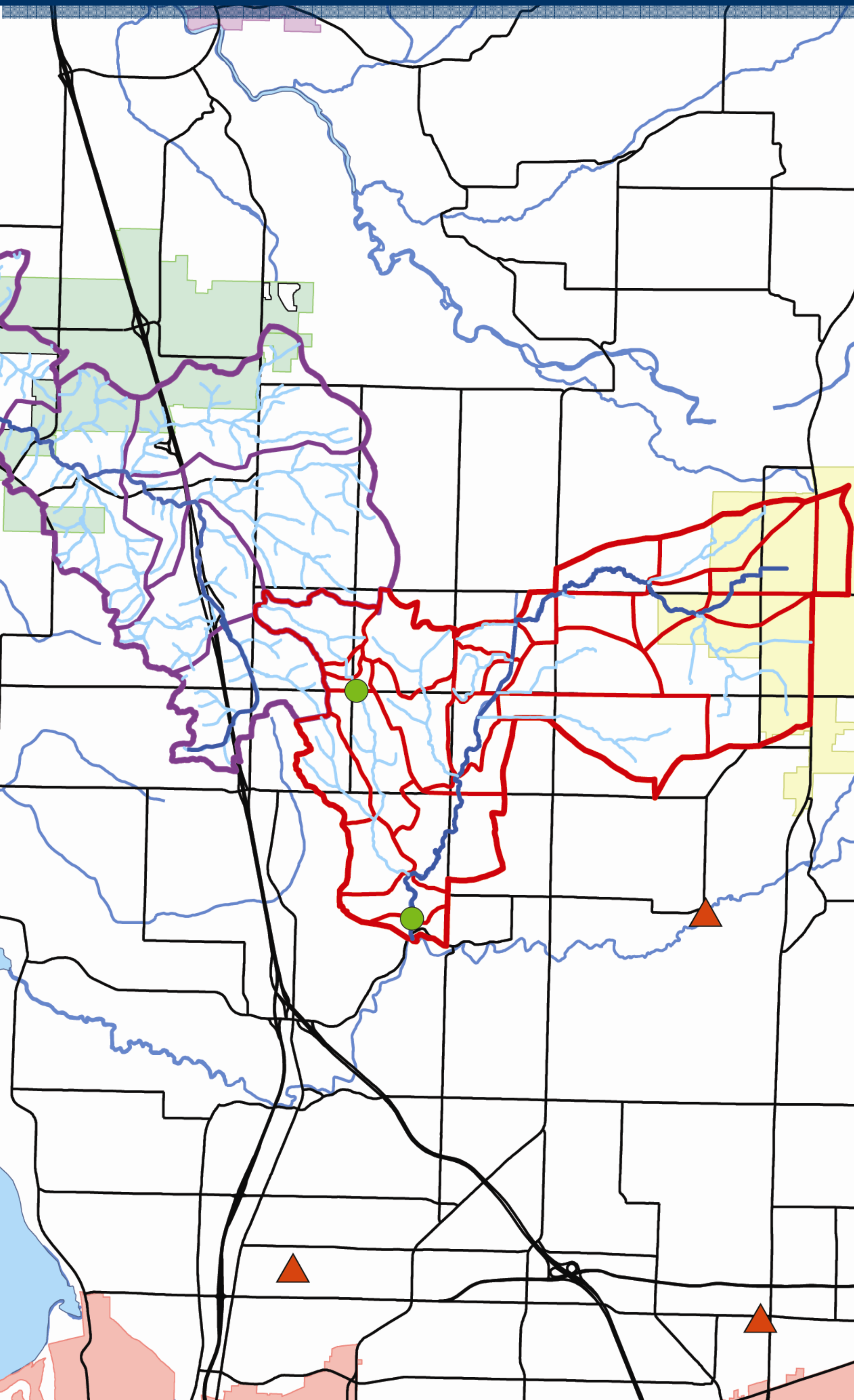
Development of the Clark County Version of the Western Washington Hydrology Model

Final Report (Revised)



Submitted to:

Clark County Public Works
Clean Water Program
1300 Franklin Street
Vancouver, Washington 98660

Prepared by:

Otak, Inc.
700 Washington Street
Suite 401
Vancouver, WA 98660
Otak Project No. 14782

January 20, 2010

This page left blank to accommodate double-sided printing

Acknowledgements

Development of the Clark County Version of the Western Washington Hydrology Model

Hydrology Report

Final (Revised)

Submitted to:

Clark County Public Works
Vancouver, Washington

Prepared by:

Otak, Inc.

Tim Kraft, P.E.
Project Manager

Ryan Billen, P.E.
Project Engineer

In partnership with:

Clear Creek Solutions, Inc.

Douglas Beyerlein, P.E.
Project Manager

Joseph Brasher
Senior Hydrologist

Shanon White
Senior Programmer

Otak Project No.: 14782
January 20, 2010

This page left blank to accommodate double-sided printing

Clark County WWHM Development
Table of Contents

Page

Appendices

Attachments

Table of Contents

Figures

Tables

Clark County WWHM Development

1.0 Introduction

1.1 Purpose

This report discusses the development of the Clark County version of the Western Washington Hydrology Model. Once approved, this continuous simulation hydrologic model will supplement the design of new flow control and runoff treatment facilities in Clark County, Washington.

1.2 Background

As mandated by the National Pollutant Discharge Elimination System (NPDES) Phase I Permit issued by the Washington State Department of Ecology (Ecology), the April 13, 2009 Clark County Stormwater Ordinance requires the use of a continuous simulation hydrologic model to design flow control and runoff treatment facilities. The continuous simulation method is a relatively new approach to stormwater modeling in Clark County and involves substantial changes from the previous modeling standard. Prior to the recent update, Clark County's Stormwater Ordinance was based upon single event stormwater modeling methods such as Santa Barbara Urban Hydrograph. Compared to single event methods, the continuous simulation process is more computationally intensive and requires abundant input data associated with hydrologic parameter values and meteorological data.

The Washington State Department of Ecology has identified several reasons why the continuous simulation method will be the new modeling standard throughout Western Washington (Washington State Department of Ecology, 2005). These reasons include:

- A continuous simulation model is capable of simulating a wider range of hydrologic responses than the single event models.
- Single event models cannot take into account storm events that may occur just before or just after the single event (the design storm) that is under consideration.
- Runoff files generated by continuous simulation are the result of a considerable effort to introduce local parameters and actual precipitation data into the model; and therefore, produce better estimations of runoff than single event models.

Specific computational standards for continuous simulation modeling are outlined in Ecology's Stormwater Management Manual for Western Washington (SMMWW). Listed among these standards is the requirement to utilize the Hydrologic Simulation Program Fortran (HSPF) model developed by the United States Environmental Protection Agency (EPA). Because direct use of the HSPF modeling program is labor intensive and requires extensive training, Ecology retained Clear Creek Solutions, Inc. to develop a streamlined continuous simulation model that could be used throughout Western Washington to design flow control and treatment facilities. The resulting modeling program—known as the Western Washington Hydrology Model (WWHM)—provides a user-friendly and easily reviewable model that is HSPF based. In comparison with the standard HSPF model, the

WWHM is a self-contained software program that requires minimal input information from the user regarding pre-developed and developed conditions at the site. Hydrologic parameter default values for the WWHM were developed based on watershed studies in King, Pierce, Snohomish, and Thurston counties (Washington State Department of Ecology, 2005). Meteorological data for this model were obtained from weather stations throughout Western Washington; with necessary data from each station being incorporated into the WWHM software package.

As previously stated, the values of hydrologic input parameters for Ecology's WWHM were calibrated using watersheds in the Puget Sound area. Because these parameter values may not be representative of all of Western Washington, Ecology encourages municipalities to develop local calibrations of HSPF parameters that can be incorporated into the WWHM (Washington State Department of Ecology, 2005). In response to this alternative, Clark County retained Otak, Inc. in partnership with Clear Creek Solutions, Inc. to develop a modified version of Ecology's WWHM program that would be more representative of Clark County hydrology. Development of the Clark County version of the WWHM is discussed in the following sections of this report as well as in Attachment 1.

1.3 Approach

Development of the Clark County version of the WWHM involved two distinct and separate tasks performed by the consultant team. The first task involved the development of calibrated parameter values that are used by the WWHM's HSPF underpinnings to simulate surface and sub surface responses to meteorological input data. As part of this task, HSPF calibration studies for two Clark County watersheds—the Mill Creek watershed and the Gee Creek watershed—were conducted. The second task performed by the consultant team involved revising the meteorological input data contained within the WWHM. This included supplying additional precipitation information, adding evaporation data from a nearby weather station, and revising the precipitation scaling factors used to represent spatial variations in precipitation throughout Clark County. Additional discussion on each of these tasks is presented in Section 1.3.1 and Section 1.3.2 below.

1.3.1 Surface Parameters

For this report, hydrologic parameters associated with conditions at or below the ground surface are referred to as "Surface Parameters". The values of these surface parameters within HSPF vary based on surface characteristics such as soil type, land use, and surface slope. To model these varying surface conditions within HSPF, up to 18 different parameter categories are used to represent each unique combination of land use, soil type, and slope (Northwest Hydraulic Consultants, 2000). The values assigned to each parameter category will determine the amount of surface runoff, subsurface interflow, and infiltration calculated by the model. Consequently, the purpose of calibration efforts related to this project was to determine the values to be assigned to the parameters for each unique combination of the surface characteristics within the Clark County version of the WWHM.

To begin the calibration process for HSPF surface parameters, several Clark County watersheds were selected for modeling based on criteria recommended by Clear Creek Solutions, Inc. These criteria were presented to the Clark County Technical Advisory Committee (TAC), which assisted in the selection process. Once selected, necessary modeling information was gathered and processed for each watershed by Otak, Inc. After formatting the necessary data, an HSPF model was created for each watershed by Clear Creek Solutions, Inc. Meteorological data were then input to the models and used to calculate runoff, which was compared against recorded flow data. Subsequent alterations to surface parameters within the models were then performed in order to produce flows that best resembled recorded data. Calibrated surface parameter values were then identified which were used to create the Clark County version of the WWHM. Note that although calibrated parameter values are included as the default values in the Clark County version of the WWHM, they may also be incorporated into any Clark County and Ecology approved HSPF-based model. See Attachment 1 of this report for a detailed discussion of the calibration procedure and results determined by Clear Creek Solutions, Inc.

1.3.2 Meteorological Data

Unlike surface parameters, meteorological data is input directly into the HSPF model and does not require calibration. For the Clark County version of the WWHM, meteorological input data from Ecology's WWHM were supplemented or revised. This includes precipitation data, precipitation scaling factors, and evaporation data.

Supplementary precipitation data were added to the period of record contained within the WWHM software package for the precipitation gage at the Portland International Airport (PDX). Precipitation data were added to account for the period of time that has elapsed since development of Ecology's WWHM in 1999. The precipitation gage at PDX is the closest gage to Clark County with sufficient precipitation data for the WWHM to utilize, and is therefore used for both Ecology's WWHM and the Clark County version of the WWHM. Spatial variations in precipitation across Clark County are accounted for using precipitation scaling factors, which scale the PDX precipitation data.

To produce revised scaling factors, daily precipitation data from precipitation stations across Clark County and Multnomah County were compared to data from the Portland International Airport (PDX). Additionally, the area of influence for each scaling factor was also revised for this study using the Thiessen polygon method.

Supplementary evaporation data were added to the Clark County version of the WWHM to provide the model with evaporation data from a weather station in closer proximity to Clark County than is available in Ecology's WWHM.

1.4 Organization

This report is divided into two main components: one describing the assumptions and input information used for calibration of the surface parameters, and the other describing the sources and analyses of the meteorological information. Each section describes the work performed by Otak, Inc. as part of the overall effort to produce an Ecology approvable version of the WWHM that is representative of Clark County. Also included as an attachment to this report is the calibration report prepared by Clear Creek Solutions, Inc., which describes the modeling procedures and results of the HSPF calibration models created for the Mill Creek and Gee Creek watersheds. The Clear Creek Solutions, Inc. report also presents the final surface parameter values that were incorporated into the Clark County version of the WWHM.

2.0 Input Data for Surface Parameter Calibration

2.1 Overview

The calibration of surface parameters for the Clark County version of the WWHM involved several steps. These steps are discussed below.

2.1.1 Step 1

The first step involved selecting watersheds suitable for calibration. Two watersheds were selected to establish the validity of calibrated parameter values and were identified as reasonably representative of pre-developed conditions in Clark County. Additionally, during this step, it was determined that soil types within Clark County would be grouped into five categories, as opposed to the soil group classification method used in the Ecology version of the WWHM. This work was performed by Otak, Inc., in conjunction with the TAC and Clark County staff, and is discussed in more detail in the following sections of this report.

2.1.2 Step 2

Once the suitable watersheds were selected, the necessary data were collected and formatted for modeling. Modeling data came from a variety of sources, including: previously created watershed models, Clark County Geographic Information Systems (GIS) data, and Clark County monitoring data. Spatial data were analyzed primarily with ArcGIS software, and quantified for each subbasin area using Excel spreadsheets. See Appendix A of this report for summary tables of the spatial information associated with each watershed.

2.1.3 Step 3

Following data collection and formatting, the resulting information was supplied to Clear Creek Solutions, Inc. for modeling and calibration. Calibrated parameter values were then incorporated into the final version of the Clark County WWHM model. See Attachment 1 of this report for the calibration report prepared by Clear Creek Solutions.

2.2 Watershed Selection Process

Several watersheds across Clark County were considered for use in the calibration of surface parameter values. These watersheds were identified using the following selection criteria. Required information and watershed attributes include:

- Hourly precipitation data available from a nearby gage spanning a period of several years.
- Hourly streamflow data available (corresponding to the precipitation data time series).
- Presence of several soil types from the five soil categories.
- A primarily rural watershed to represent pre-developed conditions.
- A watershed area of approximately 5 to 10 square miles upstream of the stream gage.

Watersheds within Clark County that best meet the above criteria include: Mill Creek, Whipple Creek, Gee Creek, Cougar Creek, Curtin Creek, and Lacamas Creek. Once identified, these watersheds were assessed individually to determine which would be suitable for calibration efforts. After further review of the characteristics of each watershed, as well as the reliability of available information, the following determinations were made regarding the six preliminary watersheds.

- Mill Creek – Mill Creek was selected for calibration purposes because it satisfied all of the initial selection criteria and has been modeled using HSPF for a recent study.
- Whipple Creek – The Whipple Creek watershed was nearly selected for calibration purposes due to the availability of data, a reasonably good distribution of soils, and previous HSPF modeling work that could be utilized for the calibration. However, upon reviewing the stream gage data for Whipple Creek, it was discovered that streamflow information is missing for significant periods of time each year, usually from mid-summer to mid-fall. Discussions with flow monitoring personnel from River Measurement, Ltd. revealed that backwater effects from beaver dams affected the stream gage, prompting the elimination of data recorded during periods of backwater. Consequently, reliable 15-minute streamflow data is unavailable for these periods of time, which limits the amount of data available for calibration efforts. Despite the streamflow data limitations, Whipple Creek could potentially be used as another watershed for comparison purposes.
- Gee Creek – The Gee Creek watershed was selected because it satisfied the initial selection criteria and has recently been modeled using the HEC-RAS program. Results and inputs from the HEC-RAS model were used to create an HSPF model of this watershed.
- Cougar Creek – At 2.99 acres, the Cougar Creek watershed is smaller than recommended, and lacks an existing HSPF model for use in calibration efforts.
- Curtin Creek – The Curtin Creek watershed was not selected due to concerns about significant off-channel storage and how that might affect calibration.
- Lacamas Creek – The Lacamas Creek watershed was not selected due to concerns about accuracy of the precipitation data. It also lacks an existing HSPF model for use in calibration efforts.

2.3 Watershed Overview

The watersheds selected for HSPF modeling are located within Clark County and are described in the following sections. Figure 1 shows the location of each watershed within the County limits.

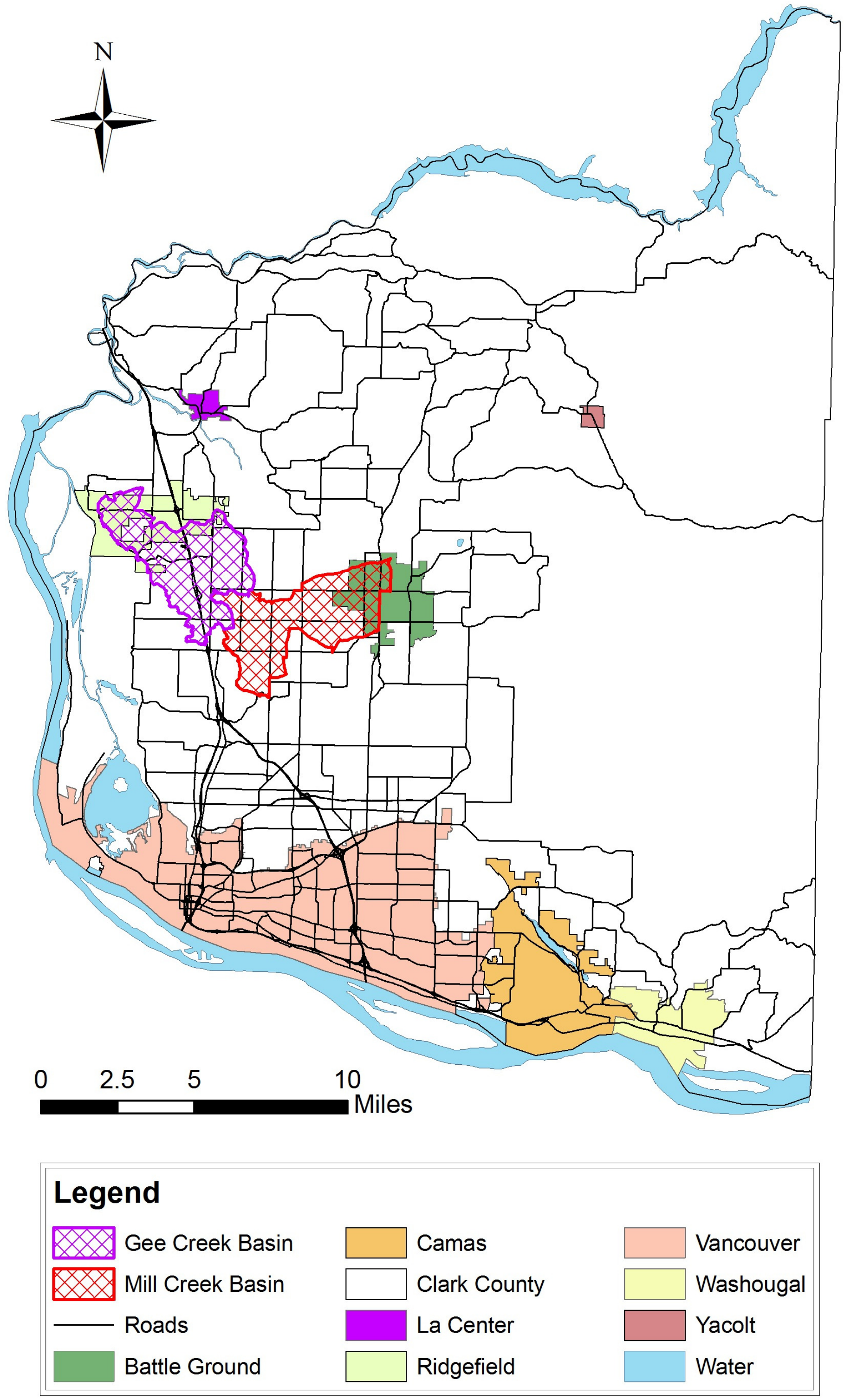


Figure 1: Vicinity Map of Gee Creek and Mill Creek Watersheds

2.3.1 Mill Creek

The Mill Creek watershed is 11.85 acres in size, and is located between the I-5 corridor and the City of Battle Ground. At present this watershed is primarily rural, although it will likely see continued development in the future due to its proximity to the City of Battle Ground. Significant growth expansion areas for the City of Battle Ground and Clark County are planned for areas of this watershed.

2.3.2 Gee Creek

The Gee Creek watershed is 11.60 acres in size, and is located along the I-5 corridor. At present this watershed is primarily rural, although it will likely see continued development in the future due to its proximity to Ridgefield and the I-5 corridor. Significant growth expansion areas for the City of Ridgefield are planned for areas of this watershed.

2.4 HSPF Modeling Data

HSPF modeling efforts for the Gee Creek and Mill Creek watersheds required several types of input data, which are identified and discussed in the following sections. These types include:

- Streamflow Data
- Precipitation Data
- Evaporation Data
- Delineated Subbasin Areas
- Routing Tables
- Soil Data
- Land Use Data
- Slope Data

2.4.1 Streamflow Data and Precipitation Data

Streamflow data and precipitation data were obtained by Otak, Inc. from a network of meteorological gages supported by Clark County Public Works. This network consists of stream gages and precipitation gages located throughout Clark County, which are maintained by River Measurement, Ltd, a subsidiary of WEST Consultants, Inc. The period of record for these gages is variable, with some gages dating back to the mid-1990's and others installed as recently as 2007.

The streamflow data used for calibration of the Mill Creek HSPF model were acquired from the MIL008 gaging station located on the left bank of Mill Creek, approximately 900 feet upstream of NE Salmon Creek Avenue. Gage equipment consists of a combined data logger and pressure transducer that measure stage height and water temperature every 15 minutes. Streamflow data were later produced by River Measurement, Ltd by means of a stage versus discharge curve. The gage was installed on May 20, 2003. Flow data, spanning the period from May 2003 to September, 2007, was used for calibration of the Mill Creek HSPF model.

A second stream gage within the Mill Creek watershed was also used for calibration purposes. This temporary gage was located on a Mill Creek tributary at NE 199th Street, and recorded 15-minute streamflow data from January 7, 2005 to January 31, 2006. See Attachment 1 of this report for additional discussion regarding this gage.

Precipitation data for the Mill Creek watershed were obtained from the SMN045 Clark County Public Works precipitation gage station at NE 156th Street near Battle Ground, WA. This gage is a Sutron electronic data logger connected to a tipping bucket. A cell phone modem provides real-time data, which is polled hourly by Clark County Public Works. This precipitation gage is not heated and is mounted to the top of a four-foot diameter aluminum corrugated metal pipe. Fifteen minute precipitation data spanning the period from May 2003 to September 2007 was used for the Mill Creek HSPF model. The SMN045 precipitation gage is located approximately 1.5 miles southeast of the Mill Creek watershed and is the closest gage that logs 15-minute precipitation data. The Battle Ground precipitation gage is somewhat closer to the eastern portion of the Mill Creek watershed; however, this station only records daily precipitation data, and therefore cannot be used for calibration of the Mill Creek HSPF since the model requires more refined data.

The streamflow data used for calibration of the Gee Creek HSPF model were acquired from the GEE028 gaging station located at Abrams Park on the left bank of Gee Creek. Gage equipment consists of an electronic data logger connected to a submersible pressure transducer, which is referenced to an outside staff gage. A crest staff gage is used at the site to verify peaks. Equipment also includes a water temperature sensor and a cell phone modem which provides real-time data. Stream gage data is recorded at 15-minute intervals, and is transmitted to Clark County Public Works on an hourly basis. Streamflow data were later produced by River Measurement, Ltd. by means of a stage versus discharge curve. Flow data spanning the period from January 2003 to September 2007 was used for calibration of the Mill Creek HSPF model.

Precipitation data for the Gee Creek watershed were obtained from two Clark County Public Works precipitation gage stations. These stations include the Ridgefield Wastewater Treatment Plant station at Ridgefield, WA, and the Salmon Creek Wastewater Treatment Plant station near Vancouver, WA. Because the Ridgefield Station is closest to the main body of the Gee Creek watershed, precipitation information from this station was used for the majority of calibration effort, ranging from October 2003 to September 2007. This station records 15-minute precipitation data using a Sutron model 9210 electronic data logger connected to a tipping bucket precipitation gage. A cell phone modem provides real-time data, which is polled hourly by Clark County Public Works. The precipitation gage is not heated, and is attached to a mast extending above the roof of the water quality lab building at the Ridgefield Treatment Plant, with the logger located inside the building.

Precipitation information obtained from the Salmon Creek Treatment Plant gage was used for a period of time prior to the installation of the Ridgefield gage, ranging from January 2003 to September 2003. This gage consists of a Sutron model 9210 electronic data logger connected to a tipping bucket precipitation gage, which is not heated. The gage is attached to a mast extending above the roof of the old control room building at the Salmon Creek Treatment Plant, with the data logger located inside the building. This station records 15-minute precipitation data.

Figure 2 shows a map of the stream gages and precipitation gages located in the vicinity of the Mill Creek and Gee Creek watersheds.

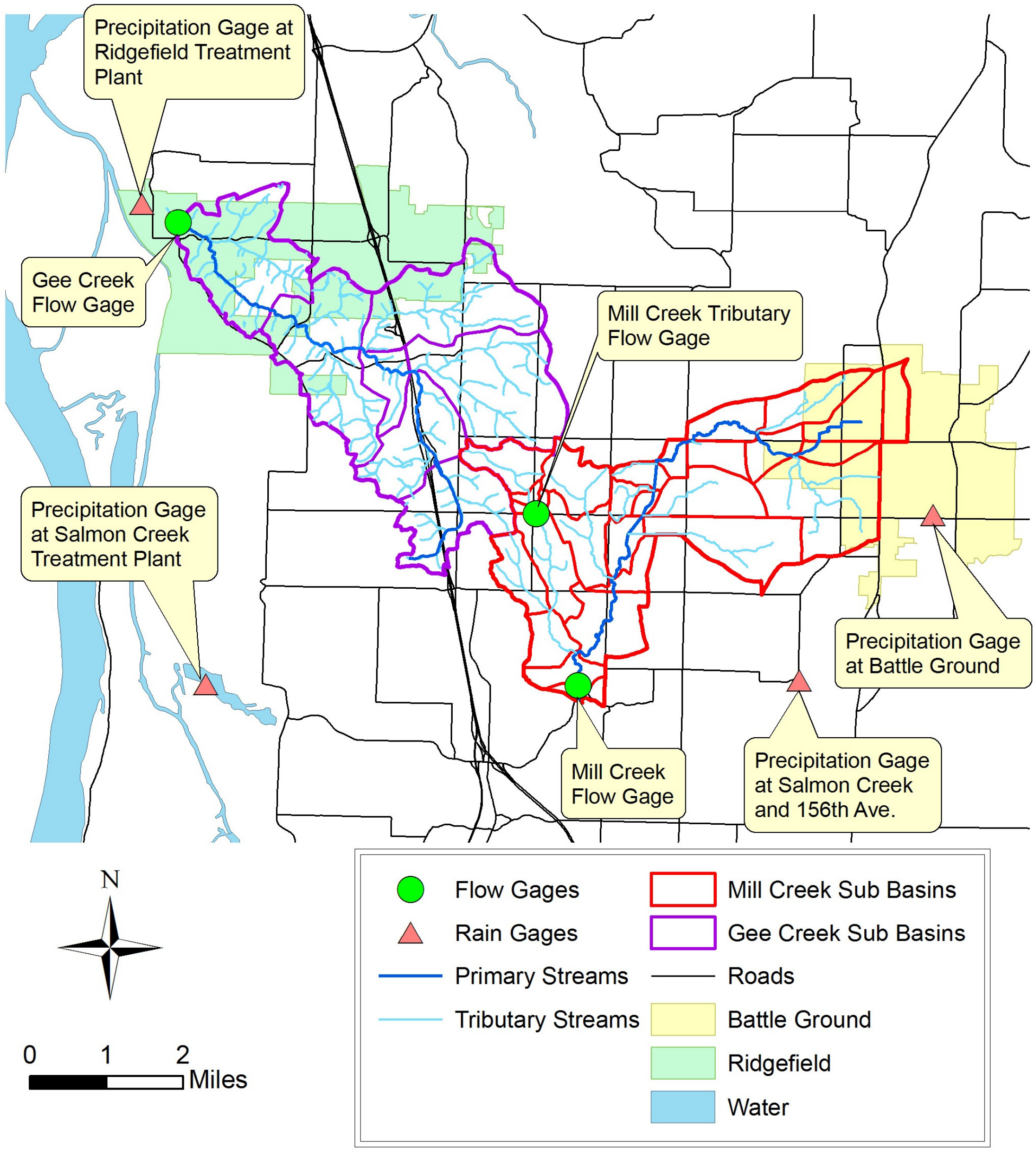


Figure 2: Location of Streamflow and Precipitation Gages Used for Calibration

2.4.2 Evaporation Data

Evaporation input data used for the Mill Creek and Gee Creek HSPF models were obtained from the Mill Creek HSPF model created by WEST Consultants. Evaporation time series data were developed by WEST Consultants using a stochastic procedure performed by MGS consultants for the Salmon Creek watershed (MGS, 2002).

2.4.3 Subbasin Delineation

Delineation of subbasins within the Mill Creek watershed was performed as part of a previous HSPF-based analysis of the watershed conducted by WEST Consultants. For a more thorough discussion of the development of the 27 Mill Creek subbasins, see the report by WEST Consultants (WEST Consultants, 2008).

Delineation of the subbasins for the Gee Creek watershed was performed as part of this calibration study. The primary methodology used to delineate the boundaries was centered on two objectives: creating boundaries that coincided with significant flow restrictions such as culverts and bridges, and creating subbasins that split the mainstem of Gee Creek into segments ranging in length from one to two miles.

The subbasins developed for HSPF modeling of the Mill Creek and Gee Creek watersheds are shown in Figure 3 and Figure 4.

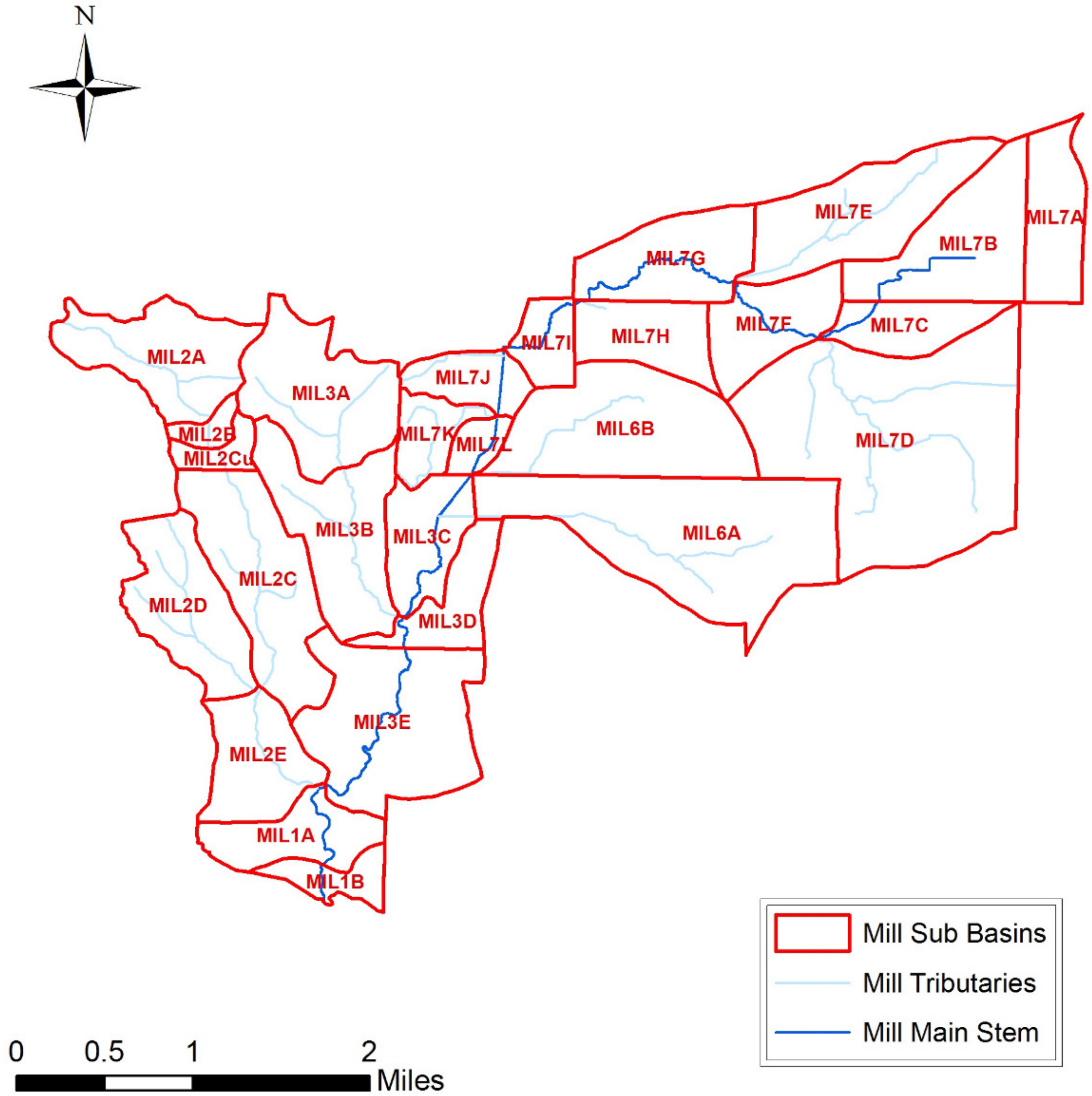


Figure 3: Subbasins Delineated for the Mill Creek Watershed by WEST Consultants

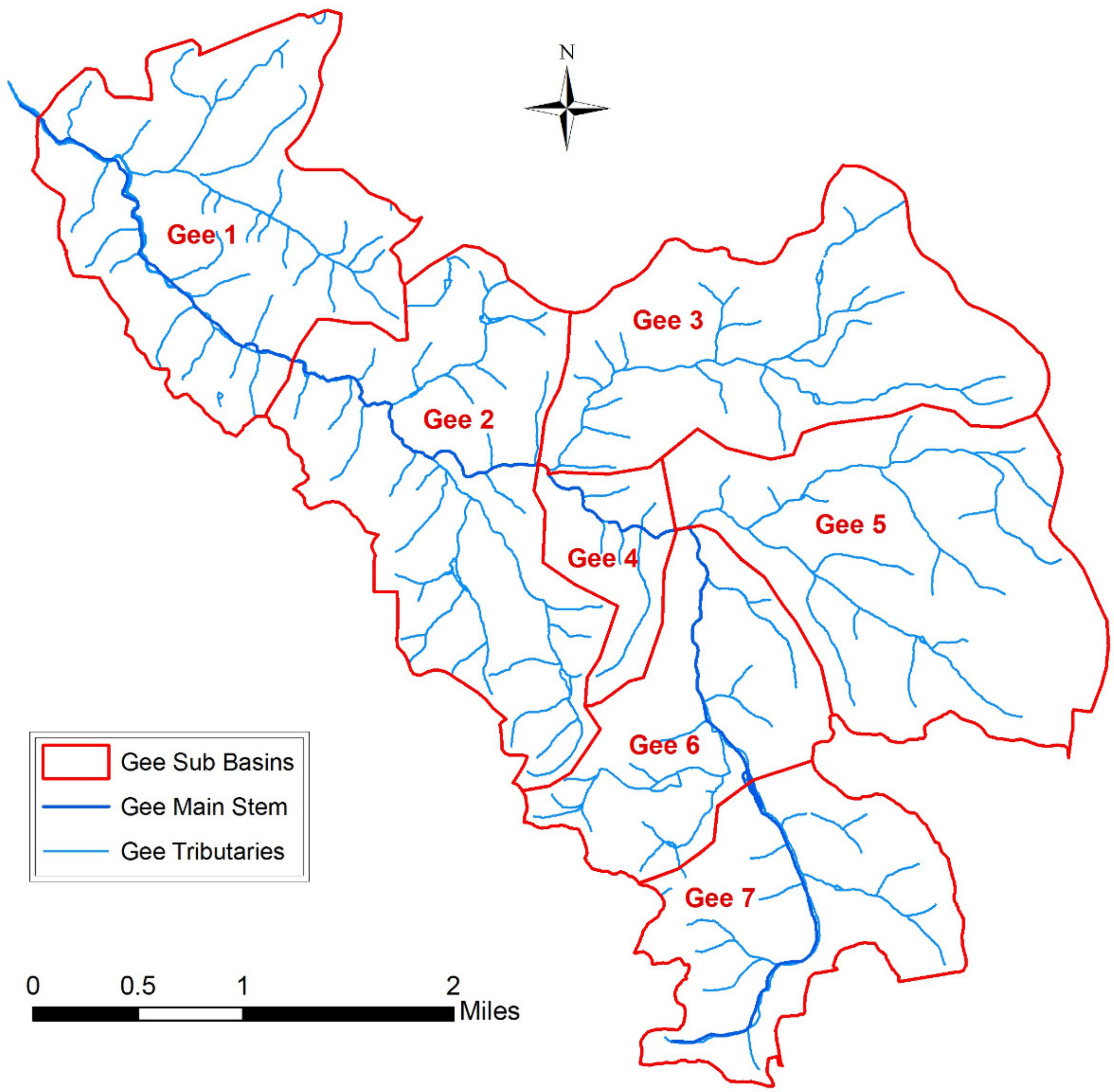


Figure 4: Subbasins Delineated for the Gee Creek Watershed

2.4.4 Flow Routing Information

Hydraulic routing of stormwater runoff through stream channels is performed by the HSPF model using Ftables (functional tables). Ftables are input tables that define the stage-storage-discharge relationship for a given subbasin. These tables account for flow attenuation and stream routing processes within the HSPF model. Ftable information for the Gee Creek subbasins was developed by the consultant team and used for model calibration. Ftable information for the Mill Creek watershed was obtained by Clear Creek Solutions, Inc. from a previous HSPF model of the watershed.

Ftables for the Mill Creek watershed were produced as part of the HSPF analysis performed previously by WEST Consultants. For a more thorough discussion of the development of the Mill Creek Ftables, see the report prepared by WEST Consultants (WEST Consultants, 2008).

Ftables for the Gee Creek watershed were produced by the consultant team. The majority of the Ftables were generated using information obtained from a previously created HEC-RAS model of the Gee Creek mainstem. This HEC-RAS model contains extensive cross-section information, and includes information on bridges and culverts located along the mainstem. Information such as average depth and storage volume associated with various streamflows was obtained by Otak, Inc. from the HEC-RAS model to create Ftables for the five subbasins that contain reaches of the mainstem. Ftables for the remaining two tributaries—GEE 3 and GEE 5—were created by Clear Creek Solutions, Inc. using Clark County contour information to determine cross-sections and channel slope.

2.4.5 Soils Data

Soil information for the Mill Creek and Gee Creek watersheds was evaluated by Otak, Inc., and placed in a table that quantifies each type of soil, land use, and slope coverage area within each subbasin. See Appendix A of this report for a summary of this information. Soils data were obtained from the soils database maintained by the National Resources Conservation Service (NRCS), formerly known as the Soil Conservation Service (U.S. Department of Agriculture, 1972). For simplicity, the term NRCS is used in this report.

2.4.5.1 Soils Classification

The Clark County version of the Western Washington Hydrology Model (WWHM) includes five soils categories to represent the many soil types found within the county limits. Although there are over 110 different soil types found throughout Clark County, similarities between the soils allows them to be grouped into categories for modeling purposes. This section discusses the methodology used to allocate each soil type into one of the five soil categories.

Clark County soils are grouped into five categories largely based on their permeability and runoff potential. These categories include:

- Category 1 – Excessively drained soils (hydrologic soil groups A & B)
- Category 2 – Well drained soils (hydrologic soil group B)
- Category 3 – Moderately drained soils (hydrologic soil groups B & C)
- Category 4 – Poorly drained soils (slowly infiltrating C soils, as well as D soils)
- Category 5 – Wetland soils (mucks).

Category 1 and 2 soils are those most suitable for traditional infiltration facilities such as trenches and drywells, while Category 3 soils may only be suitable for slower infiltrating facilities such as rain gardens and other Low Impact Development (LID) measures. Category 4 and 5 soils are those which are typically not suitable for infiltration.

In order to approximate permeability and support the classification of soils into one of the five categories, soils property information was reviewed. Pertinent information was obtained from soil survey information provided by the NRCS, geologic maps of the area, and local engineering experience. Additionally, maps showing the soil type distribution throughout Clark County were reviewed in order to identify those which cover large areas of developable land, and therefore warranted additional scrutiny prior to classification. Of the various soil property characteristics presented in the source material, the information provided by a few key attributes was considered before allocating each soil to a category. These attributes include permeability, hydrologic soil group, coverage area, geologic classification, soil descriptions, experience, and calibration. The method by which each attribute was used to support the soils classification is discussed in the following bullets.

- Permeability – Approximate permeability is listed for each soil type by the NRCS in the Soil Survey of Clark County. In general, Category 1 soils are those with very high permeability rates, Category 2 soils are those with rates greater than 0.63 inches/hour, Category 3 soils are those with rates between 0.2 and 0.63 inches/hour, and Category 4 soils are those with rates less than 0.06 inches/hour. Permeability information provided the initial basis for classifying soils; however, several soil types were reallocated based on supplementary attribute information. Supplementary information was very useful for finalizing the classifications since real-world infiltration rates are often different from those listed by the NRCS, and also because the permeability for many soil types changes based on the depth from the surface. For example, the Dollar series soil has a permeability of 0.63-2.0 inches/hour for the first 32 inches of depth; however, from 32 inches to 60 inches below the surface the permeability is listed as <0.06 inches per hour due to a layer of fragipan. In cases such as these, additional attribute information can provide clarifying and/or supporting information for classifying soils.
- Hydrologic Soil Group – The NRCS uses the hydrologic soil group classification method as an estimate of runoff potential. Soils are assigned to one of four groups beginning with "A" (low runoff potential) to "D" (high runoff potential). The hydrologic soil group classifications are generally well correlated with permeability. For the Clark County WWHM, the NRCS Hydrologic Soil Group classifications were used to verify and support the soils allocation between the 5 categories. In general, Category 1 soils are those in groups "A" and "B", Category 2 soils are those in group "B", Category 3 soils are those in groups "B" and "C", Category 4 soils are those in groups "C" and "D", and Category 5 soils –wetland soils— are generally associated with group "D".

- Coverage Area – A review of soils distributions throughout Clark County shows that certain soils are much more common in developing area than others. For example, Gee series soils cover an area of 20,000 acres near Ridgefield, whereas the Gumboot series soils cover a much smaller area of 1,500 acres in a northeastern part of the county that is not likely to develop in the near future. Because of these coverage differences, more predominant soils such as Gee were more thoroughly evaluated before assigning them to a soil category. This includes reviewing additional source material such as geology maps and considering experience with the soils.
- Geologic Classification – The geologic map of the Vancouver area produced by the Washington State Department of Natural Resources provides background information on soils formations in Clark County. This map depicts the locations of different soils formations and deposits, as well as the geologic time period in which they formed. Additionally, the map provides a description of the material type found in a particular area, which is useful for supporting or clarifying a soil group classification. For example, the map shows that Hillsboro soil types Hia, Hib, Hic, Hid, Hie, and Hif are located in an area of sand sized flood deposits, which supports placing them in a different soil group as Hillsboro soil types Hoa, Hob, Hoc, Hod, Hoe, and Hog; which are located primarily in an area of fine grained flood deposits. Similarly, the Sr, Su, and Tha soil type are located in areas of peat deposits, which justifies placing them in Category 5 as wetland soils.
- Soil Descriptions – The NRCS soil survey provides a detailed description of each soil type, including how well-drained the soil is, as well as the USDA texture. For soils that are difficult to categorize based on permeability and the hydrologic soils group, description information provides a supplementary tool in deciding the appropriate category.
- Experience – Decades of development work in Clark County has yielded valuable information regarding the infiltration capacity of some of the more common soil groups. For example, the Lauren series soil types Leb, Lgb, Lgd, Lgf, Lib are known to have very high infiltration rates, and were therefore placed in Category 1. Alternately, the Hillsboro series soil types are known to have extremely variable infiltration rates, which supports the decision to divide them between Category 2 and Category 3.
- Calibration – Initial calibration efforts for the Mill Creek and Gee Creek watersheds revealed that placing the Gee series soils in Category 4 instead of Category 3 provides a much better overall calibration for both watersheds. Consequently, the Gee series soils were placed in Category 4, which is consistent with the classification that would result based on permeability.

In developing the final soils classification, the following steps were implemented:

Step 1: A preliminary classification was developed by assigning all soils to Category 2, Category 3, and Category 4 based on the NRCS permeability. As mentioned previously, Category 2 soils are those with rates greater than 0.63 inches/hour, Category 3 soils are those with rates between 0.2 and 0.63 inches/hour, and Category 4 soils are those with rates less than 0.06 inches/hour. Soils with a listed permeability rate of 0.06 – 0.02 were set aside to be classified based on supplementary information. Where two or more permeability rates are provided for different layers, the rate associated with the more dominant (thicker) layer was used. Soils with no permeability rate listed were allocated based on the hydrologic soil group classification, with type "A" soils being placed in Category 1.

Step 2: Soils with infiltration properties that are reasonably well known from experience were identified. Soils that are known to have extremely high infiltration rates were moved into Category 1. These include the Lauren series, Wind River series, and Sifton soils. The Hillsboro series—well known for highly variable infiltration rates—were divided between Category 2 and Category 3 based on NRCS permeability, geologic maps, and description information.

Step 3: Soils identified as wetland soils (muck) were placed in Category 5.

Step 4: Soils distribution maps were reviewed to determine those which are most prevalent throughout the county. Supplementary attribute information for these particular soils were reviewed, including hydrologic soil group, geologic classification, and soil description. Additionally, supplementary soil property information was reviewed for all soils with a listed permeability rate of 0.06 – 0.02. Soils which were allocated/reallocated after reviewing their attributes include:

- Salkum (SaC) – Placed in Category 2 based on NRCS information indicating that this soil is well drained with a very high water capacity.
- Dollar (Dob) – Moved from Category 4 to Category 3 based on an NRCS permeability of 0.63 - 2.0 inches per hour for the top 32 inches of soil, as well as NRCS information indicating that this soil is moderately well drained.
- McBee (McB, MeA, MiA) – Moved from 2 to 3 based on NRCS information indicating that these soils are somewhat poorly drained.
- Powell (Pob, PoD, PoE) – Placed in Category 3 based on NRCS information indicating that this soil is moderately well drained with a moderate water capacity.
- Sauvie (Sna) – Moved from Category 2 to Category 3 based on a hydrologic soil group classification of "D" as well as an NRCS permeability of 0.2 – 0.63 inches per hour for the top 32 inches of soil.

- Cove (CvA, CwA) – Placed in Category 4 based on NRCS information indicating that this soil is very poorly drained with a hydrologic soil group classification of “D”.
- Gumboot (GuB) – Placed in Category 4 based on NRCS information indicating that this soil is poorly drained with a hydrologic soil group classification of “D”.
- Hockinson (HtA, HuB, HvA) – Placed in Category 4 based on NRCS information indicating that this soil is mostly somewhat poorly drained with a hydrologic soil group classification of “D”.

See Appendix B of this report for the designation of each soil type found within Clark County to one of the five soil categories. This approach to soil classification has been incorporated into the user interface of the Clark County version of the WWHM. The distribution of soil categories within the Mill Creek and Gee Creek watersheds is shown in Figure 5 and Figure 6.

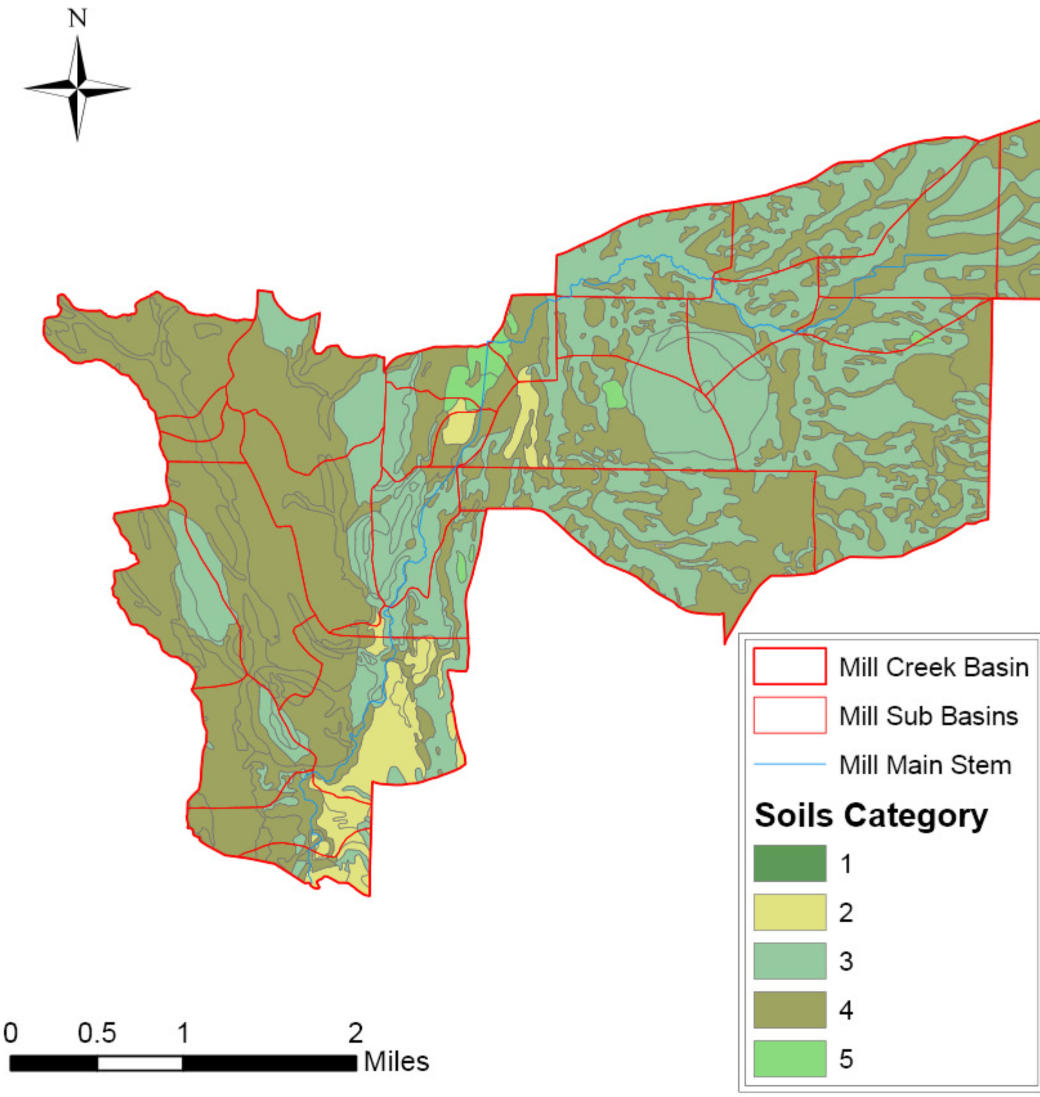


Figure 5: Soil Category Distribution in the Mill Creek Watershed

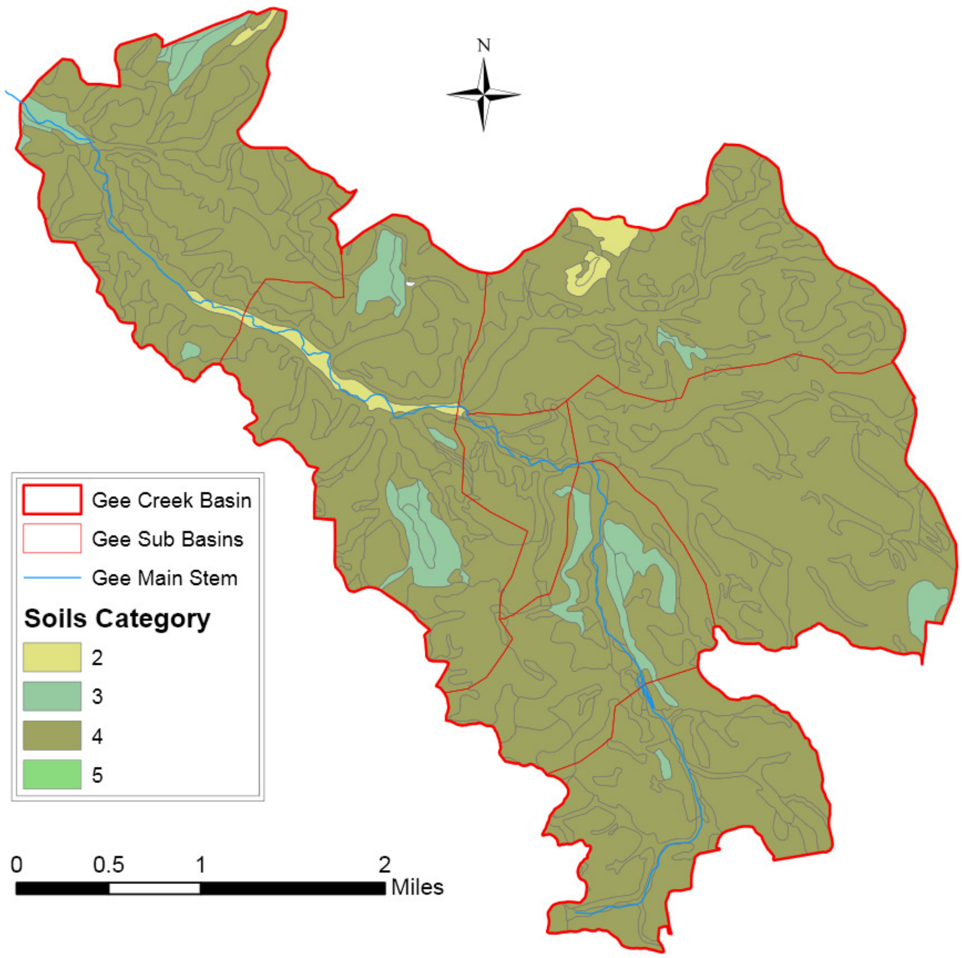


Figure 6: Soil Category Distribution in the Gee Creek Watershed

2.4.6 Land Use Data

Land use information for the Mill Creek and Gee Creek watersheds was evaluated by Otak, Inc. and placed in a table that quantifies each type of soil, land use, and slope coverage area within each subbasin. See Appendix A of this report for a summary of this information.

The land use information for the Mill Creek and Gee Creek watersheds was obtained from a GIS shapefile provided by Clark County. Classification of land use was performed using 2002 infra-red photography, 2002 Lidar, and DNR waterbody data. Resulting classifications were further scrubbed using current use and property type data. The land use data supplied by Clark County was grouped into five categories including: fields, forest, pavement, water, and buildings. For modeling purposes these five land use categories were condensed into three groups: forest, field, and impervious. The impervious category includes all water, pavement and building areas. To account for dispersion processes, impervious areas were separated into two categories: effective impervious and ineffective impervious. See Section 2.4.8 of this report for discussion on how this was performed.

The initial distribution of land cover throughout the Mill Creek and Gee Creek watersheds is displayed in Figure 7 and Figure 8.

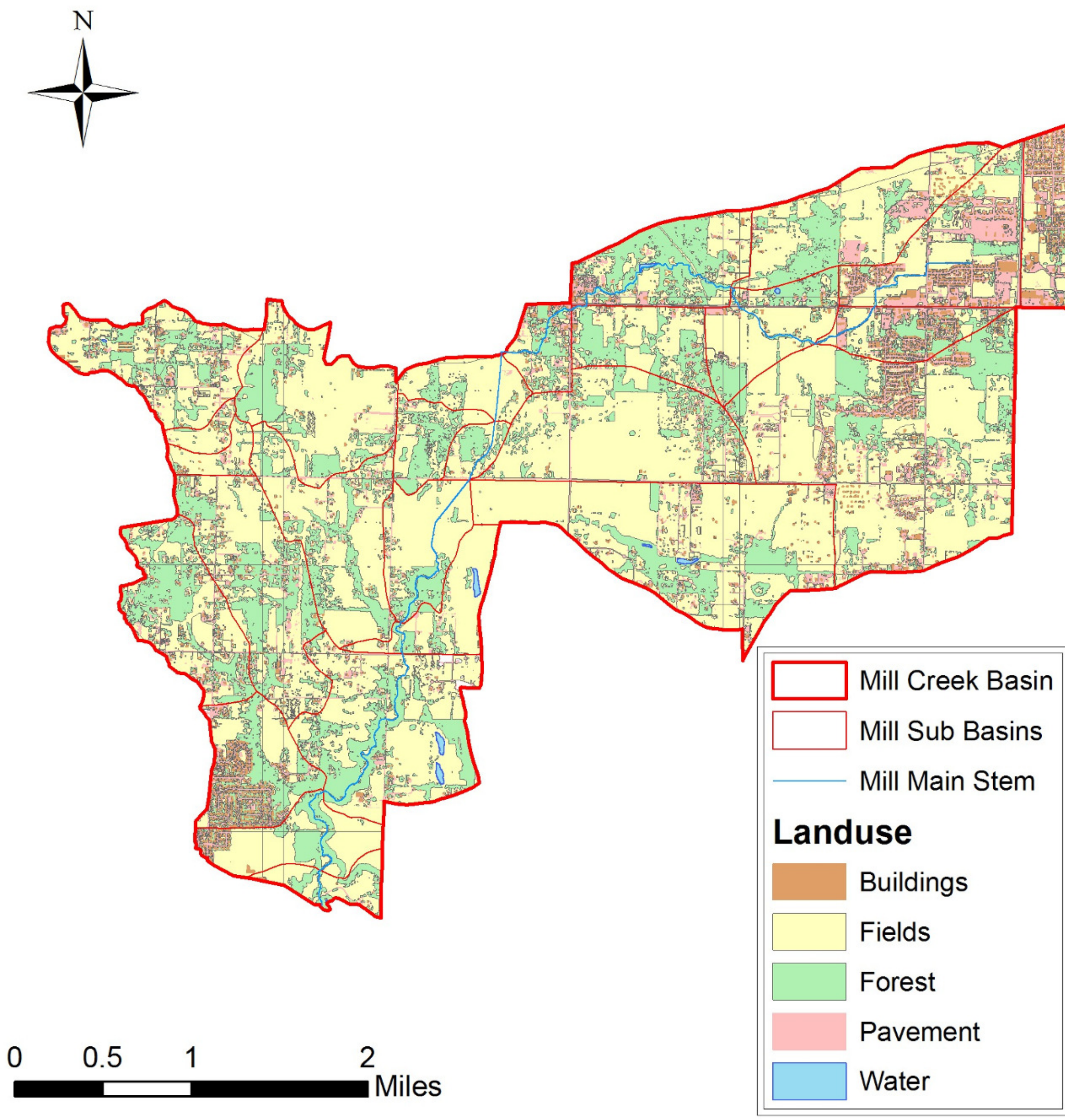


Figure 7: Land Use Coverage within the Mill Creek Watershed

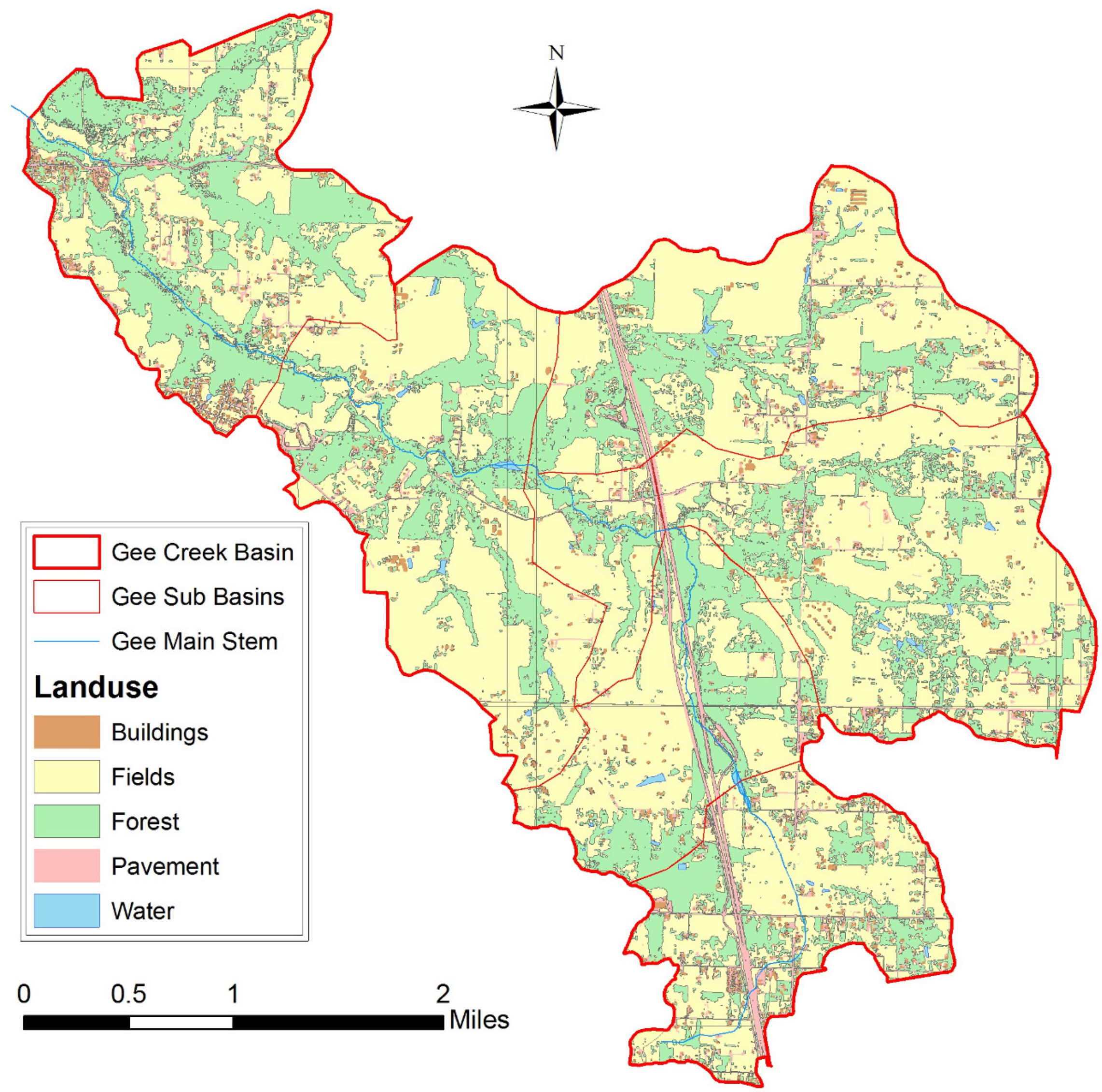


Figure 8: Land Use Coverage within the Gee Creek Watershed

2.4.7 Slope Data

Slope information for the Mill Creek and Gee Creek watersheds was evaluated by Otak, Inc. and placed in a table that quantifies each type of soil, land use, and slope coverage area within each subbasin. See Appendix A of this report for a summary of this information.

The slope data for the Mill Creek and Gee Creek watersheds were obtained from a GIS shapefile provided by Clark County. Slope ranges were calculated from Lidar derived contour data from 2002. For HSPF modeling purposes, slope data were grouped into three different categories: flat, medium, and steep. Flat slopes are those ranging from 0 percent to 5 percent, medium slopes range from 5 percent to 15 percent, and steep slopes were those identified as greater than 15 percent. The resulting distribution of these three slopes categories are shown in Figures 9 and 10.

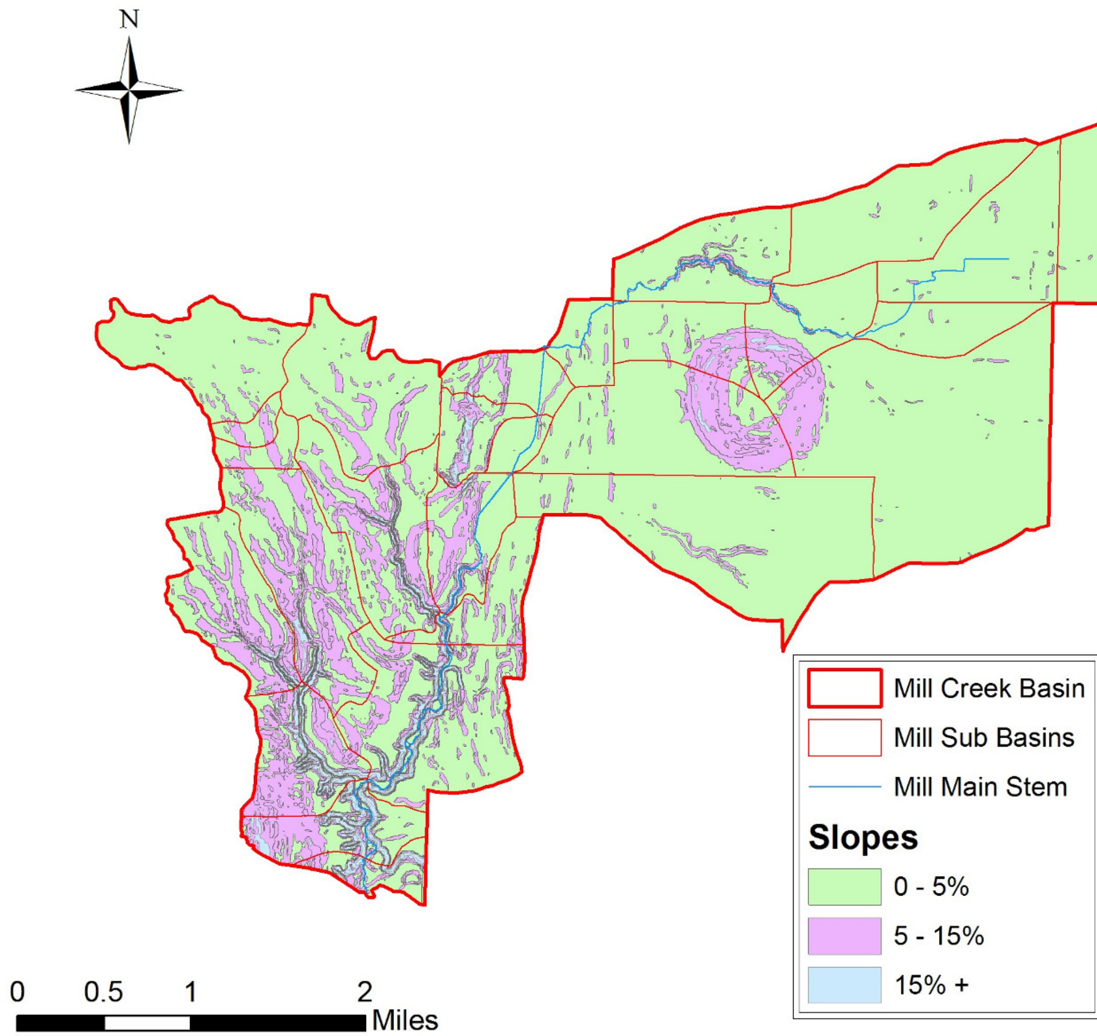


Figure 9: Distribution of Land Slopes within the Mill Creek Watershed

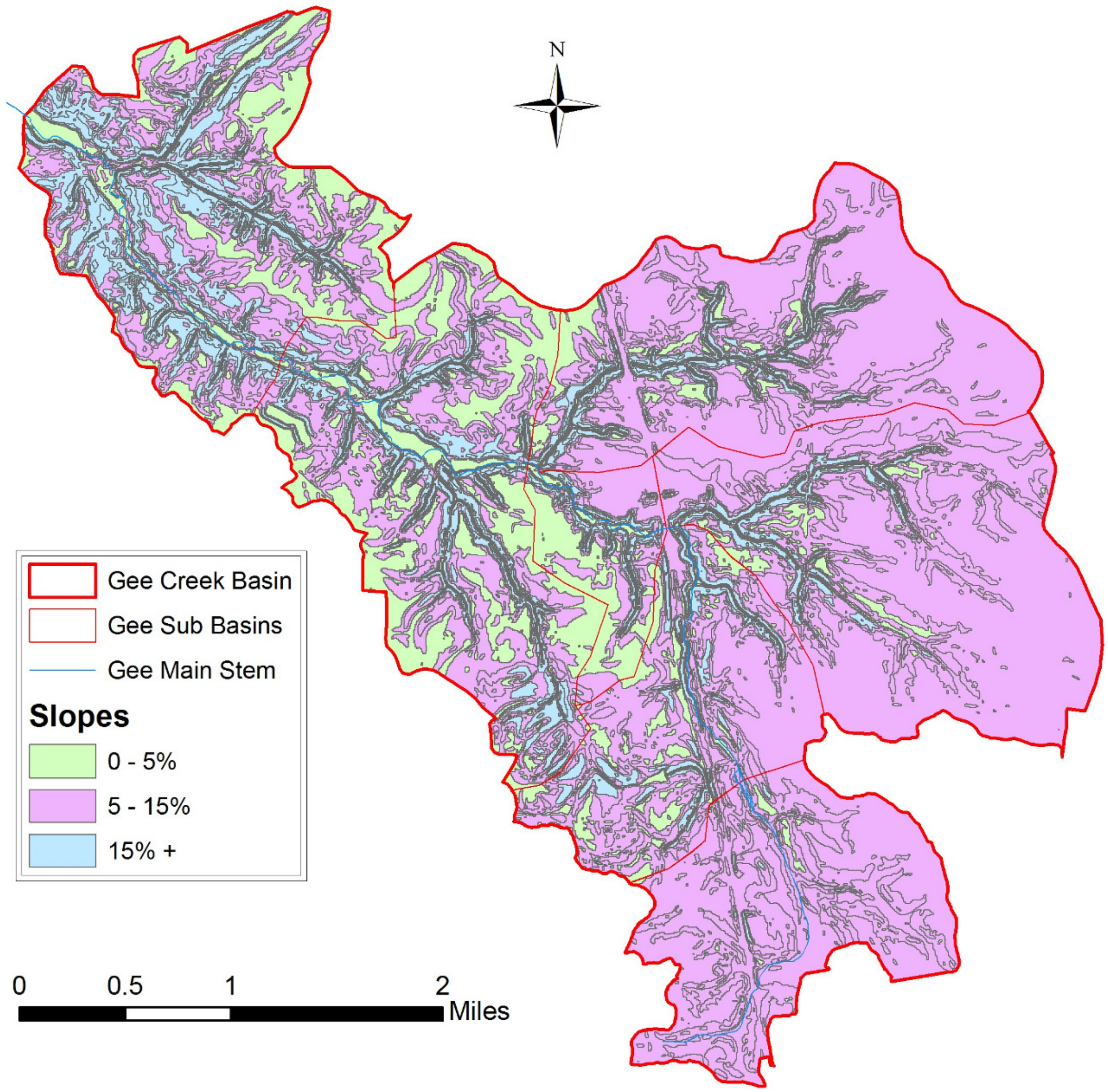


Figure 10: Distribution of Land Slopes within the Gee Creek Watershed

2.4.8 Assumptions

The following assumptions were made as part of the modeling efforts for the Mill Creek and Gee Creek watersheds:

- Effective/Ineffective Impervious Area – For HSPF modeling efforts, it was assumed that the amount of effective impervious surface from all roadway areas was 75 percent, and the amount of effective impervious surface from all buildings was 25 percent. The remaining portions of the building and roadway areas were modeled as ineffective impervious, and were allocated to the "field" land use category. Impervious areas listed as water were left as 100 percent effective impervious. The application of these effective impervious percentages was applied prior to consolidation of the three types of impervious surfaces into one category.

- Category 1 Soils – Category 1 soils are non-existent in both watersheds, meaning that calibrated values for this soil category will not be achieved with this analysis. However, because Category 1 soils are very well drained, it is anticipated that new development projects situated on Category 1 soil will typically utilize infiltration to achieve flow control, in which case they would not need to match pre-developed discharge rates from the site. Therefore, it is assumed that for Category 1 soils, obtaining calibrated soil parameter values that are specific to Clark County will not be essential. Instead, the use of generally accepted hydrologic parameter values for well drained soils should be sufficient.

2.4.9 Calibration Results

See Attachment 1 of the report for detailed discussion of the modeling process and calibration results as determined by Clear Creek Solutions, Inc.

3.0 Meteorological Input Data

For the Clark County version of the WWHM, meteorological input data from Ecology's WWHM were supplemented or revised. This includes evaporation data, precipitation data, and precipitation scaling factors.

3.1 Evaporation Data

Supplementary evaporation data were added to the Clark County version of the WWHM to provide the model with evaporation data from a weather station in closer proximity to Clark County than is available in Ecology's WWHM. The Ecology version of the WWHM uses pan evaporation data from the Puyallup weather station as the default for modeling the effects of evaporation in Clark County. However, because the Puyallup station is located over 100 miles north of Clark County, the applicability of this gage to Clark County may not be the most accurate. Therefore, the Clark County version of the WWHM uses long-term pan evaporation data from the Aurora weather station in Aurora, Oregon. This station is approximately 30 miles south of Clark County and should provide a more accurate representation of evaporation due to proximity. Pan evaporation data from this station were recorded as daily values and were obtained by the consultant team. These data were subsequently formatted for use with the WWHM's hourly time step by dividing the daily values by 24. The period of record from the Aurora station used within the Clark County version of the WWHM spans from October 1948 to September 2008.

3.2 Supplementary Precipitation Data

The Ecology version of the WWHM uses hourly precipitation data from the weather station at the Portland International Airport (PDX) as the default precipitation time series data for Clark County. This precipitation data spans a period beginning in October 1948 and ending in September 1999. The Clark County version of the WWHM incorporates this same hourly precipitation data, and supplements it with nine years of additional hourly precipitation data recorded at PDX from October 1999 to September 2008.

3.3 Precipitation Scaling Factors

3.3.1 Overview

For continuous simulation modeling using the WWHM, a minimum of 20 years, preferably 40 to 50 years, of continuous hourly precipitation data is required to statistically evaluate storm events and size proposed flow control and runoff treatment facilities (Washington State Department of Ecology, 2005). Currently, the only precipitation gage station in the vicinity of Clark County with a precipitation record of sufficient length and frequency is located at PDX. All other gages in Clark County have a shorter period of record, or do not supply hourly data. Because these other stations are currently not qualified for direct use in a continuous simulation model, they were instead used to produce revised precipitation scaling factors that account for spatial variations in precipitation quantities. Once determined, precipitation scaling factors are applied to PDX precipitation data to appropriately scale the data based on geographic location within the county. The Clark County version of the WWHM model incorporates these revised scaling factors into the software program and will automatically select the appropriate factor based upon the proposed project location as input by the user.

Prior to this report precipitation scaling factors for Clark County were developed by Clear Creek Solutions, Inc. in 1999 using precipitation isopluvial maps for the 25-year storm event. The isopluvial maps used to generate these original scaling factors were produced several decades ago and were generated using precipitation data available at that time (Miller et al., 1973). The installation of precipitation gage stations across Clark County in recent years has made additional precipitation information available to supplement the creation of revised scaling factors. In addition to incorporating this added precipitation data, revised scaling factors were produced using an alternate depth-based methodology that has several advantages over the isopluvial approach, including:

- Depth-Based Scaling Factors – Precipitation scaling factors generated from isopluvial maps are based on precipitation intensities related to a storm event of a particular return period. Using peak intensity values from a single large storm event to generate scaling factors neglects intensity relationships associated with storm events from other return periods, particularly the typical day-to-day storm events. The depth-based method of evaluating precipitation scaling factors utilizes all recorded precipitation information for comparison purposes regardless of the return period.
- Spatial Allocation – The WWHM requires discrete, polygonal areas to represent precipitation scaling factors that can be programmed into the model. The use of isopluvial maps to produce these areas presents a challenge, since creation of the polygon sizes and shapes requires arbitrary interpretation of the isopluvial lines. Additionally, the size, shape, and location of each polygonal area might vary depending on the return period of the storm event used to create the polygons. For this study, the methodology for spatially allocating the updated precipitation factors involved creating polygons that are centered on precipitation gage locations, whose boundaries define the area that is closest to each gage relative to all other gages. These are also referred to as Thiessen polygons (McCuen, 1998). This method is straightforward and can easily accommodate additional precipitation gage stations that become available in the future.

Additional information regarding the methodology used to create the revised scaling factors is discussed in Section 3.3.3 of this report.

3.3.2 Precipitation Data

The data used to establish revised scaling factors for Clark County were obtained from 15 precipitation gage stations located throughout Clark County and Multnomah County. These precipitation gage stations contain varying periods of record, ownership, and frequency of data collection. Table 1 provides relevant information associated with each gage, and Figure 11 shows the locations of these stations throughout the Clark/Multnomah County area.

Table 1: Precipitation Gage Station Information

#	Station Name	Data Source	Station ID	Period of Analysis		Total Period of Record	
				Begin	End	Begin	End
1	Ridgefield	Clark County	1	Oct, 2003	Sep, 2008	Oct, 2003	Sep, 2008
2	Salmon Creek Treatment Plant	Clark County	2	Apr, 2003	Sep, 2008	Apr, 2003	Sep, 2008
3	Salmon Creek @ 156th Ave	Clark County	3	Oct, 2002	Sep, 2008	Oct, 2002	Sep, 2008
4	Venersborg	Clark County	4	Jul, 2003	Sep, 2008	Jul, 2003	Sep, 2008
5	Yacolt	Clark County	5	Apr, 2003	Sep, 2008	Apr, 2003	Sep, 2008
6	Orchards	Clark County	6	Jul, 2003	Sep, 2008	Jul, 2003	Sep, 2008
7	Lacamas	Clark County	7	Mar, 2004	Sep, 2008	Mar, 2004	Sep, 2008
8	Cape Horn	Clark County	8	Mar, 2003	Sep, 2008	Mar, 2003	Sep, 2008
9	Merwin Dam	NCDC	COOP 455305	Dec, 1971	Jul, 2008	Nov, 1971	Sep, 2008
10	Battle Ground	NCDC	COOP 450482	Oct, 1949	Sep, 2008	May, 1928	Sep, 2008
11	Vancouver NNE	NCDC	COOP 458773	Oct, 1949	Sep, 2007	Jan, 1856	Sep, 2008
12	I-5 Bridge	NCDC	COOP 458778	Oct, 1949	Feb, 1959	Mar, 1902	Feb, 1959
13	PDX	NCDC	COOP 356751	Oct, 1949	Aug, 2008	Jan, 1926	Sep, 2008
14	Portland NWSFO	NCDC	COOP 356750	Apr, 1996	Sep, 2007	Apr, 1996	Sep, 2008
15	Troutdale	NCDC	COOP 358634	Jan, 1977	Sep, 2007	Aug, 1965	Sep, 2008

It should be noted that the Lacamas station actually consists of two gages that are in close proximity to one another: the Lacamas gage at Goodwin Road and the newly installed

Lacamas gage at Heritage Trail. The Heritage Trail station was installed on November 5, 2007 with the intent to eventually replace the station at Goodwin Road, which has a history of measurement problems.

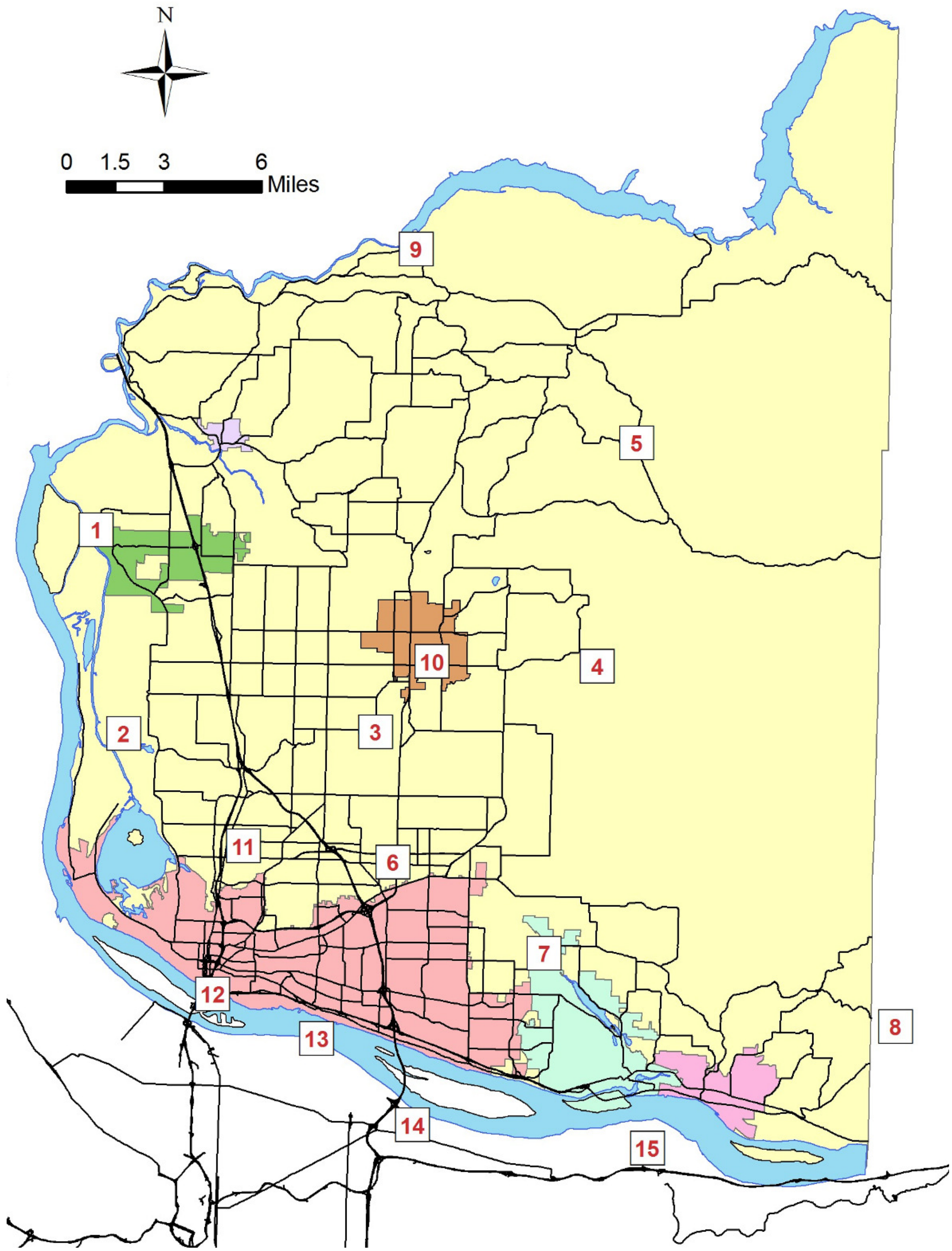


Figure 11: Precipitation Gage Stations Used to Generate Precipitation Scaling Factors

3.3.3 Analysis

3.3.3.1 Scaling Factor Determination

The procedure used to determine updated precipitation scaling factors involved comparing cumulative precipitation data from the PDX gage to cumulative precipitation data from each of the 14 other gage stations. A plot of cumulative precipitation from two precipitation gage stations over the same period of time shows the relationship between those two stations, which can then be used to establish the scaling factor. The plot of cumulative precipitation versus cumulative precipitation is generally referred to as a double mass plot, and is typically used to check gage consistency (McCuen, 1998). The slope of the line that results from plotting the comparison of cumulative data provides the scaling factor between the two stations. See Figure 12 for the resulting double mass plot when data from the Orchards station is compared to data from PDX.

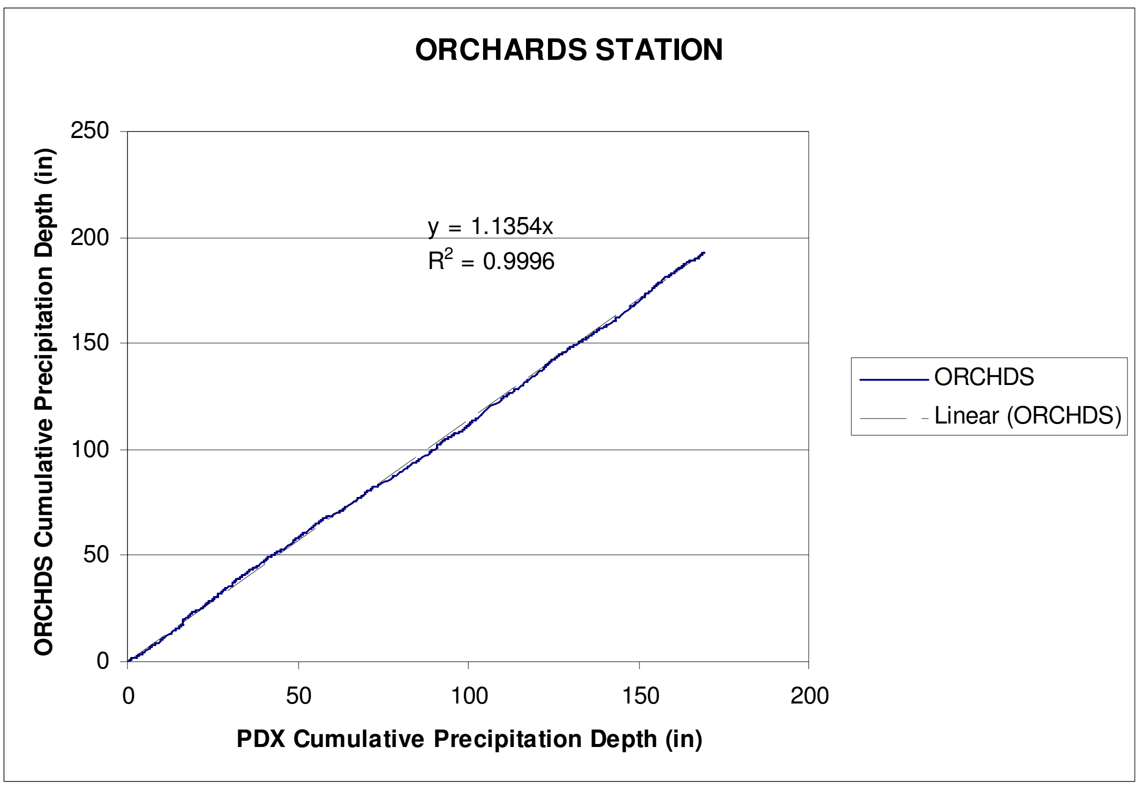


Figure 12: Double Mass Plot of Precipitation Data from the Orchards and PDX Stations

As shown in Figure 12, the slope of the "best fit" line for this data plot has a slope of 1.14 and a coefficient of determination value of 0.9996, suggesting that the data is highly correlated. Using the slope as the scaling factor yields a value of 1.14 for the Orchards area, which signifies that on average, 14 percent more precipitation fell in Orchards as compared to PDX. Plotting the cumulative precipitation data from both stations versus time generates the plot shown in Figure 13. The plot of scaled PDX data using the 1.14 scaling factor is also included in this figure.

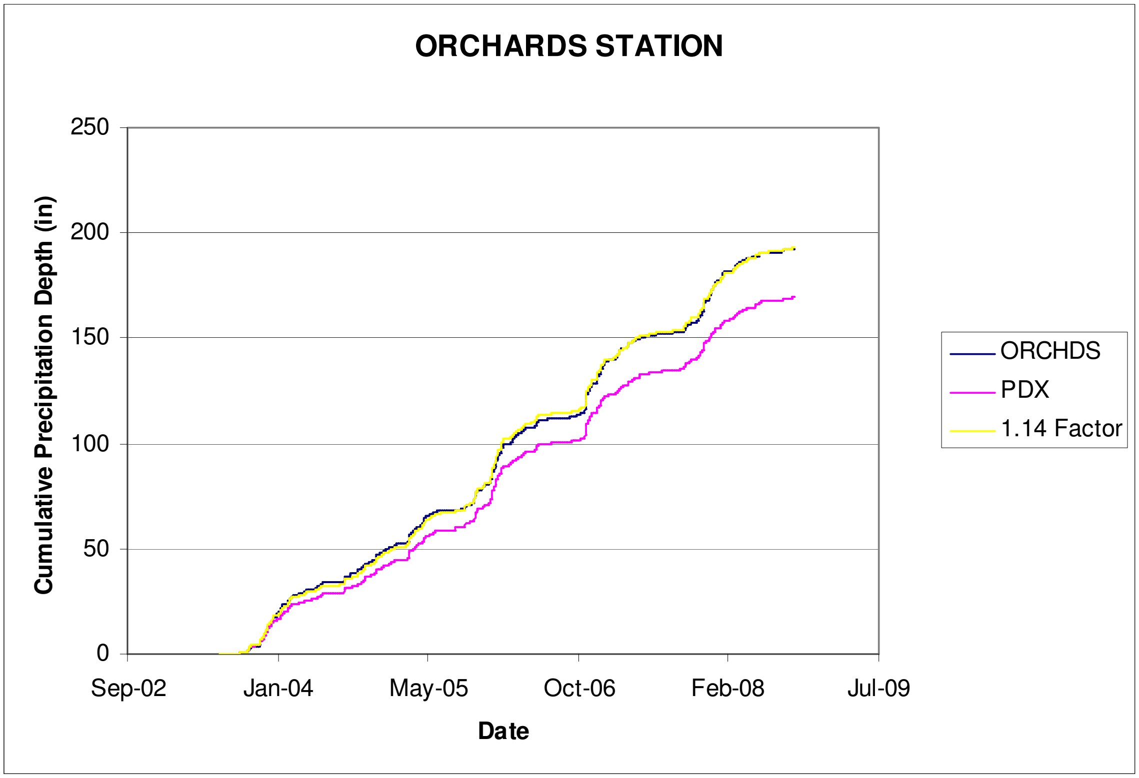


Figure 13: Plot of Cumulative Precipitation vs. Time

The figure above demonstrates the effectiveness of using the double mass curve approach for generating scaling factors that match precipitation depths over time. See Appendix C for double mass curve plots and Appendix D for cumulative precipitation depths versus time for each station as compared to PDX.

The use of a double mass curve to evaluate scaling factors provides station comparisons that are primarily depth-based. A depth-based approach ensures that the appropriate long-term volume of precipitation is applied to a site being modeled, rather than an approach where scaling factors are based on comparisons of peak intensities of a single large storm event.

Resulting scaling factors for each of the 15 precipitation gage stations are presented in Table 2. Each scaling factor was based on the results of the double mass curve plots, which are included in Appendix C. These factors were supplied to Clear Creek Solutions, Inc., and were incorporated into the Clark County version of the WWHM. Note that the scaling factor for the Lacamas gage was developed by averaging the scaling factors from the old Lacamas gage at Goodwin Road and the recently installed Lacamas gage at Heritage Trail.

Table 2: Revised Clark County Scaling Factors

Station	Precipitation Scaling Factor
Ridgefield	1.11
Salmon Creek Treatment Plant	1.06
Salmon Creek @ 156th Ave	1.31
Venersborg	1.82
Yacolt	2.01
Orchards	1.14
Lacamas	1.30
Cape Horn	2.13
Merwin Dam	2.02
Battle Ground	1.40
Vancouver NNE	1.11
I-5 Bridge	1.02
PDX	1.00
Portland NWSFO	1.18
Troutdale	1.37

3.3.3.2 Spatial Allocation of Scaling Factors

After generation of the precipitation scaling factors, the area of influence for each factor within Clark County was determined. The most direct and straightforward method of calculating this was to create Thiessen polygons. This process involves creating a polygon around each precipitation gage station that encompasses the area that is closest to that station relative to all other stations (McCuen, 1998). This method provides an unbiased way of allocating the precipitation scaling factors across the county and can easily accommodate new gages that are installed in the future. The Thiessen polygons generated for Clark County stations are shown in Figure 14.

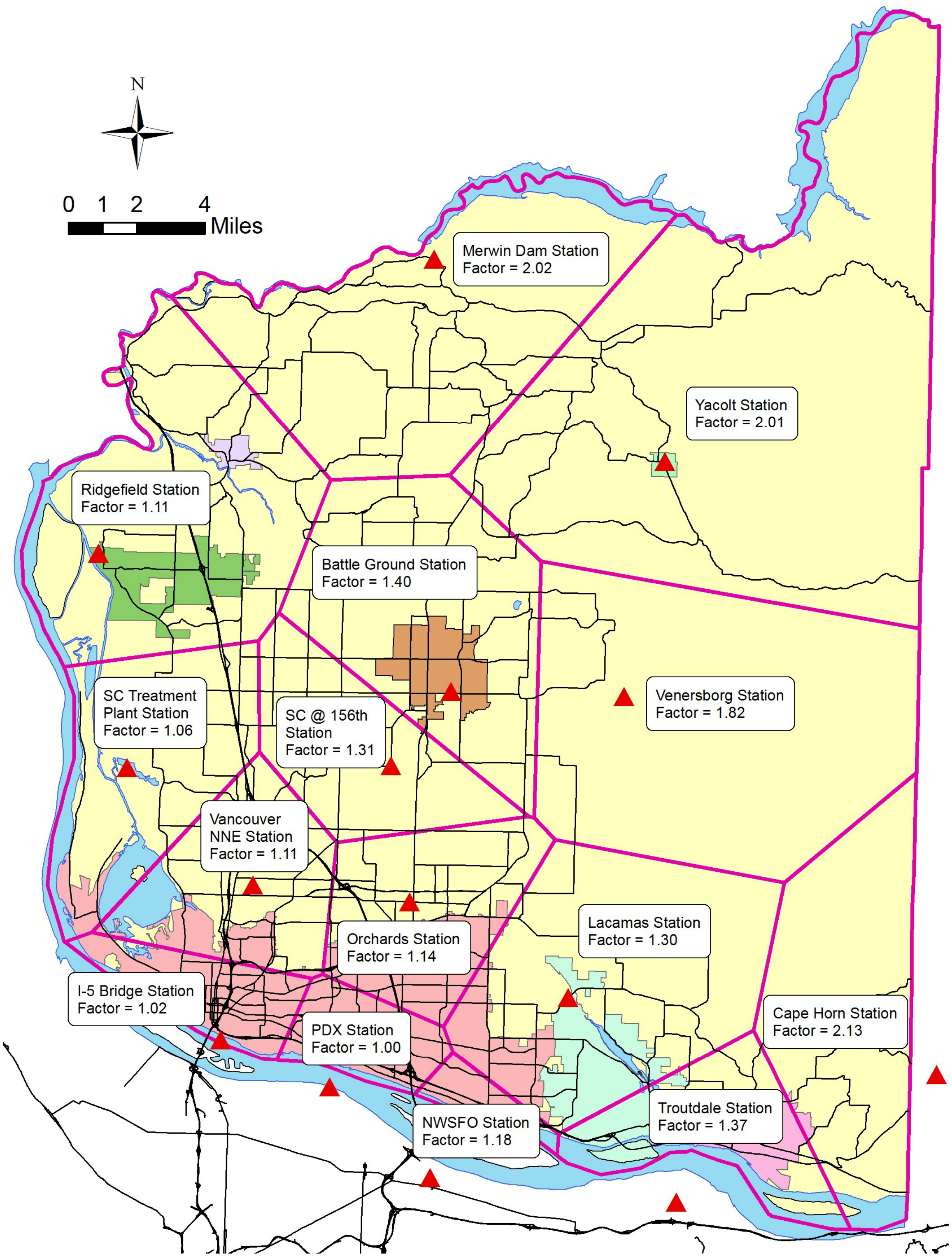


Figure 14: Clark County Precipitation Scaling Factors and Associated Thiessen Polygons

3.3.4 Assumptions and Limitations

Several assumptions were made during the determination of revised scaling factors for Clark County. These include:

- Station Relocation – Several longer term precipitation gage stations have been moved one or more times during their period of record, including the PDX gage. For these gages, it was assumed that station relocations would have minimal impacts; hence no efforts were made to correct the data. This assumption was based on the understanding that the relocated stations are relatively close to their original locations. For the generation of Thiessen polygons around these stations, the location of the longest period of record was used, which may differ from a gage's present location.
- Missing Data – Most of the precipitation gage stations included in this study have periods where data were not recorded or was discarded during QA/QC review due to concerns about data accuracy. To ensure that cumulative depth values were evenly compared, PDX data were discarded for comparable periods of time as those stations with missing data.
- Snowfall – The majority of gages used to produce precipitation scaling factors were not heated, and therefore did not record snow as precipitation data until it melted. However, because the comparisons for this study are depth-based and involve years of data, it was assumed that the delay in precipitation recording between heated and non-heated gages would have a negligible impact. Additionally, most gages are located in areas of minimum snowfall.
- Polygon Generation – Polygons generated using the Thiessen polygon method are shown as calculated and were not modified to account for any features which may impact precipitation depths such as elevation.

In addition to the assumptions and limitations sited above, one of the primary concerns associated with a depth-based approach is that precipitation intensities will be distorted due to differences in precipitation frequencies. Frequency differences occur when precipitation occurs more often (i.e., more days of the year) at one station than another. This is a concern because a precipitation scaling factor is only able to scale the data from the long-term gage (i.e., the PDX gage); it cannot add additional periods of precipitation to match the number of recorded precipitation periods of the comparison station. As a result, stations where precipitation occurs more frequently than the long-term gage will have precipitation scaling factors that are increased to account for the additional depth generated by the extra periods of precipitation. Accounting for the excess depth in this manner will result in scaling factors that overstate peak intensities to some degree. The opposite is true for stations with lower precipitation frequencies than the long-term gage.

For the Clark County scaling factors, the potential existence and impact of intensity distortion was evaluated by reviewing hourly precipitation values from several stations and comparing them to hourly precipitation values at PDX. This method was limited to stations which provide hourly precipitation data recordings. A comparison of all the hourly precipitation values greater than zero from each station over the same period of time was made by creating a probability versus intensity graph. This graph shows the percentage of hourly intensity values that exceeded a given value during the period of record. The graph generated for the hourly intensity comparison of the Ridgefield and PDX gage stations is shown below in Figure 15. This figure also includes the graph that results from scaling the PDX hourly intensities by the depth-based scaling factor of 1.11 for the Ridgefield gage.

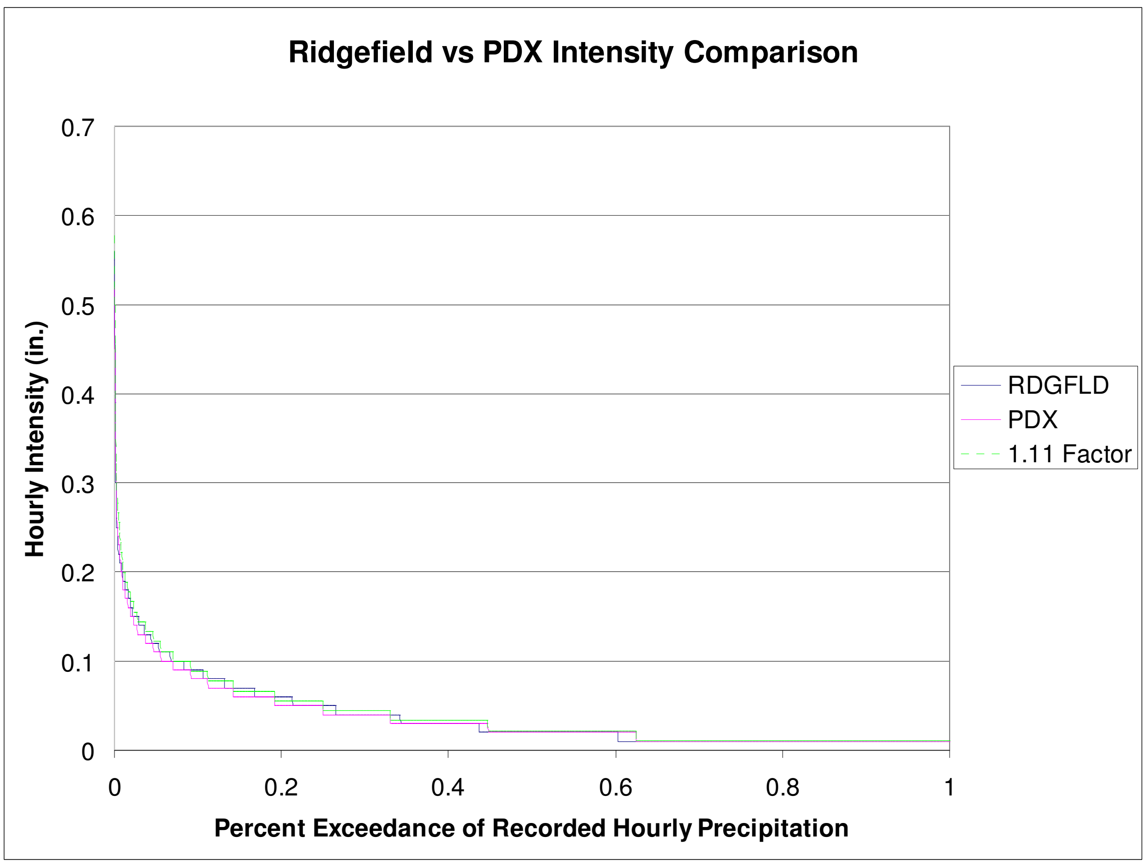


Figure 15: Comparison of Ridgefield and PDX Hourly Intensities

The comparison graphs presented in Figure 15 show that using a scaling factor of 1.11 for the Ridgefield station is appropriate with respect to intensity as well as to depth. This is evident by the fact that the graph of the scaled PDX intensity data is very similar to the graph of the Ridgefield intensity data. Likewise, intensity comparison graphs for several other Clark County precipitation stations, which have relatively low scaling factors of approximately 1.3 or less, indicate that the depth-based scaling factor approach will also closely approximate intensity comparisons. See Appendix E of this report for additional intensity comparison graphs.

In contrast, intensity comparison graphs for stations with high scaling factors of 1.82 or greater show significant distortion of precipitation intensities. See Figure 16 for the intensity comparison graph for the Yacolt station versus the PDX station.

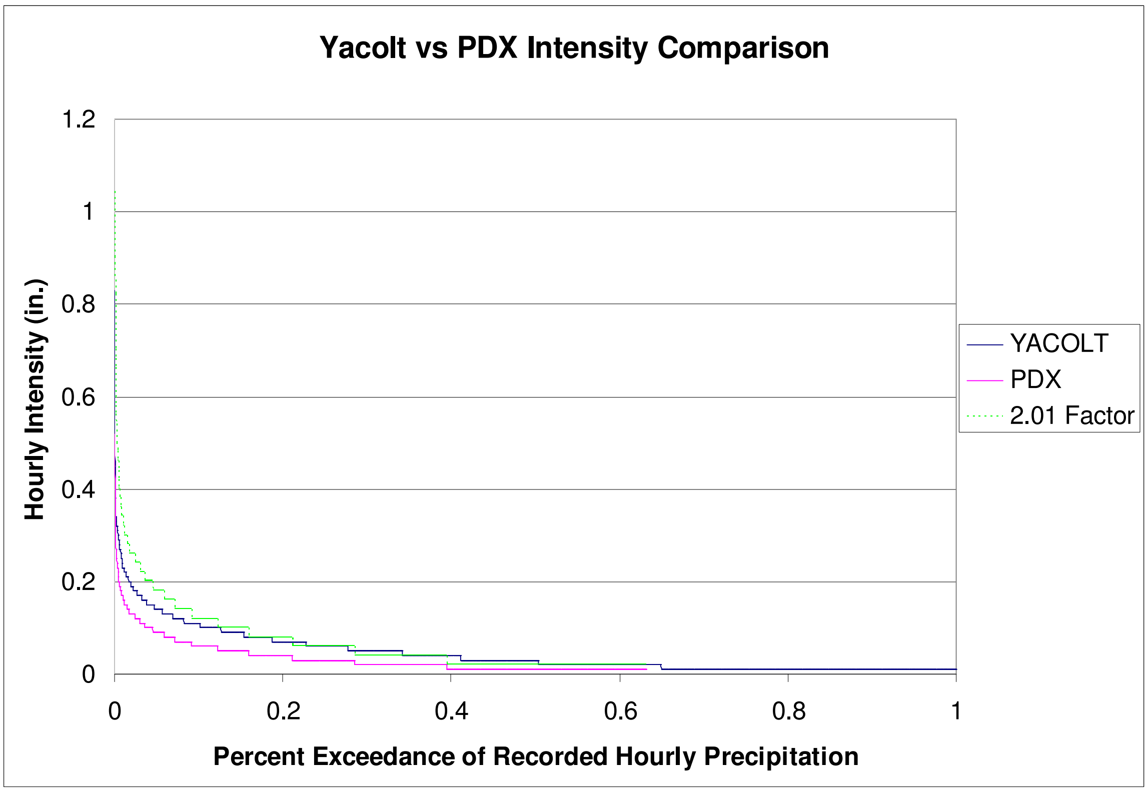


Figure 16: Comparison of Yacolt and PDX Hourly Intensities

The scaled PDX intensity values presented in Figure 16 show that using a 2.01 scaling factor to approximate Yacolt precipitation will overestimate the intensities that occur during higher intensity storm events. As mentioned previously, this outcome is the result of differences in precipitation frequency between the Yacolt station and the PDX station. In order to match the precipitation depths between these two stations, intensity values from the PDX station must be overstated to account for additional periods of precipitation at the Yacolt station. For stations such as Yacolt, a single scaling factor cannot appropriately represent both intensity and depth. However, because the depth approach will match volumes, it was assumed that this methodology would take precedence. Additionally, regions of Clark County that are subject to the most severe intensity distortion are found at the extreme north and east, and are unlikely to see significant development in the near future. Once sufficient hourly precipitation data becomes available in these regions, the Clark County version of the WWHM may be updated to better represent precipitation within these regions of the county.

3.3.5 Scaling Factor Validation

A simple analysis was performed in order to evaluate how well precipitation scaling factors calculated from a single large storm event compared to the overall scaling factors recommended for use with the Clark County version of the WWHM. Table 3 shows the amount of precipitation that occurred at each of the 15 gage stations during a two week period from November 1, 2006 to November 15, 2006. This storm event was selected for analysis because it was one of the largest storm events to occur in recent years. According to data recorded at the Orchards station, a total of 49.17 inches of precipitation fell during 2006, with over 21 percent of the annual amount occurring during this two week period.

Analysis was performed by summing the total precipitation for each gage and recording this as the event depth. The event scaling factor was determined by dividing the event depth for each gage by the event depth for the PDX gage. A comparison of the event scaling factors to the overall scaling factors developed for the Clark County version of the WWHM was also performed, with the percent difference between the two factors recorded in Table 3.

Table 3: Calculated Scaling Factors for a November 2006 Storm Event

Station	Event Depth (in)	Event Factor	Overall Precip Factor	Percent Difference
Ridgefield	9.17	1.04	1.11	-6%
Salmon Creek Treatment Plant	NA	NA	1.06	NA
Salmon Creek @ 156th Ave	11.22	1.28	1.31	-2%
Venersborg	16.24	1.85	1.82	2%
Yacolt	17.01	1.94	2.01	-4%
Orchards	10.41	1.19	1.14	4%
Lacamas	3.67	0.42	1.30	-68%
Cape Horn	17.2	1.96	2.13	-8%
Merwin Dam	13.37	1.52	2.02	-25%
Battle Ground	12.35	1.41	1.40	0%
Vancouver NNE	10.72	1.22	1.11	10%
I-5 Bridge	NA	NA	1.02	NA
PDX	8.78	1.00	1.00	0%
Portland NWSFO	11.49	1.31	1.18	11%
Troutdale	10.00	1.14	1.37	-17%

The numbers presented in Table 3 show that the event scaling factors for most stations are reasonably close to the overall scaling factors, with a few exceptions. The Lacamas station event factor differed considerably, and presumably had difficulties recording data during this event. The recording equipment for this station is located beneath a power pole and has a consistent history of measuring problems, resulting in the installation of a new precipitation gage at Heritage Trail in late 2007. The event factor for the Merwin Dam station is also off by a significant amount. However, this is somewhat expected considering that this station is the farthest away from PDX, and likely subjected to different weather patterns. Event factors from all other stations appear reasonably consistent with the overall scaling factors. Additionally, there is no consistent trend suggesting that the overall precipitation scaling factors are too high or too low. Instead, for some stations the event factor is larger than the overall factor, and for other stations the overall factor is larger than the event factor.

References

Clark County Department of Assessment and GIS (2008). Shapefile information for various surface layers. Vancouver, WA.

McCuen, Richard H. (1998). Hydrologic Analysis and Design. Prentice-Hall, Inc. Upper Saddle River, NJ.

MGS Engineering Consultants, (2002). Extended Precipitation Time-Series for Continuous Simulation Hydrological Modeling in Western Washington. Prepared for Washington State Department of Transportation.

Miller, J.F.; Frederick, R.H.; and Tracey, R.J. (1973). NOAA Atlas 2: Precipitation-Frequency Atlas of the Western United States: Volume IX—Washington. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service.

Northwest Hydraulic Consultants (2000). Primer on the use of Continuous Hydrologic Simulation Models for Stormwater Management. Seattle, WA.

U.S. Army Corp of Engineers (2008). HEC-RAS, River Systems Analysis. Hydrologic Engineering Center. Davis, CA.

U.S. Department of Agriculture, Soil Conservation Service (1972). Soil Survey of Clark County, Washington.

Washington State Department of Ecology (2005). Stormwater Management Manual for Western Washington. Publication Numbers 05-10-029 through 05-10-033. Olympia, WA.

WEST Consultants (2008). Hydrologic and Hydraulic Analyses of the Mill Creek Watershed (draft). Clark County Department of Public Works, Clean Water Program, Vancouver, WA.

This page left blank to accommodate double-sided printing

Appendices

This page left blank to accommodate double-sided printing

Appendix A — Watershed Surface Data

otak

This page left blank to accommodate double-sided printing

MILL CREEK (Landuse Areas using Effective Impervious*)

Slope, Landuse, & Soil data by Sub-basin (acres) using revised soil classifications of 12-23-09

Slope	Flat Slope (0-5%)										
Landuse	Forest					Field					Impervious
Soil Category	1	2	3	4	5	1	2	3	4	5	NA
BASIN											
MIL1A	0.00	0.64	1.10	5.12	0.00	0.00	38.02	5.88	18.60	0.00	0.99
MIL1B	0.00	4.59	0.88	0.94	0.00	0.00	19.01	6.25	11.36	0.00	1.15
MIL2A	0.00	0.00	0.00	83.82	0.00	0.00	0.00	0.00	201.39	0.00	14.06
MIL2B	0.00	0.00	0.00	2.79	0.00	0.00	0.00	0.00	22.67	0.00	1.22
MIL2C	0.00	0.00	3.21	68.36	0.00	0.00	0.00	7.94	111.47	0.00	9.11
MIL2Cu	0.00	0.00	0.00	5.16	0.00	0.00	0.00	0.00	36.58	0.00	0.48
MIL2D	0.00	0.00	14.99	56.50	0.00	0.00	0.00	28.95	59.24	0.00	7.75
MIL2E	0.00	0.00	2.68	11.20	0.00	0.00	0.00	6.09	28.15	0.00	10.33
MIL3A	0.00	0.00	21.59	62.25	0.00	0.00	0.00	72.10	151.69	0.00	4.38
MIL3B	0.00	0.19	9.35	36.76	0.00	0.00	0.69	32.80	122.26	0.00	5.52
MIL3C	0.00	0.00	22.24	0.84	0.00	0.00	0.00	71.63	22.77	0.00	1.57
MIL3D	0.00	0.51	14.65	1.27	0.10	0.00	3.25	61.44	32.80	3.17	5.04
MIL3E	0.00	20.38	25.42	29.26	0.00	0.00	101.59	62.98	80.92	0.00	14.70
MIL6A	0.00	0.02	53.07	64.58	0.01	0.00	0.58	221.59	328.66	0.04	24.03
MIL6B	0.00	3.97	31.03	18.18	0.19	0.00	27.34	91.67	156.28	9.98	9.91
MIL7A	0.00	0.00	8.37	7.76	0.00	0.00	0.00	58.49	67.29	0.00	58.20
MIL7B	0.00	0.00	13.98	27.98	0.00	0.00	0.00	110.66	106.87	0.00	86.93
MIL7C	0.00	0.00	22.55	12.79	2.61	0.00	0.00	44.25	33.87	0.00	33.10
MIL7D	0.00	0.00	114.76	94.00	1.59	0.00	0.00	364.67	321.77	0.20	66.05
MIL7E	0.00	0.00	59.93	40.79	0.00	0.00	0.00	159.73	89.22	0.00	22.55
MIL7F	0.00	0.00	39.67	10.13	0.00	0.00	0.00	59.60	46.89	0.00	8.06
MIL7G	0.00	0.00	85.78	29.64	0.00	0.00	0.00	81.65	36.31	0.00	19.73
MIL7H	0.00	0.00	39.57	12.17	0.00	0.00	0.00	54.33	29.31	0.00	4.80
MIL7I	0.00	1.74	4.35	27.86	0.52	0.03	2.25	8.68	25.42	11.59	9.55
MIL7J	0.00	0.06	2.02	8.19	0.22	0.00	0.01	8.88	39.33	41.07	0.51
MIL7K	0.00	0.12	8.45	14.12	0.28	0.00	4.10	23.36	11.40	4.22	1.39
MIL7L	0.00	13.31	1.40	6.72	0.00	0.00	5.30	4.69	20.94	0.00	0.74
TOTAL	0.00	45.52	601.03	739.20	5.52	0.03	202.14	1648.33	2213.44	70.27	421.87

Slope	Moderate Slope (5-15%)										
Landuse	Forest					Field					Impervious
Soil Category	1	2	3	4	5	1	2	3	4	5	NA
BASIN											
MIL1A	0.00	0.73	1.04	13.98	0.00	0.00	5.48	2.22	51.96	0.00	4.61
MIL1B	0.00	3.09	1.03	2.98	0.00	0.00	4.89	4.93	9.53	0.00	0.27
MIL2A	0.00	0.00	0.00	3.50	0.00	0.00	0.00	0.00	6.12	0.00	0.12
MIL2B	0.00	0.00	0.00	2.63	0.00	0.00	0.00	0.00	10.19	0.00	0.56
MIL2C	0.00	0.00	2.70	71.18	0.00	0.00	0.00	10.06	108.30	0.00	7.52
MIL2Cu	0.00	0.00	0.00	1.39	0.00	0.00	0.00	0.00	10.55	0.00	0.88
MIL2D	0.00	0.00	8.41	44.36	0.00	0.00	0.00	30.22	41.37	0.00	5.48
MIL2E	0.00	0.00	6.41	40.06	0.00	0.00	0.00	20.43	60.43	0.00	17.01
MIL3A	0.00	0.00	1.20	12.59	0.00	0.00	0.00	10.98	30.82	0.00	0.50
MIL3B	0.00	0.25	5.14	34.28	0.00	0.00	0.54	22.08	74.87	0.00	2.04
MIL3C	0.00	0.00	17.49	0.17	0.00	0.00	0.00	49.61	1.54	0.00	0.86
MIL3D	0.00	0.10	6.22	0.56	0.03	0.00	0.20	15.85	7.39	0.30	0.47
MIL3E	0.00	8.16	14.22	23.90	0.00	0.00	22.03	15.10	42.45	0.00	3.32
MIL6A	0.00	0.00	6.97	7.37	0.13	0.00	0.00	6.98	2.63	0.00	0.54
MIL6B	0.00	0.08	34.34	0.40	0.00	0.00	1.97	85.68	4.12	0.65	3.50
MIL7A	0.00	0.00	0.35	0.17	0.00	0.00	0.00	0.46	0.02	0.00	0.10
MIL7B	0.00	0.00	0.08	0.26	0.00	0.00	0.00	1.59	1.94	0.00	0.76
MIL7C	0.00	0.00	0.02	0.46	0.00	0.00	0.00	0.15	0.12	0.00	0.20
MIL7D	0.00	0.00	6.82	0.89	0.00	0.00	0.00	59.93	1.88	0.00	3.40
MIL7E	0.00	0.00	0.66	0.12	0.00	0.00	0.00	0.86	0.37	0.00	0.19
MIL7F	0.00	0.00	14.31	0.41	0.00	0.00	0.00	32.76	1.63	0.00	1.01
MIL7G	0.00	0.00	15.69	1.09	0.00	0.00	0.00	3.83	0.36	0.00	0.02
MIL7H	0.00	0.00	22.76	0.45	0.00	0.00	0.00	22.29	0.50	0.00	1.14
MIL7I	0.00	0.00	0.89	2.17	0.00	0.00	0.00	1.33	1.26	0.18	0.18
MIL7J	0.00	0.00	0.76	5.47	1.94	0.00	0.00	1.71	11.47	0.96	0.04
MIL7K	0.00	0.04	10.35	7.98	0.79	0.00	0.00	6.05	4.61	0.24	0.27
MIL7L	0.00	0.00	0.00	0.81	0.00	0.00	0.00	0.00	0.78	0.00	0.00
TOTAL	0.00	12.47	177.84	279.63	2.89	0.00	35.10	405.08	487.23	2.34	54.98

Slope	Steep Slope (15%+)											
Landuse	Forest					Field					Impervious	
Soil Category	1	2	3	4	5	1	2	3	4	5	NA	
BASIN												
MIL1A	0.00	1.43	2.26	26.46	0.00	0.00	0.38	0.19	6.96	0.00	0.64	
MIL1B	0.00	4.63	0.99	5.90	0.00	0.00	0.46	0.34	1.03	0.00	0.00	
MIL2A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MIL2B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MIL2C	0.00	0.00	0.00	7.83	0.00	0.00	0.00	0.03	2.20	0.00	0.05	
MIL2Cu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MIL2D	0.00	0.00	0.03	6.11	0.00	0.00	0.00	0.02	0.49	0.00	0.04	
MIL2E	0.00	0.00	1.81	24.32	0.00	0.00	0.00	0.49	2.74	0.00	0.20	
MIL3A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MIL3B	0.00	0.00	1.30	8.44	0.00	0.00	0.00	0.34	1.36	0.00	0.03	
MIL3C	0.00	0.00	3.98	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.00	
MIL3D	0.00	0.00	2.74	0.00	0.00	0.00	0.00	0.52	0.00	0.00	0.00	
MIL3E	0.00	7.63	8.08	19.56	0.00	0.00	0.67	1.61	1.15	0.00	0.04	
MIL6A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MIL6B	0.00	0.00	1.26	0.00	0.00	0.00	0.00	1.43	0.00	0.00	0.00	
MIL7A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MIL7B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MIL7C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MIL7D	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MIL7E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MIL7F	0.00	0.00	0.05	0.00	0.00	0.00	0.00	3.60	0.00	0.00	0.09	
MIL7G	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	
MIL7H	0.00	0.00	1.46	0.00	0.00	0.00	0.00	1.06	0.00	0.00	0.02	
MIL7I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
MIL7J	0.00	0.00	0.30	0.43	0.14	0.00	0.00	0.01	0.04	0.00	0.00	
MIL7K	0.00	0.00	6.38	1.91	0.00	0.00	0.00	1.19	0.19	0.00	0.01	
MIL7L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
TOTAL	0.00	13.68	31.23	100.97	0.14	0.00	1.52	11.38	16.15	0.00	1.14	**7581.1**

*Uses the assumption that building areas will be 25% effective impervious, while pavement will be 75% effective impervious

GEE CREEK (Landuse Areas using Effective Impervious*)

Slope, Landuse, & Soil data by Sub-basin (acres) using revised soil classifications of 12-23-09

Slope	Flat Slope (0-5%)										
Landuse	Forest					Field					Impervious
Soil Category	1	2	3	4	5	1	2	3	4	5	NA
BASIN											
GEE1	0.00	5.01	6.35	73.34	0.00	0.00	5.62	17.27	189.85	0.00	11.88
GEE2	0.00	15.71	6.68	59.32	0.00	0.00	17.41	48.66	296.52	0.00	14.81
GEE3	0.00	0.04	0.15	23.27	0.00	0.00	0.37	1.70	46.06	0.00	1.62
GEE4	0.00	0.51	0.00	14.28	0.00	0.00	0.02	0.06	92.19	0.00	1.17
GEE5	0.00	0.00	0.00	21.91	0.00	0.00	0.00	0.00	30.93	0.00	2.52
GEE6	0.00	0.00	0.98	24.24	0.00	0.00	0.00	2.39	69.90	0.00	9.02
GEE7	0.00	0.00	0.00	2.63	0.00	0.00	0.00	0.00	8.29	0.00	1.12
TOTAL	0.00	21.27	14.17	218.99	0.00	0.00	23.41	70.07	733.74	0.00	42.14

Slope	Moderate Slope (5-15%)										
Landuse	Forest					Field					Impervious
Soil Category	1	2	3	4	5	1	2	3	4	5	NA
BASIN											
GEE1	0.00	4.30	11.15	187.14	0.00	0.00	2.68	15.11	374.66	0.00	22.54
GEE2	0.00	6.11	9.73	161.34	0.23	0.00	4.84	73.96	443.40	0.02	8.82
GEE3	0.00	1.98	0.83	234.95	0.00	0.00	47.41	8.18	761.29	0.00	37.40
GEE4	0.00	0.34	0.56	32.13	0.00	0.00	0.01	1.79	102.21	0.00	7.92
GEE5	0.00	0.00	10.06	301.75	0.00	0.00	0.00	18.74	959.62	0.00	32.11
GEE6	0.00	0.00	34.33	175.96	0.00	0.00	0.00	59.79	311.40	0.00	24.88
GEE7	0.00	0.00	0.99	225.97	0.00	0.00	0.00	7.22	561.42	0.00	63.17
TOTAL	0.00	12.73	67.65	1319.23	0.23	0.00	54.94	184.80	3514.01	0.02	196.85

Slope	Steep Slope (15%+)											
Landuse	Forest					Field					Impervious	
Soil Category	1	2	3	4	5	1	2	3	4	5	NA	
BASIN												
GEE1	0.00	1.38	20.79	278.12	0.00	0.00	0.22	4.98	110.48	0.00	4.14	
GEE2	0.00	3.45	3.13	144.60	0.03	0.00	0.64	2.44	81.75	0.04	2.30	
GEE3	0.00	0.08	0.14	84.41	0.00	0.00	0.00	0.33	13.31	0.00	1.43	
GEE4	0.00	0.24	0.00	32.09	0.00	0.00	0.03	0.00	6.28	0.00	0.03	
GEE5	0.00	0.00	0.00	48.01	0.00	0.00	0.00	0.00	19.15	0.00	0.32	
GEE6	0.00	0.00	9.35	35.82	0.00	0.00	0.00	4.16	30.16	0.00	0.72	
GEE7	0.00	0.00	0.35	1.23	0.00	0.00	0.00	0.93	1.37	0.00	0.11	
TOTAL	0.00	5.15	33.77	624.27	0.03	0.00	0.89	12.84	262.49	0.04	9.05	**7422.8**

*Uses the assumption that building areas will be 25% effective impervious, while pavement will be 75% effective impervious

Appendix B — Clark County Soil Groups

This page left blank to accommodate double-sided printing

Soil Classifications (Revised 12-23-09)

Map Symbol	Soil Name	HSG	SCS Permeability (in/hr)	Dominant USDA Texture	Depth from surface
SG 1					
LeB	LAUREN	B	0.63 - 2.0 (6.3 - 20 deeper than 33in)	Very Gravelly Coarse Sandy Loam	33-70
LgB	LAUREN	B	0.63 - 2.0 (6.3 - 20 deeper than 33in)	Very Gravelly Coarse Sandy Loam	33-70
LgD	LAUREN	B	0.63 - 2.0 (6.3 - 20 deeper than 33in)	Very Gravelly Coarse Sandy Loam	33-70
LgF	LAUREN	B	0.63 - 2.0 (6.3 - 20 deeper than 33in)	Very Gravelly Coarse Sandy Loam	33-70
LlB	LAUREN	B	0.63 - 2.0 (6.3 - 20 deeper than 33in)	Very Gravelly Coarse Sandy Loam	33-70
Ro	ROUGH BROKEN LAND	A	Too variable		
SvA	SIFTON	B	2.0 - 6.3 (>20 deeper than 16in)	Very Gravelly Loamy Coarse Sand and Very Gravelly Coarse Sand	10-60 inches
WnB	WIND RIVER VARIANT	B	6.3 - 20	Loamy Coarse Sand and Coarse Sand	24-62 inches
WnD	WIND RIVER VARIANT	B	6.3 - 20	Loamy Coarse Sand and Coarse Sand	24-62 inches
WnG	WIND RIVER VARIANT	B	6.3 - 20	Loamy Coarse Sand and Coarse Sand	24-62 inches
WrB	WIND RIVER VARIANT	B	6.3 - 20	Loamy Coarse Sand and Coarse Sand	24-62 inches
WrF	WIND RIVER VARIANT	B	6.3 - 20	Loamy Coarse Sand and Coarse Sand	24-62 inches
	PITS	A			
	BONNEVILLE STONY SAND LOAM	A			
SG 2					
BpB	BEAR PRARIE	B	0.63 - 2.0	Gravelly Loam	51-75 inches
BpC	BEAR PRARIE	B	0.63 - 2.0	Gravelly Loam	51-75 inches
CnB	CINEBAR	B	0.63 - 2.0	Silt Loam and Loam	0-65 inches
CnD	CINEBAR	B	0.63 - 2.0	Silt Loam and Loam	0-65 inches
CnE	CINEBAR	B	0.63 - 2.0	Silt Loam and Loam	0-65 inches
CnG	CINEBAR	B	0.63 - 2.0	Silt Loam and Loam	0-65 inches
CrE	CINEBAR	B	0.63 - 2.0	Silt Loam	0-60 inches
CrG	CINEBAR	B	0.63 - 2.0	Silt Loam	0-60 inches
CsF	CISPUS	B	> 20	Very Cobbly Sand	24-53 inches
CtA	CLOQUATO	B	>6.30	Sandy loam and sand	40-72 inches
HlA	HILLSBORO	B	2.0 - 6.3	Sandy loam and sand	36-62 inches
HlB	HILLSBORO	B	2.0 - 6.3	Sandy loam and sand	36-62 inches
HlC	HILLSBORO	B	2.0 - 6.3	Sandy loam and sand	36-62 inches
HlD	HILLSBORO	B	2.0 - 6.3	Sandy loam and sand	36-62 inches
HlE	HILLSBORO	B	2.0 - 6.3	Sandy loam and sand	36-62 inches
HlF	HILLSBORO	B	2.0 - 6.3	Sandy loam and sand	36-62 inches
KeC	KINNEY	B	0.63 - 2.0	Gravelly silt loam, gravelly silty clay loam, and gravelly clay loam	0-60 inches
KeE	KINNEY	B	0.63 - 2.0	Gravelly silt loam, gravelly silty clay loam, and gravelly clay loam	0-60 inches
KeF	KINNEY	B	0.63 - 2.0	Gravelly silt loam, gravelly silty clay loam, and gravelly clay loam	0-60 inches
KnF	KINNEY	B	0.63 - 2.0	Gravelly silt loam, gravelly silty clay loam, and gravelly clay loam	0-60 inches
LaE	LARCHMOUNT	B	0.63 - 2.0	Cobbly Silt Loam and Clay Loam	0-62 inches
LaG	LARCHMOUNT	B	0.63 - 2.0	Cobbly Silt Loam and Clay Loam	0-62 inches
LcG	LARCHMOUNT	B	0.63 - 2.0	Silty Loam and Clay Loam	0-62 inches
MsB	MOSSYROCK	B	0.63 - 2.0	Silt Loam	23-60 inches
NbA	NEWBERG	B	2.0 - 6.3	Fine Sandy Loam and Sandy Loam	7-52 inches
NbB	NEWBERG	B	2.0 - 6.3	Fine Sandy Loam and Sandy Loam	7-52 inches
PhB	PILCHUCK	C	6.3 - 20	Fine Sand	0-60 inches
PuA	PUYALLUP	B	6.3 - 20	Gravelly Sand	27-60 inches
SaC	SALKUM	B	0.06 - 0.20	Heavy Silty Clay Loam	31-55 inches
VaB	VADER	B	2.0 - 6.3	Silt Loam and Loam	0-30 inches
VaC	VADER	B	2.0 - 6.3	Silt Loam and Loam	0-30 inches
WaA	WASHOUGAL	B	0.63 - 2.0	Very Gravelly Loam and Very Gravelly Coarse Sandy Loam	22-36 inches
WgB	WASHOUGAL	B	0.63 - 2.0	Very Gravelly Loam and Very Gravelly Coarse Sandy Loam	22-36 inches
WgE	WASHOUGAL	B	0.63 - 2.0	Very Gravelly Loam and Very Gravelly Coarse Sandy Loam	22-36 inches
WhF	WASHOUGAL	B	0.63 - 2.0	Very Gravelly Loam and Very Gravelly Coarse Sandy Loam	22-36 inches
YaA	YACOLT	B	0.63 - 2.0	Cobbly Loam	39-61 inches
YaC	YACOLT	B	0.63 - 2.0	Cobbly Loam	39-61 inches
YcB	YACOLT	B	0.63 - 2.0	Cobbly Loam	39-61 inches

Map Symbol	Soil Name	HSG	SCS Permeability (in/hr)	Dominant USDA Texture	Depth from surface

SG 3

DoB	DOLLAR	C	<0.06	Loam	32-60 inches
HcB	HESSON	C	0.2 - 0.63	Clay	22-91 inches
HcD	HESSON	C	0.2 - 0.63	Clay	22-91 inches
HcE	HESSON	C	0.2 - 0.63	Clay	22-91 inches
HcF	HESSON	C	0.2 - 0.63	Clay	22-91 inches
HgB	HESSON	C	0.2 - 0.63	Gravelly Clay	22-91 inches
HgD	HESSON	C	0.2 - 0.63	Gravelly Clay	22-91 inches
HhE	HESSON	C	0.2 - 0.63	Gravelly Clay	22-91 inches
HoA	HILLSBORO	B	0.63 - 2.0	Silt Loam	0-86 inches
HoB	HILLSBORO	B	0.63 - 2.0	Silt Loam	0-86 inches
HoC	HILLSBORO	B	0.63 - 2.0	Silt Loam	0-86 inches
HoD	HILLSBORO	B	0.63 - 2.0	Silt Loam	0-86 inches
HoE	HILLSBORO	B	0.63 - 2.0	Silt Loam	0-86 inches
HoG	HILLSBORO	B	0.63 - 2.0	Silt Loam	0-86 inches
HsB	HILLSBORO	B	0.63 - 2.0	Silt Loam	0-86 inches
McB	McBEE	C	0.63 - 2.0	Silty Clay Loam, Clay	0-65 inches
MeA	McBEE	C	0.63 - 2.0	Silty Clay Loam, Clay	0-65 inches
MIA	McBEE	C	0.63 - 2.0 (>20 deeper than 44in)	Gravelly Fine Sandy Loam	19-44 inches
OeD	OLEQUA	B	0.2 - 0.63	Heavy Silt Loam and Silty Clay Loam	17-90 inches
OeE	OLEQUA	B	0.2 - 0.63	Heavy Silt Loam and Silty Clay Loam	17-90 inches
OeF	OLEQUA	B	0.2 - 0.63	Heavy Silt Loam and Silty Clay Loam	17-90 inches
OlB	OLYMPIC	B	0.2 - 0.63	Gravelly Clay Loam	44-59 inches
OlD	OLYMPIC	B	0.2 - 0.63	Gravelly Clay Loam	44-59 inches
OlE	OLYMPIC	B	0.2 - 0.63	Gravelly Clay Loam	44-59 inches
OlF	OLYMPIC	B	0.2 - 0.63	Gravelly Clay Loam	44-59 inches
OmE	OLYMPIC	B	0.2 - 0.63	Gravelly Clay Loam	44-59 inches
OmF	OLYMPIC	B	0.2 - 0.63	Gravelly Clay Loam	44-59 inches
OpC	OLYMPIC VARIANT	C	0.2 - 0.63	Heavy Clay Loam and Heavy silty Clay Loam	0-33 inches
OpE	OLYMPIC VARIANT	C	0.2 - 0.63	Fractured Basalt	0-33 inches
OpG	OLYMPIC VARIANT	C	0.2 - 0.63	Fractured Basalt	0-33 inches
OrC	OLYMPIC VARIANT	C	0.2 - 0.63	Fractured Basalt	0-33 inches
PoB	POWELL	C	0.06 - 0.20	Silt Loam	23-63 inches
PoD	POWELL	C	0.06 - 0.20	Silt Loam	23-63 inches
PoE	POWELL	C	0.06 - 0.20	Silt Loam	23-63 inches
SmA	SAUVIE	B	0.2 - 0.63	Silty Clay Loam and Silt Loam	0-63 inches
SmB	SAUVIE	B	0.2 - 0.63	Silty Clay Loam and Silt Loam	0-63 inches
SnA	SAUVIE	D	2.0 - 6.3	Fine Sandy Loam	36-63 inches
SpB	SAUVIE	B	0.2 - 0.63	Silty Clay Loam and Silt Loam	0-63 inches

SG 4

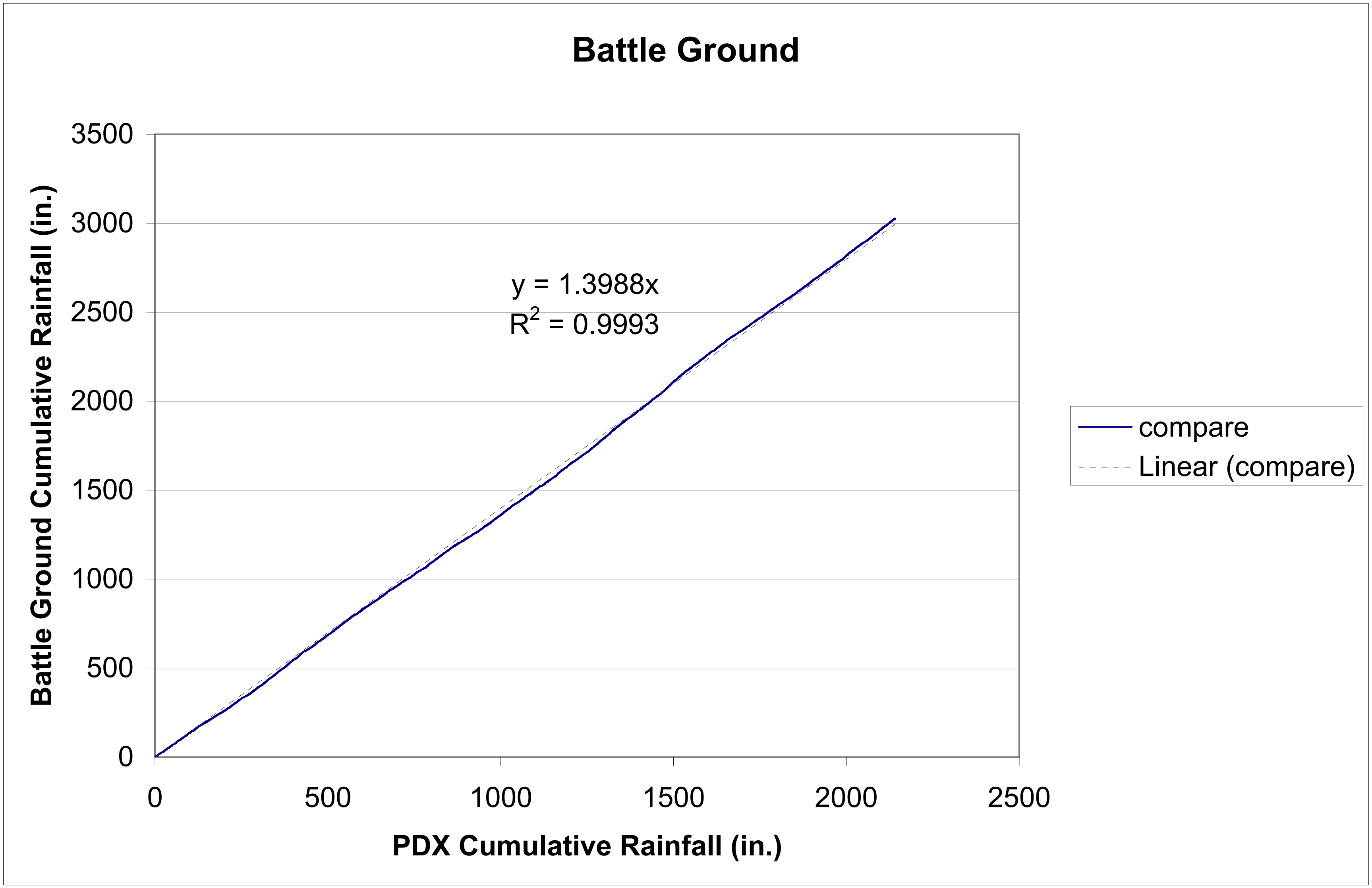
CvA	COVE	D	0.06 - 0.20	Gravelly Silty Clay Loam	21-60 inches
CwA	COVE	D	0.06 - 0.20	Silt Loam	21-60 inches
GeB	GEE	C	<0.06	Silty Clay Loam	22-72 inches
GeD	GEE	C	<0.06	Silty Clay Loam	22-72 inches
GeE	GEE	C	<0.06	Silty Clay Loam	22-72 inches
GeF	GEE	C	<0.06	Silty Clay Loam	22-72 inches
GuB	GUMBOOT	D	0.06 - 0.2	Gravelly Silty Clay Loam, Clay Loam	12-50 inches
HtA	HOCKINSON	D	0.06 - 0.2	Fine Sandy Loam and Loam	23-51 inches
HuB	HOCKINSON	D	0.06 - 0.2	Fine Sandy Loam and Loam	23-51 inches
HvA	HOCKINSON	D	0.06 - 0.2	Fine Sandy Loam and Loam	23-51 inches
LrC	LAUREN	C	<0.06	Very Gravelly Clay Loam	14-60 inches
LrF	LAUREN	C	<0.06	Very Gravelly Clay Loam	14-60 inches
MnA	MINNIECE	D	<0.06	Silty Clay and Clay Basalt Bedrock	0-48 inches
MnD	MINNIECE	D	<0.06	Silty Clay and Clay Basalt Bedrock	0-48 inches
MoA	MINNIECE VARIANT	D	<0.06	Very Gravelly Clay Loam	22-60 inches
OdB	ODNE	D	<0.06	Silt Loam, silty Clay Loam, Clay Loam, and Loam	0-50 inches
OhD	OLEQUA VARIANT	C	<0.06	Silty Clay and Clay	32-82 inches
OhF	OLEQUA VARIANT	C	<0.06	Silty Clay and Clay	32-82 inches
SlB	SARA	D	<0.06	Heavy Silty Clay Loam and Silty Clay	10-70 inches
SlD	SARA	D	<0.06	Heavy Silty Clay Loam and Silty Clay	10-70 inches
SlF	SARA	D	<0.06	Heavy Silty Clay Loam and Silty Clay	10-70 inches

SG 5

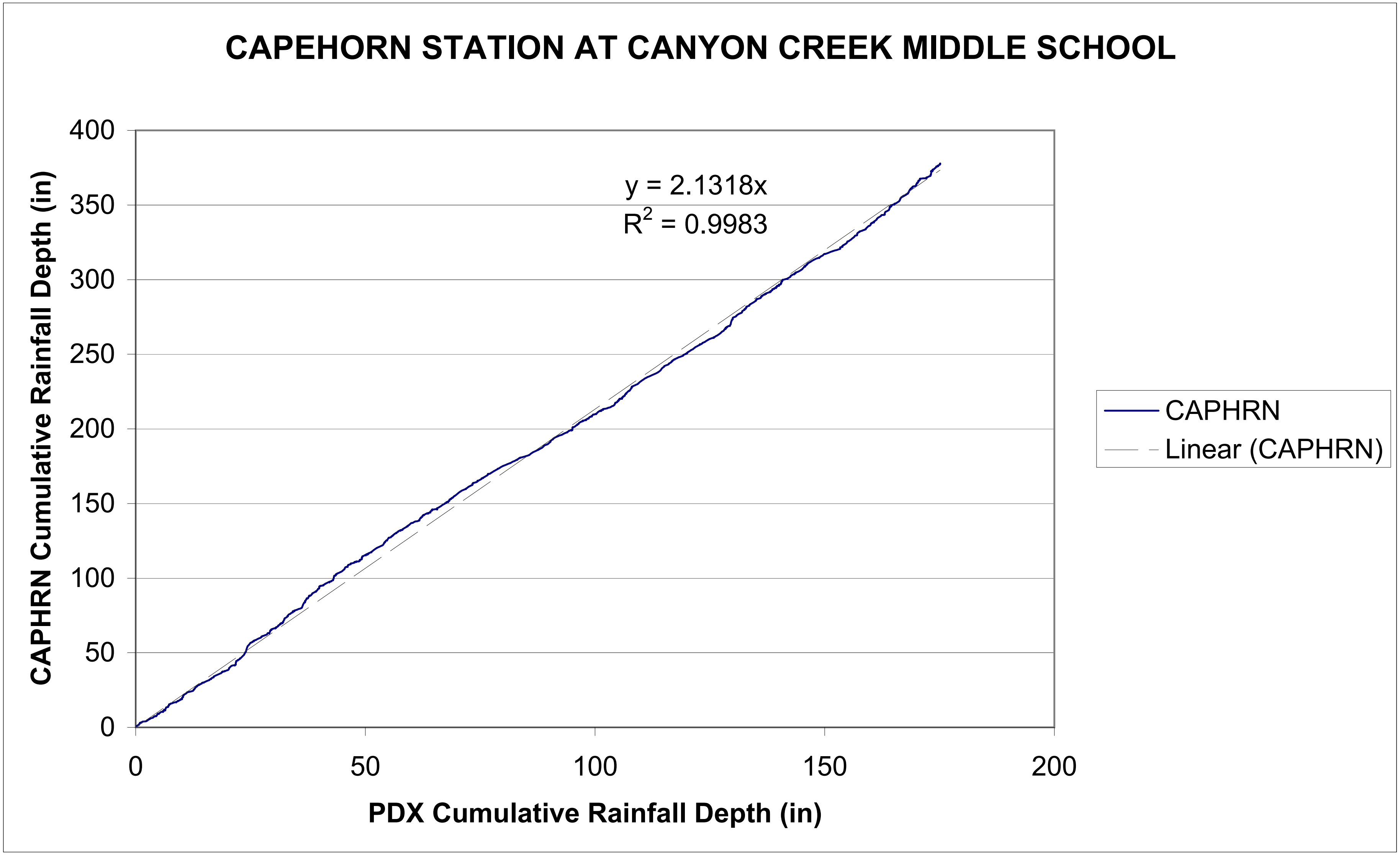
Sr	SEMIAHMOO	C	0.63 - 2.0	Muck	0-40 inches
Su	SEMIAHMOO VARIANT	D	0.63 - 2.0	Muck	0-30 inches
ThA	TISCH	D	0.2 - 0.63	Muck	31-45 inches

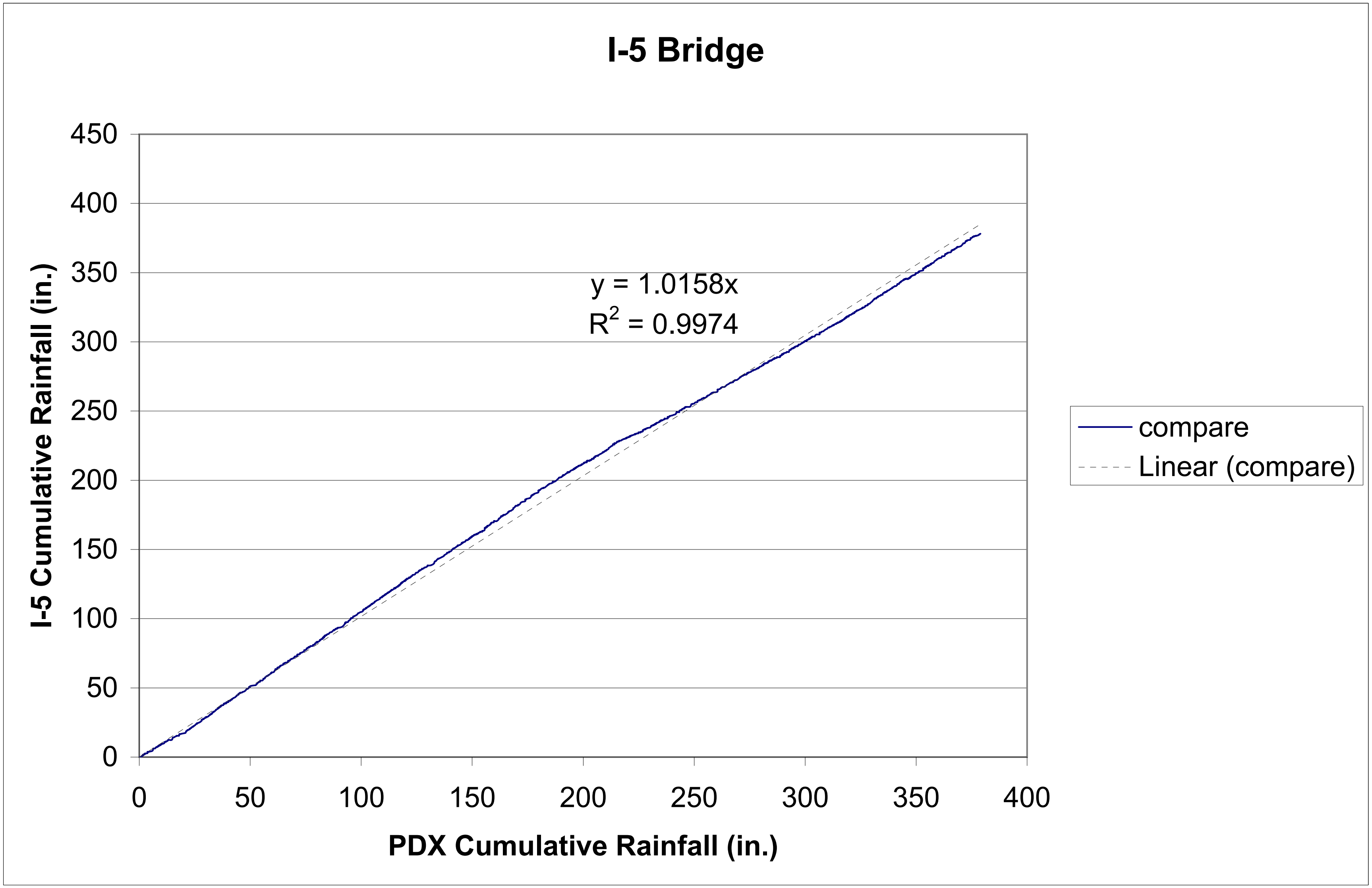
Appendix C — Double Mass Curve Plots

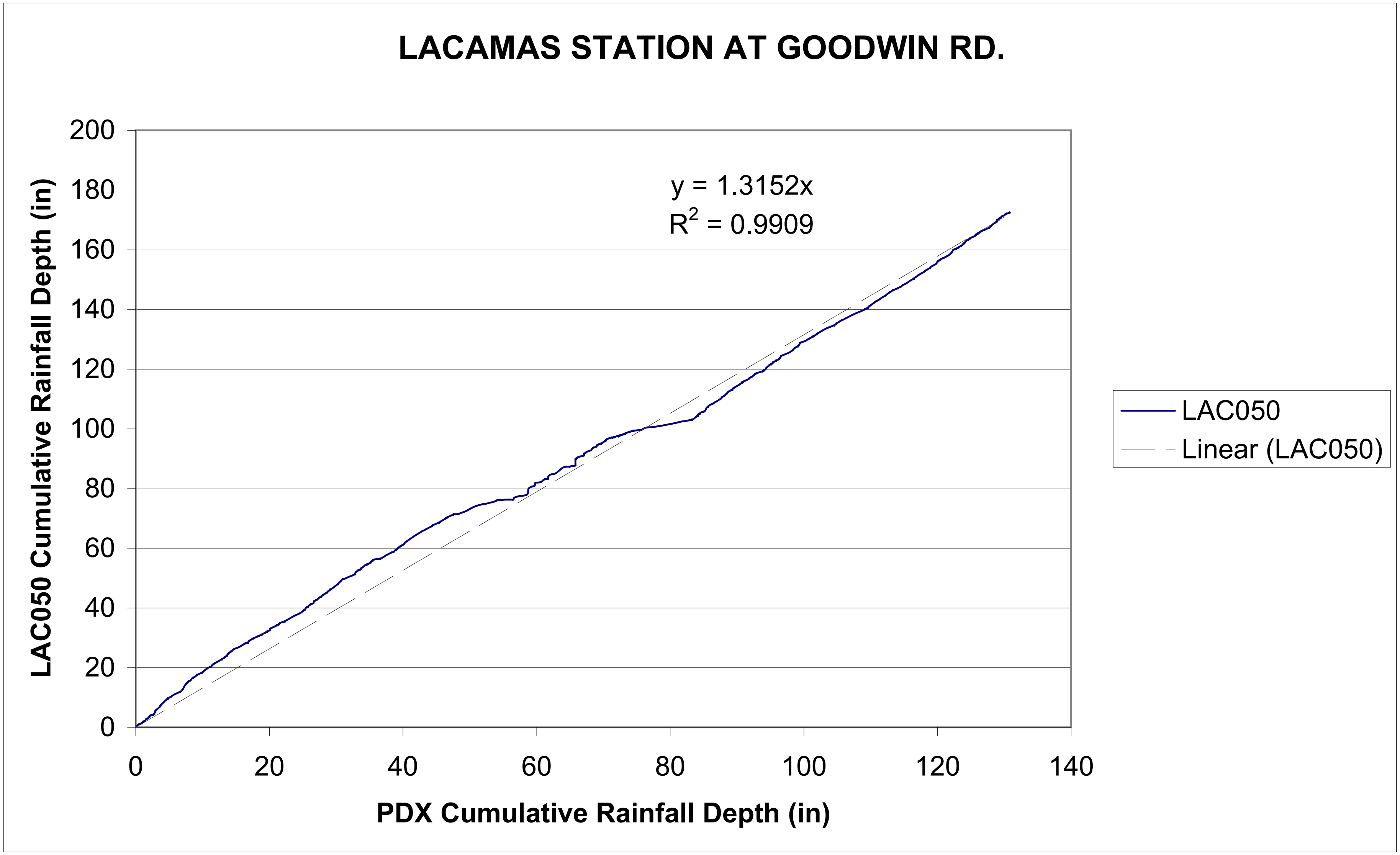
This page left blank to accommodate double-sided printing

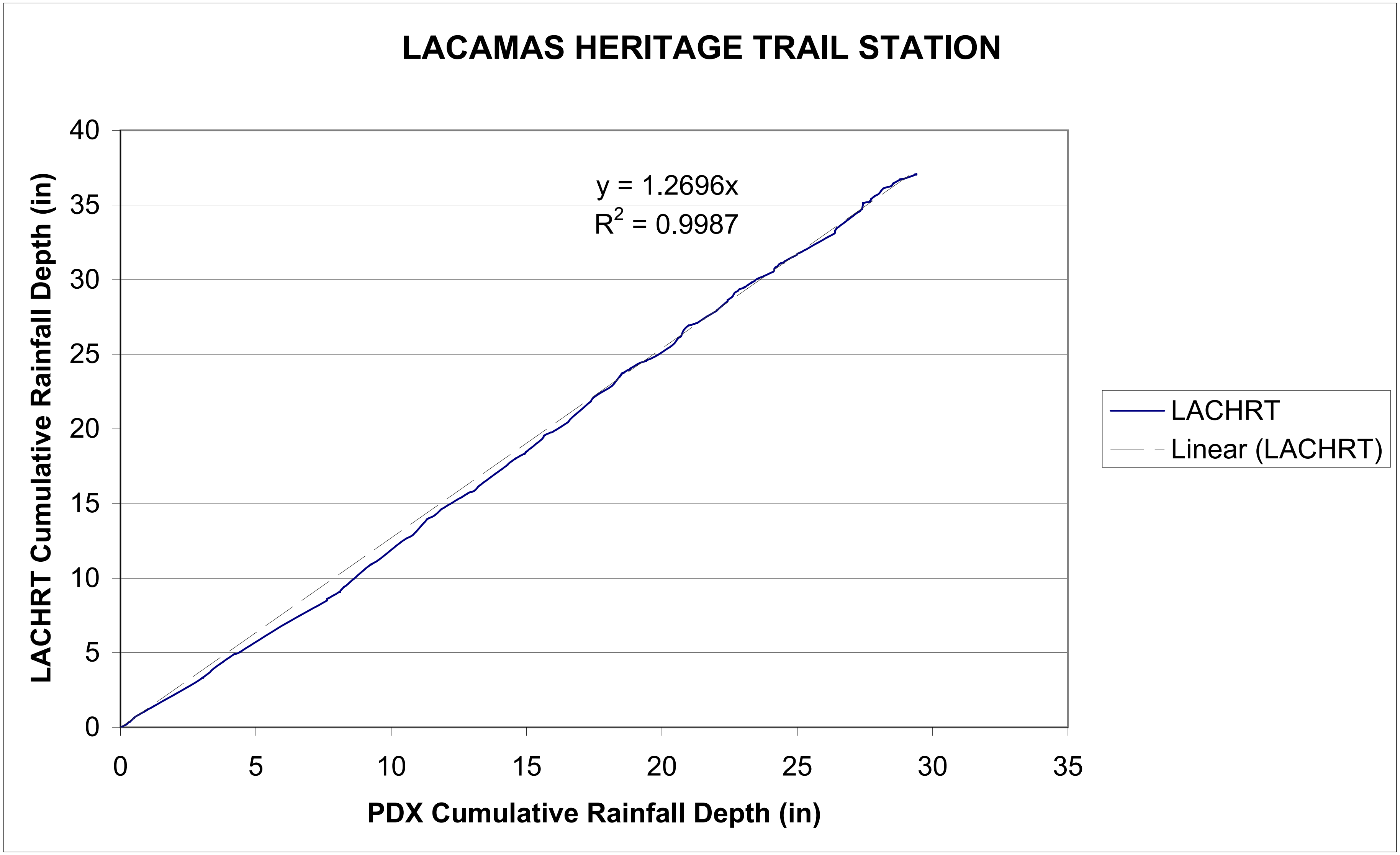


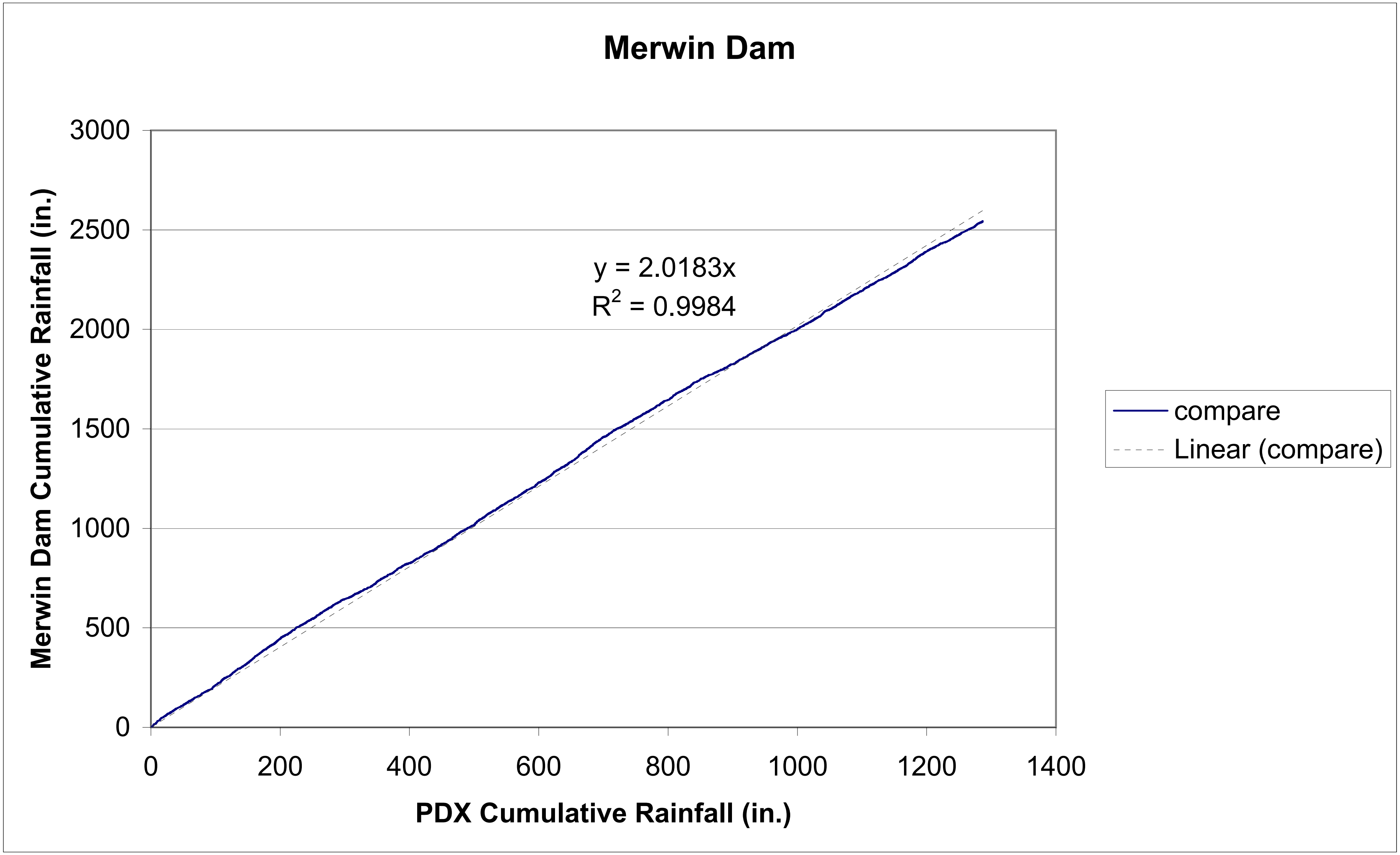
Battle Ground
y = 1.3988x
R2 = 0.9993
Battle Ground Cumulative Rainfall (in.)
PDX Cumulative Rainfall (in.)
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
compare
Linear (compare)


CAPEHORN STATION AT CANYON CREEK MIDDLE SCHOOL
y = 2.1318x
R2 = 0.9983
CAPHRN Cumulative Rainfall Depth (in)
PDX Cumulative Rainfall Depth (in)
CAPHRN
Linear (CAPHRN)
0
50
100
150
200
250
300
350
400
0
50
100
150
200

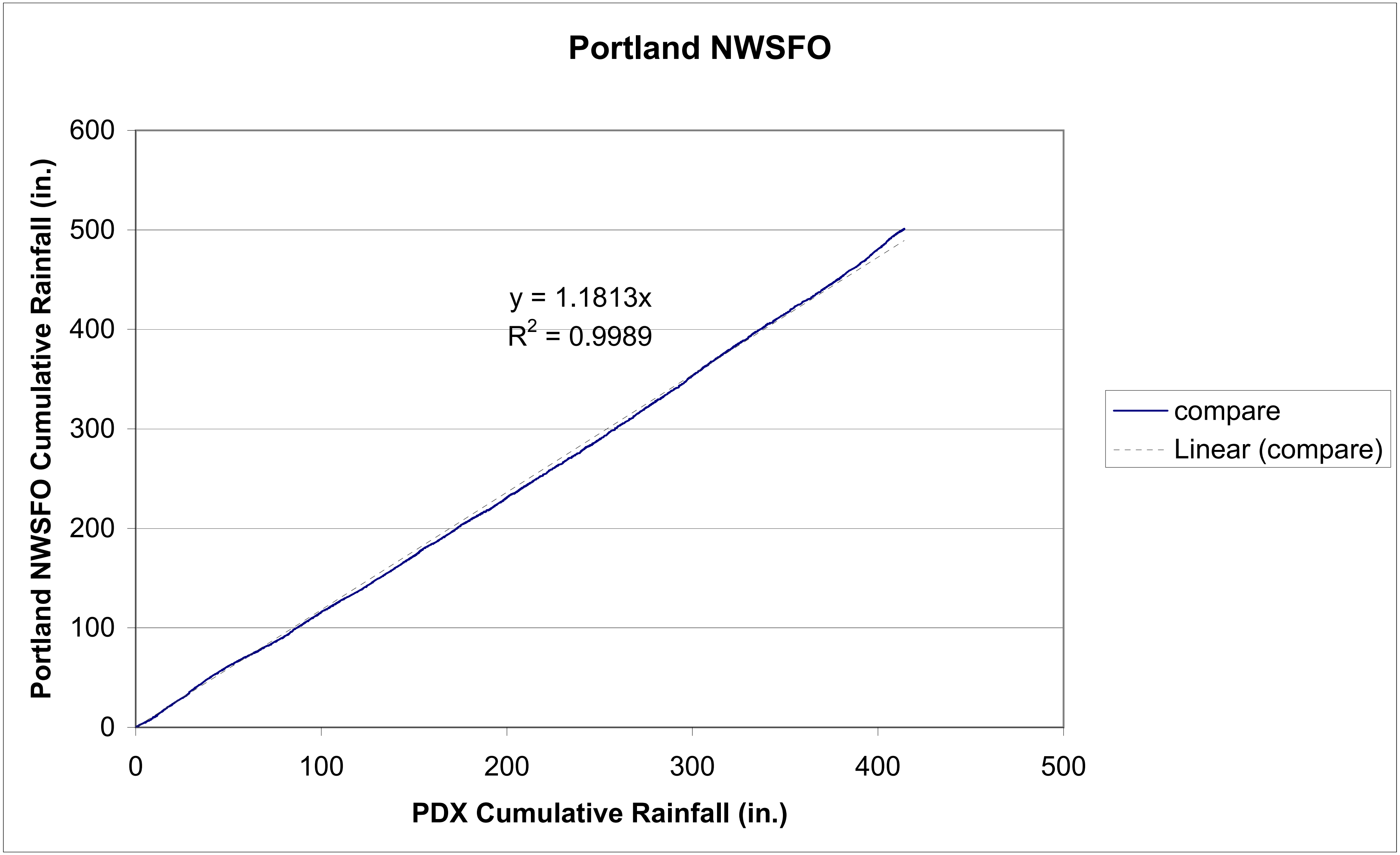

I-5 Bridge
y = 1.0158x
R^2 = 0.9974
I-5 Cumulative Rainfall (in.)
PDX Cumulative Rainfall (in.)
0
50
100
150
200
250
300
350
400
450
compare
Linear (compare)


LACAMAS STATION AT GOODWIN RD.
y = 1.3152x
R2 = 0.9909
LAC050 Cumulative Rainfall Depth (in)
PDX Cumulative Rainfall Depth (in)
LAC050
Linear (LAC050)
0
20
40
60
80
100
120
140
160
180
200
0
20
40
60
80
100
120
140

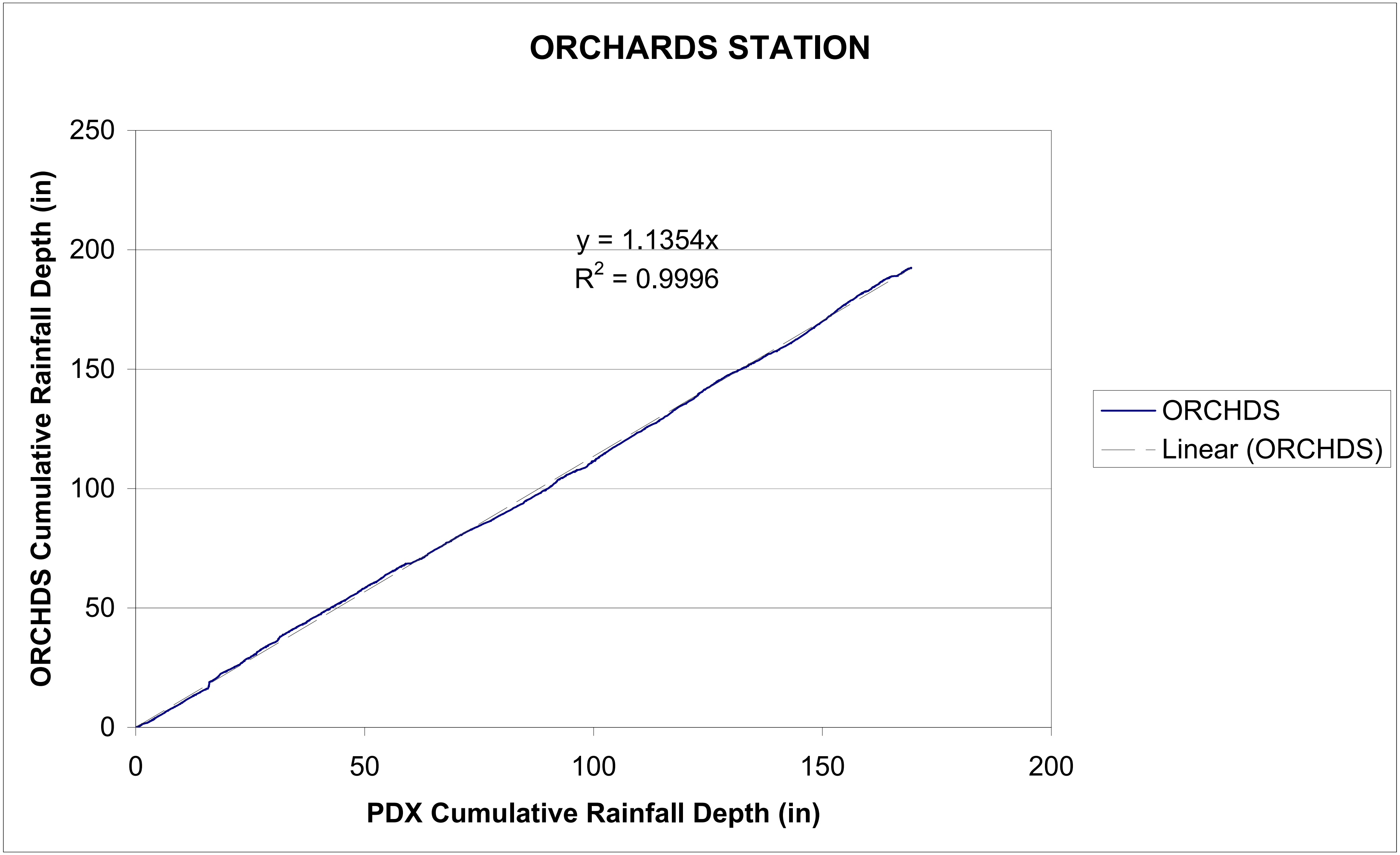

LACAMAS HERITAGE TRAIL STATION
y = 1.2696x
R2 = 0.9987
LACHRT Cumulative Rainfall Depth (in)
PDX Cumulative Rainfall Depth (in)
0
5
10
15
20
25
30
35
40
LACHRT
Linear (LACHRT)

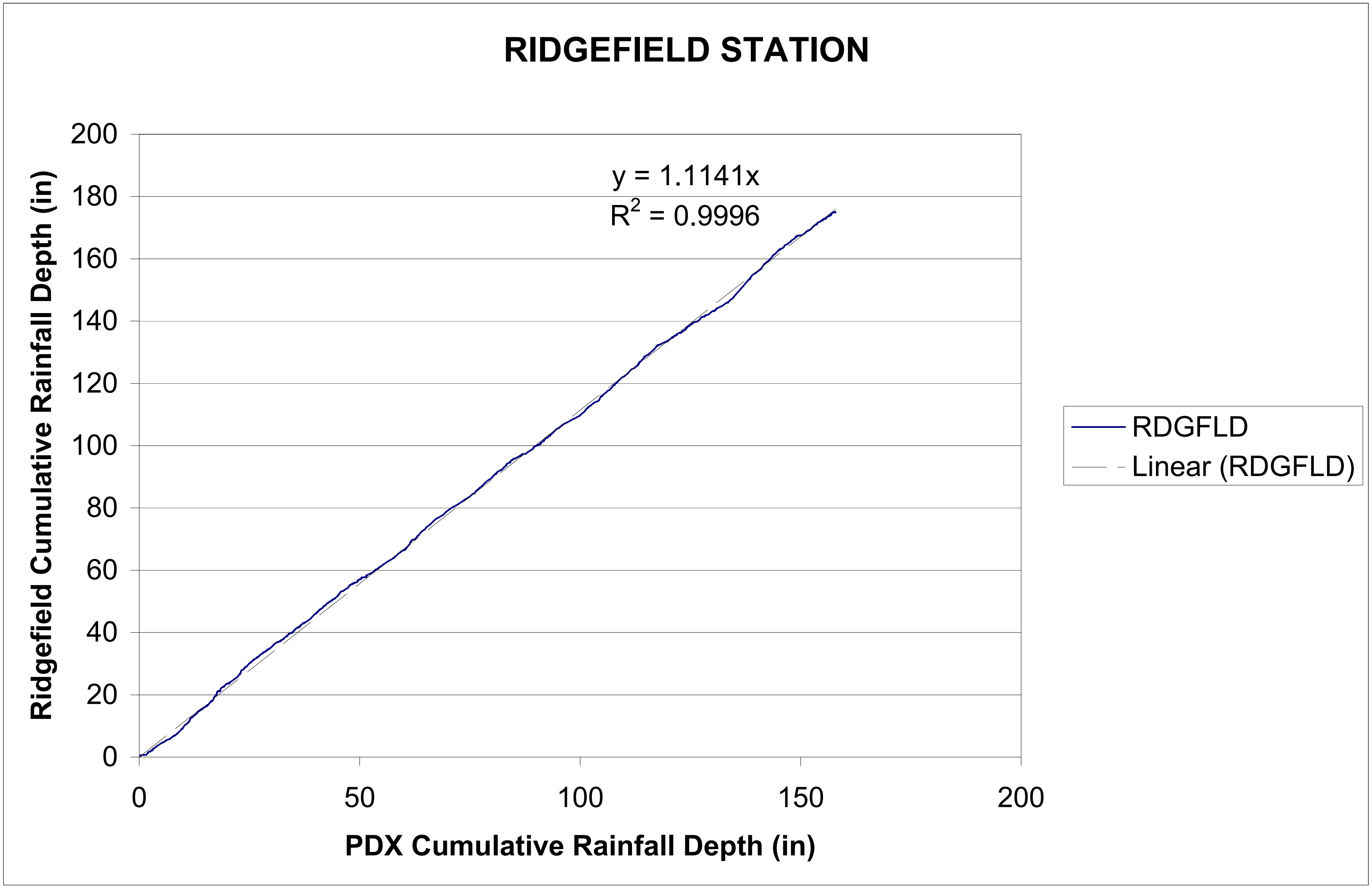


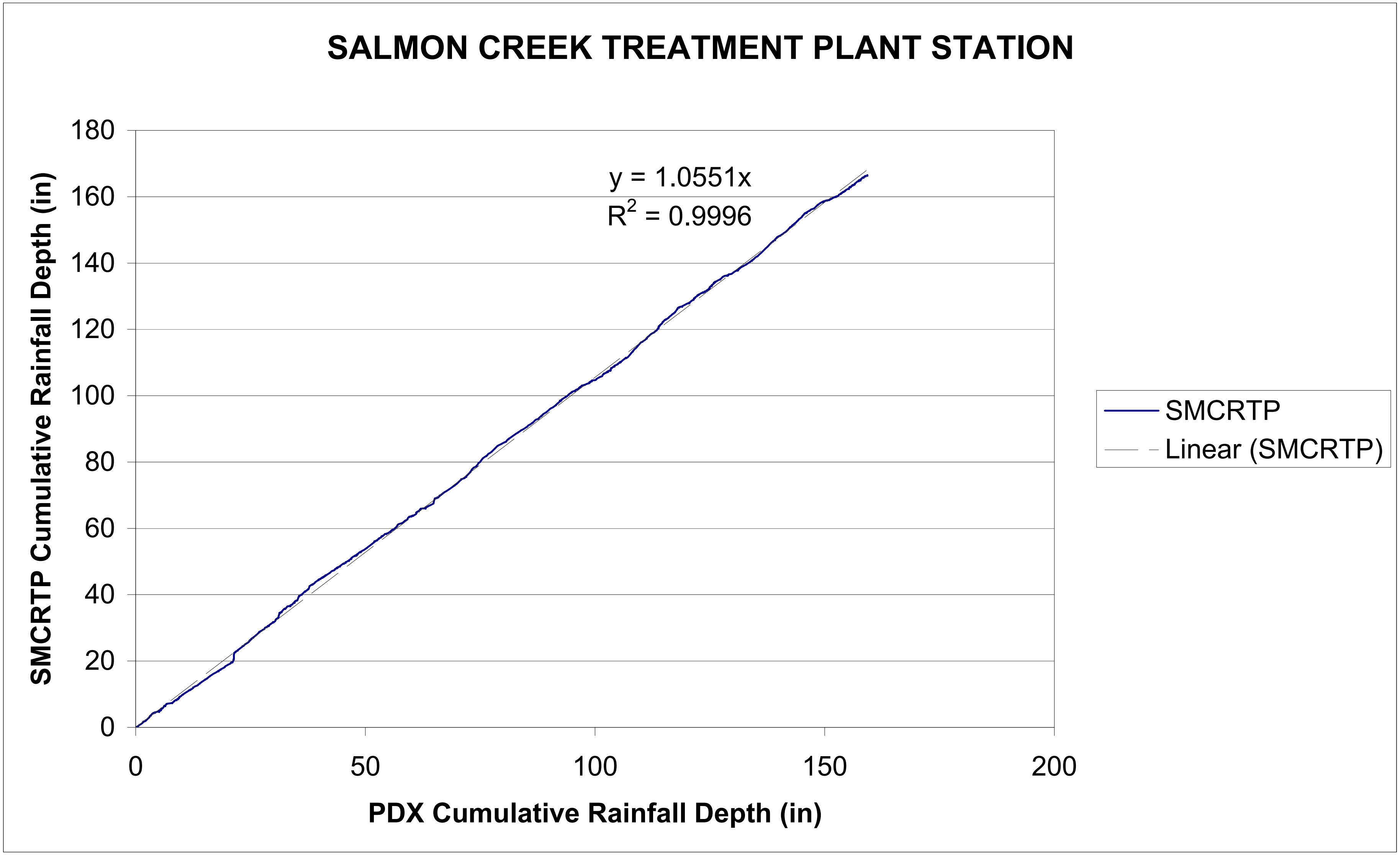
Merwin Dam
Merwin Dam Cumulative Rainfall (in.)
PDX Cumulative Rainfall (in.)
3000
2500
2000
1500
1000
500
0
0
200
400
600
800
1000
1200
1400
y = 2.0183x
R^2 = 0.9984
compare
Linear (compare)

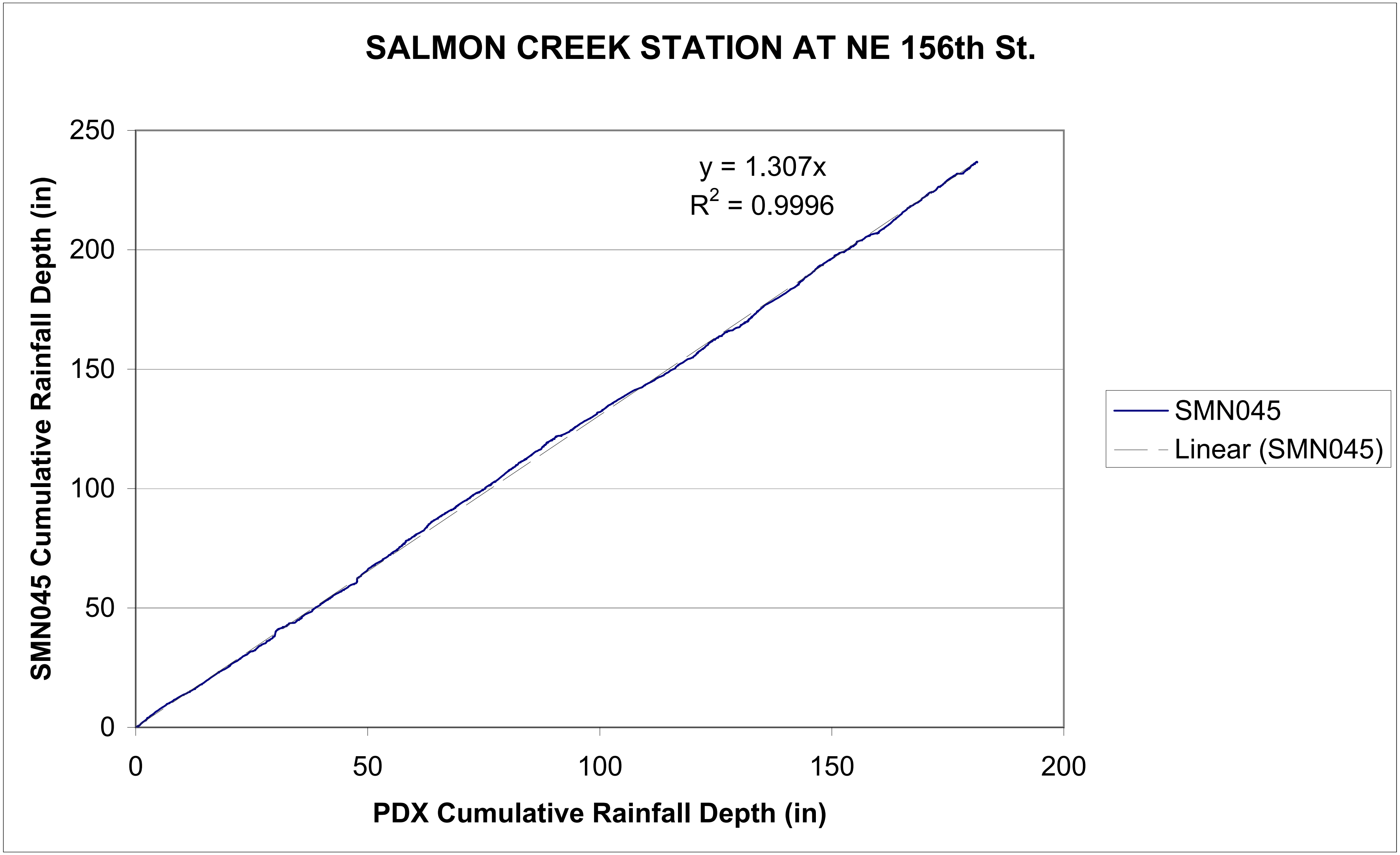


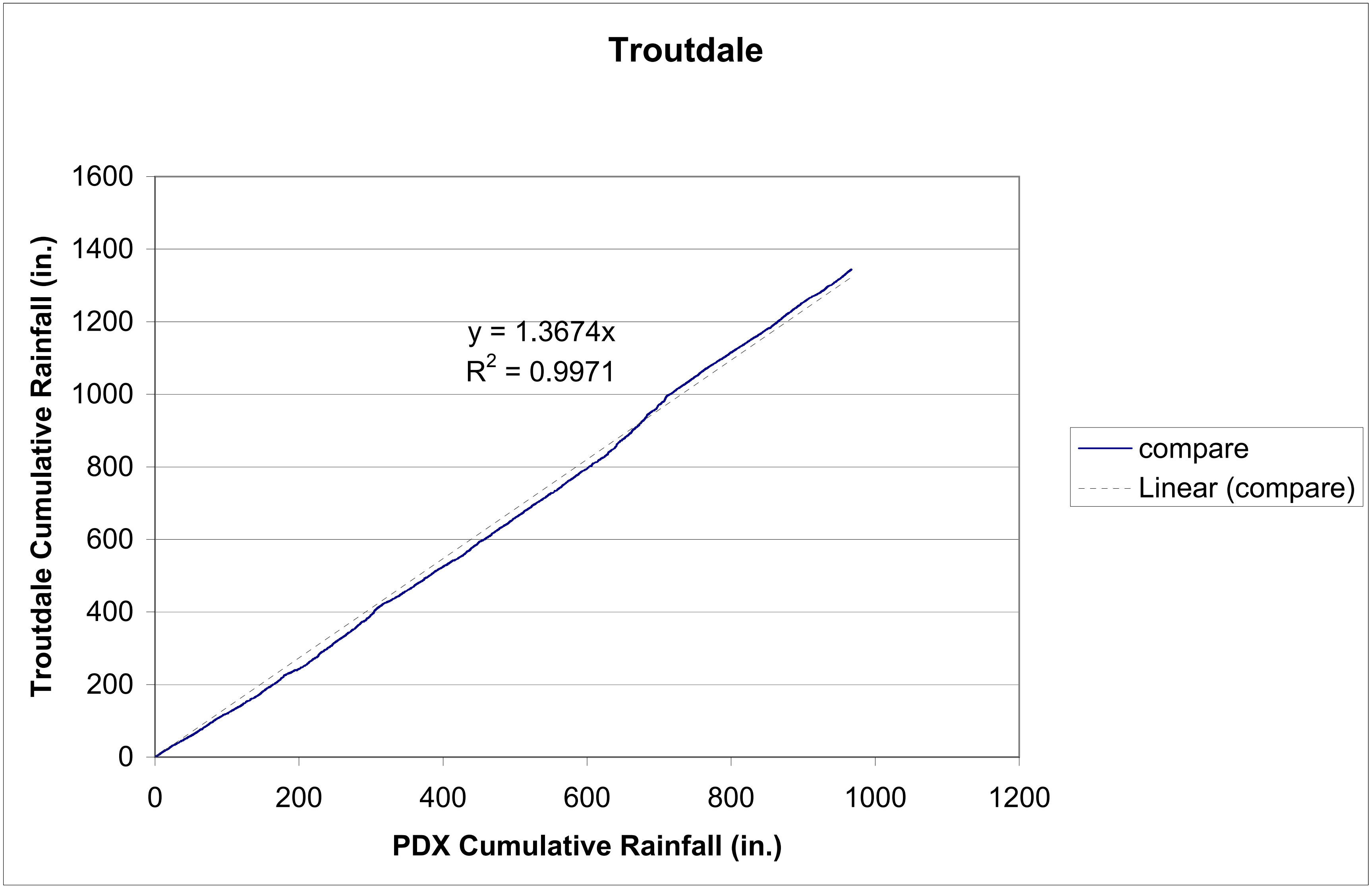
Portland NWSFO
y = 1.1813x
R^2 = 0.9989
Portland NWSFO Cumulative Rainfall (in.)
PDX Cumulative Rainfall (in.)
0
100
200
300
400
500
600
compare
Linear (compare)

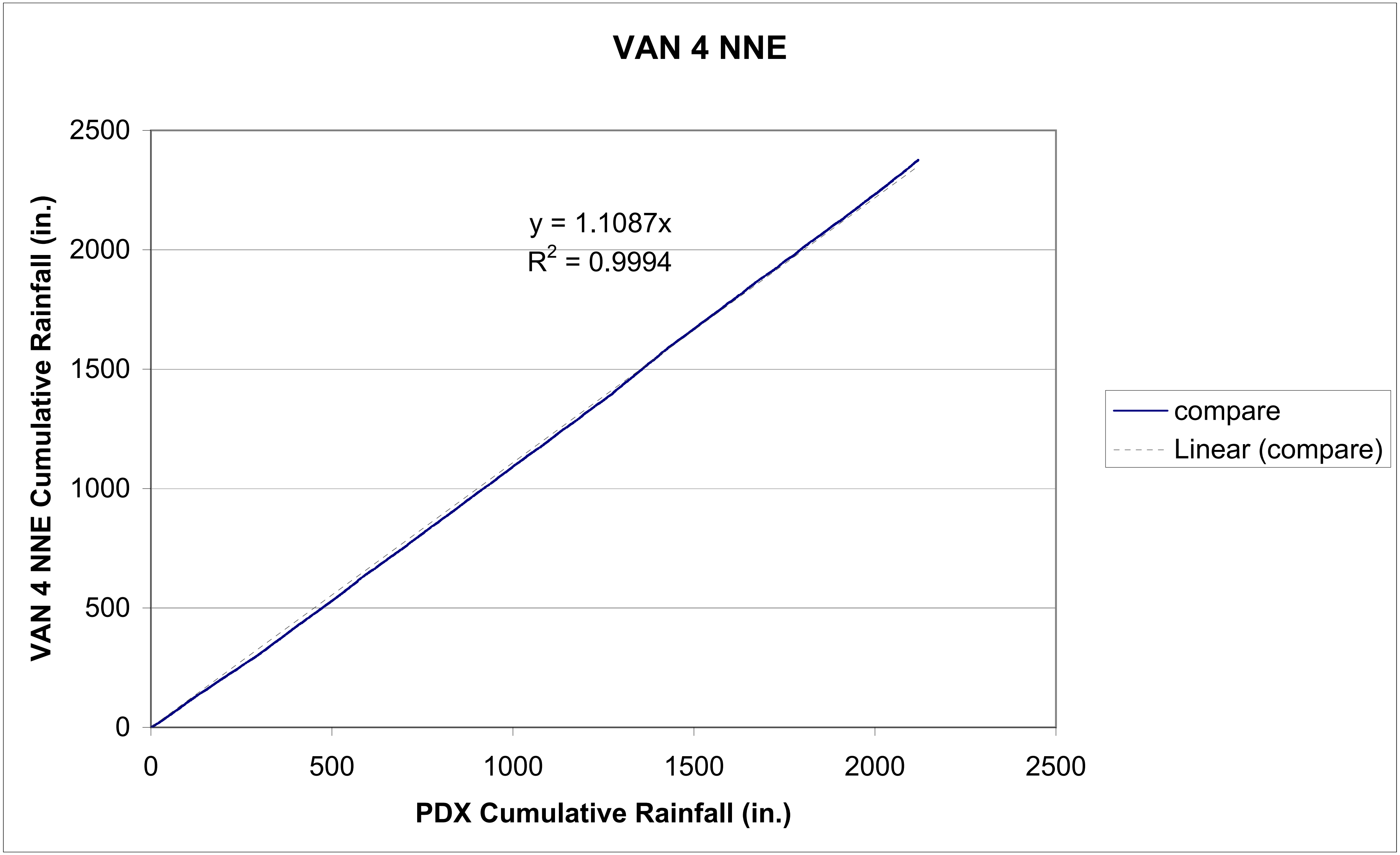

ORCHARDS STATION
y = 1.1354x
$R^2 = 0.9996$
250
200
150
100
50
0
0
50
100
150
200
ORCHDS Cumulative Rainfall Depth (in)
PDX Cumulative Rainfall Depth (in)
ORCHDS
Linear (ORCHDS)

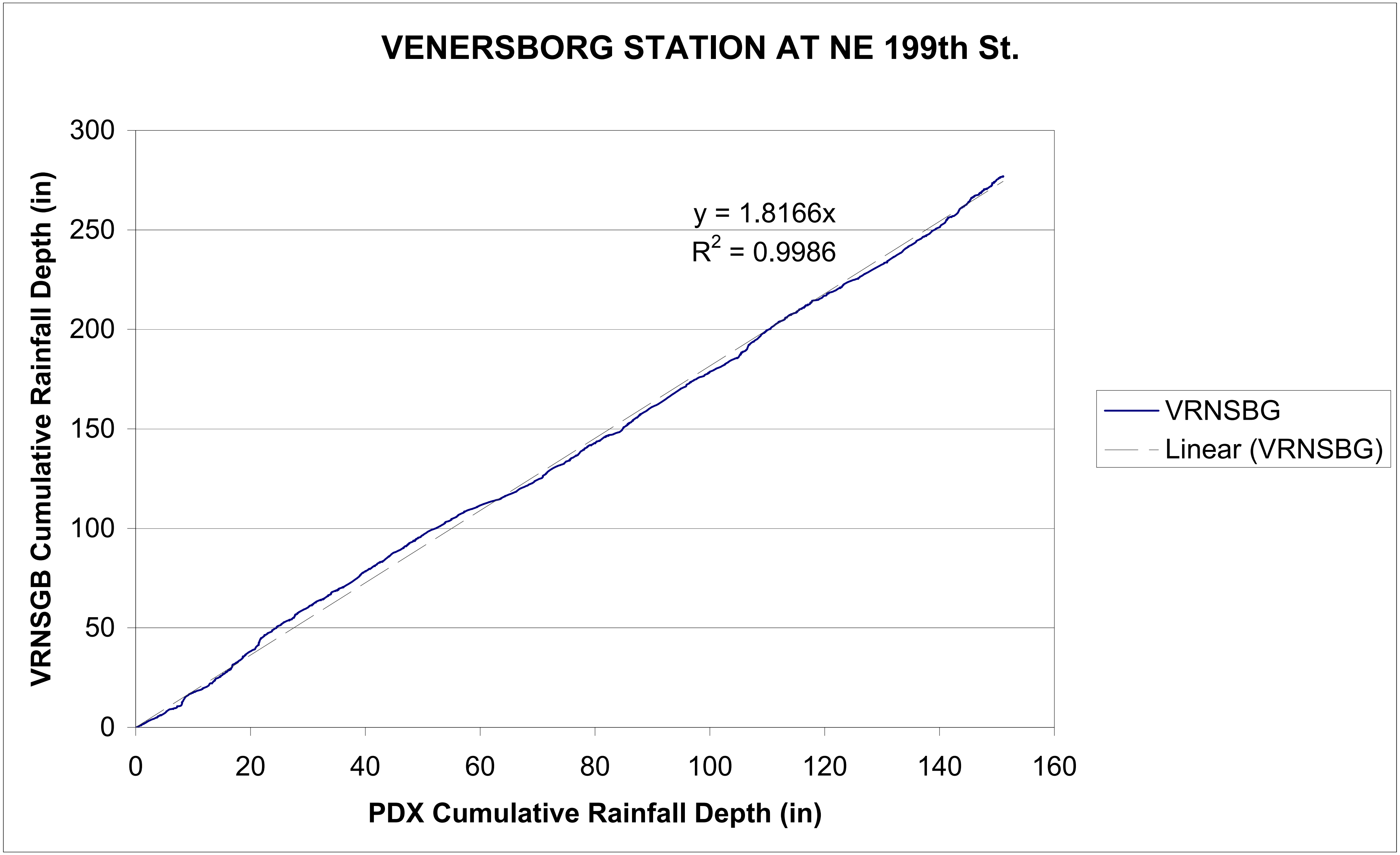

RIDGEFIELD STATION
y = 1.1141x
R2 = 0.9996
Ridgefield Cumulative Rainfall Depth (in)
PDX Cumulative Rainfall Depth (in)
0
20
40
60
80
100
120
140
160
180
200
0
50
100
150
200
RDGFLD
Linear (RDGFLD)


SALMON CREEK TREATMENT PLANT STATION
y = 1.0551x
R2 = 0.9996
SMCRTP Cumulative Rainfall Depth (in)
PDX Cumulative Rainfall Depth (in)
0
20
40
60
80
100
120
140
160
180
0
50
100
150
200
SMCRTP
Linear (SMCRTP)

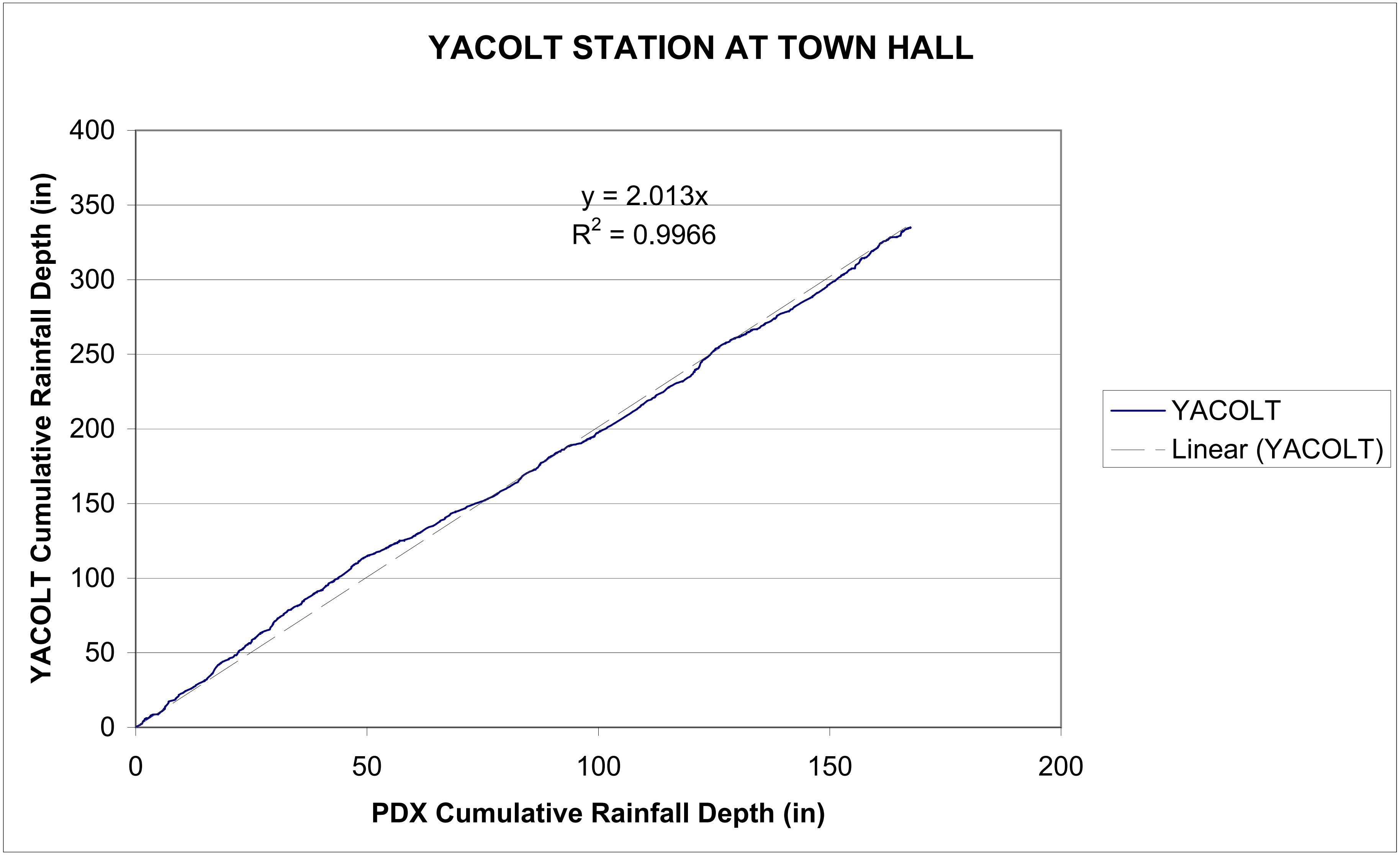

SALMON CREEK STATION AT NE 156th St.
y = 1.307x
R2 = 0.9996
250
200
150
100
50
0
0
50
100
150
200
SMN045 Cumulative Rainfall Depth (in)
PDX Cumulative Rainfall Depth (in)
SMN045
Linear (SMN045)


Troutdale
y = 1.3674x
R^2 = 0.9971
Troutdale Cumulative Rainfall (in.)
PDX Cumulative Rainfall (in.)
compare
Linear (compare)
0
200
400
600
800
1000
1200
1400
1600
0
200
400
600
800
1000
1200


VAN 4 NNE
y = 1.1087x
R2 = 0.9994
VAN 4 NNE Cumulative Rainfall (in.)
PDX Cumulative Rainfall (in.)
0
500
1000
1500
2000
2500
compare
Linear (compare)

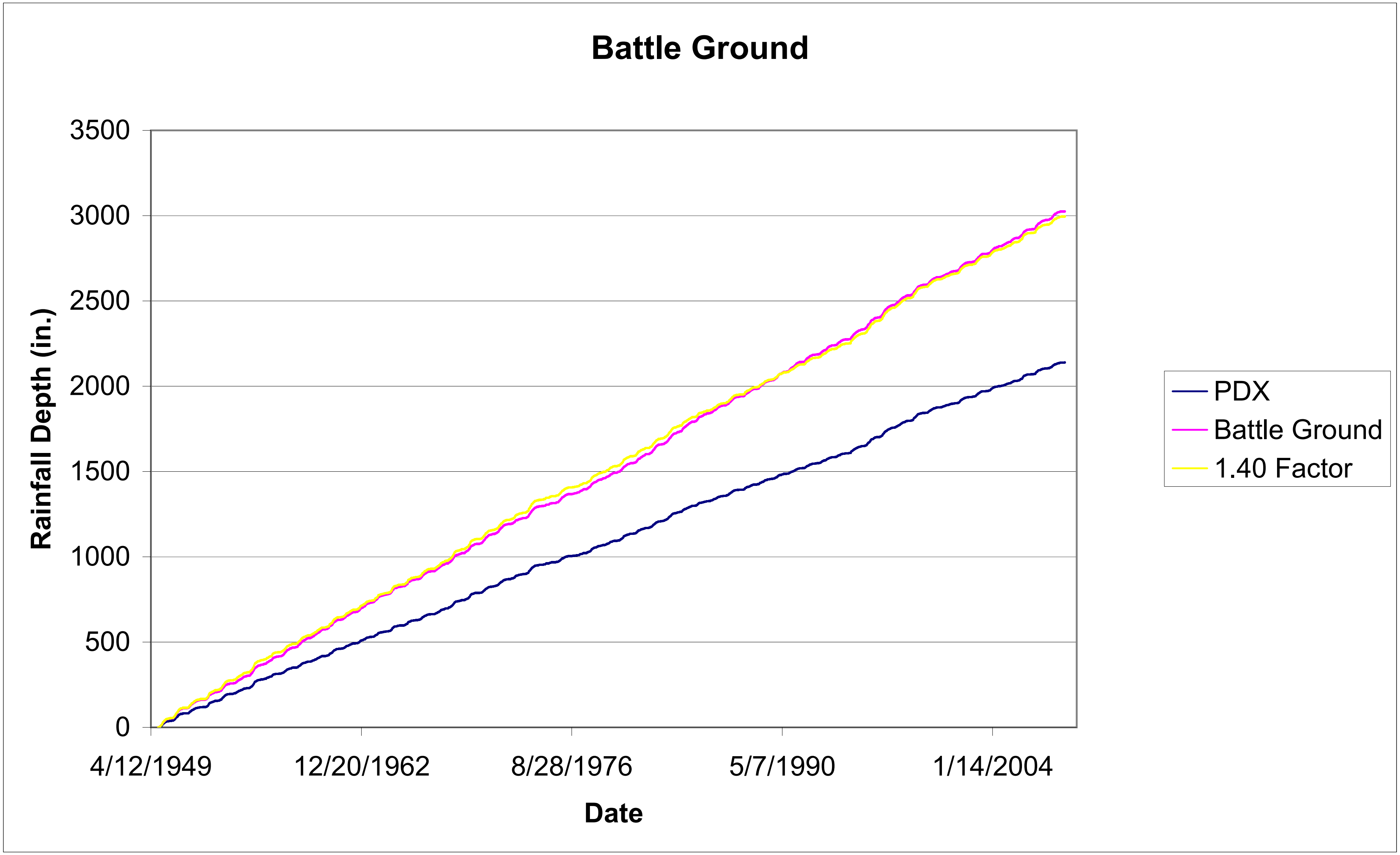


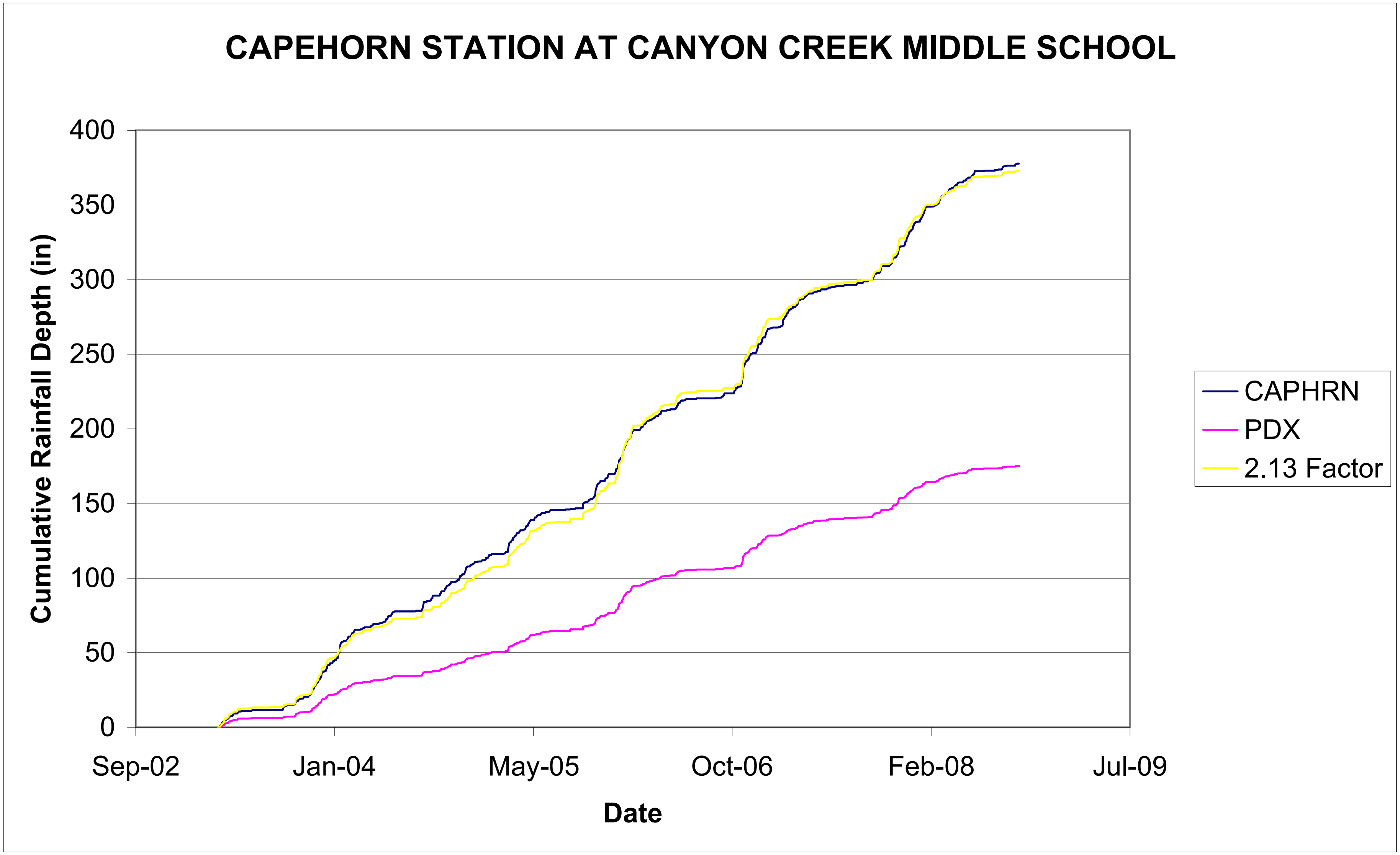
VENERSBORG STATION AT NE 199th St.
y = 1.8166x
R2 = 0.9986
VRNSGB Cumulative Rainfall Depth (in)
PDX Cumulative Rainfall Depth (in)
VRNSBG
Linear (VRNSBG)
0
50
100
150
200
250
300
0
20
40
60
80
100
120
140
160

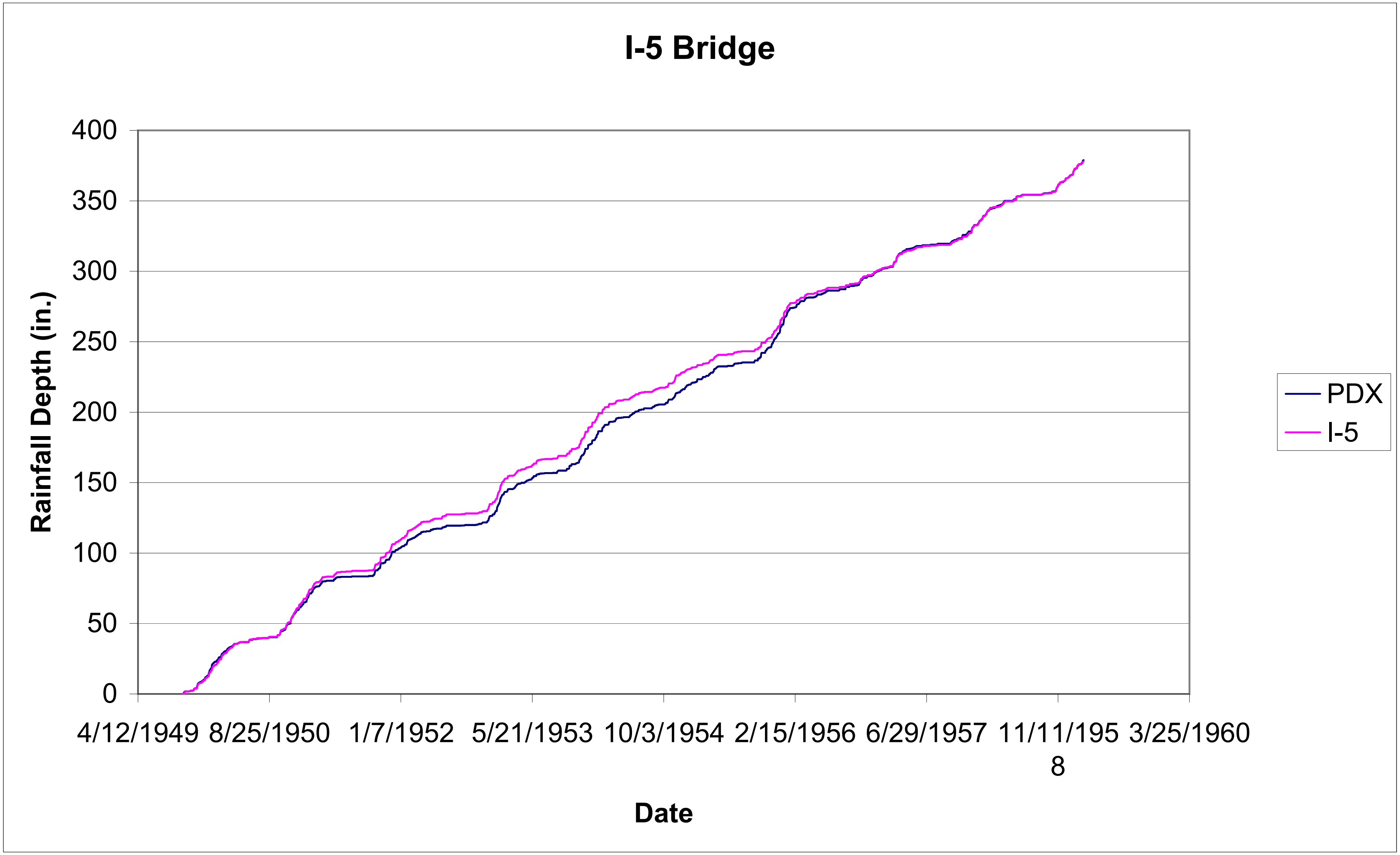

YACOLT STATION AT TOWN HALL
y = 2.013x
R^2 = 0.9966
YACOLT Cumulative Rainfall Depth (in)
PDX Cumulative Rainfall Depth (in)
YACOLT
Linear (YACOLT)
0
50
100
150
200
250
300
350
400
0
50
100
150
200

Appendix D — Cumulative Precipitation Plots

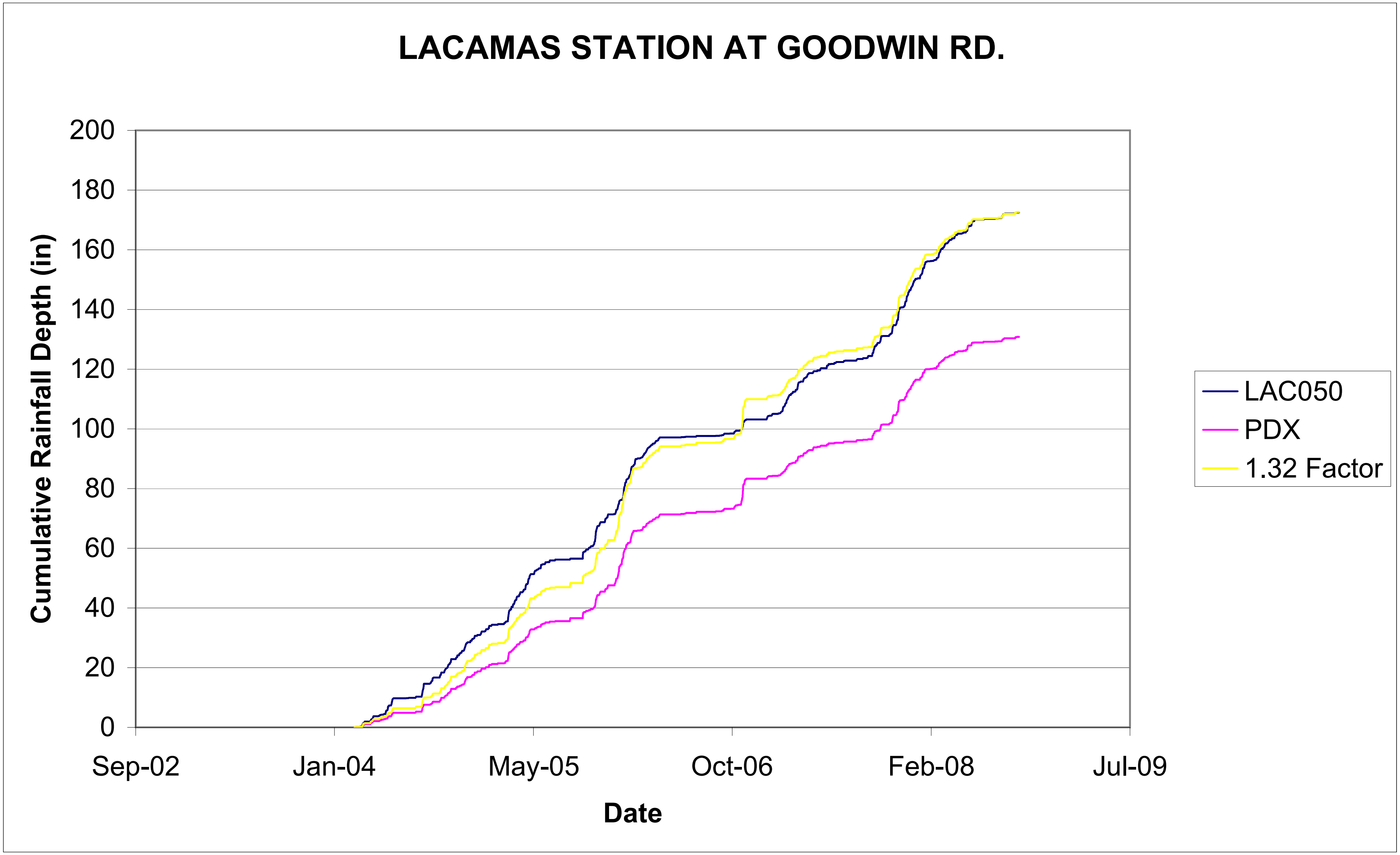
This page left blank to accommodate double-sided printing


Battle Ground
Rainfall Depth (in.)
3500
3000
2500
2000
1500
1000
500
0
4/12/1949
12/20/1962
8/28/1976
5/7/1990
1/14/2004
Date
PDX
Battle Ground
1.40 Factor

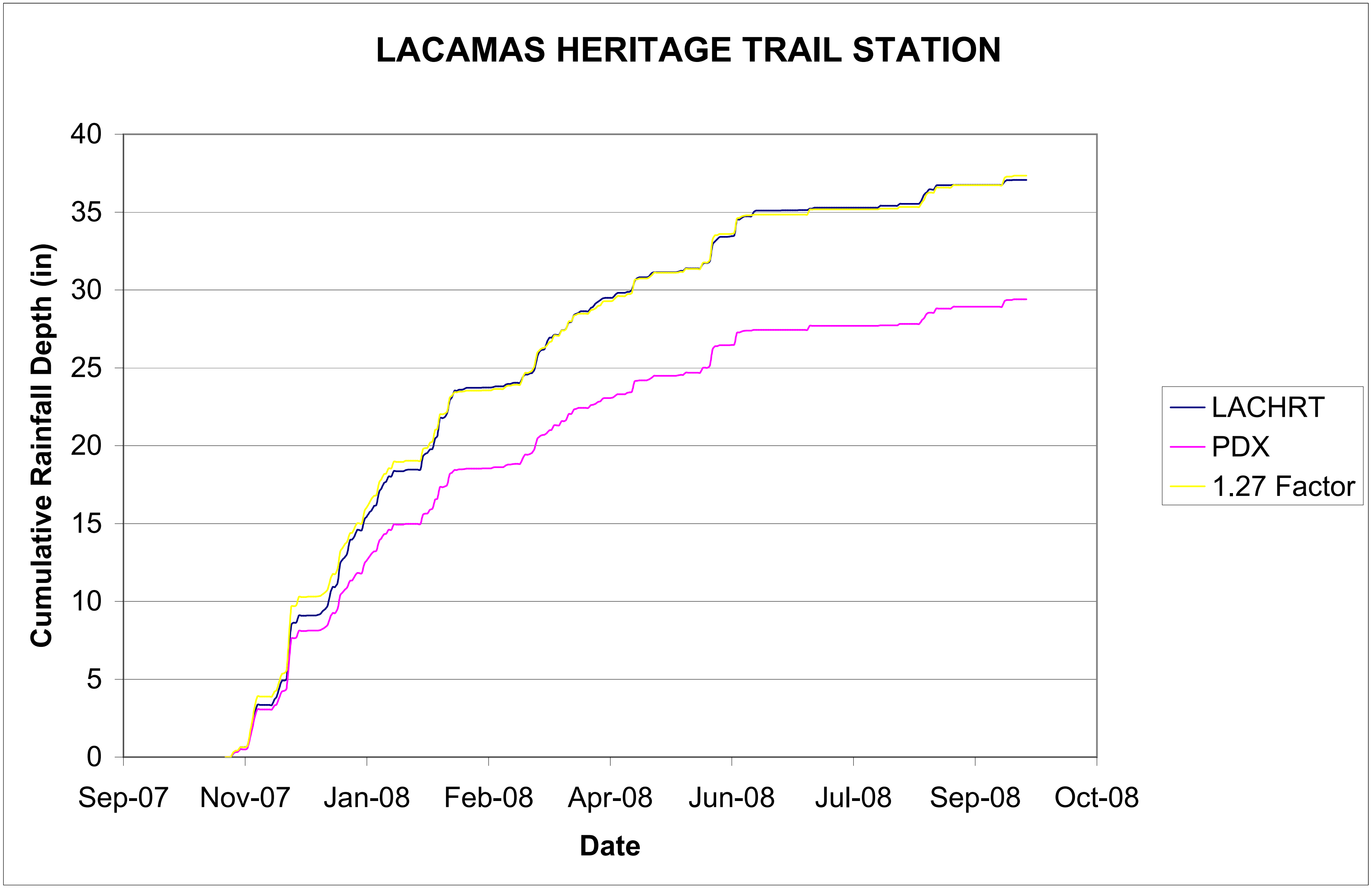

CAPEHORN STATION AT CANYON CREEK MIDDLE SCHOOL
Cumulative Rainfall Depth (in)
400
350
300
250
200
150
100
50
0
Sep-02
Jan-04
May-05
Oct-06
Feb-08
Jul-09
Date
CAPHRN
PDX
2.13 Factor



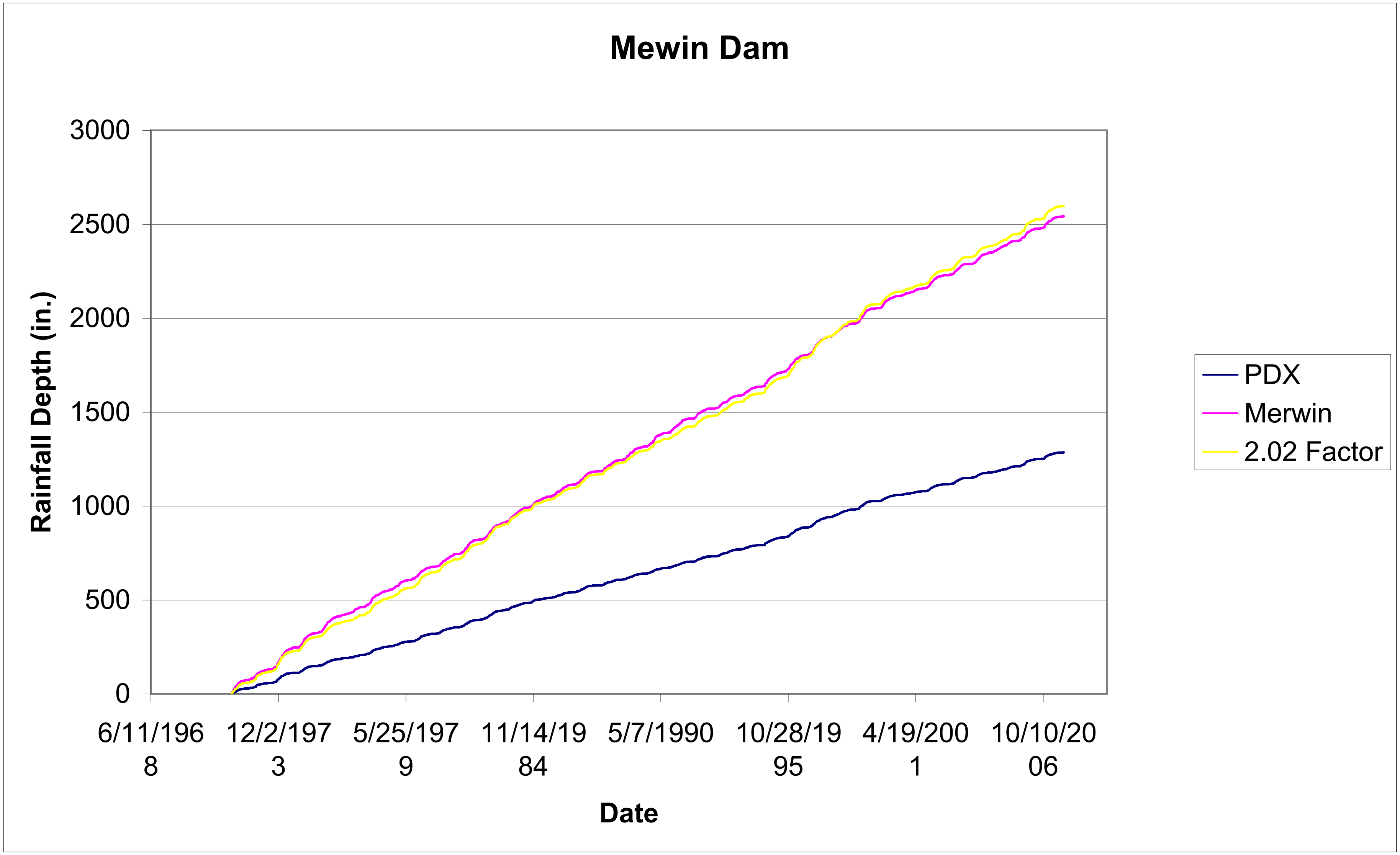
I-5 Bridge
400
350
300
250
200
150
100
50
0
Rainfall Depth (in.)
4/12/1949
8/25/1950
1/7/1952
5/21/1953
10/3/1954
2/15/1956
6/29/1957
11/11/1958
3/25/1960
Date
PDX
I-5

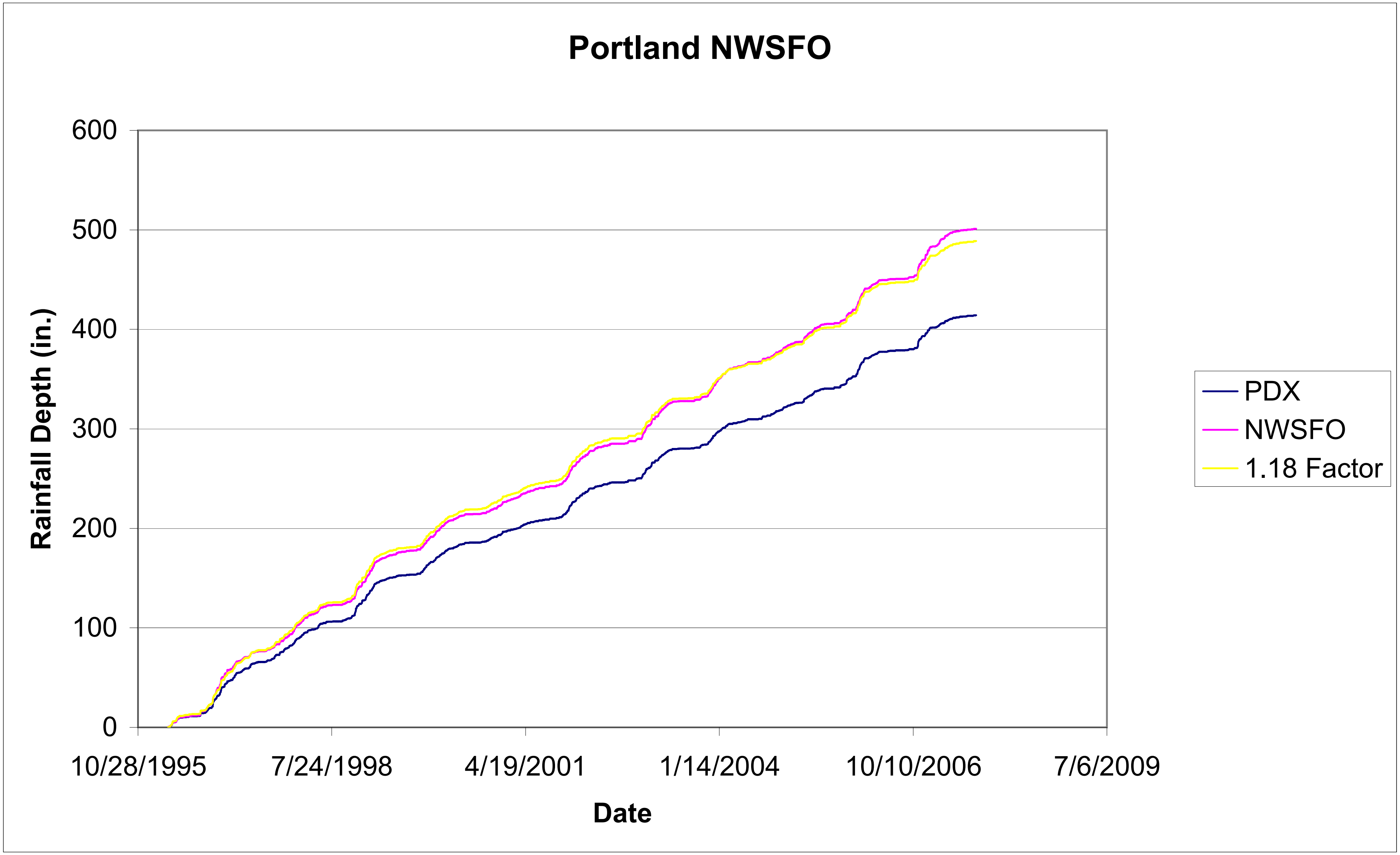


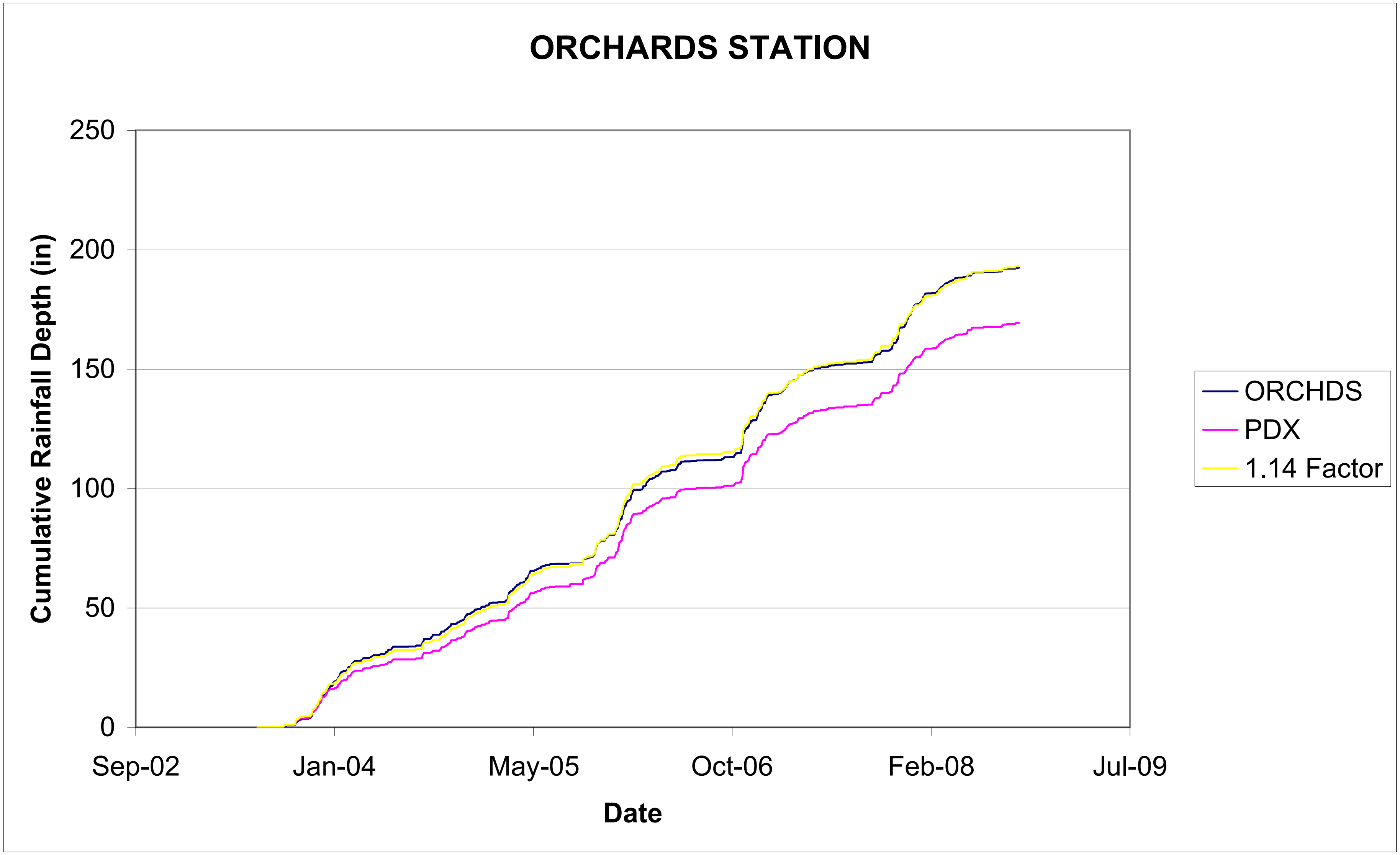
LACAMAS STATION AT GOODWIN RD.
Cumulative Rainfall Depth (in)
200
180
160
140
120
100
80
60
40
20
0
Sep-02
Jan-04
May-05
Oct-06
Feb-08
Jul-09
Date
LAC050
PDX
1.32 Factor

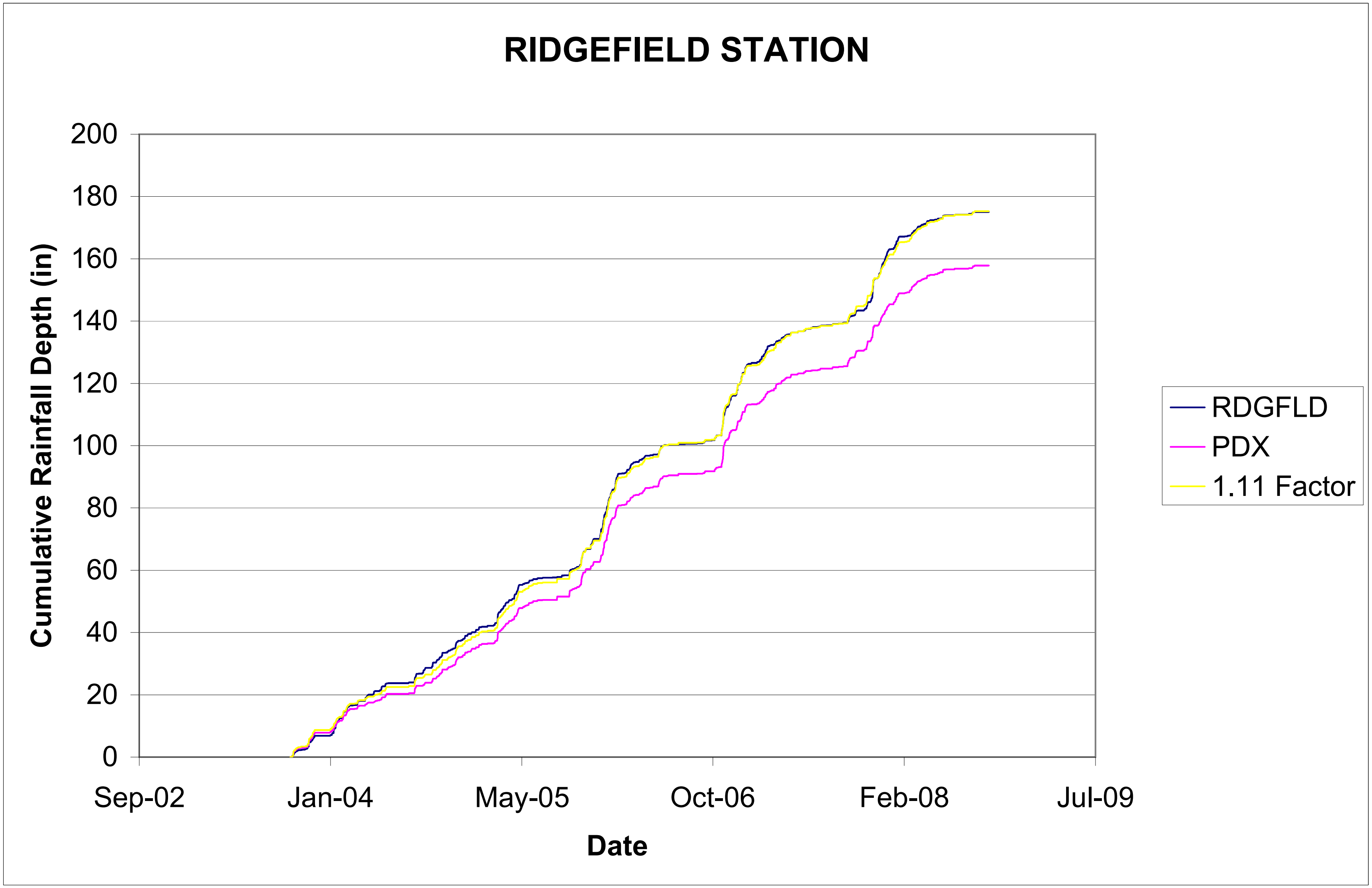


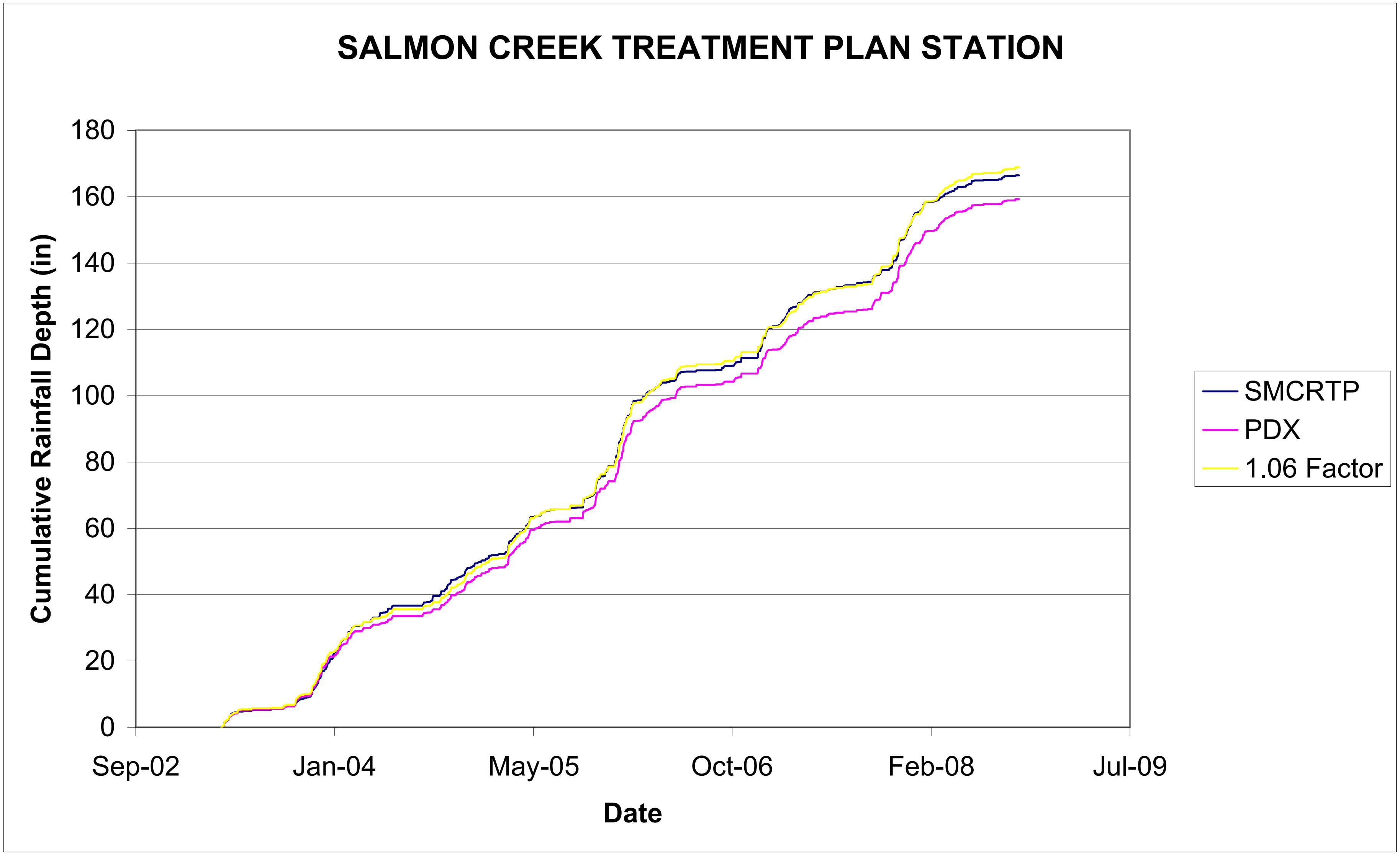
LACAMAS HERITAGE TRAIL STATION
Cumulative Rainfall Depth (in)
40
35
30
25
20
15
10
5
0
Sep-07
Nov-07
Jan-08
Feb-08
Apr-08
Jun-08
Jul-08
Sep-08
Oct-08
Date
LACHRT
PDX
1.27 Factor


Mewin Dam
3000
2500
2000
1500
1000
500
0
Rainfall Depth (in.)
6/11/1968
12/2/1973
5/25/1979
11/14/1984
5/7/1990
10/28/1995
4/19/2001
10/10/2006
Date
PDX
Merwin
2.02 Factor

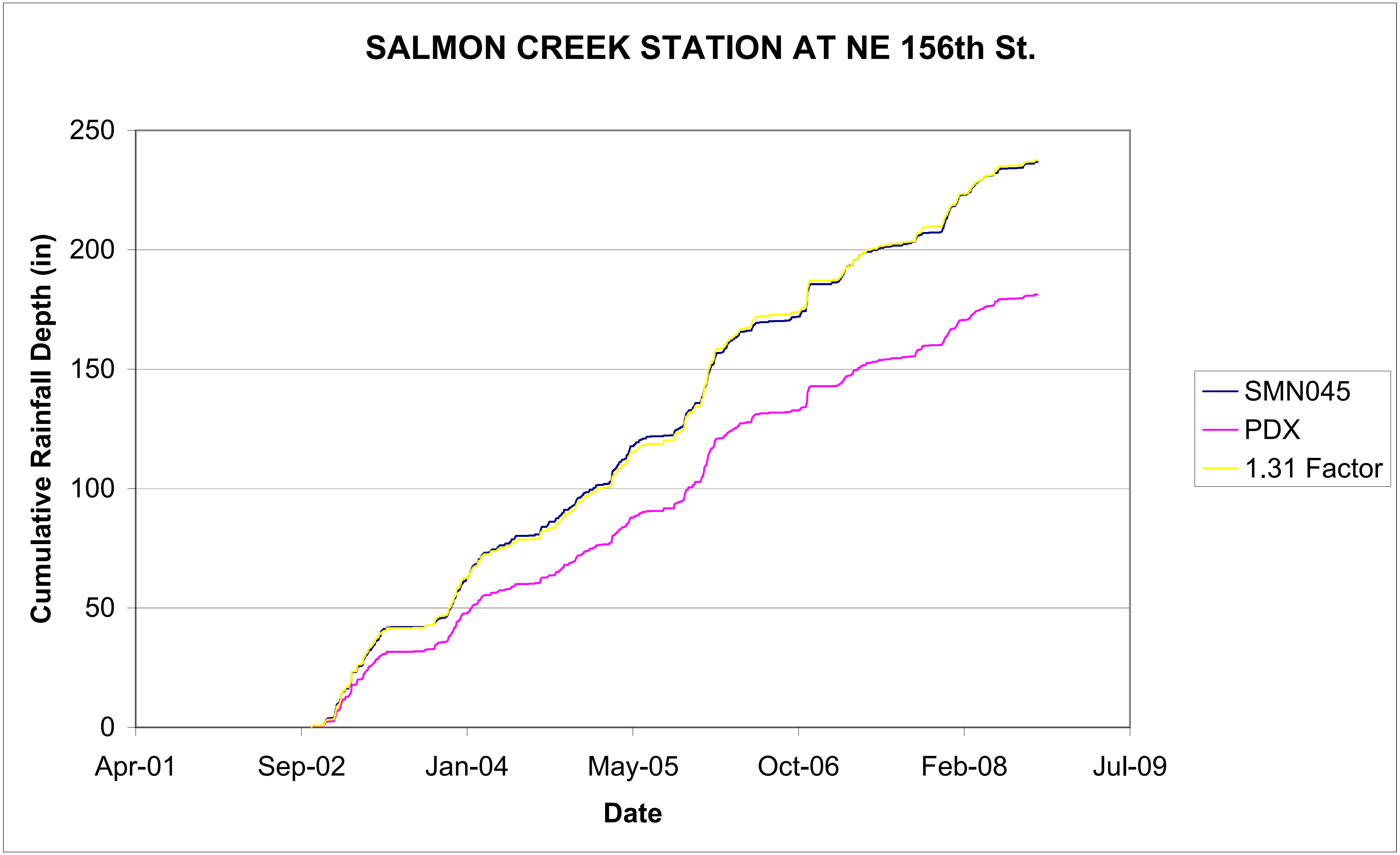

Portland NWSFO
600
500
400
300
200
100
0
Rainfall Depth (in.)
10/28/1995
7/24/1998
4/19/2001
1/14/2004
10/10/2006
7/6/2009
Date
PDX
NWSFO
1.18 Factor

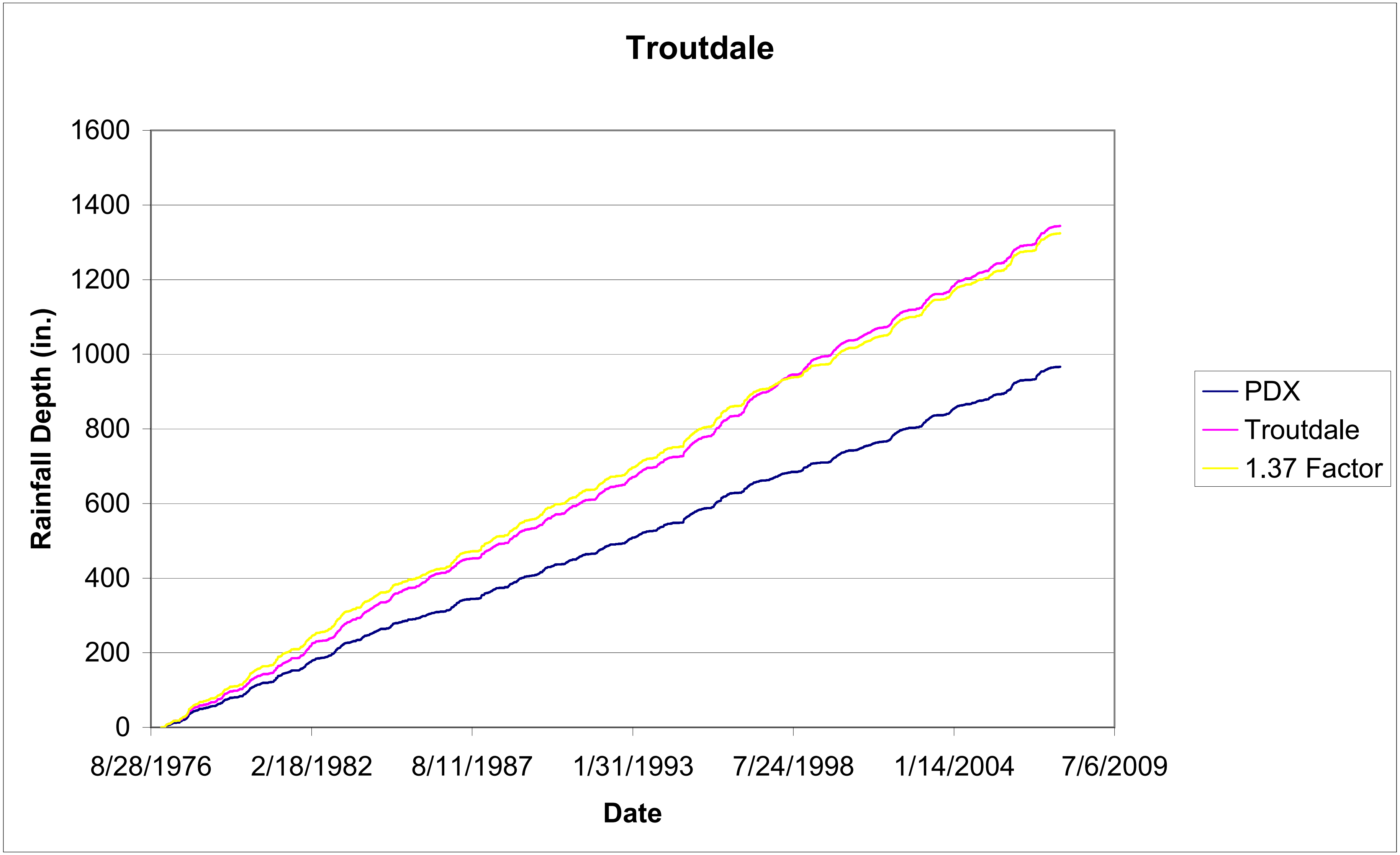

ORCHARDS STATION
Cumulative Rainfall Depth (in)
250
200
150
100
50
0
Sep-02
Jan-04
May-05
Oct-06
Feb-08
Jul-09
Date
ORCHDS
PDX
1.14 Factor

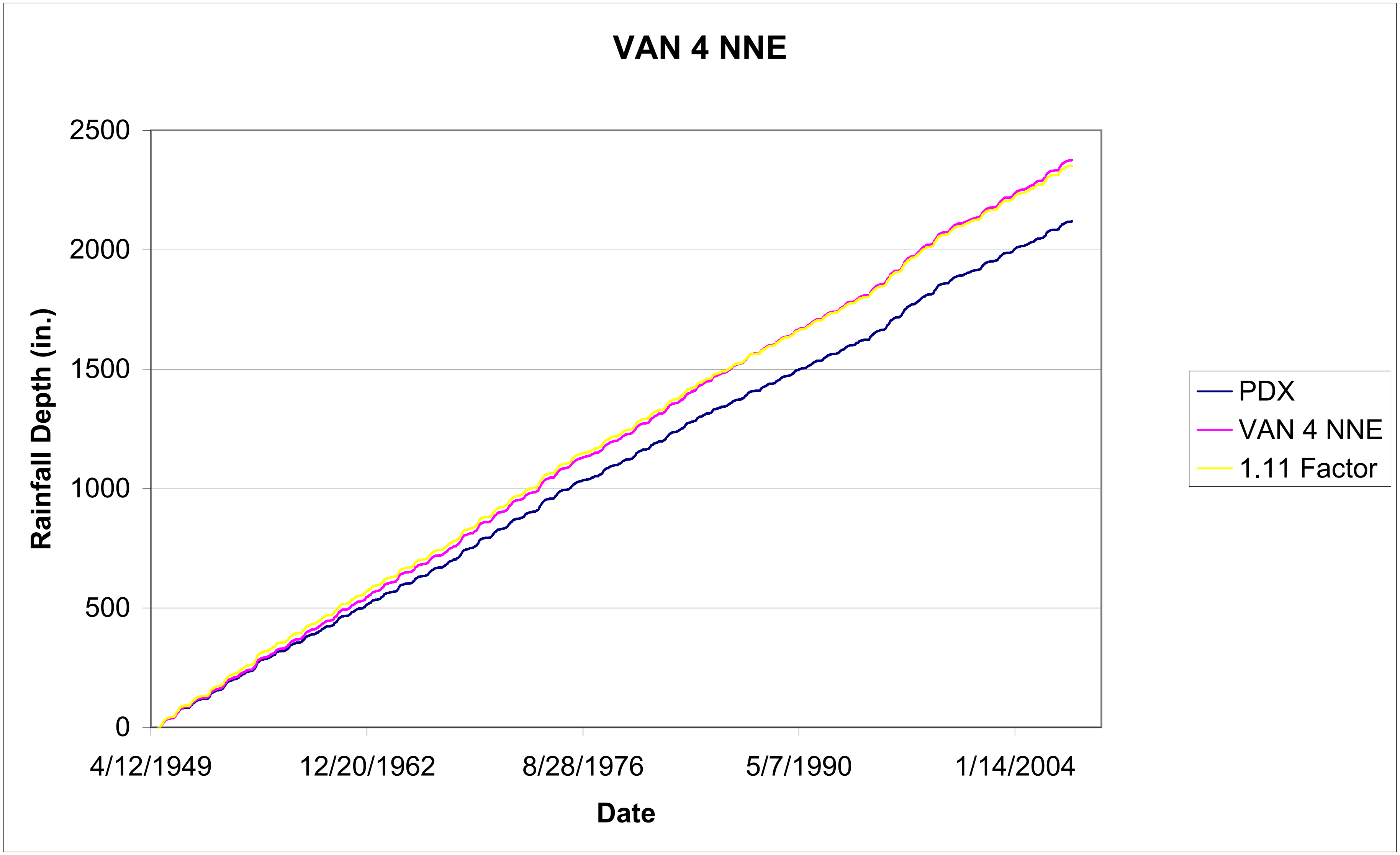

RIDGEFIELD STATION
Cumulative Rainfall Depth (in)
200
180
160
140
120
100
80
60
40
20
0
Sep-02
Jan-04
May-05
Oct-06
Feb-08
Jul-09
Date
RDGFLD
PDX
1.11 Factor



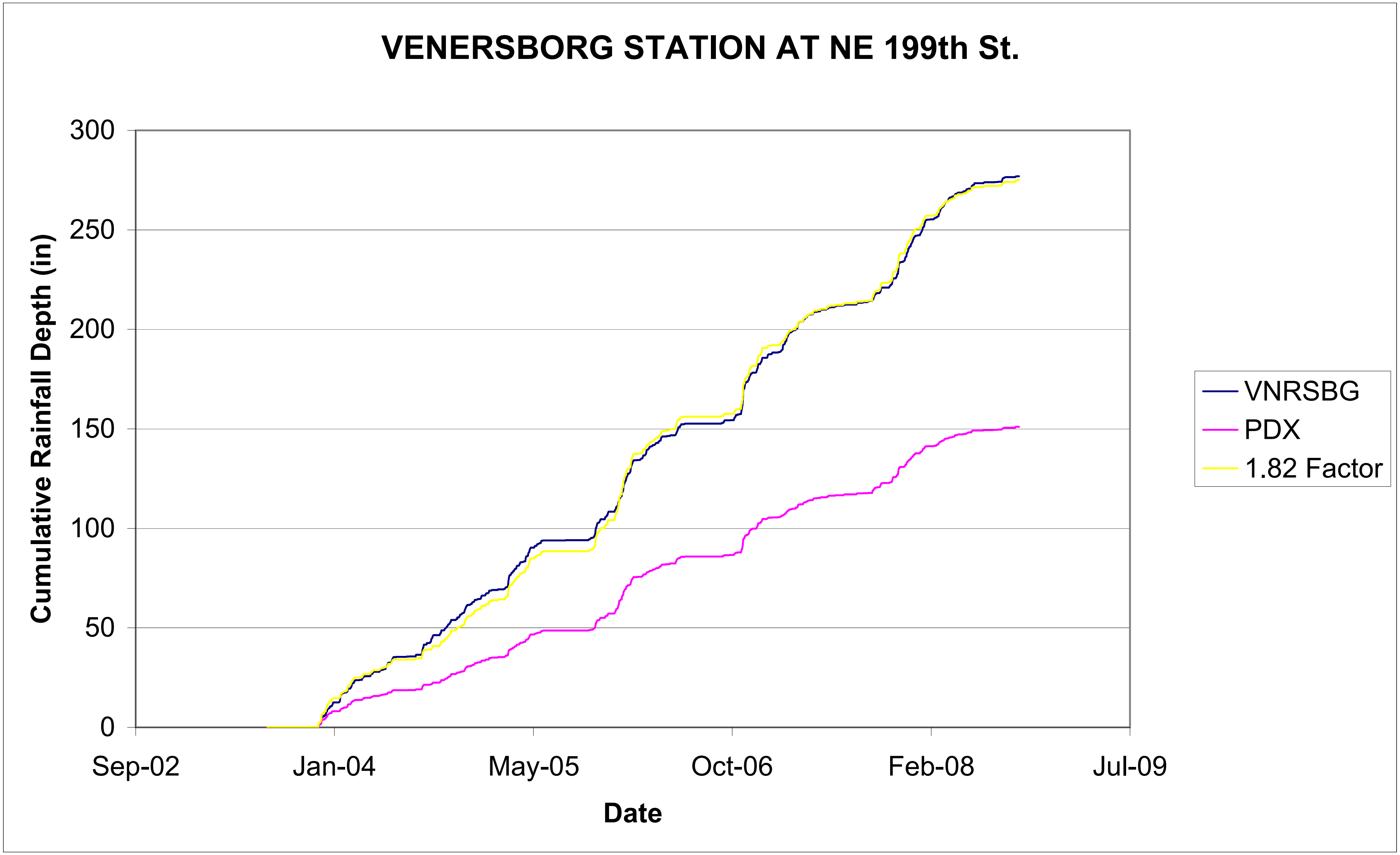
SALMON CREEK TREATMENT PLAN STATION
Cumulative Rainfall Depth (in)
0
20
40
60
80
100
120
140
160
180
Sep-02
Jan-04
May-05
Oct-06
Feb-08
Jul-09
Date
SMCRTP
PDX
1.06 Factor

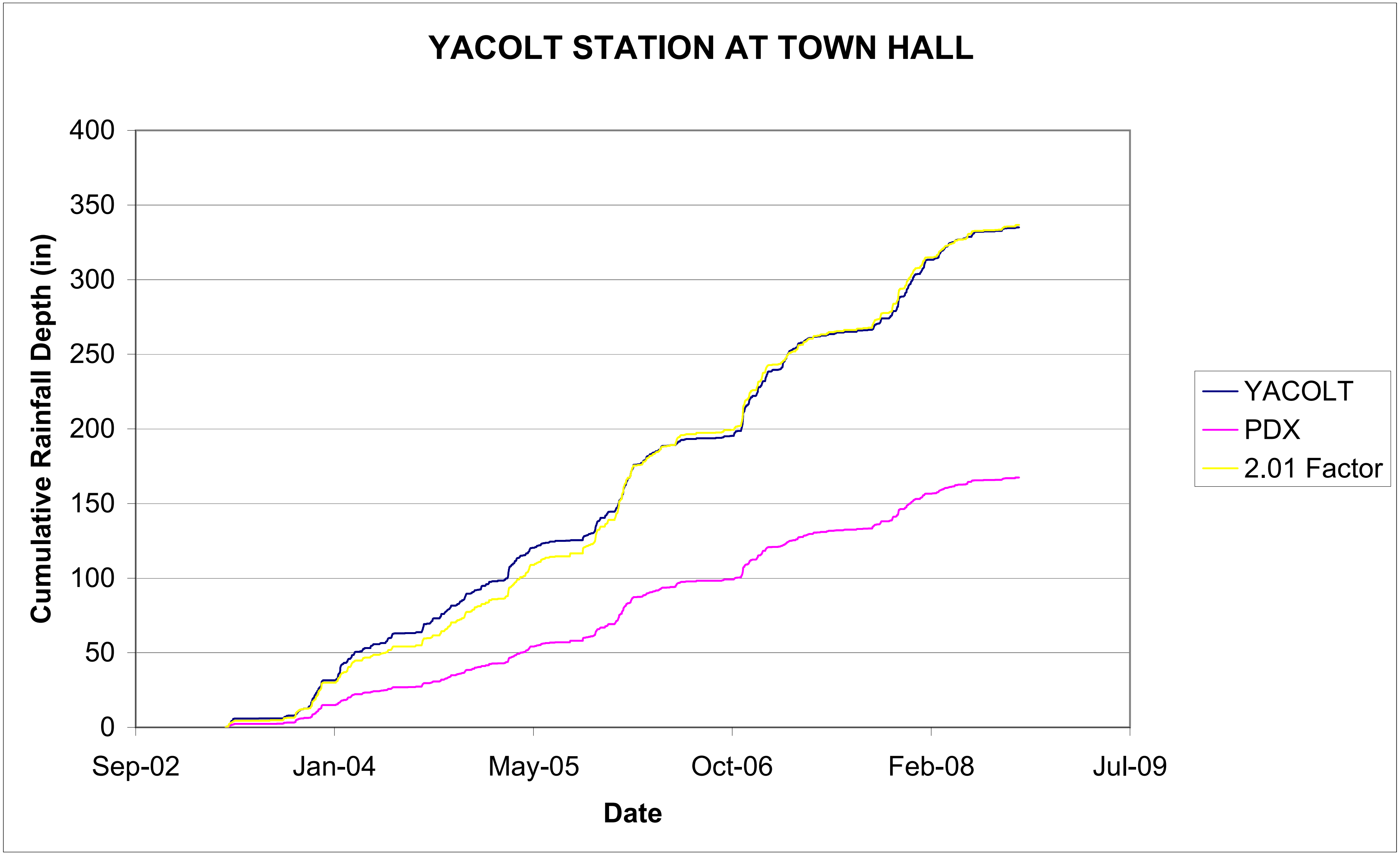

SALMON CREEK STATION AT NE 156th St.
Cumulative Rainfall Depth (in)
250
200
150
100
50
0
Apr-01
Sep-02
Jan-04
May-05
Oct-06
Feb-08
Jul-09
Date
SMN045
PDX
1.31 Factor


Troutdale
1600
1400
1200
1000
800
600
400
200
0
Rainfall Depth (in.)
8/28/1976
2/18/1982
8/11/1987
1/31/1993
7/24/1998
1/14/2004
7/6/2009
Date
PDX
Troutdale
1.37 Factor



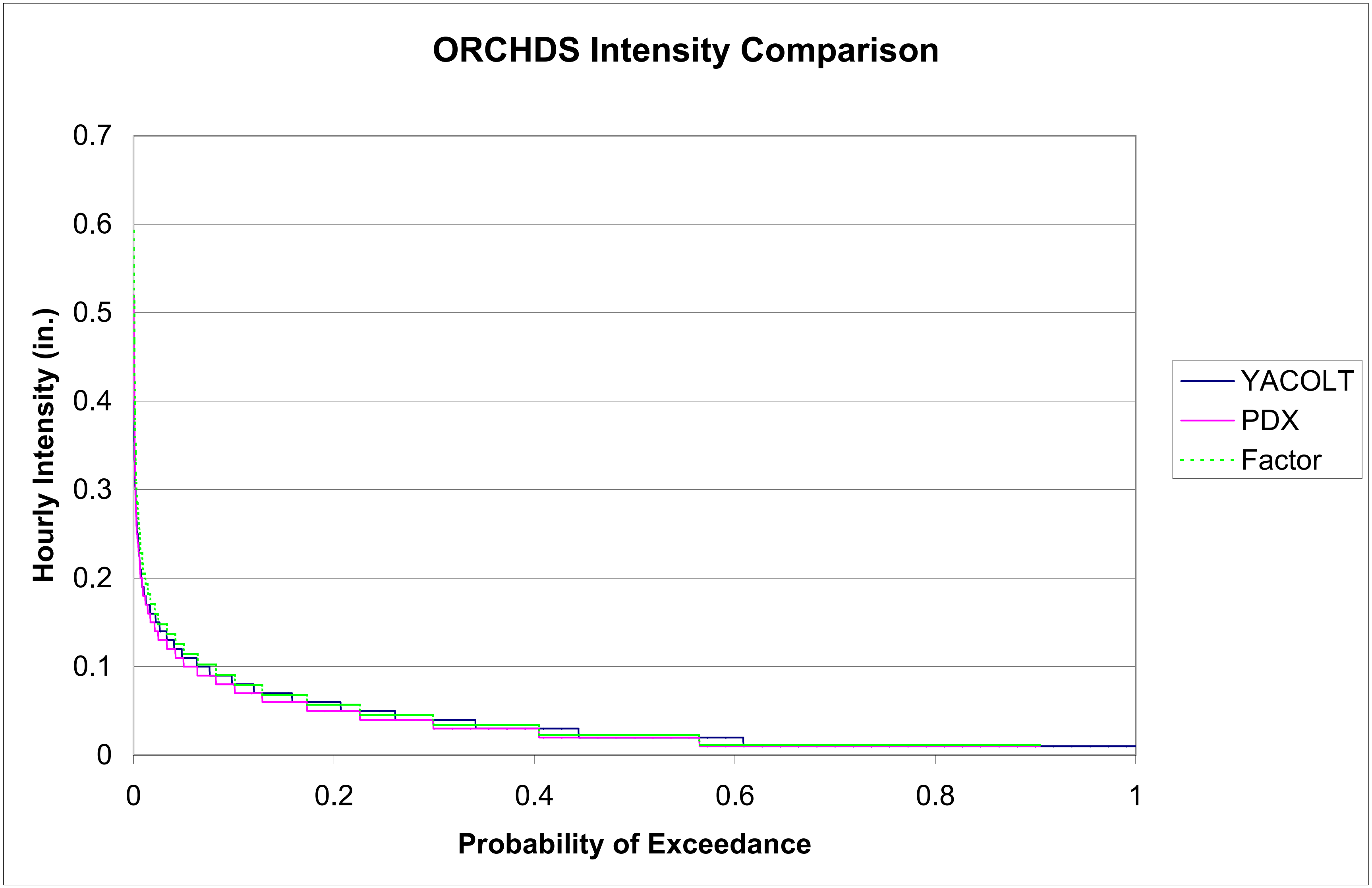
VAN 4 NNE
2500
2000
1500
1000
500
0
Rainfall Depth (in.)
4/12/1949
12/20/1962
8/28/1976
5/7/1990
1/14/2004
Date
PDX
VAN 4 NNE
1.11 Factor

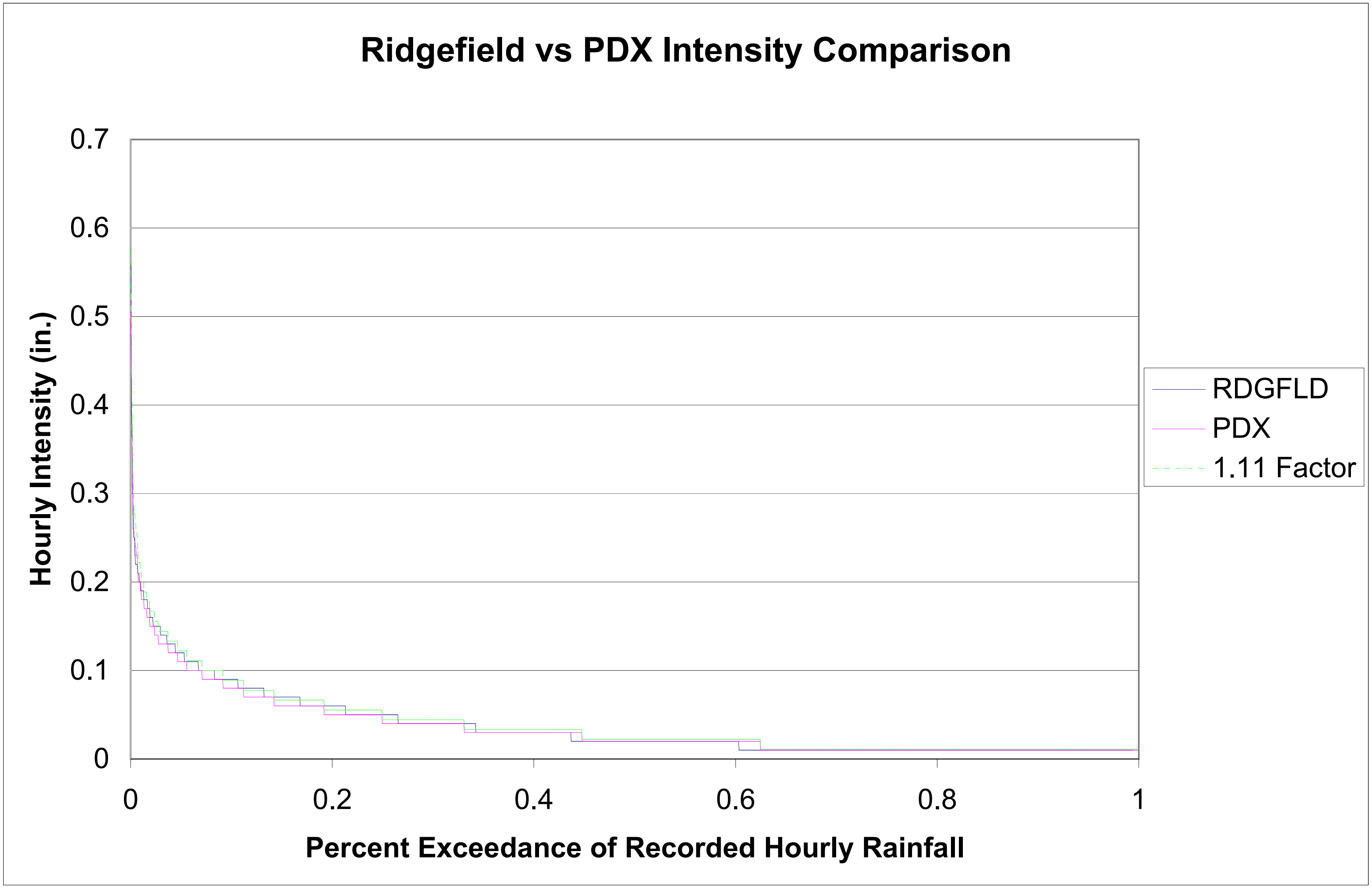

VENERSBORG STATION AT NE 199th St.
Cumulative Rainfall Depth (in)
300
250
200
150
100
50
0
Sep-02
Jan-04
May-05
Oct-06
Feb-08
Jul-09
Date
VNRSBG
PDX
1.82 Factor


YACOLT STATION AT TOWN HALL
Cumulative Rainfall Depth (in)
400
350
300
250
200
150
100
50
0
Sep-02
Jan-04
May-05
Oct-06
Feb-08
Jul-09
Date
YACOLT
PDX
2.01 Factor

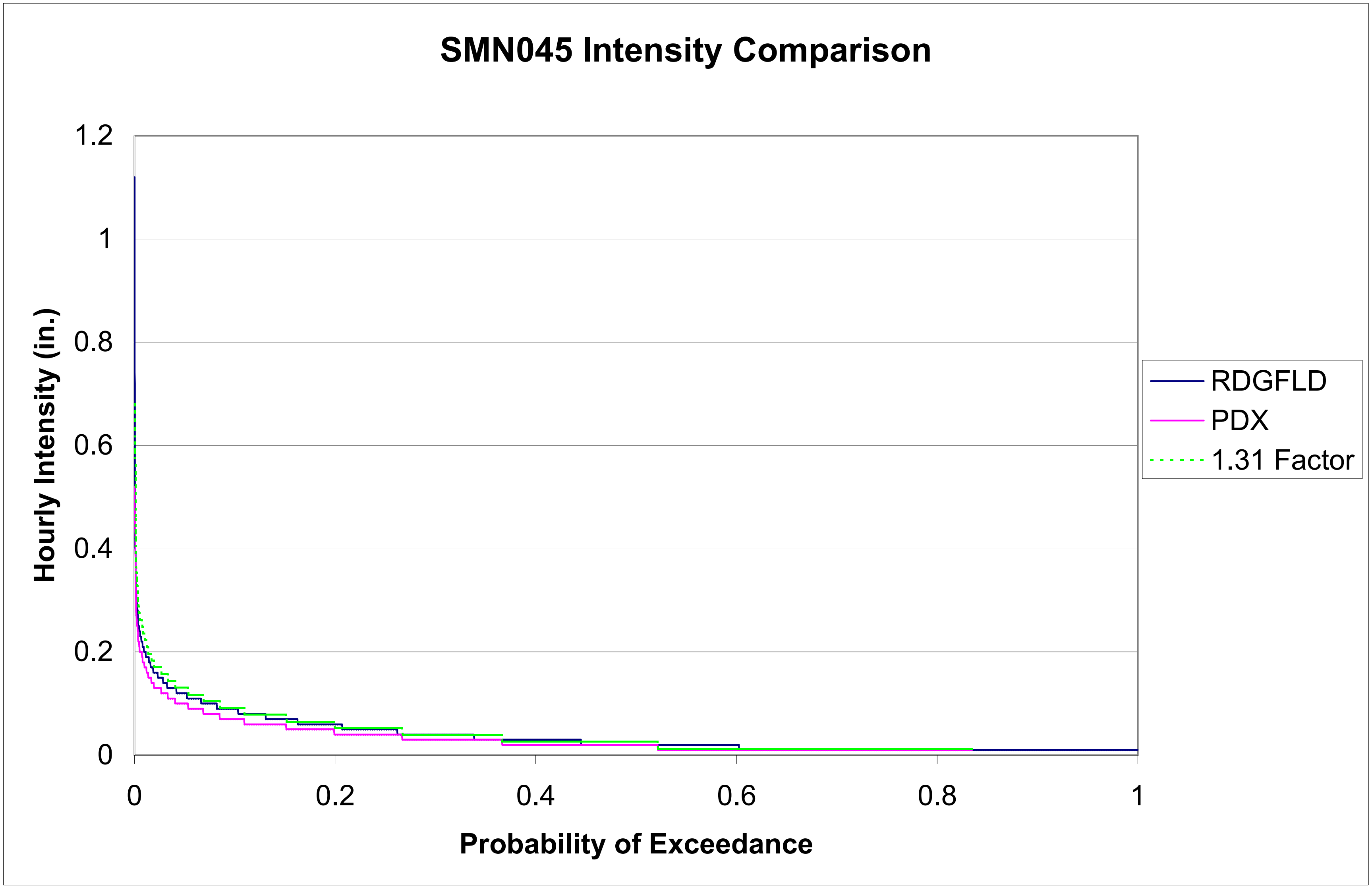
Appendix E — Hourly Intensity Plots

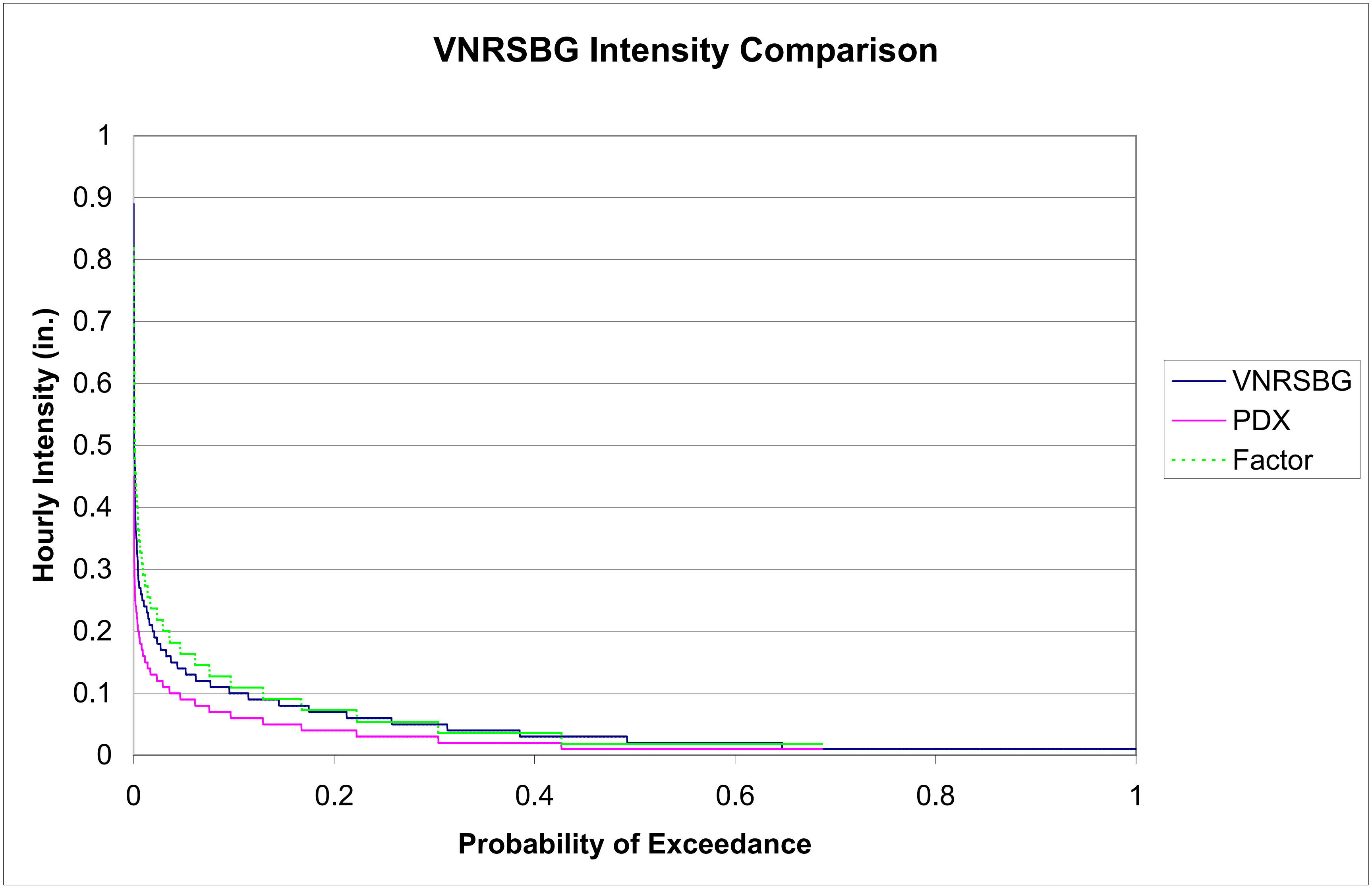
This page left blank to accommodate double-sided printing


ORCHDS Intensity Comparison
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Hourly Intensity (in.)
0
0.2
0.4
0.6
0.8
1
Probability of Exceedance
YACOLT
PDX
Factor

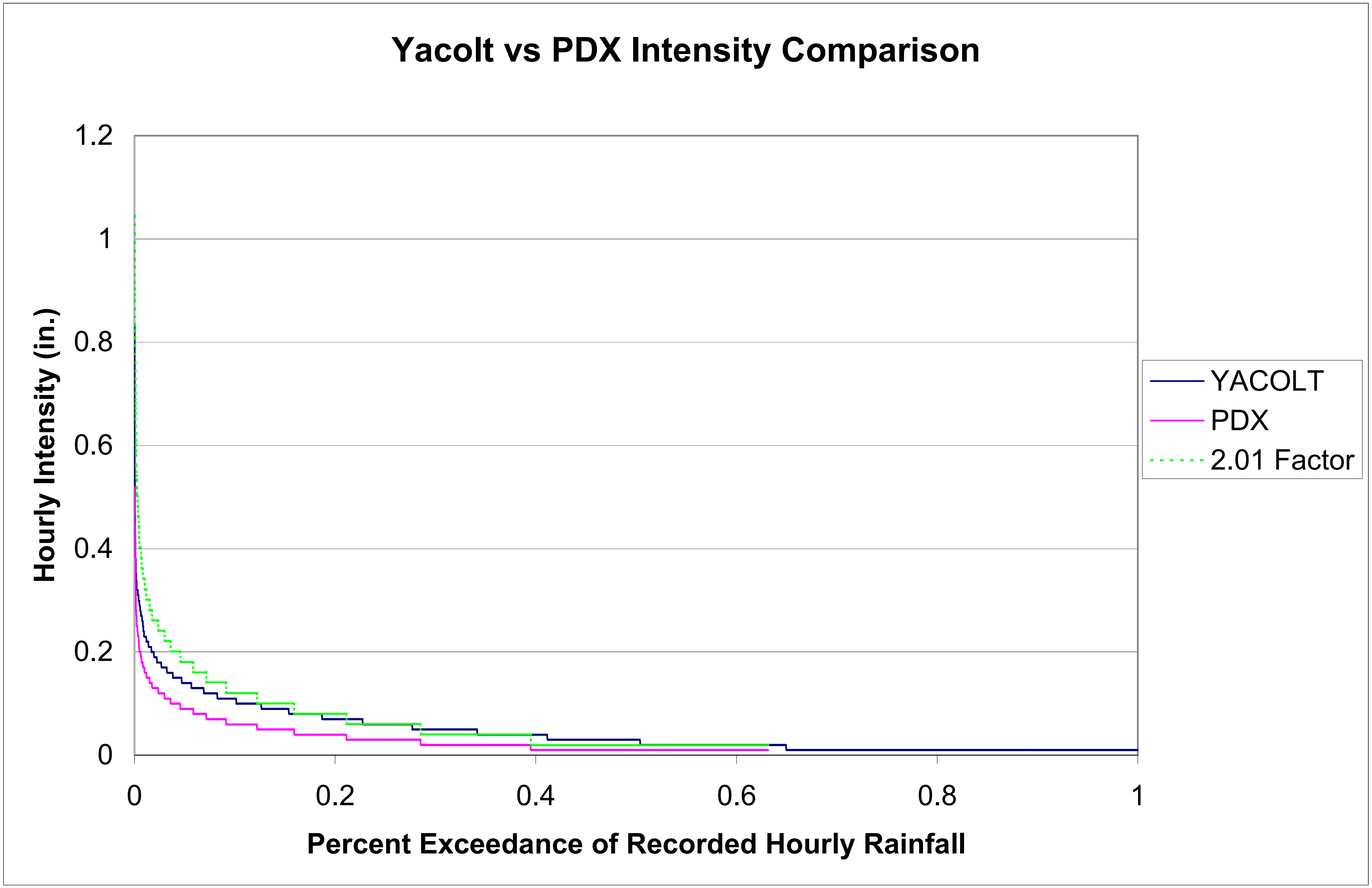


Ridgefield vs PDX Intensity Comparison
Hourly Intensity (in.)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
Percent Exceedance of Recorded Hourly Rainfall
RDGFLD
PDX
1.11 Factor


SMN045 Intensity Comparison
Hourly Intensity (in.)
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Probability of Exceedance
RDGFLD
PDX
1.31 Factor



VNRSBG Intensity Comparison
Hourly Intensity (in.)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
Probability of Exceedance
VNRSBG
PDX
Factor


Yacolt vs PDX Intensity Comparison
1.2
1
0.8
0.6
0.4
0.2
0
Hourly Intensity (in.)
0
0.2
0.4
0.6
0.8
1
Percent Exceedance of Recorded Hourly Rainfall
YACOLT
PDX
2.01 Factor

Hydrologic Modeling of Clark County Watersheds with the U.S. EPA Hydrologic Simulation Program – FORTRAN (HSPF)

Final Report (Revised)

Prepared by

Clear Creek Solutions, Inc.
15800 Village Green Drive #3
Mill Creek, WA 98012

Submitted to

Otak, Inc.
700 Washington Street, Suite 401
Vancouver, WA 98660

19 January 2010

This page is left blank intentionally to accommodate double-sided printed.

ABSTRACT

As mandated by the National Pollutant Discharge Elimination System (NPDES) Phase I Permit issued by the Washington State Department of Ecology (DOE), the recently updated Clark County Stormwater Ordinance requires the use of a continuous simulation hydrologic model to design flow control and runoff treatment facilities. The continuous simulation approach to stormwater modeling is exemplified by the EPA's HSPF model, and is fundamentally different from previous stormwater modeling methods used to design flow control and runoff treatment facilities in Clark County. Prior to the recent update, Clark County's Stormwater Ordinance was based upon single event stormwater modeling methods such as Santa Barbara Urban Hydrograph. Compared to single event methods, the continuous simulation process is more computationally intensive, and involves multiple pre-programmed hydrologic parameters. To ensure that the values of these parameters are representative of Clark County hydrology, hydrologic parameters specific to Clark County have been verified by calibration. Although calibrated parameter values will be included as the default values in the Clark County version of the WWHM, they may be incorporated into any approved HSPF-based model.

The Department of Ecology's flow control approach is based on a flow duration standard that is designed to prevent increased erosion and pollution due to land development activities. This flow duration design standard requires evaluation of runoff under both pre-project and post-project conditions for a critical range of rainfall events simulated through continuous stormwater modeling. To support implementation of this flow control standard, the Department of Ecology sponsored the development of the Western Washington Hydrology Model (WWHM), a software tool to assist in the evaluation of impacts of proposed development and redevelopment projects and design of flow control mitigation measures.

WWHM uses the continuous stormwater and watershed modeling approach of the U.S. EPA Hydrologic Simulation Program - FORTRAN (HSPF) computer program. HSPF is a comprehensive watershed model of hydrology and water quality, which includes modeling of both land surface and subsurface hydrologic and water quality processes, linked and closely integrated with corresponding stream and reservoir processes. It is considered a premier, high-level model among those currently available for comprehensive watershed assessments.

In order to employ HSPF as the hydrologic stormwater engine for WWHM, it must be calibrated to watersheds that reflect the range of climatic, topographic, soil, and land use conditions within Clark County. In this study, model simulations were performed for the Mill Creek and Gee Creek watersheds. Topographic, soils, and land use/cover information was used to develop the model segmentation and parameter inputs for the watershed models. Both quantitative and qualitative comparisons were performed to support the model performance evaluation effort.

Based on the model results presented and discussed in this report, the HSPF application to the Mill Creek and Gee Creek watersheds provides a sound, calibrated and validated hydrologic watershed model for Clark County. The resulting model parameters are appropriate for use in WWHM, and for impact evaluation of hydromodification management alternatives. The calibration results, based on the weight-of-evidence approach described herein, demonstrate a good representation of the observed data. This is the outcome of a wide range of graphical comparisons and measures of model performance for flow duration and individual storm event simulations. These comparisons demonstrate conclusively that the model is a good representation of the water balance and hydrology of the watersheds.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENTS

This study was performed by Clear Creek Solutions, Inc., under contract to Otak, Inc., a contractor to Clark County. Mr. Tim Kraft of Otak was the primary contact with Clark County and provided extensive data and information throughout this study. Ryan Billen of Otak also provided GIS information and other data from WEST Consultants' HSPF calibration of the Mill Creek watershed and GIS information for the Gee Creek watershed plus the watershed figures included in this report. Recorded streamflow, rainfall, and evaporation time series data were provided by WEST Consultants office in Salem, Oregon. We would like to extend our appreciation to all these individuals for their support and assistance on this investigation.

For Clear Creek Solutions, Mr. Douglas Beyerlein, P.E., was the Project Manager, responsible for the overall conduct of the study, including the modeling approach, methods development, calibration, and report preparation. Mr. Shanon White was responsible for performing data processing and watershed GIS characterization and segmentation. Mr. Joseph Brascher assisted in GIS characterization, model setup, and calibration.

This page is left blank intentionally to accommodate double-sided printed.

SECTION 1.0

INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

As mandated by the National Pollutant Discharge Elimination System (NPDES) Phase I Permit issued by the Washington State Department of Ecology (DOE), the recently updated Clark County Stormwater Ordinance requires the use of a continuous simulation hydrologic model to design flow control and runoff treatment facilities. The continuous simulation approach to stormwater modeling is exemplified by the EPA's HSPF model, and is fundamentally different from previous stormwater modeling methods used to design flow control and runoff treatment facilities in Clark County. Prior to the recent update, Clark County's Stormwater Ordinance was based upon single event stormwater modeling methods such as Santa Barbara Urban Hydrograph. Compared to single event methods, the continuous simulation process is more computationally intensive, and involves multiple pre-programmed hydrologic parameters. To ensure that the values of these parameters are representative of Clark County hydrology, hydrologic parameters specific to Clark County have been verified by calibration. Although calibrated parameter values will be included as the default values in the Clark County version of the WWHM, they may be incorporated into any approved HSPF-based model.

The Department of Ecology's flow control approach is based on a flow duration standard that is designed to prevent increased erosion and pollution due to land development activities. This flow duration design standard requires evaluation of runoff under both pre-project and post-project conditions for a critical range of rainfall events simulated through continuous stormwater modeling. To support implementation of this flow control standard, the Department of Ecology sponsored the development of the Western Washington Hydrology Model (WWHM), a software tool to assist in the evaluation of impacts of proposed development and redevelopment projects and design of flow control mitigation measures.

WWHM uses the continuous stormwater and watershed modeling approach of the U. S. EPA Hydrologic Simulation Program - FORTRAN (HSPF) computer program (Bicknell et al., 2001). HSPF is a comprehensive watershed model of hydrology and water quality, which includes modeling of both land surface and subsurface hydrologic and water quality processes, linked and closely integrated with corresponding stream and reservoir processes. It is considered a premier, high-level model among those currently available for comprehensive watershed assessments. HSPF has enjoyed widespread usage and acceptance, since its initial release in 1980, as demonstrated through hundreds of applications across the U.S. and abroad. HSPF is jointly supported and maintained by both the U.S. EPA and the USGS. In addition, HSPF is the primary watershed model included in the EPA BASINS modeling system (U.S. EPA, 2001).

In order to employ HSPF as the hydrologic stormwater engine for WWHM and apply WWHM in Clark County, it must be calibrated to watersheds that reflect the range of climatic, topographic, soil, and land use conditions within Clark County. Once the calibrated model parameters reflect the variation in hydrologic responses between different land types within Clark County watersheds, those parameters can be used within WWHM and applied to proposed areas of development to estimate how that development would impact stormwater runoff, and to design mitigation measures to minimize that impact. This report describes the watersheds selected for calibration of HSPF parameters, and the subsequent model setup, parameterization, and calibration validation efforts.

1.2 SELECTED WATERSHED DOMAINS

Through a review of Clark County watersheds with appropriate streamflow and meteorologic data to support an HSPF model calibration, both the Mill Creek and Gee Creek watersheds were selected as a basis for developing calibrated model parameters (see Figure 1.1 provided by Otak). These watersheds encompass an appropriate range of land use, soils, vegetation, and climatic conditions that represent Clark County. Thus, HSPF calibrated parameter values from these two watersheds can be extended to the remainder of the county.

Mill Creek is a tributary of Salmon Creek, draining in a southwesterly direction. Watershed elevations range from 446 feet to 134 feet at the confluence with Salmon Creek. The watershed is a moderately developed suburban and rural area approximately 11.85 square miles in size with moderate precipitation (approximately 40 inches per year). It is located just to the east of Interstate 5, which runs north-south through Clark County, and north of the City of Vancouver.

The Mill Creek watershed was chosen because of previous hydrologic modeling of the watershed by WEST Consultants (2008) using HSPF. At the time of the calibration effort Mill Creek had a 52-month record of available continuous streamflow data collected by Clark County. The HSPF model constructed for this watershed is calibrated by adjusting parameter values, within expected ranges, so that the simulated model streamflows match well with the recorded streamflow data. Selection of the calibration period for this watershed is discussed in Section 4.2.

Gee Creek flows through the Ridgefield National Wildlife Refuge to the Columbia River, draining in a northwesterly direction. Watershed elevations range from 440 feet in the upper part of the watershed to 30 feet at the stream gaging station. The watershed is a mostly rural area, approximately 11.6 square miles in size, with moderate precipitation (approximately 40 inches per year). It is located just to the west of the Mill Creek watershed.

The Gee Creek watershed was chosen because of previous hydraulic modeling of the watershed by WEST Consultants using HEC-RAS. At the time of the calibration effort Gee Creek had a 53-month record of available continuous streamflow data collected by River Measurement for Clark County. The HSPF model constructed for this watershed is calibrated by adjusting parameter values, within expected ranges, so that the simulated model streamflows match well with the recorded streamflow data. Selection of the calibration period for this watershed is discussed in Section 4.3.

1.3 THIS REPORT

In this report we describe the application of HSPF to the Mill Creek and Gee Creek watersheds as part of the effort to establish representative hydrologic parameters for selected climate, soil, topographic and land use conditions within Clark County. This report describes the model setup, parameterization, and calibration of HSPF for these watersheds.

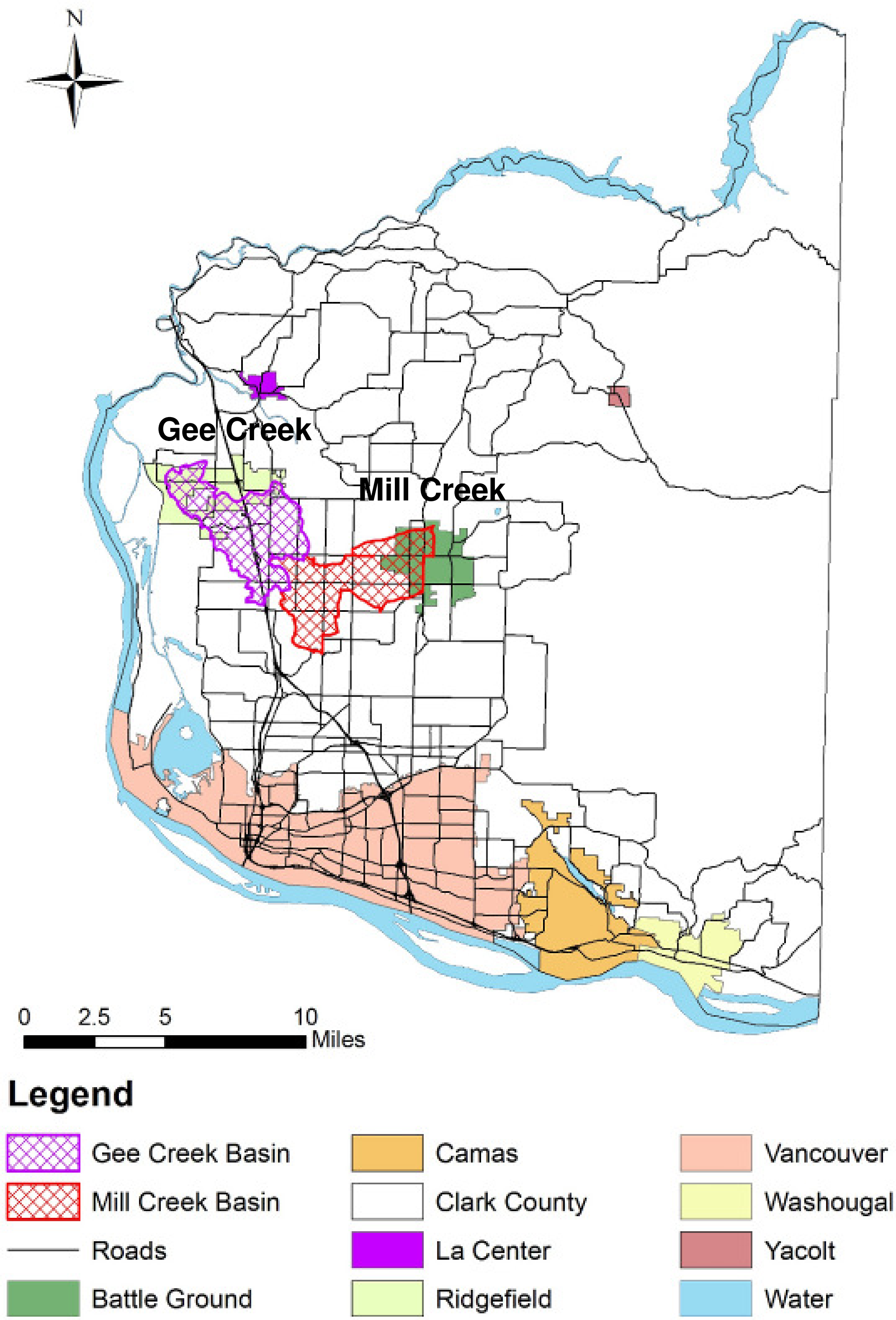


Figure 1.1 Mill Creek and Gee Creek Watersheds

1.4 CONCLUSIONS AND RECOMMENDATIONS

Table 1.1 provides a weight-of-evidence summary of the various model-data comparisons performed for the simulations of the Mill Creek HSPF model, discussed above. The overall model performance, shown in the last column, reflects our assessment of good model performance for the calibration period for Mill Creek.

Based on the model results presented and discussed in this report, and summarized in Table 1.1, we conclude that the current HSPF application to the Mill Creek watershed provides a sound, calibrated hydrologic watershed model. The resulting model parameters are appropriate for use in WWHM, and for impact evaluation of flow control alternatives. The calibration results, based on the weight-of-evidence approach described herein, demonstrates a good representation of the observed data. This is the outcome of a wide range of graphical comparisons and measures of the model performance for flow duration and storm event simulations. These comparisons demonstrate conclusively that the model is a good representation of the hydrology of the watershed.

However, because of the relatively short calibration periods available for Mill Creek we recommend a follow-up validation of the HSPF calibration parameter values if and when additional observed streamflow data become available. A minimum validation period of record of three to five years with no or few data gaps will be needed at each gaging location to provide the appropriate number of new storm events to adequately judge the soundness of the selected HSPF parameter values.

Table 1.1 Weight-of-Evidence for Model Performance for Mill Creek

Calibration Component	Mill Creek	Overall Model Performance
Flow Duration Curves		Very Good
Upstream Gage	Good	
Downstream Gage	Very Good	
Peak Flow Events		Very Good
Upstream Gage	Good	
Downstream Gage	Good to Excellent	

Table 1.2 provides the weight-of-evidence summary of the various model-data comparisons performed for the Gee Creek HSPF model. The overall model performance, shown in the last column, reflects our assessment of good model performance for the calibration period for Gee Creek.

Based on the model results presented and discussed in this report, and summarized in Table 1.2, we conclude that the current HSPF application to the Gee Creek watershed provides a sound, calibrated hydrologic watershed model. The resulting model parameters are appropriate for use in WWHM, and for impact evaluation of flow control alternatives. The calibration results, based on the weight-of-evidence approach described herein, demonstrates a good representation of the observed data. This is the outcome of a wide range of graphical comparisons and measures of the model performance for flow duration and storm event simulations. These comparisons demonstrate conclusively that the model is a good representation of the hydrology of the watershed.

However, because of the relatively short calibration period available for Gee Creek we recommend a follow-up validation of the HSPF calibration parameter values if and when additional observed streamflow data become available. A minimum validation period of record of three to five years with no or few data gaps will be needed to provide the appropriate number of new storm events to adequately judge the soundness of the selected HSPF parameter values.

Table 1.2 Weight-of-Evidence for Model Performance for Gee Creek

Calibration Component	Overall Model Performance
Flow Duration Curves	Very Good
Peak Flow Events	Fair to Excellent

SECTION 2.0

DATA NEEDS FOR WATERSHED HYDROLOGIC MODELING

Database development is a major portion of the total modeling effort, requiring acquisition of data from a variety of sources, developing estimation procedures when needed data are not available, applying available techniques to fill-in missing data, and ensuring consistency and accuracy of the information obtained. All time-series data is placed in the form of a Watershed Data Management (WDM) file (Lumb and Kittle, 1988). The purpose of this section is to identify the data needs for HSPF and present findings of the availability and sources of these data. Ultimately, the findings in this section will determine the timeframe the data are capable of supporting for model simulation for the calibration period.

Data requirements for HSPF are extensive, in both spatial and temporal detail. Typical data requirements for an HSPF application can be categorized as input/execution data, watershed/channel characterization data, and calibration data. Input/execution data include precipitation and evaporation time series that drive the model simulations. Watershed/channel characterization data include land use, topography, hydrography, and channel characteristics (e.g. cross section, slope, roughness); they are input to the model as snapshot representations of existing watershed conditions during the simulation period. Calibration data consist of observed/recorded flow time series from a station located in or at the outlet of the watershed.

In order to simulate a watershed for a particular time period, the periods of record for the observed precipitation, evaporation, and flow time series must encompass that simulation period. This section discusses the availability of these time series data for the watershed.

2.1 METEOROLOGICAL DATA – PRECIPITATION AND EVAPORATION

County precipitation data were provided for the Mill Creek and Gee Creek watersheds by River Measurement, a division of WEST Consultants. The precipitation gage is located just south of the watershed at NE 156th Street in Vancouver. According to the WEST 2008 report, the gage is located at 189 feet elevation. It has been in operation starting October 1, 1999. The precipitation data are available through September 30, 2007.

Pan evaporation data were available from WEST Consultants' HSPF modeling of Mill Creek (WEST Consultants, 2008).

Figure 2.1 shows the locations of nearby precipitation stations in Clark County.

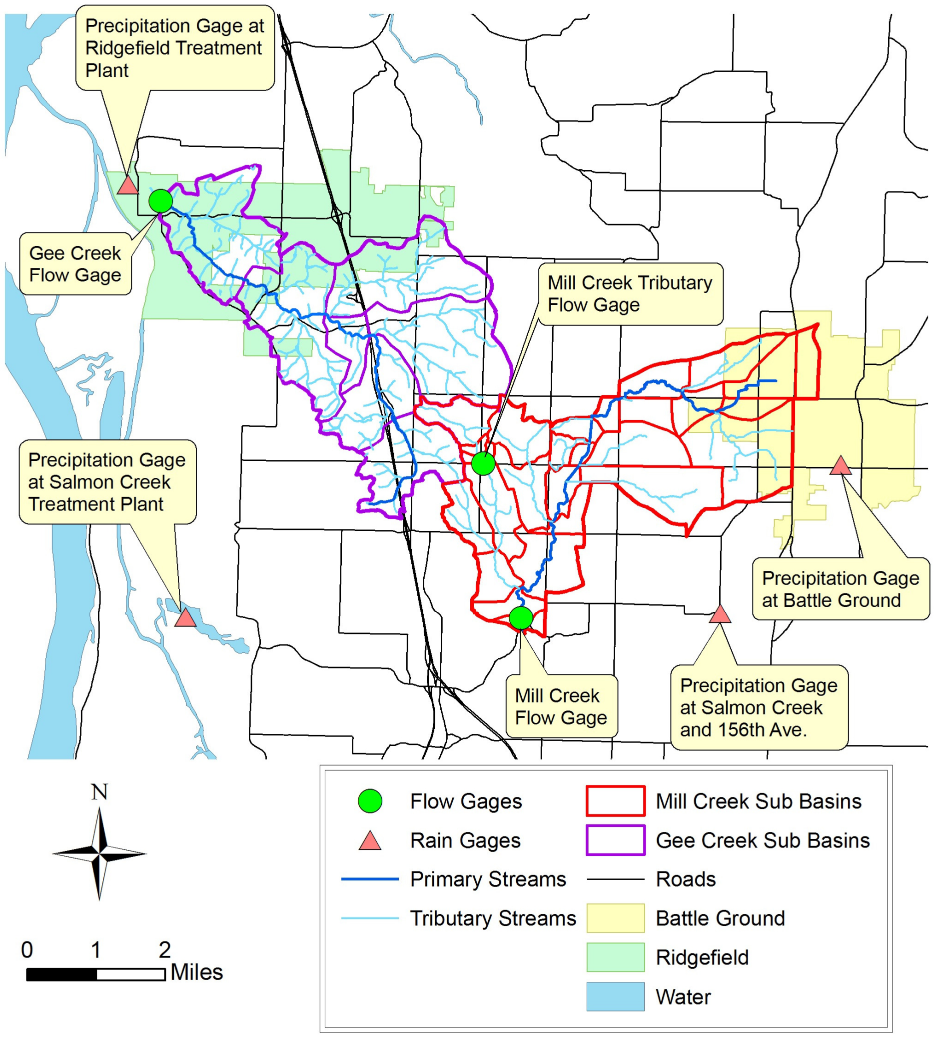


Figure 2.1 Clark County Precipitation Stations near Mill Creek and Gee Creek

2.2 STREAMFLOW

Two streamflow gages are located in the Mill Creek watershed. Hourly observed data were provided by River Measurement and Clark County Public Works. Table 2.4 lists information about the streamflow gages.

Table 2.4 Streamflow Gage Stations

Watershed	Gage Location	Drainage Area (ac)	Period of Record
Mill Creek	Near Mouth	7497*	5/2003 - 9/2007
Mill Trib	NE 199th Street	404	1/2005 - 1/2006
Gee Creek	At Abrams Park	7423	1/2003 - 9/2007

*The entire Mill Creek watershed area is 7581 acres.

Visual inspection of the hourly streamflow data found missing and erroneous data for both Mill Creek gages.

At the Mill Creek downstream gage near the mouth the streamflow record showed missing periods prior to December 2004 and after March 2007. These periods of record were ignored for calibration purposes and the calibration was focused on the period of December 1, 2004, through April 1, 2007.

At the Mill tributary upstream gage at NE 199th Street the streamflow record showed numerous missing periods between January 2005 and January 2006. The recorded streamflow data were used in the calibration effort, but only minor effort was made to try to match the recorded streamflow hydrographs at this gage location.

The remaining Mill Creek streamflow records appeared to be complete and representative of the hydrology of their individual drainage areas.

One streamflow gage is located in the Gee Creek watershed at Abrams Park on the left bank of Gee Creek. Hourly observed data were provided by River Measurement. Table 2.4 lists information about the streamflow gage. Visual inspection of the hourly streamflow data found the data for this gage to be complete. Steve Gustafson of River Measurement provided information on the Gee Creek rating curve and changes to the ratings during the calibration period. This information was taken into account when calibrating Gee Creek streamflow.

SECTION 3.0

WATERSHED SEGMENTATION

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

Information describing the characteristics of the watershed, including topography, drainage patterns, meteorological variability, soils conditions, vegetative covering, and the land use distribution are required for segmenting the watershed into individual land segments that demonstrate a similar hydrologic and water quality response.

Information describing the channels, floodplain morphology, culverts, and other hydraulic features within the watershed allows for the segmentation of the conveyance system (both natural and artificial) into discrete sections with similar hydraulic and water quality behavior. Locations of dams/reservoirs, point source discharges, gages/data collectors, culverts, and diversions provides information to develop a segmentation scheme that supports modeling localized conditions within the watershed.

3.1 GEOGRAPHIC INFORMATION SYSTEMS (GIS) COVERAGES

For this project the main tool used for watershed segmentation to delineate, characterize, and group areas within the subject watershed was ArcGIS. GIS coverages defining geologic, hydrologic, and anthropologic boundaries, systems, and points were obtained from information supplied either directly or indirectly by Clark County.

3.1.1 Land Use/Cover

The watershed's land use/cover data were developed from the GIS information provided by Clark County to Otak. To use the land use/cover data in the HSPF models the data needed to be standardized to one set of HSPF model pervious and impervious land uses. The correspondence established between the respective categories is given in Table 3.1.

In both the Mill Creek and Gee Creek watersheds the two dominate land uses/covers are forest and field. As used elsewhere in Western Washington, the forest land cover category encompasses the typical second-growth evergreen and deciduous trees found throughout the low lands. In contrast, the field land use is a new category that represents agricultural areas, pastures, and rural and suburban lawns where there has been only minor soil alternation and compaction. A separate lawn category describes urban lawns and landscaping and was not considered significant enough in these watersheds to be included in the land use/cover delineation.

The land use/cover data are shown for the Mill Creek and Gee Creek watersheds in Figure 3.1 (provided by Otak).

Table 3.1 Correlation between GIS and HSPF Model Land Use/Cover Categories

GIS Land Use/Cover	HSPF Land Use/Cover
Lawns	FIELD
Pasture	FIELD
Structures	IMPERVIOUS
Paved surfaces (concrete, asphalt)	IMPERVIOUS
Agricultural lots	FIELD
Trees	FOREST

Based on these HSPF model land use/cover categories and the land use/cover shown for the Mill Creek watershed (Figure 3.1), the Mill Creek total area of the corresponding HSPF land use/covers is shown in Table 3.2.

Table 3.2 Mill Creek Watershed Areas by HSPF Land Use Category

Land Use	Total Area (ac)	Percent of Watershed
Forest	2010.12	26.5%
Field	5092.99	67.2%
Impervious	477.99	6.3%
Total	7581.10	100.0%

Based on these HSPF model land use/cover categories and the land use/cover shown for the Gee Creek watershed (Figure 3.1), the Gee Creek total area of the corresponding HSPF land use/covers is shown in Table 3.3.

Table 3.3 Gee Creek Watershed Areas by HSPF Land Use Category

Land Use	Total Area (ac)	Percent of Watershed
Forest	2317.48	31.2%
Field	4857.25	65.4%
Impervious	248.04	3.3%
Total	7422.78	100.0%

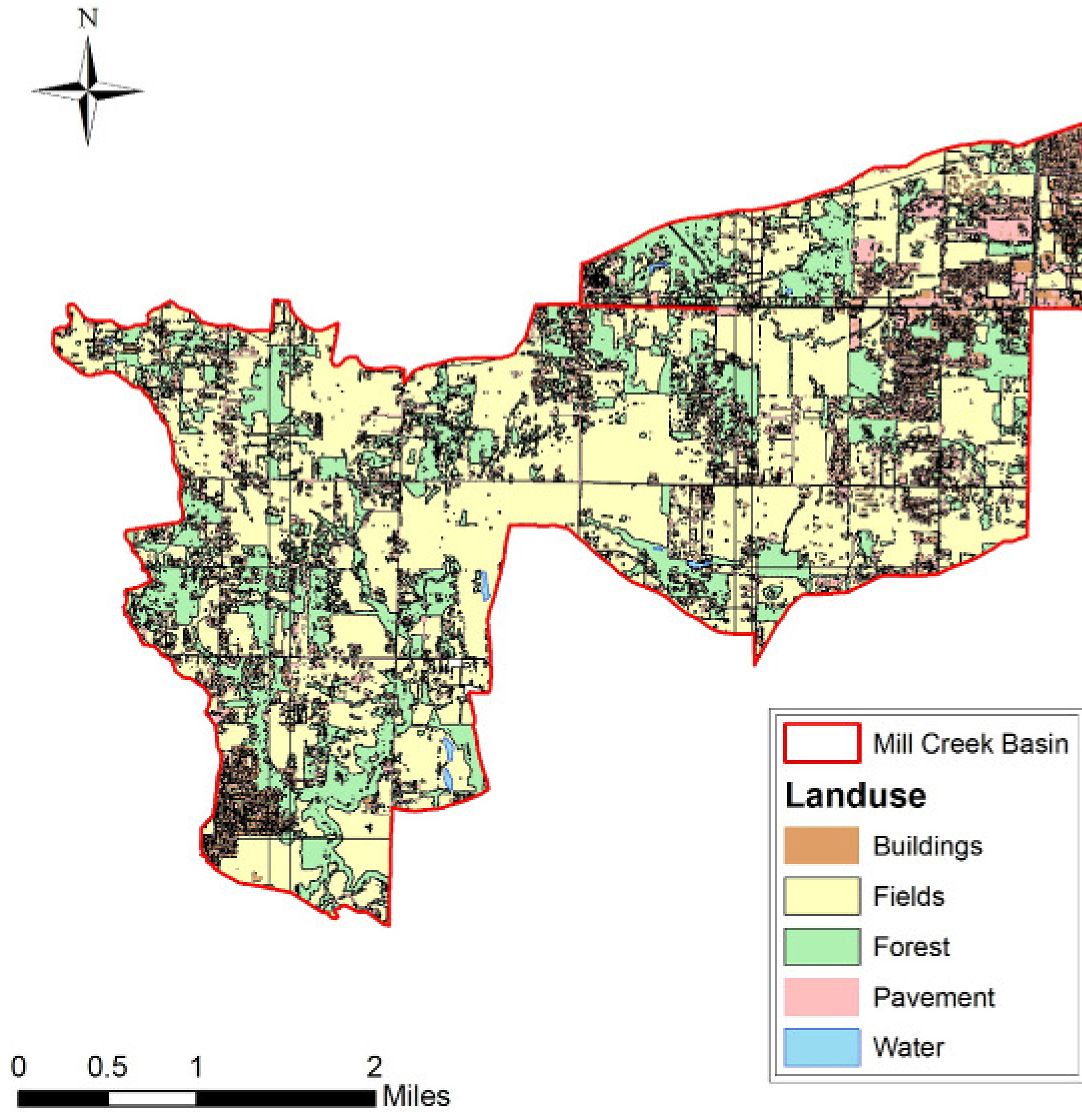


Figure 3.1 Mill Creek Watershed Land Use/Cover

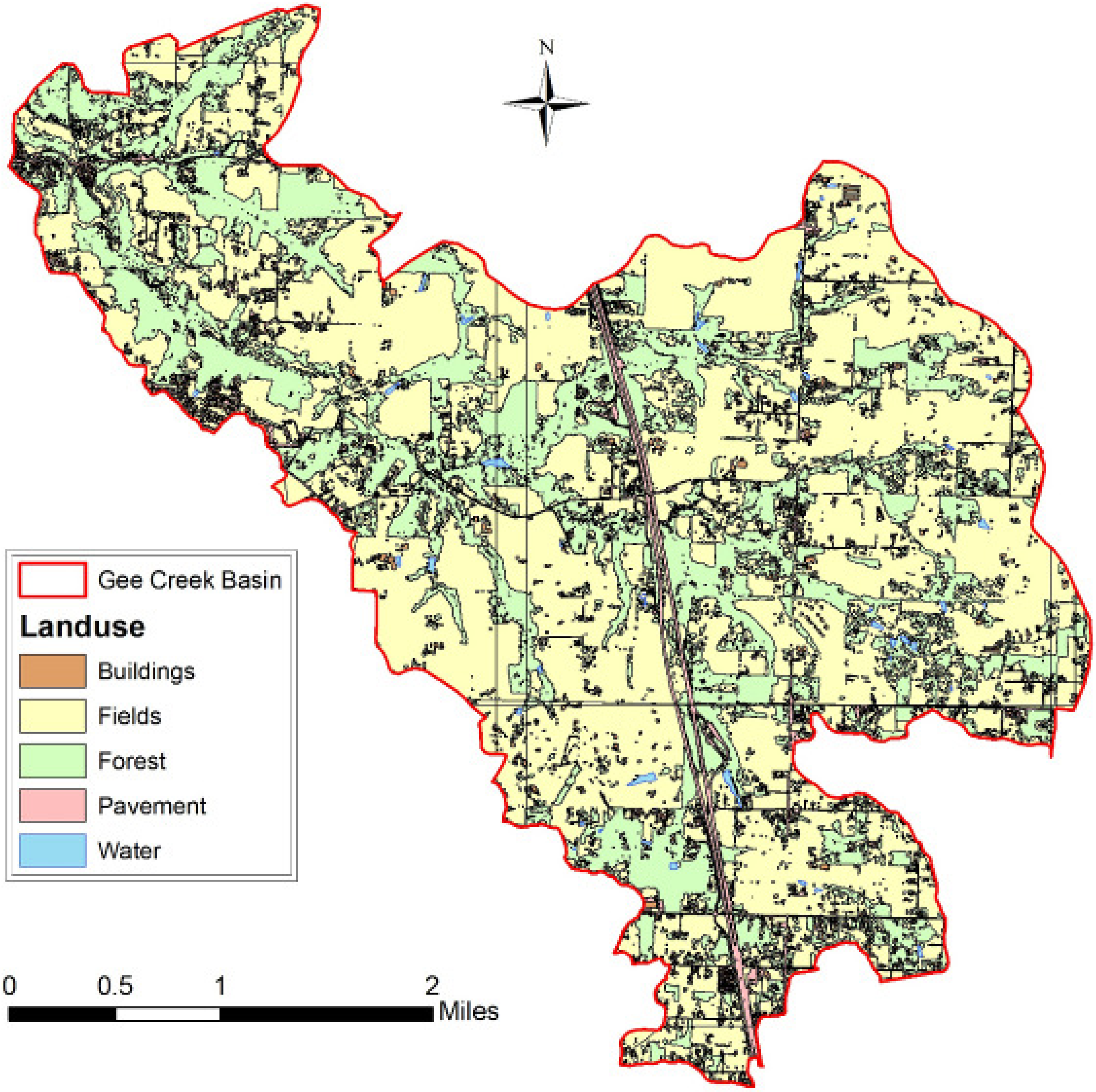


Figure 3.2 Gee Creek Watershed Land Use/Cover

3.1.2 Soils/Land Slope

The soils and land slope coverages were combined with the land use/cover GIS shape file to produce the specific PERLND and IMPLND categories used in the HSPF models. The soils coverage was provided by Clark County to Otak. Land slopes were generated from a digital elevation map (DEM).

The soils of Clark County were classified into five different groups based on soil characteristics. From a hydrologic calibration perspective, the most important soil characteristic is infiltration. Therefore, infiltration rates and soil moisture storage capability played the major role in the selection of the soils for each of the five groups. The five groups are:

SG1: Excessively Drained soils (hydrologic soil groups A & B)
SG2: Well Drained Soils (hydrologic soil group B)
SG3: Moderately Drained soils (hydrologic soil groups B & C)
SG4: Poorly Drained soils (slowly infiltrating C soils, as well as D soils)
SG5: Wetlands soils (mucks)

Table 3.4 lists the soils within each group.

Land slopes were divided into three groups: flat (0-5%), moderate (5-15%), and steep (>15%).

Table 3.4 Clark County Soil Groups (UPDATE)

Map Symbol	Soil Name	HSG	SCS Permeability (in/hr)	Dominant USDA Texture	Depth from surface
			SG 1		
LeB	LAUREN	B	0.63 - 2.0 (6.3 - 20 deeper than 33in)	**Very Gravelly Coarse Sandy Loam**	**33-70**
LgB	LAUREN	B	0.63 - 2.0 (6.3 - 20 deeper than 33in)	**Very Gravelly Coarse Sandy Loam**	**33-70**
LgD	LAUREN	B	0.63 - 2.0 (6.3 - 20 deeper than 33in)	**Very Gravelly Coarse Sandy Loam**	**33-70**
LgF	LAUREN	B	0.63 - 2.0 (6.3 - 20 deeper than 33in)	**Very Gravelly Coarse Sandy Loam**	**33-70**
LlB	LAUREN	B	0.63 - 2.0 (6.3 - 20 deeper than 33in)	**Very Gravelly Coarse Sandy Loam**	**33-70**
Ro	ROUGH BROKEN LAND	A	Too variable		
SvA	SIFTON	B	2.0 - 6.3 (>20 deeper than 16in)	**Very Gravelly Loamy Coarse Sand and Very Gravelly Coarse Sand**	**10-60 inches**
WnB	WIND RIVER VARIANT	B	6.3 - 20	**Loamy Coarse Sand and Coarse Sand**	**24-62 inches**
WnD	WIND RIVER VARIANT	B	6.3 - 20	**Loamy Coarse Sand and Coarse Sand**	**24-62 inches**
WnG	WIND RIVER VARIANT	B	6.3 - 20	**Loamy Coarse Sand and Coarse Sand**	**24-62 inches**
WrB	WIND RIVER VARIANT	B	6.3 - 20	**Loamy Coarse Sand and Coarse Sand**	**24-62 inches**
WrF	WIND RIVER VARIANT	B	6.3 - 20	**Loamy Coarse Sand and Coarse Sand**	**24-62 inches**
	PITS	A			
	BONNEVILLE STONY SAND LOAM	A			
			SG 2		
BpB	BEAR PRARIE	B	0.63 - 2.0	**Gravelly Loam**	**51-75 inches**
BpC	BEAR PRARIE	B	0.63 - 2.0	**Gravelly Loam**	**51-75 inches**
CnB	CINEBAR	B	0.63 - 2.0	**Silt Loam and Loam**	**0-65 inches**
CnD	CINEBAR	B	0.63 - 2.0	**Silt Loam and Loam**	**0-65 inches**
CnE	CINEBAR	B	0.63 - 2.0	**Silt Loam and Loam**	**0-65 inches**
CnG	CINEBAR	B	0.63 - 2.0	**Silt Loam and Loam**	**0-65 inches**
CrE	CINEBAR	B	0.63 - 2.0	**Silt Loam**	**0-60 inches**
CrG	CINEBAR	B	0.63 - 2.0	**Silt Loam**	**0-60 inches**

Map Symbol	Soil Name	HSG	SCS Permeability (in/hr)	Dominant USDA Texture	Depth from surface
CsF	CISPUS	B	> 20	**Very Cobbly Sand**	**24-53 inches**
CtA	CLOQUATO	B	>6.30	**Sandy loam and sand**	**40-72 inches**
HlA	HILLSBORO	B	2.0 - 6.3	**Sandy loam and sand**	**36-62 inches**
HlB	HILLSBORO	B	2.0 - 6.3	**Sandy loam and sand**	**36-62 inches**
HlC	HILLSBORO	B	2.0 - 6.3	**Sandy loam and sand**	**36-62 inches**
HlD	HILLSBORO	B	2.0 - 6.3	**Sandy loam and sand**	**36-62 inches**
HlE	HILLSBORO	B	2.0 - 6.3	**Sandy loam and sand**	**36-62 inches**
HlF	HILLSBORO	B	2.0 - 6.3	**Sandy loam and sand**	**36-62 inches**
KeC	KINNEY	B	0.63 - 2.0	**Gravelly silt loam, gravelly silty clay loam, and gravelly clay loam**	**0-60 inches**
KeE	KINNEY	B	0.63 - 2.0	**Gravelly silt loam, gravelly silty clay loam, and gravelly clay loam**	**0-60 inches**
KeF	KINNEY	B	0.63 - 2.0	**Gravelly silt loam, gravelly silty clay loam, and gravelly clay loam**	**0-60 inches**
KnF	KINNEY	B	0.63 - 2.0	**Gravelly silt loam, gravelly silty clay loam, and gravelly clay loam**	**0-60 inches**
LaE	LARCHMOUNT	B	0.63 - 2.0	**Cobbly Silt Loam and Clay Loam**	**0-62 inches**
LaG	LARCHMOUNT	B	0.63 - 2.0	**Cobbly Silt Loam and Clay Loam**	**0-62 inches**
LcG	LARCHMOUNT	B	0.63 - 2.0	**Silty Loam and Clay Loam**	**0-62 inches**
MsB	MOSSYROCK	B	0.63 - 2.0	**Silt Loam**	**23-60 inches**
NbA	NEWBERG	B	2.0 - 6.3	**Fine Sandy Loam and Sandy Loam**	**7-52 inches**
NbB	NEWBERG	B	2.0 - 6.3	**Fine Sandy Loam and Sandy Loam**	**7-52 inches**
PhB	PILCHUCK	C	6.3 - 20	**Fine Sand**	**0-60 inches**
PuA	PUYALLUP	B	6.3 - 20	**Gravelly Sand**	**27-60 inches**
SaC	SALKUM	B	0.06 - 0.20	**Heavy Silty Clay Loam**	**31-55 inches**
VaB	VADER	B	2.0 - 6.3	**Silt Loam and Loam**	**0-30 inches**
VaC	VADER	B	2.0 - 6.3	**Silt Loam and Loam**	**0-30 inches**
WaA	WASHOUGAL	B	0.63 - 2.0	**Very Gravelly Loam and Very Gravelly Coarse Sandy Loam**	**22-36 inches**
WgB	WASHOUGAL	B	0.63 - 2.0	**Very Gravelly Loam and Very Gravelly Coarse Sandy Loam**	**22-36 inches**
WgE	WASHOUGAL	B	0.63 - 2.0	**Very Gravelly Loam and Very Gravelly Coarse Sandy Loam**	**22-36 inches**
WhF	WASHOUGAL	B	0.63 - 2.0	**Very Gravelly Loam and Very Gravelly Coarse Sandy Loam**	**22-36 inches**
YaA	YACOLT	B	0.63 - 2.0	**Cobbly Loam**	**39-61 inches**

Map Symbol	Soil Name	HSG	SCS Permeability (in/hr)	Dominant USDA Texture	Depth from surface
YaC	YACOLT	B	0.63 - 2.0	**Cobbly Loam**	**39-61 inches**
YcB	YACOLT	B	0.63 - 2.0	**Cobbly Loam**	**39-61 inches**

SG 3

DoB	DOLLAR	C	<0.06	**Loam**	**32-60 inches**
HcB	HESSON	C	0.2 - 0.63	**Clay**	**22-91 inches**
HcD	HESSON	C	0.2 - 0.63	**Clay**	**22-91 inches**
HcE	HESSON	C	0.2 - 0.63	**Clay**	**22-91 inches**
HcF	HESSON	C	0.2 - 0.63	**Clay**	**22-91 inches**
HgB	HESSON	C	0.2 - 0.63	**Gravelly Clay**	**22-91 inches**
HgD	HESSON	C	0.2 - 0.63	**Gravelly Clay**	**22-91 inches**
HhE	HESSON	C	0.2 - 0.63	**Gravelly Clay**	**22-91 inches**
HoA	HILLSBORO	B	0.63 - 2.0	**Silt Loam**	**0-86 inches**
HoB	HILLSBORO	B	0.63 - 2.0	**Silt Loam**	**0-86 inches**
HoC	HILLSBORO	B	0.63 - 2.0	**Silt Loam**	**0-86 inches**
HoD	HILLSBORO	B	0.63 - 2.0	**Silt Loam**	**0-86 inches**
HoE	HILLSBORO	B	0.63 - 2.0	**Silt Loam**	**0-86 inches**
HoG	HILLSBORO	B	0.63 - 2.0	**Silt Loam**	**0-86 inches**
HsB	HILLSBORO	B	0.63 - 2.0	**Silt Loam**	**0-86 inches**
McB	McBEE	C	0.63 - 2.0	**Silty Clay Loam, Clay**	**0-65 inches**
MeA	McBEE	C	0.63 - 2.0	**Silty Clay Loam, Clay**	**0-65 inches**
MIA	McBEE	C	0.63 - 2.0 (>20 deeper than 44in)	**Gravelly Fine Sandy Loam**	**19-44 inches**
OeD	OLEQUA	B	0.2 - 0.63	**Heavy Silt Loam and Silty Clay Loam**	**17-90 inches**
OeE	OLEQUA	B	0.2 - 0.63	**Heavy Silt Loam and Silty Clay Loam**	**17-90 inches**
OeF	OLEQUA	B	0.2 - 0.63	**Heavy Silt Loam and Silty Clay Loam**	**17-90 inches**
OlB	OLYMPIC	B	0.2 - 0.63	**Gravelly Clay Loam**	**44-59 inches**
OlD	OLYMPIC	B	0.2 - 0.63	**Gravelly Clay Loam**	**44-59 inches**
OlE	OLYMPIC	B	0.2 - 0.63	**Gravelly Clay Loam**	**44-59 inches**

Map Symbol	Soil Name	HSG	SCS Permeability (in/hr)	Dominant USDA Texture	Depth from surface
OIF	OLYMPIC	B	0.2 - 0.63	**Gravelly Clay Loam**	**44-59 inches**
OmE	OLYMPIC	B	0.2 - 0.63	**Gravelly Clay Loam**	**44-59 inches**
OmF	OLYMPIC	B	0.2 - 0.63	**Gravelly Clay Loam**	**44-59 inches**
OpC	OLYMPIC VARIANT	C	0.2 - 0.63	**Heavy Clay Loam and Heavy silty Clay Loam**	**0-33 inches**
OpE	OLYMPIC VARIANT	C	0.2 - 0.63	**Fractured Basalt**	**0-33 inches**
OpG	OLYMPIC VARIANT	C	0.2 - 0.63	**Fractured Basalt**	**0-33 inches**
OrC	OLYMPIC VARIANT	C	0.2 - 0.63	**Fractured Basalt**	**0-33 inches**
PoB	POWELL	C	0.06 - 0.20	**Silt Loam**	**23-63 inches**
PoD	POWELL	C	0.06 - 0.20	**Silt Loam**	**23-63 inches**
PoE	POWELL	C	0.06 - 0.20	**Silt Loam**	**23-63 inches**
SmA	SAUVIE	B	0.2 - 0.63	**Silty Clay Loam and Silt Loam**	**0-63 inches**
SmB	SAUVIE	B	0.2 - 0.63	**Silty Clay Loam and Silt Loam**	**0-63 inches**
SnA	SAUVIE	D	2.0 - 6.3	**Fine Sandy Loam**	**36-63 inches**
SpB	SAUVIE	B	0.2 - 0.63	**Silty Clay Loam and Silt Loam**	**0-63 inches**

SG 4

CvA	COVE	D	0.06 - 0.20	**Gravelly Silty Clay Loam**	**21-60 inches**
CwA	COVE	D	0.06 - 0.20	**Silt Loam**	**21-60 inches**
GeB	GEE	C	<0.06	**Silty Clay Loam**	**22-72 inches**
GeD	GEE	C	<0.06	**Silty Clay Loam**	**22-72 inches**
GeE	GEE	C	<0.06	**Silty Clay Loam**	**22-72 inches**
GeF	GEE	C	<0.06	**Silty Clay Loam**	**22-72 inches**
GuB	GUMBOOT	D	0.06 - 0.2	**Gravelly Silty Clay Loam, Clay Loam**	**12-50 inches**
HtA	HOCKINSON	D	0.06 - 0.2	**Fine Sandy Loam and Loam**	**23-51 inches**
HuB	HOCKINSON	D	0.06 - 0.2	**Fine Sandy Loam and Loam**	**23-51 inches**
HvA	HOCKINSON	D	0.06 - 0.2	**Fine Sandy Loam and Loam**	**23-51 inches**
LrC	LAUREN	C	<0.06	**Very Gravelly Clay Loam**	**14-60 inches**
LrF	LAUREN	C	<0.06	**Very Gravelly Clay Loam**	**14-60 inches**

Map Symbol	Soil Name	HSG	SCS Permeability (in/hr)	Dominant USDA Texture	Depth from surface
MnA	MINNIECE	D	<0.06	**Silty Clay and Clay Basalt Bedrock**	**0-48 inches**
MnD	MINNIECE	D	<0.06	**Silty Clay and Clay Basalt Bedrock**	**0-48 inches**
MoA	MINNIECE VARIANT	D	<0.06	**Very Gravelly Clay Loam**	**22-60 inches**
OdB	ODNE	D	<0.06	**Silt Loam, silty Clay Loam, Clay Loam, and Loam**	**0-50 inches**
OhD	OLEQUA VARIANT	C	<0.06	**Silty Clay and Clay**	**32-82 inches**
OhF	OLEQUA VARIANT	C	<0.06	**Silty Clay and Clay**	**32-82 inches**
SlB	SARA	D	<0.06	**Heavy Silty Clay Loam and Silty Clay**	**10-70 inches**
SlD	SARA	D	<0.06	**Heavy Silty Clay Loam and Silty Clay**	**10-70 inches**
SlF	SARA	D	<0.06	**Heavy Silty Clay Loam and Silty Clay**	**10-70 inches**

SG 5

Sr	SEMIAHMOO	C	0.63 - 2.0	**Muck**	**0-40 inches**
Su	SEMIAHMOO VARIANT	D	0.63 - 2.0	**Muck**	**0-30 inches**
ThA	TISCH	D	0.2 - 0.63	**Muck**	**31-45 inches**

Figure 3.3 illustrates the soils coverage for the Mill Creek watershed.

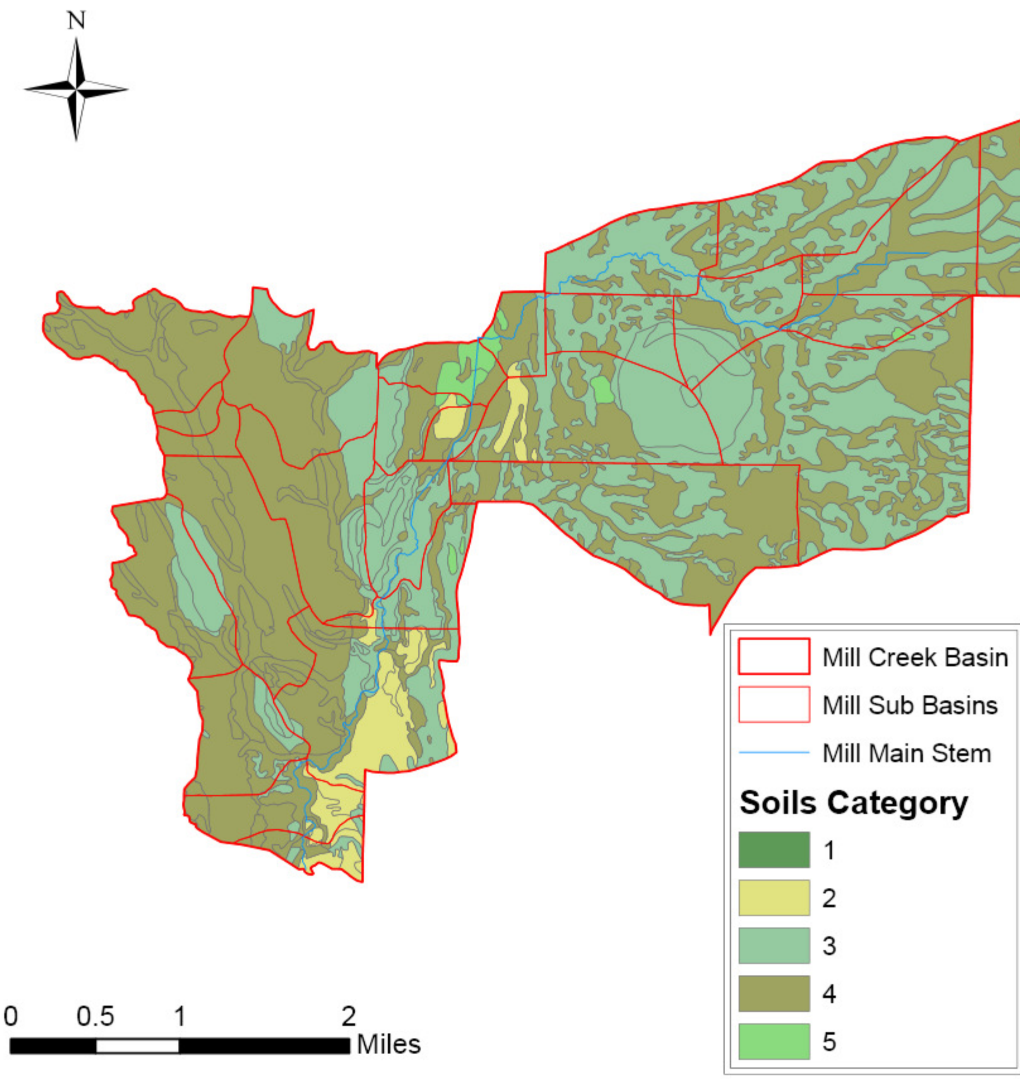


Figure 3.3 Mill Creek Watershed Soils Coverage

As shown in Table 3.5, the Mill Creek watershed is 54% Group 4 soils with 41% Group 3, 4% Group 2, and 1% Group 5.

Figure 3.4 illustrates the soils coverage for the Gee Creek watershed.

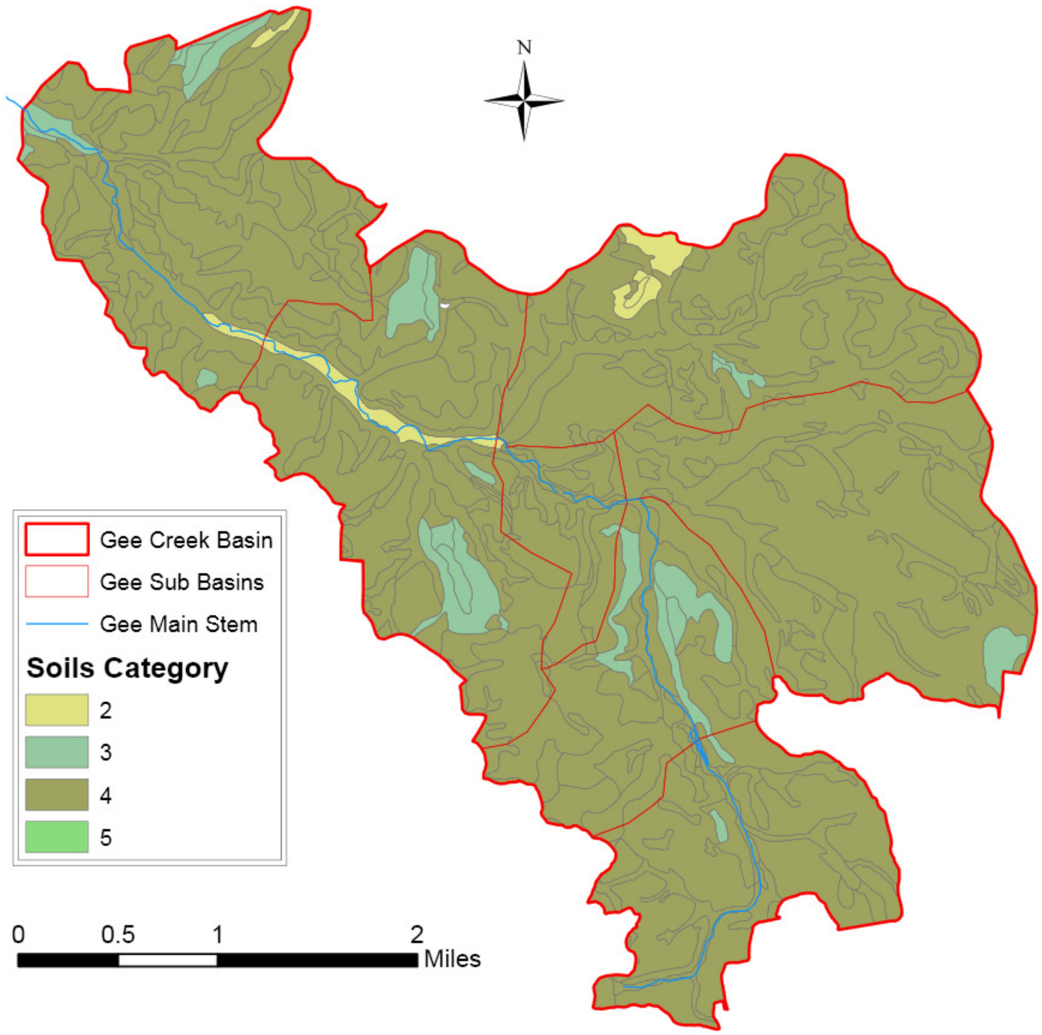


Figure 3.4 Gee Creek Watershed Soils Coverage

As shown in Table 3.6, the Gee Creek watershed is 93% Group 4 soils with 5% Group 3, and 2% Group 2.

Table 3.5 Mill Creek Watershed Soils

Soil Group	Total Area (ac)	Percent of Watershed
1	0.03	0.0%
2	310.42	4.4%
3	2874.89	40.5%
4	3836.62	54.0%
5	81.15	1.1%
Total	7103.11	100.0%

Table 3.6 Gee Creek Watershed Soils

Soil Group	Total Area (ac)	Percent of Watershed
1	0.00	0.0%
2	118.39	1.7%
3	383.29	5.3%
4	6672.73	93.0%
5	0.32	0.0%
Total	7174.73	100.0%

3.2 SUBBASIN DELINEATION

Initial segmentation typically involves grouping areas that have similar topographical features, use practices for a given land, meteorological conditions, contain a fairly uniform stream segment, and/or are a region of particular interest. Once the subbasins and channel segments have been defined, these subbasins must then be further characterized to: 1) develop the representative model categories (i.e., PERLNDs and IMPLNDs); 2) define the physical parameters (e.g., elevation, slopes, channel length) for HSPF using available data; and 3) establish parameter values for HSPF based on past applications in the region and past experience with the model.

The Mill Creek subbasin delineation and resulting stream channel segmentation (Figure 3.5, provided by Otak) were almost exactly the same as those used by the HSPF model of the Mill Creek watershed developed by WEST Consultants. As described above, Clark County and Otak provided the GIS coverage for those subbasins (Table 3.2). The delineation resulted in 27 subbasins ranging in size from 40 to 1036 acres, as listed in Table 3.7. The total land area input to the model is 7581 acres, or approximately 12 square miles.

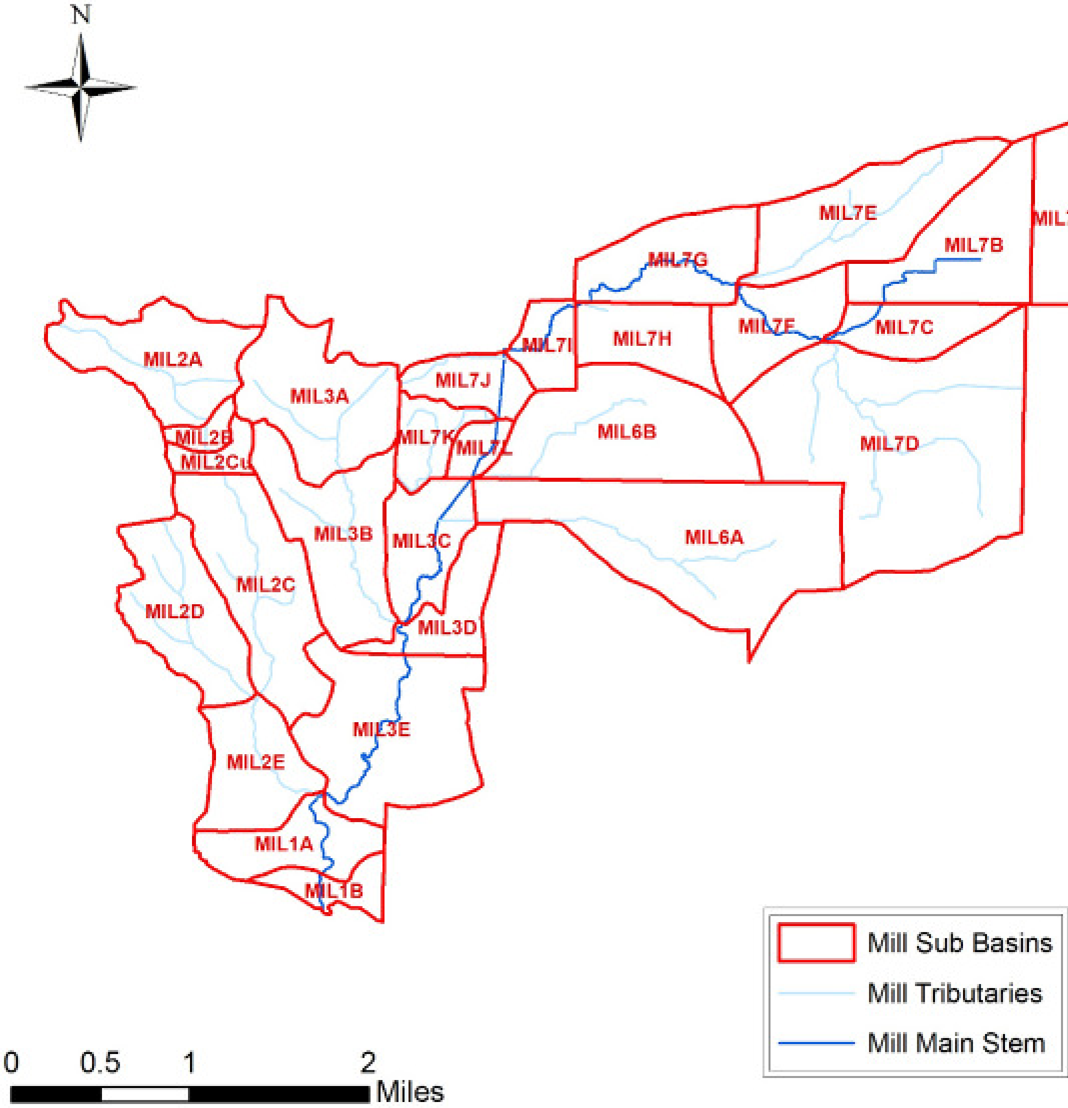


Figure 3.5 Mill Creek Subbasins

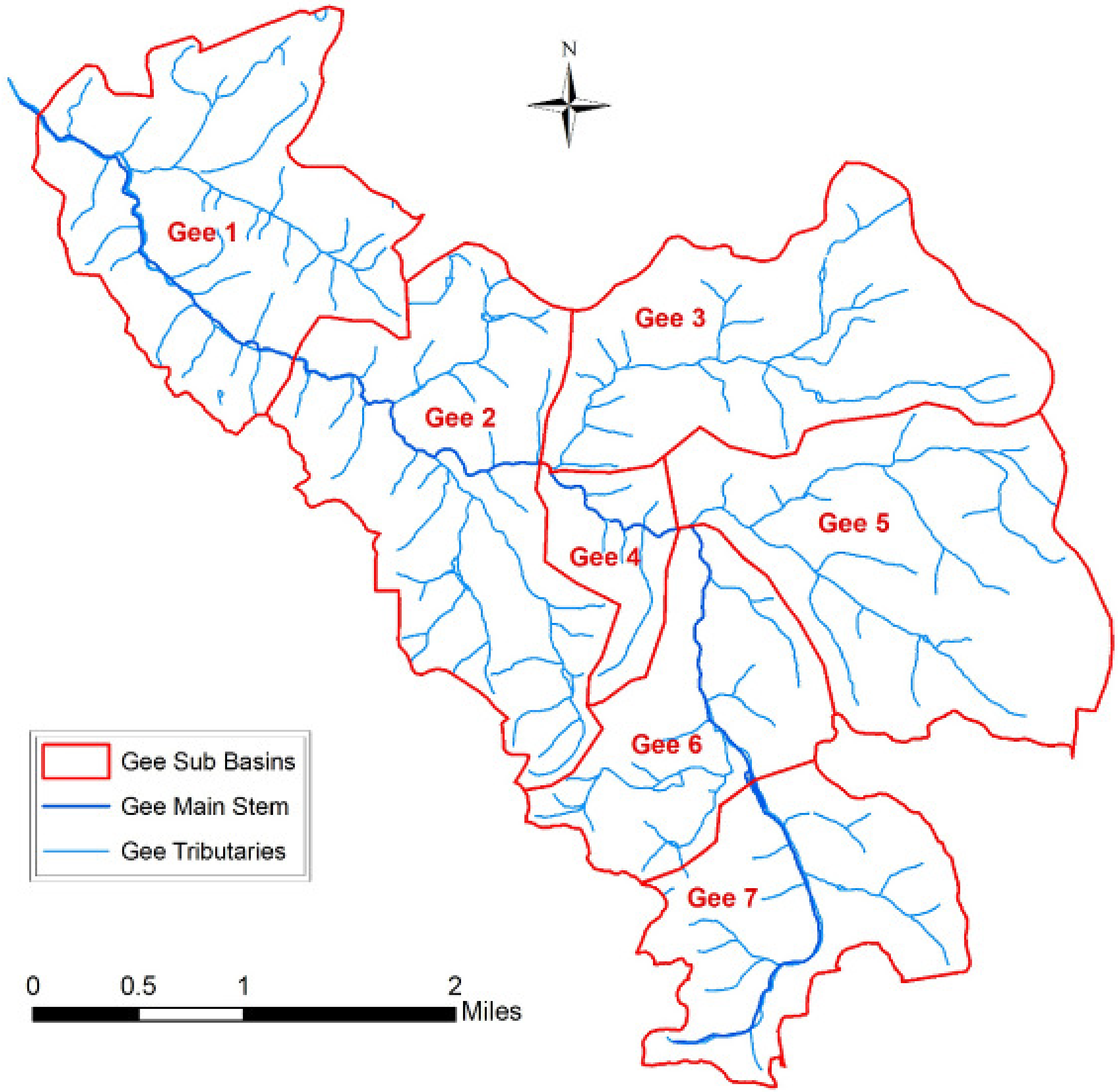


Figure 3.6 Gee Creek Subbasins

Table 3.7 Mill Creek Subbasin Areas

Subbasin	Area (ac)	Area (mi2)	Stream Reach
MIL1A	188.7	0.29	19
MIL1B	84.2	0.13	20
MIL2A	309.0	0.48	23
MIL2B	40.1	0.06	24
MIL2C	410.0	0.64	26
MIL2Cu	55.0	0.09	25
MIL2D	304.0	0.47	27
MIL2E	232.4	0.36	28
MIL3A	368.1	0.58	21
MIL3B	358.2	0.56	22
MIL3C	193.1	0.30	16
MIL3D	156.6	0.24	17
MIL3E	503.2	0.79	18
MIL6A	717.2	1.12	15
MIL6B	482.0	0.75	14
MIL7A	201.2	0.31	1
MIL7B	351.0	0.55	2
MIL7C	150.1	0.23	3
MIL7D	1035.9	1.62	4
MIL7E	374.4	0.59	6
MIL7F	218.2	0.34	5
MIL7G	274.8	0.43	7
MIL7H	189.9	0.30	8
MIL7I	98.0	0.15	9
MIL7J	123.6	0.19	11
MIL7K	107.5	0.17	12
MIL7L	54.7	0.09	13
Total	7581.1	11.85	

The Gee Creek subbasin delineation and resulting stream channel segmentation (Figure 3.6, provided by Otak) were developed by Otak based on discussions with Clear Creek Solutions. As described above, Clark County and Otak provided the GIS coverage for those subbasins (Table 3.2). The delineation resulted in seven subbasins ranging in size from 40 to 1036 acres, as listed in Table 3.8. The total land area input to the model is 7423 acres, or approximately 11.6 square miles.

Table 3.8 Gee Creek Subbasin Areas

Subbasin	Area (ac)	Area (mi2)	Stream Reach
GEE1	1347.0	2.10	1
GEE2	1405.9	2.20	2
GEE3	1265.0	1.98	3
GEE4	291.8	0.46	4
GEE5	1445.1	2.26	5
GEE6	793.1	1.24	6
GEE7	874.8	1.37	7
Total	7422.8	11.60	

3.3 LAND CATEGORIES/SEGMENTS FOR MODELING

All land area in an HSPF model is categorized as either pervious (PERLND) or impervious (IMPLND). The model allows for further subdivisions of these major land categories based on land use, soils, slopes, climate, etc. to represent the range of the hydrologic (and, when appropriate, water quality) response of different landscape conditions within the watershed.

3.3.1 PERLND Types

PERLND types are selected so that a given set of parameters represents the presumably homogeneous hydrologic response from that land type. For this application, the process involved grouping land area by soil type, land use/cover, and slope. The PERLND categories were developed based on the following scheme:

- soils: Group 1, 2, 3, 4, and 5
- land use/cover: forest, field, urban lawn
- land slope: flat (0-5%), moderate (5-15%), steep (>15%)

The soils, land use/cover, and land slope GIS coverages were overlain using ArcGIS and PERLND categories were assigned as unique combinations of these three coverages. The maximum possible number of PERLND's was 45 (Table 3.9), but less may occur if certain soil types, land uses, or slopes are not represented in their respective GIS coverages. Twenty-five (25) unique soil-land use-slope combinations occurred in the Mill Creek watershed. Twenty-four (24) were found in the Gee Creek watershed.

Table 3.9 Possible PERLND Categories

Soil Group 1	Soil Group 2	Soil Group 3	Soil Group 4	Soil Group 5
1,Forest,Flat	2,Forest,Flat	3,Forest,Flat	4,Forest,Flat	5,Forest,Flat
1,Forest,Moderate	2,Forest,Moderate	3,Forest,Moderate	4,Forest,Moderate	5,Forest,Moderate
1,Forest,Steep	2,Forest,Steep	3,Forest,Steep	4,Forest,Steep	5,Forest,Steep
1,Field,Flat	2,Field,Flat	3,Field,Flat	4,Field,Flat	5,Field,Flat
1,Field,Moderate	2,Field,Moderate	3,Field,Moderate	4,Field,Moderate	5,Field,Moderate
1,Field,Steep	2,Field,Steep	3,Field,Steep	4,Field,Steep	5,Field,Steep
1,Lawn,Flat	2,Lawn,Flat	3,Lawn,Flat	4,Lawn,Flat	5,Lawn,Flat
1,Lawn,Moderate	2,Lawn,Moderate	3,Lawn,Moderate	4,Lawn,Moderate	5,Lawn,Moderate
1,Lawn,Steep	2,Lawn,Steep	3,Lawn,Steep	4,Lawn,Steep	5,Lawn,Steep

3.3.2 IMPLND Types

IMPLND areas are equated to effective impervious area (EIA) for modeling purposes. A distinction is made between total impervious area and effective impervious area. Total impervious area consists of all surfaces that do not infiltrate runoff, including all roofs, paved streets, sidewalks, driveways, and parking lots. Effective impervious area (EIA) is defined as area that is hydraulically connected to receiving stream channels; i.e., area where there is no opportunity for surface runoff from an impervious site to infiltrate into the soil before it reaches a conveyance system (pipe, ditch, stream, etc.). There are three IMPLND types in the Mill Creek and Gee Creek HSPF models. The IMPLND types vary by the three land slope categories, the same as for the PERLND types.

Because it is extremely expensive and time consuming to look at every impervious surface in a watershed to determine whether or not it is hydraulically connected to a stream, average EIA values are commonly used. The EIA percentage was based on an average for the land uses because the GIS data did not provide sufficient land category detail to identify unique land use EIA values for each. In both the Mill Creek and Gee Creek watershed an average EIA value of 25% for structures (houses, buildings, etc.) and 75% for pavement areas (roads, sidewalks, driveways, parking lots, etc.). These are typical EIA values for suburban and rural areas.

3.4 FINAL PERLND AND IMPLND AREAS BY SUBBASIN

Determining the PERLND/IMPLND areas within each subbasin via the methodology above was performed within the framework of a GIS system (ArcView). Table 3.10 summarizes the PERLND/IMPLND areas by subbasin in the Mill Creek watershed. A logical numbering system was developed for the PERLND combinations of soil type, land use, and slope, for use in the model. This PERLND Land Segment (PLS) numbering system is included in Table 3.10 and is keyed to the HSPF parameter values presented in Appendix A. It should be noted that the HSPF parameter values shown in Appendix A are the values recommended for use in WWHM3 for Clark County soils. They are not necessarily exactly the same as the Mill Creek and Gee Creek calibration values, but are an adjusted composite of the values from the two watersheds for use throughout the entire county.

Table 3.10 PERLND Areas (acres) by Subbasin in the Mill Creek Watershed

	Soil Group	1	2	2	2	2	2	2	3	3	3	3	3	3
	Land Cover	Field	Forest	Forest	Forest	Field	Field	Field	Forest	Forest	Forest	Field	Field	Field
	Land Slope	Flat	Flat	Moderate	Steep	Flat	Moderate	Steep	Flat	Moderate	Steep	Flat	Moderate	Steep
Subbasin	PLS #	4	10	11	12	13	14	15	19	20	21	22	23	24
MIL1A		0.00	0.64	0.73	1.43	38.02	5.48	0.38	1.10	1.04	2.26	5.88	2.22	0.19
MIL1B		0.00	4.59	3.09	4.63	19.01	4.89	0.46	0.88	1.03	0.99	6.25	4.93	0.34
MIL2A		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL2B		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL2C		0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.21	2.70	0.00	7.94	10.06	0.03
MIL2Cu		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL2D		0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.99	8.41	0.03	28.95	30.22	0.02
MIL2E		0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.68	6.41	1.81	6.09	20.43	0.49
MIL3A		0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.59	1.20	0.00	72.10	10.98	0.00
MIL3B		0.00	0.19	0.25	0.00	0.69	0.54	0.00	9.35	5.14	1.30	32.80	22.08	0.34
MIL3C		0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.24	17.49	3.98	71.63	49.61	0.43
MIL3D		0.00	0.51	0.10	0.00	3.25	0.20	0.00	14.65	6.22	2.74	61.44	15.85	0.52
MIL3E		0.00	20.38	8.16	7.63	101.59	22.03	0.67	25.42	14.22	8.08	62.98	15.10	1.61
MIL6A		0.00	0.02	0.00	0.00	0.58	0.00	0.00	53.07	6.97	0.00	221.59	6.98	0.00
MIL6B		0.00	3.97	0.08	0.00	27.34	1.97	0.00	31.03	34.34	1.26	91.67	85.68	1.43
MIL7A		0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.37	0.35	0.00	58.49	0.46	0.00
MIL7B		0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.98	0.08	0.00	110.66	1.59	0.00
MIL7C		0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.55	0.02	0.00	44.25	0.15	0.00
MIL7D		0.00	0.00	0.00	0.00	0.00	0.00	0.00	114.76	6.82	0.00	364.67	59.93	0.00
MIL7E		0.00	0.00	0.00	0.00	0.00	0.00	0.00	59.93	0.66	0.00	159.73	0.86	0.00
MIL7F		0.00	0.00	0.00	0.00	0.00	0.00	0.00	39.67	14.31	0.05	59.60	32.76	3.60
MIL7G		0.00	0.00	0.00	0.00	0.00	0.00	0.00	85.78	15.69	0.60	81.65	3.83	0.13
MIL7H		0.00	0.00	0.00	0.00	0.00	0.00	0.00	39.57	22.76	1.46	54.33	22.29	1.06
MIL7I		0.03	1.74	0.00	0.00	2.25	0.00	0.00	4.35	0.89	0.00	8.68	1.33	0.00
MIL7J		0.00	0.06	0.00	0.00	0.01	0.00	0.00	2.02	0.76	0.30	8.88	1.71	0.01
MIL7K		0.00	0.12	0.04	0.00	4.10	0.00	0.00	8.45	10.35	6.38	23.36	6.05	1.19
MIL7L		0.00	13.31	0.00	0.00	5.30	0.00	0.00	1.40	0.00	0.00	4.69	0.00	0.00
Total		0.03	45.52	12.47	13.68	202.14	35.10	1.52	601.03	177.84	31.23	1648.33	405.08	11.38
Percent		0.00%	0.64%	0.18%	0.19%	2.85%	0.49%	0.02%	8.46%	2.50%	0.44%	23.21%	5.70%	0.16%

Table 3.10 cont'd. PERLND Areas (acres) by Subbasin in the Mill Creek Watershed

	Soil Group	4	4	4	4	4	4	5	5	5	5	5	5
	Land Cover	Forest	Forest	Forest	Field	Field	Field	Forest	Forest	Forest	Field	Field	Field
	Land Slope	Flat	Moderate	Steep	Flat	Moderate	Steep	Flat	Moderate	Steep	Flat	Moderate	Steep
Subbasin	PLS #	28	29	30	31	32	33	37	38	39	40	41	42
MIL1A		5.12	13.98	26.46	18.60	51.96	6.96	0.00	0.00	0.00	0.00	0.00	0.00
MIL1B		0.94	2.98	5.90	11.36	9.53	1.03	0.00	0.00	0.00	0.00	0.00	0.00
MIL2A		83.82	3.50	0.00	201.39	6.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL2B		2.79	2.63	0.00	22.67	10.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL2C		68.36	71.18	7.83	111.47	108.30	2.20	0.00	0.00	0.00	0.00	0.00	0.00
MIL2Cu		5.16	1.39	0.00	36.58	10.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL2D		56.50	44.36	6.11	59.24	41.37	0.49	0.00	0.00	0.00	0.00	0.00	0.00
MIL2E		11.20	40.06	24.32	28.15	60.43	2.74	0.00	0.00	0.00	0.00	0.00	0.00
MIL3A		62.25	12.59	0.00	151.69	30.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL3B		36.76	34.28	8.44	122.26	74.87	1.36	0.00	0.00	0.00	0.00	0.00	0.00
MIL3C		0.84	0.17	0.00	22.77	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL3D		1.27	0.56	0.00	32.80	7.39	0.00	0.10	0.03	0.00	3.17	0.30	0.00
MIL3E		29.26	23.90	19.56	80.92	42.45	1.15	0.00	0.00	0.00	0.00	0.00	0.00
MIL6A		64.58	7.37	0.00	328.66	2.63	0.00	0.01	0.13	0.00	0.04	0.00	0.00
MIL6B		18.18	0.40	0.00	156.28	4.12	0.00	0.19	0.00	0.00	9.98	0.65	0.00
MIL7A		7.76	0.17	0.00	67.29	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL7B		27.98	0.26	0.00	106.87	1.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL7C		12.79	0.46	0.00	33.87	0.12	0.00	2.61	0.00	0.00	0.00	0.00	0.00
MIL7D		94.00	0.89	0.00	321.77	1.88	0.00	1.59	0.00	0.00	0.20	0.00	0.00
MIL7E		40.79	0.12	0.00	89.22	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL7F		10.13	0.41	0.00	46.89	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL7G		29.64	1.09	0.00	36.31	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL7H		12.17	0.45	0.00	29.31	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MIL7I		27.86	2.17	0.00	25.42	1.26	0.00	0.52	0.00	0.00	11.59	0.18	0.00
MIL7J		8.19	5.47	0.43	39.33	11.47	0.04	0.22	1.94	0.14	41.07	0.96	0.00
MIL7K		14.12	7.98	1.91	11.40	4.61	0.19	0.28	0.79	0.00	4.22	0.24	0.00
MIL7L		6.72	0.81	0.00	20.94	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		739.20	279.63	100.97	2213.44	487.23	16.15	5.52	2.89	0.14	70.27	2.34	0.00
Percent		10.41%	3.94%	1.42%	31.16%	6.86%	0.23%	0.08%	0.04%	0.00%	0.99%	0.03%	0.00%

Table 3.11 PERLND Areas (acres) by Subbasin in the Gee Creek Watershed

	Soil Group	2	2	2	2	2	2	3	3	3	3	3	3
	Land Cover	Forest	Forest	Forest	Field	Field	Field	Forest	Forest	Forest	Field	Field	Field
	Land Slope	Flat	Moderate	Steep	Flat	Moderate	Steep	Flat	Moderate	Steep	Flat	Moderate	Steep
Subbasin	PLS #	10	11	12	13	14	15	19	20	21	22	23	24
GEE1		5.01	4.30	1.38	5.62	2.68	0.22	6.35	11.15	20.79	17.27	15.11	4.98
GEE2		15.71	6.11	3.45	17.41	4.84	0.64	6.68	9.73	3.13	48.66	73.96	2.44
GEE3		0.04	1.98	0.08	0.37	47.41	0.00	0.15	0.83	0.14	1.70	8.18	0.33
GEE4		0.51	0.34	0.24	0.02	0.01	0.03	0.00	0.56	0.00	0.06	1.79	0.00
GEE5		0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.06	0.00	0.00	18.74	0.00
GEE6		0.00	0.00	0.00	0.00	0.00	0.00	0.98	34.33	9.35	2.39	59.79	4.16
GEE7		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.35	0.00	7.22	0.93
Total		21.27	12.73	5.15	23.41	54.94	0.89	14.17	67.65	33.77	70.07	184.80	12.84
Percent		0.30%	0.18%	0.07%	0.33%	0.77%	0.01%	0.20%	0.94%	0.47%	0.98%	2.58%	0.18%

Table 3.11 cont'd. PERLND Areas (acres) by Subbasin in the Gee Creek Watershed

	Soil Group	4	4	4	4	4	4	5	5	5	5	5	5
	Land Cover	Forest	Forest	Forest	Field	Field	Field	Forest	Forest	Forest	Field	Field	Field
	Land Slope	Flat	Moderate	Steep	Flat	Moderate	Steep	Flat	Moderate	Steep	Flat	Moderate	Steep
Subbasin	PLS #	28	29	30	31	32	33	37	38	39	40	41	42
GEE1		73.34	187.14	278.12	189.85	374.66	110.48	0.00	0.00	0.00	0.00	0.00	0.00
GEE2		59.32	161.34	144.60	296.52	443.40	81.75	0.00	0.23	0.03	0.00	0.02	0.04
GEE3		23.27	234.95	84.41	46.06	761.29	13.31	0.00	0.00	0.00	0.00	0.00	0.00
GEE4		14.28	32.13	32.09	92.19	102.21	6.28	0.00	0.00	0.00	0.00	0.00	0.00
GEE5		21.91	301.75	48.01	30.93	959.62	19.15	0.00	0.00	0.00	0.00	0.00	0.00
GEE6		24.24	175.96	35.82	69.90	311.40	30.16	0.00	0.00	0.00	0.00	0.00	0.00
GEE7		2.63	225.97	1.23	8.29	561.42	1.37	0.00	0.00	0.00	0.00	0.00	0.00
Total		218.99	1319.23	624.27	733.74	3514.01	262.49	0.00	0.23	0.03	0.00	0.02	0.04
Percent		3.05%	18.39%	8.70%	10.23%	48.98%	3.66%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

NOTE: The HSPF parameter values for the Pervious Land Segment (PLS) numbers listed above are shown in Appendix A.

3.5 RCHRES SEGMENTS

When a watershed is divided into subbasins, the hydrographic divisions follow the same geographic boundaries as the land area. HSPF calculates the hydraulic response of each hydrographic segment (RCHRES) in the same manner, whether the segment is a stream reach or a reservoir. There are many critical specifications that need to be made for each RCHRES, including length, elevation change, and the depth-surface area-storage volume-discharge relationships. These relationships are called FTABLEs, for function tables, in HSPF. Length and elevation change were obtained from the GIS streams and DEM coverages. The other relationships are based on cross-sectional data.

The modeling scheme for a watershed includes every subbasin draining to a RCHRES. In the Mill Creek watershed there are a total of 27 RCHRESs, nine representing tributaries to the main stem of Mill and five representing the gaged tributary draining subbasins MIL2A through MIL2E on the western side of the watershed. All of the stream reaches were based on FTABLEs provided in previous HSPF modeling work of Mill Creek by WEST Consultants and provided to Clear Creek Solutions by Otak.

In the Gee Creek watershed there are a total of seven RCHRESs, two representing tributaries to the main stem of Gee. The five mainstem stream reaches were based on FTABLEs from previous HEC-RAS modeling work of Gee Creek by WEST Consultants and provided to Clear Creek Solutions by Otak.

3.6 FTABLE DEVELOPMENT

Within the channel module (RCHRES) of HSPF, each stream reach is represented by an FTABLE. An FTABLE will typically contain numerous depth-surface area-volume-discharge relationships to cover the range of flows expected to occur.

In order to develop an FTABLE, the geometric and hydraulic properties of the channel must first be defined using measured data or estimated values. Fortunately, as mentioned above, this information had been previously collected to construct an HSPF model of the Mill Creek watershed and a HEC-RAS model of Gee Creek. The original cross-section data used for the FTABLE construction were obtained from FEMA flood insurance studies of Mill Creek and Gee Creek by WEST Consultants. The flood insurance study HEC-RAS models of Mill Creek and Gee Creek provided depth (stage) and volume information for various user-selected discharges.

In developing the stream reach segmentation for the HSPF application, reach endpoints were selected to correspond with the previous HSPF model's reach endpoints. Thus, the geometric and hydraulic properties used in developing the previous model could be used directly in this calibration effort.

SECTION 4.0

CALIBRATION

4.1 CALIBRATION PROCEDURES AND COMPARISONS

Calibration of a watershed with HSPF is an iterative process of making parameter changes, running the model and producing comparisons of simulated and observed values, and interpreting the results. The procedures have been well established over the past 20 years as described in the HSPF Application Guide (Donigian et al., 1984) and recently summarized by Donigian (2002).

Hydrologic simulation combines physical characteristics of a watershed and observed meteorologic data to produce a simulated hydrologic response. HSPF simulates flow to the stream network from four components: surface runoff from hydraulically connected impervious areas, surface runoff from pervious areas, interflow from pervious areas, and shallow groundwater flow from pervious areas. Because historic streamflow is not divided into these four units, the relative relationship among these components must be inferred from the examination of many events over several years of continuous simulation.

Characteristics of a watershed that control the hydrologic response include topography, vegetation and other ground cover, the amount of impervious surface area, soil composition and structure, and the stream/reservoir network. The HSPF model simulates the hydrologic response of a watershed by quantifying the hydrologic activity initiated by meteorological inputs and controlled by a set of user-defined input parameters that describe the physical characteristics of the watershed. The input parameters affect the water budget by influencing the overall volume of water that flows to the stream and the distribution of pathways among that flow.

Calibration of HSPF to represent the hydrology of the Mill Creek and Gee Creek watersheds is an iterative trial-and-error process. Simulated results are compared with recorded data for the entire calibration period, including both wet and dry conditions, to see how well the simulation represents the hydrologic response observed under a range of climatic conditions.

By iteratively adjusting specific calibration parameter values, within accepted and physically realistic ranges, the simulation results are changed until an acceptable comparison of simulation and recorded data is achieved.

4.2 CALIBRATION SUMMARY

The observed and simulated streamflow was compared at two flow gaging sites in the Mill Creek watershed and one gaging station in the Gee Creek watershed. The HSPF calibration parameter values were adjusted to produce simulated flow hydrographs that mimicked the observed streamflow's response to rainfall. Each watershed was calibrated separately with different parameter values and then a final calibration was made with a composite, average set of parameter values representing both watersheds. It is this average set of HSPF parameter values that will be used in WWHM3.

There are a number of statistical comparisons that can be made between the simulated and observed streamflow time series. These statistical comparisons are more useful for calibrations that include a relatively long (5+ year) calibration period and that have a substantial base flow in addition to individual peak flow events. The Mill Creek calibration does not fit this criterion. The calibration periods (described below) are relatively short with some gaps (missing periods) in the record. As a result, the accuracy of the calibrations is judged on the ability to match individual hydrographs and to produce a good match of the observed flow duration curve. Gee Creek has a longer and more complete streamflow record, but other problems were observed with the streamflow data that effectively reduced the calibration period to the last three years (2005-2007) and, as with Mill Creek, the focus of the calibration was to match individual hydrographs and to produce a good match of the observed flow duration curve.

The primary focus of the calibrations was on the peak flows, as the stormwater modeling in WWHM is based on the surface runoff and interflow components of the hydrologic response (these two runoff components produce the peak flows).

The Mill Creek calibration results are shown below for the Mill Creek tributary at NE 199th Street and Mill Creek near the mouth. The entire calibration period was from May 2003 through September 2007; observed flow data for the NE 199th Street gage was limited to January 2005 through January 2006. The period with the most flow events at the NE 199th Street gage was January through May 2005. Based on a visual comparison of flow peaks and volumes the simulation of this period is good.

The Mill calibration near the mouth includes the entire calibration period of May 2003 through September 2007. The hydrographs show the entire period plus the specific flow events for the months of June through December 2003, December 2003, January through March 2004, December 2004 through March 2005, April through August 2005, October through December 2005, January through March 2006, October through December 2006, and January through March 2007. A few events were oversimulated (simulated greater than observed) and some were undersimulated. A better match of simulated flow with observed data could have been made if the sole purpose of the calibration was to produce HSPF parameter values for only Mill Creek and not for all of Clark County. However, that said, there was still a good match of the simulated flow peaks with the observed peaks for most events.

4.3 CALIBRATION RESULTS FOR MILL CREEK WATERSHED

This section presents and discusses the comparison of model results with the observed data, performed for the calibration period for Mill Creek at the upstream NE 199th Street gage and the downstream gage near the mouth of Mill Creek.

4.3.1 Flow Duration Comparisons

The flow duration curve is a primary component of the weight-of-evidence assessment for model performance because it reflects the overall hydrologic regime of the contributing watershed. Figures 4.1 and 4.2 illustrate the percent chance of flow exceedance across the range of observed flows for NE 199th Street and the gage near the mouth, respectively.

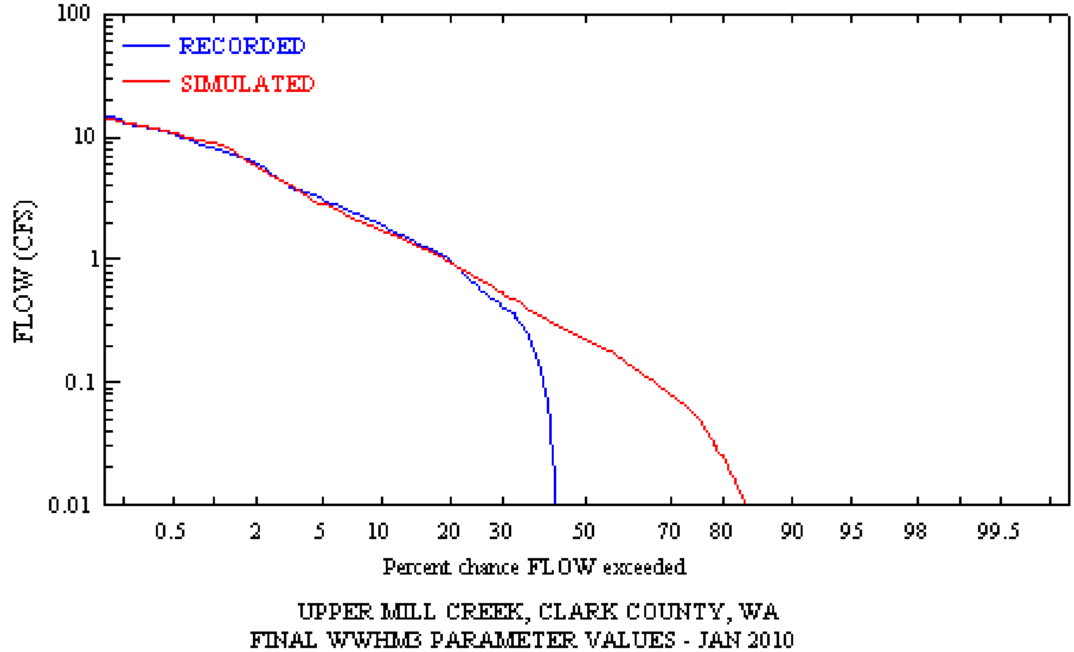


Figure 4.1 Mill Tributary at NE 199th Street Calibration Flow Duration Curves

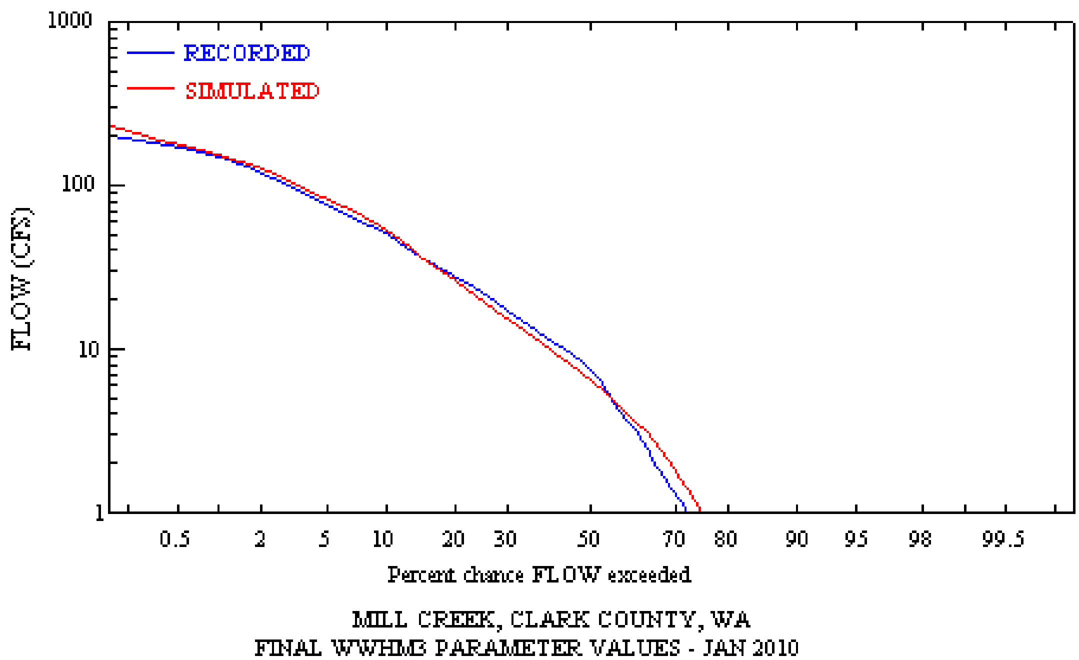


Figure 4.2 Mill Creek near Mouth Calibration Flow Duration Curves

The calibration period shows a good agreement between the flow duration curves through the full range of observed flows above 1 cfs. For the upper Mill Creek gage at NE 199th Street there is a slight oversimulation of flows greater than 10 cfs and an undersimulation of low flows below 1 cfs.

At the lower gage near the mouth of Mill Creek there is a good agreement between the recorded and simulated flow duration curves for all flows. The simulated results show less base flow than recorded below 0.5 cfs. This is not important for the purposes of this calibration, which is more focused on high flows produced by stormwater runoff than low flows produced by groundwater discharge. Also, it should be noted that observed/recorded flows less than 0.5 cfs are often suspect due to the difficulties of measuring such low flows.

4.3.2 Storm Event Comparisons

The most important step in model calibration is to examine representation of individual storm hydrographs. During calibration, adjustments to surface runoff, interflow, and recession parameters may be performed to improve overall agreement after examining a number of individual event simulations. Individual storm simulations will show larger deviations from observed values than for daily and monthly totals, often due to dynamic variations in rainfall spatial distributions not accurately represented by the gage network. Also, we will often see timing differences due to clock errors, either in the rainfall or flow gage instrumentation. Consequently it is necessary to examine a number of flow events to assess the simulation accuracy; this is performed by reviewing the mean daily flow results, storm volumes and peaks, and individual hydrographs often at hourly time intervals.

Figures 4.3 and 4.4 show how the model produces Mill tributary flow simulations for the entire 2005 calibration period at the NE 199th Street gage. While there are some obvious events where the simulated flow events do not match the observed (most obviously March and May 2005 peaks), in general the simulated values only show minor deviations from the observed values. The resulting flow patterns are clearly similar.

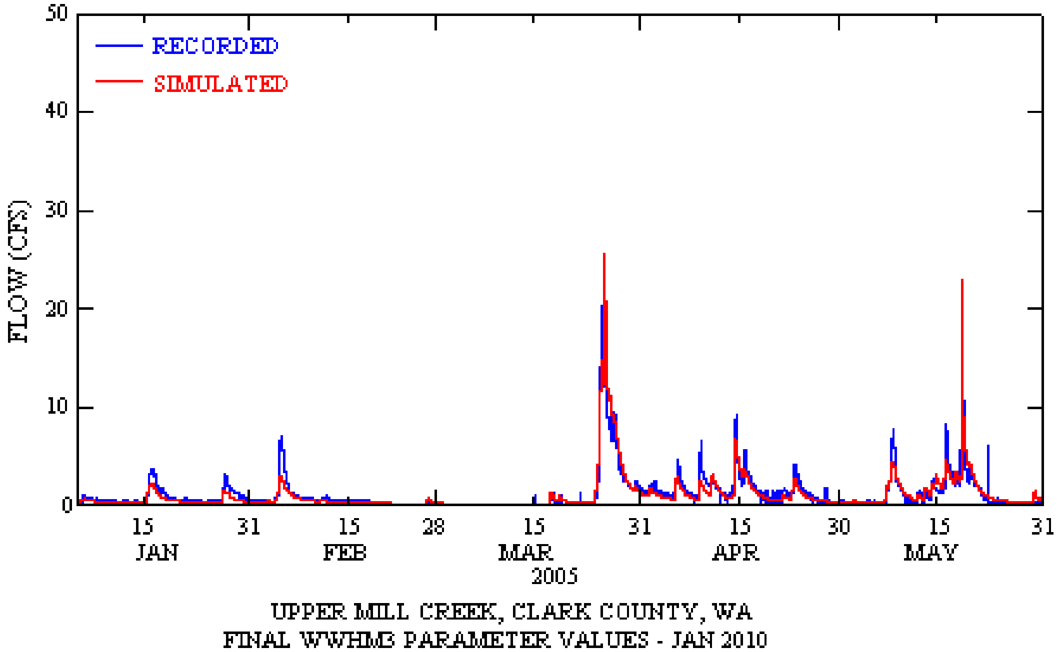


Figure 4.3 Mill Trib at NE 199th Street (January – May 2005)

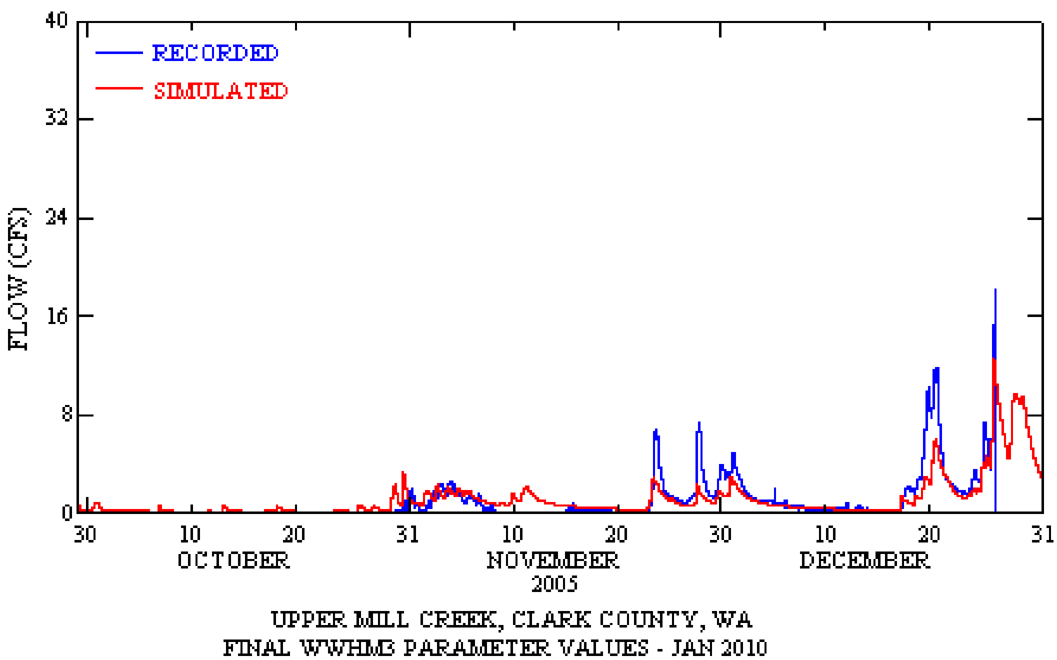


Figure 4.4 Mill Trib at NE 199th Street (October – December 2005)

A comparison of the Mill Creek flows at the downstream gage (near the mouth) shows, in general, very good match between the simulated and observed data.

The entire calibration period is shown in Figure 4.5. This figure shows that almost all of the hydrologic events of any significance occur between November and March. Calibration periods where there is a very good or better match between the simulated and observed flow data include December 2004 through March 2005 (Figure 4.10), October through December 2005 (Figure 4.12), January through March 2006 (Figure 4.13), and January through March 2007 (Figure 4.15). The simulated peak flows are low compared to the observed data for the January through March 2004 events (Figure 4.9) and are high for the April through August 2005 (Figure 4.11) events. There is a mixture of low and high simulated peak flows for the period of October through December 2006 (Figure 4.14) events. The fact that there are both low and high simulation periods demonstrates that there is no specific bias in the modeling results.

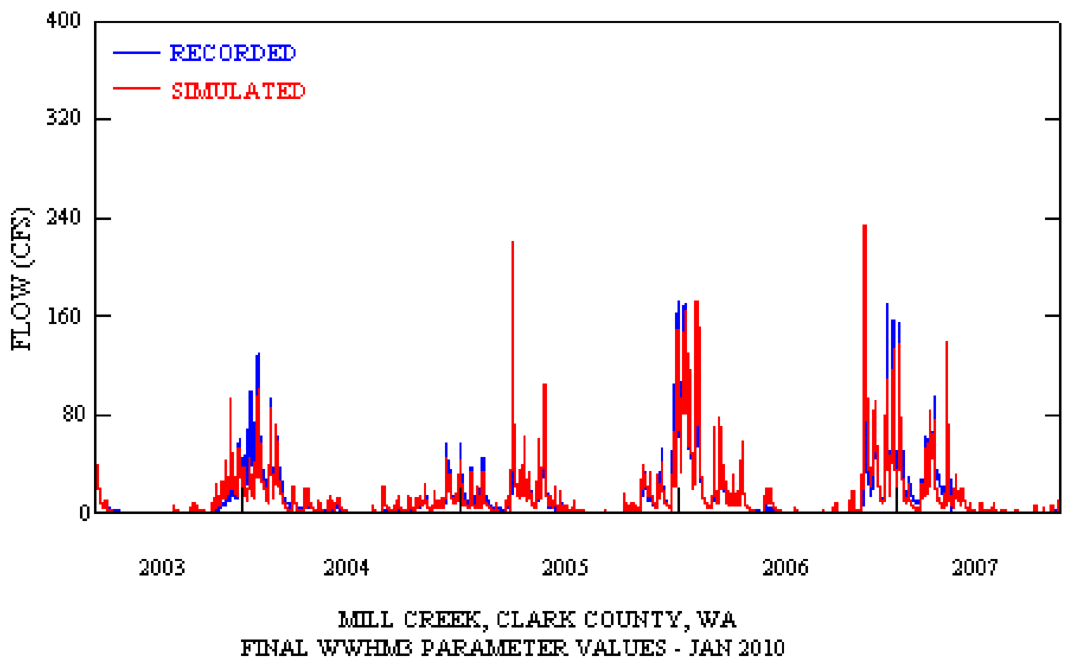


Figure 4.5 Mill Creek near mouth (May 2003 – Sep 2007)

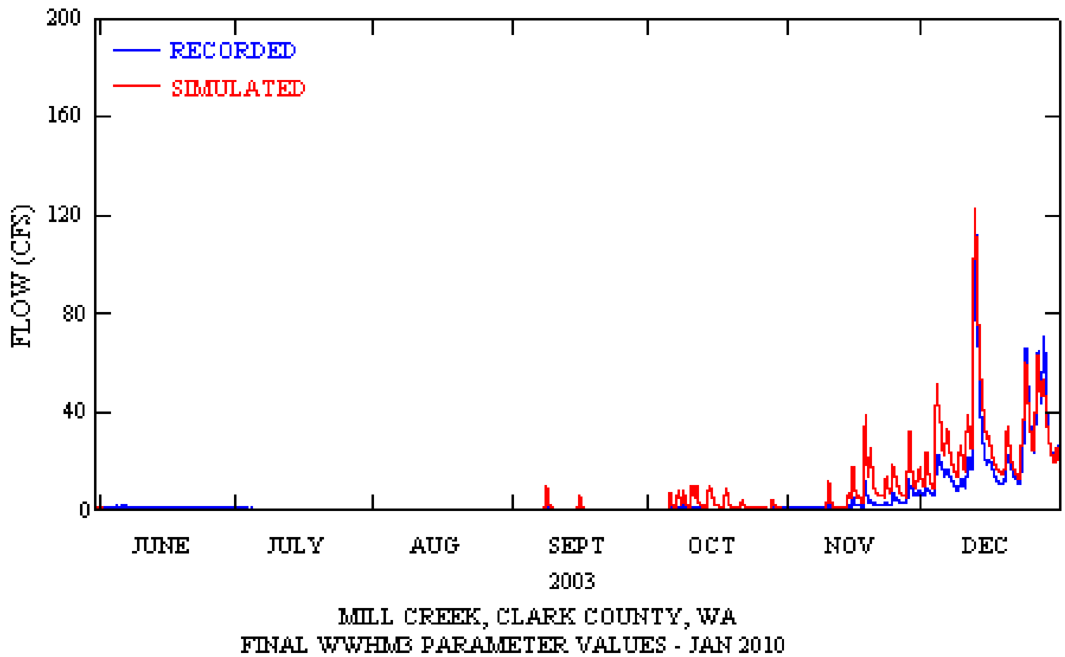


Figure 4.6 Mill Creek near mouth (June – December 2003)

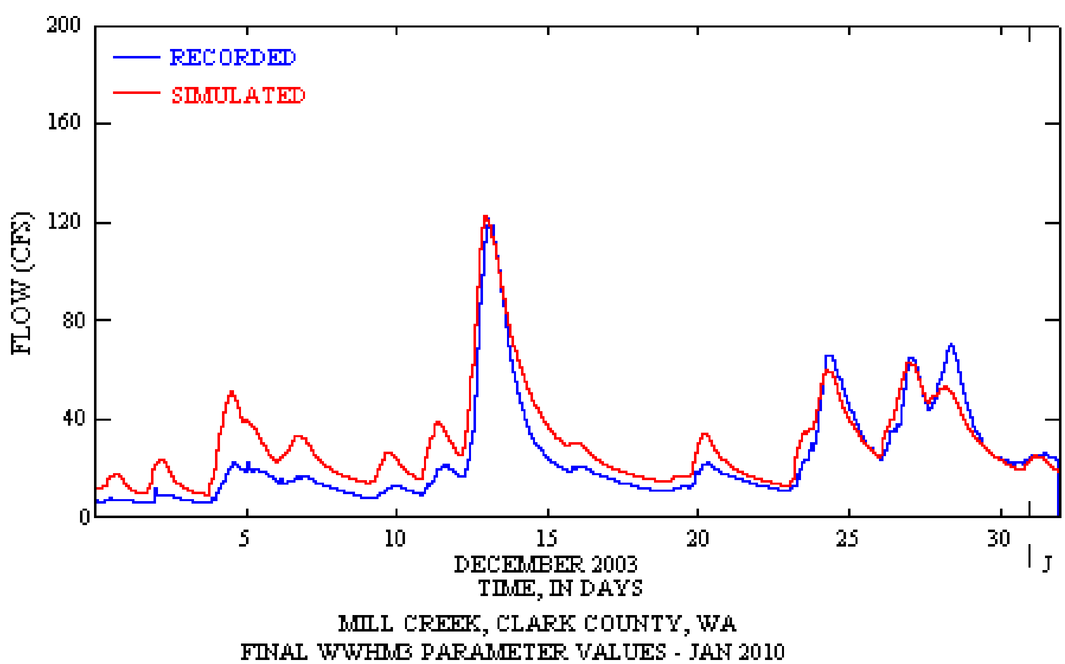


Figure 4.7 Mill Creek near mouth (December 2003)

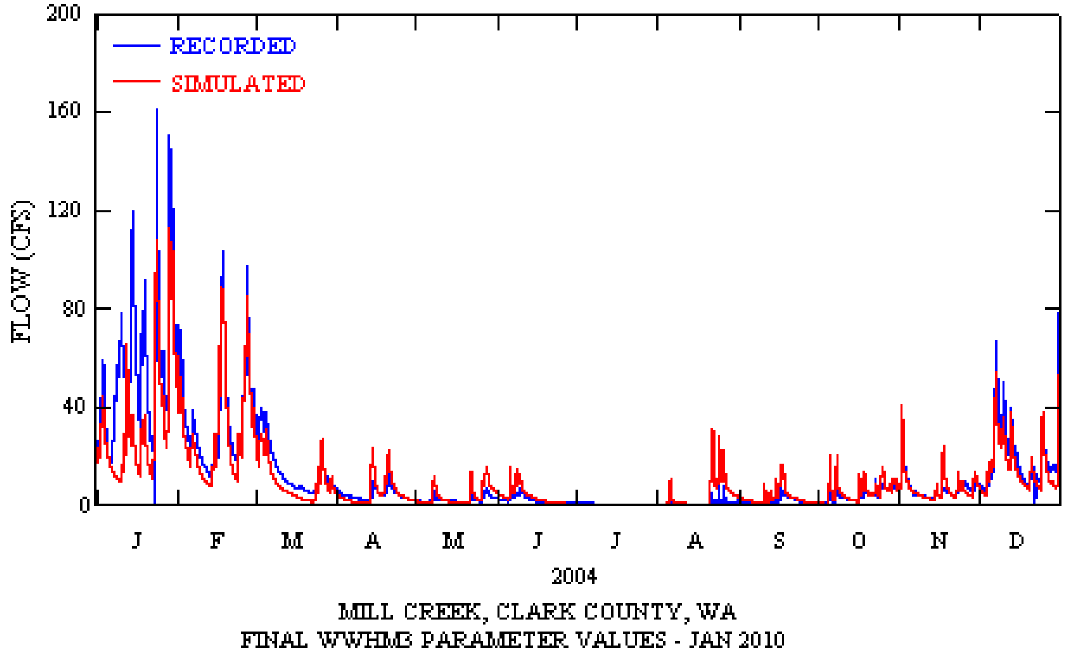


Figure 4.8 Mill Creek near mouth (January – December 2004)

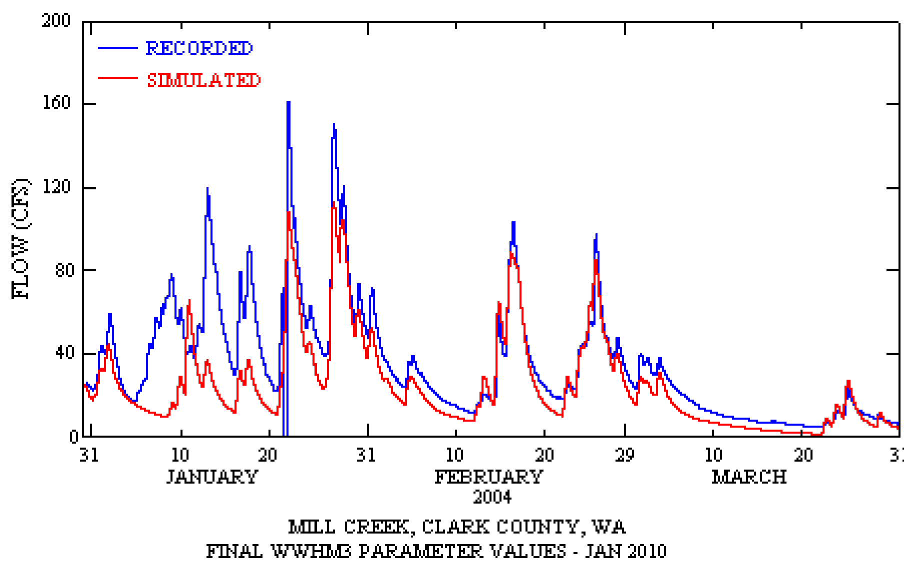


Figure 4.9 Mill Creek near mouth (January – March 2004)

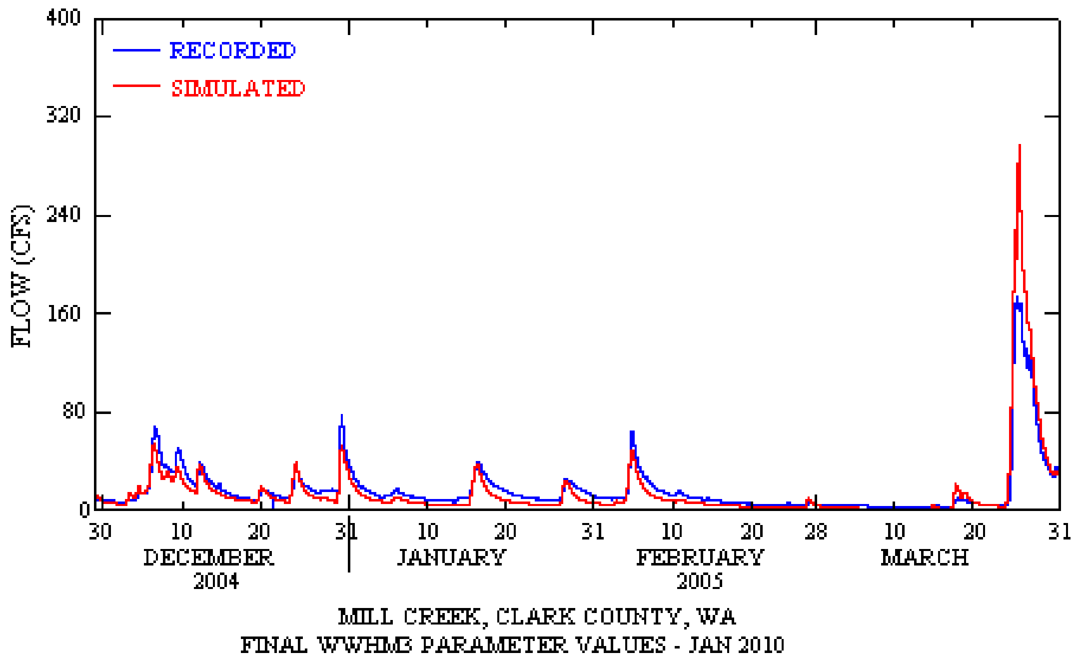


Figure 4.10 Mill Creek near mouth (December 2004 – March 2005)

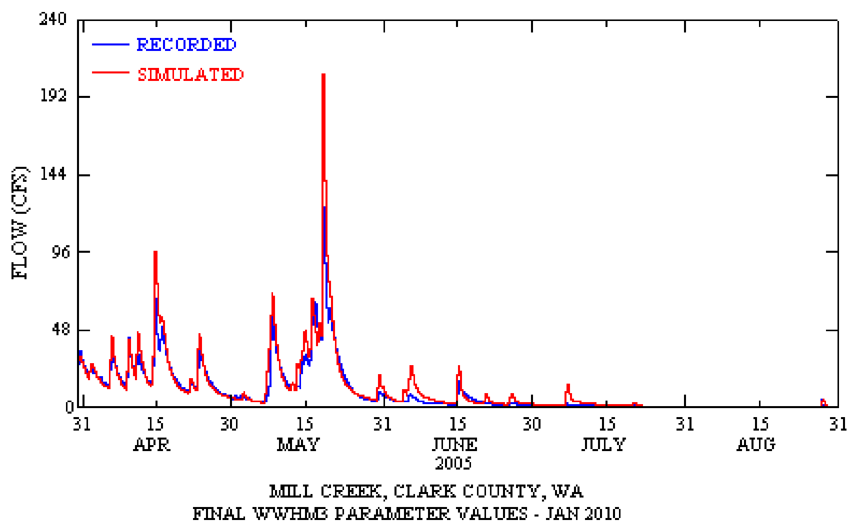


Figure 4.11 Mill Creek near mouth (April – August 2005)

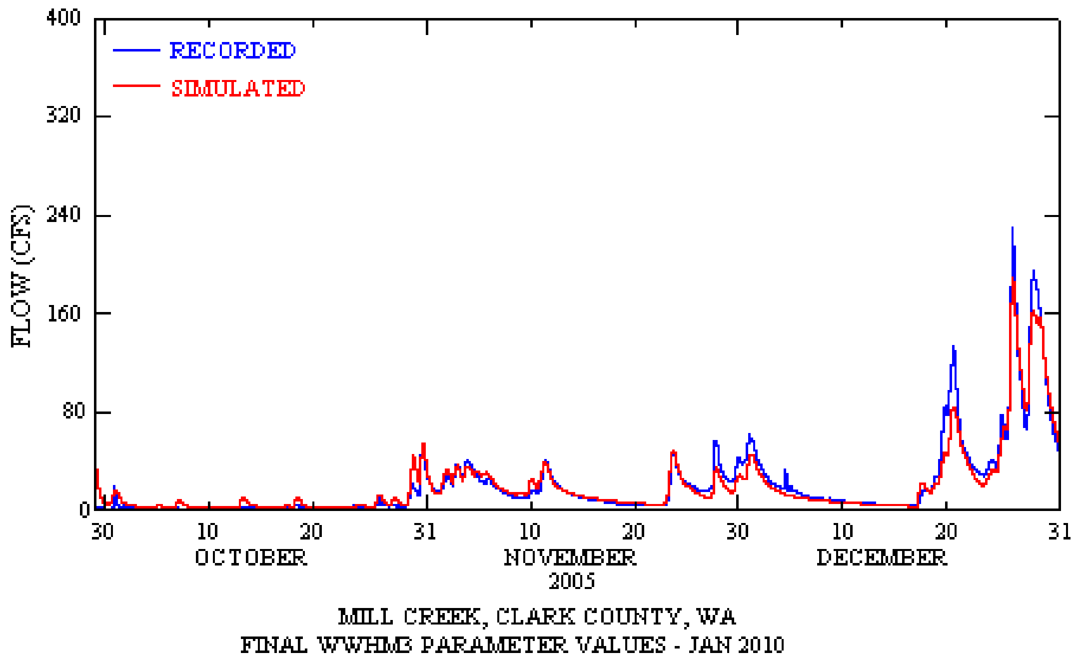


Figure 4.12 Mill Creek near mouth (October – December 2005)

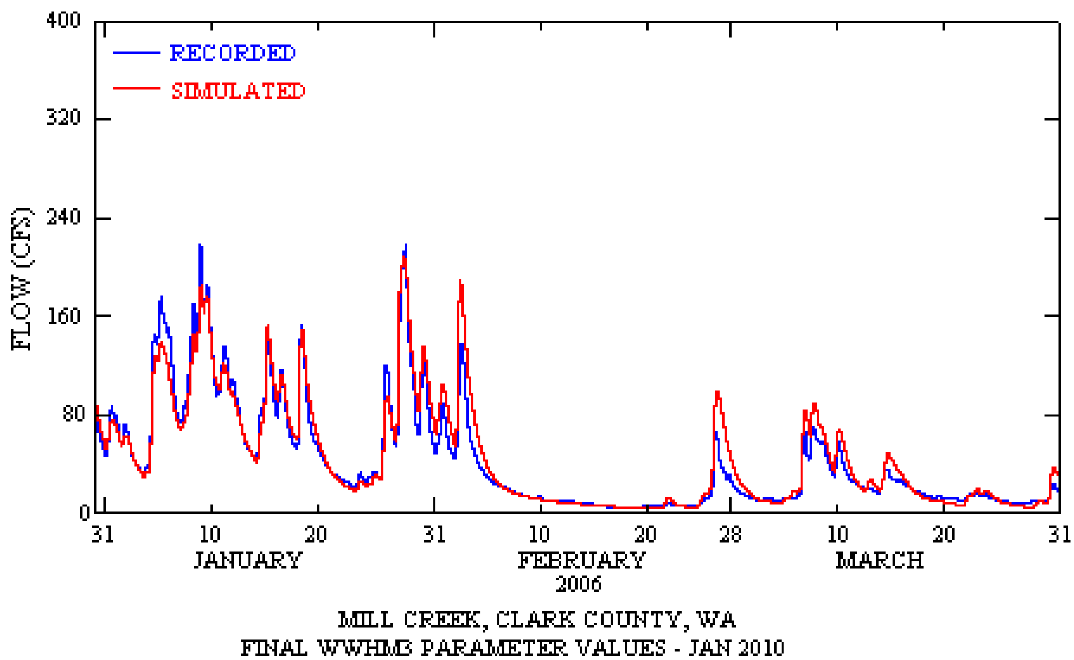


Figure 4.13 Mill Creek near mouth (January – March 2006)

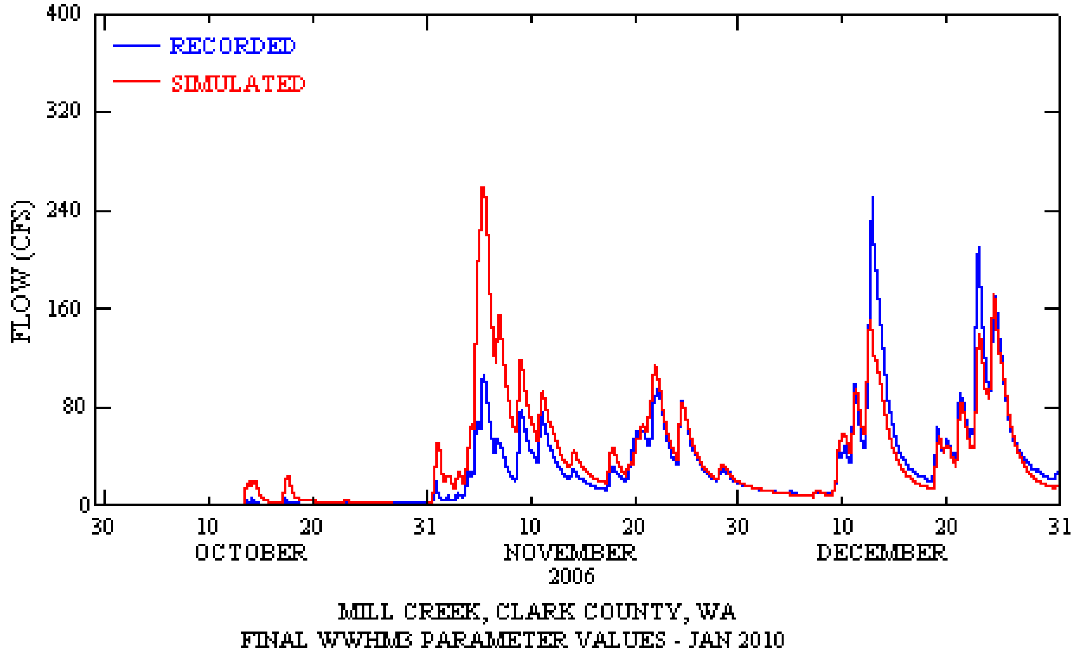


Figure 4.14 Mill Creek near mouth (October – December 2006)

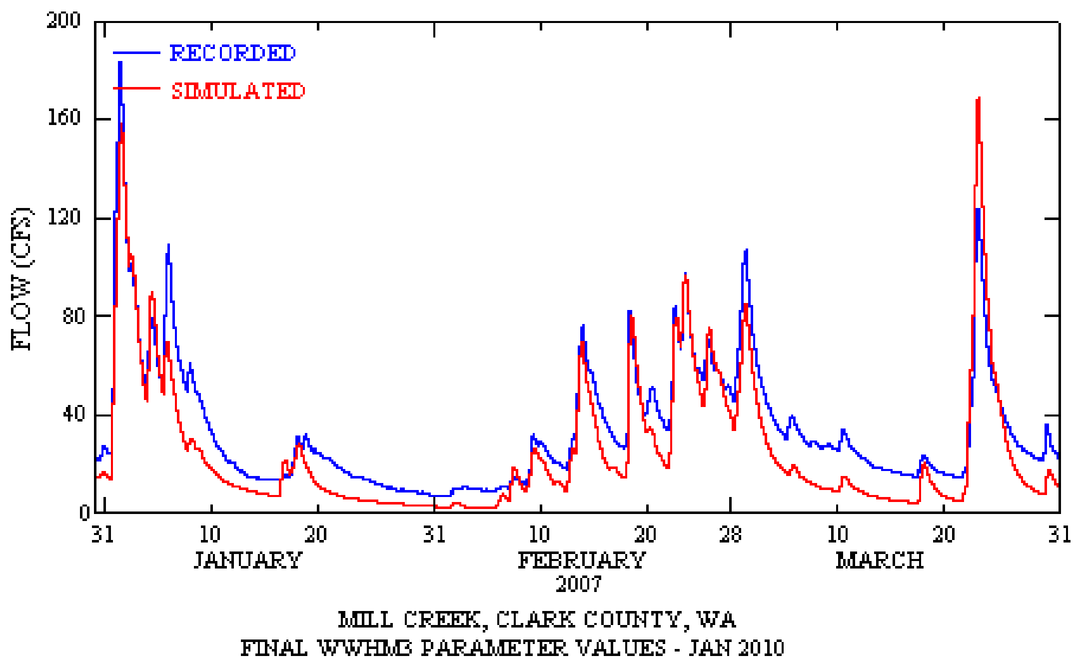


Figure 4.15 Mill Creek near mouth (January – March 2007)

4.4 CALIBRATION RESULTS FOR GEE CREEK WATERSHED

This section presents and discusses the comparison of model results with the observed data, performed for the calibration period for Gee Creek at gage near the mouth of the creek.

4.4.1 Flow Duration Comparisons

The flow duration curve is a primary component of the weight-of-evidence assessment for model performance because it reflects the overall hydrologic regime of the contributing watershed. Figure 4.16 illustrates the percent chance of flow exceedance across the range of observed flows for the gage near the mouth.

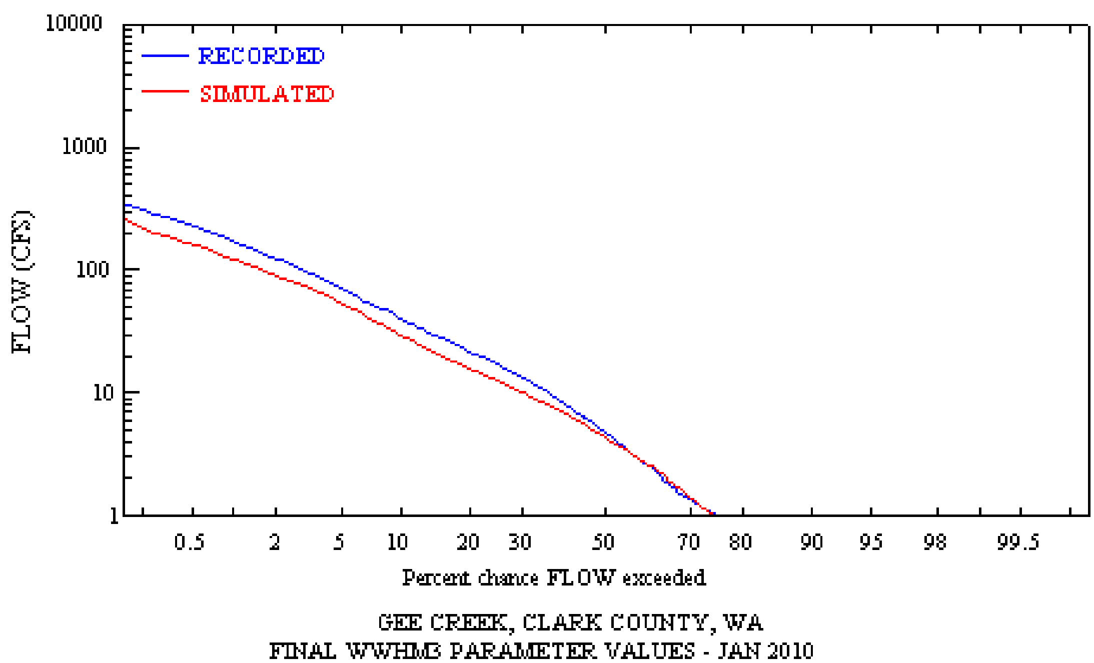


Figure 4.16 Gee Creek near Mouth Calibration Flow Duration Curves

The calibration period shows a good agreement between the flow duration curves through the full range of observed flows above 1 cfs. There is a slight undersimulation of flows greater than 10 cfs. The simulated results also show less base flow than recorded below 1 cfs. This is not important for the purposes of this calibration, which is more focused on high flows produced by stormwater runoff than low flows produced by groundwater discharge. Also, it should be noted that observed/recorded flows less than 1 cfs are often suspect due to the difficulties of measuring such low flows.

4.4.2 Storm Event Comparisons

The most important step in model calibration is to examine representation of individual storm hydrographs. During calibration, adjustments to surface runoff, interflow, and recession parameters may be performed to improve overall agreement after examining a number of individual event simulations. Individual storm simulations will show larger deviations from observed values than for daily and monthly totals, often due to dynamic variations in rainfall spatial distributions not accurately represented by the gage network. Also, we will often see timing differences due to clock errors, either in the rainfall or flow gage instrumentation. Consequently it is necessary to examine a number of flow events to assess the simulation accuracy; this is performed by reviewing the mean daily flow results, storm volumes and peaks, and individual hydrographs often at hourly time intervals.

A comparison of the Gee Creek flows at the gaging site (near the mouth) shows, in general, very good match between the simulated and observed data.

The entire calibration period is shown in Figure 4.17. This figure shows that almost all of the hydrologic events of any significance occur between November and March. Calibration periods where there is a very good or better match between the simulated and observed flow data include October through December 2004 (Figure 4.18), October through December 2005 (Figure 4.20), January through March 2006 (Figure 4.21), October through December 2006 (Figure 4.22), January through March 2007 (Figure 4.23), and April through September 2007 (Figure 4.24). The simulated peak flows are low compared to the observed data for the January through March 2004 events (Figure 4.17) and are high for the March 2005 (Figure 4.19) event. The fact that there are both low and high simulation periods demonstrates that there is no specific bias in the modeling results.

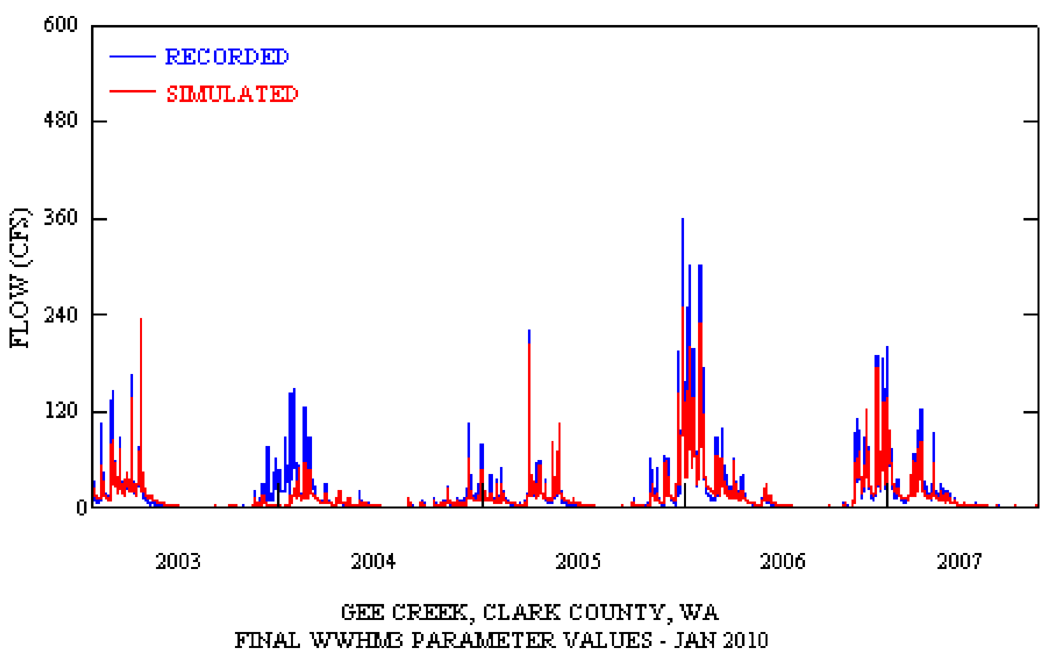


Figure 4.17 Gee Creek (May 2003 – September 2007)

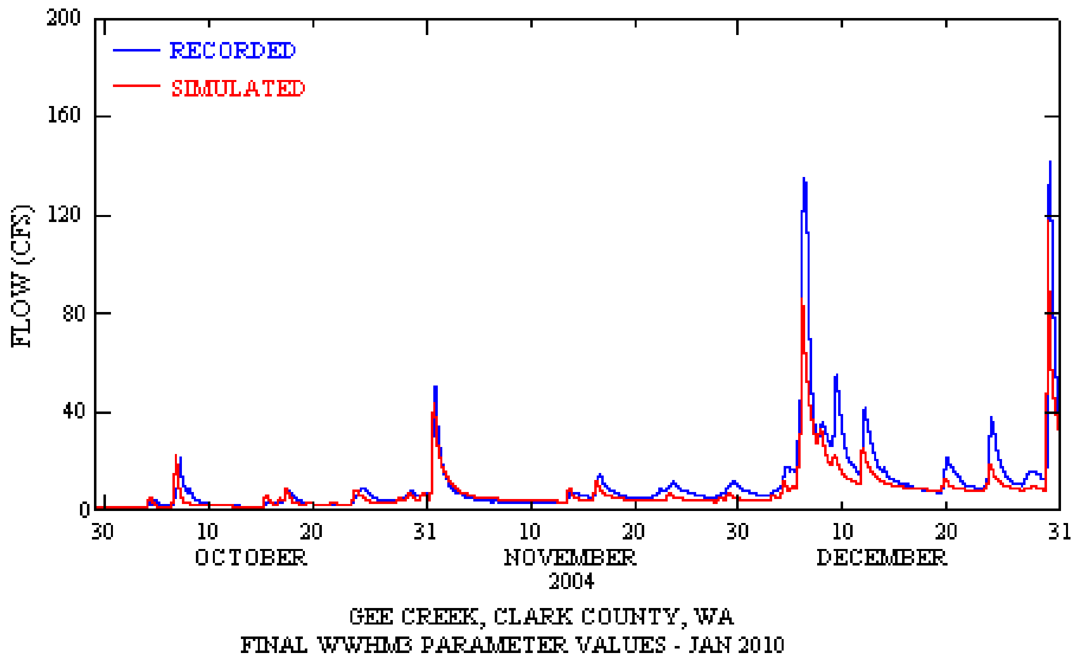


Figure 4.18 Gee Creek (October – December 2004)

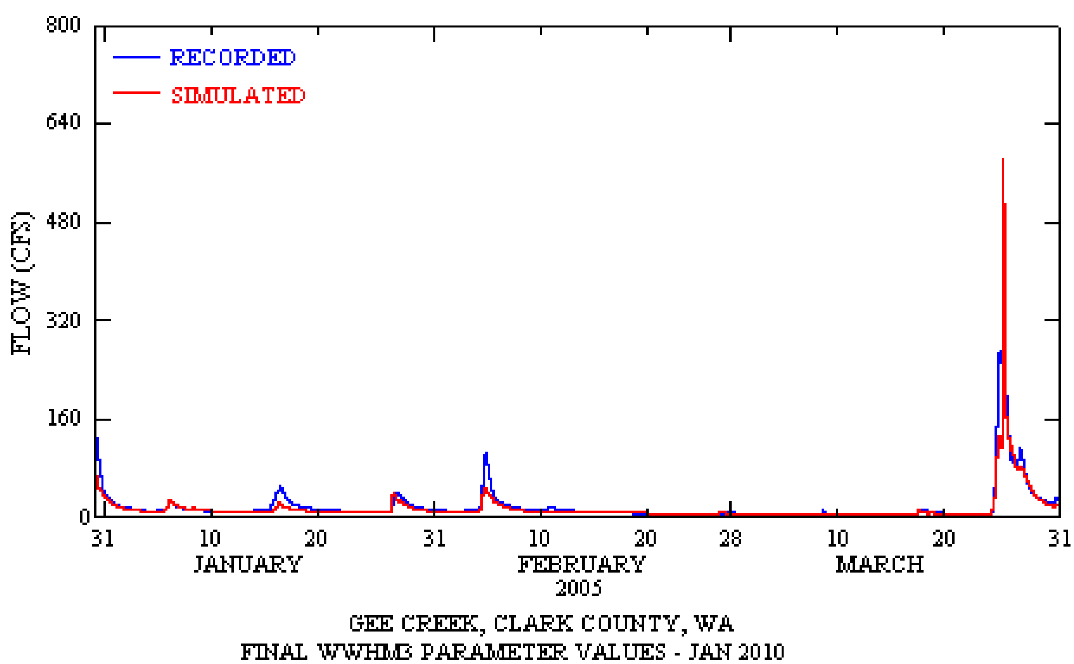


Figure 4.19 Gee Creek (January – March 2005)

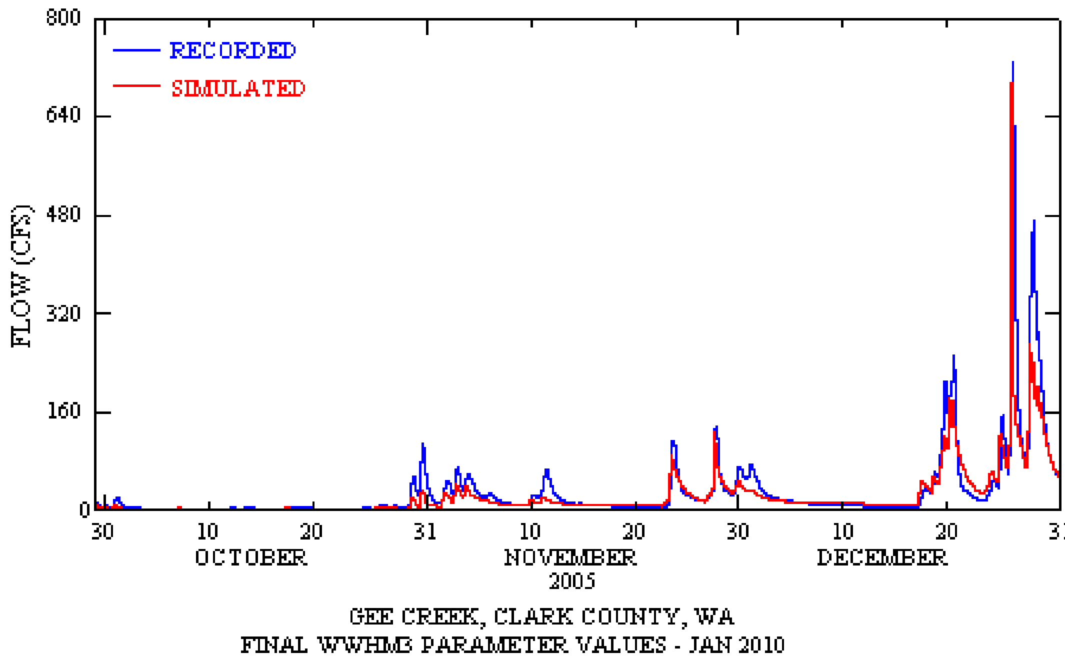


Figure 4.20 Gee Creek (October – December 2005)

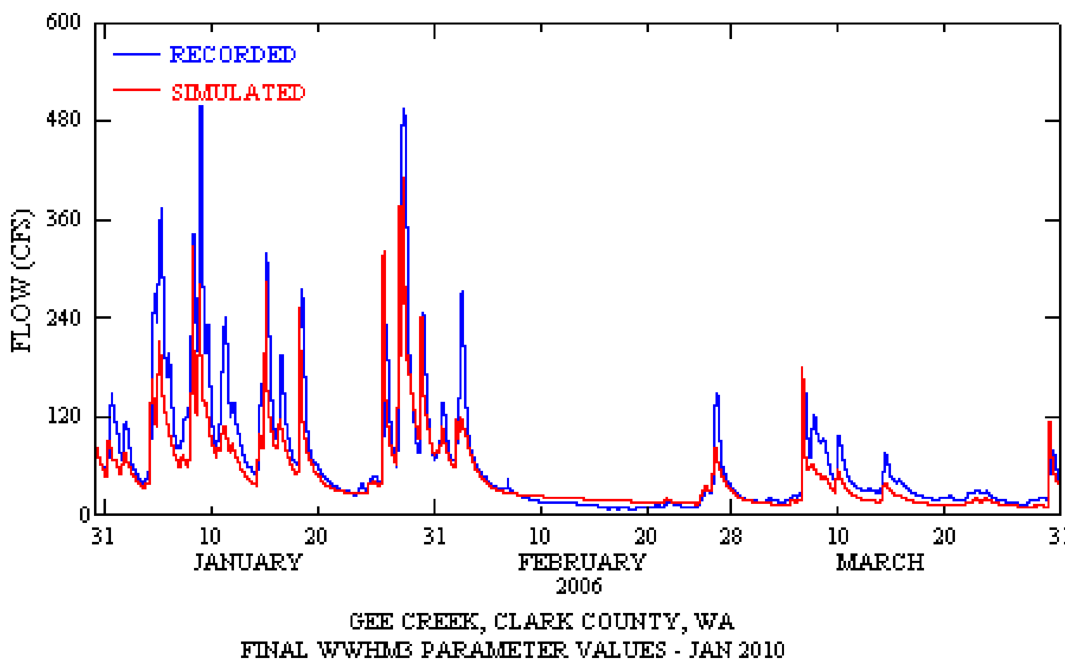


Figure 4.21 Gee Creek (January – March 2006)

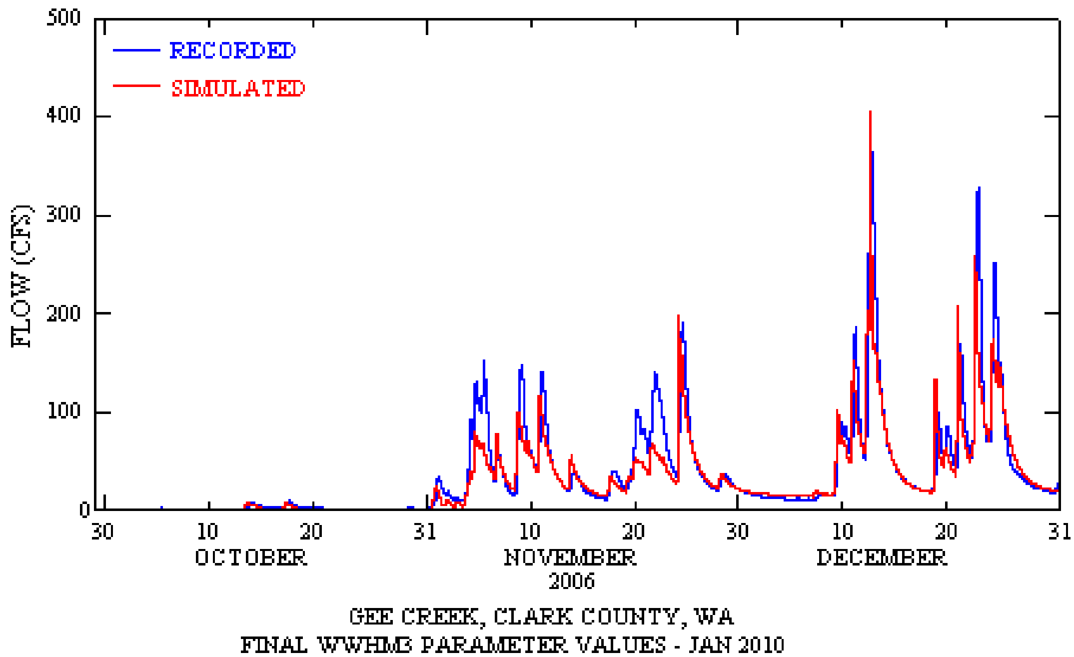


Figure 4.22 Gee Creek (October – December 2006)

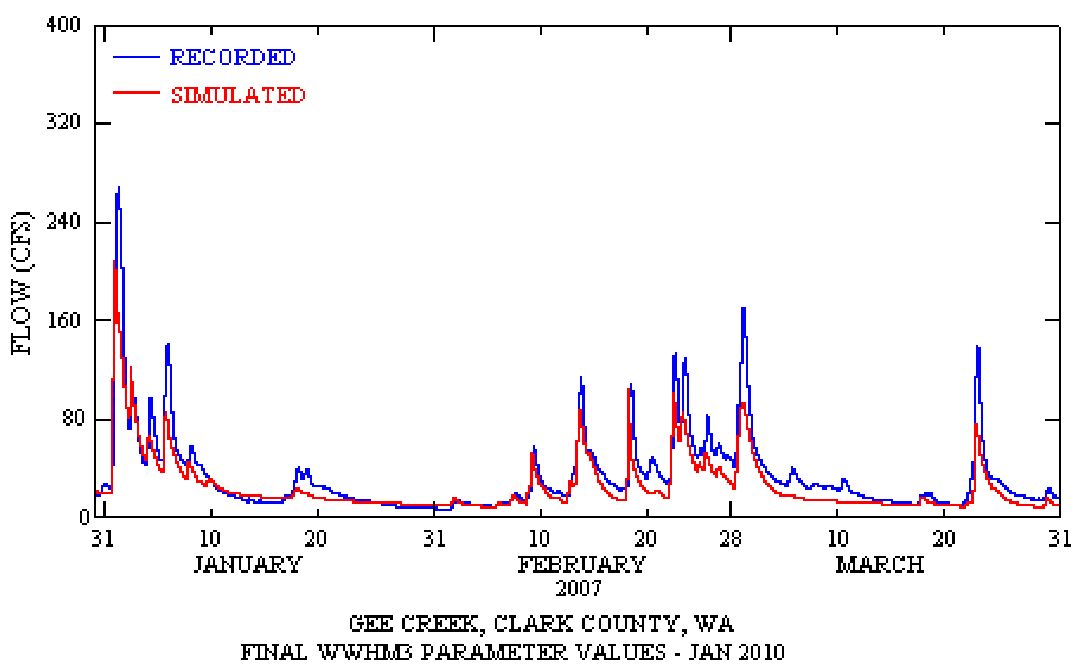


Figure 4.23 Gee Creek (January – March 2007)

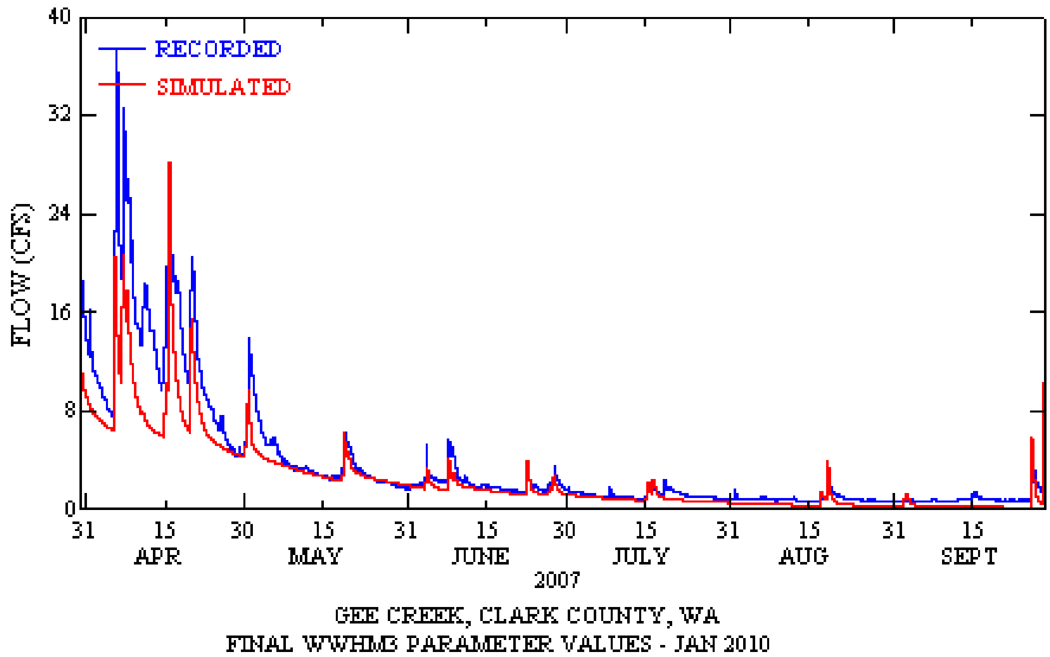


Figure 4.24 Gee Creek (April – September 2007)

4.5 CALIBRATION RESULTS SUMMARY

The observed and simulated streamflow was compared at two flow gaging sites in the Mill Creek watershed and one gaging station in the Gee Creek watershed. The HSPF calibration parameter values were adjusted to produce simulated flow hydrographs that mimicked the observed streamflow's response to rainfall. Each watershed was calibrated separately with different parameter values and then a final calibration was made with a composite, average set of parameter values representing both watersheds. It is this average set of HSPF parameter values that will be used in WWHM3.

The calibration periods are relatively short and the number of individual peak flow events is relatively small due to limited observed flow data. As a result, we judged the accuracy of the calibrations on the ability to match individual hydrographs and to produce a good match of the observed flow duration curve.

The primary focus of the calibrations was on the peak flows, as the stormwater modeling in WWHM is based on the surface runoff and interflow components of the hydrologic response (these two runoff components produce the peak flows). The Mill calibration results show a good match for the Mill tributary upstream at the NE 199th Street gage and a very good match at the downstream gage near the mouth of Mill Creek. The Gee calibration results show a very good match at the gaging site near the mouth of Gee Creek.

4.6 CONCLUSIONS AND RECOMMENDATIONS

Table 4.1 provides a limited weight-of-evidence summary of the various model-data comparisons performed for the simulation of the Mill Creek and Gee Creek watershed models, as discussed above. The overall model performance, shown in the last column, reflects our assessment of good-to-very good model performance for the calibration periods for both Mill Creek and Gee Creek.

Based on the model results presented and discussed in Section 4, and summarized in Table 4.1, we conclude that the current HSPF applications to the Mill Creek watershed and Gee Creek watershed provide a sound, calibrated set of HSPF parameter values for Clark County. No validation of the calibration parameter values was attempted due to the lack of additional observed streamflow data.

The resulting model parameters are appropriate for use in WWHM, and for an impact evaluation of flow control alternatives. The calibration results, based on the weight-of-evidence approach described herein, demonstrates a good representation of the observed data. This is the outcome of a wide range of graphical comparisons and measures of the model performance for flow duration and individual storm event simulations. These comparisons demonstrate conclusively that the model is a good representation of the water balance and hydrology of the watersheds.

However, because of the relatively short calibration periods available for both Mill Creek and Gee Creek we recommend a follow-up validation of the HSPF calibration parameter values if and when additional observed streamflow data become available. A minimum validation period of record of three to five years with no or few data gaps will be needed at each gaging station to provide the appropriate number of new storm events to adequately judge the soundness of the selected Clark County HSPF parameter values.

Table 4.1 Weight-of-Evidence for Model Performance

Calibration Component	Mill Creek	Gee Creek	Overall Model Performance
Flow Duration Curves		Very Good	Very Good
Upstream Gage	Good		
Downstream Gage	Very Good		
Peak Flow Events		Fair to Excellent	Very Good
Upstream Gage	Good		
Downstream Gage	Good to Excellent		

Section 5.0

REFERENCES

Bicknell, B.R., J.C. Imhoff, J.L. Kittle Jr., T.H. Jobes, and A.S. Donigian, Jr., 2001. Hydrological Simulation Program - Fortran (HSPF). User's Manual for Release 12. U.S. EPA National Exposure Research Laboratory, Athens, GA, and U.S. Geological Survey, Water Resources Division, Reston, VA.

Donigian, A.S., Jr., J.C. Imhoff, B.R. Bicknell and J.L. Kittle, Jr., 1984. Application Guide for the Hydrological Simulation Program - FORTRAN EPA 600/3-84-066, Environmental Research Laboratory, U.S. EPA, Athens, GA. 30613.

Donigian, A.S., Jr., 2002. Watershed Model Calibration and Validation: The HSPF Experience. WEF-National TMDL Science and Policy 2002, November 13-16, 2002. Phoenix AZ, WEF-2002 Specialty Conference Proceedings on CD-ROM.

Lumb, A.M., Carsel, R.F., and Kittle, J.L., Jr., 1988. Data management for water-quality modeling development and use, Proceedings of the 4th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, Feb, 1988, Anaheim, CA.

U.S. EPA, 2001. Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), Version 3.0 User's Manual: U. S. Environmental Protection Agency, EPA-823-C-01-001, Office of Water, Washington DC.

WEST Consultants, 2008. Hydrologic and Hydraulic Analyses of the Mill Creek Watershed (draft). Clark County Department of Public Works, Clean Water Program, Vancouver, WA.

Appendix A

FINAL CLARK COUNTY HSPF PARAMETER VALUES

Final HSPF Clark County HSPF Parameter Values

PLS #	PLS Name	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
1	Soil Group 1, Forest, Flat Slopes (0-5%)	12.00	2.00	400	0.05	0.00	0.960
2	Soil Group 1, Forest, Moderate Slopes (5-15%)	12.00	2.00	400	0.10	0.00	0.960
3	Soil Group 1, Forest, Steep Slopes (>15%)	12.00	2.00	400	0.15	0.00	0.960
4	Soil Group 1, Field, Flat Slopes (0-5%)	12.00	1.50	400	0.05	0.00	0.960
5	Soil Group 1, Field, Moderate Slopes (5-15%)	12.00	1.50	400	0.10	0.00	0.960
6	Soil Group 1, Field, Steep Slopes (>15%)	12.00	1.50	400	0.15	0.00	0.960
7	Soil Group 1, Lawn, Flat Slopes (0-5%)	12.00	1.00	400	0.05	0.00	0.960
8	Soil Group 1, Lawn, Moderate Slopes (5-15%)	12.00	1.00	400	0.10	0.00	0.960
9	Soil Group 1, Lawn, Steep Slopes (>15%)	12.00	1.00	400	0.15	0.00	0.960
10	Soil Group 2, Forest, Flat Slopes (0-5%)	11.00	0.20	400	0.05	0.00	0.960
11	Soil Group 2, Forest, Moderate Slopes (5-15%)	11.00	0.20	400	0.10	0.00	0.960
12	Soil Group 2, Forest, Steep Slopes (>15%)	11.00	0.20	400	0.15	0.00	0.960
13	Soil Group 2, Field, Flat Slopes (0-5%)	11.00	0.15	400	0.05	0.00	0.960
14	Soil Group 2, Field, Moderate Slopes (5-15%)	11.00	0.15	400	0.10	0.00	0.960
15	Soil Group 2, Field, Steep Slopes (>15%)	11.00	0.15	400	0.15	0.00	0.960
16	Soil Group 2, Lawn, Flat Slopes (0-5%)	11.00	0.10	400	0.05	0.00	0.960
17	Soil Group 2, Lawn, Moderate Slopes (5-15%)	11.00	0.10	400	0.10	0.00	0.960
18	Soil Group 2, Lawn, Steep Slopes (>15%)	11.00	0.10	400	0.15	0.00	0.960
19	Soil Group 3, Forest, Flat Slopes (0-5%)	6.00	0.08	400	0.05	0.00	0.960
20	Soil Group 3, Forest, Moderate Slopes (5-15%)	6.00	0.08	400	0.10	0.00	0.960
21	Soil Group 3, Forest, Steep Slopes (>15%)	6.00	0.08	400	0.15	0.00	0.960
22	Soil Group 3, Field, Flat Slopes (0-5%)	6.00	0.06	400	0.05	0.00	0.960
23	Soil Group 3, Field, Moderate Slopes (5-15%)	6.00	0.06	400	0.10	0.00	0.960
24	Soil Group 3, Field, Steep Slopes (>15%)	6.00	0.06	400	0.15	0.00	0.960
25	Soil Group 3, Lawn, Flat Slopes (0-5%)	6.00	0.05	400	0.05	0.00	0.960
26	Soil Group 3, Lawn, Moderate Slopes (5-15%)	6.00	0.05	400	0.10	0.00	0.960
27	Soil Group 3, Lawn, Steep Slopes (>15%)	6.00	0.05	400	0.15	0.00	0.960
28	Soil Group 4, Forest, Flat Slopes (0-5%)	6.00	0.04	400	0.05	0.00	0.960
29	Soil Group 4, Forest, Moderate Slopes (5-15%)	6.00	0.04	400	0.10	0.00	0.960
30	Soil Group 4, Forest, Steep Slopes (>15%)	6.00	0.04	400	0.15	0.00	0.960
31	Soil Group 4, Field, Flat Slopes (0-5%)	6.00	0.03	400	0.05	0.00	0.960
32	Soil Group 4, Field, Moderate Slopes (5-15%)	6.00	0.03	400	0.10	0.00	0.960
33	Soil Group 4, Field, Steep Slopes (>15%)	6.00	0.03	400	0.15	0.00	0.960
34	Soil Group 4, Lawn, Flat Slopes (0-5%)	6.00	0.02	400	0.05	0.00	0.960
35	Soil Group 4, Lawn, Moderate Slopes (5-15%)	6.00	0.02	400	0.10	0.00	0.960
36	Soil Group 4, Lawn, Steep Slopes (>15%)	6.00	0.02	400	0.15	0.00	0.960
37	Soil Group 5, Forest, Flat Slopes (0-5%)	6.00	0.50	100	0.001	0.00	0.960
38	Soil Group 5, Forest, Moderate Slopes (5-15%)	6.00	0.50	100	0.01	0.00	0.960
39	Soil Group 5, Forest, Steep Slopes (>15%)	6.00	0.50	100	0.10	0.00	0.960
40	Soil Group 5, Field, Flat Slopes (0-5%)	6.00	0.40	100	0.001	0.00	0.960
41	Soil Group 5, Field, Moderate Slopes (5-15%)	6.00	0.40	100	0.01	0.00	0.960
42	Soil Group 5, Field, Steep Slopes (>15%)	6.00	0.40	100	0.10	0.00	0.960
43	Soil Group 5, Lawn, Flat Slopes (0-5%)	6.00	0.30	100	0.001	0.00	0.960
44	Soil Group 5, Lawn, Moderate Slopes (5-15%)	6.00	0.30	100	0.01	0.00	0.960
45	Soil Group 5, Lawn, Steep Slopes (>15%)	6.00	0.30	100	0.10	0.00	0.960

PLS #	PLS Name	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
1	Soil Group 1, Forest, Flat Slopes (0-5%)	2.0	2.0	0.00	0.00	0.00
2	Soil Group 1, Forest, Moderate Slopes (5-15%)	2.0	2.0	0.00	0.00	0.00
3	Soil Group 1, Forest, Steep Slopes (>15%)	2.0	2.0	0.00	0.00	0.00
4	Soil Group 1, Field, Flat Slopes (0-5%)	2.0	2.0	0.00	0.00	0.00
5	Soil Group 1, Field, Moderate Slopes (5-15%)	2.0	2.0	0.00	0.00	0.00
6	Soil Group 1, Field, Steep Slopes (>15%)	2.0	2.0	0.00	0.00	0.00
7	Soil Group 1, Lawn, Flat Slopes (0-5%)	2.0	2.0	0.00	0.00	0.00
8	Soil Group 1, Lawn, Moderate Slopes (5-15%)	2.0	2.0	0.00	0.00	0.00
9	Soil Group 1, Lawn, Steep Slopes (>15%)	2.0	2.0	0.00	0.00	0.00
10	Soil Group 2, Forest, Flat Slopes (0-5%)	2.0	2.0	0.00	0.00	0.00
11	Soil Group 2, Forest, Moderate Slopes (5-15%)	2.0	2.0	0.00	0.00	0.00
12	Soil Group 2, Forest, Steep Slopes (>15%)	2.0	2.0	0.00	0.00	0.00
13	Soil Group 2, Field, Flat Slopes (0-5%)	2.0	2.0	0.00	0.00	0.00
14	Soil Group 2, Field, Moderate Slopes (5-15%)	2.0	2.0	0.00	0.00	0.00
15	Soil Group 2, Field, Steep Slopes (>15%)	2.0	2.0	0.00	0.00	0.00
16	Soil Group 2, Lawn, Flat Slopes (0-5%)	2.0	2.0	0.00	0.00	0.00
17	Soil Group 2, Lawn, Moderate Slopes (5-15%)	2.0	2.0	0.00	0.00	0.00
18	Soil Group 2, Lawn, Steep Slopes (>15%)	2.0	2.0	0.00	0.00	0.00
19	Soil Group 3, Forest, Flat Slopes (0-5%)	2.5	2.0	0.00	0.00	0.00
20	Soil Group 3, Forest, Moderate Slopes (5-15%)	2.5	2.0	0.00	0.00	0.00
21	Soil Group 3, Forest, Steep Slopes (>15%)	2.5	2.0	0.00	0.00	0.00
22	Soil Group 3, Field, Flat Slopes (0-5%)	2.5	2.0	0.00	0.00	0.00
23	Soil Group 3, Field, Moderate Slopes (5-15%)	2.5	2.0	0.00	0.00	0.00
24	Soil Group 3, Field, Steep Slopes (>15%)	2.5	2.0	0.00	0.00	0.00
25	Soil Group 3, Lawn, Flat Slopes (0-5%)	2.5	2.0	0.00	0.00	0.00
26	Soil Group 3, Lawn, Moderate Slopes (5-15%)	2.5	2.0	0.00	0.00	0.00
27	Soil Group 3, Lawn, Steep Slopes (>15%)	2.5	2.0	0.00	0.00	0.00
28	Soil Group 4, Forest, Flat Slopes (0-5%)	3.0	2.0	0.00	0.00	0.00
29	Soil Group 4, Forest, Moderate Slopes (5-15%)	3.0	2.0	0.00	0.00	0.00
30	Soil Group 4, Forest, Steep Slopes (>15%)	3.0	2.0	0.00	0.00	0.00
31	Soil Group 4, Field, Flat Slopes (0-5%)	3.0	2.0	0.00	0.00	0.00
32	Soil Group 4, Field, Moderate Slopes (5-15%)	3.0	2.0	0.00	0.00	0.00
33	Soil Group 4, Field, Steep Slopes (>15%)	3.0	2.0	0.00	0.00	0.00
34	Soil Group 4, Lawn, Flat Slopes (0-5%)	3.0	2.0	0.00	0.00	0.00
35	Soil Group 4, Lawn, Moderate Slopes (5-15%)	3.0	2.0	0.00	0.00	0.00
36	Soil Group 4, Lawn, Steep Slopes (>15%)	3.0	2.0	0.00	0.00	0.00
37	Soil Group 5, Forest, Flat Slopes (0-5%)	10.0	2.0	0.00	0.00	0.70
38	Soil Group 5, Forest, Moderate Slopes (5-15%)	10.0	2.0	0.00	0.00	0.70
39	Soil Group 5, Forest, Steep Slopes (>15%)	10.0	2.0	0.00	0.00	0.70
40	Soil Group 5, Field, Flat Slopes (0-5%)	10.0	2.0	0.00	0.00	0.50
41	Soil Group 5, Field, Moderate Slopes (5-15%)	10.0	2.0	0.00	0.00	0.50
42	Soil Group 5, Field, Steep Slopes (>15%)	10.0	2.0	0.00	0.00	0.50
43	Soil Group 5, Lawn, Flat Slopes (0-5%)	10.0	2.0	0.00	0.00	0.35
44	Soil Group 5, Lawn, Moderate Slopes (5-15%)	10.0	2.0	0.00	0.00	0.35
45	Soil Group 5, Lawn, Steep Slopes (>15%)	10.0	2.0	0.00	0.00	0.35

PLS #	PLS Name	CEPSC	UZSN	NSUR	INTFW	IRC	LZETP
1	Soil Group 1, Forest, Flat Slopes (0-5%)	0.20	1.50	0.35	0.0	0.40	0.70
2	Soil Group 1, Forest, Moderate Slopes (5-15%)	0.20	1.50	0.35	0.0	0.40	0.70
3	Soil Group 1, Forest, Steep Slopes (>15%)	0.20	1.50	0.35	0.0	0.40	0.70
4	Soil Group 1, Field, Flat Slopes (0-5%)	0.15	1.50	0.30	0.0	0.40	0.40
5	Soil Group 1, Field, Moderate Slopes (5-15%)	0.15	1.50	0.30	0.0	0.40	0.40
6	Soil Group 1, Field, Steep Slopes (>15%)	0.15	1.50	0.30	0.0	0.40	0.40
7	Soil Group 1, Lawn, Flat Slopes (0-5%)	0.10	1.30	0.25	0.0	0.40	0.25
8	Soil Group 1, Lawn, Moderate Slopes (5-15%)	0.10	1.30	0.25	0.0	0.40	0.25
9	Soil Group 1, Lawn, Steep Slopes (>15%)	0.10	1.30	0.25	0.0	0.40	0.25
10	Soil Group 2, Forest, Flat Slopes (0-5%)	0.20	1.40	0.35	1.0	0.40	0.70
11	Soil Group 2, Forest, Moderate Slopes (5-15%)	0.20	1.40	0.35	1.0	0.40	0.70
12	Soil Group 2, Forest, Steep Slopes (>15%)	0.20	1.40	0.35	1.0	0.40	0.70
13	Soil Group 2, Field, Flat Slopes (0-5%)	0.15	1.40	0.30	1.0	0.40	0.40
14	Soil Group 2, Field, Moderate Slopes (5-15%)	0.15	1.40	0.30	1.0	0.40	0.40
15	Soil Group 2, Field, Steep Slopes (>15%)	0.15	1.40	0.30	1.0	0.40	0.40
16	Soil Group 2, Lawn, Flat Slopes (0-5%)	0.10	1.20	0.25	1.0	0.40	0.25
17	Soil Group 2, Lawn, Moderate Slopes (5-15%)	0.10	1.20	0.25	1.0	0.40	0.25
18	Soil Group 2, Lawn, Steep Slopes (>15%)	0.10	1.20	0.25	1.0	0.40	0.25
19	Soil Group 3, Forest, Flat Slopes (0-5%)	0.20	1.00	0.35	4.0	0.40	0.70
20	Soil Group 3, Forest, Moderate Slopes (5-15%)	0.20	1.00	0.35	4.0	0.40	0.70
21	Soil Group 3, Forest, Steep Slopes (>15%)	0.20	1.00	0.35	4.0	0.40	0.70
22	Soil Group 3, Field, Flat Slopes (0-5%)	0.15	1.00	0.30	4.0	0.40	0.40
23	Soil Group 3, Field, Moderate Slopes (5-15%)	0.15	1.00	0.30	4.0	0.40	0.40
24	Soil Group 3, Field, Steep Slopes (>15%)	0.15	1.00	0.30	4.0	0.40	0.40
25	Soil Group 3, Lawn, Flat Slopes (0-5%)	0.10	0.80	0.25	4.0	0.40	0.25
26	Soil Group 3, Lawn, Moderate Slopes (5-15%)	0.10	0.80	0.25	4.0	0.40	0.25
27	Soil Group 3, Lawn, Steep Slopes (>15%)	0.10	0.80	0.25	4.0	0.40	0.25
28	Soil Group 4, Forest, Flat Slopes (0-5%)	0.20	0.40	0.35	2.0	0.40	0.70
29	Soil Group 4, Forest, Moderate Slopes (5-15%)	0.20	0.40	0.35	2.0	0.40	0.70
30	Soil Group 4, Forest, Steep Slopes (>15%)	0.20	0.40	0.35	2.0	0.40	0.70
31	Soil Group 4, Field, Flat Slopes (0-5%)	0.15	0.40	0.30	2.0	0.40	0.40
32	Soil Group 4, Field, Moderate Slopes (5-15%)	0.15	0.40	0.30	2.0	0.40	0.40
33	Soil Group 4, Field, Steep Slopes (>15%)	0.15	0.40	0.30	2.0	0.40	0.40
34	Soil Group 4, Lawn, Flat Slopes (0-5%)	0.10	0.20	0.25	2.0	0.40	0.25
35	Soil Group 4, Lawn, Moderate Slopes (5-15%)	0.10	0.20	0.25	2.0	0.40	0.25
36	Soil Group 4, Lawn, Steep Slopes (>15%)	0.10	0.20	0.25	2.0	0.40	0.25
37	Soil Group 5, Forest, Flat Slopes (0-5%)	0.20	3.00	0.50	1.0	0.70	0.80
38	Soil Group 5, Forest, Moderate Slopes (5-15%)	0.20	3.00	0.50	1.0	0.70	0.80
39	Soil Group 5, Forest, Steep Slopes (>15%)	0.20	3.00	0.50	1.0	0.70	0.80
40	Soil Group 5, Field, Flat Slopes (0-5%)	0.15	3.00	0.50	1.0	0.70	0.60
41	Soil Group 5, Field, Moderate Slopes (5-15%)	0.15	3.00	0.50	1.0	0.70	0.60
42	Soil Group 5, Field, Steep Slopes (>15%)	0.15	3.00	0.50	1.0	0.70	0.60
43	Soil Group 5, Lawn, Flat Slopes (0-5%)	0.10	3.00	0.50	1.0	0.70	0.40
44	Soil Group 5, Lawn, Moderate Slopes (5-15%)	0.10	3.00	0.50	1.0	0.70	0.40
45	Soil Group 5, Lawn, Steep Slopes (>15%)	0.10	3.00	0.50	1.0	0.70	0.40