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Streamflow Modeling of Johnson Creek Subwatersheds Using the Precipitation Runoff Modeling System

Theophilus Matthew Malone
Portland State University

STREAMFLOW MODELING OF JOHNSON CREEK SUBWATERSHEDS USING THE PRECIPITATION RUNOFF MODELING SYSTEM

BY

THEOPHILUS MATTHEW MALONE

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Project Advisor:
Dr. William Fish

Portland State University

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Jenifer Antak, BES

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Dr. Rick Johnson, PSU CEE

Megan Falcone, PSU CEE

Arial Lewis, PSU CEE

Jerad Hoffman, PSU CEE

Surface Water Analysis Group, Otak Inc

ABSTRACT

Johnson Creek, in the Portland, Oregon metropolitan region, has several pollutants on the U.S. Environmental Protection Agency's (EPA) 303(d) list including excess heat, low dissolved oxygen, and harmful bacteria. Understanding streamflow response to precipitation events is an important component to evaluating water quality trends and calculating the Total Maximum Daily Load (TMDL) for pollutants of concern. Investigating the streamflow-precipitation relationship on the subwatershed scale can give insight to the hydrologic response of a given watershed. However, developing rating curves for several subwatersheds can be cost and time prohibitive. The objective of this project was to develop a hydrologic model using the Precipitation Runoff Modeling System (PRMS), developed by the United States Geological Survey (USGS) to validate streamflow estimates for subwatersheds lacking a significant period of record.

ESRI's ArcMap, a geographic information system (GIS), was used to characterize the target drainage basins and extract basin-specific parameters for upper watersheds of Johnson Creek. The Johnson Creek Upper Watershed (JCUW) model was calibrated to an existing streamflow gage at Regner Road, in Gresham, Oregon. Calibrated parameters were substituted into a second PRMS model characterizing the Sunshine Creek Subwatershed, which lies within the JCUW. The Sunshine Creek model was used to validate a flow time-series derived from a pressure transducer and a rating curve.

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1. INTRODUCTION

A watershed is an area of land where all precipitation which falls within its boundaries eventually drains to one common location such as a stream, creek, or river, and ultimately outfalls to a lake, sea, or ocean. Before reaching the watershed outlet, several physical processes partition water into different flow pathways such as surface runoff, interflow, and groundwater flow. Vegetation creates abstractions by intercepting precipitation before it falls to the ground. This increases the precipitation's travel time through the watershed or removes it from the watershed through evaporation.

Once precipitation reaches the ground, it takes one of several pathways through the physical landscape. In natural basins, much of the precipitation infiltrates into the ground and is either absorbed by vegetation and released back into the air (transpiration), flows through shallow subsurface pathways towards a water body (interflow), or infiltrates deeper to recharge aquifers (groundwater). Runoff occurs in natural basins when the underlying soil is fully saturated or has surpassed its infiltration capacity. In urbanized basins, a significant portion of precipitation falls onto hard surfaces such as pavement or concrete, and immediately runs off onto adjacent vegetated areas, directly into adjacent receiving waters, or into stormwater conveyance systems to be treated or routed to nearby receiving waters.

Scientists and engineers attempt to model these physical hydrologic processes (e.g. infiltration, evaporation, and runoff) through empirical and theoretical relationships or equations. Measureable data such as solar radiation, precipitation depth, and air temperature are used as inputs to these equations. Physical characteristics of a watershed such as slope, percent impervious surface, soil type, vegetation type and density, and aspect are used to adjust equation coefficients. Models are used as predictive tools to aid in the understanding of our physical environment.

1.1 Background

1.1.1 Study Area

The Johnson Creek Watershed is a rain-dominated basin that drains approximately 54 mi^2. Over the creek's 26 river miles, it passes through six municipal jurisdictions (Portland, Milwaukie, Gresham, Happy Valley, Damascus, and Boring) and two county jurisdictions (Multnomah, and Clackamas) before its confluence with the Willamette River in Milwaukie, Oregon (See Figure 1).

Historically, the creek was used by indigenous peoples as fishing grounds for Cutthroat, Chinook, and Steelhead. The watershed was originally largely forested with extensive and diverse vegetation. As the region was settled by descendants of European colonists, much of the upland and riparian zones were logged and low-lying floodplains filled. In 1930 the United States Works Progress Administration (WPA) widened, deepened, and lined the banks of Johnson Creek with large rock in an attempt to control flooding caused by floodplain infill (City of Portland, 2014).

More recently, public agencies and local non-profits have made extensive efforts to rehabilitate Johnson Creek (City of Portland, 2001). Several restoration projects have been undertaken throughout the watershed, in an attempt to return natural floodplain function and increase habitat for native fish populations. However, the basin still remains largely urbanized, contributing to excess surface water runoff.

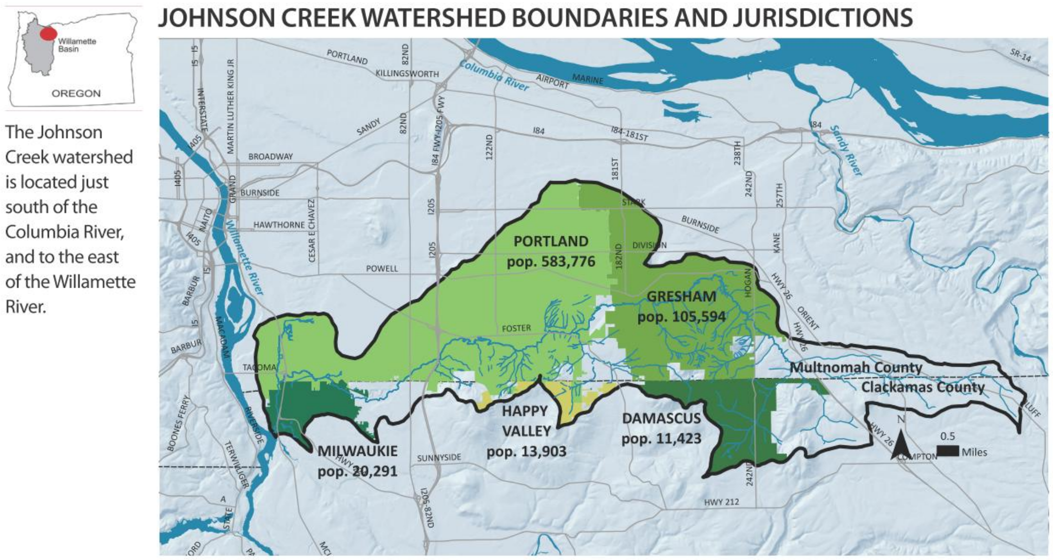

Figure 1: Johnson Creek Watershed location and boundaries map (Johnson Creek Watershed Council, 2012)

1.1.2 Water Quality

To protect and improve water quality in the United States, the US Environmental Protection Agency (EPA) maintains a listing of all impaired and threatened water bodies identified by the states. A daily allowable amount, or Total Maximum Daily Load (TMDL), is established for pollutants of concern. Johnson Creek currently has several 303(d) listings including temperature, dissolved oxygen, pesticides, and bacteria. Follow the following link for information specific to the streams within the Willamette watershed (including Johnson Creek):

(http://www.deq.state.or.us/WQ/TMDLs/willamette.htm)

Degraded water quality adversely effects fish populations and can pose a human health risk.

1.1.3 Section 319 Grant

The funding source for this study was an EPA Section 319 grant issued to the Johnson Creek Watershed Council. In 1987, amendments to the Clean Water Act (CWA) included the Section 319 Nonpoint Source Management Program. "Under Section 319, states, territories and tribes receive grant money that supports a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects and monitoring to assess the success of specific nonpoint source implementation projects." (EPA, 2014)

The Oregon Department of Environmental Quality issued the funds to the Johnson Creek Watershed Council, which in turn funded the East Multnomah Soil and Water Conservation District (EMSWCD) to participate in this study. The United States Geological Survey (USGS) matched the EMSWCD in funding the Johnson Creek Hydrology Study.

1.2 Scope

The Johnson Creek Hydrology Study has three components including the installation of streamflow monitoring equipment, a volunteer monitoring program, and hydrologic modeling. The following section briefly outlines the scope of the Johnson Creek Hydrology Study and the components therein.

1.2.1 Monitoring Equipment

Pressure transducers were installed at two locations in the Johnson Creek Watershed: one in Sunshine Creek at its confluence with Johnson Creek and the other in Johnson Creek at Telford Road. Pressure transducers measure and report hydrostatic pressure corresponding to the stage (or depth) of a water body. Through periodic flow measurements at the installation site, a rating curve can be developed relating the measured hydrostatic pressure to volumetric flow.

Four staff gages like the one pictured in Figure 2 below, were also installed within the watershed. A staff gage consists of a ridged wood or metal backing with measurements marked at regular intervals. Staff gages attempt to provide the same comparable data as pressure transducers for less cost, although reading must be taken in-person. Frequent readings are time prohibitive for one person, however with a coordinated volunteer force, regular readings are feasible.

Figure 2: Staff gage installed on the north fork of Johnson Creek

1.2.2 Volunteer Monitoring

As discussed above, volunteers were needed to take staff gage readings as well as conduct flow measurements. During the 2013 calendar year, several volunteers, including the author, from the City of Portland, the USGS, Portland State University, and local residents traveled to each staff gage site and took readings. Stage data from the gages was collected at least weekly. At one location, on Badger Creek, data was collected more frequently thanks to a local resident who checked the staff gage regularly on her way home from work.

1.2.3 Data Processing

Staff gage and pressure transducer data sets were processed by Adam Stonewall, Hydrologist with the USGS. A rating curve and a subsequent streamflow time series was produced for the Sunshine Creek gage location. This time series was then used as the measured streamflow to compare with model output from PRMS.

1.2.4 Hydrologic Modeling

To better understand the hydrologic response to precipitation events in the subject subwatersheds, a hydrologic model was proposed. Given the short period of record available from the Johnson Creek Hydrology Study, calibrating a hydrologic model to Sunshine Creek flows was inadvisable. Typically a significantly longer period of record is used to calibrate a model due to climate's yearly variability. A similar but non-overlapping length of time is often used to validate the calibrated model to evaluate its accuracy.

Due to these limitations, two hydrologic models were used. The first model was developed for the Johnson Creek Upper Watershed (JCUW) (see Figure 3) calibrated to the Regner Road stream gage with a period of record dating back to 1998. The second model was developed to characterize the Sunshine Creek Subwatershed (SCS) (see Figure 3). The calibrated parameters from the JCUW were placed within the SCS model. Measured streamflow for Sunshine Creek was then compared to simulated streamflow.

Temporal and scaling issues arising from this procedure are discussed in Section 4: Summary and Conclusions.

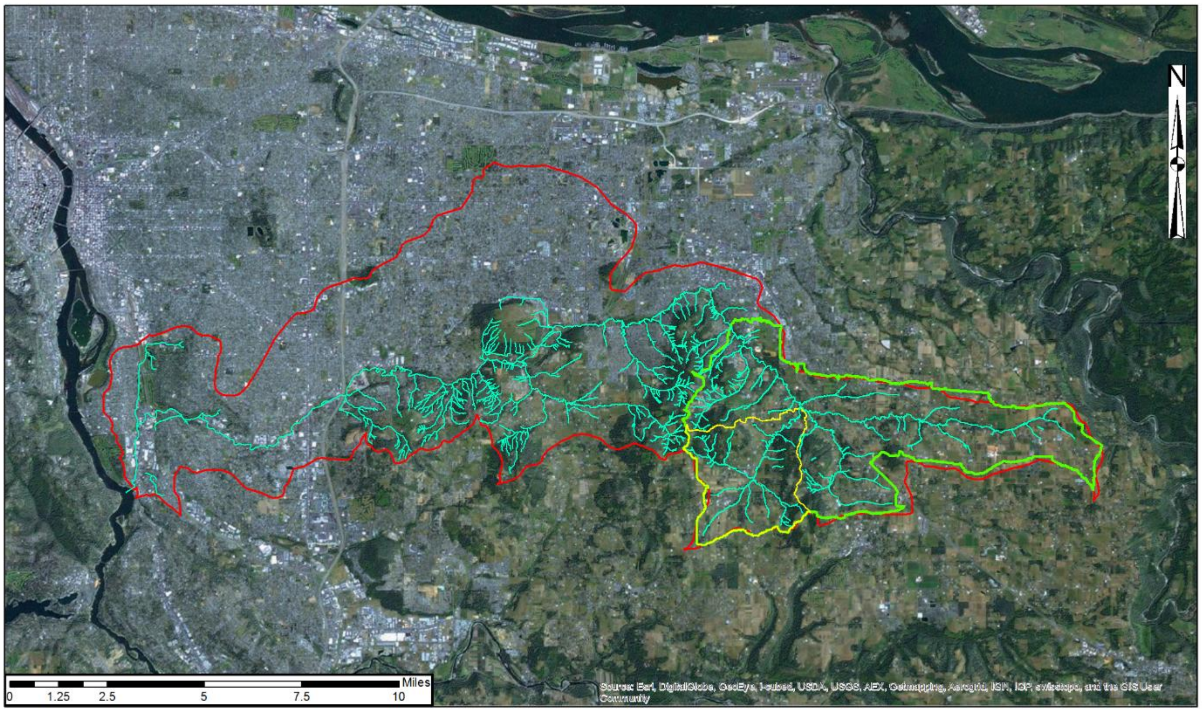

Figure 3: The Johnson Creek Watershed (red), the calibrated model of the JC upper watershed gaged at Regner Road (green), and the validation Sunshine Creek watershed (yellow)

2. HYDROLOGIC MODEL OF JOHNSON CREEK SUBWATERSHEDS

Hydrologic modeling is widely used as a tool to predict streamflow, groundwater levels, water supply, and flooding risk by simulating hydrologic processes in a given drainage basin. Two main classes of hydrologic models exist: deterministic and stochastic. A deterministic model has a set processing algorithm that produces one result or set of results for one given input or set of inputs. A stochastic model contains one or more random elements and is used to simulate processes wherein the input to output relationship is stochastically or randomly determined. A deterministic model contains no stochastic elements and is used to simulate processes wherein the input variables have a direct (e.g. linear, power, log, etc.) relationship with the output variables.

2.1 Precipitation Runoff Modeling System

2.1.1 Conceptual Model

The PRMS was selected as the hydrologic modeling system for this study. PRMS was developed in 1983 by Leavesley et al. at the USGS Colorado Water Resources Center in Denver, Colorado. The runoff model is part of the Module Modeling System (MMS), a framework of applications for simulating streamflow. The MMS was not fully implemented in this study due to the incompatibility of some MMS software with current operating systems.

PRMS is a deterministic, physical-process modeling system (Leavesley et al., 1983) and is used to simulate streamflow in both urban and rural watersheds. The model uses computational modules representing hydrologic system components and is defined by one or more system of equations. Figure 4 shows compartments and modules represented in PRMS, as well as common data inputs (i.e. solar radiation, precipitation, and air temperature) PRMS relies on user input of to generate streamflow output.

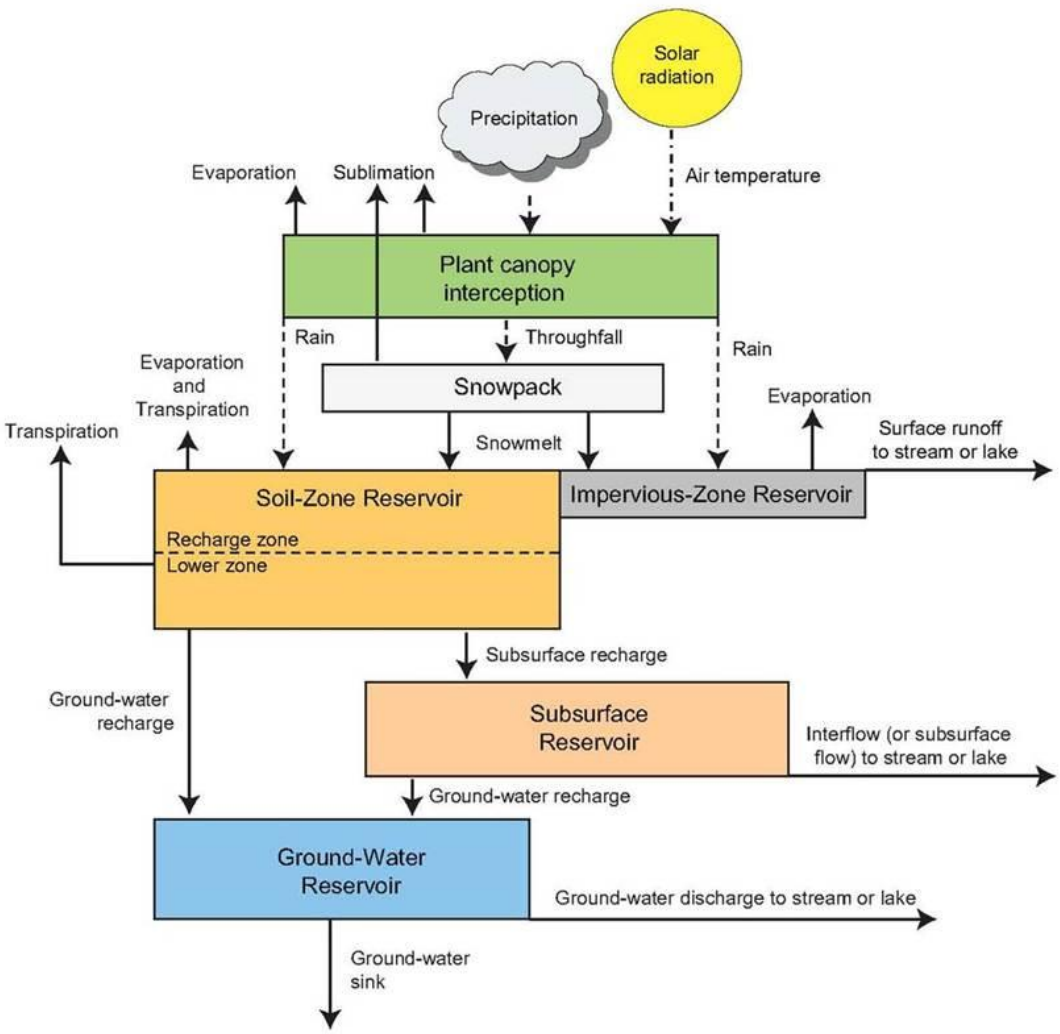

Figure 4: Conceptual framework of models within PRMS with arrows representing water distribution and pathways

2.1.2 Hydraulic Response Units

PRMS has to modeling modes, and can function as either a distributed-parameter or lumped-parameter model. For this study, the lumped-parameter mode was used. Watersheds are partitioned into parcels of homogeneous hydrologic response based on watershed characteristics such as slope, percent impervious surface, soil type, vegetation type and density, and aspect. These parcels are called Hydraulic Response Units (HRUs). Both water and energy balance are calculated for each HRU for the time step chosen (e.g. daily). (Leavesley et al., 1983)

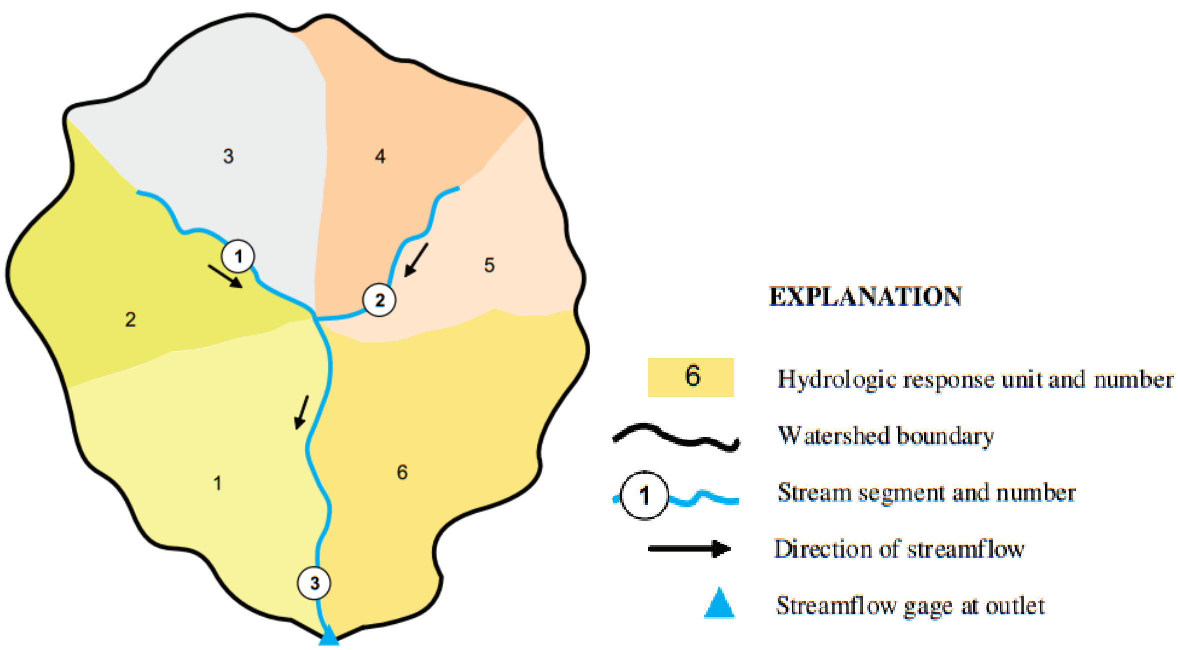

Figure 5: A simplified representation of six HRUs and three reaches within a watershed (Adapted from Markstrom et al., 2008)

For this study HRUs were delineated based on three watershed characteristics: soil type, cover type, and slope. Unlike Figure 5, HRUs in this study consist of several non-contiguous parcels of land. Each are homogeneous with respect to all three characteristics, but are spread throughout the basin. For example, two sections of forested areas one mile apart share the same soil type and slope, these two homogenous sections are assigned to the same HRU. Limitations to this approach are discussed in Section 5 of this report.

2.1.3 Physics Based Modules

To characterize the hydrologic components as accurately as possible each module reflects a physical process which is governed by physics- or empirical-based equations. Each module allocates water distribution according to its set of equation, or “subroutine”. (Leavesley et al., 1983) This section will overview some of the key equations PRMS uses within modules to route flows.

Table 1: Variable definitions and units for selected PRMS governing equations below

Variable Name (1983)	Definition	Units
PTN	Net precipitation	in
PPT	Total precipitation	in
PTF	Precipitation falling through canopy	in
COVDN	Seasonal cover density, N = W [winter] or S [summer]	-
STOR	Maximum interception storage	in
XIN	Current depth on interception storage	in
EVC	Monthly pan-adjustment coefficient for each month	-
PET	Potential evapotranspiration	in/day
EPAN	Daily pan-evaporation loss	in
TAVC	Daily mean temperature	°C
DYL	Hours of sunshine per day	hrs
VDSAT	Saturated water-vapor density (absolute humidity) at the daily mean air temperature	g/m^3
VPSAT	Saturated vapor pressure at TAVC	millibars
RIN	Amount of evaporation potential	in
CTS	Coefficient for month	-
Cl	Elevation correction factor	-
CH	Humidity index	-
e_2	Saturation vapor pressure for the mean maximum air temperature for the warmest month of the year	millibars
e_1	Saturation vapor pressure for the mean minimum air temperature	millibars

	for the warmest month of the year	
E2	Median elevation of each HRU	ft

2.1.3.1 Interception

Interception is vegetation catching precipitation before it is able to reach the ground, it is therefore reasonable for it to be a function of cover density and the storage available for the type of vegetation present. Equation 1 below shows how cover density relates to precipitation received on an HRU.

$$PTN = [PPT * (1. - COVDN)] + (PTF * COVDN)$$

Equation 1: Calculating net precipitation on an HRU, adapted from (Leavesley et al., 1983)

PTF is calculated in the following series of equations.

$$PTF = PPT - (STOR - XIN) \qquad \text{for } PPT > (STOR - XIN)$$
$$PTF = 0 \qquad \text{for } PPT \leq (STOR - XIN)$$

Equation Set 2: Series of equations calculating the precipitation falling through the canopy (Leavesley et al., 1983)

Intercepted rain is assumed to evaporate at a rate governed by the potential evapotranspiration.

2.1.3.2 Evapotranspiration

Evapotranspiration is the summation of evaporation and transpiration, or the vaporization of soil moisture by vegetation. Three methods available in the potential evapotranspiration subroutine are described below. The first method available is an equation based off of pan-evaporation data.

$$PET = EPAN * EVC$$

Equation 3: Potential evapotranspiration as a function of pan-evaporation rate (Leavesley et al., 1983)

The second method available is a set of equations based on daily mean temperature.

$$PET = CTS * DYL^2 * VDSAT$$

$$VDSAT = 216.7 * \frac{VPSAT}{TAVC+273.3}$$

$$VPSAT = 6.180 * EXP\,[17.26939 * \frac{TAVC}{TAVC+273.3}]$$

Equation Set 4: Potential evapotranspiration as a function of temperature and sunshine hours possible, among other variables explained above (Leavesley et al., 1983)

The third method available is a set of equations also based on daily mean temperature.

$$PET = CTS * (TAVF-CTX) * RIN\ (13)$$

$$CTX = 27.5 - 0.25 * (e_2 - e_1) - (\frac{E2}{1000}])$$

$$CTS = [Cl + (13.0 * CH)]^{-1}$$

$$CH = (\frac{50}{e2 - e1})$$

Equation Set 5: Potential evapotranspiration as a function of pan-evaporation rate at temperature (Leavesley et al., 1983)

2.2 Experimental Methods

2.2.1 Data Collection

Several data sets were used as either time series input for HRU delineation and parameterization. This section outlines the source of each data set as well as the data obtained or collected if readily available.

2.2.1.1 Soil

Soil data for the study was obtained through the NRCS online Web Soil Survey (websoilsurvey.nrcs.usda.gov). An area covering the extent of the Johnson Creek Watershed was downloaded on 4/25/2013. The data was then clipped to the subwatersheds of focus.

2.2.1.2 Cover

Cover data was provided by the City of Portland Bureau of Environmental Services (BES) and complied by the Intertwine. The data set characterized type of cover in the Portland Metro area as of 2010 and included three levels of discretization. For the purpose of this exercise, the least resolute scale was used. PRMS further bins the data into only five groups.

2.2.1.3 Slope

Slope data was derived from Digital Elevation Model (DEM) produced from City of Portland LiDAR data. The Slope geoprocessing tool in ArcMap was applied to the DEM and calculated percent slope. Further discussion on processing elevation data is included in Section 2.2.2.

2.2.1.4 Precipitation

A precipitation time series is required as an input to the PRMS model. Water is then routed to through each PRMS module as appropriate given modeling parameters. (See Figure 4) The

USGS maintains a City of Portland rain gage network called the Hydra Network. Follow the following link for a map of all rain gages included in the Hydra Network:

(http://or.water.usgs.gov/non-usgs/bes/raingage_info/clickmap.html)

Figure 6 shows the location of the two gages closest to the SCS and JCUW. While the Cottrell School rain gage is located within the boundaries, due to the average distance from the centroid of both basins, the Gresham Fire Department Rain Gage was chosen as the primary gage for this study. The daily total was extracted from the gage data file for the period of record, dating back to June 1998.

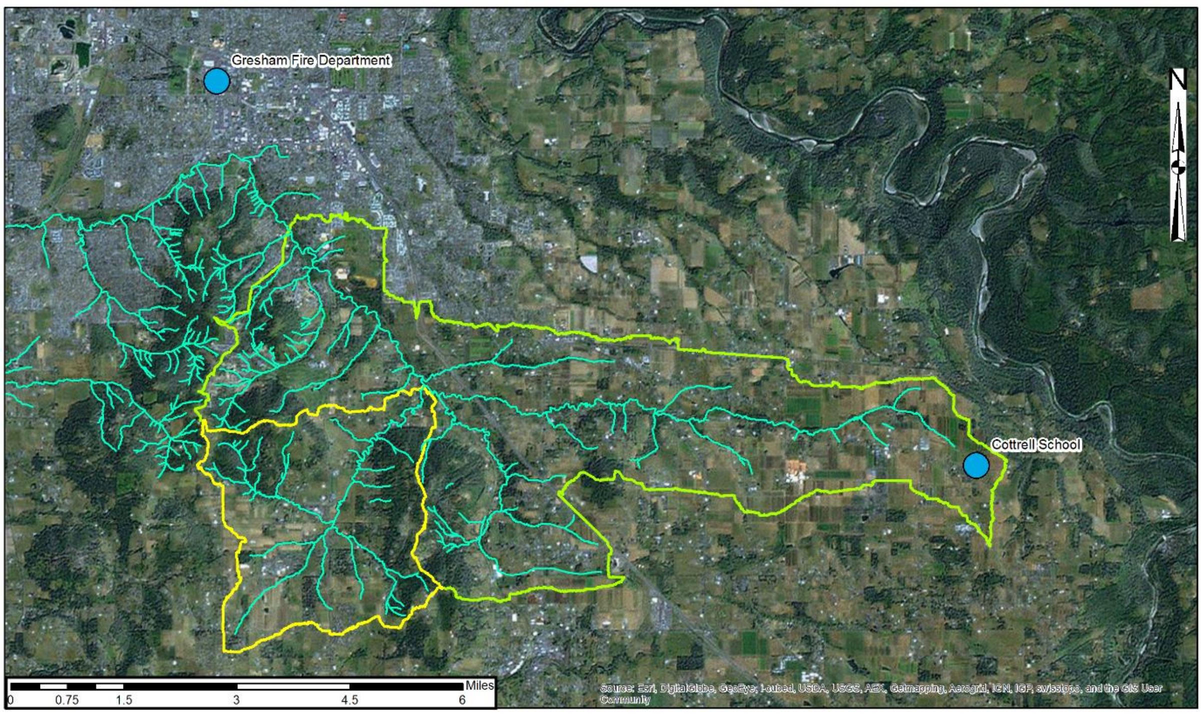

Figure 6: Reference location of the two closest rain gages available from the Hydra Network (http://or.water.usgs.gov/non-usgs/bes/raingage_info/clickmap.html)

2.2.1.5 Temperature

Daily maximum and minimum air temperature values were obtained using Downsizer, a tool developed by Ward-Garrison et.al. with the USGS, which accesses National Weather Service (NWS), Natural Resources Conservation Service (NRCS), and USGS databases. Temperature time series were taken from the Portland International Airport approximately 10.5 miles northwest from the Regner Road Gage. The times series was extracted for the period of record dating back to September 1998.

2.2.2 GIS Geoprocessing

Several geoprocessing tools within the geographic information system (GIS), ESRI ArcMap, were used to delineate, characterize, and parameterize each Hydraulic Response Unit (HRU). Each data set, received in a variety of formats, was converted to ArcMap feature class (i.e. polygon). The resulting polygon layers were then merged to create individual parcels of land with homogeneous attributes with respect to the three characterizing parameters (slope, soil, and cover) Figure 7 below shows the process through which data was taken from raw data to parameterized HRUs.

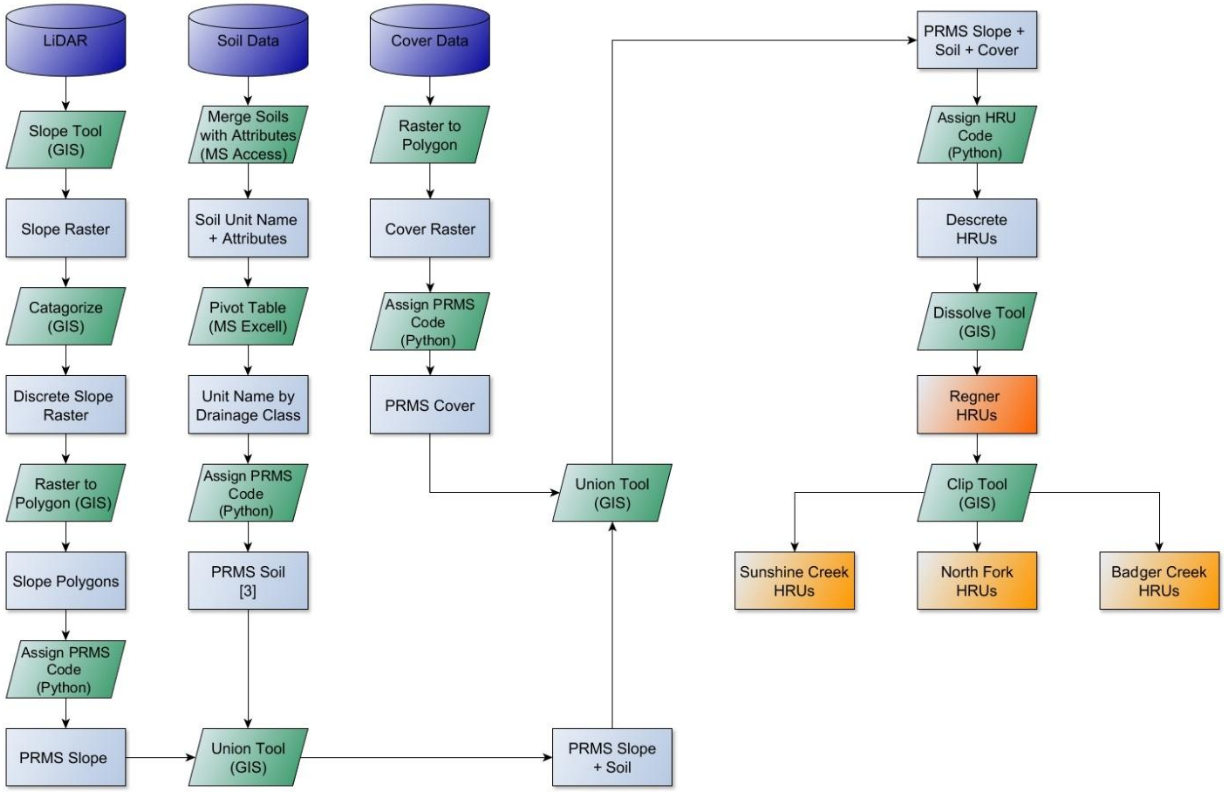

Figure 7: Processes used to parameterize and delineate hydraulic response units

Custom scripts written in the programming language Python were used to assign each data point a PRMS value. The PRMS parameter names and available classifications are as follows: hru_slope (actual value), cover_typ (0 = bare soil; 1 = grasses; 2 = shrubs; 3 = trees; 4 = coniferous), soil_type (1 = sand; 2 = loam; 3 = clay). Due to the resolution differences in the data sources and the PRMS HRU input format each data set was reclassified to match the PRMS parameter resolution. Table 2 shows the reclassification assignments for each data set.

Table 2: HRU Delineation Values Reclassified into PRMS Parameters

Percent Slope	PRMS Slope Value	Cover Class	PRMS Cover Code	Drainage Class	PRMS Soil Code
0 - 0.99	0.005	Paved	Bare Soil	Poorly Drained	Clay
1 - 1.99	0.015	Buildings	Bare Soil	Somewhat Poorly Drained	Clay
2 - 2.99	0.025	Agriculture	Grasses	Moderately Well Drained	Loam
3 - 3.99	0.035	Low Sparse Veg (0-2 ft)	Shrubs	Well Drained	Sand
4 - 4.99	0.045	Low Vegetation (2-7 ft)	Shrubs	Somewhat Excessively Drained	Sand
5 - 6.99	0.060	Large Shrub/Small Trees (7-30 ft)	Trees		
7 - 8.99	0.080	Broadleaf (over 30 ft)	Trees		
9 -10.99	0.100	Conifers (30 - 120ft)	Coniferous		
11 - 12.99	0.120	Conifers (over 120ft)	Coniferous		
13 - 16.99	0.150				
17 - 21.99	0.195				
22 - 29.99	0.260				
30 - 41.99	0.360				
42 - 49.99	0.460				
> 50	0.500				

2.2.3 Running PRMS

PRMS can be run with or without a graphic user interface (GUI). Advantages of the GUI are the ability to change the input files and model-run start and end times without having to edit the individual control files with a text editor. See Figure 8 for the Single Run GUI. Another advantage is the inclusion of run-time graphs that plot variable values. PRMS will output a spreadsheet with all simulated and input variables available for the user to analyze and plot, however it will also produce plots while running the model.

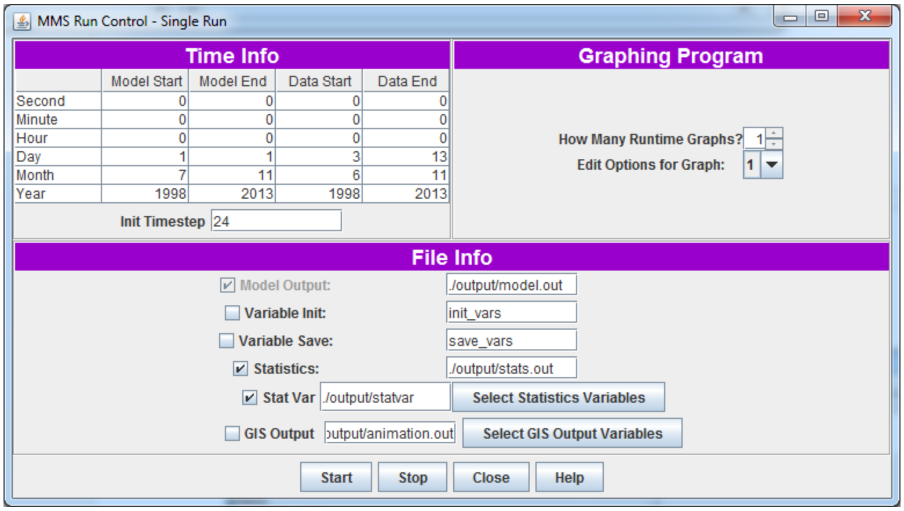

Figure 8: The GUI for a single PRMS run in daily-mode

Run-time graphs allow the user to track multiple variables as they are being modeled. This can aid in visually trouble-shooting a model without the need to create a separate plot. The user can specify how many run-time graphs to be produced and what variables they contain. The graphs have limited labeling and customization abilities however; the user cannot specify the range of values to be plotted without changing the model start and/or end time.

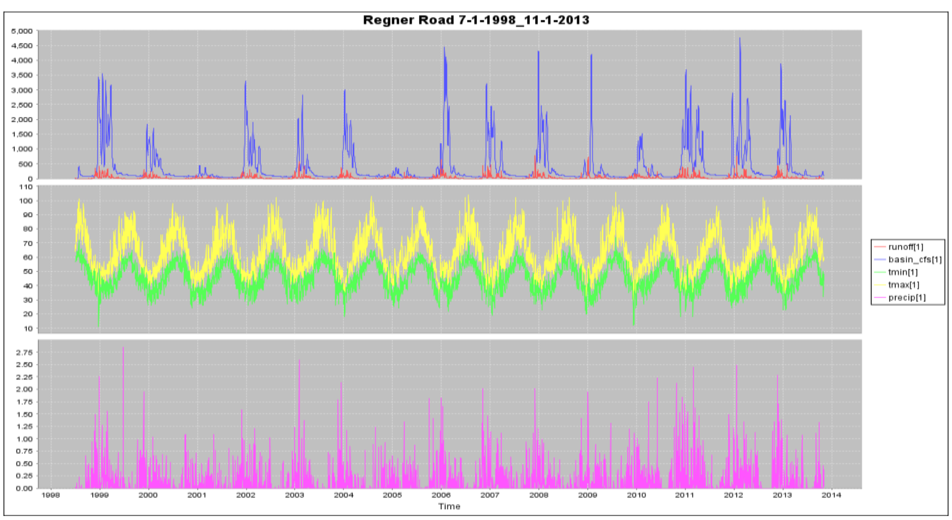

Figure 9: Example PRMS runtime graph (prior to calibration) for JCUW including maximum and minimum temperature, precipitation

2.3 Calibration

Calibration is an important step in developing a hydrologic model, or any predictive model. Many calibration algorithms exist, but most follow similar procedures. Objective functions are used to determine how well the model is simulating each observed value. Objective function values describe the correlation or goodness of fit between observed and simulated streamflow. Input parameters are altered and the simulated values are tested again against the observed values. If the objective function indicates a better fit than the previous step, the new parameter values are substituted for the current values and the process starts over. If the objective functions indicate a worse fit, the current parameter values are retained and a different set of new parameter values are tested. For this study an automatic-calibration tool called LUCA (Let Us CAlibrate) provided by the USGS was used. The calibration procedure used is detailed in the following section.

2.3.1 LUCA

Data used for calibration was obtained from the USGS National Water Information System website (http://waterdata.usgs.gov/nwis). As discussed earlier, the Regner Road stream gage in Gresham, Oregon was selected because the length of available data. The period of record dates back to 1998 and contains average daily flow and water temperature measurements.

A multiple objective, step-wise calibration system, able to adjust multiple parameters simultaneously, was used to calibrate PRMS for the Johnson Creek Subwatershed model. The model was calibrated using a different set of parameters for each step. Parameters and objective functions selected were based on discussions with John Risley, Hydrologic Modeler with USGS, as well as previous research conducted by (Hay and Umemoto, 2006), (Moriasi et al., 2007), and (Hay et al., 2006).

Calibration steps included: 1) Water Balance, using objective functions for monthly mean, mean monthly, and annual mean flows; 2) Daily Timing of Flow, using objective functions for daily and monthly mean flows; 3) Daily Timing of Low Flows, using objective functions for daily and monthly mean flows; 4) Daily Timing of High Flows, also using objective functions for daily and monthly mean flows. For steps 2-4 the daily flow objective function was given more weight than the monthly mean. Each set of four steps was repeated six rounds. Table 3 below outlines the parameters calibrated each step.

Table 3: Parameter calibration algorithm including parameter descriptions (Adapted from calibration procedures provided by USGS)

Calibration Data Set	Number of Objective Functions Used	PRMS Parameters Used to Calibrate Model State	Parameter Range min	Parameter Range max	Parameter Description
Water Balance	3 OFs – Monthly Mean, Mean Monthly, & Annual Mean	rain_cbh_adj	0.2	5	Precipitation adjustment factor for rain days
Water Balance	3 OFs – Monthly Mean, Mean Monthly, & Annual Mean	snow_cbh_adj	0.2	5	Precipitation adjustment factor for snow days
Daily Flow Timing (all flows)	2 OFs – Daily & Monthly Mean	adjmix_rain	0.2	3	Factor to adjust rain proportion in mixed rain/snow events
Daily Flow Timing (all flows)	2 OFs – Daily & Monthly Mean	cecn_coef	0	10	Convection condensation energy coefficient
Daily Flow Timing (all flows)	2 OFs – Daily & Monthly Mean	emis_noppt	0.757	1	Emissivity of air on days without precipitation
Daily Flow Timing (all flows)	2 OFs – Daily & Monthly Mean	freeh2o_cap	0.01	0.2	Free-water holding capacity of snowpack
Daily Flow Timing (all flows)	2 OFs – Daily & Monthly Mean	K_coef	0	24	Travel time of flood wave from one segment to the next downstream
Daily Flow Timing (all flows)	2 OFs – Daily & Monthly Mean	potet_sublim	0.1	0.75	Proportion of PET that is sublimated from snow surface
Daily Flow Timing (all flows)	2 OFs – Daily & Monthly Mean	slowcoef_lin	0	1	Linear coefficient in equation to route gravity-reservoir storage down slope
Daily Flow Timing (all flows)	2 OFs – Daily & Monthly Mean	soil_moist_max	0.001	20	Maximum available water holding capacity of soil profile
Daily Flow Timing (all flows)	2 OFs – Daily & Monthly Mean	soil_rechr_max	0.001	10	Maximum available water holding capacity of soil recharge zone
Daily Flow Timing (high flows)	2 OFs – Daily & Monthly Mean	fastcoef_lin	0.1	1	Coefficient to route preferential-flow storage down slope
Daily Flow Timing (high flows)	2 OFs – Daily & Monthly Mean	pref_flow_den	0	1	Fraction of the soil zone in which preferential flow occurs
Daily Flow Timing (high flows)	2 OFs – Daily & Monthly Mean	sat_threshold	1	20	Water holding capacity of the gravity and preferential flow reservoirs
Daily Flow Timing (high flows)	2 OFs – Daily & Monthly Mean	smidx_coef	0.0001	1	Coefficient in non-liner surface
Daily Flow Timing (low flows)	2 OFs – Daily & Monthly Mean	gwflow_coef	0	1	Linear Coef. to compute groundwater discharge from each GWR
Daily Flow Timing (low flows)	2 OFs – Daily & Monthly Mean	soil2gw_max	0	5	Max amount of capillary reservoir excess routed directly to the GWR
Daily Flow Timing (low flows)	2 OFs – Daily & Monthly Mean	ssr2gw_rate	0	1	Linear Coef. to route water from the gravity reservoir to the GWR
Daily Flow Timing (low flows)	2 OFs – Daily & Monthly Mean	ssr2gw_exp	0	3	Exponent Coef. to route water from the gravity reservoir to the GWR

Each objective function was evaluated using a Shuffle Complex Evolution global optimization algorithm (SCE). Developed by Duan et al. (1992), the algorithm addresses the issues inherent to optimization when several local minima or maxima exist in the parameter space. Figure 10 below, reproduced from (Hay and Umemoto, 2006), illustrates the SCE procedures used.

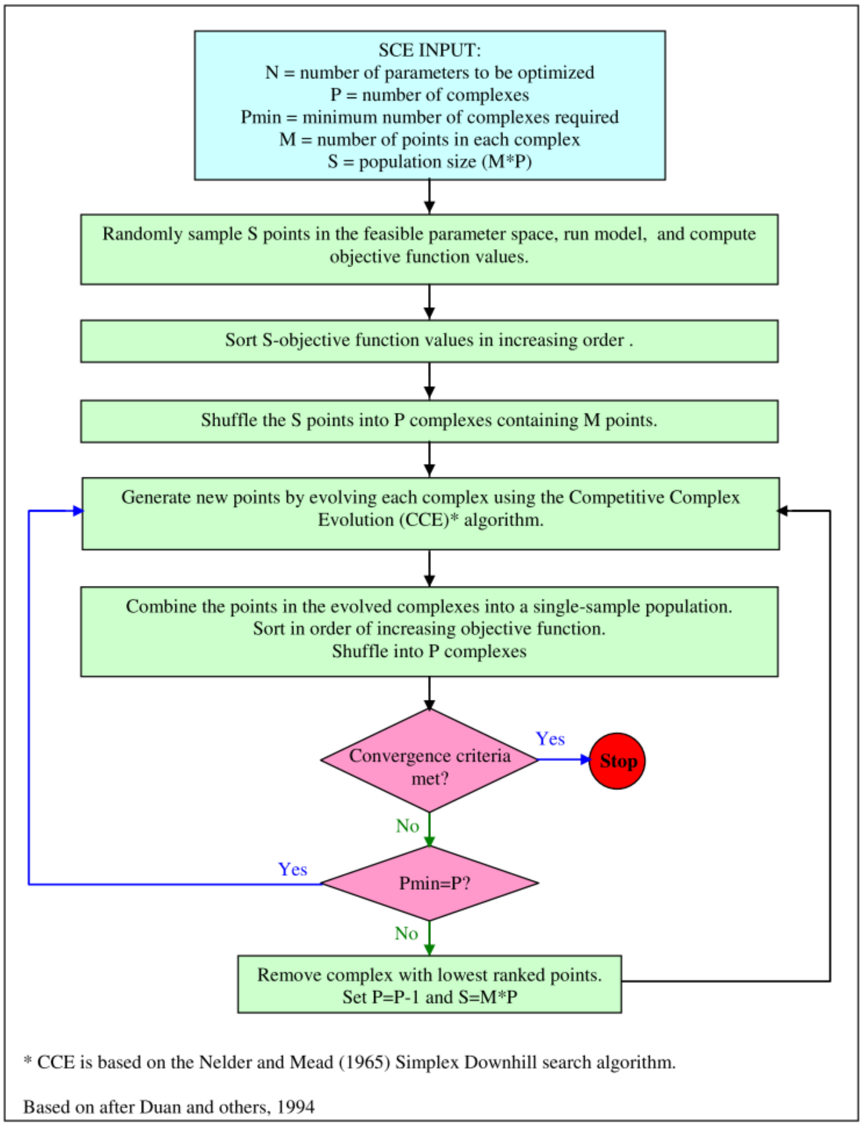

Figure 10: Flowchart of the Shuffled Complex Evolution (SCE) algorithm.

While LUCA is a powerful tool aiding in the calibration process, it does have limitations. HRU specific parameters, as well as soil zone and groundwater reservoir parameters, are dimensioned by the number of HRUs. LUCA cautioned against calibrating individual parameter values for each HRU. Instead one parameter is averaged across all HRUs, and that mean value is adjusted for calibration.

2.3.2 Manual Calibration

Due to limitations of LUCA, manual calibration techniques were also necessary. Several parameters were estimated based on other physical characteristics of the subwatersheds. For example, carea_max, used in the runoff module, is the maximum possible area contributing to surface runoff. Similar to the Curve Number used in the Rational Method, the maximum contributing area is the surface area that is capable of routing precipitation to runoff. The Curve Number based on land use type was used as a surrogate for estimating this value. When selecting a Curve number, a quality of “fair” was used, and the hydrologic soil group (A, B, C, and D) was selected based off of the soil types sand, loam, and clay.

2.3.3 Objective Function Values

Objective function values were calculated for each calibration round discussed above. Significant changes in objective function values and the description for each calibration procedure can be found in Table 4 below. The final parameter configuration conveyed in this report uses the final calibration method because it provides the lowest PBIAS value and while other objective function values remain relatively unchanged from previous methods in the calibration process.

Table 4: Evolution of objective function values through the calibration process

Calibration Description	PBIAS[1]	NRMSE[2]	PPMCC[3]	NSE[4]
GIS Uncalibrated Parameters	-34.4%	0.0735	0.333	0.0163
LUCA Automatic-Calibration (Hay et al., 2006)	-32.8%	0.0480	0.785	0.580
LUCA Automatic-Calibration (USGS, 2014)	-6.56%	0.0506	0.736	0.533
Manual-Calibration: Canopy density by cover type for summer and winter	-2.77%	0.0508	0.741	0.530
Manual-Calibration: Changed soil max values (Risley, 1994)	-9.25%	0.0465	0.782	0.606
Manual-Calibration: Changed maximum contributing area of each HRU by cover type based on SCS curve number	-1.51%	0.0468	0.784	0.601
LUCA Automatic-Calibration: Split the flow regime and calibrated to high and low streamflow (above and below average flow) for steps 3 and 4 respectively (USGS, 2014) and (Hay and Umemoto, 2006)	-0.55%	0.0495	0.772	0.554

S = Simulated, O = Observed; $\overline{S}$ = Mean Simulated, $\overline{O}$ = Mean Observed, n = number of observations

1. (Percent Bias) $PBIAS = 100\% * (\sum (O - S) / \sum O))$
2. (Normalized Root Mean Square Error) $NRMSE = \sqrt{(\sum (O - S)^2 / n)} / (O_{max} - O_{min})$
3. (Pearson Product-Moment Correlation Coefficient) $r = (\sqrt{(\sum (O - \overline{O})(S - \overline{S}))}) / (\sqrt{(\sum (O - \overline{O})^2)} * \sqrt{(\sum (S - \overline{S})^2)})$
4. (Nashe-Sutcliffe Efficiency) $NSE = 1- (\sum (O - S)^2 / \sum (O - \overline{O})^2)$

3. RESULTS

Results from this study include time series plots of observed versus simulated streamflow for both the Johnson Creek Upper Watershed gaged at Regner Road and the Sunshine Creek Subwatershed. Objective function values for each basin are also reported.

3.1.1 Regner Road Gage

Figure 11 shows the simulated streamflow time series output from PRMS versus the observed streamflow measured at the Regner Road gage. This plot shows that PRMS is matching the timing of the peaks but is not matching the intensity for the higher peaks. To visualize how well PRMS is simulating streamflow, Figure 12 shows the same output for a shorter time window.

The same trend can be seen looking at only one year of the simulation period. The model fails to meet the 642 cfs peak December 30th, 2005, and only reaches 339 cfs (on December 31st, 2005). Two other areas where the model seems to have difficulty are overestimating peaks after a long dry period, and accurately modeling the recession curve after a long wet period. For intermittent peaks the model performs well.

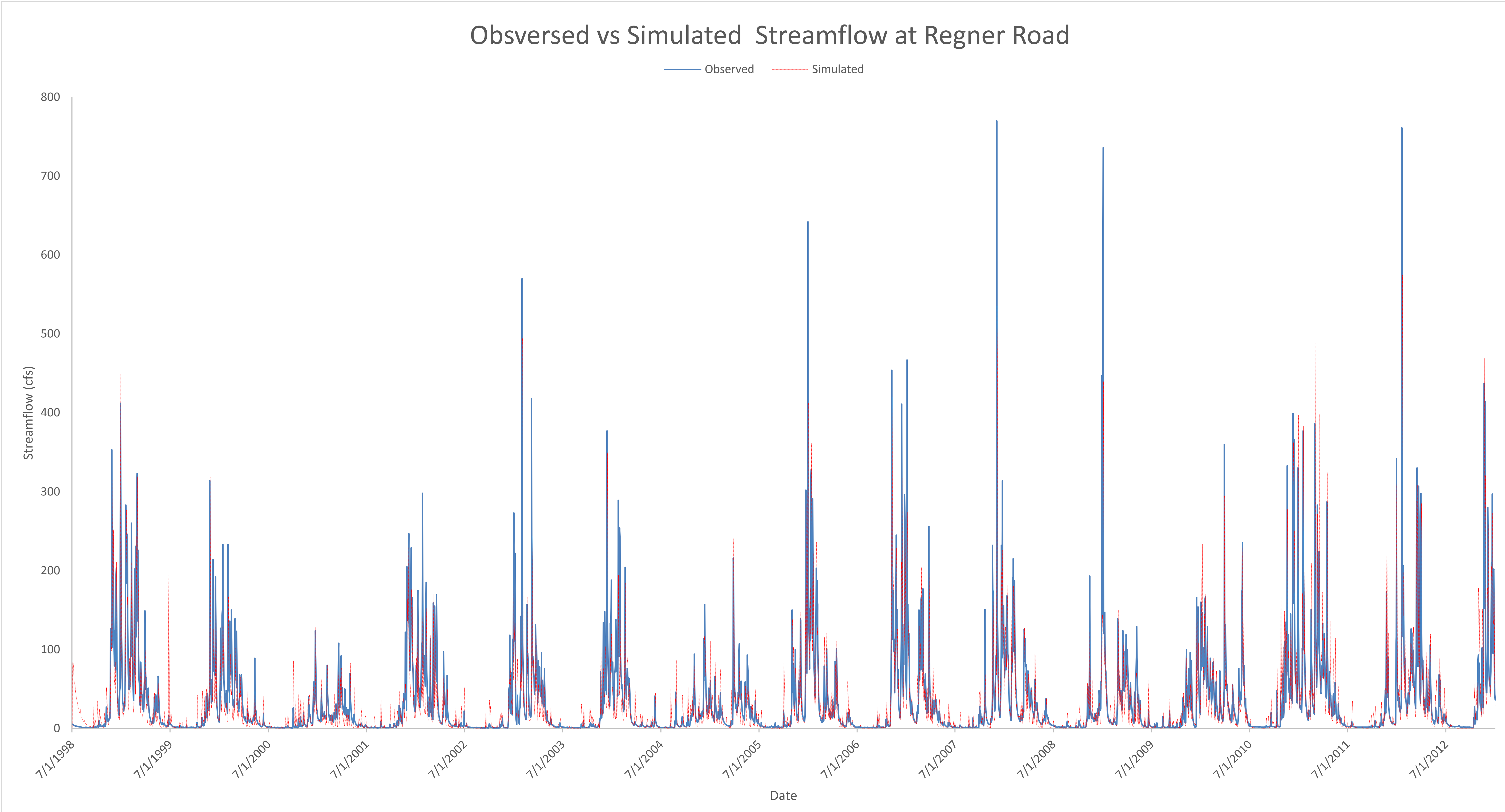

Figure 11: Observed and simulated streamflow for Johnson Creek Upper Watershed at Regner Road between 7/1/1998-12/31/2012

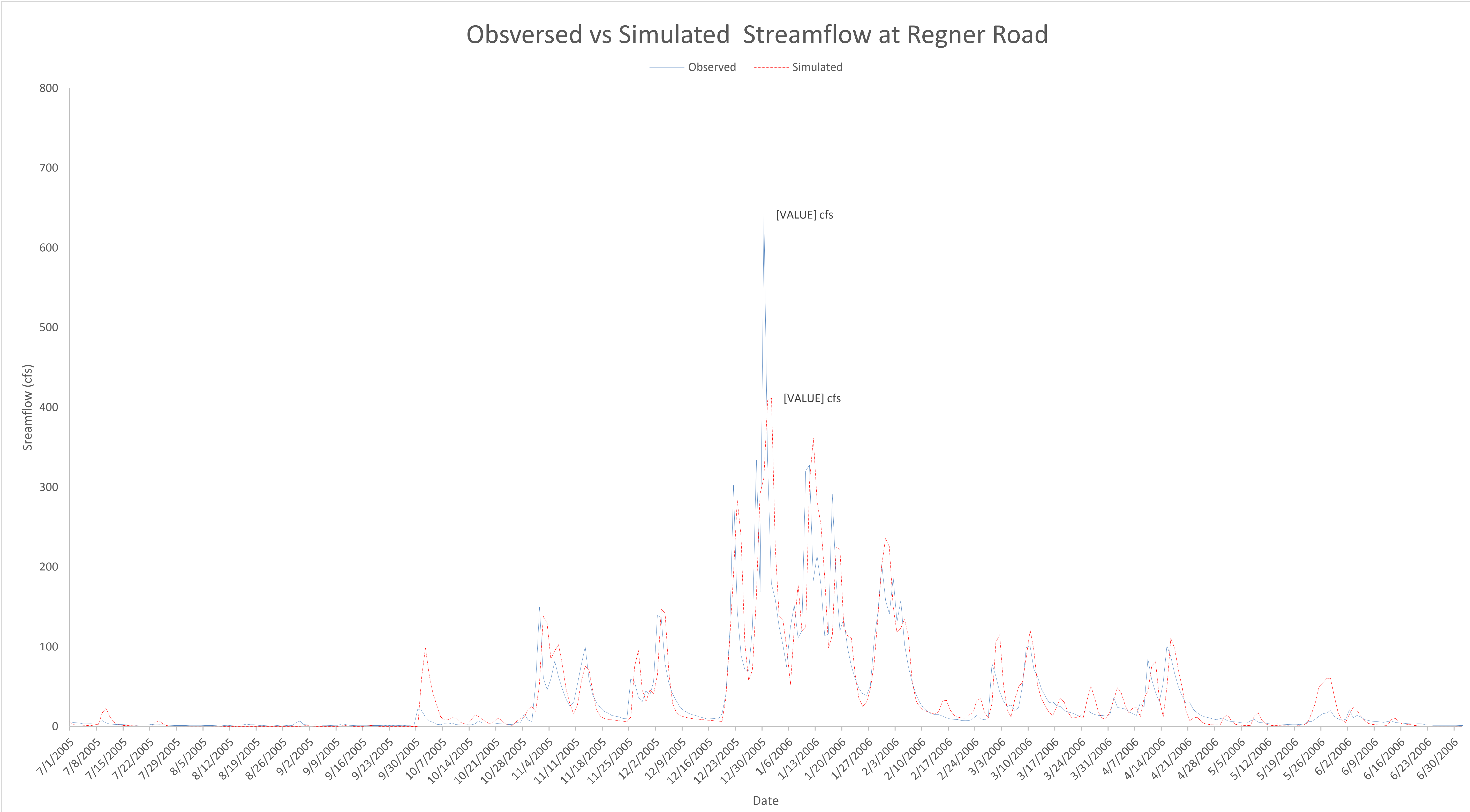

Figure 12: Enlarged plot of observed and simulated streamflow for Johnson Creek Upper Watershed at Regner Road between 7/1/2005-7/1/2006

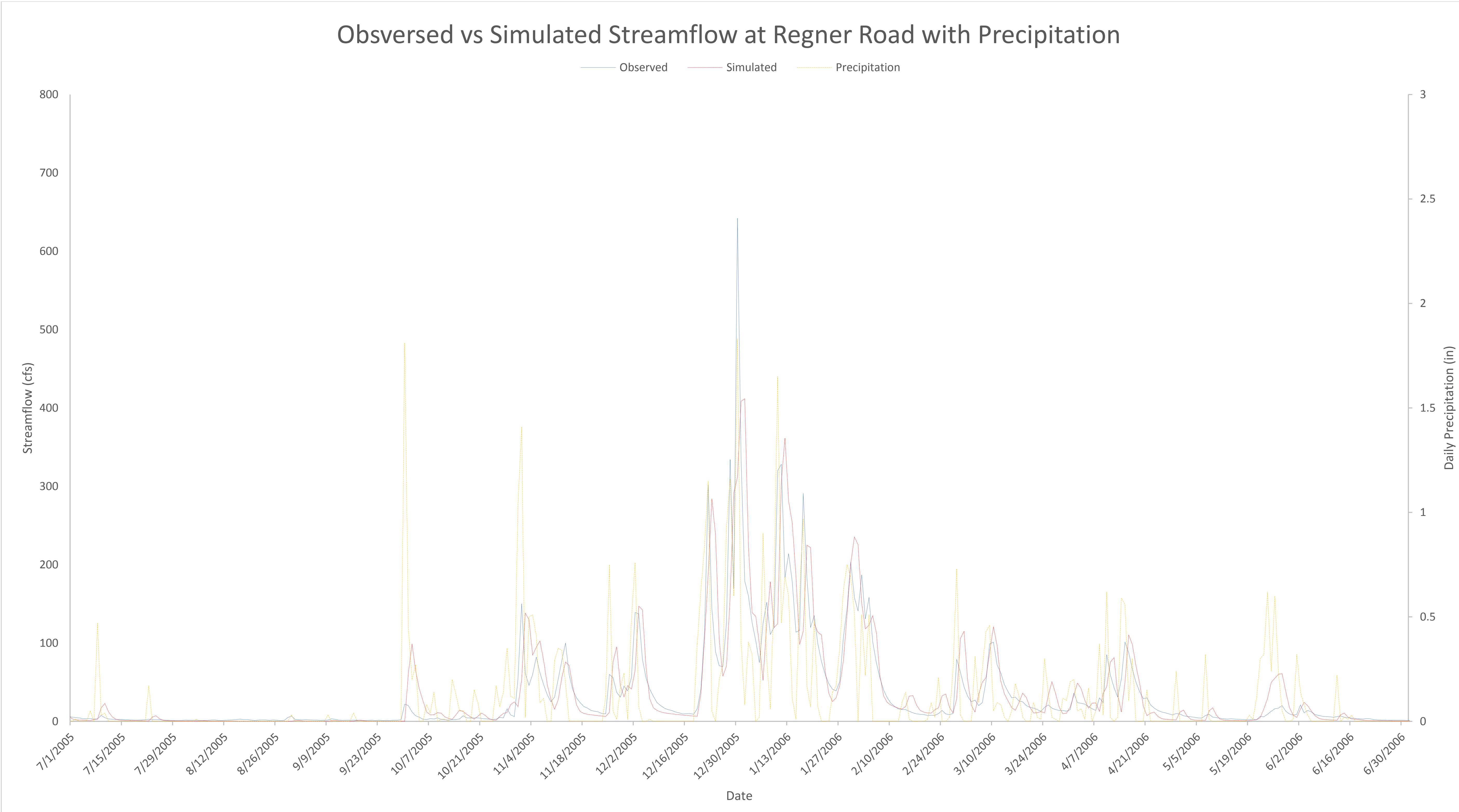

Figure 13: Enlarged plot of observed and simulated streamflow for Johnson Creek Upper Watershed at Regner Road including daily precipitation totals between 7/1/2005-7/1/2006

3.1.2 Sunshine Creek Subwatershed

After the JCUW PRMS model was calibrated, the calibrated parameters were substituted into a second SCS Model. Initial soil zone moisture, soil zone recharge, groundwater storage, and subsurface storage values were updated to reflect the values reported in the JCUW model for the end of the calibration period. Figure 14: Observed and simulated streamflow for Sunshine Creek between 1/1/2013-10/31/2013Figure 14 on the next page shows the simulated streamflow time series output from PRMS versus the observed streamflow for sunshine Creek.

Like the results of the JCUW model, the SCS model does not reach the highest peak flows. The model was only able to model 64.49 cfs of the 113.26 cfs peak flow. However, the SCS simulates precipitation event after a significant dry period better than the JCUW model. The timing of the model is consistent with observed peaks and precipitation events (see Figure 16).

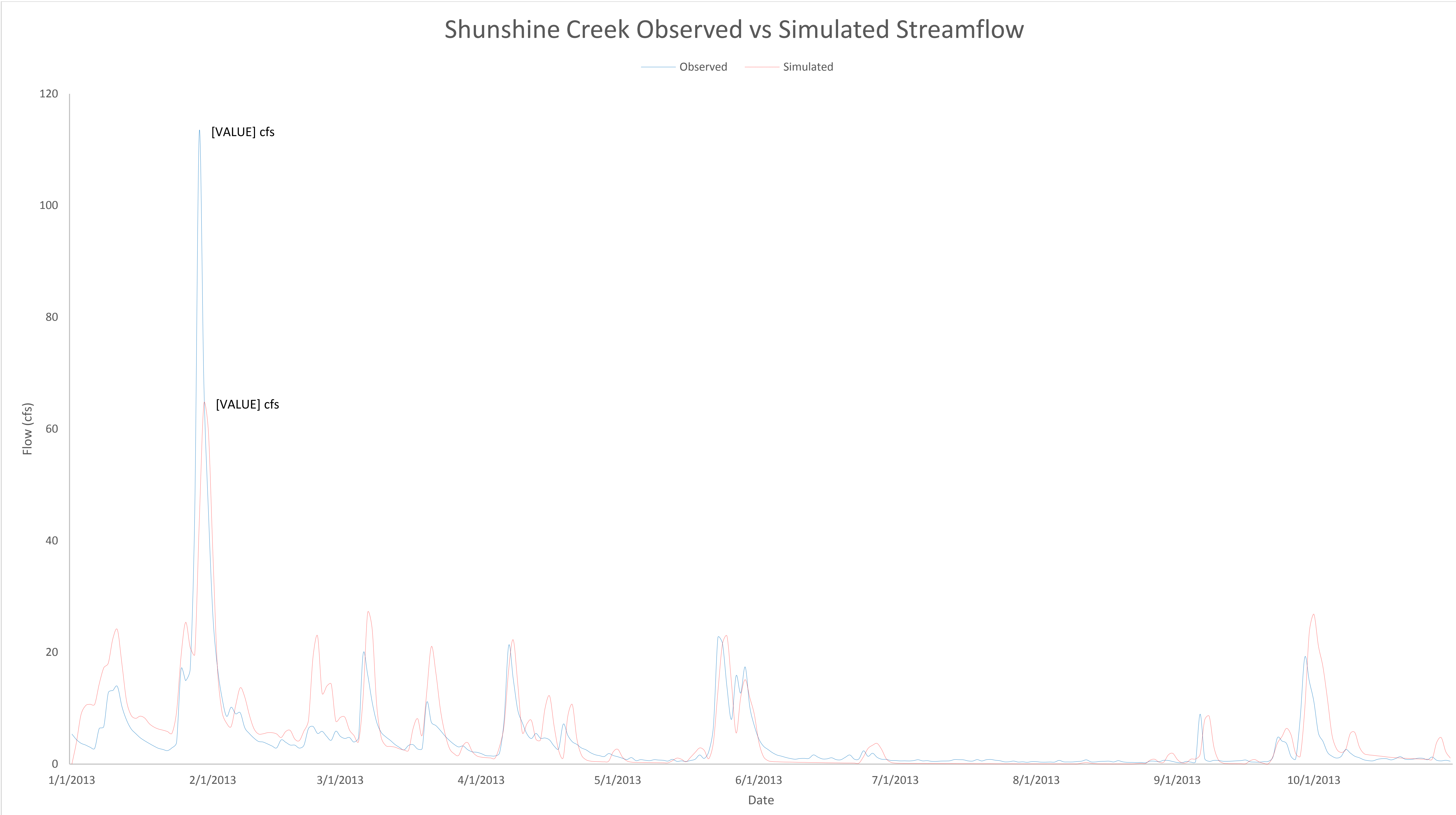

Figure 14: Observed and simulated streamflow for Sunshine Creek between 1/1/2013-10/31/2013

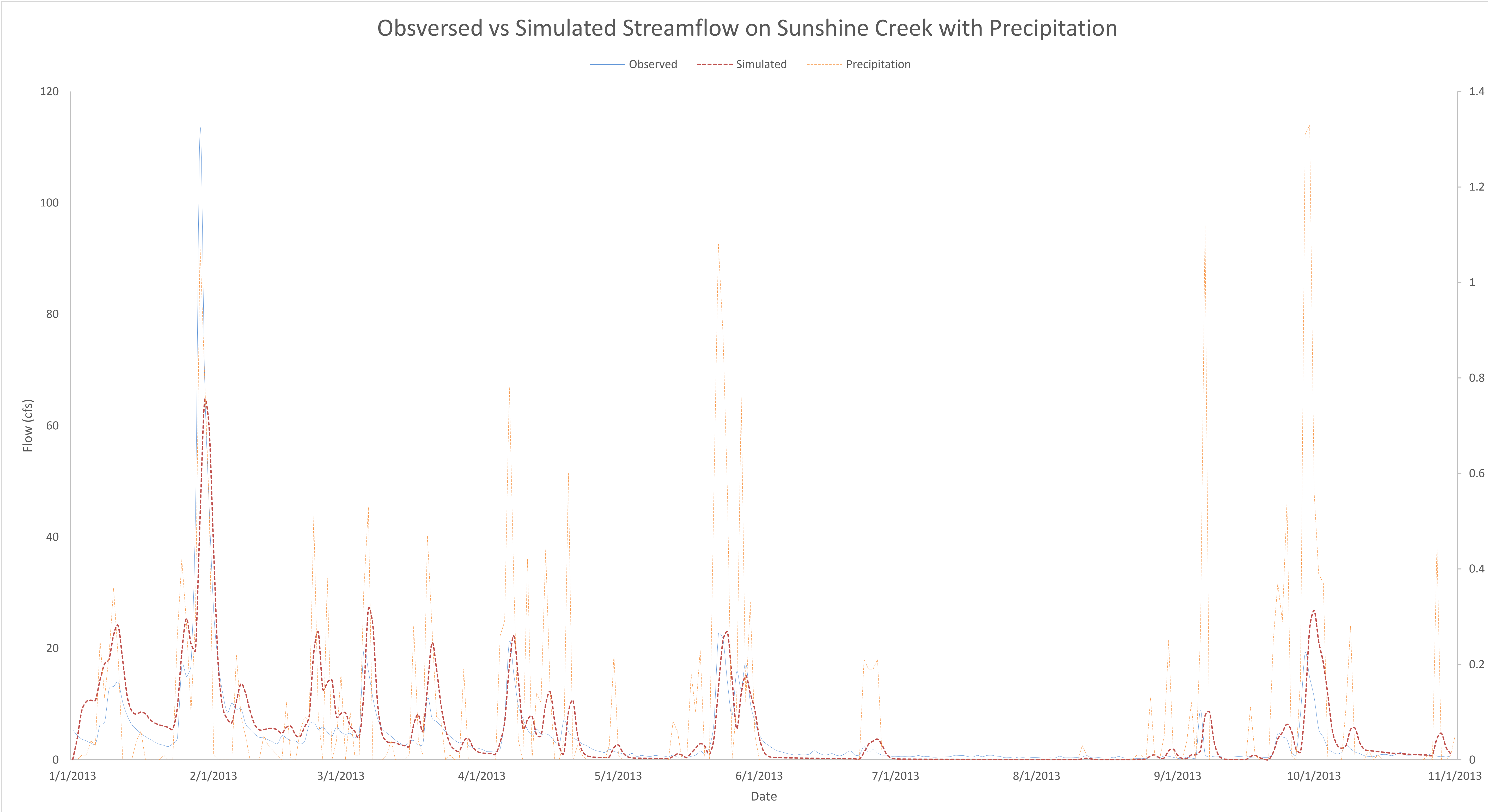

Figure 15: Observed and simulated streamflow for Sunshine Creek between 1/1/2013-10/31/2013

3.1.3 Model Correlation

As described above, objective function values describe the correlation or goodness of fit between observed and simulated streamflow. For the JCUW and SCS models four objective function values are reported below in S = Simulated, O = Observed; = Mean Simulated, = Mean Observed, n = number of observations

(Percent Bias) PBIAS = 100% * (∑ (O – S) / ∑ O)).

Table 5: Objective function values for the JCUW and SCS model

Basin Name	PBIAS[1]	NRMSE[2]	PPMCC[3]	NSE[4]
Johnson Creek Upper Watershed	-1.51%	0.0468	0.784	0.602
Sunshine Creek Subwatershed	16.5%	0.0516	0.708	0.596

S = Simulated, O = Observed; $\overline{S}$ = Mean Simulated, $\overline{O}$ = Mean Observed, n = number of observations

1. (Percent Bias) PBIAS = 100% * (∑ (O – S) / ∑ O))
2. (Normalized Root Mean Square Error) NRMSE = $\sqrt{(\sum (O - S)^2 / n)} / (O_{max} - O_{min})$
3. (Pearson Product-Moment Correlation Coefficient) r = $(\sqrt{(\sum (O - \overline{O})(S - \overline{S}))}) / (\sqrt{(\sum (O - \overline{O})^2)} * \sqrt{(\sum (S - \overline{S})^2)})$
4. (Nashe-Sutcliffe Efficiency) NSE = $1 - (\sum (O - S)^2 / \sum (O - \overline{O})^2)$

3.1.4 Error Analysis

All precipitation-runoff models contain errors (Risley, 1994). Typical hydrological errors include inadequate input data, inadequate physical processes algorithms, and inadequate parameter estimation (Troutman, 1985). These three error sources can be categorized as data error, model error, and parameter error and are explained below.

3.1.4.1 Data Error

Input data to the PRMS include precipitation, temperature, streamflow, and basin physical characteristics. Each data source has measurement error associated with the data collection methods. Due to the lack of rain gage density in the JCUW, rainfall data from one or two rain gages must be used to characterize the rainfall distribution of the entire basin. If the average elevation of the modeled watershed is higher than the rain gage used, an underestimation of basin rainfall is possible (Risely, 1994). Depending on how protected from the wind a rain gage is, error can range from a few percent up to 20 percent (Larson and Peck, 1974).

Temperature is another potential source of data error. Maximum and minimum temperature values used were collected at the Portland International Airport (PDX), located approximately 18 miles from the JCUW. Columbia River, located adjacent to the airport, may have a muting influence on high and low temperatures.

3.1.4.2 Model Error

Model errors arise when the hydrologic model has inadequate subroutines with respect to modeling physical processes in a basin. Empirical equations are not a perfect representation of a physical process, and often contain a error. When combining multiple empirical relationships throughout a model, these errors compound and produce overall model error. While some models minimize this source of error, all hydrologic model contain error.

> "Accurately ascertaining what part of simulation error can be attributed to model weakness rather than to input data or parameter estimation is difficult, if not impossible. … some PRMS algorithms, such as subsurface flow and evapotranspiration, might require improvement in future applications for forests of the Pacific Northwest" (Risley, 1994)

3.1.4.3 Parameter Error

Parameter error occurs when unsuitable parameter values are chosen for a basin. Due to cost restraints, it is not feasible to directly measure every input parameter in a basin. Therefore parameters must be estimated utilizing knowledge of the region, using surrogate parameters and typical values, or through the use of parameter optimization. In this study parameter values were estimated using automatic-calibration and manual-calibration techniques. For more discussion of calibration procedures, see Section 2.3.

4. SUMMARY AND CONCLUSIONS

Water quality is an important aspect of overall stream health. Studying the hydrology of a watershed provides better understanding of factors influencing water quality. The PRMS hydrologic model of the Johnson Creek headwaters aims to validate streamflow measurements taken as part of the Johnson Creek Hydrology Study. Using GIS tools to characterize the subject drainage basins and estimating other physical processes, model parameters were compiled for the Johnson Creek Upper Watershed and the Sunshine Creek Subwatershed encompassed by the former.

Parameters not obtained by estimation or geoprocessing were calibrated to the Regner Road stream gage. The calibrated parameters were then transferred from the Johnson Creek Upper Watershed (JCSW) model to the Sunshine Creek Subwatershed (SCS) model. Geoprocessed parameters and other estimated physical parameters were combined with calibrated parameters. The outcome was successful within the bounds of assumed cumulative error (i.e. data error, model error, and parameter).

The primary limitation of this process is spatial scale disparity between the two subwatersheds, which translates into parameter error for the SCS. The JCUW is a factor of 3 larger than the SCS. The spatial difference directly translates into a temporal difference as well. Travel time for water to reach the stream gage is likely significantly less in the smaller subwatershed. While attempts to minimize limitations and error were made, the results of this study and future results using the procedure applied should be taken only as supplemental information until further research is made into the scientific validity of the methods involved.

5. RECOMMENDATIONS

The purpose of this section is to highlight possible improvements to the Johnson Creek Subwatershed PRMS model.

5.1.1 Underlying Geology

Soil data was incorporated into the model by categorizing the drainage characteristics into three soil groups: clay, loam, and sand. However, this classification only accounts for the surficial soil and the interflow contribution to streamflow. Variations in underlying geology affect groundwater flow rate. Groundwater accounts for a significant component of stream baseflow. The model may be improved by adjusting the subsurface transport coefficients to better reflect the physical characteristics of groundwater reservoirs.

5.1.2 Precipitation Gage Spatial Averaging

The current PRMS model developed for this study uses precipitation data from the Gresham Fire Station Rain Gage located at 1333 NW Eastman Pkwy, Gresham, Oregon. This gage provides a representative rainfall distribution to the area surrounding the Regner Stream Gage. However, the precipitation contributing to the headwaters of Johnson Creek, near Damascus, Oregon and Boring, Oregon, is likely better categorized by the Cottrell School Rain Gage located at 36225 SE Proctor Rd, Boring, Oregon (See Figure 6). Spatial averaging techniques described by Larson and Peck (1974) could be applied to the time series generated by each gage to better represent rainfall distribution in the subwatersheds.

5.2 Groundwater Simulation

PRMS can be coupled with a three-dimensional finite-difference groundwater modeling system named MODFOLW. The coupled model is named Groundwater Surface-water FLOW (GSFLOW). The surface runoff model developed for this study would stand to benefit from a higher resolution groundwater model. PRMS provides groundwater routing capabilities, however, they are limited due to the temporal-scale differences in surface runoff and groundwater flow. Subsurface routing occurs on the order of weeks to months, and surface runoff occurs on the order of hours to days. This temporal difference is accounted for in GSFLOW and may yield more accurate results than PRMS alone. Figure 16 shows a schematic flow exchange between PRMS and MODFLOW.

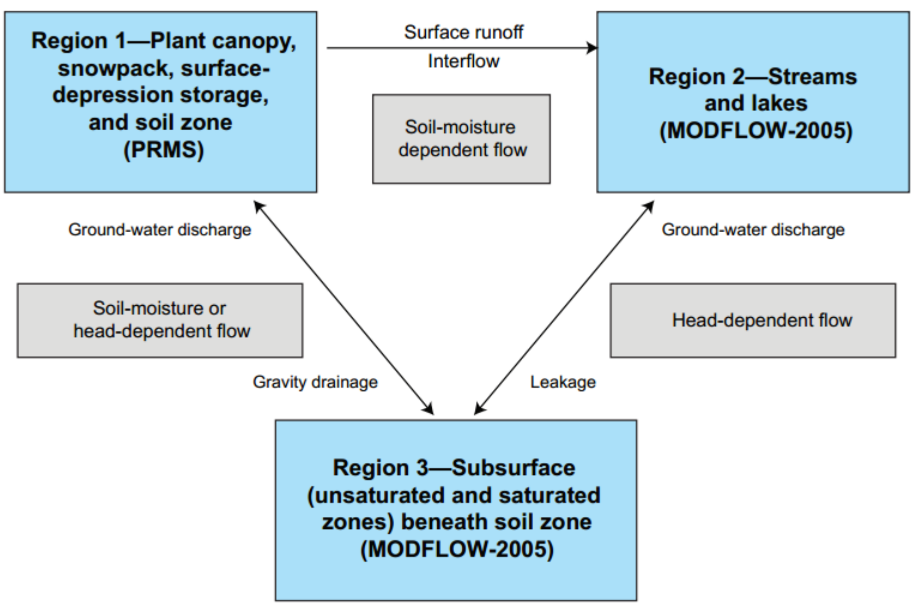

Figure 16: Schematic diagram of the exchange of flow among the three regions in GSFLOW (Adapted from Markstrom et al., 2008)

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