Appendix G

Whipple Creek Watershed-Scale Stormwater Plan Report

Water Quality Model Calibration Report

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1. INTRODUCTION

1.1 Background

The Whipple Creek basin has been adversely impacted by changes in stormwater, a result of development that mainly occurred over the last three decades, in some areas with limited, or no stormwater controls. Consequently, Whipple Creek's designated beneficial use of salmon habitat is seriously degraded.

The Washington State Department of Ecology issued a 2013-2018 Phase I Municipal Stormwater Permit (Permit) that requires Clark County (County) to select a watershed and perform watershed-scale stormwater planning as outlined in section S5.C.5.c. This section states that "the objective of watershed-scale stormwater planning is to identify a stormwater management strategy or strategies that would result in hydrologic and water quality conditions that fully support 'existing uses' and 'designated uses', as those terms are defined in WAC 173-201A-020, throughout the stream system."

Whipple Creek is not specifically listed in WAC 173-201A-602. The designated uses for streams not specifically listed are:

- Salmonid spawning, rearing, and migration;
- Primary contact recreation;
- Domestic, industrial, and agricultural water supply;
- Stock watering;
- Wildlife habitat;
- Shellfish harvesting;
- Commerce and navigation;
- Boating; and
- Aesthetic values.

Among these, the salmonid uses are the most challenging to maintain and restore, typically requiring habitat conditions equivalent to those found in a predominantly forested watershed.

The 2010 Clark County Stream Health Report rated Whipple Creek as poor for flow, water quality, and biological health (Department of Environmental Services, 2010). The Washington State Department of Ecology (Ecology) includes Whipple Creek in its 303(d) Category 5 list (polluted waters requiring a TMDL) for fecal coliform bacteria, temperature and bio-assessment (B-IBI) and Category 2 list (waters of concern) for dissolved oxygen (Ecology, 2015).

1.2 Study area

Whipple Creek watershed is located in southwest Clark County, draining west from low hills to the Columbia River flood plain. The watershed was once dominated by rural and agricultural land uses. It is currently moderately developed with a mix of rural, urban, and urbanizing areas at the northern edge of the Vancouver Urban Growth Area (UGA). Approximately 4.4 square miles of the 12.1 square mile basin is inside the UGA. Historic clearing and development impacts have degraded stream habitat and caused areas of severe channel instability and erosion. Impacts from these changes to land cover are consistent with those documented elsewhere around Washington State for channel stability, water quality, and overall ecological function. General land use in Whipple Creek includes developed urban areas, low density rural residential, and some agriculture.

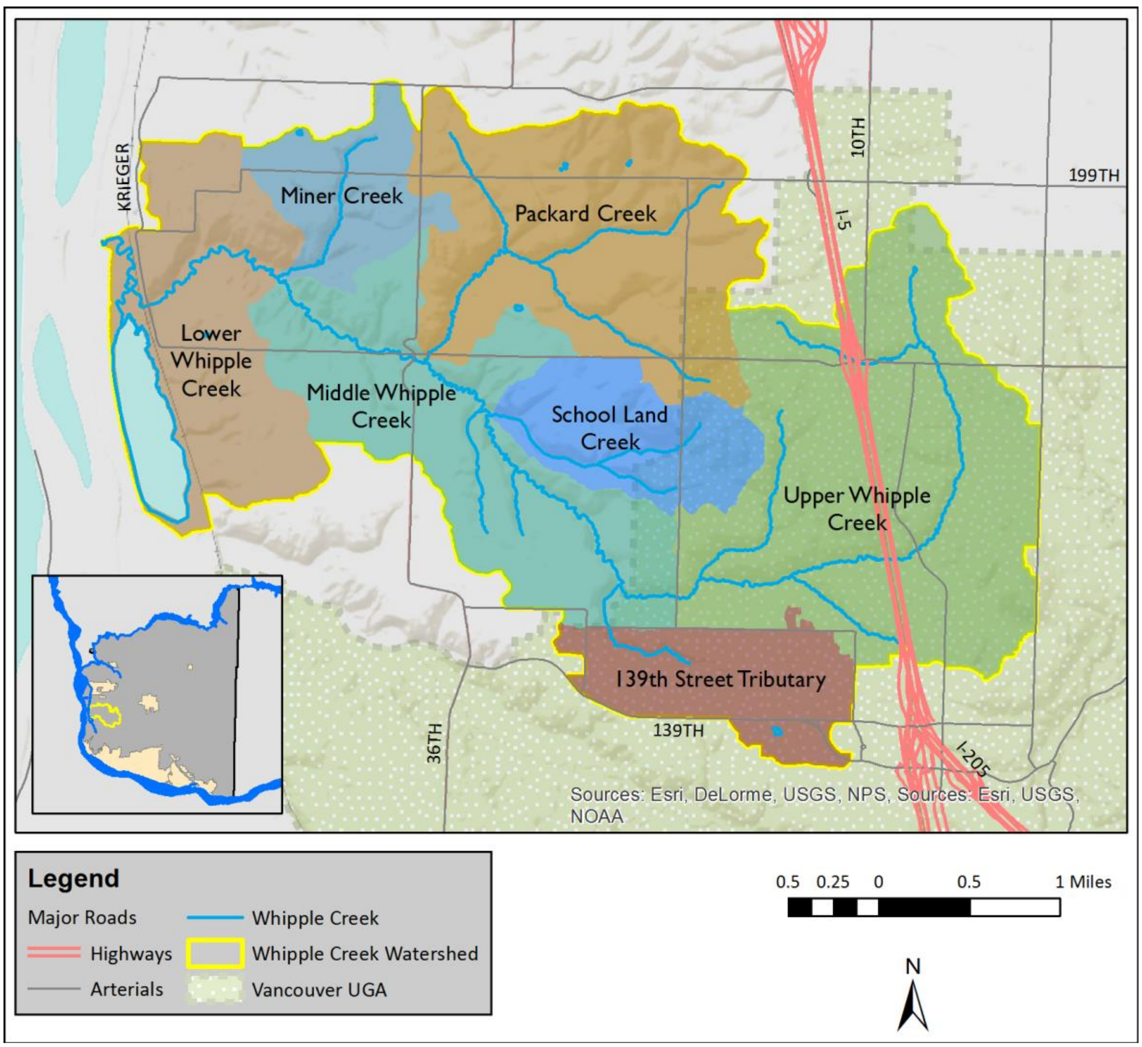

Figure 1. Map of Whipple Creek Basin

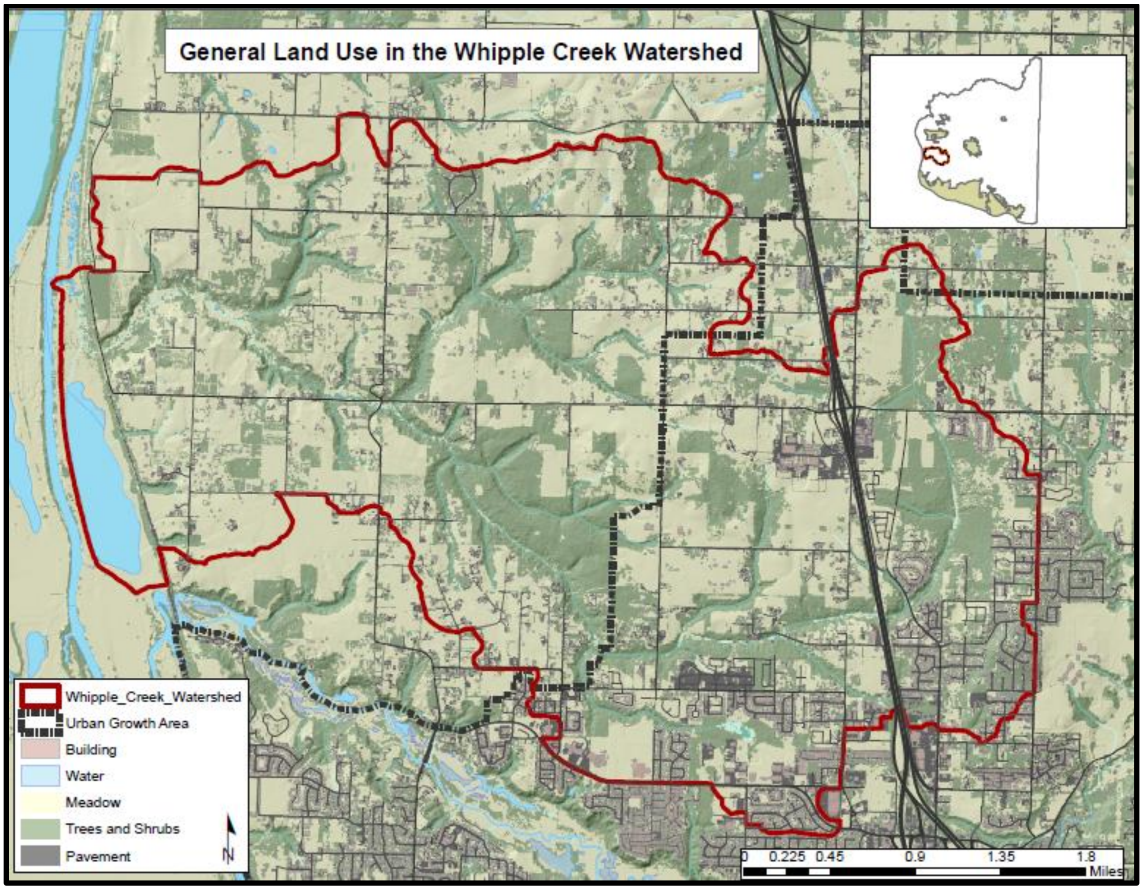

Figure 2. General Land Use in the Whipple Creek Watershed

Table 1. Current Land Use of Whipple Creek Study Area, 2014

Land Use	Acres	Percent of Total Area
Impervious	731.34	9.5%
Forest	2397.14	31.0%
Pasture	2640.19	34.2%
Lawn	1761.78	22.8%
Water	191.62	2.5%
Total	7722.07	100.0%

1.3 Objectives

The objective of the water quality model is to simulate four water quality constituents (water temperature, dissolved copper, dissolved zinc, and fecal coliform) in Whipple Creek and develop a calibrated HSPF model for the watershed.

Clark County Clean Water Division conducted the Long-term Index Site Project (LISP) to monitor stream water quality beginning in 2002. The project collected information about stream health status and trends at 10 stations along 10 streams including Whipple Creek. The LISP station in the Whipple Creek watershed, named WPL050, is located in the main stem near NW 179th Street. WPL050, along with either other monitoring stations used at various times to collect data, is shown in Figure 3.

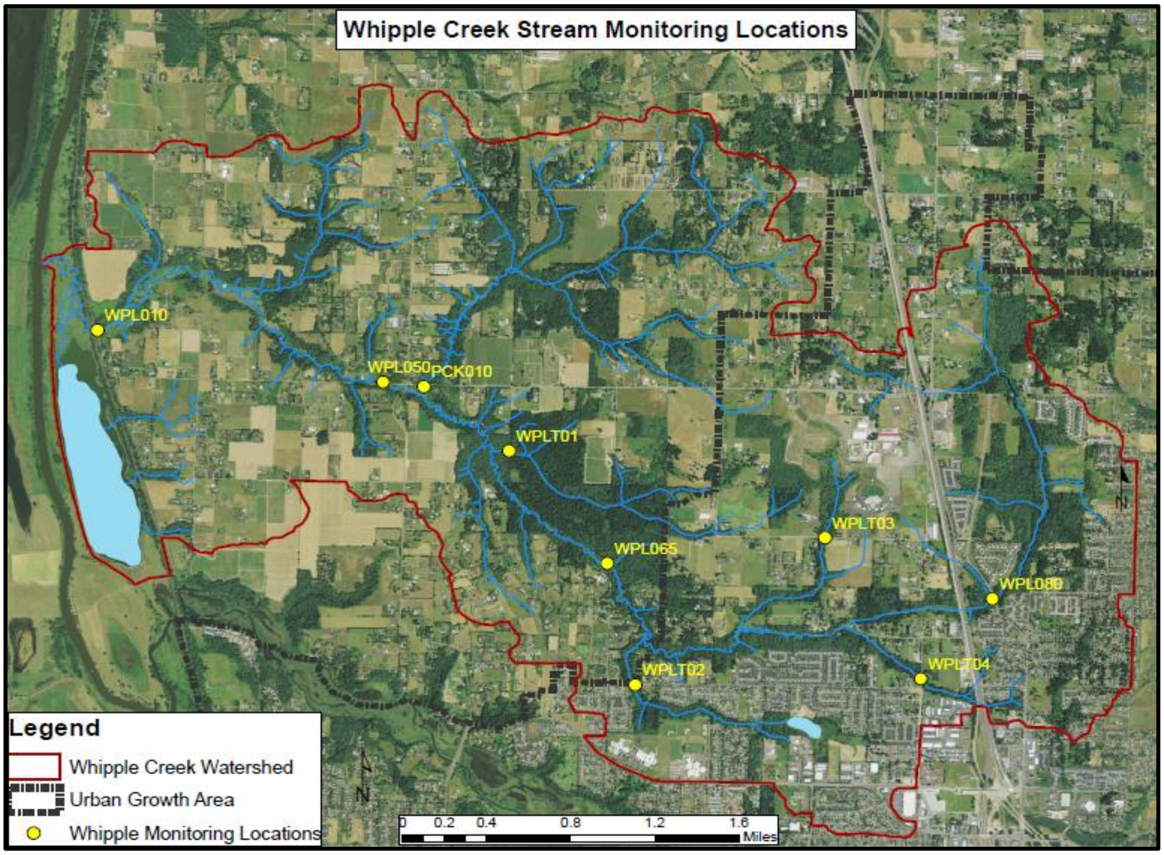

Figure 3: WPL050 and Other Monitoring Station Locations

Physiochemical and bacteria samples and measurements were collected monthly. Temperature data loggers were typically deployed during late spring and summer months from May through September. As part of Whipple Creek watershed planning, Clean Water Program staff also collected water quality data (water temperature, dissolved copper, dissolved zinc, and fecal coliform) from May 2014 to 2015.

The HSPF model water quality calibration used the same period of record as the hydrology calibration (water years 2004 through 2008).

1.4 Washington State Water Quality Standards

1.4.1 Temperature

Stream temperature is one of the most important environmental influences on salmon biology. Under the state water quality stream standards, temperature is measured as the 7-day average of the daily maximum temperatures (7DADMax). The highest 7DADMax temperature allowed to meet standards for Whipple Creek's beneficial uses is 63.5°F (17.5°C).

1.4.2 Metals (copper and zinc)

Washington State's dissolved metals' acute and chronic water quality criteria are targeted toward high frequency sampling applying 1-hour and 4-day average concentrations, respectively, that are not to be exceeded more than once every three years on the average. The concentration thresholds are determined by an equation as a function of water hardness.

1.4.3 Fecal Coliform

The Washington State standards utilize two criteria for bacteria: 1) not exceeding a geometric mean value of 100 colonies / 100 mL and 2) not more than 10 percent of all samples (or any single sample when less than ten sample points exist) exceeding 200 colonies / 100 mL.

1.4.3 Summary

Table 2.Whipple Creek watershed state designated uses and water quality standards criteria

Parameter	Applicable Designated Use	State WQ Standard Criteria
Temperature	Aquatic Life: salmonid spawning, rearing, and migration	7-Day Average Daily Maximum (7-DADMax) of 17.5°C
Dissolved Copper	Aquatic Life – most sensitive biota: Toxic substances	Acute and chronic criteria math formulas incorporating water hardness
Dissolved Zinc	Aquatic Life – most sensitive biota: Toxic substances	Acute and chronic criteria math formulas incorporating water hardness
Fecal Coliform	Primary contact recreation	< geometric mean of 100 colonies / 100 mL and <10% of samples: 200 colonies / 100 mL

2. METHODOLOGY

2.1 Water Quality Model Development

In HSPF, a watershed is represented by a group of hydrologically similar areas referred to as hydrologic response units (HRUs) that drain to a stream segment, lake, or reservoir referred to as a RCHRES (composed of open or closed channels). HRUs reflect areas in a sub-watershed of similar land covers, surficial geology, and other factors deemed important to produce a similar hydrologic response to rainfall and potential evapotranspiration. HRUs are categorized as either pervious or impervious land segments, termed PERLND (PERvious LaND) or IMPLND (IMPervious LaND), respectively.

A PERLND is represented conceptually within HSPF by three interconnected water storage zones—an upper zone, a lower zone, and a groundwater zone.

An IMPLND is represented by surface storage, evaporation, and runoff processes. The hydraulics of stream reaches is simulated using storage routing (Donigian, Imhoff, & Ambrose 1995).

The HSPF model of the Whipple Creek watershed was developed by 1) compiling and processing required input data, 2) configuring the model to represent the watershed, and 3) calibrating the model to improve simulation accuracy.

The Whipple Creek water quality model was developed based on a previously calibrated HSPF hydrology model (see Appendix F for details). The HSPF hydrology model was expanded by adding several water quality blocks or modules to all pervious (PERLND) and impervious (IMPLND) lands within the watershed. The water quality modules include several parameters to represent production, removal, and transport of sediment and pollutants. The HSPF model uses several built-in equations to calculate soil detachment and soil washoff.

The Whipple Creek hydrologic model is divided into 27 sub-basins and 28 stream reaches. Land covers within each sub-basin are: forest, pasture, lawn, wetlands (only 1%) and impervious areas (rooftops, sidewalks and roadways). See Table 3 and Figure 4.

Table 3. Five Land Covers and Acres within Each Sub-basin of Whipple Creek

Sub-basin	Impervious	Forest	Pasture	Lawn	Water	Total
GL	21.51	140.74	271.28	32.27	184.85	650.65
WC1	28.62	146.62	234.87	95.33	1.78	507.22
WC1A	21.71	145.38	190.22	82.40	0.00	439.71
WC2	23.50	127.58	253.21	92.49	0.00	496.78
WC3	5.11	63.38	82.42	17.81	0.44	169.16
WC3A	10.96	43.70	140.85	35.14	0.00	230.65
WC4	8.84	167.20	77.35	29.33	0.00	282.72
WC4A	16.04	258.89	168.15	79.22	0.00	522.30
WC5	19.77	77.47	35.97	44.48	0.00	177.69
WC5A	116.27	83.06	60.81	298.77	2.53	561.44
WC6	37.08	49.31	6.91	42.24	0.00	135.54
WC6A	32.75	35.80	80.82	52.69	0.50	202.56
WC6B	38.52	19.15	21.28	40.51	0.00	119.46
WC7	10.13	52.61	50.90	25.97	0.22	139.83
WC7A	7.84	24.42	14.93	16.91	0.00	64.10
WC7B	17.23	12.17	18.93	18.53	0.00	66.86
WC7C	29.93	28.13	9.19	74.21	0.00	141.46
WC7D	35.86	23.44	3.09	90.50	1.30	154.19
WC75	32.26	14.31	35.22	57.27	0.00	139.06
WC8	67.30	179.85	68.29	144.39	0.00	459.83
WC9	35.20	99.05	107.10	77.69	0.00	319.04
WC9A	55.87	44.34	47.41	76.89	0.00	224.51
PC1	8.93	109.20	84.36	17.27	0.00	219.76
PC1A	6.87	74.26	92.84	35.88	0.00	209.85
PC1B	6.98	63.73	79.12	27.53	0.00	177.36
PC2	21.28	196.59	212.73	87.46	0.00	518.06
PC2A	14.98	116.76	191.94	68.60	0.00	392.28
Total	**731.34**	**2397.14**	**2640.19**	**1761.78**	**191.62**	**7722.07**

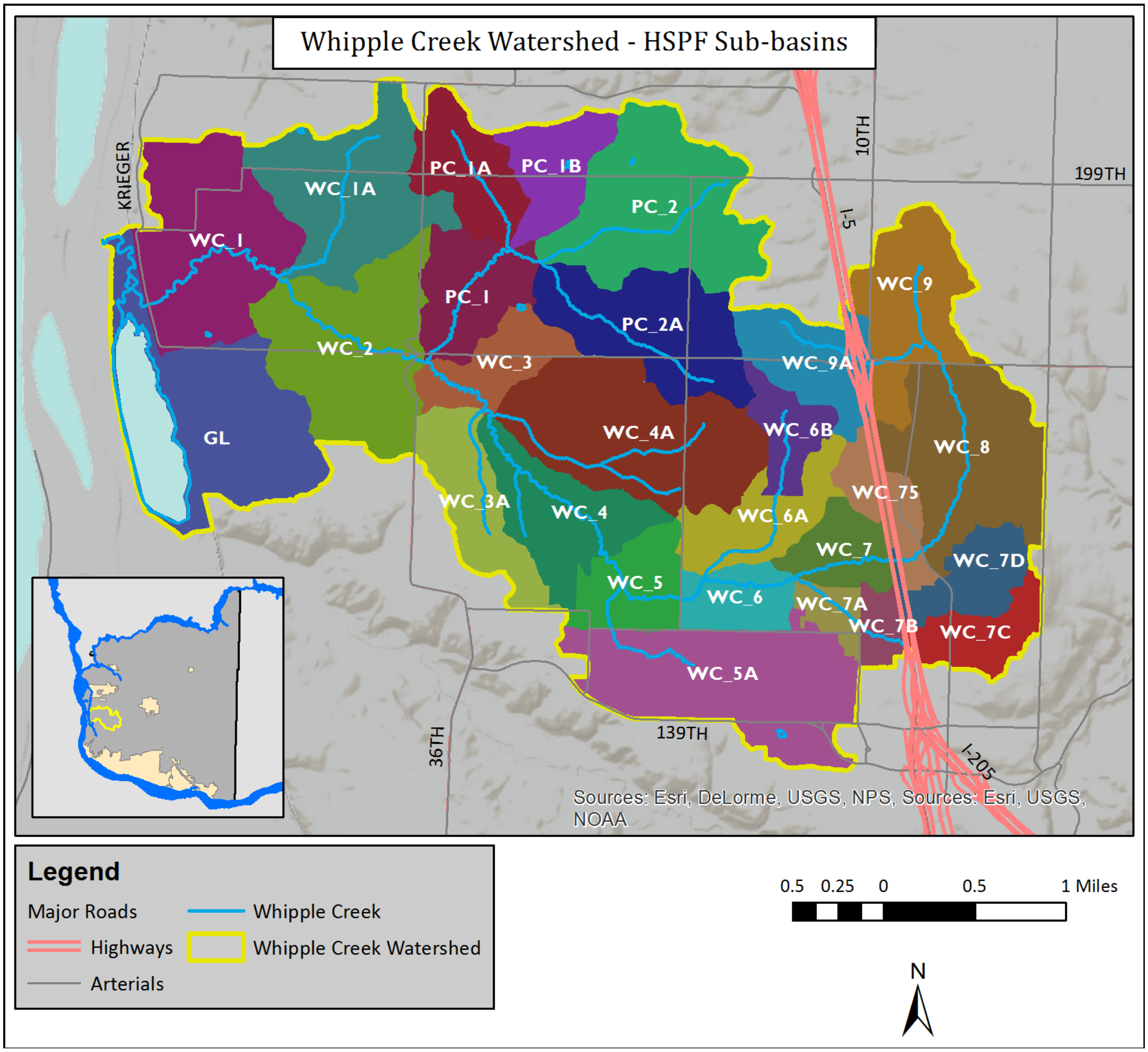

Figure 4. Whipple Creek Sub-basins

2.2 Water Quality Model Input

Input data for the HSPF model includes spatial data (land cover, topography, geology, and soils), hydraulic characteristics of stream segments (RCHRESs), meteorological data, streamflow, and water quality data. Spatial data were used to develop model HRUs (PERLNDs, IMPLNDs) and RCHRESs. Hydraulic characteristics for each stream segment were estimated from a HEC-RAS model of the Whipple Creek watershed developed by West Consultants in 2008.

Other meteorological data required for the Whipple Creek model simulations comprise air temperature, dew point temperature, wind speed, solar radiation, cloud cover, and evaporation. These data (except evaporation) were obtained from data used to support the

Whipple Creek water quality model on 6/23/2015 and 3/3/2016 from atmospheric data gages maintained by MesoWest at the University of Utah. Using GEMPAK (General Environmental Meteorological Package) parameters, raw data was obtained from the KVOU (Vancouver, WA), KPDX (Portland, OR), and POBO (Portland, OR) gages from 2002-2015.

Continuous streamflow and discrete temperature and water-quality data were used to calibrate model parameters pertaining to constituent simulations. Streamflow and water quality data were collected at the stream monitoring stations shown above in Figure 3**Error! Reference source not found.**.

2.3 Model Configuration

In addition to hydrologic model input data, several modules of water quality data were added to the Whipple Creek HSPF model to simulate water quality constituents. The following is a list of input blocks used in the water quality model:

- PERLND: ATEMP, SED, PSTEMP, PWTGAS, PQUAL
- IMPLND: ATEMP, SLD, IWTGAS, IQUAL
- RCHRES: HTRCH, SEDTRN, GQUAL

Copper, zinc, and fecal coliform each had their own PQUAL, IQUAL, GQUAL blocks in the HSPF input file.

3. DEVELOPMENT OF INPUT DATA

3.1. Water Quality Time Series Data Sources

HSPF requires time series input data which include weather data and soil temperature data.

HSPF Weather Data Requirements:

- PRECIPITATION - Surface runoff is directly dependent on precipitation.
- POTENTIAL EVAPOTTRANSPIRATION - Evaporation directly from soil layers and vegetative surface and transpiration through plants.
- AIR TEMPERATURE - Function of elevation – conductive-convective heat transport.
- WIND SPEED - Heat exchange rate – heat balance in water bodies.
- SOLAR RADIATION - Heat balance in water bodies – snow melt – plankton growth rate.
- DEWPOINT TEMP - Determines when precipitation is considered as snow.
- CLOUD COVER - Cloud cover affects long-wave radiation balance.

Data used to support the Whipple Creek water quality model were obtained on 6/23/2015 and 3/3/2016 from atmospheric data gages maintained by MesoWest at the University of Utah. Using GEMPAK (General Environmental Meteorological Package) parameters, raw data was obtained from the KVOU (Vancouver, WA), KPDX (Portland, OR), and POBO (Portland, OR) gages from 2002-2015. The variables collected included air temperature, relative humidity, wind speed, dewpoint temperature, and three measurements of cloud cover data. The data contained several duplicate measurements, instances where multiple measurements were taken per hour, and data gaps. HSPF requires one measurement per hour, so the data were formatted in Microsoft Excel to match the organizational structure required by HSPF.

The methodology used to format the data consisted of the following: An hourly date time list was created for the period of record as an indexed comparison. A VLOOKUP table was made to assign measurements to the ordered list of dates and times from main list. All gaps in the data were identified. Data gaps in the KVOU data set were compared to and replaced by the KPDX gage data. Each data series was exported in a space delimited file and uploaded to a WDM file through SARA Time Series, developed by AQUA TERRA for the San Antonio River Authority. MesoWest database documentation can be found in Appendix A of the N-AWIPS 5.6 User's Guide.

3.2. HSPF Application and Utility Modules

Soil temperature (heat transfer through soil surface) data were retrieved from the AgWeatherNet database, maintained by Washington State University. The gage station, WSU Vancouver RE records meteorological data on a 15-minute time step. Soil temperature measurements are taken at an eight-inch depth. Monthly average soil temperatures and air temperature data were retrieved for the entire period of record of the station, from July 2008 to October 2015. A scatter plot of air temperature and soil temperature data was used to find a linear regression for each month over the approximately 9-year period. This linear regression equation was used to populate the coefficients in the PSTEMP section of the PERLND module to represent monthly ground temperature fluctuations. Specifically, the ASLT and BSLT input coefficients were populated using the slope and y-intercept from the regression equation. The model assumes the upper layer soil temperature (ULTP1 and ULTP2) follows the same regression as the surface soil temperature in relation to air temperature. The lower/ groundwater layer (LGTP1) was assumed constant at 48 degrees Fahrenheit.

To model fecal coliform bacteria, a debase EPA excel spreadsheet was utilized to estimate initial values for critical parameters such as SQOLIM (asymptotic limit for the storage of fecal coliform bacteria on the land surface) and WSQOP (daily buildup limit).

4. CALIBRATION AND VALIDATION RESULTS

This section represents a summary of watershed model simulation results. The presentation of water quality modeling results focused on the main stem stream reaches, where the calibrated model exhibited the best fit to the available data.

As described earlier in the report, water quality and quantity monitoring included data collection of water temperature, fecal coliforms, dissolved copper, and dissolved zinc at multiple sites. However, the model calibration focused on site WPL050.

4.1 Temperature

Stream temperature is one of the most important environmental influences on salmon biology. Under the state water quality stream standards, Whipple Creek is designated "Salmonid Spawning, Rearing, and Migration" and has the aquatic life temperature criteria highest 7DADMax temperature of 63.5°F (17.5°C). Summer stream temperature data collected approximately at river mile 3.1 of Whipple Creek (WPL050) show that this criterion is often exceeded, especially in the hotter months of July and August.

Water temperature simulations are accomplished in HSPF by the HTRCH section of the RCHRES (simulate heat exchange and water temperature) module. Changes in RCHRES water temperature are simulated by three major processes:

(1) heat transfer through movement of water into and out of each RCHRES;

(2) heat transfer across the air-water interface; and

(3) heat transfer across the water-streambed boundary.

Many parameters can be adjusted in temperature calibration, including PSTEMP (ASLT, BSLT, ULTP1, and ULTP2), IWTGAS (AWTF and BWTF) and RCHRES (KATRAD, KCOND, KEVAP, etc.). The temperature of overland flow will generally come into a dynamic equilibrium with the in-stream flow due to the heat capacity within the stream being much larger than that in the surface flow. BASINS/HSPF training Exercise 10 indicated that the RECRES parameters KATRAD, KCOND, KEVAP and CFSAEX are generally the most important calibration parameters.

Spot measurements of water temperature are available for RCHRES 120 (WPL050), for the period of 2007 and 2008. The data from this station were compared with the simulated water temperature to calibrate the HSPF model. RCHRES 120 is the only reach with water temperature data available for the model calibration period. The calibrated values of parameters related to RCHRES water temperature at WPL050 (RCHRES 120) were applied to all other stream reaches in the model.

A long-term simulation of water temperature showed a range between 40 °F and 69 °F and a mean temperature of 54 °F for water years 2007 and 2008. The observed (recorded) water temperature ranged between 39 °F and 68 °F for the same period (See Figure 5). A comparison between the simulated and observed/recorded temperatures shows a good match. Based on the limited recorded data the water temperature results are considered a very good to excellent calibration.

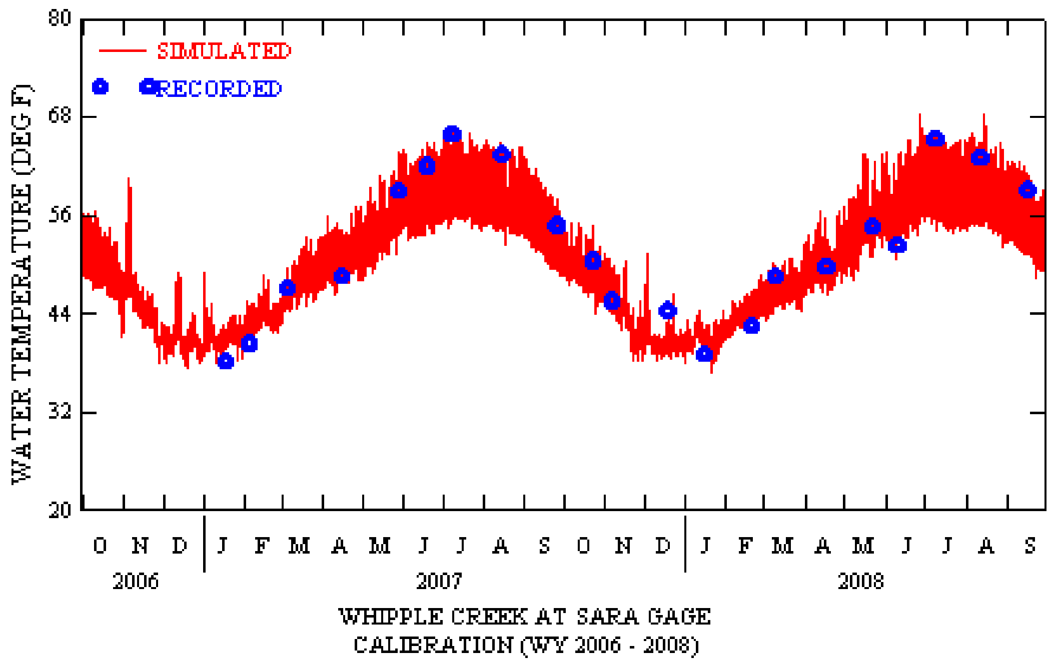

Figure 5: Whipple Creek Simulated and Recorded Water Temperature at WPL050

4.2 Dissolved Copper and Zinc

The fate of heavy metals in a water system is determined primarily by partitioning to water and particulate matter (including phytoplankton) and by transport. Partitioning is described in general by sorption to particulates, precipitation in minerals, and complexation in solution. The kinetic constant for sorption is not temperature-dependent.

Copper and zinc transport from land surfaces is simulated by accumulation and washoff of the dissolved form and the constituent associated with sediment. These processes are accomplished by the PQUAL and IQUAL modules (within PERLND and IMPLND modules, respectively).

Interflow and groundwater inflow of copper and zinc are simulated by input of constant concentration values assigned to simulated interflow and groundwater inflow. Instream changes in metals concentrations are simulated by the GQUAL module within the RCHRES module. GQUAL simulates dissolved constituent concentrations and concentrations associated with sand, silt, and clay. Process-related parameters affecting distribution of metals between the dissolved phase and sediment adsorption include partitioning coefficients and adsorption/desorption rate parameters (Allison and Allison, 2005).

Initial estimates for daily accumulation of copper and zinc onto land surfaces were obtained from King and Snohomish County HSPF models. Calibration was accomplished by comparing simulated concentrations and observed concentrations measured at site WPL050.

A limited number of recent monthly dissolved copper and dissolved zinc samples have been collected from Whipple Creek's WPL050 main stem stream monitoring station starting in water year 2014. Because the water quality simulation period ended in 2008 the simulated values could not be compared directly with the recorded (monitored) data, but general ranges and trends could be reproduced for comparison purposes.

Numeric water quality criteria are published chapter 173-201A WAC. They specify the levels of pollutants allowed in receiving water to protect drinking water uses, aquatic life, and recreation in and on the water. Narrative water quality criteria (e.g. WAC 173-201A-240(1)) limit the toxic, radioactive, or other deleterious material concentrations that may be discharged to levels below those that have the potential to:

- Adversely affect designated water uses (beneficial uses)
- Cause acute or chronic toxicity to biota
- Impair aesthetic values
- Adversely affect human health

Washington State's dissolved metals' acute and chronic water quality criteria are targeted toward high frequency sampling applying 1-hour and 4-day average concentrations, respectively, that are not to be exceeded more than once every three years on the average.

Based on limited available Whipple Creek metals data set, dissolved metals do not appear to be a significant water quality issue at this time, even when applying the relatively conservative estimate of water hardness from one of the county's low density residential runoff monitoring sites.

Figure 6 and Figure 7 boxplots show that none of the dissolved copper or dissolved zinc monthly samples collected to date exceed either of their respective state standard's acute or chronic criteria.

The highest dissolved copper sample value of 3.37 ug/L (depicted in Figure 6 as a red asterisk outlier) represents only 69% and 92% of the acute and chronic criteria levels, respectively.

The highest dissolved zinc sample value of 2.24 ug/L (depicted in Figure 7) is only about 6% and 7% of its criteria, respectively, representing even lower proportions. Median and mean WPL050 dissolved copper values are only about one-third of even the chronic criterion.

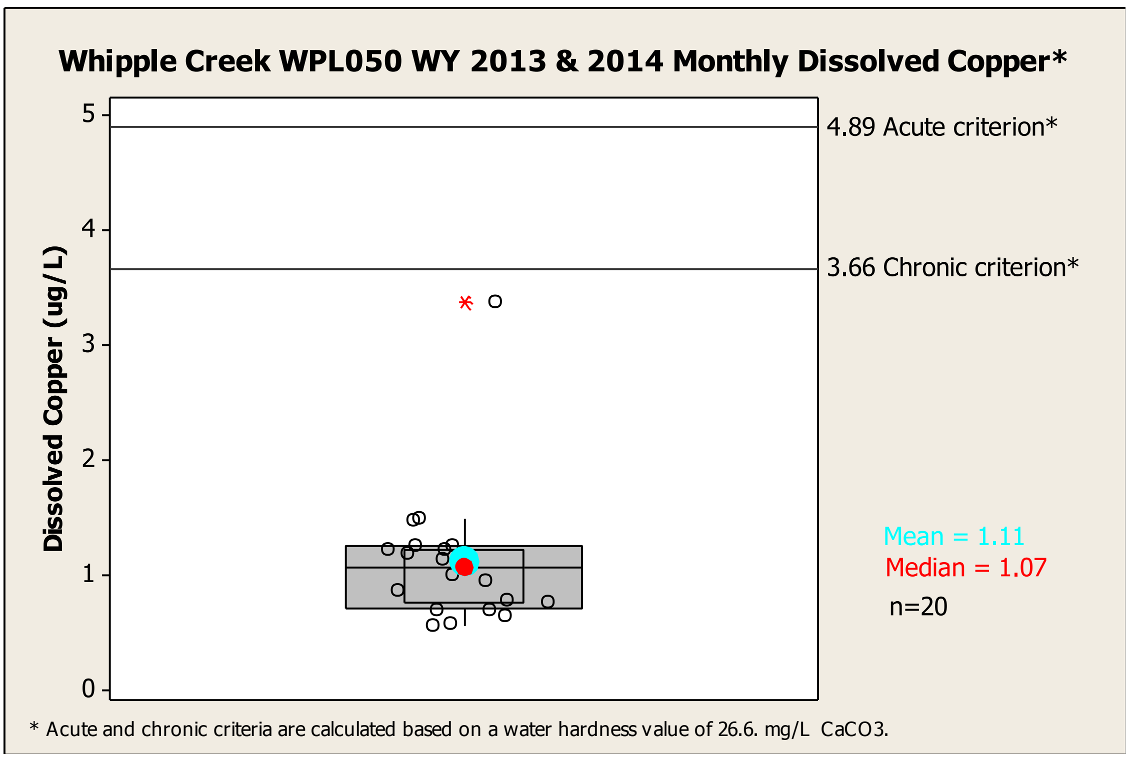

Figure 6. Whipple Creek WPL050 water years 2013 and 2014 monthly dissolved copper values with state criteria based on median LDR hardness

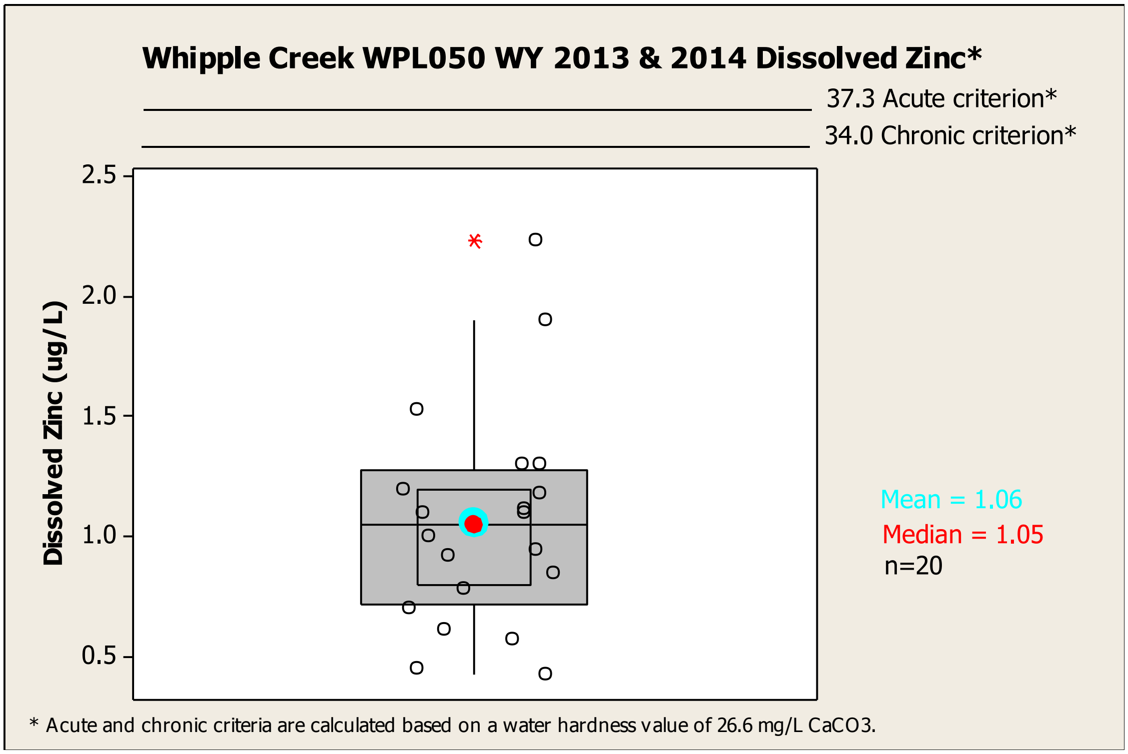

Figure 7. Whipple Creek WPL050 water years 2013 and 2014 monthly dissolved zinc values with state criteria based on median LDR hardness

Since sediment plays an important role in modeling dissolved copper and zinc, the parameters of sediment block were adjusted several times based on existing water quality models and published data in EPA Technical Note 8 until the model produced results that were within a reasonable limit (Donigian, Bicknell, Love & Duda, 2006).

The water quality model was then run many times until the simulated values appeared to be within acceptable range. Since only less than two years of water quality data for dissolved copper and zinc is available, none of which is in the calibration period, the model results were only compared with observed data on a graphical basis. (The simulated results are for the water quality calibration period of October 2003 through September 2008; while the observed/recorded copper and zinc are for the period of January 2013 through April 2015.)

The recorded copper data are shown in Figure 8.

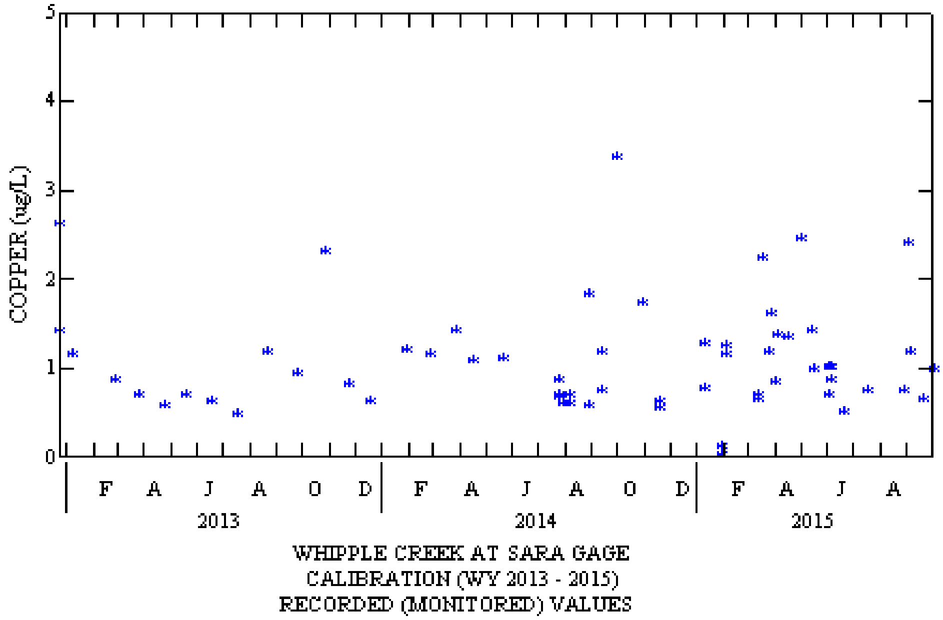

Figure 8: Observed dissolved copper at WPL050.

The simulated daily dissolved copper values are shown in Figure 9.

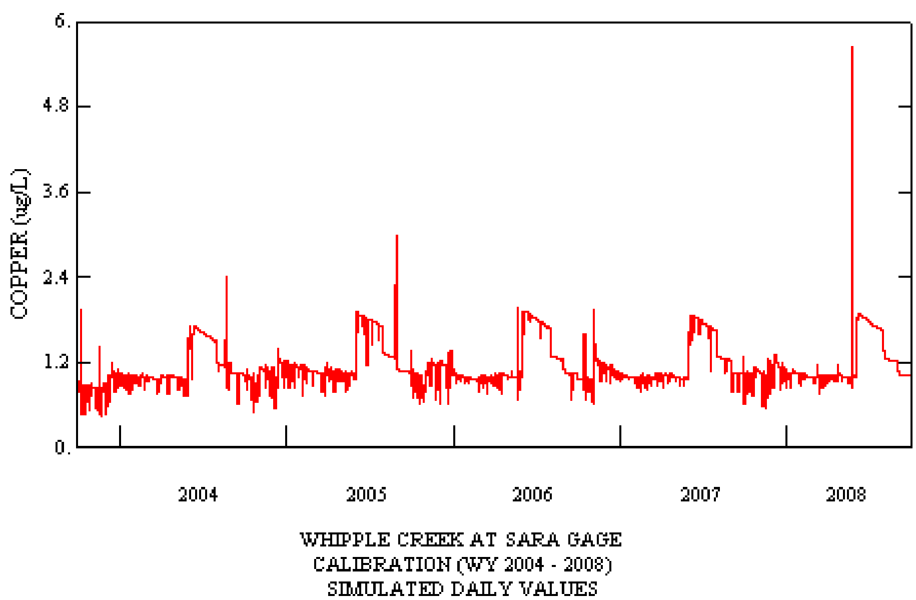

Figure 9: Simulated daily dissolved copper at WPL050.

The simulated annual average dissolved copper values are shown in Figure 10.

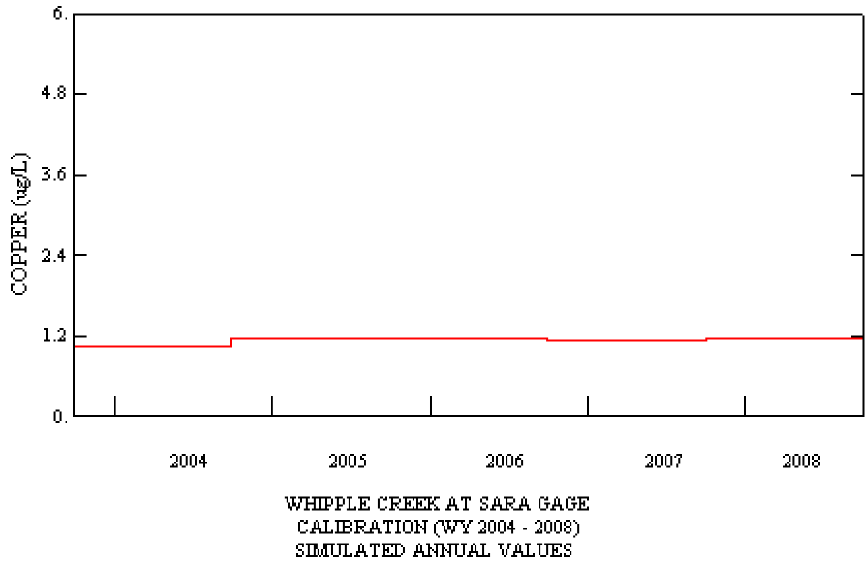

Figure 10: Simulated annual average dissolved copper at WPL050.

Comparable results for zinc are shown in Figures 11, 12, and 13.

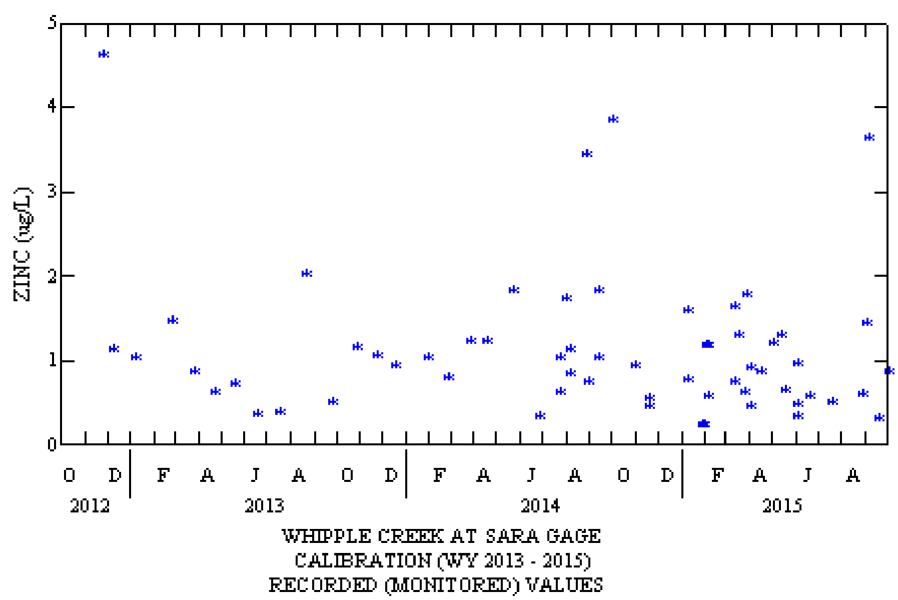

Figure 11: Observed dissolved zinc at WPL050.

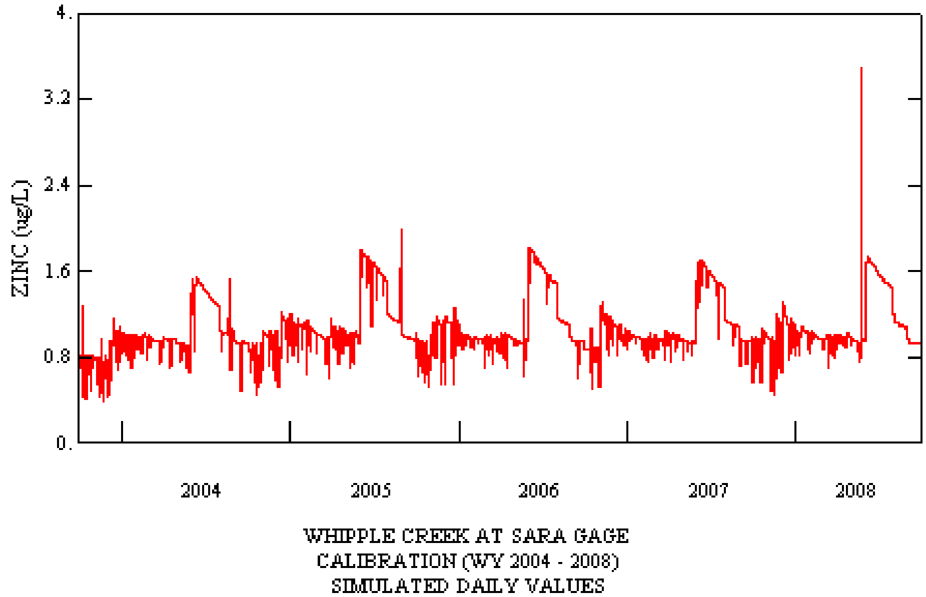

Figure 12: Simulated daily dissolved zinc at WPL050.

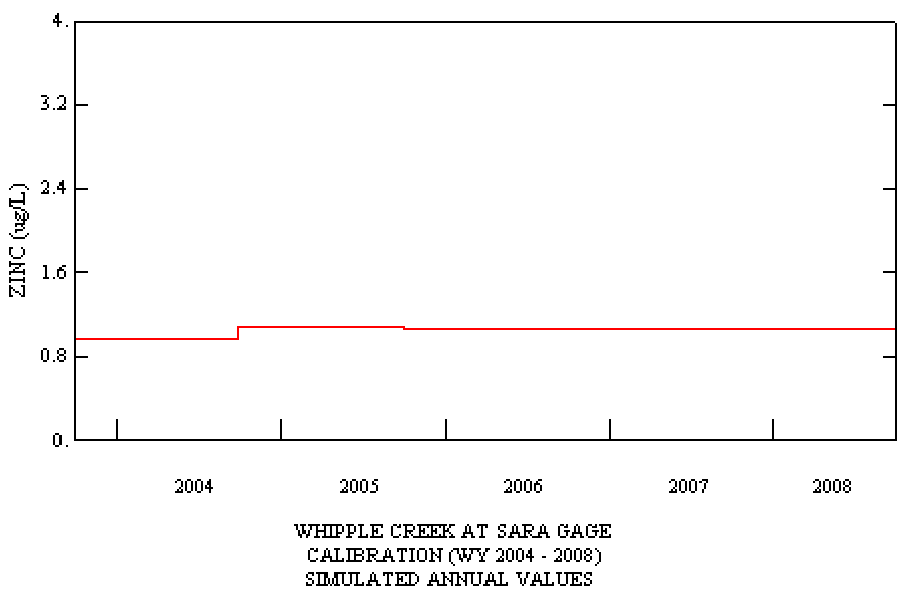

Figure 13: Simulated annual average dissolved zinc at WPL050

4.3 Fecal Coliform

Using the Whipple Creek's calibrated hydrology model, a watershed-scale bacterial transport model was generated to simulate the transport of bacteria from the land surface to the stream channel. In HSPF, this is accomplished by linking the fecal coliform simulation to the streamflow simulation. The following sections summarize the simulation of fecal coliform bacteria in the PERLND, IMPLND, and RCHRES modules.

The PQUAL module is used to simulate the transport of fecal coliform bacteria from pervious land segments. This module simulates storages and fluxes of bacteria along three flow paths: overland flow, interflow, and base flow. There are 11 model parameters used to simulate fecal coliform bacteria (

Table 4). Collectively, these parameters govern the total fecal coliform loading from each HRU to a given stream reach.

The processes by which the transport of fecal coliform bacteria is simulated can be split into two categories: surface and subsurface (interflow and base flow) (see Figure 14).

The surface processes begin with deposition of animal wastes containing fecal coliform bacteria onto the land surface by numerous sources in the watershed (people, pets, livestock, and wildlife). Fecal coliform deposition is established by the accumulation rate (ACCUM). These bacteria are stored on the surface (SQO) and are allowed to accumulate until the storage limit (SQOLIM) is reached.

Bacteria are removed from surface storage by either die-off or washoff. The removal rate (REMQOP) of the stored bacteria through die-off is defined by the ratio of the accumulation rate (ACCUM) and the storage limit (SQOLIM). Bacteria remaining in storage are removed through washoff by overland flow.

The amount of bacteria removed from surface storage (SOQUAL) during a given storm event is controlled by both the amount of overland flow generated (SURO) and the susceptibility of the bacteria to washoff by overland flow (WSFAC). SURO is identified for each HRU during the hydrologic calibration. WSFAC is a function of the rate of runoff that results in 90 percent washoff of stored fecal coliform bacteria in a given hour (WSQOP).

Table 4. Parameters used in the simulation of the transport and storage of fecal coliform bacteria

Parameter	Definition	Unit
ACCUM	Accumulation rate of fecal coliform bacteria on the land surface.	number of colonies per acre per day
AOQUAL	Transport of fecal coliform bacteria through base flow (ground-water discharge).	number of colonies per day
AQO	Storage of fecal coliform bacteria in active ground water.	number of colonies per ft^3
IOQUAL	Transport of fecal coliform bacteria through interflow.	number of colonies per day
IQO	Storage of fecal coliform bacteria in interflow.	number of colonies per feet
REMQOP	Removal rate (die-off) for fecal coliform bacteria stored on the land surface. Removal rate is based on the ratio of ACCUM/SQOLIM.	1 per day
SOQUAL	Transport of fecal coliform bacteria through overland flow.	number of colonies per acre per day
SQO	Storage of fecal coliform bacteria on the land surface.	number of colonies per acre
SQOLIM	Asymptotic limit for the storage of fecal coliform bacteria on the land surface if no washoff occurs.	number of colonies per acre
WSFAC	Susceptibility of fecal coliform bacteria to washoff. Susceptibility is defined by 2.30/WSQOP.	per inch
WSQOP	Rate of surface runoff that results in 90-percent washoff of the stored fecal coliform bacteria in one hour.	inches per hour

IQUAL is used to simulate the transport of fecal coliform bacteria from impervious land segments. The IQUAL module only simulates surface washoff of fecal coliform bacteria because impervious land segments do not have a subsurface component. The transport processes in IQUAL are identical to those used in the surface washoff component of PQUAL. Generally, bacteria stored on an impervious land segment are more susceptible to washoff than those stored on pervious land segments.

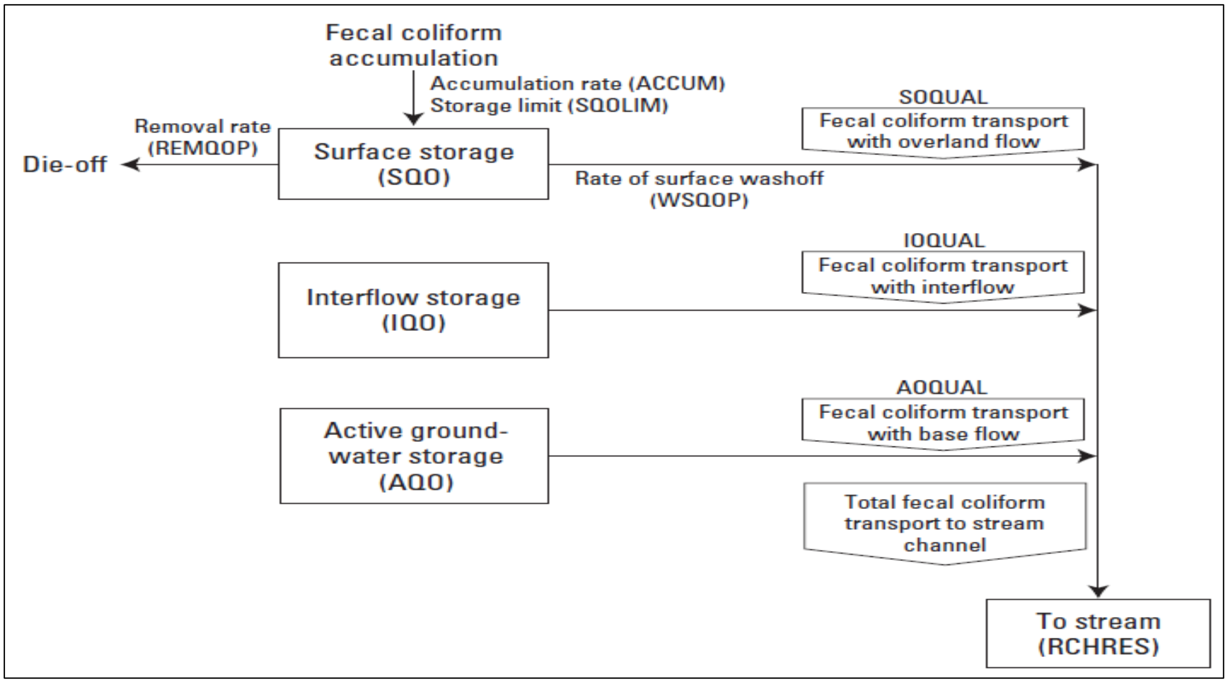

Figure 14: Routing processes by the HSPF for the simulation of fecal coliform bacteria transport

Monthly fecal coliform samples were collected for over ten years at WPL050, from February 2004 through April 2014. One year of monthly fecal coliform samples were also collected at other water quality sites, WPL010, WPL080, and PCK010 during water year 2012 from October 2011 through September 2012 (see Figure 3).

In addition to a general summary of their overall pattern in the watershed, fecal coliform results were also evaluated seasonally using Washington State's current surface water quality standards for the designated beneficial use of primary contact recreation (Ecology, 2016).

The standards utilize two required criteria for bacteria: 1) not exceeding a geometric mean value of 100 colonies per 100 mL and 2) not more than 10 percent of all samples (or any single sample when less than ten sample points exist) exceeding 200 colonies per 100 mL. Geometric means are based on the antilogarithm of the arithmetic mean of the season's individual sample logarithms (base 10) values. To help meet the standard's preference of five or more data collection events within a season for evaluation of the geometric mean, this assessment defines wet seasons as extending 7 months from October through the following April and dry seasons as extending 5 months from May through September.

Fecal coliform were detected in all samples from baseflow and storm events. The geometric mean of all baseflow event samples was 262 CFU/100 ml while the geometric mean during storm events was 1865 CFU/100 ml.

Fecal coliform concentrations are extremely difficult to predict. One reason for this is that many of the larger loadings of bacterial material probably occur not only during storms, but also during somewhat random but "catastrophic" events, such as failure or illicit sewer connections of waste disposal facilities, which can produce large, unpredictable concentrations. Therefore, efforts were made to attain general agreement between the simulated concentrations by adjusting loading rates, both surface and subsurface runoff-associated by land cover.

Model accuracy simulating fecal concentrations is substantially less than the other water quality parameters, but, as shown in Figure 15, the simulated results follow the general trend and range of observed/recorded fecal coliform concentrations for water years 2004 through 2008.

The fecal coliform results should be viewed in terms of the number of water quality standard exceedances rather than just the calculated concentrations. Note that number of exceedances was reported when comparing future scenario fecal coliform results in the watershed-scale report.

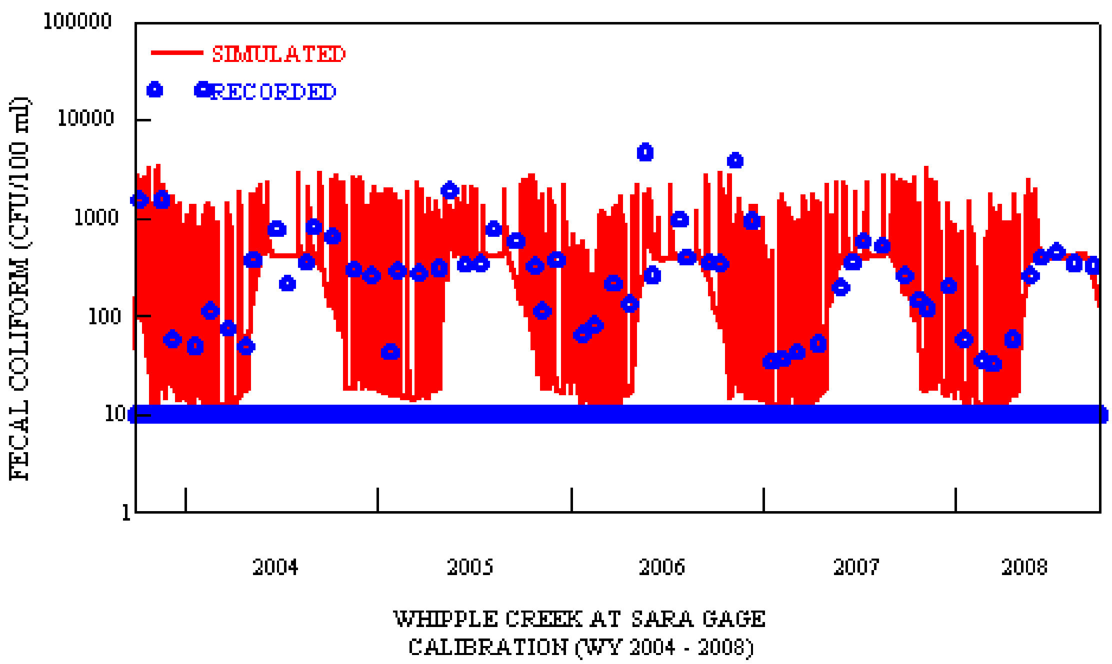

Figure 15: Simulated and observed fecal coliform concentrations (ug/L) at WPL050.

5. CONCLUSIONS

The water quality calibration results show a good match between the simulated and observed/ recorded water temperature and fecal coliform values for the calibration period of record.

There were no observed copper and zinc concentration values for the calibration period, but the general concentration range for both copper and zinc was between 0 and 5 ug/L, and the simulated values were also within the same range.

Overall, the water quality calibration is considered good to very good. The water quality calibration model can be used to model water quality for both existing land covers and future development conditions and scenarios. For fecal coliform, the number of exceedances should be reported due to the difficulty in predicting high concentrations. For temperature, copper and zinc, the model can be used to report actual value.

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