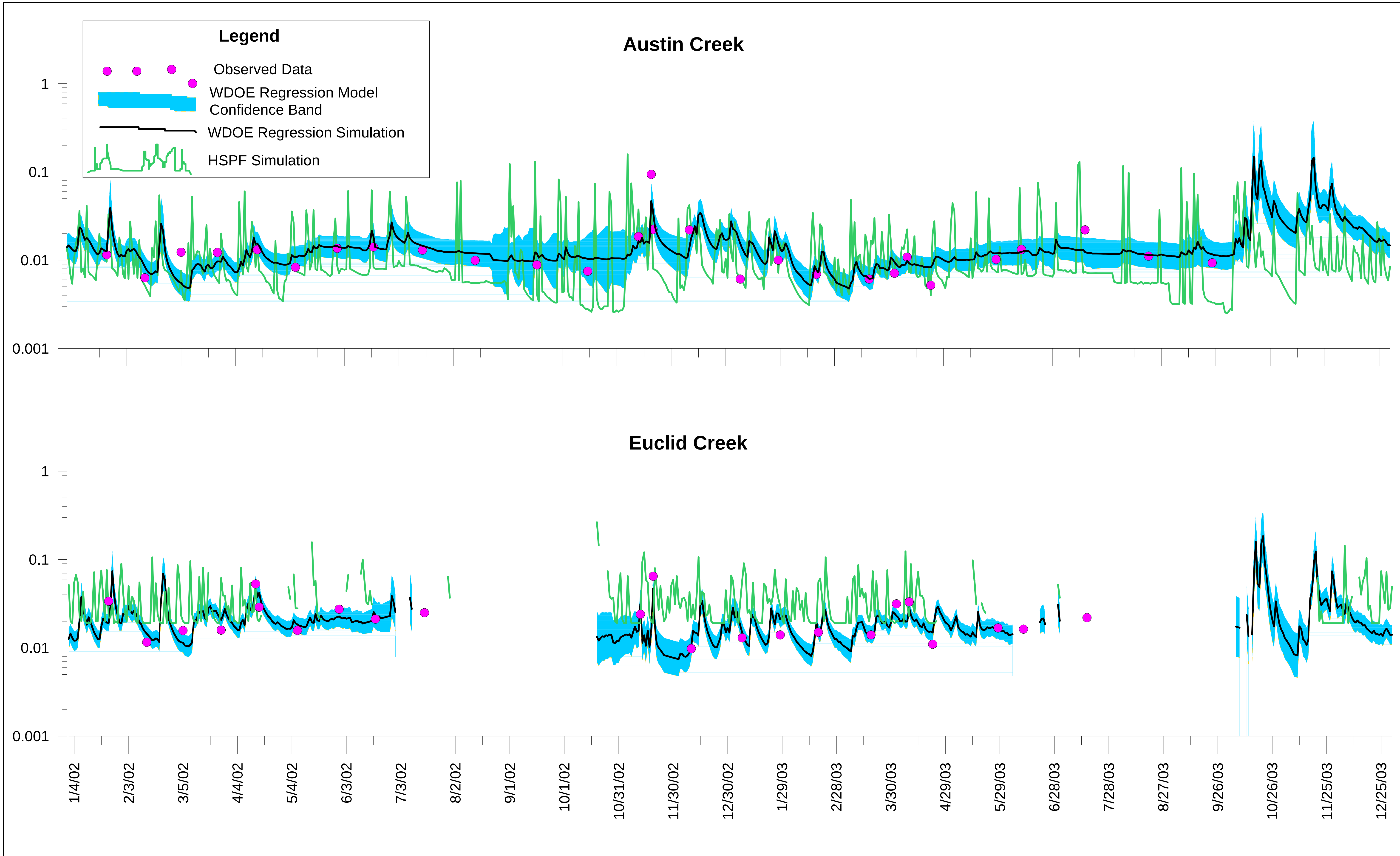





**Figure 3-10a**
Comparison of WDOE Regression Model and HSPF Results
Total Phosphorus (mg/L)