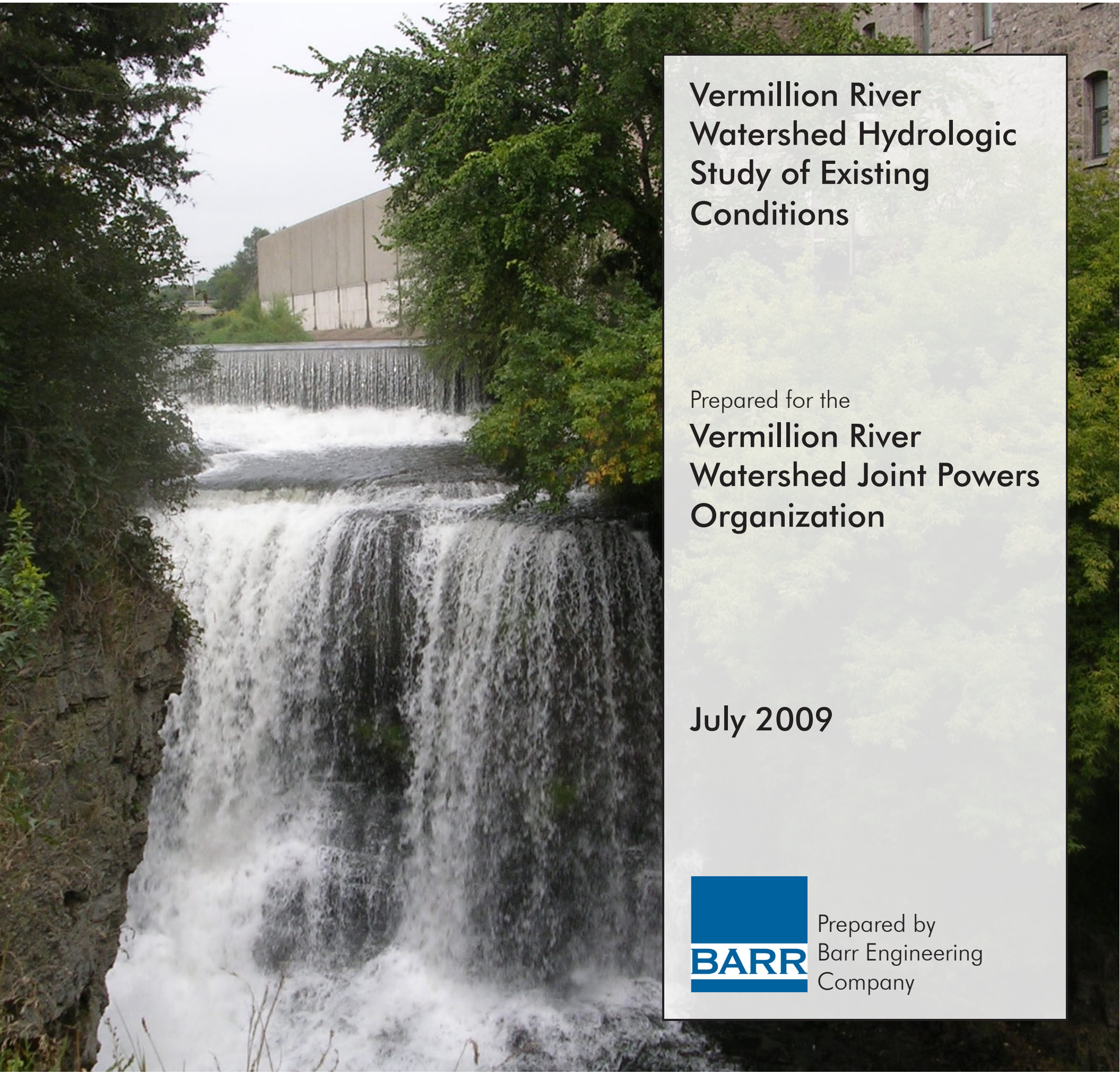




# Vermillion River Watershed Hydrologic Study of Existing Conditions

Prepared for the  
**Vermillion River  
Watershed Joint Powers  
Organization**

July 2009



Prepared by  
Barr Engineering  
Company



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***Prepared for the  
Vermillion River Watershed Joint Powers Organization***

***July 2009***



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# 1.0 Executive Summary

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This report describes the methodology and results of hydrologic and hydraulic modeling of the Vermillion River watershed in portions of Dakota and Scott Counties completed for the Vermillion River Watershed Joint Powers Organization (VRWJPO). Previous modeling analyses of the watershed focused on flows in the Vermillion River (rather than the tributaries) and were developed using curve number method. The calibrated XP-SWMM model for this study was developed independently of previous models, and only referenced results from previous studies as a means of final validation of calibrated model results.

The Vermillion River is located in the central portion of Dakota County and southeastern corner of Scott County and flows northeast towards the Mississippi River. The study area is defined by the Vermillion River watershed hydrologic boundary to the south and west, and by topography to the north and east as shown in [Figure 2-1](#).

The 2005 VRWJPO watershed plan defines that development within the watershed be regulated through a set of development standards; the peak flow rate in the Vermillion River or its tributaries should not increase from existing conditions and total runoff volume should not increase due to development in the watershed. The calibrated XP-SWMM model developed for this study reflects 2005 conditions in the watershed, and provides the VRWJPO with a tool to regulate development by predicting how future development will influence flows in the Vermillion River.

The hydrology and hydraulics of the Vermillion River watershed were modeled using XP-SWMM, Version 10.6, which uses rainfall and watershed information to generate runoff using the Horton Equation that is routed simultaneously through pipe, stream, and overland flow networks. Rainfall data used in the XP-SWMM model was developed by combining NEXRAD data with precipitation measurements at monitoring stations throughout the study area. PEST, a parameter estimation software package, was selected to automate the calibration process of the XP-SWMM model. The automated process ensured that the best calibrated parameters were selected, and provided unbiased results. The XP-SWMM model was calibrated to stage recordings at seven stream monitoring stations located in the Vermillion River from two independent storm events (Event D—August 2002 and Event G—September 2004). The calibrated model was then subject to an extensive validation process that included comparing calibrated model results to:

- Two additional independent storm events (Event A—July 2000 and Event C—June 2002).
- The event of record at the USGS station (September 1992).
- The discharge frequency curve at the USGS station.
- The 100-year flows calculated by USGS regression equations and transfer method at the USGS station.
- Flows defined in previous studies.

Following validation of the model the total volume and peak flow rates were summarized at 61 standard locations where streams cross municipal boundaries for the 1-, 2-, 10-, 50-, and 100-year 4-day design events, see Section 4.2.3. Results at these standard locations can be used by the VRWJPO to regulate proposed development in order to ensure that peak flows and total runoff volume do not increase in the Vermillion River or its tributaries.

Additionally, subwatershed hydrologic parameters (e.g., percent impervious or hydraulic conductivity) were determined for each individual land use classification and hydrologic soil group within the watershed and are included in [Appendix F](#). For example, the percent impervious is defined for each land use classification, which provides greater detail to the single impervious value used for each subwatershed. Similarly, infiltration parameters are defined for each hydrologic soil group throughout the watershed. This provides the VRWJPO with a consistent set of hydrologic parameters for communities and developers to utilize when modeling proposed development in any portion of the watershed. This standard set of hydrologic parameters eliminates the uncertainty associated with selecting the proper curve number, and ensures that the increase in runoff associated with modifying the land use type is properly accounted for when modeling the impact of future development.

## 2.0 Introduction

---

### 2.1 General

The Vermillion River watershed is located south of the Minneapolis-St. Paul metropolitan area in Dakota and Scott Counties. The watershed drains to the northeast where the Vermillion River ultimately drains into the Mississippi River. The VRWJPO jurisdictional area covers approximately 335 square miles. The area included in this study is approximately 225 square miles, which covers portions of 19 different cities and townships. The study area upstream of the Hastings Dam is shown in [Figure 2-1](#). Portions of the Vermillion River hydrologic boundary to the west and north contribute runoff intermittently and were not included in this analysis. Runoff from approximately 9 square miles located to the west of the study area primarily drain to Keller Lake, and ultimately north to the Minnesota River, and an additional roughly 36 square miles in Rosemont and Inver Grove Heights were identified as primarily discharging directly to the Mississippi River, and was removed from the analysis. The majority of the watershed is undeveloped with agricultural areas occupying the largest portion of the watershed.

### 2.2 Study Purpose

The focus of this study was to provide a calibrated hydrologic model of the existing conditions within the Vermillion River watershed upstream of the Hastings dam and to provide peak flow rates and total volume at municipal boundaries located within the study area. The calibrated model and results from this analysis are tools that the VRWJPO can use to create flow and volume standards throughout the Vermillion River watershed to regulate the impacts of future development.

### 2.3 Developing Consensus

Meetings were held on a consistent basis throughout the project with the Independent Technical Review (ITR) Group. The VRWJPO appointed members to the ITR Committee to review modeling methodology and results throughout the study. The group included representatives from both Dakota and Scott Counties as well as an independent technical reviewer from the University of Minnesota. Comments from the ITR Committee ensured that the project approach was technically sound and acceptable for use in developing discharge standards at municipal boundaries throughout the watershed.

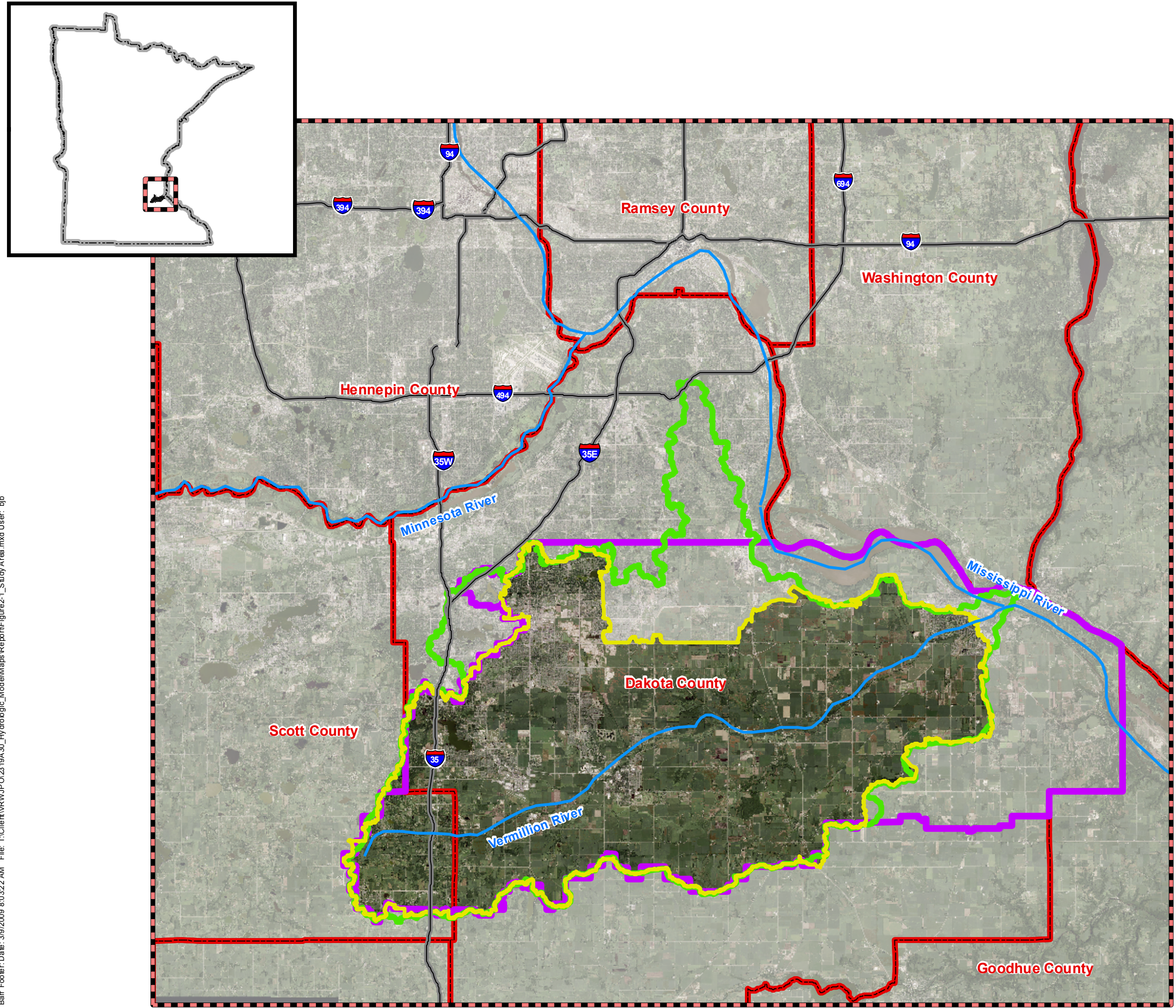
In addition to meetings with the ITR Committee, modeling methods and results were presented to the Technical Advisory Group (TAG) several times during the study. Communities within the VRWJPO boundary were represented on the TAG committee and were given opportunities to review subwatershed delineations, standard locations, and preliminary results. TAG meetings provided each community the opportunity to review the progress of the study, voice concerns, and discuss issues specific to each community. Finally, the VRWJPO Board was updated on the progress for the analysis during the study. Comments from the ITR Committee, TAG committee, and VRWJPO Board provided guidance and ensured that the final XP-SWMM model would address the concerns of communities located within the VRWJPO boundary, and ultimately provide a useful tool for the VRWJPO to regulate future development within the watershed.

## **2.4 XP-SWMM Model Development**

The XP-SWMM model combined culvert and cross section information from previous models with new survey data collected by County surveyors and cross sections developed from County-supplied LiDAR data sets. The scope for this analysis included:

1. Compiling all pertinent data Cities provided about the storm sewers in the study area.
2. Field surveying to collect missing crossing and storm sewer information including diameters, lengths, and inverts.
3. Combining watersheds delineated for local municipal storm water management plans with new watershed divides developed based on topography.
4. Developing an XP-SWMM computer model of the Vermillion River study area to analyze flow rates for the calibration events.
5. Calibrating the XP-SWMM model to observed flows for the selected calibration events.
6. Verifying calibrated model parameters with selected validation events, a previous large historical event, and comparison of calibrated 100-year flows to previous models and studies in portions of the watershed.





- Legend**
- Vermillion River Study Area
  - Vermillion River Watershed Hydrologic Boundary
  - Vermillion River Watershed Jurisdictional Boundary
  - US Interstate System
  - River
  - County Boundary

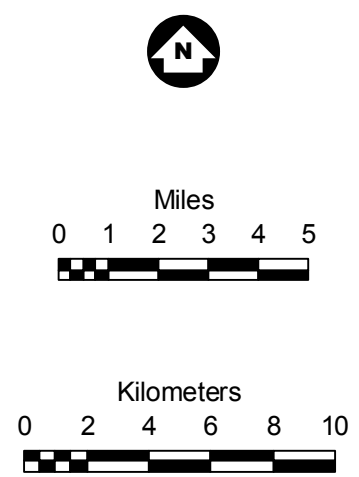


Figure 2-1

STUDY AREA  
VRWJPO Hydrologic Model  
Vermillion River Watershed



## 3.0 Background

---

As part of the VRWJPO Watershed Plan published in 2005, the VRWJPO set an objective to minimize the impacts of runoff from future development through a set of development standards focusing on limiting peak runoff rate and total runoff volume. The VRWJPO was able to adopt a set of standards to address total runoff volume from proposed development, but did not have a consistent watershed-wide hydrologic model to develop peak flow rate standards throughout the watershed.

A comprehensive hydrologic model would allow the VRWJPO to uniformly set flow and volume standards at locations where a municipal boundary crosses the Vermillion River or one of its tributaries. This allows the VRWJPO to regulate increases to peak discharges in the stream network caused by development in the watershed, as well as monitor the total amount for runoff upstream of each standard location. In addition, a complete hydrologic model will provide an overall picture of the watershed and can be used as a tool to identify locations with flooding potential and resolve discrepancies in estimated flow rates between communities.

### 3.1 Previous Studies

Previous hydrologic models of the Vermillion River watershed each had a specific purpose and were limited in scope. All of them were primarily focused on flows in the Vermillion River (not on the tributaries) and the results vary greatly. These previous models should only be used to draw conclusions that are supported by the appropriate level of detail in the analysis:

1. The Soil Conservation Service (SCS—now the NRCS) completed a study of the Vermillion River in 1974 using the TR-20 model. In 1980, the results from this model were used to define flows for the Flood Insurance Study (FIS). The model was not very detailed and was not calibrated to gage data, and therefore is not appropriate for use to establish rate controls at community boundaries.
2. The US Army Corps of Engineers (U.S. COE) model developed in July 1998 using the HEC-1 model. The purpose of this model was to develop a calibrated hydrologic model of the watershed, and to assess the effects of current and future land use on watershed runoff. The model was calibrated to the United States Geological Survey (USGS) gage at Empire for four storm events between 1992 and 1997. Calibration involved uniformly lowering the subwatershed curve numbers to match flows; different subwatershed curve numbers were used for various frequency events. Because the frequency of the design event influenced the

curve number, rather than the associated land use type, this model would not be appropriate to develop flow standards throughout a developing watershed where modifications to land use classifications define the impacts. This model used large watershed areas and lacked sufficient detail to determine flow standards at each location where a tributary crossed a municipal boundary.

3. The Montgomery-Watson-Harza (MWH) analysis (2002) imported the U.S. COE HEC-1 model into HEC-HMS. The purpose of this model was primarily to define the existing runoff volumes and assess the implications of increased runoff volume with development. The model was calibrated to three gages (South Fork at 220th, Empire, and Hastings) for two storm events in 1998 and one in 2000 (all with return periods of 2 to 5 years). Calibration involved revising the subwatershed curve numbers to match the flows at the gages; subwatershed curve numbers varied from the U.S. COE curve numbers by -7 to +13 percent. Similar to the U.S. COE model, the frequency of the design event influenced the curve number, rather than the associated land use type. Therefore, this model would not be appropriate to develop flow standards throughout a developing watershed where modifications to land use classifications define the impacts. Additionally this model lacked sufficient detail to determine flow standards at each location a tributary crossed a municipal boundary.

Table 3-1 compares the flows determined by three previous studies. The 1974 study did not calculate the flows at the USGS gage. For this reason, the flow rate for the FIS model is an approximation based on the flow upstream and downstream of the gage. The MWH volume study shows a reduction in flows of about 1,200 cfs at the WOMP station when compared to the U.S. COE model completed in 1998. This represents about 25 percent reduction from the effective FIS published in 1980.

**Table 3-1 Peak Flow Rates from Previous Studies**

| Station         | SCS 1980 FIS model (1974) | U.S. COE Model (1998) | MWH Volume Study (2002) |
|-----------------|---------------------------|-----------------------|-------------------------|
|                 | TR-20                     | HEC-1                 | HEC-HMS                 |
| WOMP (Hastings) | 8,100                     | 7,435                 | 6,193                   |
| USGS (Empire)   | ~6,000                    | 5,427                 | 4,468                   |

---

*Review of Existing Hydrologic Studies of the Vermillion River Watershed. Mohseni, 2004*

## 4.0 Methodology

---

### 4.1 XP-SWMM Computer Model

The United States Environmental Protection Agency's Storm Water Management Model (SWMM), with a computerized graphical interface provided by XP Software (XP-SWMM), was the surface water computer-modeling package used for this study. XP-SWMM uses rainfall and watershed information to generate runoff that is routed simultaneously through pipe and overland flow networks. Simultaneous routing means that flow in the entire system is modeled for each time increment simultaneously, then the model moves on to the next time increment, and so on (other models calculate runoff by subwatershed for the entire duration of the storm, before moving to the next subwatershed). Simultaneous routing allows the model to account for flows in pipes, flow detained in ponding areas, and effects of backwater conditions (such as water surcharging at catch basins and backflow through pipes), all of which do occur in the Vermillion River study area.

XP-SWMM, Version 10.6 was used to model the storm sewer, channels, streams, and overland flow systems within the study area. Data was input regarding: (a) pipe locations, sizes, geometry, materials, and elevations; (b) storage basin elevation, volume, and outflow characteristics; (c) surface flow characteristics including channel cross sections; and (d) rainfall amount and distribution.

### 4.2 Hydrologic Modeling

XP-SWMM requires two types of information for hydrologic modeling, watershed data, and climatic data. These data are used to generate runoff hydrographs and is described in [Section 4.2.1](#) and [Section 4.2.2](#).

#### 4.2.1 Watershed Data

Examination of the watershed characteristics for the study area involved assessments of topography and drainage patterns, soil types, land use and residential density, and the impervious fraction of the land in the watershed. ArcView geographic information system (GIS) software was used extensively in assessing the watershed characteristics.

##### 4.2.1.1 Watershed Area

The Vermillion River study area was subdivided to create subwatersheds that were generally between 0.25 to 2.0 square miles. Subwatershed divides were developed from two sources, in urban developed

areas watershed divides were taken from the existing municipal stormwater management plans, and in undeveloped or areas without a stormwater management plan LiDAR topographic data obtained from Dakota and Scott Counties were used to develop subwatershed divides. [Figure 4-1](#) illustrates the final watershed divides used to develop the XP-SWMM model.

### ***Watersheds in Urban Areas***

Municipal stormwater management plans include varying levels of detail and watersheds of varying sizes. Generally, hydrologic models perform better if the range in subwatershed size is not too large, so that subwatersheds include hydrologic processes on the same scale. In addition, uniform adjustments to watershed parameters make more sense on subwatersheds of similar size.

Subwatersheds in municipal plans were merged together to create subwatersheds approximately 1 square mile in area, within the range of 0.25 to 2 square miles for development of the XP-SWMM model. Watershed divides obtained from municipal plans were collected from the following sources:

***Elko New Market***—In January 2007, the cities of Elko and New Market joined to form one city, Elko New Market. A storm water management plan for the City of Elko (now the eastern half of the city) was published in 2004. Prior to developing the XP-SWMM model, updated subwatershed divides that covered the new City of Elko New Market were provided and used in this model.

***Farmington***—The Farmington plan was approved by the VRWJPO Board in 2008. The subwatershed divides used in the plan were used for this model.

***Hastings***—The Hastings plan was approved by the VRWJPO Board in 2008. Subwatersheds from the plan were incorporated into this analysis.

***Lakeville***—The storm water management plan for the City of Lakeville was published in 1997. The 1997 plan was under revision and accepted by the VRWJPO Board in 2008 during this study. New subwatersheds had not been developed at the beginning of this study, so the subwatersheds developed for the 1997 plan were used.

Subwatersheds from municipal plans were merged so composite subwatersheds were delineated to significant storage areas (e.g., ponds, road crossings, etc.). While the Vermillion River Watershed model is not intended to include every culvert or storm sewer segment, it is important to include enough storage in the upstream areas in order to accurately estimate peak flows and simulate the recession curve of the hydrograph. First, storm sewer maps and flow arrows from the municipal plans

were used to merge smaller subwatersheds to a reasonable size (~0.25 square mile). If there did not appear to be much storage in watersheds less than 0.25 square mile, upstream subwatersheds were merged with downstream subwatersheds until a road crossing or pond was included that would restrict flow.

### ***Watersheds in Rural Areas***

The ArcHydro automated watershed delineation tool in GIS was used to create subwatersheds in the areas outside municipalities with stormwater plans that ranged in size between 0.25 to 2.0 square miles. ArcHydro is an ArcGIS-based program that supports water resources applications. The subwatershed divides developed using ArcHydro were compared to subwatershed divides that had been developed for the recent Dakota County FIS update project to identify potential errors.

#### **4.2.1.2 Watershed Naming Convention**

Watersheds used in the Vermillion River model were named using an abbreviation and numbering system. Abbreviations for each watershed were assigned based on the downstream primary tributary. Numbering began at the downstream end of each primary tributary and progressed upstream. Primary tributaries with less than two watersheds were given the same abbreviation as the Vermillion River with an additional identifier; Tributary O located in the southwest portion of the drainage area is an example of this. Tributary O is a primary tributary with a single watershed; the watershed name for Tributary O is “VRTribo-44”. This was done to minimize the number of watershed groupings and make small watersheds easier to locate. A map of the watersheds used in the Vermillion River model is included in [Figure 4-1](#). [Section 4.3.2.1](#) provides additional information on naming of tributaries.

#### **4.2.1.3 Impervious Data**

All land use practices within a watershed affect the quantity and timing of runoff generated. Each land use generates a different quantity of runoff due primarily to the amount of impervious area within that watershed. [Figure 4-2](#) shows the land use for the complete study area. The impervious area input into the XP-SWMM computer model that generates runoff is, by definition, hydraulically connected to the drainage systems being analyzed. This directly connected impervious percentage includes driveways, rooftops, and parking areas that are directly connected to the storm sewer system. Runoff from the portion of a rooftop draining onto adjacent pervious areas was not treated as connected impervious areas.



The percent of directly connected impervious area pertaining to each land use type was calculated using 2005 land cover data developed by Applied Ecological Services (AES), which was based on the Minnesota Land Cover Classification System (MLCCS) for the western portion of the Vermillion River watershed and the 2005 Metropolitan Council land use classifications. The AES land cover data set is shown in [Figure 4-3](#), and the impervious percentages assigned to each land cover classification are listed in [Table 4-1](#). These percentages were used to calculate the percentage of directly connected impervious area for each 2005 Met Council land use classification based on the land cover types within each land use.

**Table 4-1 Land Cover Percent Impervious**

| <b>AES Land Cover Classification <sup>1</sup></b> | <b>Total Percent Impervious (%)</b> | <b>Directly Connected Percent Impervious (%)</b> |
|---------------------------------------------------|-------------------------------------|--------------------------------------------------|
| Asphalt                                           | 100%                                | 100% or 0% <sup>2</sup>                          |
| Concrete                                          | 100%                                | 100% or 0% <sup>2</sup>                          |
| Commercial Roof                                   | 100%                                | 86% or 0% <sup>3</sup>                           |
| Residential Roof                                  | 100%                                | 33% or 0% <sup>4</sup>                           |
| Forest                                            | 0%                                  | 0%                                               |
| Corn                                              | 0%                                  | 0%                                               |
| Tall Grass                                        | 0%                                  | 0%                                               |
| Lawn                                              | 0%                                  | 0%                                               |
| Bare Soil                                         | 0%                                  | 0%                                               |
| Pond                                              | 100%                                | 100%                                             |
| Reservoir                                         | 100%                                | 100%                                             |
| Wetland                                           | 6%                                  | 6%                                               |

<sup>1</sup> Land cover classifications from Applied Ecological Services, 2007

<sup>2</sup> Assumed to be 100 percent directly connected. In Agricultural, Airport, and Farmstead Metropolitan Council land use classifications assumed to be 0 percent.

<sup>3</sup> Assumed to be 86 percent directly connected. In Airport, Metropolitan Council land use classification assumed to be 0 percent.

<sup>4</sup> Assumed to be 33 percent directly connected. In Agricultural, Airport, and Farmstead Metropolitan Council land use classifications assumed to be 0 percent.

The percent impervious assigned to each 2005 Met Council land use classification, listed in [Table 4-2](#), was used to calculate the impervious area for each subwatershed in the study area. The average directly connected percent impervious area over the entire study area was 7.3 percent of the total watershed area. The directly connected imperviousness assumptions were not modified during model calibration because of the high level of accuracy in the AES land cover data set. See

[Appendix A](#) for the detailed methodology of how a percent impervious value was calculated for each 2005 Met Council Land Use from the AES land cover data set.

**Table 4-2 Land Use Percent Impervious**

| <b>2005 Metropolitan Council<br/>Land Use Classification</b> | <b>Total Percent<br/>Impervious<br/>(Percent)</b> | <b>Directly Connected<br/>Percent Impervious<br/>(Percent)</b> |
|--------------------------------------------------------------|---------------------------------------------------|----------------------------------------------------------------|
| Agricultural                                                 | 1.7                                               | 0.0                                                            |
| Airport                                                      | 5.4                                               | 0.0                                                            |
| Extractive (e.g., gravel pits)                               | 5.7                                               | 5.7                                                            |
| Farmstead                                                    | 14.8                                              | 0.0                                                            |
| Golf Course                                                  | 4.8                                               | 4.8                                                            |
| Industrial and Utility                                       | 62.8                                              | 59.1                                                           |
| Institutional                                                | 35.8                                              | 34.3                                                           |
| Major Highway                                                | 54.2                                              | 54.2                                                           |
| Manufactured Housing Parks                                   | 40.7                                              | 32.3                                                           |
| Mixed Use Commercial and Other                               | 100.0                                             | 97.6                                                           |
| Mixed Use Industrial                                         | 59.0                                              | 55.5                                                           |
| Mixed Use Residential                                        | 33.0                                              | 28.4                                                           |
| Multifamily                                                  | 58.3                                              | 47.3                                                           |
| Office                                                       | 75.1                                              | 70.9                                                           |
| Park, Recreational, or Preserve                              | 11.0                                              | 11.0                                                           |
| Retail and Other Commercial                                  | 79.0                                              | 75.7                                                           |
| Seasonal/Vacation                                            | 18.4                                              | 15.7                                                           |
| Single Family Attached                                       | 41.7                                              | 30.3                                                           |
| Single Family Detached                                       | 27.5                                              | 20.6                                                           |
| Undeveloped                                                  | 6.5                                               | 6.5                                                            |
| Water                                                        | 100.0                                             | 100.0                                                          |

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*Land use classifications from Metropolitan Council, June 2005.*

#### **4.2.1.4 Watershed Width and Slope**

Watershed “width” is key parameter in establishing the subwatershed time of concentration.

Following methodology in the SWMM user’s manual (*Storm Water Management Model; Version 4 User’s Manual*, U.S. EPA 1988) watershed width was calculated by dividing the watershed area by the longest flow path.

The average slope (ft/ft) for each watershed was estimated using ArcHydro and a Digital Elevation Model (DEM) created from Dakota and Scott County LIDAR data. Average watershed slopes were not modified during model calibration.

XP-SWMM generates runoff from each of the subwatersheds as the product of velocity (from Manning's equation based on the difference between total depth and depression storage and the average subwatershed slope), depth and width (flow area). If overland flow is visualized as running down-slope off an idealized, rectangular subwatershed, then the width of the subwatershed is the physical width of overland flow. The lateral flow per unit width is computed and multiplied by the width to obtain the runoff rate.

#### **4.2.1.5 Infiltration Data**

The Natural Resource Conservation Service (NRCS) soil survey geographic (SSURGO) database released in July 2006 was used to determine the hydrologic soil group classifications of the soils within the study area. For areas where the hydrologic soil group was undefined, a hydrologic soil group was assigned based on the surrounding soils. [Figure 4-4](#) depicts the hydrologic soil group classifications throughout the study area. The predominant soil type in the study area is Type B that indicates moderate infiltration rates.

Infiltration is the movement of water into the soil surface. For a given storm event, the infiltration rate will vary with time. At the beginning of the storm, the initial infiltration rate is the maximum infiltration that can occur because the soil surface is typically drier and full of air spaces. As the storm event continues, the infiltration rate will gradually decrease as the air space in the soil fills with water. For long storms, the infiltration rate will reach a constant value, the minimum infiltration rate. The Horton infiltration equation was used to simulate this variation of infiltration rate with time.

Horton infiltration parameters were calculated for each subwatershed. These parameters are used for the generation of runoff from the individual subwatersheds. Horton infiltration input parameters include, minimum value of infiltration capacity ( $F_c$ ), initial infiltration capacity ( $F_o$ ), and the decay coefficient ( $k$ ). [Table 4-3](#) summarizes the initial input parameters used for the Vermillion River hydrologic model. The table includes the Horton infiltration values for each hydrologic soil group. The initial infiltration rate, minimum infiltration rate and decay coefficient values were selected using guidelines established in the SWMM User's Manual, and the initial infiltration rate and minimum infiltration rate were then modified as part of the calibration process.

**Table 4-3 Initial Uncalibrated Horton Infiltration Parameters**

| Hydrologic Soil Group | F <sub>o</sub> (in/hr) | F <sub>c</sub> (in/hr) | k (1/sec) |
|-----------------------|------------------------|------------------------|-----------|
| A                     | 5.0                    | 0.38                   | 0.00115   |
| B                     | 3.0                    | 0.23                   | 0.00115   |
| C                     | 2.0                    | 0.10                   | 0.00115   |
| D                     | 1.0                    | 0.03                   | 0.00115   |

Composite infiltration values were calculated by computing a weighted average based on the percentage of each soil type in the watershed.

#### 4.2.1.6 Depression Storage Data

Depression storage, which includes the areas that must be filled with water prior to generating runoff from both pervious and impervious areas, were set within the general range of published values. It represents the initial loss caused by surface ponding, surface wetting, and interception. The model handles depression storage differently for pervious and impervious areas. The impervious depression storage is replenished during dry simulation periods by evaporation. The water stored as pervious depression storage is subject to both infiltration and evaporation. The impervious depression storage was assumed to be 0.06 inches for impervious surfaces located within the study area, which is within the range of published values in the U.S. EPA SWMM Version 5.0 User's Manual. Pervious land cover classifications in [Figure 4-3](#) were assigned depression storage values listed in [Table 4-4](#).

**Table 4-4 Pervious Land Cover Depression Storage Values**

| Land Cover Classification | Pervious Depression Storage (inches) |
|---------------------------|--------------------------------------|
| Forest                    | 0.3                                  |
| Corn                      | 0.2                                  |
| Tall Grass                | 0.2                                  |
| Lawn                      | 0.15                                 |
| Bare Soil                 | 0.1                                  |

*U.S. EPA SWMM Version 5.0 Users Manual, October 2005*

For each Met Council land use classification an area weighted average was calculated in ArcGIS based on the previously assigned land cover depression storage values. This was required because the AES land cover data set only covered the western portion of the watershed. The pervious depression storage inputs used in the XP-SWMM model are summarized in [Table 4-5](#).



**Table 4-5 Pervious Land Use Depression Storage Values**

| <b>2005 Met Council Land Use</b> | <b>Pervious Depression Storage<br/>(inches)</b> |
|----------------------------------|-------------------------------------------------|
| Agricultural                     | 0.197                                           |
| Airport                          | 0.170                                           |
| Extractive                       | 0.135                                           |
| Farmstead                        | 0.167                                           |
| Golf Course                      | 0.153                                           |
| Industrial and Utility           | 0.171                                           |
| Institutional                    | 0.169                                           |
| Major Highway                    | 0.194                                           |
| Manufactured Housing Parks       | 0.159                                           |
| Mixed Use Commercial and Other   | 0.150                                           |
| Mixed Use Industrial             | 0.161                                           |
| Mixed Use Residential            | 0.183                                           |
| Multifamily                      | 0.166                                           |
| Office                           | 0.171                                           |
| Park, Recreational, or Preserve  | 0.177                                           |
| Railway                          | 0.010                                           |
| Retail and Other Commercial      | 0.173                                           |
| Seasonal/Vacation                | 0.150                                           |
| Single Family Attached           | 0.171                                           |
| Single Family Detached           | 0.169                                           |
| Undeveloped                      | 0.178                                           |
| Water                            | 0.080                                           |

#### 4.2.1.7 Overland Flow Roughness Data

Overland flow is surface runoff that occurs as sheet flow over land surfaces prior to concentrating into defined channels. In order to estimate the overland flow or runoff rate a modified version of Manning's equation is used by XP-SWMM. A key parameter in the Manning's equation is the roughness coefficient. The shallow flows typically associated with overland flow result in substantial increases in surface friction. As a result, the roughness coefficients typically used in open channel flow calculations are not applicable to overland flow estimates. These differences can be accounted for by using an effective roughness parameter instead of the typical Manning's roughness parameter.

Typical values for the effective roughness parameter are published in the U.S. COE *HEC-1 User's Manual*, June 1998; and *EPA SWMM Manual*, October 2005. After reviewing the above references,

pervious roughness coefficients were selected for each pervious land cover classification, and are included in [Table 4-6](#). The impervious roughness coefficient for all impervious surfaces within the study area was assumed to be 0.014.

**Table 4-6 Land Cover Pervious Roughness Coefficients**

| Land Cover Classification | Pervious Roughness Coefficient |
|---------------------------|--------------------------------|
| Forest                    | 0.6                            |
| Corn                      | 0.2                            |
| Tall Grass                | 0.2                            |
| Lawn                      | 0.24                           |
| Bare Soil                 | 0.1                            |

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U.S. COE *HEC-1 User's Manual*, June 1998 and *EPA SWMM Version 5.0 Users Manual*, October 2005

Similar to depression storage an area weighted average pervious roughness coefficient was calculated for each Met Council land use classification based on previously assigned land cover roughness coefficients. This was required because the AES land cover data set only covered the western portion of the watershed. The pervious roughness coefficients used in the XP-SWMM model are summarized in [Table 4-7](#).

**Table 4-7 Pervious Land Use Roughness Coefficients**

| 2005 Met Council Land Use       | Pervious Roughness Coefficient |
|---------------------------------|--------------------------------|
| Agricultural                    | 0.21*                          |
| Airport                         | 0.23                           |
| Extractive                      | 0.14                           |
| Farmstead                       | 0.26                           |
| Golf Course                     | 0.24                           |
| Industrial and Utility          | 0.24                           |
| Institutional                   | 0.25                           |
| Major Highway                   | 0.22                           |
| Manufactured Housing Parks      | 0.24                           |
| Mixed Use Commercial and Other  | 0.24                           |
| Mixed Use Industrial            | 0.23                           |
| Mixed Use Residential           | 0.30                           |
| Multifamily                     | 0.26                           |
| Office                          | 0.23                           |
| Park, Recreational, or Preserve | 0.28                           |

| <b>2005 Met Council Land Use</b> | <b>Pervious Roughness Coefficient</b> |
|----------------------------------|---------------------------------------|
| Railway                          | 0.01                                  |
| Retail and Other Commercial      | 0.17                                  |
| Seasonal/Vacation                | 0.24                                  |
| Single Family Attached           | 0.25                                  |
| Single Family Detached           | 0.27*                                 |
| Undeveloped                      | 0.28                                  |
| Water                            | 0.12                                  |

\* Agricultural and Single Family Detached pervious roughness coefficients are initial values. These two values were included as part of the calibration process and final calibrated values vary slightly over the watershed.

#### **4.2.1.8 Landlocked Basins**

The ArcHydro sink evaluation tool in GIS was used to identify low-lying areas within the Vermillion River watershed that do not generate runoff. Landlocked areas were identified by comparing the volume of runoff generated by the 100-year, 10-day snowmelt event with the available storage volume in each low-lying area. The Met Council 10-meter DEM was used to identify low-lying areas. (There was too much “noise” in the County LIDAR data for ArcHydro to accurately identify low-lying areas in the topography. For this reason, a DEM with a lower resolution and less “noise” was used to identify low-lying areas in the landlocked basin analysis). The Met Council DEM is based on USGS quadrangle maps with publication dates between 1979 to 1990.

Runoff volume generated by the 100-year, 10-day snowmelt event (7.2 inches of runoff) within the drainage area to each low-lying area was calculated and then compared to the total available storage volume. (Storage volume in each basin was calculated from the water level in each pond because the volume below the water level is not included in the DEM grid, and it is assumed that the basins will not be empty at the beginning of any precipitation or snowmelt event.) If the generated runoff volume from the 100-year, 10-day event was less than the volume of the basin, it was identified as landlocked. A snowmelt event was used to determine if a low-lying area was landlocked because little to no infiltration occurs during a snowmelt event, therefore no infiltration assumptions are required to determine the amount of runoff during the event (i.e., It is assumed that no infiltration occurs during a snowmelt event). Landlocked areas were removed from the contributing watershed area in the XP-SWMM model and are shown in [Figure 4-5](#).

## **4.2.2 Precipitation Data**

Precipitation data for model calibration and validation was collected from several sources including Next Generation Radar (NEXRAD) radar data, 15-minute precipitation data obtained from the National Climatic Data Center (NCDC), and daily precipitations obtained from the National Weather Service (NWS) to develop accurate precipitation hyetographs. Combining precipitation data from several sources allowed development of hyetographs that closely approximated both the distribution and magnitude of precipitation that occurred over the study area. Precipitation for analysis of the design events were created following industry standards of TP-40 using the metrological modeling component of HEC-HMS.

### **4.2.2.1 Calibration and Validation Event Precipitation**

The XP-SWMM model was calibrated to two independent storm events agreed on by the ITR committee prior to beginning calibration. Event D where approximately 3 inches of precipitation occurred on August 4, 2002 and Event G where approximately 4.6 inches of precipitation occurred between September 14-15, 2004. Results from the calibrated XP-SWMM model were validated by comparing calibrated model results to observed data from two independent events of similar magnitude, Event A where 4.3 inches occurred between July 5-9, 2000, and Event C where 3.7 inches occurred between June 2-7, 2002. See [Appendix B](#) for a detailed discussion of the selection of each calibration and validation event.

Precipitation files for the calibration and validation events were developed by combining Next Generation Radar (NEXRAD) data from the NCDC with Ground Truth Rainfall (GTR) data obtained from the NWS. NEXRAD continuously collects precipitation intensity data at approximately 5-minute intervals over the entire Vermillion River study area. Unit hyetographs were developed for each subwatershed in the study area based on NEXRAD intensity data collected from the Minneapolis and La Crosse radar stations. The total rainfall amount for each storm event was calculated based on the GTR data obtained from the NWS. Final hyetographs for XP-SWMM were created by multiplying each unit hyetograph created based on NEXRAD data by the respective GTR amount.

### **4.2.2.2 Historical Event Precipitation**

NEXRAD data was unavailable during the 1992 historical event chosen to validate the calibrated model. For this event 15-minute precipitation data obtained from the Northfield gage located just south of the study area was used to determine the distribution of rainfall and calculate a unit

hyetograph. The unit hyetograph was then combined with daily GTR data obtained from the three monitoring stations located within the study area. The study area was broken into three sections using the Thessien polygon method, and a distribution was assigned to each section of the study area.

[Figure 4-6](#) shows the locations of monitoring stations used to develop precipitation data for the 1992 event.

#### **4.2.2.3 Design Event Precipitation**

Previous studies of the watershed, including the U.S. COE July 1998 study, found the 4-day design event to be the critical duration for this watershed, and in the 2006 VRWJPO development standards the VRWJPO identified the 4-day event as the critical duration. Additionally, as part of this study the 4-day design event was confirmed as the critical duration event by evaluating design events of longer and shorter durations.

The meteorologic model component of HEC-HMS was used to develop the frequency based 4-day design event used in the XP-SWMM model. The frequency based design event is developed by combining precipitation totals from shorter duration storm events that have an equal return period to create the hyetograph for the overall 4-day event. The 4-day point precipitation totals are included in [Table 4-8](#). The precipitation totals for the 100-, 50-, 10-, and 2-year return periods were defined in the U.S. COE July 1998 study of the Vermillion River which used Technical Paper 40 and Technical Paper 49 and National Weather Service Hydro-35 to determine the point precipitation for each return frequency. The precipitation totals for the 1-year return period was calculated based on precipitation values defined by the 1998 study of the Vermillion River. A trend line was fit to the precipitation totals plotted on a semi-log axis, and the 1-year return period precipitation value was determined as shown in [Figure 4-7](#).



**Table 4-8 Hypothetical Rainfall Event Point Precipitation (inches)**

| Duration  | Return Frequency |        |         |         |          |
|-----------|------------------|--------|---------|---------|----------|
|           | 1-Year           | 2-Year | 10-Year | 50-Year | 100-Year |
| 5-minute  | 0.4              | 0.43   | 0.59    | 0.76    | 0.84     |
| 15-minute | 0.7              | 0.84   | 1.2     | 1.6     | 1.7      |
| 1-hour    | 1.1              | 1.4    | 2.1     | 2.7     | 3.0      |
| 2-hour    | 1.3              | 1.7    | 2.5     | 3.2     | 3.5      |
| 3-hour    | 1.45             | 1.8    | 2.7     | 3.5     | 3.9      |
| 6-hour    | 1.7              | 2.1    | 3.2     | 4.0     | 4.5      |
| 12-hour   | 2.02             | 2.5    | 3.7     | 4.7     | 5.3      |
| 24-hour   | 2.2              | 2.8    | 4.2     | 5.4     | 6.0      |
| 2-day     | 2.6              | 3.3    | 4.8     | 6.3     | 7.0      |
| 4-day     | 3.2              | 4.0    | 5.6     | 7.5     | 8.3      |

HEC-HMS applies an area correction factor using the depth area reduction curves in TP 40, which are shown in [Figure 4-8](#), to each depth listed in [Table 4-8](#) to convert the point precipitation depths to an appropriate aerial precipitation depth based on drainage area. The area correction factor accounts for the fact that intense precipitation is less likely to occur uniformly over a large watershed than it is at a single point, and the average precipitation over an area is less than precipitation at a single point (HEC-HMS Users Manual, U.S. COE, 2000). Following the guidelines from *Technical Report 60: Earth Dams and Reservoirs* published by the Soil Conservation Service (June 1976), area correction factors are not applied to drainage areas less than 10 square miles.

Finally, HEC-HMS develops the frequency based hyetograph using the alternating block method using the precipitation depths from the shorter duration storms that have spatially adjusted based on the drainage area being analyzed (HEC-HMS Users Manual, U.S. COE, 2000). The design event hyetograph is developed so that the peak of the storm occurs at the center with decreasing intensities on either end. By design, critical storm events with lesser duration are nested in the overall 4-day event distribution for similar drainage areas. That way only one design event is required to obtain critical flows throughout the watershed (i.e., location of a subwatershed in the drainage network is irrelevant because the critical duration storm event for each subwatershed is nested within the 4-day precipitation hyetograph.). As shown in [Figure 4-9](#) design events of shorter duration and similar drainage area are nested within the 4-day hyetographs developed in HEC-HMS that are used as the design event precipitation input in the XP-SWMM model. This methodology is similar to the methodology used to develop the standard SCS Type II, 24-hour storm hyetograph; therefore, the 4-day frequency based design storm developed using HEC-HMS has the same peak intensity of the

SCS Type II 24-hour design event and shorter duration frequency based storms as shown in [Figure 4-10](#).

Applying an aerial adjustment factor to each point precipitation value used to compute the frequency based hyetograph results in a reduction of the total amount of precipitation for a design event with a specified return period and duration. For example, the 100-year, 4-day frequency based storm event is 8.3 inches for a tributary drainage area of 0 to 10 square miles. However, for a tributary area of 115 square miles the 100-year, 4-day frequency based storm even is only 7.925 inches. The final spatial precipitation inputs used in the XP-SWMM model are included in [Table 4-9](#).

**Table 4-9      Spatially Adjusted Hypothetical Rainfall Event Point Precipitation (inches)**

| <b>Percent Exceedence</b> | <b>0 sq mi</b> | <b>20 sq mi</b> | <b>115 sq mi</b> | <b>225 sq mi</b> |
|---------------------------|----------------|-----------------|------------------|------------------|
| 100                       | 3.200          | 3.154           | 3.055            | 3.030            |
| 50                        | 4.000          | 3.943           | 3.819            | 3.788            |
| 10                        | 5.600          | 5.520           | 5.347            | 5.302            |
| 2                         | 7.500          | 7.393           | 7.161            | 7.102            |
| 1                         | 8.300          | 8.182           | 7.925            | 7.859            |

Additionally because a different aerial adjustment factor is applied to each precipitation input in [Table 4-8](#) prior to developing the frequency based hyetograph; hyetographs for storms of similar return period and duration will have different shapes depending on the drainage area. Frequency based hyetographs for larger drainage areas will have a lower peak intensity but higher intensities at the beginning and end of the storm event than the frequency based hyetograph for smaller drainage areas. This stipulates that high peak intensities are unlikely to occur uniformly throughout the entire watershed. [Figure 4-11](#) illustrates how the shape of the frequency based hyetograph varies for hypothetical storm events with similar return periods and durations.

For the Vermillion River model, the tributary drainage area to each standard location was calculated and the frequency based hyetograph for the appropriate drainage area was used to determine peak flows at standard locations.

### **4.3    Hydraulic Modeling**

Hydrographs generated from hydrologic modeling in XP-SWMM were routed from overland conveyances into the storm sewer and stream network. Due to the significant portion of undeveloped

area within the watershed the Vermillion River system is primarily a single-tiered network (i.e., flow is primarily routed through an overland network, and storm sewer is not in place for most of the watershed). However for locations where roads, railroads, driveways, or other crossings intersect the stream network both the culvert and overflow conduits were included in the model to accurately model the conveyance of the system.

#### **4.3.1 Bridges and Culverts**

Bridge and culvert data were taken from previous models developed for municipalities within the study area, the Dakota County Digital Flood Insurance Rate Map (DFIRM) models, as-built drawings provided by the municipalities within the study area, and field surveys performed by Dakota and Scott Counties. Bridge and culvert data gathered included pipe invert elevations, lengths, diameters, and material type. All elevations entered into the model are in feet above Mean Sea Level (NAVD 88). A typical roughness coefficient was chosen for culverts that were surveyed. The roughness coefficients were unchanged for culverts that were included in previous models. An inlet type was assigned to all culverts included in the model. This allowed XP-SWMM to determine the controlling flow condition in the pipe (i.e., whether the flow in the pipe is controlled by the inlet size, barrel capacity, or tail-water conditions) and accurately estimate the water surface elevation upstream and downstream of each pipe throughout each event.

##### **4.3.1.1 South Branch Bridge**

The South Branch of the Vermillion River monitoring station (SB-802) is located on the 200<sup>th</sup> Street East bridge. In 2003, the bridge was replaced but the monitoring station remained on the bridge. Construction of the new bridge modified the area available to convey flow under the bridge, which prevented calibration of the model to the events selected prior to 2003. For Events A, C, and D the older bridge is included in the XP-SWMM model. However, for Event G and the calibrated design event models the current 200<sup>th</sup> Street East bridge is used in the model. This allowed the XP-SWMM model to accurately simulate conditions at this monitoring station during the selected calibration events.

##### **4.3.1.2 SC-804 Stream Section**

Channel cross section inverts at monitoring stations were calculated based on the elevation of the monitoring station and the measured distance from the monitoring station to the streambed (measure down distance) provided by the Minnesota Department of Natural Resources (DNR). The Minnesota DNR provided one measure down distance at each monitoring station for each year because the

measure down distance varies slightly over time due to scour of the streambed or sediment build up. The invert was modified between calibration and validation events at monitoring station SC-804 to accurately simulate the starting water surface elevation for each precipitation event. Adjustments were not required at other monitoring gages to simulate a variable invert elevation due to scour of the streambed or sediment build up.

### **4.3.2 Stream Network**

The stream network modeled in XP-SWMM includes the Vermillion River, primary contributing tributaries, and most secondary tributaries. The Vermillion River and primary tributaries follow the stream centerlines in the VRWJPO buffered streams inventory. Stream centerlines that were not included in the VRWJPO buffered streams inventory or the DNR stream inventory were digitized in ArcGIS based on topology, landscape, and culvert locations. Following the development of the stream network all tributaries included in the XP-SWMM model were named, and cross sections were used to model the hydraulic capacity of the system.

#### **4.3.2.1 Tributary Naming Convention**

Primary tributaries to the Vermillion River were named using a consistent set of guidelines. A standardized naming convention was developed to keep the tributary, stream, and creek names consistent with those previously assigned by the DNR or the Dakota County DFIRM. The naming guidelines outlined below are listed in descending order of importance.

##### *Tributary Naming Guidelines*

1. Utilize the name published by the DNR.
2. Utilize the name published in the Dakota County DFIRM.
3. Remaining unnamed tributaries were assigned a letter beginning at the downstream end of the study area, the Hastings Dam.

The naming convention is intended to easily differentiate between tributaries that were either named by the DNR or in the Dakota County DFIRM and tributaries named for this study. Naming conventions for streams used in the Dakota County DFIRM and those named for this Vermillion River model is outlined in [Table 4-10](#).

**Table 4-10 Naming Conventions**

|                          | <b>Dakota County<br/>DFIRM Stream</b> | <b>Stream not included in the<br/>Dakota County DFIRM</b> |
|--------------------------|---------------------------------------|-----------------------------------------------------------|
| <b>Primary Tributary</b> | Tributary 1                           | Tributary A                                               |
| <b>Second Tributary</b>  | Tributary 1A<br>Tributary 1B          | Tributary A1<br>Tributary A2                              |
| <b>Third Tributary</b>   | -                                     | Tributary A1.1                                            |

Primary tributaries to the Vermillion River are labeled and shown in [Figure 4-12](#). The lettered tributaries were included in the model and were previously unnamed by the DNR or DFIRM.

Secondary tributaries not named in the Dakota County DFIRM that are tributary to a reaches named in the DFIRM, use the naming convention established in the DFIRM. The lettering for these reaches begins where the DFIRM left off. An example of this is Tributary 1, which is shown in [Figure 4-13](#).

#### **4.3.2.2 Cross Section Selection**

Stream cross sections in the Vermillion River Hydrologic model were selected from cross sections developed for the Dakota County DFIRM and other HEC-RAS models developed for the municipalities within the study area or were cut from the available topographic information. The cross sections used in the Vermillion River model were selected using the following set of guidelines based on the distance from a Standard Location. Standard locations were defined using a methodology defined by the ITR Committee where the Vermillion River or a tributary crossed a municipal boundary (see Section 4.7 for further discussion of Standard Locations).

##### *At Standard Locations (Municipal Boundaries)*

1. Include all lettered DFRIM cross sections 1,000 feet upstream and downstream of a standard location, or until then next upstream or downstream road crossing.
2. If no lettered DFIRM cross sections, or road crossings are located within 1,000 feet from a standard location include the next lettered cross section within 2,000 feet from the standard location.
3. If no lettered DFIRM cross sections are located between standard locations and upstream or downstream of road crossings or watershed boundary use the most restrictive non-lettered cross section based on flow area during the 100-year event.

##### *Between Road Crossings, Watershed Boundaries, and >1,000 feet from Standard Locations*

1. Select the most restrictive lettered DFIRM cross section based on flow area during the 100-year event.



2. If no lettered DFIRM cross sections are located between road crossings or watershed boundaries select the most restrictive non-lettered cross section based on flow area during the 100-year event.

Selecting the most restrictive cross section for a given reach has two major advantages. Since XP-SWMM accounts for storage in all flow conveyance elements (channels, culvert, pipes, manholes, etc.) the potential to over estimate the available storage volume in a given system exists if stage-storage data are entered in addition to unrestrictive cross sections (i.e., double counting of storage). Therefore using the most restrict cross section will minimize this potential source of error. Second, utilizing the most restrictive cross section will accurately model the actual flow capacity of the stream. [Figure 4-14](#) illustrates the cross sections selected along part of the Vermillion River in the northeast portion of the study area.

#### **4.3.3 Apple Valley Inflows**

There are two locations that hydraulically connect the City of Apple Valley to the downstream watershed. Subwatersheds were delineated to both of these outlets at the beginning of the project. However, the cities of Apple Valley and Lakeville and the VRWJPO reached an agreement defining the maximum allowable flow rates at these locations prior to calibrating the model. The XP-SWMM modeling was based on flow rates provided by the City of Apple Valley. However, the flow standards are based on the agreement between Apple Valley and Lakeville. The agreed upon flow rates were reviewed by the ITR Committee and incorporated into the final flow standards. Based on discussions with the ITR Committee it was determined that Apple Valley inflows would not be incorporated into the calibration or validation events. The first Apple Valley outlet is the pump station at the outlet from Cobble Stone Lake that discharges south across 160<sup>th</sup> Street W. into Lakeville. The municipalities agreed that the allowable flow rate should be the maximum capacity of the pump station. The second location is the outlet from McNamara pond, which outlets across 160<sup>th</sup> Street W. through a 60-inch RCP storm sewer system. The municipalities agreed on flow rates that were developed as part of a previous modeling effort. [Table 4-11](#) includes the maximum inflows from Apple Valley that were reviewed and accepted by the ITR Committee and incorporated into the final XP-SWMM design event simulations, as well as the flow rates used for the Apple Valley flow standards.

**Table 4-11 Apple Valley/Lakeville Intercommunity Flows**

| Design Event | Modeled Cobblestone Lake Outlet (cfs) | Flow Standard Cobblestone Lake Outlet (cfs) | Modeled McNamara Pond Outlet (cfs) | Flow Standard McNamara Pond Outlet (cfs) |
|--------------|---------------------------------------|---------------------------------------------|------------------------------------|------------------------------------------|
| 100-Year     | 27.0                                  | 27.0                                        | 77.0                               | 80.0                                     |
| 50-Year      | 27.0                                  | 27.0                                        | 77.0                               | 80.0                                     |
| 10-Year      | 27.0                                  | 27.0                                        | 76.7                               | 77.0                                     |
| 2-Year       | 27.0                                  | 27.0                                        | 55.0                               | 55.0                                     |
| 1-Year       | 27.0                                  | 27.0                                        | 44.9                               | 45.0                                     |

The capacity of the pipe from McNamara Pond restricts flows from McNamara Pond during larger events. The agreed upon flow rates did not influence model calibration because no flow was generated from either Apple Valley subwatershed during the selected events.

## 4.4 Groundwater Modeling

The contribution of groundwater to the Vermillion River and its tributaries in the study area was approximated through review of stream flow monitoring station records. The contributions of groundwater and surface water were separated using the recorded data and those values were interpolated and extrapolated to other locations in the watershed. The groundwater flows immediately prior to the calibration or validation event were input in the model as initial conditions. As a result, initial conditions inputs to the XP-SWMM model were allowed to vary between calibration and validation events. This was required in order for PEST to calibrate the model, otherwise PEST would over-adjust a parameter to try to compensate for the initial difference between the observed data from the monitoring station and the modeled output.

Similarly, the entire period of record was analyzed for each monitoring station within the study area. The lowest reoccurring flow at each monitoring station was selected as the design event base flow. The ITR Committee approved the base flows for the design events prior to using them the XP-SWMM model. [Table 4-12](#) summarizes the base flows by storm event that were used in the XP-SWMM model.

**Table 4-12 Base Flow Values used in the Vermillion River XP-SWMM Model**

| <b>Monitoring Station</b> | <b>Event A (cfs)</b> | <b>Event C (cfs)</b> | <b>Event D (cfs)</b> | <b>Event G (cfs)</b> | <b>Design Events (cfs)</b> |
|---------------------------|----------------------|----------------------|----------------------|----------------------|----------------------------|
| SC-804                    | 10                   | 9                    | 17                   | 3                    | 1                          |
| VR-807                    | 20                   | 15                   | 34                   | 66                   | 10                         |
| NC-808                    | 5                    | 10                   | 7                    | 4                    | 2                          |
| MC-801                    | 15                   | 18                   | 16                   | 7                    | 6                          |
| USGS                      | 70                   | 50                   | 70                   | 44                   | 30                         |
| SB-802                    | 15                   | 35                   | 31                   | 10                   | 9                          |
| VR-803                    | 120                  | 83                   | 83                   | 66                   | 58                         |
| WOMP                      | 85                   | 160                  | 130                  | 90                   | 50                         |

## 4.5 Model Calibration

There are eleven stream monitoring stations located throughout the Vermillion River watershed. The Dakota County Soil and Water Conservation District (SWCD) operates seven monitoring stations (SC-804, VR-807, NC-801, MC-808, SB-802, VR-809 and VR-803) located in the Dakota County portion of the watershed. The Dakota County SWCD in cooperation with the Metropolitan Council also operates the station located at the Hastings dam, the outlet of the watershed. The Scott County SWCD operates two gages (V12 and V24) located in the Scott County portion of the watershed, and the USGS manages a monitoring station in Dakota County near Empire, located approximately in the middle of the watershed. The monitoring stations located in Scott County (V12 and V24) and one located in the western portion of Dakota County (VR-809) were not operating during the selected calibration events.

The recorded volumes and runoff coefficients were calculated at the remaining gages for each calibration event, and the results are included in [Table 4-13](#). The runoff coefficient was calculated as:

$$C = V_{ro} / V_p$$

Where: C is the runoff coefficient for the area upstream of each monitoring station

$V_{ro}$  is the runoff volume measured at the monitoring station during following a precipitation event

$V_p$  is the volume of precipitation that occurred over the area upstream of the monitoring station

**Table 4-13 Total Volume and Runoff Coefficients at Monitoring Stations Located in the Vermillion River Watershed**

| Monitoring Station | Event D                        |                              |                           | Event G                        |                              |                           |
|--------------------|--------------------------------|------------------------------|---------------------------|--------------------------------|------------------------------|---------------------------|
|                    | <i>Rainfall Volume (ac-ft)</i> | <i>Runoff Volume (ac-ft)</i> | <i>Runoff Coefficient</i> | <i>Rainfall Volume (ac-ft)</i> | <i>Runoff Volume (ac-ft)</i> | <i>Runoff Coefficient</i> |
| SC-804             | 6,300                          | 790                          | 0.125                     | 10,300                         | 670                          | 0.065                     |
| VR-807             | 9,700                          | 1,690                        | 0.173                     | 16,100                         | 2,400                        | 0.149                     |
| NC-808             | 4,300                          | 700                          | 0.164                     | 6,200                          | 700                          | 0.113                     |
| MC-801             | 6,100                          | 800                          | 0.131                     | 9,200                          | 780                          | 0.084                     |
| USGS               | 19,000                         | 2,560                        | 0.135                     | 30,100                         | 2,270                        | 0.075                     |
| SB-802             | 5,300                          | 420                          | .079                      | 7,700                          | 420                          | 0.054                     |
| VR-803             | 28,600                         | 2,460                        | 0.086                     | 44,000                         | 1,060                        | 0.024                     |
| WOMP               | 37,700                         | 5,450                        | 0.145                     | 56,000                         | 5,360                        | 0.096                     |

The analysis indicated the predicted volume and run off coefficients for VR-803 were lower than the immediate upstream and downstream USGS and WOMP gages. Further observation of the source data showed that the recorded peak values at VR-803 were less than the immediate upstream and downstream gages, and conversations with members of the ITR Committee and TAG revealed additional uncertainty about the accuracy of the data at the VR-803 monitoring station. Based on uncertainties in the recorded data monitoring station VR-803 was not used to calibrate the XP-SWMM model. Data from the remaining stream monitoring stations in the Vermillion River watershed, shown in [Figure 4-15](#), were used for calibration of the XP-SWMM model.

Data from monitoring stations shown in [Figure 4-15](#) were used to calibrate the model to two independent storm events agreed on by the ITR committee: Event D where approximately 3 inches of precipitation occurred on June 4, 2002, and Event G where approximately 4.6 inches of precipitation occurred during September 14-15, 2004. See [Appendix B](#) for a discussion of how the calibration events were determined.

PEST, a parameter estimation software package, was chosen to automate the calibration process of the XP-SWMM model. Initially, the XP-SWMM model was calibrated to flow data recorded at the stream monitoring stations. The initial calibration revealed that the flow data from the six gages operated by the Dakota County SWCD contained some uncertainty. Further investigation revealed that no high-flow field measurements were available to develop the rating curves for each monitoring station. The absence of high-flow field measurements meant that high-flows predicted by the rating curves are extrapolated from much lower flow observations as shown in [Figure 4-16](#) through

[Figure 4-25](#). In addition, tail water effects (i.e., high water in the main stem of the Vermillion River) influenced recorded flows for the gage located on the South Branch of the Vermillion River and to a lesser extent on North and Middle Creeks.

As a result, the XP-SWMM model was calibrated to water surface elevation rather than flows. Calibrating to stage reduces the uncertainty of the measurement because it is directly observed, rather than estimated from rating curves applied to observations. The Dakota County Surveyors visited all of the county gages to survey a reference mark that could be used to convert measured stage into water surface elevation. (**Note:** Stage could not be used directly because it did not refer to a measured water depth in the stream.)

Parameters that were found to be insensitive (i.e., a large change in a parameter had a negligible impact on model results) were not included in the calibration process. This allowed PEST to calibrate the XP-SWMM model more efficiently because PEST could not modify parameters that did not influence model results. Initial sensitivity analyses indicated that the peak flows and overall shape of the hydrograph were sensitive to watershed infiltration parameters, depression storage, and channel Manning's "n" values. Since the initial infiltration coefficient ( $F_o$ ) and depression storage have the same effect on the hydrograph (reducing the first part of the hydrograph), it was determined that the initial infiltration parameter would be calibrated and the depression storage parameter would not be included in the calibration process. In addition, it was determined that the initial conditions just prior to the beginning of the storm event had a significant impact on the model results. This resulted in calculating a different initial infiltration coefficient ( $F_o$ ) for each calibration event, rather than one calibrated value, to take into account the difference in moisture in the soil just prior to the calibration event. However, for the remaining calibration parameters listed in [Table 4-14](#), only one calibrated value was calculated for both calibration events.

The model was calibrated to one gage at a time moving from the most upstream gage to the most downstream gage. Parameters were calibrated only for the watershed and stream reaches located between a given gage and the next upstream gage. For example, only parameters for the watersheds shown in orange in [Figure 4-26](#) were modified as part of the calibration process at the USGS gage. As each gage was calibrated, calibrated parameters were incorporated into the model before calibrating the next downstream gage. Several parameters were adjusted during calibration, with each parameter allowed to vary between specified upper and lower limits; the initial values and upper and lower limits for each calibration parameter are specified in [Table 4-14](#).

To speed up the calibration process with PEST, scale factors were chosen for most parameters, rather than absolute values. The scale factors and original default parameter value are multiplied to determine the calibrated parameter. [Table 4-15](#) and [Table 4-16](#) include the resulting range for the final XP-SWMM parameters.

**Table 4-14 Allowable Range for Calibration Parameters**

| Calibration Parameter                            | Initial Value | Minimum | Maximum |
|--------------------------------------------------|---------------|---------|---------|
| Scale $F_o$ – Event D                            | 1.0           | 0.3     | 2.0     |
| Scale $F_o$ – Event G                            | 1.0           | 0.3     | 2.0     |
| Scale $F_c$                                      | 1.0           | 0.3     | 2.0     |
| Pervious “n” for Agriculture Land Use            | 0.21          | 0.2     | 0.3     |
| Pervious “n” for Single Family Detached Land Use | 0.27          | 0.2     | 0.4     |
| Scale factor for Channel Manning’s Coefficient   | 1.0           | 0.86    | 1.14    |

**Table 4-15 Allowable Infiltration Parameter Range for Hydrologic Soil Group**

| XP-SWMM Parameter                  | A     | B     | C    | A/D   | B/D   | C/D   | D     |
|------------------------------------|-------|-------|------|-------|-------|-------|-------|
| Initial $F_o$ (in/hr)              | 5     | 3     | 2    | 5     | 3     | 2     | 1     |
| Maximum $F_o$ (in/hr) <sup>1</sup> | 10    | 6     | 4    | 10    | 6     | 4     | 2     |
| Minimum $F_o$ (in/hr) <sup>2</sup> | 1.5   | 0.9   | 0.6  | 1.5   | 0.9   | 0.6   | 0.3   |
| Initial $F_c$ (in/hr)              | 0.38  | 0.23  | 0.10 | 0.03  | 0.03  | 0.03  | 0.03  |
| Maximum $F_c$ (in/hr) <sup>1</sup> | 0.76  | 0.46  | 0.20 | 0.06  | 0.06  | 0.06  | 0.06  |
| Minimum $F_c$ (in/hr) <sup>2</sup> | 0.114 | 0.069 | 0.03 | 0.009 | 0.009 | 0.009 | 0.009 |

<sup>1</sup> Maximum infiltration values were calculated by multiplying the maximum allowed scale factor of 2 in [Table 4-14](#) by the initial infiltration value

<sup>2</sup> Minimum infiltration values were calculated by multiplying the minimum allowed scale factor of 0.3 in [Table 4-14](#) by the initial infiltration value

**Table 4-16 Allowable Range for Calibrated XP-SWMM Parameters**

| Calibration Parameter                            | Initial Value | Minimum | Maximum |
|--------------------------------------------------|---------------|---------|---------|
| Pervious “n” for Agriculture Land Use            | 0.21          | 0.2     | 0.3     |
| Pervious “n” for Single Family Detached Land Use | 0.27          | 0.2     | 0.4     |
| Channel Manning’s Coefficient *                  | 0.034         | 0.029   | 0.039   |

\* Channel Manning’s Coefficient varies throughout the model depending on channel characteristics. 0.034 is intended to provide an example of how the calibration process will vary the XP-SWMM parameter (i.e., in locations where the initial Manning’s Coefficient is 0.034 the range of allowable calibrated values is 0.029-0.039. This range will vary depending on the initial Manning’s Coefficient).



In order to allow some variability between the calibration in rural and urban areas, the roughness coefficient (Manning's "n") for overland flow was included for agriculture (the dominant land use in rural areas) and single family detached homes (the dominant land use in urban areas).

To calibrate the XP-SWMM model, PEST ran through an iterative process adjusting parameters to calibrate to the two selected calibration storm events simultaneously (i.e., the calibrated parameters provide the best fit when looking at both the results from Event D and Event G together, rather than one event individually). The calibration precipitation events were calibrated simultaneously, because the hydrologic parameters should not vary between precipitation event (e.g., the hydraulic conductivity should be constant for both precipitation events.) However, while both events were calibrated simultaneously initial conditions parameters (e.g., initial infiltration rate and base flow) were allowed to vary between events.

## 4.6 Model Validation

Following the calibration process, the model was validated by comparing calibrated model results to observed data for events of similar magnitude, various discharge-frequency curves, and models used by municipalities as part of local stormwater plans. A list of validation standards that the calibrated model was subject to are listed below.

1. **Events of Similar Magnitude**—The calibrated model was validated by comparing modeled results of two separate validation storm events to observed data. These validation events were selected and approved by the ITR Committee prior to beginning the calibration process.
2. **Historical Event of Greater Magnitude**—The 1992 event of record at the USGS station was input into the calibrated model and results were compared to observed data. The 1992 event resulted in the flood of record at the USGS gage, and was significantly larger than the storm events selected for calibrating and validating the model.
3. **Discharge-Frequency Curve**—100-year flow predicted by the calibrated XP-SWMM model at the USGS station was compared to the discharge-frequency curve developed by following the guidelines in Bulletin 17B (U.S.G.S., 1982).
4. **USGS Regression Equation**—The 100-year flow predicted by the calibrated XP-SWMM model at the USGS station was compared to the discharge-frequency curve developed using the 1997 USGS regression equations.
5. **USGS Transfer Method**—The 100-year flow at the USGS station predicted by the calibrated XP-SWMM model was compared to predicted flows using the USGS gage transfer method.

6. **Municipal Models**—The 100-year model results were compared to city models obtained from municipalities prior to developing the calibrated XP-SWMM model.
7. **DFIRM Model**—The 100-year model results were compared to the flows calculated for the Dakota County DFIRM analysis.

The primary validation of the XP-SWMM model was the Events of Similar Magnitude, using two additional storm events as described in point one above. Event A where 4.3 inches of precipitation occurred during July 5-9, 2000, and Event C where 3.7 inches of precipitation occurred during June 2-7, 2002.

Similar to calibration, validation was based on observed water surface elevations from a network of seven stream gages operated in the Vermillion River watershed by the Dakota County SWCD. Instantaneous water surface elevation and peak water surface elevation were used for the validation process to verify that the results accurately modeled observed data. See [Section 5.2](#) for a detailed explanation of each validation method and analysis of validation results, and [Appendix B](#) for a discussion on the selection of the validation events.

## 4.7 Municipal Standard Locations

Standard locations were identified based on a standardized methodology approved by the ITR committee. The methodology was intended to provide standard locations at municipal boundaries while avoiding locations that have a small drainage area, or areas where the stream meanders back and forth across a municipal boundary.

### *Methodology to Develop Municipal Standard Locations*

1. Identify locations where the VRWJPO buffered stream inventory intersected with the Met Council 2007 municipal boundaries.
2. Eliminated locations where the stream meanders back and forth across municipal boundary over short distances of less than 0.5 miles.
3. Added locations where the buffered streams inventory starts 200 feet from a municipal boundary
4. Added two inflows from Apple Valley and one outflow at the Hastings WOMP station
5. Eliminated locations where the total drainage area was less than 0.25 square miles or the intermediate drainage area to the next upstream location was less than 0.25 square miles.
6. Added locations at planned 2030 municipal growth boundaries.

Following this methodology resulted in 61 standard locations located throughout the watershed and are shown in [Figure 4-27](#).

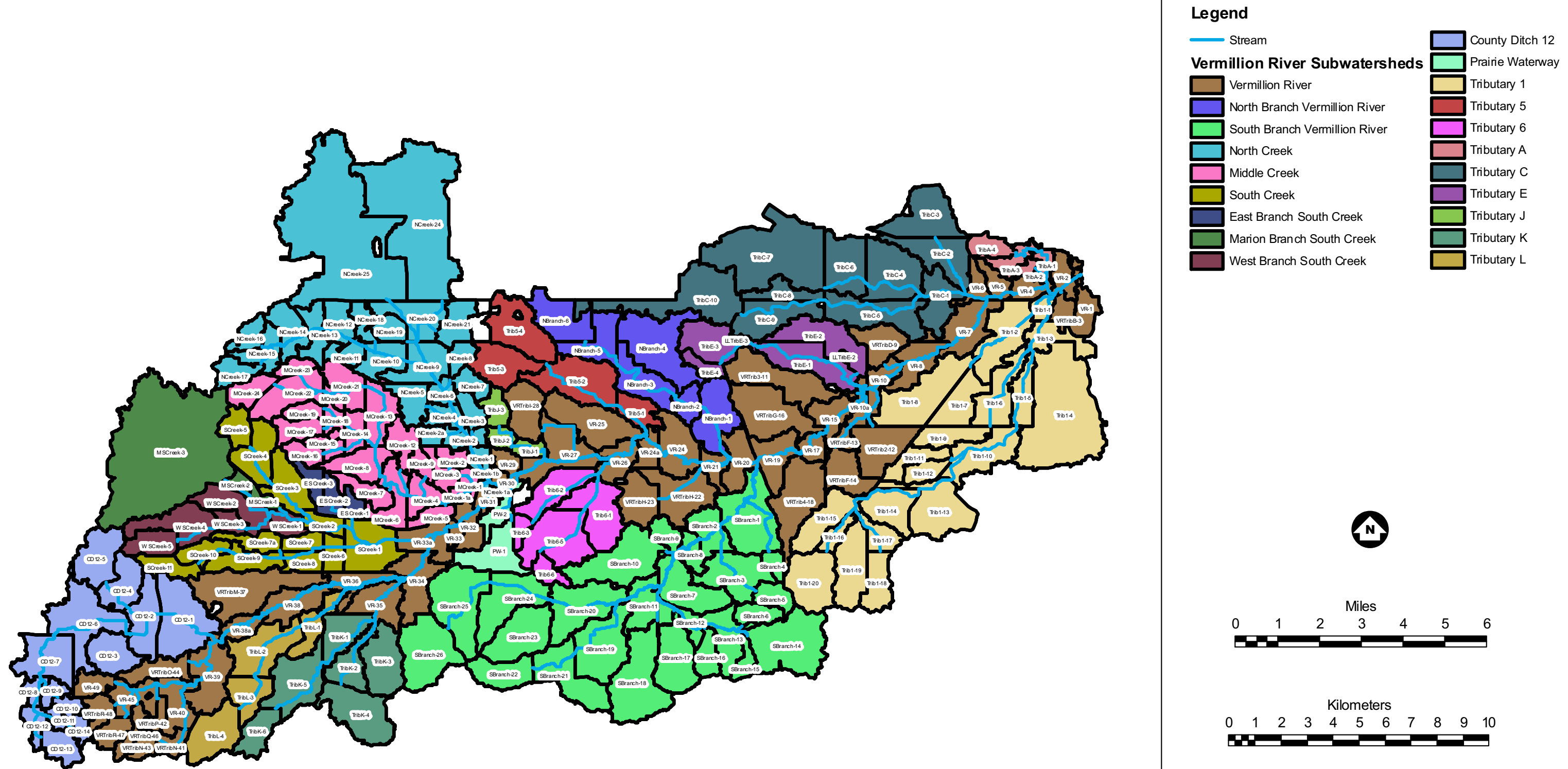


Figure 4-1

SUBWATERSHEDS

VRWJPO Hydrologic Model

Vermillion River Watershed

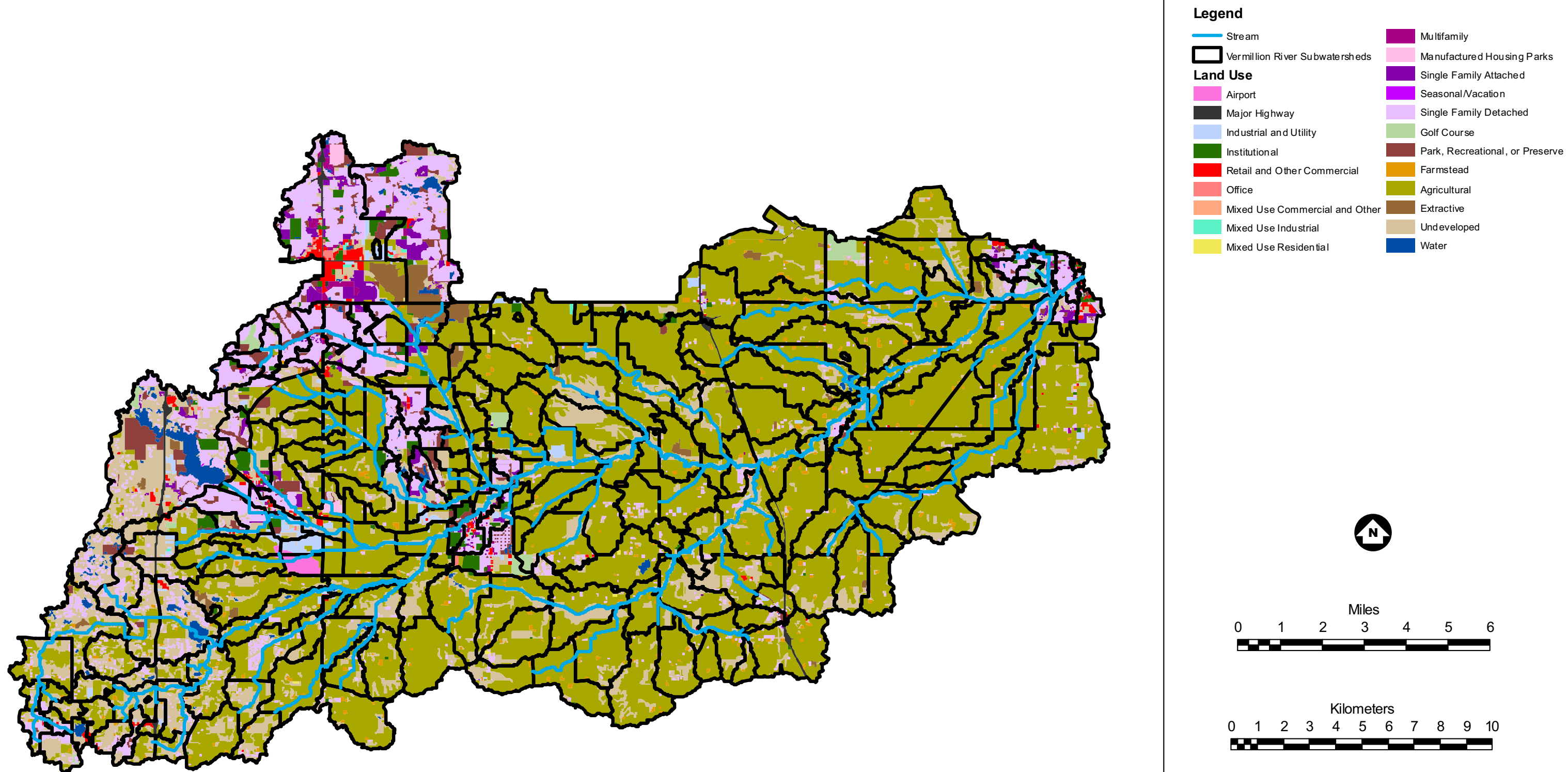
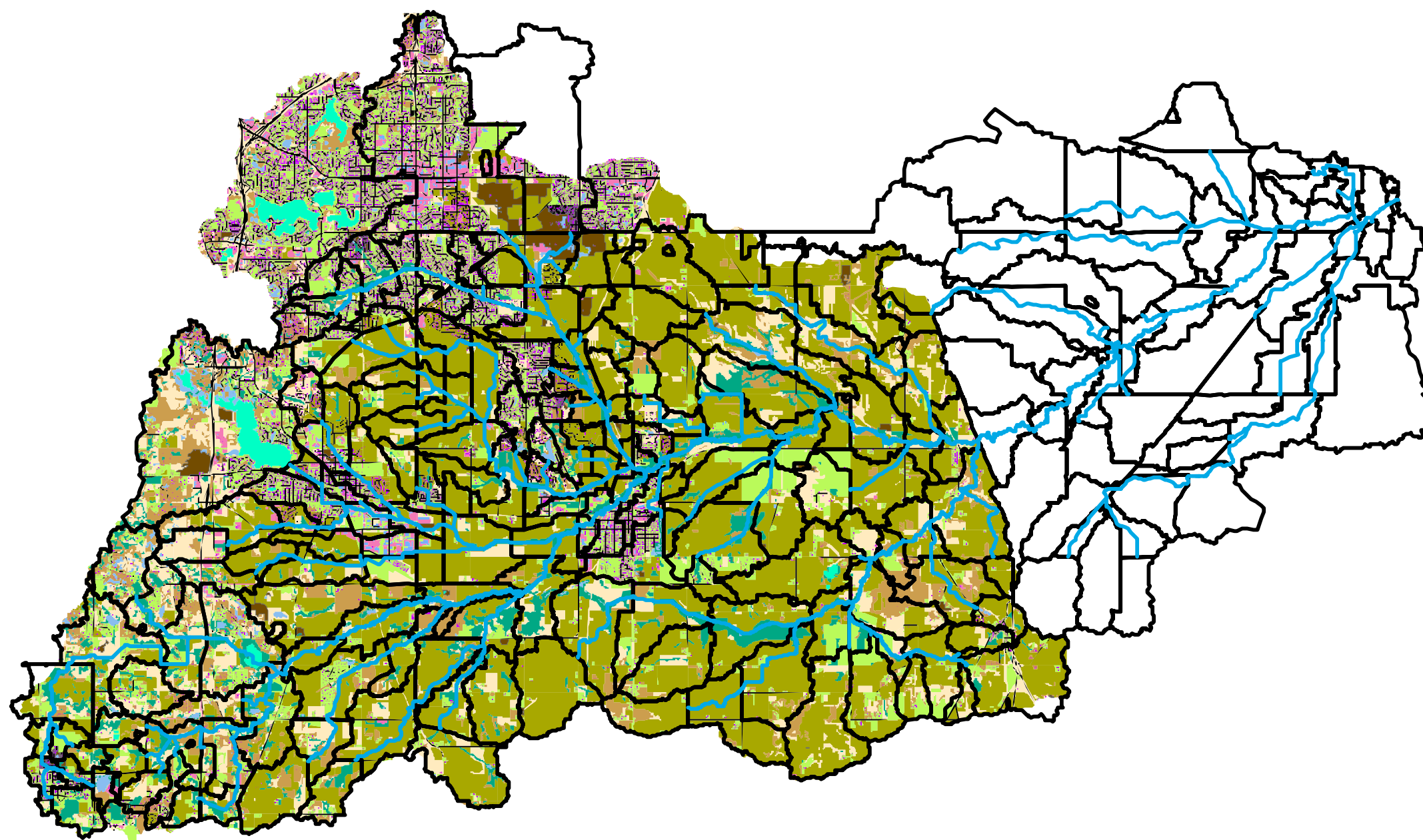


Figure 4-2

MET COUNCIL LAND USE (2005)  
VRWJPO Hydrologic Model  
Vermillion River Watershed





## Legend

- Stream
- Vermillion River Subwatersheds
- Asphalt
- Concrete
- Residential Roof
- Commercial Roof
- Forest
- Corn
- Tall Grass
- Lawn
- Bare Soil
- Pond
- Reservoir
- Vegetated Pond

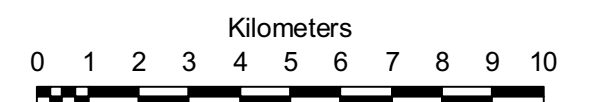
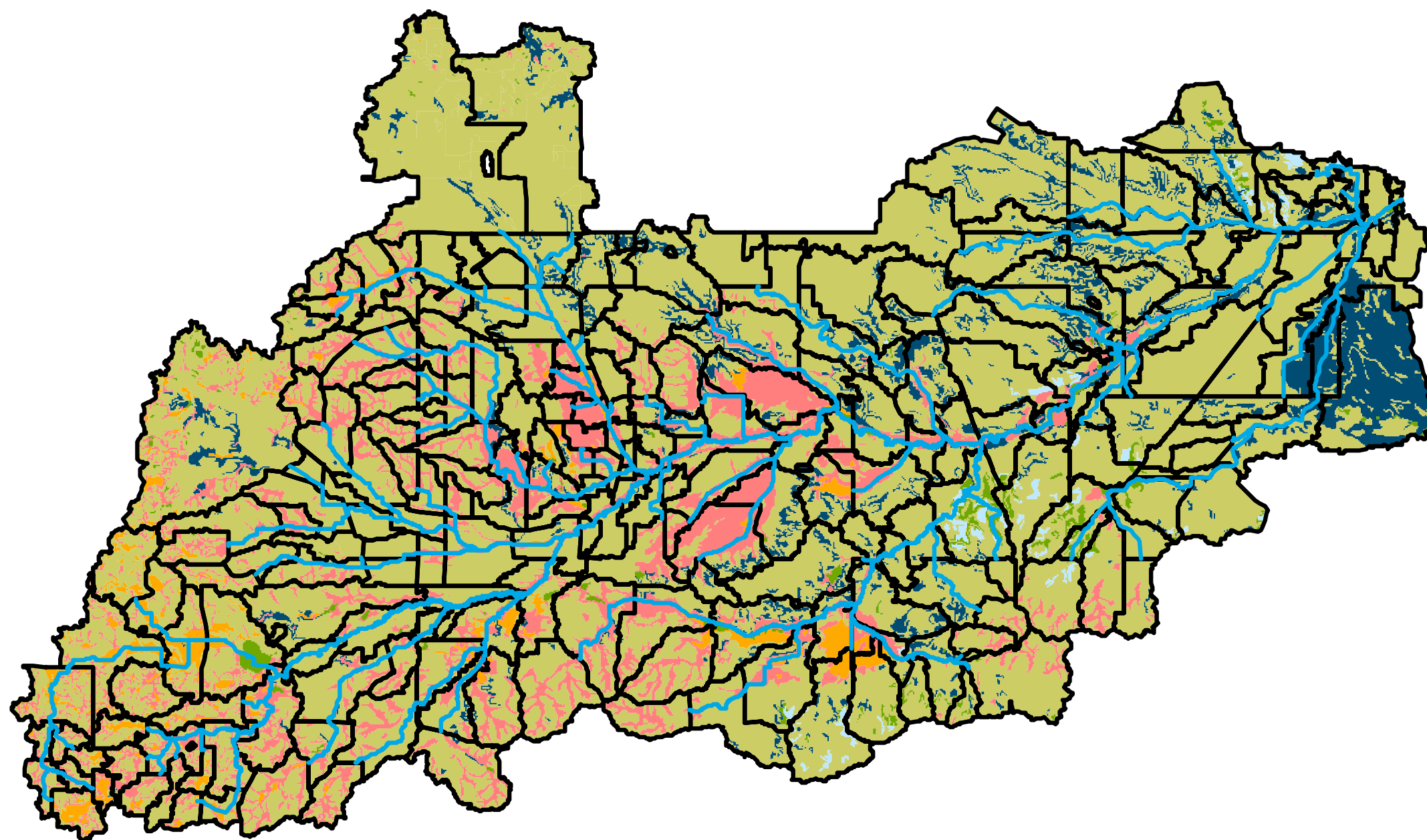


Figure 4-3

AES LAND COVER (2005)  
VRWJPO Hydrologic Model  
Vermillion River Watershed



## Legend

Stream

Vermillion River Subwatersheds

## Hydrologic Soil Group

A

A/D

B

B/D

C

D

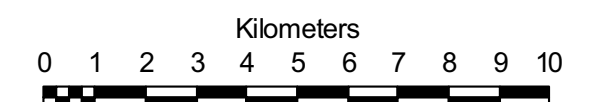
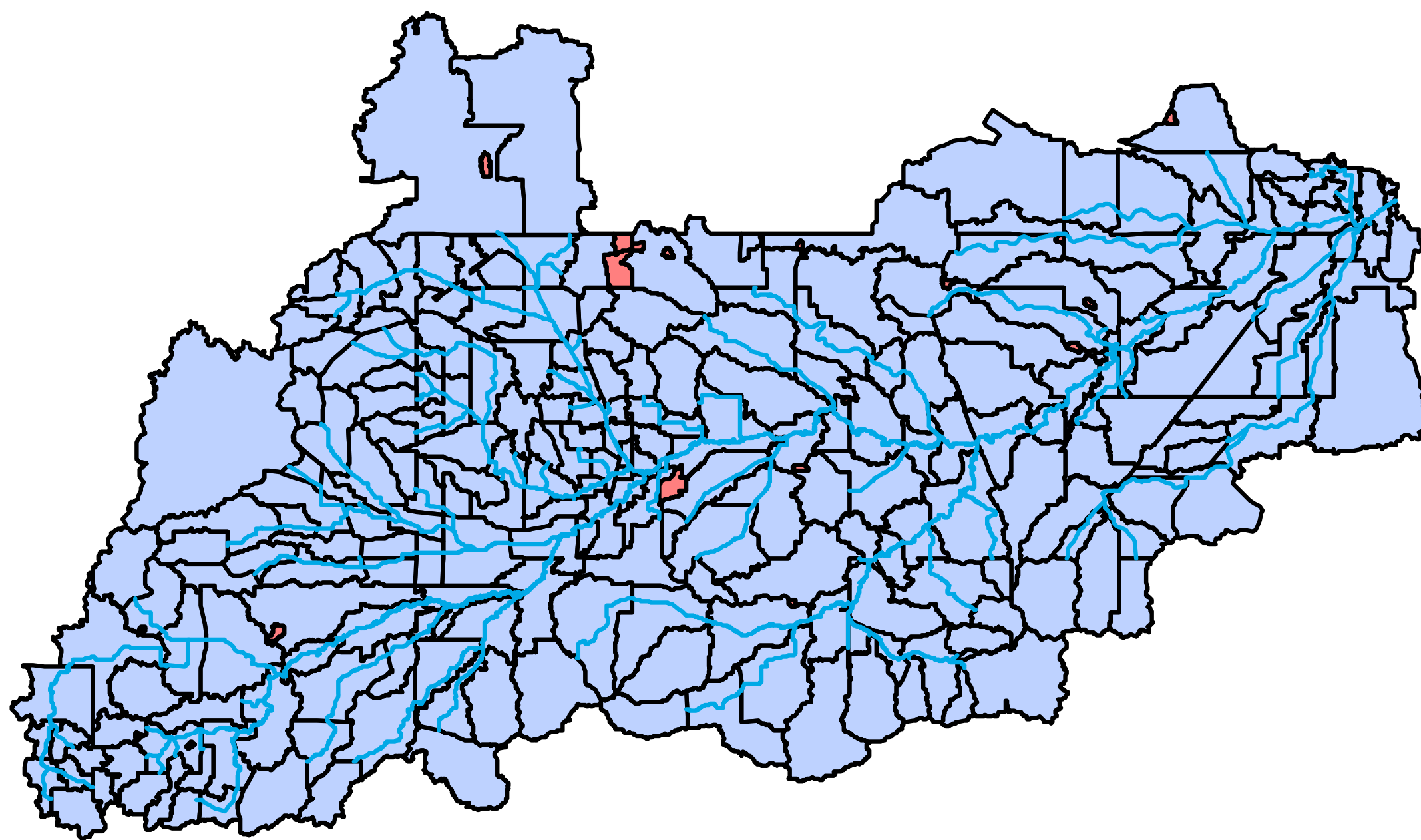


Figure 4-4

HYDROLOGIC SOIL GROUP  
VRWJPO Hydrologic Model  
Vermillion River Watershed





## Legend

Stream

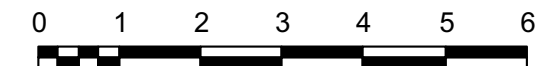
## Vermillion River Subwatersheds

Contributing Drainage Area

Land Locked Area



Miles



Kilometers

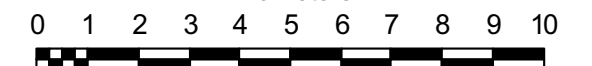
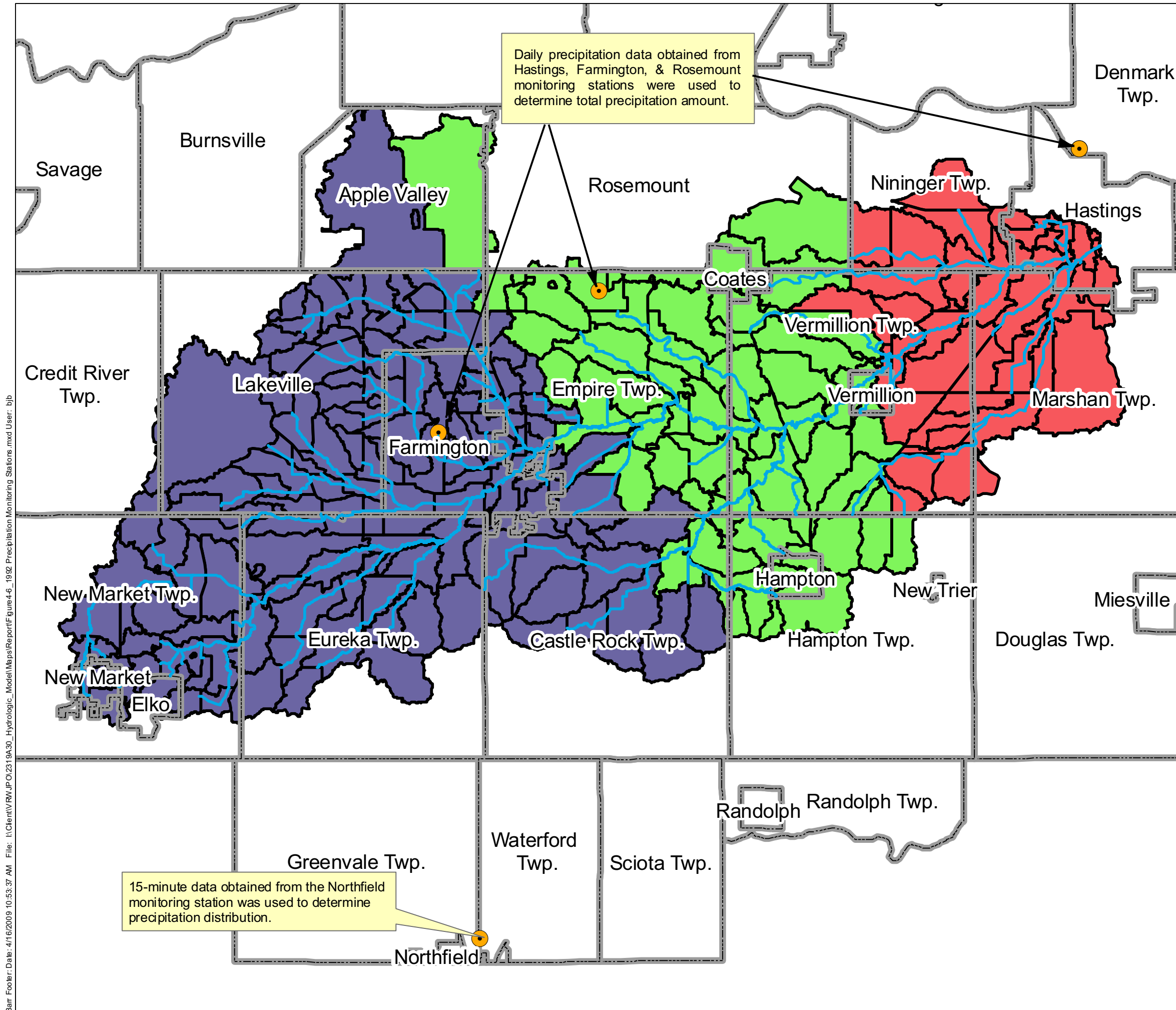


Figure 4-5

LAND LOCKED BASINS  
VRWJPO Hydrologic Model  
Vermillion River Watershed



## Legend

Stream

Weather Stations

## Vermillion River Subwatersheds

### Precipitation Gage

Farmington

Hastings

Rosemont

City Boundaries

\* Precipitation gage assigned to each watershed was determined using the Thessen Polygon method.

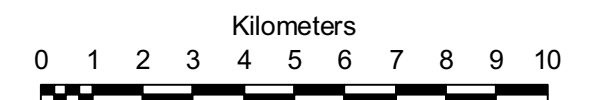
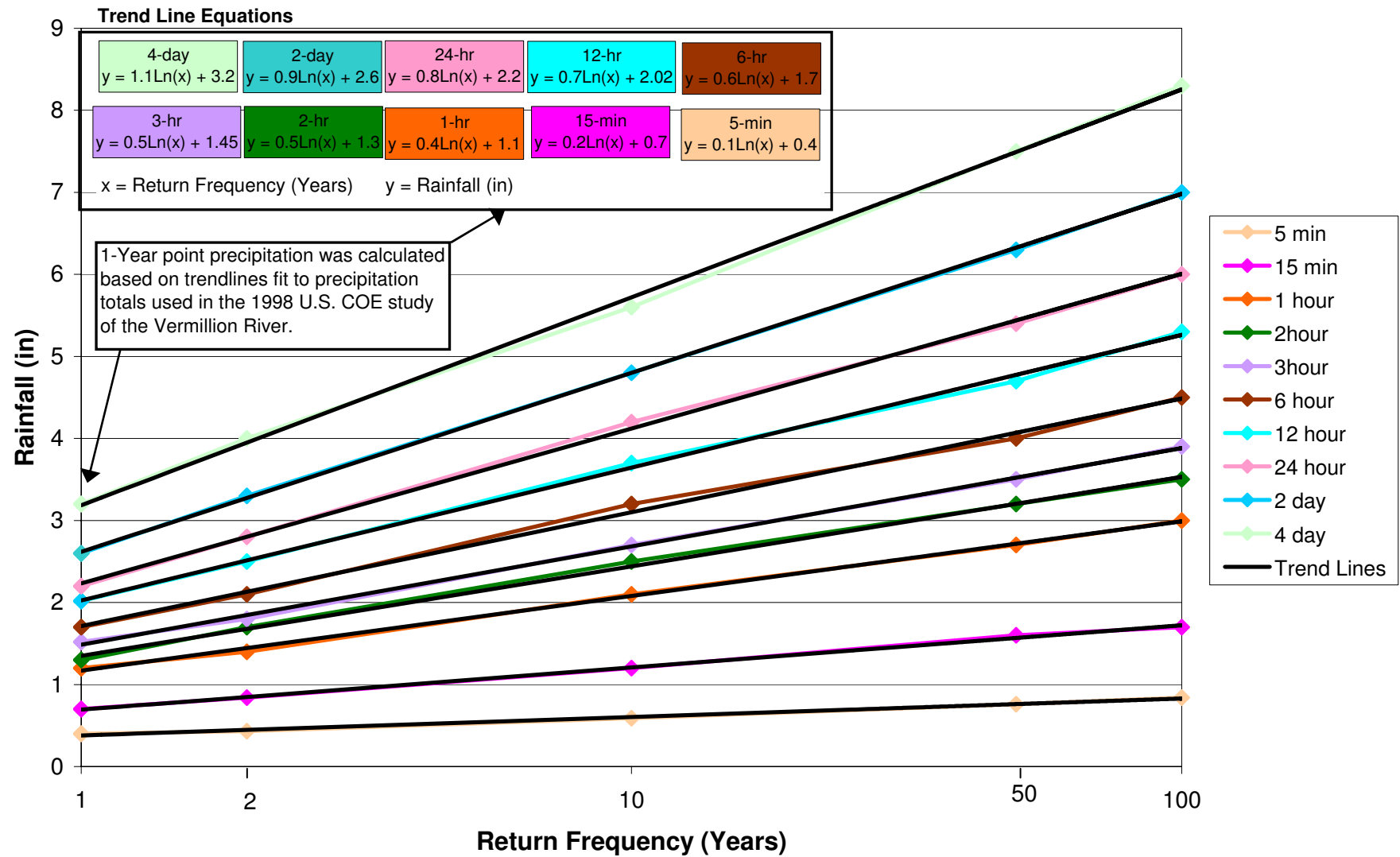


Figure 4-6

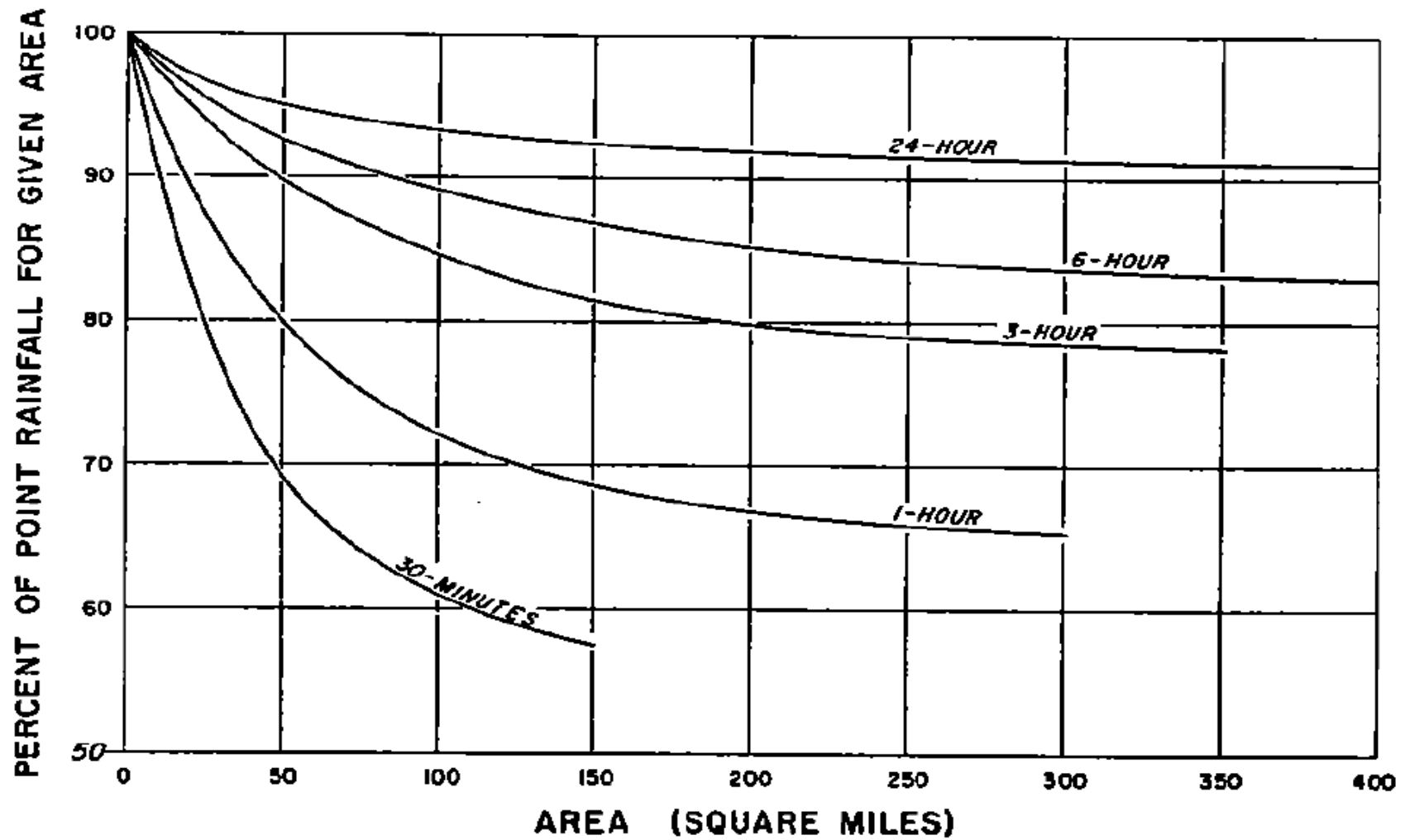
1992 EVENT PRECIPITATION  
MONITORING STATIONS  
VRWJPO Hydrologic Model  
Vermillion River Watershed

**Figure 4-7. Calculation of 1-Year Hypothetical Point Precipitation**



**Figure 4-8. NWS TP 40 Depth Area Reduction Curves**

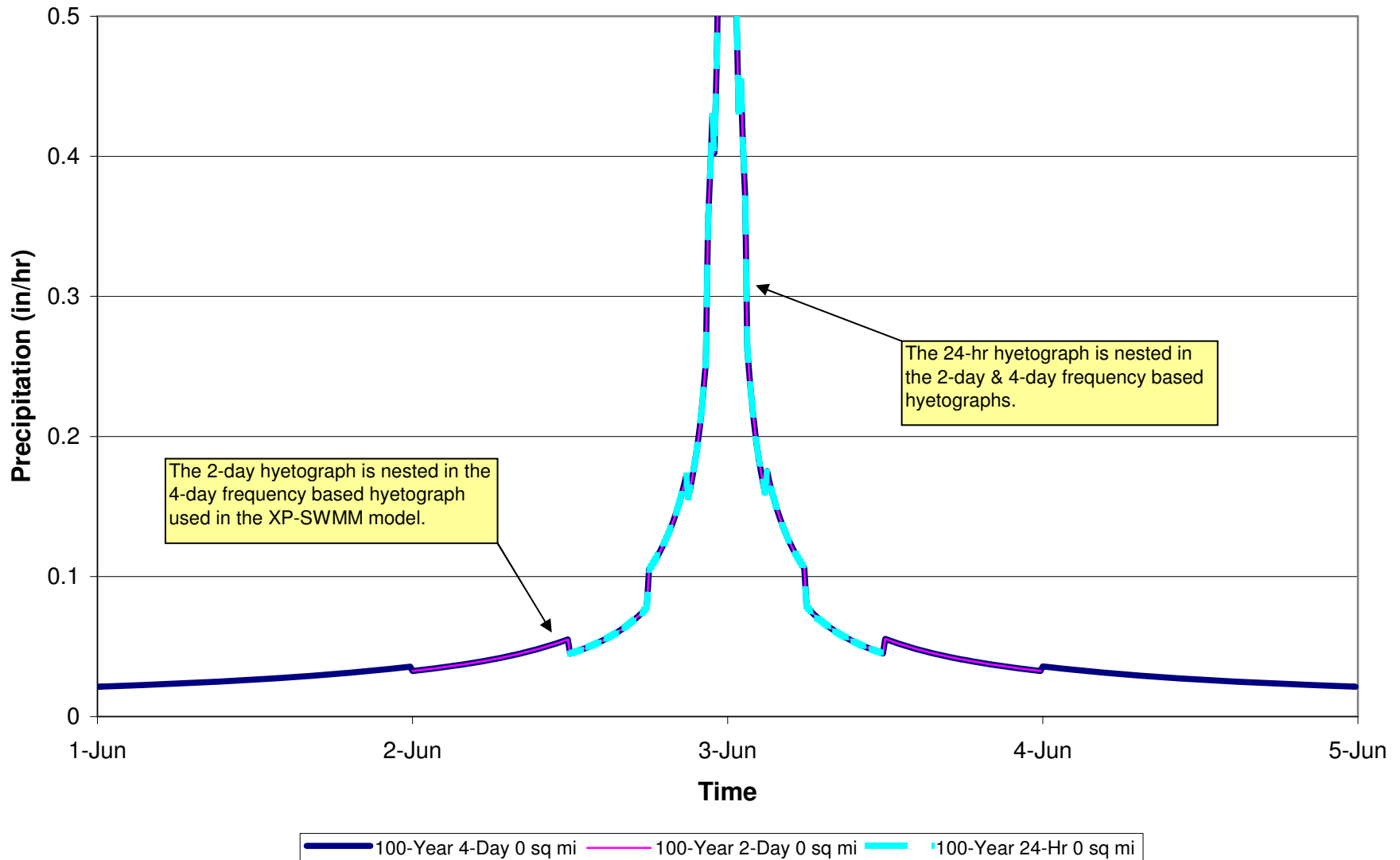
*HEC-HMS applies TP 40 depth area reduction curves to adjust point precipitation.*



National Weather Service. 1961. Technical Paper 40: Rainfall Frequency Atlas for the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. U.S. Department of Commerce, Washington DC.

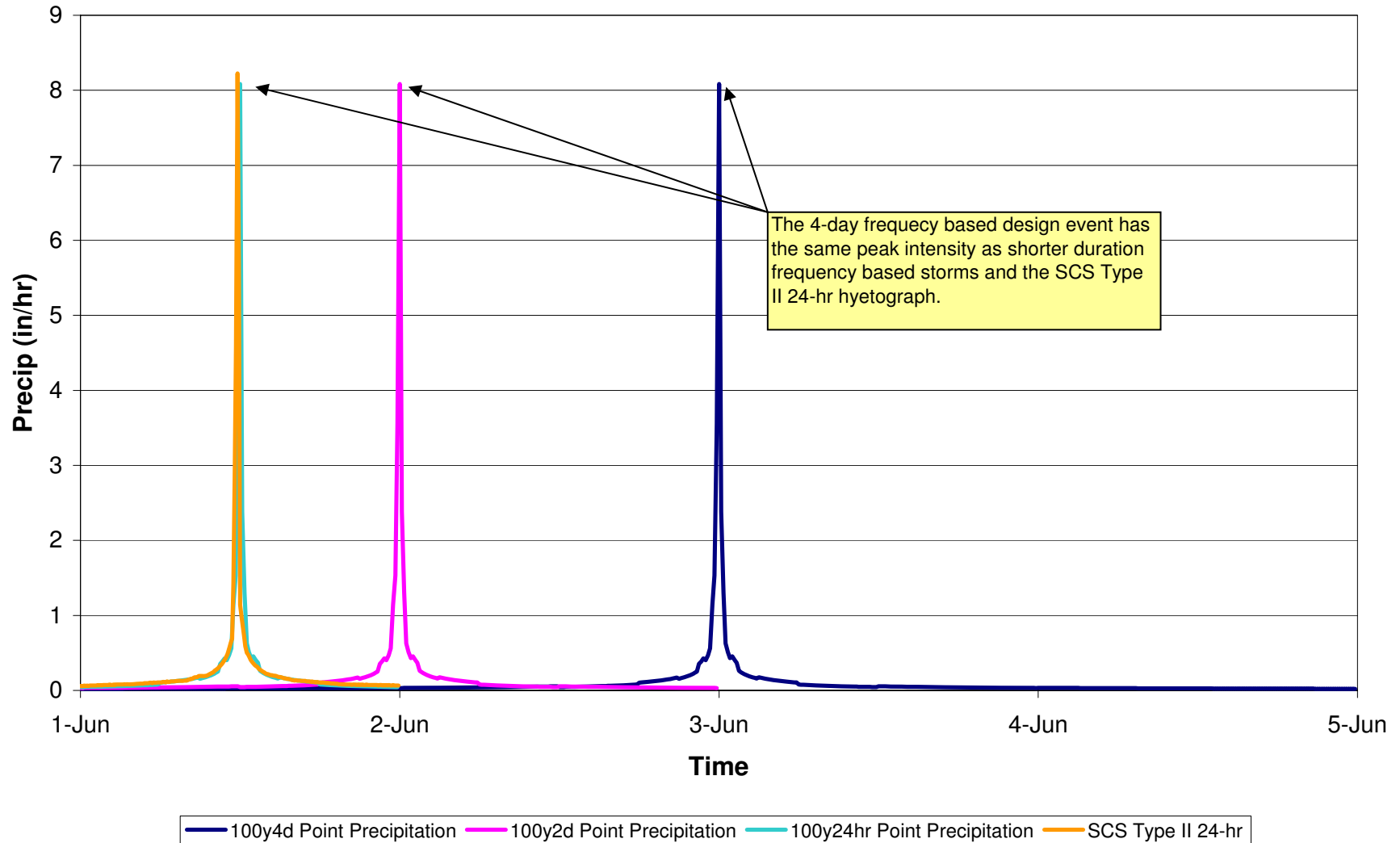
**Figure 4-9. Nested Frequency Based Storms of Shorter Duration**

*Hyetographs for the 24-hr, 2-day, & 4-day frequency based storms are plotted with peak intensities occurring at the same time*



**Figure4-10. Frequency Based and SCS Type II Peak Intensity**

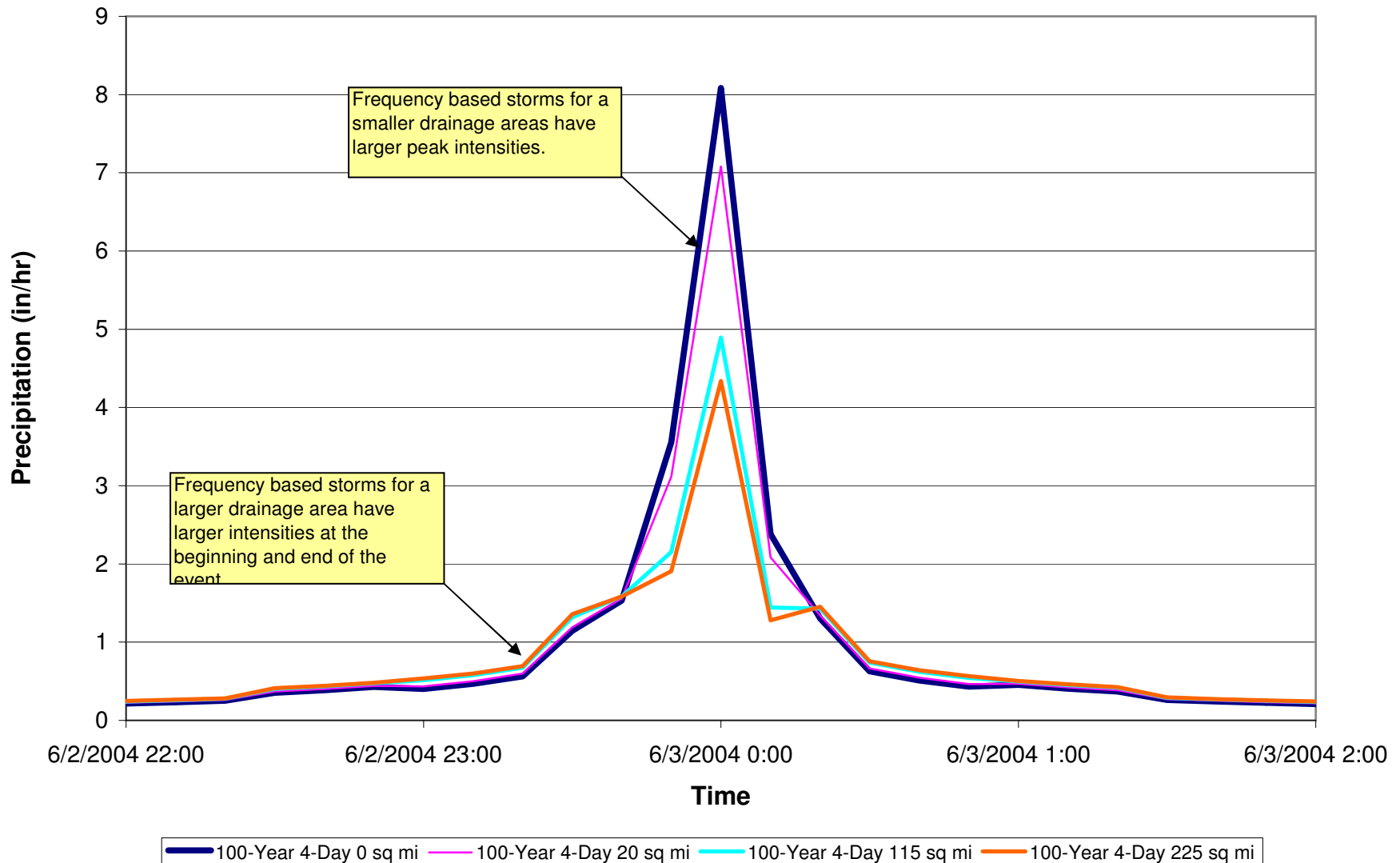
*Precipitation for all hyetographs begins on June 1*

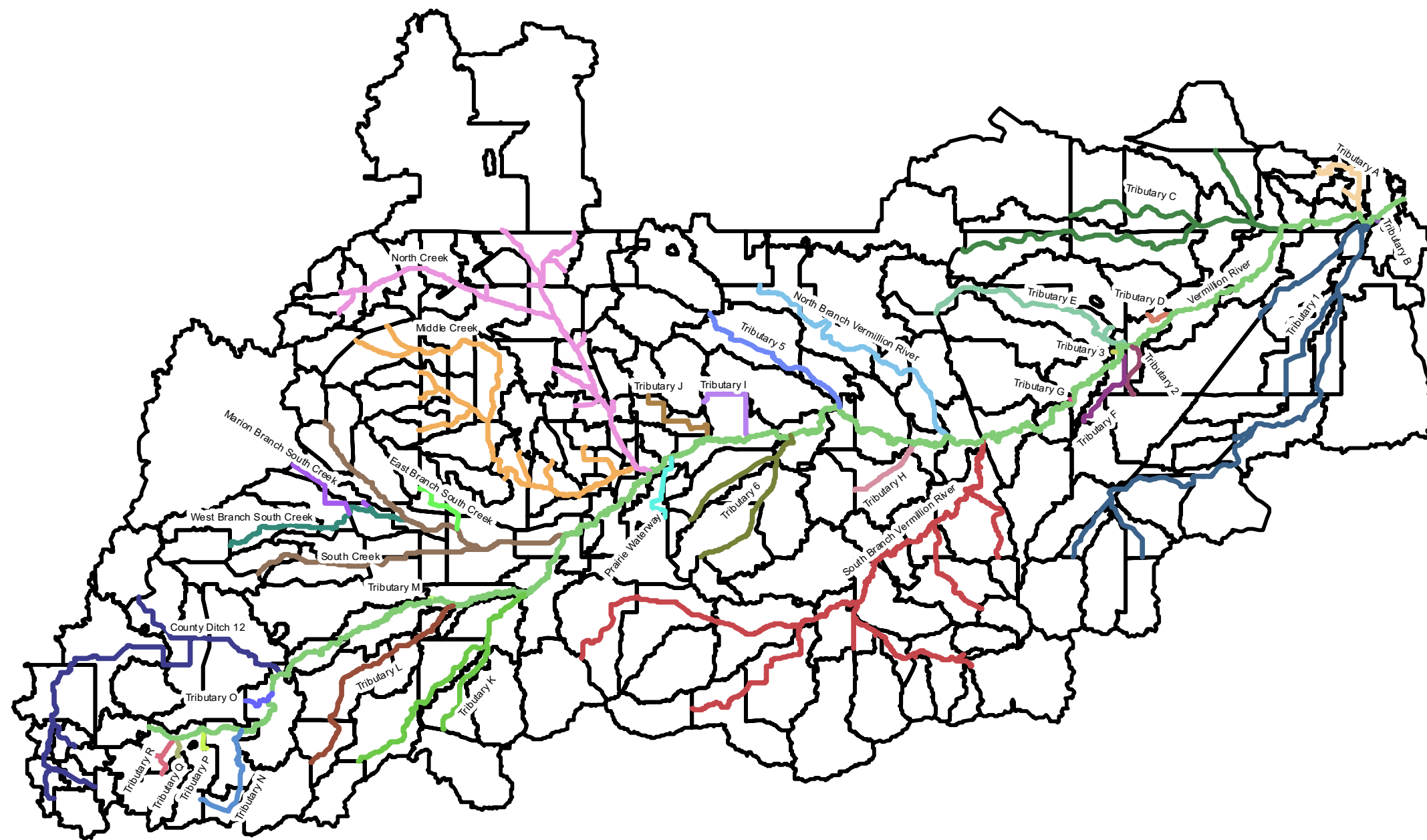




**Figure 4-11. Frequency Based Hyetographs for Varying Drainage Areas**

*Hyetographs were developed using HEC-HMS. Precipitation for the hyetographs below occurs on June 1-5*





## Legend

### Stream

#### StrmName

- |                               |             |
|-------------------------------|-------------|
| Vermillion River              | Tributary A |
| County Ditch 12               | Tributary B |
| South Branch Vermillion River | Tributary C |
| North Branch Vermillion River | Tributary D |
| North Creek                   | Tributary E |
| Middle Creek                  | Tributary F |
| South Creek                   | Tributary G |
| East Branch South Creek       | Tributary H |
| Marion Branch South Creek     | Tributary I |
| West Branch South Creek       | Tributary J |
| Prairie Waterway              | Tributary K |
| Tributary 1                   | Tributary L |
| Tributary 2                   | Tributary M |
| Tributary 3                   | Tributary N |
| Tributary 4                   | Tributary O |
| Tributary 5                   | Tributary P |
| Tributary 6                   | Tributary Q |
|                               | Tributary R |

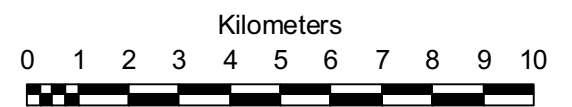
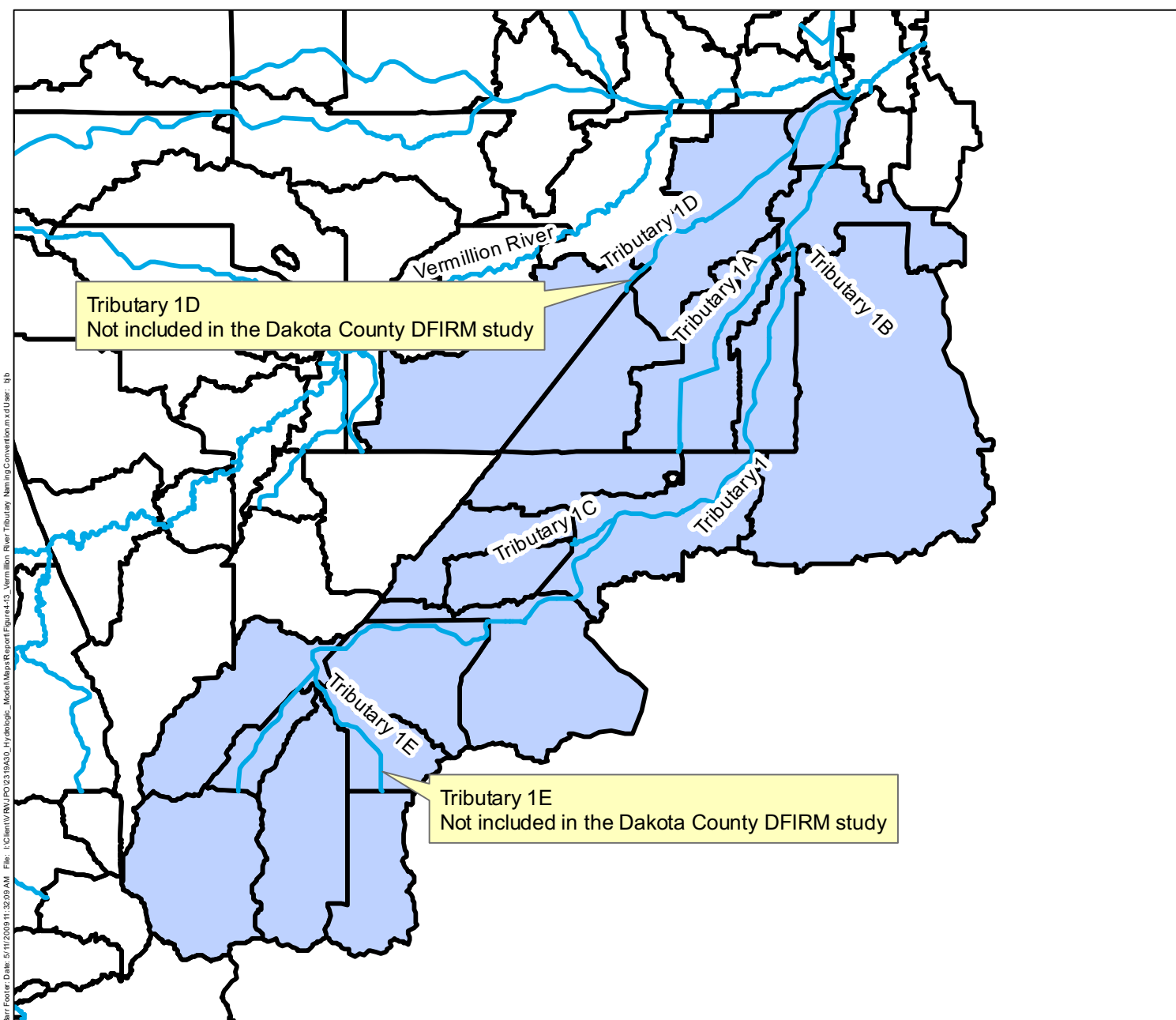


Figure 4-12

VERMILLION RIVER STREAM NETWORK  
VRWJPO Hydrologic Model  
Vermillion River Watershed



## Legend

Stream

## Vermillion River Subwatersheds

Tributary 1 Subwatersheds

Other Subwatersheds

Tributary 1 is a primary tributary to the Vermillion River and was named in the Dakota County DFIRM analysis. The naming convention shown follows the guidelines given in Table 4-10.

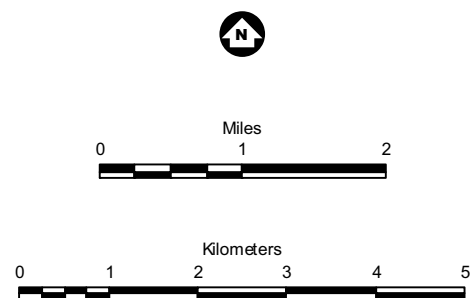
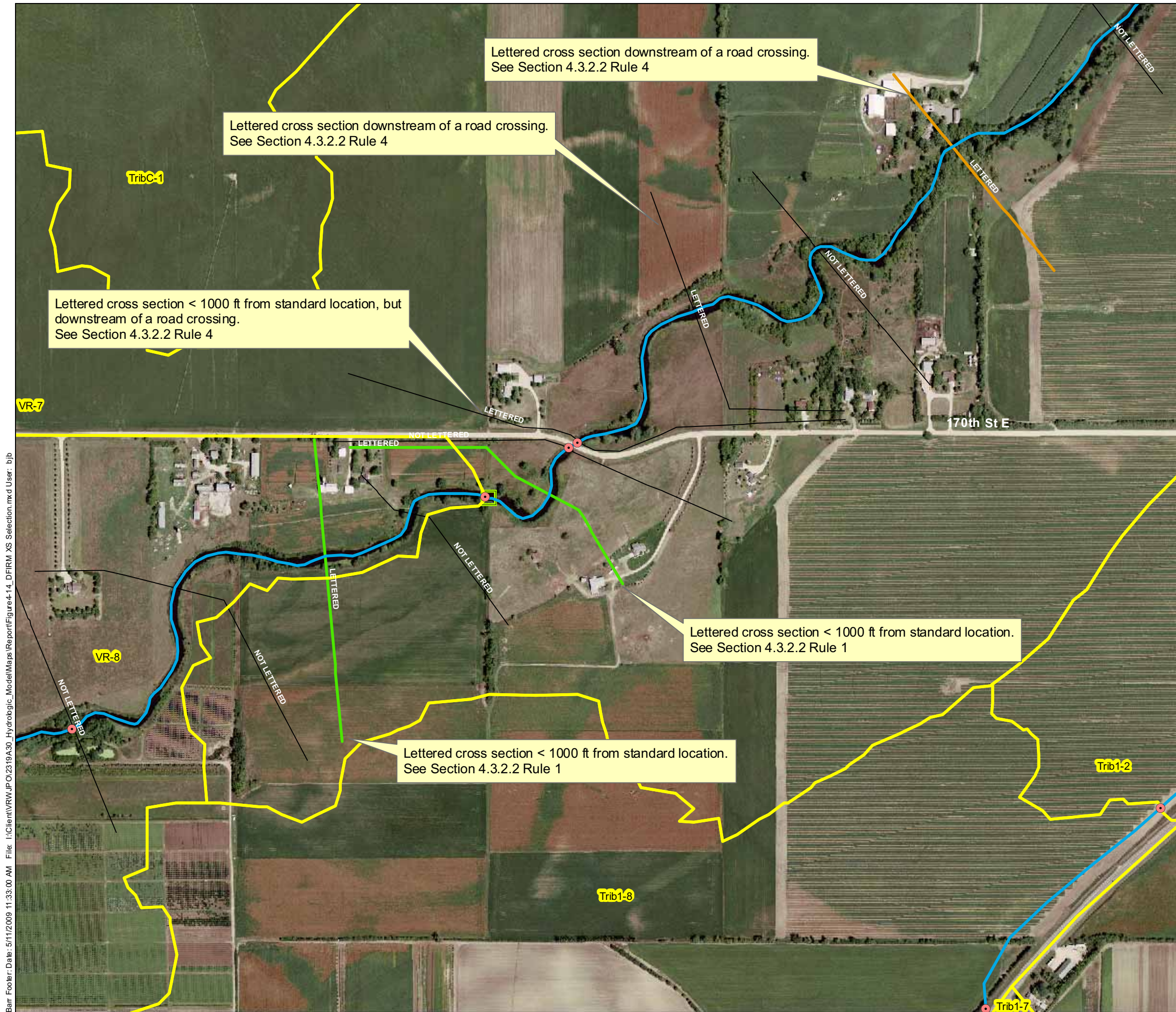


Figure 4-13

TRIBUTARY NAMING CONVENTION  
VRWJPO Hydrologic Model  
Vermillion River Watershed





## Legend

Vermillion River Subwatersheds

Stream Centerline

● XP-SWMM Node Location

Flow Standard Location

## DFIRM Cross Sections

Not used

1000 ft US/DS from Flow Standard Location

Most restrictive

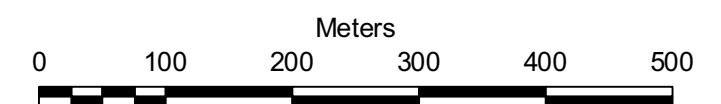
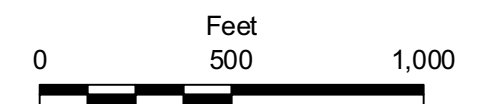
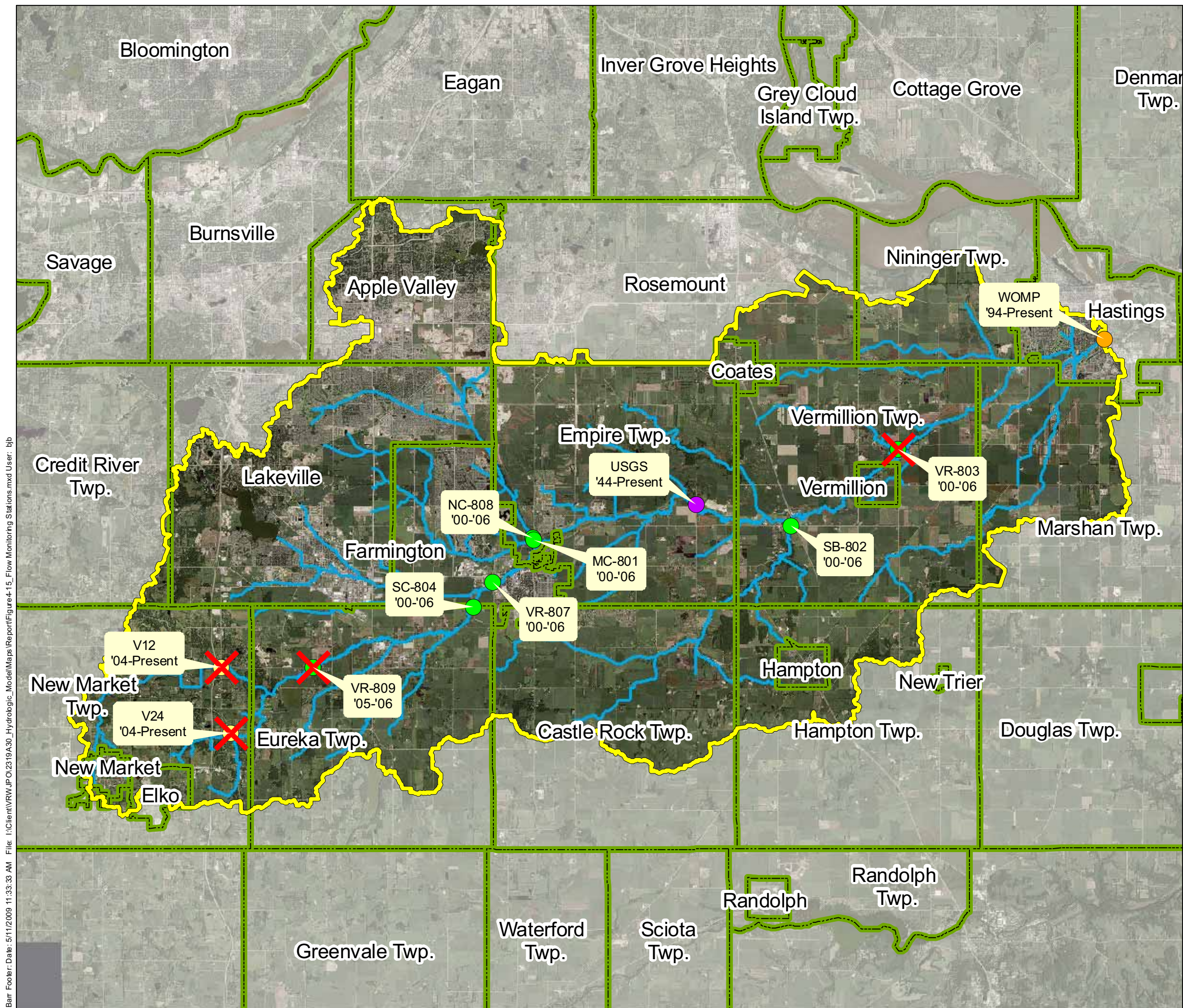


Figure 4-14

DAKOTA COUNTY DFIRM  
CROSS SECTION SELECTION  
VRWJPO Hydrologic Model  
Vermillion River Watershed





### Legend

- Vermillion River Study Area
- Stream
- Municipal Boundaries

### Monitoring\_Stations

#### Operating Organization

- Dakota County SWCD
- Scott County SWCD
- USGS
- Met Council

UnusedGages

\* Years listed below monitoring station ID is the period of record the station has been in operation.

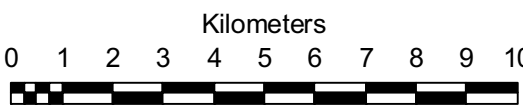


Figure 4-15

FLOW MONITORING STATIONS  
VRWJPO Hydrologic Model  
Vermillion River Watershed



Figure 4-16. Event D Flow Extrapolation (SC-804)

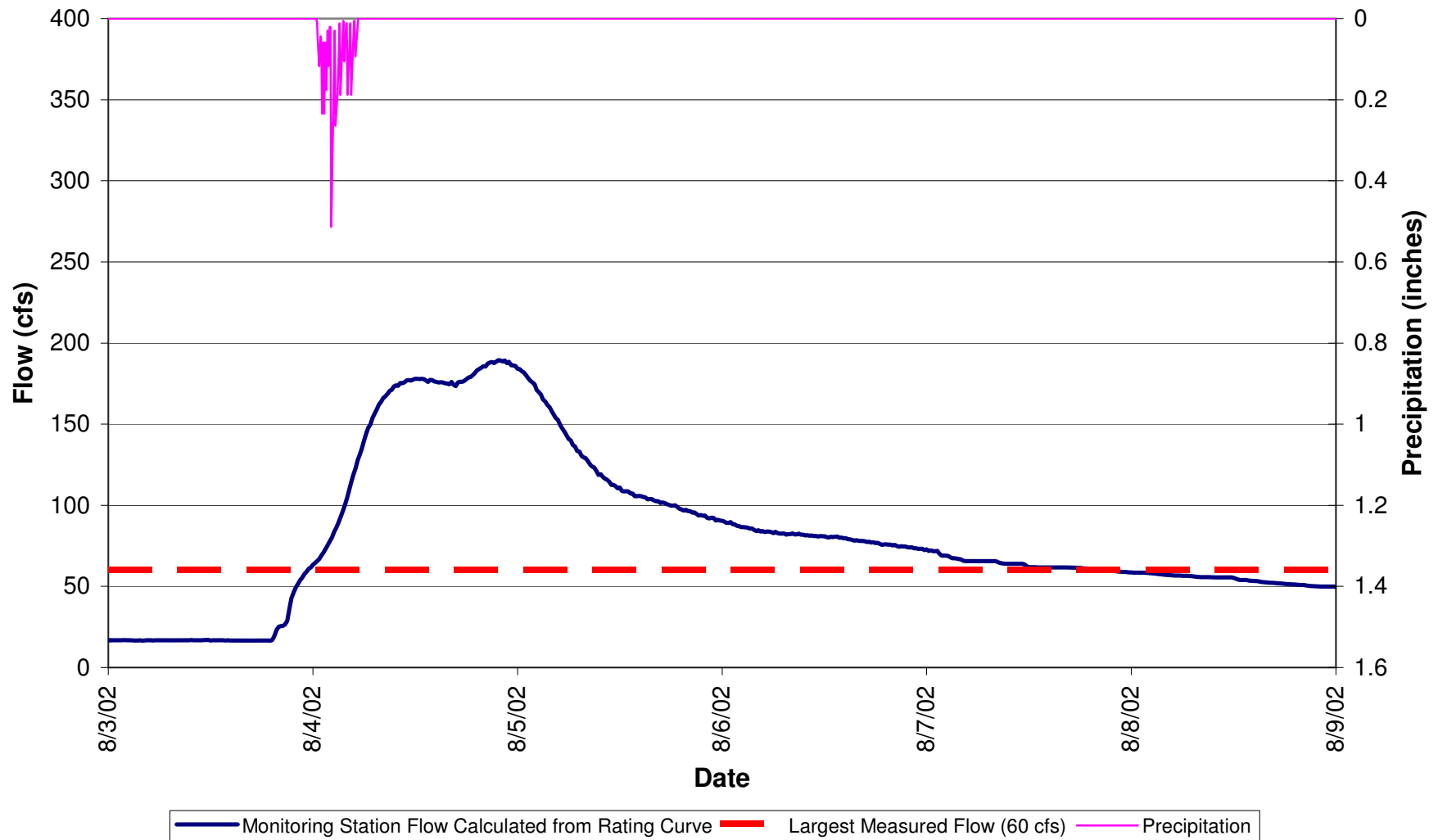




Figure 4-17. Event D Flow Extrapolation (VR-807)

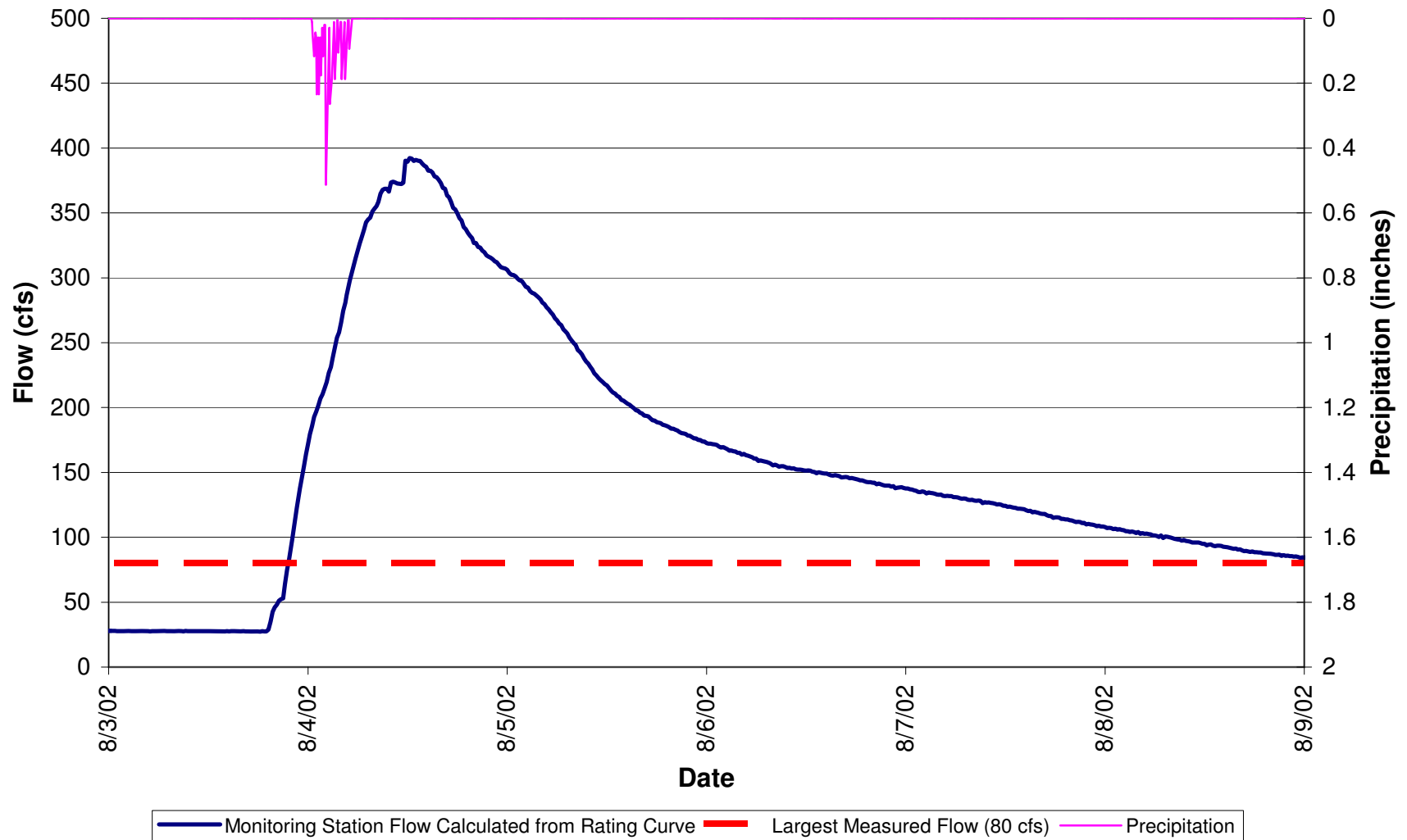


Figure 4-18. Event D Flow Extrapolation (NC-808)

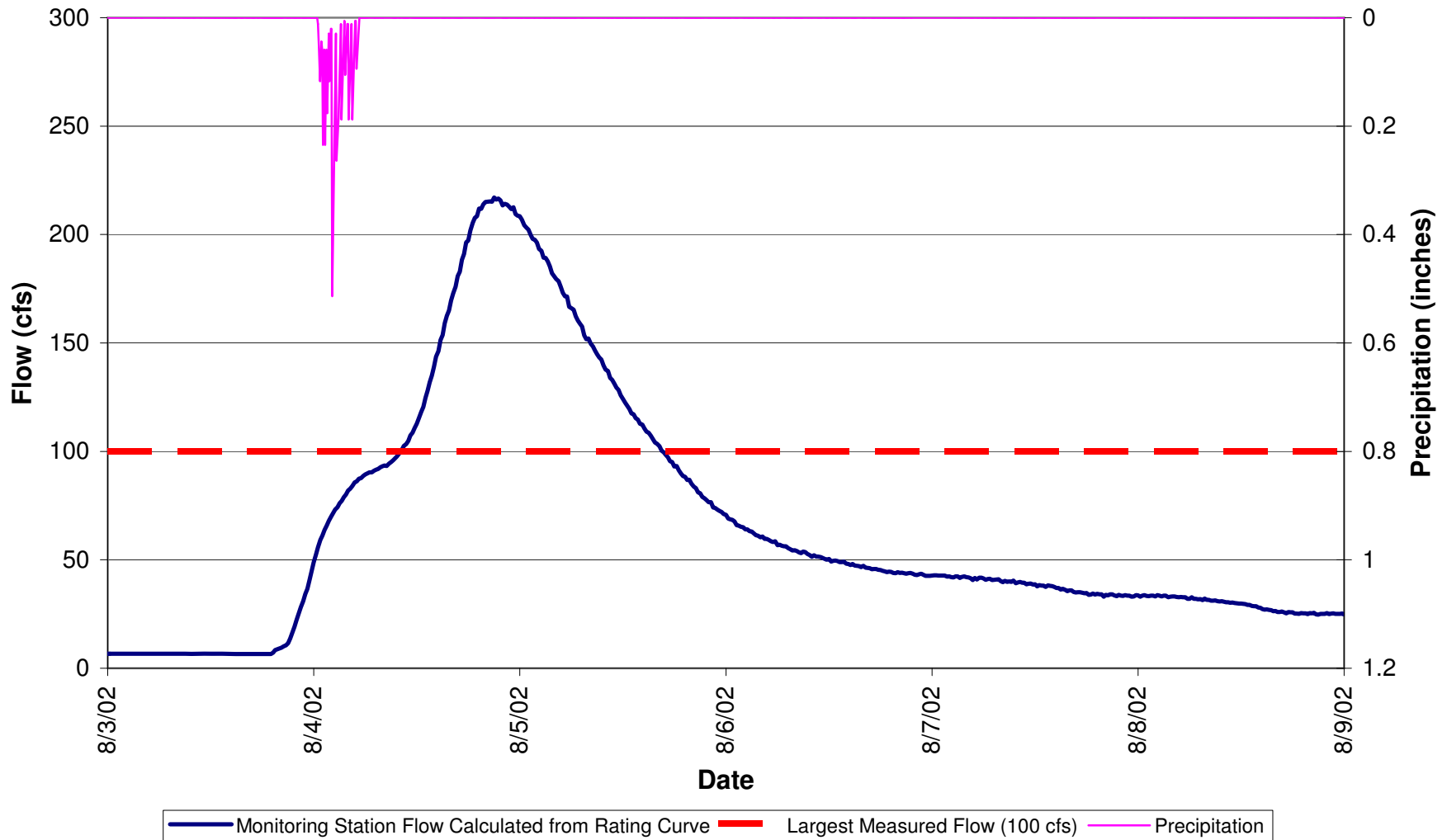


Figure 4-19. Event D Flow Extrapolation (MC-801)

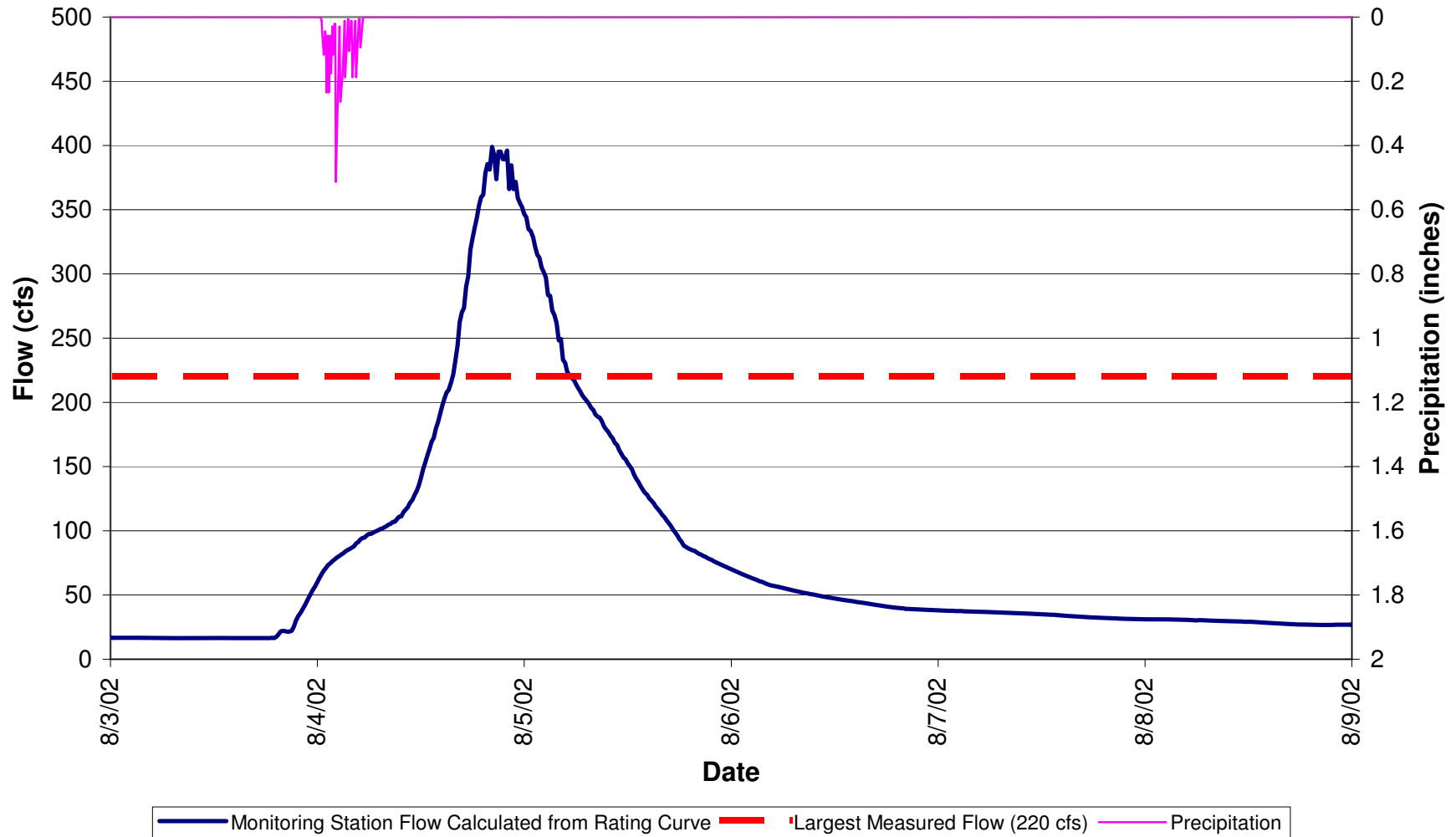


Figure 4-20. Event D Flow Extrapolation (SB-802)

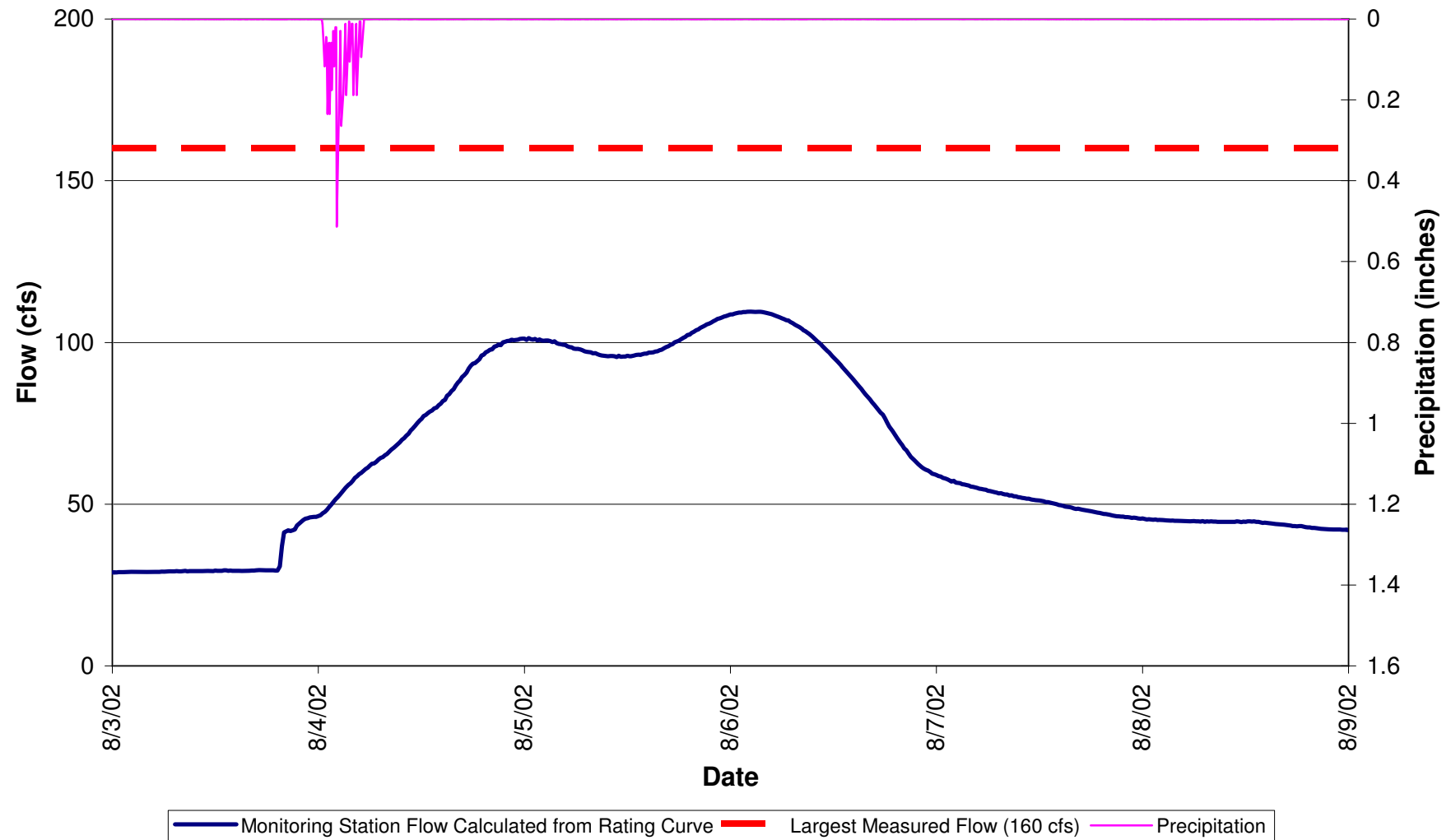


Figure 4-21. Event G Flow Extrapolation (SC-804)

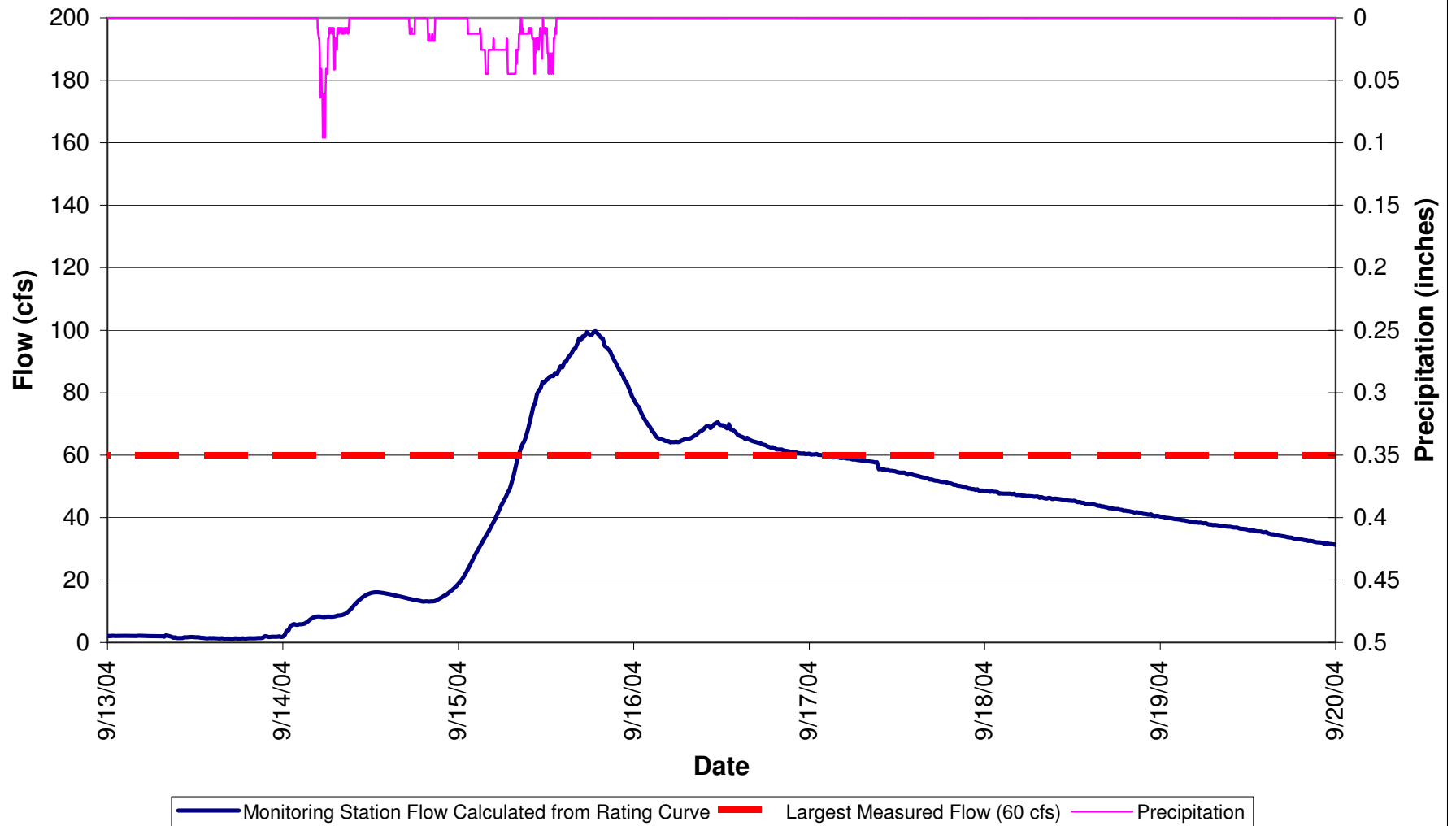




Figure 4-22. Event G Flow Extrapolation (VR-807)

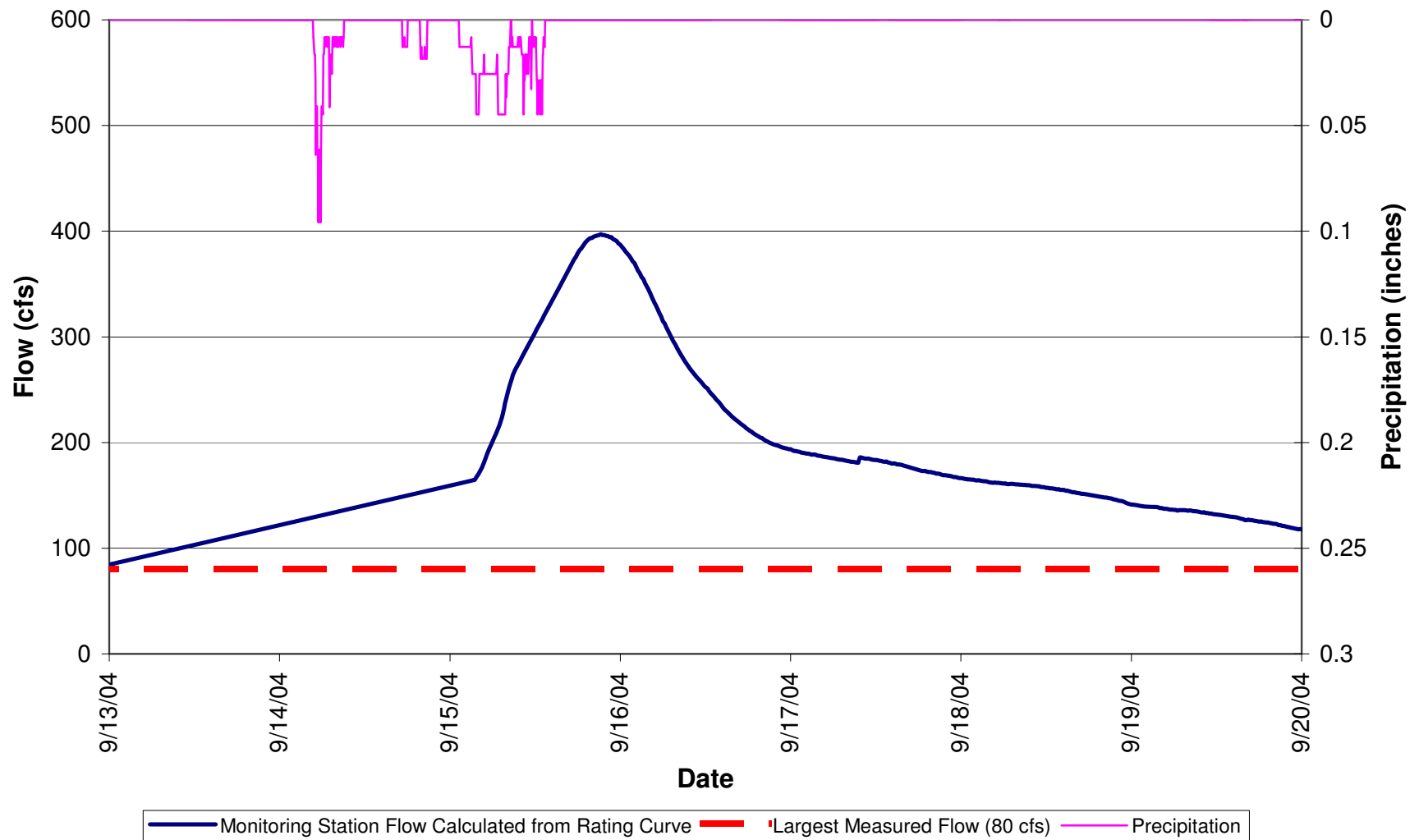


Figure 4-23. Event G Flow Extrapolation (NC-808)

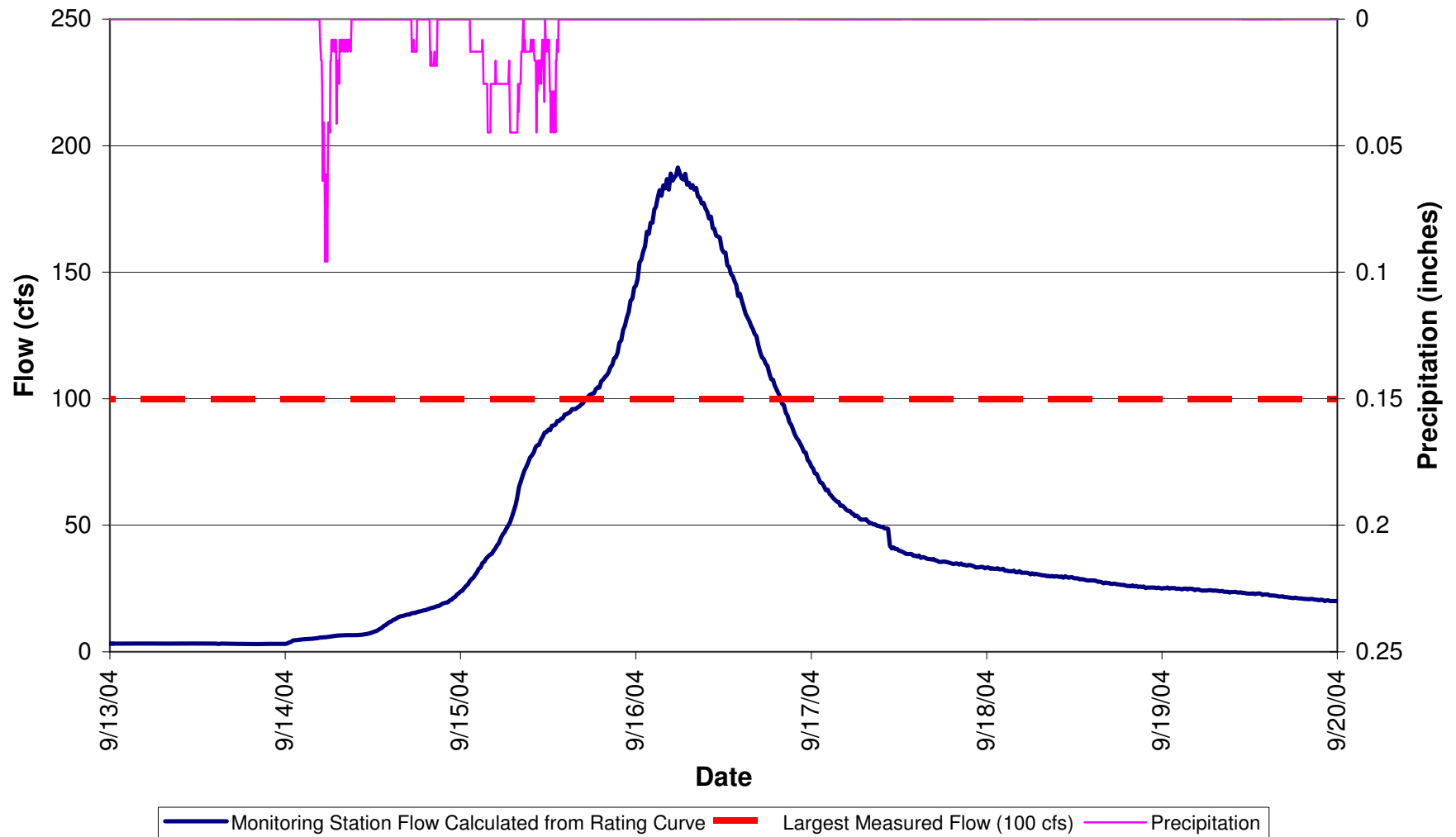


Figure 4-24. Event G Flow Extrapolation (MC-801)

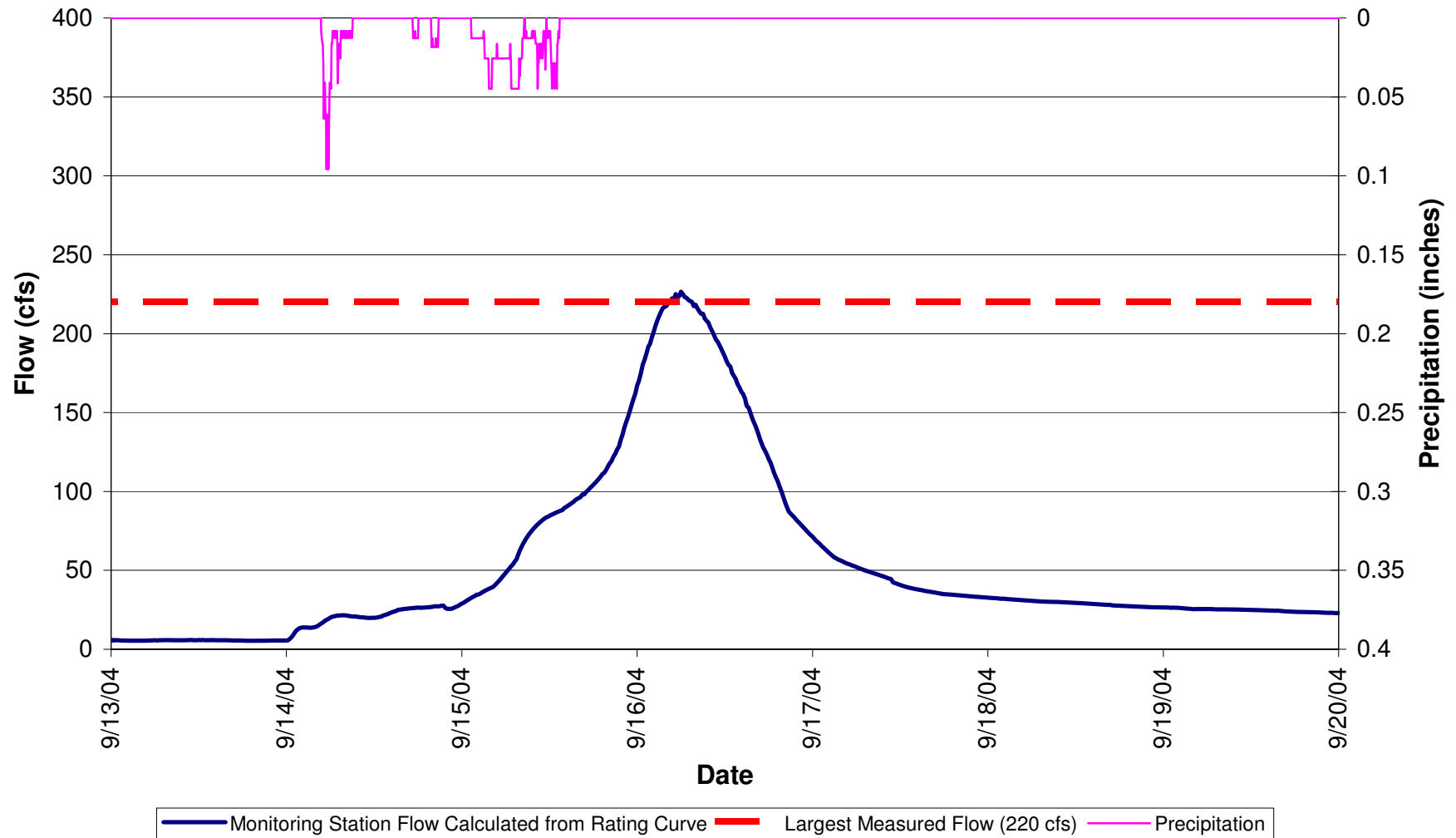
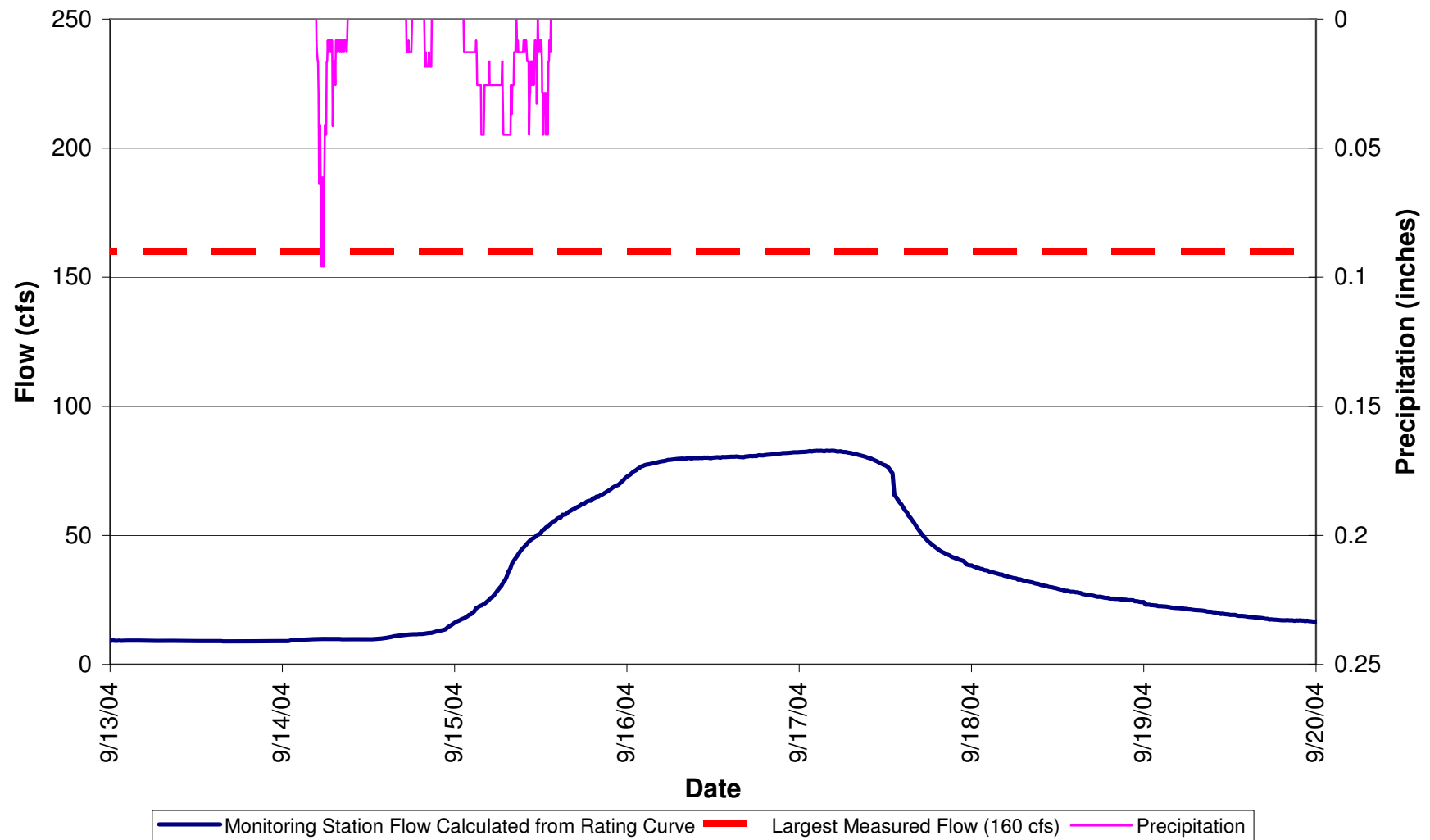


Figure 4-25. Event G Flow Extrapolation (SB-802)



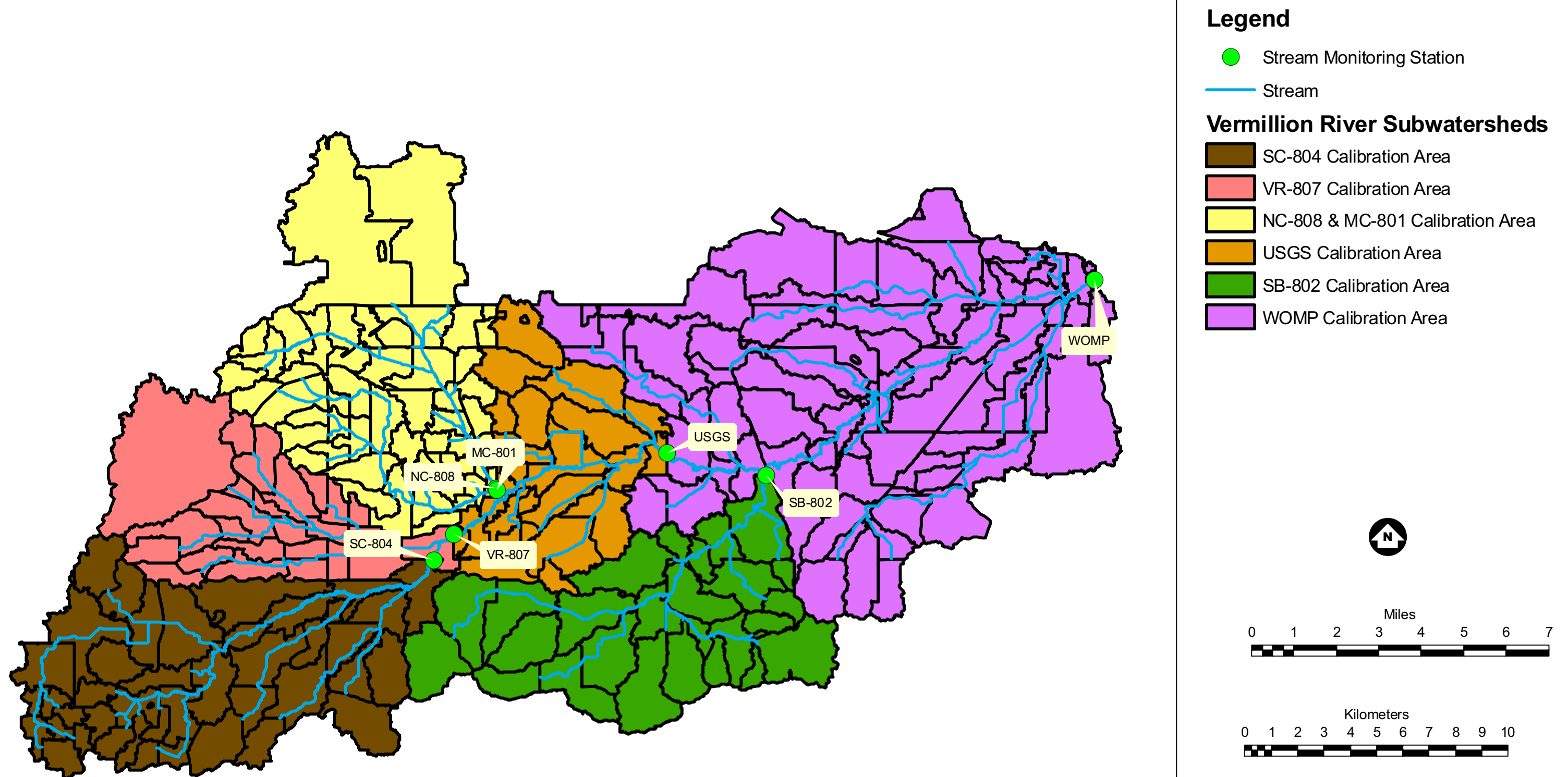
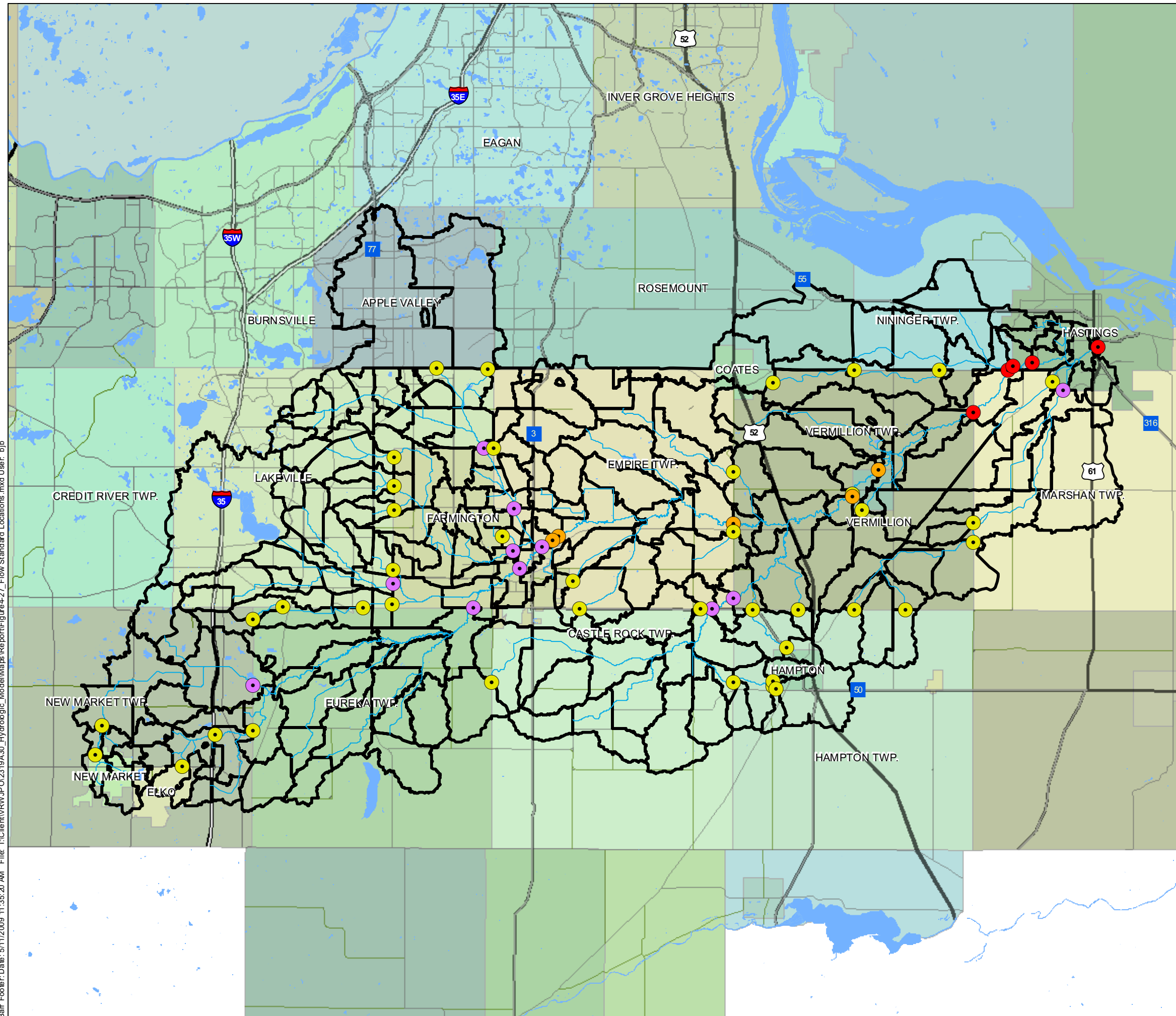


Figure 4-26

CALIBRATION AREAS  
VRWJPO Hydrologic Model  
Vermillion River Watershed



Barr Footer: Date: 5/11/2009 11:35:20 AM File: I:\Client\VRW\PO\2319A30\_Hydrologic\_Model\Maps\Report\Figure4-27\_Flow Standard Locations.mxd User: bjb



## Legend

Vermillion River Subwatersheds

SWMM Links

Lakes

## Standard Locations

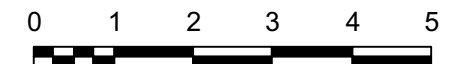
### Tributary Drainage Area

- 0-10 square miles
- 10-67.5 square miles
- 67.5-170 square miles
- 170-225 square miles

Community Boundaries Source:  
Metropolitan Council, Updated as of 07/01/2005.



Miles



Kilometers

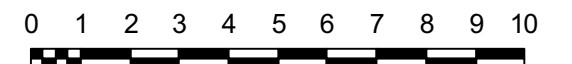


Figure 4-27

STANDARD LOCATIONS  
Vermillion River Hydrologic Model  
Vermillion River Watershed 59

## 5.0 Modeling Results

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### 5.1 Calibration Results

As discussed in [Section 4.5](#), the XP-SWMM model was calibrated to two independent storm events agreed on by the ITR committee prior to beginning calibration. Calibration was automated using PEST, which stopped calibration when the calibrated parameters were obtained. In addition, calibration statistics were calculated for each event to further verify the fit to observed data. Finally, the calibrated infiltration values were calculated for each hydrologic soil group and land use type.

For Event D where approximately 3 inches of precipitation occurred on August 4, 2002, the measured peak flow rate was 615 cfs at the USGS monitoring station. For Event G where approximately 4.6 inches of precipitation occurred between September 14-15, 2004, the measured peak flow rate was 427 cfs at the USGS station.

Comparisons of the observed and modeled hydrographs from the seven calibration sites are shown for each calibration event in [Figure 5-1](#) through [Figure 5-14](#). Overall, the modeled hydrographs reflect a good fit with the measured flows. In some cases, the modeled hydrographs do not reflect the same shape as the observed hydrograph or are ‘missing’ runoff peaks or troughs throughout the storm events, in comparison with observed conditions. This could be a result of a combination of errors:

- Inconsistency in measured stage data at some gages due to water splashing, debris, or other restrictions that prevented the flow monitoring station from functioning properly
- Variation in the amount and timing of precipitation that occurred at each calibration site in comparison to the recorded NEXRAD precipitation data
- Variability between the total amount of precipitation that actually occurred and what was recorded by GTR.

Statistics were used to determine the degree of success of the XP-SWMM model in matching observed water surface elevations. Three statistics were calculated to evaluate the XP-SWMM model calibration: the Nash-Stucliffe efficiency index, peak-weighted root mean square error, and root mean squared error.

The Nash-Sutcliffe efficiency index is a widely used statistic for assessing the goodness of fit of hydrologic models to observed data. The Nash-Sutcliffe coefficient of efficiency ( $E_f$ ) was calculated for each storm event at the seven calibration stations to evaluate the goodness of fit of the modeled

hydrographs with observed conditions. The values of the Nash-Sutcliffe coefficient of efficiency range between negative infinity ( $-\infty$ ) and 1 with 1 indicating a perfect fit to the observed data. The Nash-Sutcliffe coefficient of efficiency equation is shown below:

$$E_f = 1 - \frac{\sum_{i=1}^n (\hat{Y}_i - Y_i)^2}{\sum_{i=1}^n (Y_i - \bar{Y})^2}$$

Where,

$\hat{Y}_i$  and  $Y_i$  = predicted and measured stage values, respectively;

$\bar{Y}$  = mean of the measured stage values; and

n = sample size.

The peak-weighted root mean square error is identical to the calibration objective function included in the HEC-1 computer program (U.S. COE, June 1998). It compares all flows, squaring differences, and it weights the squared differences. The weight assigned to each ordinate is proportional to the magnitude of the ordinate with the maximum weighting being applied to the peak observation. The sum of the weighted, squared differences is divided by the number of computed hydrograph ordinates; thus yielding the mean squared error. Taking the square root yields the root mean squared error. This function is an implicit measure of comparison of the magnitudes of the peaks, volumes, and times of peak of the two hydrographs. (*HEC-HMS Technical Reference Manual*, U.S. COE 2000). The values of the peak-weighted root mean square statistic may range between 0-1, with 0 indicating a perfect fit to observed data.

$$Z = \left\{ \frac{1}{n} \left[ \sum_{i=1}^n (Y_o(i) - Y_p(i))^2 \left( \frac{Y_o(i) + Y_o(\text{mean})}{2Y_o(\text{mean})} \right) \right] \right\}^{1/2}$$

Where,

n = sample size

$Y_o$  = Observed stage

$Y_p$  = Predicted stage

Finally, the root mean squared error was calculated for each monitoring station. The root mean square is the square of the Pearson product moment correlation coefficient (r). It compares the proportion of the variance of the observed data to the variance of the results from the XP-SWMM simulation. The values of the root mean squared statistic may range between 0-1, with 1.0 indicating a perfect fit to observed data.

$$r^2 = \left( \frac{\sum_{i=1}^n (x - \bar{x})(y - \bar{y})}{\sqrt{\sum_{i=1}^n (x - \bar{x})^2 \sum_{i=1}^n (y - \bar{y})^2}} \right)^2$$

Where,

x = Observed stage

$\bar{x}$  = Mean observed stage

y = Predicted stage

$\bar{y}$  = Mean predicted stage

n = Sample size

The results for the calibration statistics are summarized in [Table 5-1](#) and [Table 5-2](#). In general, the calculated statistics indicate a good fit between observed and modeled conditions. The larger amount of uncertainty in the calibration results at the upstream end of the study area (monitoring station SC-804 in particular) may be attributed to questionable monitoring station data, given the relatively good fit at the remaining downstream gages.

**Table 5-1 Event D XP-SWMM Model Calibration Statistics**

| Monitoring Station | $E_f$ | Z    | $r^2$ |
|--------------------|-------|------|-------|
| SC-804             | 0.40  | 0.45 | 0.76  |
| VR-807             | 0.48  | 0.57 | 0.72  |
| NC-808             | 0.78  | 0.32 | 0.86  |
| MC-801             | 0.86  | 0.35 | 0.94  |
| USGS               | 0.75  | 0.41 | 0.81  |
| SB-802             | 0.44  | 0.40 | 0.86  |
| WOMP               | 0.13  | 0.33 | 0.24  |

---

\* Event D calibration statistics were calculated for 8/3/02 18:00 to 8/8/02 00:00

**Table 5-2 Event G XP-SWMM Model Calibration Statistics**

| Monitoring Station | $E_f$ | Z    | $r^2$ |
|--------------------|-------|------|-------|
| SC-804             | -0.27 | 0.75 | 0.25  |
| VR-807             | -0.15 | 0.68 | 0.41  |
| NC-808             | 0.84  | 0.26 | 0.87  |
| MC-801             | 0.91  | 0.30 | 0.92  |
| USGS               | 0.88  | 0.36 | 0.88  |
| SB-802             | 0.61  | 0.22 | 0.81  |
| WOMP               | 0.68  | 0.27 | 0.83  |

---

\* Event G calibration statistics were calculated for 9/14/04 to 9/20/04

The two storm events used for calibration varied in rainfall magnitude, intensity, and duration. The final calibrated parameters resulted in the best fit to observed measurements for both storm events are summarized in [Table 5-3](#). In addition to the calibrated scale factors, [Appendix C](#), [Appendix D](#), and [Appendix E](#) include a complete inventory of all the hydrologic and hydraulic model inputs.

**Table 5-3 Calibrated Parameters**

| Calibration Parameter                     | SC-804 | VR-807 | MC-801<br>and<br>NC-808 | USGS | SB-802 | WOMP |
|-------------------------------------------|--------|--------|-------------------------|------|--------|------|
| Scale Factor: Fo Event D                  | 1.25   | 1.00   | 1.00                    | 0.84 | 1.09   | 0.73 |
| Scale Factor: Fo Event G                  | 1.42   | 1.00   | 1.33                    | 2.00 | 0.3    | 0.9  |
| Scale Factor: Fc                          | 1.27   | 1.00   | 0.60                    | 0.64 | 1.02   | 1.05 |
| Agriculture Pervious Roughness            | 0.30   | 0.21   | 0.30                    | 0.20 | 0.30   | 0.30 |
| Single Family Detached Pervious Roughness | 0.20   | 0.27   | 0.38                    | 0.20 | 0.40   | 0.20 |
| Scale Factor: Channel Roughness           | 1.14   | 1.00   | 0.99                    | 1.14 | 1.05   | 0.86 |

The calibration parameters for the intermediate drainage area to the VR-807 monitoring station were not changed as part of the calibration process. In the month prior to Event G the DNR removed a series of beaver dams in the Vermillion River upstream of VR-807. The removal of the dams influenced recordings at the monitoring station of VR-807 that would skew calibration results at that gage. Additionally the Event D simulated hydrograph provided a good fit to the observed data without modifying the calibration parameters. Finally, PEST was able to calculate calibrated parameters for the downstream USGS monitoring station without modifying the parameters for the subwatershed upstream of VR-807.

The Horton initial infiltration rate parameter is the maximum rate at which the soil can infiltrate precipitation at the beginning of the storm. It is sensitive to the initial moisture content in the soil. For example soil with a lower initial infiltration parameter has a higher water content than soil with a lower moisture content. The initial infiltration rate represents the infiltration capacity at the beginning of the storm event (i.e., an initial condition) and was allowed to vary between the calibration events to account for the variation in moisture content of the soil at the beginning of each calibration event. [Figure 5-15](#) and [Figure 5-16](#) show the spatial distribution of calibrated initial infiltration values for Event D and Event G.

The Horton asymptotic infiltration parameter is the hydraulic conductivity of the soil, or the maximum constant rate at which water will infiltrate through the soil under saturated conditions. The asymptotic infiltration parameter is constant for a given soil type, and is not dependant on the initial moisture content in the soil. Therefore, the asymptotic infiltration parameter does not vary between events, like the initial infiltration parameter. As discussed in [Section 4.5](#) the asymptotic infiltration parameter was calibrated to both events simultaneously, and not allowed to vary between events. [Figure 5-17](#) shows the spatial distribution of the calibrated asymptotic infiltration rates throughout



the watershed. The calibrated asymptotic infiltration parameters are lower in the northwestern portion of the watershed where soil has been compacted due to urban development that reduces the rate at which water can infiltrate through the soil. Conversely, the asymptotic infiltration rates are higher in the eastern portion of the watershed where the soil is more sandy and less development has occurred.

### 5.1.1 Calibration Parameters for Validation and Design Events

The initial infiltration parameters for Event D were used as the initial infiltration parameters in the validation events (Event A and Event C). The calibrated Event D initial infiltration parameters indicated a dry antecedent moisture condition (AMC) in the soil for the precipitation event. The Event G initial infiltration parameters were slightly larger, but also indicated a dry AMC for the storm event. To determine which set of parameters to use for the validation events the precipitation record prior to each event was analyzed to determine which initial infiltration parameters would most accurately simulate each validation event. Table 5-4 includes a summary of the cumulative precipitation prior to each event.

**Table 5-4 Precipitation Prior to Calibration and Validation Events**

| <b>Event</b> | <b>Precipitation Total<br/>5 Days Prior to Event<br/>(inches)</b> | <b>Precipitation Total<br/>10 Days Prior to<br/>Event (inches)</b> |
|--------------|-------------------------------------------------------------------|--------------------------------------------------------------------|
| Event A      | 0.68                                                              | 0.99                                                               |
| Event C      | 0.74                                                              | 0.92                                                               |
| Event D      | 0.66                                                              | 1.21                                                               |
| Event G      | 0.00                                                              | 2.33                                                               |

---

\* Precipitation totals take from Rosemount Gage

Based on the precipitation five to ten days prior to each event it was determined that the initial infiltration for Event D would most accurately approximate the initial infiltration prior to each validation event. The remaining calibrated parameters were identical for both Event D and Event G and were used for the validation event simulations.

The initial infiltration parameters for Event D were also used to define the initial infiltration rate for the design event simulations. The calibrated Event D initial infiltration parameters indicated a dry antecedent moisture condition in the soil. The calibrated initial infiltration parameters were uniformly adjusted by dividing the calibrated Event D initial infiltration parameters by a factor of three, which follows the methodology described in the U.S. EPA SWMM Version 5.0 User's Manual

to determine initial infiltration parameters that more accurately represent a moist antecedent moisture condition. The adjusted initial infiltration parameters simulate soils with higher moisture content, which increases runoff rates, and therefore flow rates at the gaging stations for the design events. The remaining calibrated parameters were identical for both Event D and Event G and were used for the design event simulations.

As discussed in [Section 4.5](#), to speed up the calibration process with PEST, scale factors were used for most parameters, rather than absolute values. The scale factors and original default parameter value are multiplied to determine the calibrated parameter. The advantage of calibrating the XP-SWMM model using scale factors is that the relationship between the calibrated parameter and the initial assumption remains intact for each calibrated area shown in [Figure 5-18](#). For example, the calibrated initial infiltration for each hydrologic soil group can be calculated from each calibrated initial infiltration parameter in the model. If the XP-SWMM model parameters were calibrated to absolute values then infiltration parameters would vary between watersheds, and not by hydrologic soil group. This will prove beneficial when future development occurs in the watershed and the current subwatersheds are modified because there will not be any questions regarding infiltration parameters because adjacent watersheds will have similar hydrologic soil group parameters. The updated infiltration parameters for new watersheds can be calculated from the calibrated hydrologic soil group properties. Calibrated parameters for each calibration area shown in [Figure 5-18](#) are included in [Table 5-5](#).

**Table 5-5 Calibrated Parameters for Hydrologic Soil Groups**

| Hydrologic Soil Group                 | A       | B       | C       | A/D     | B/D     | C/D     | D       |
|---------------------------------------|---------|---------|---------|---------|---------|---------|---------|
| <b>Event D</b>                        |         |         |         |         |         |         |         |
| <b>SC-804</b>                         |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 6.25    | 3.75    | 2.5     | 6.25    | 3.75    | 2.5     | 1.25    |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.483   | 0.292   | 0.127   | 0.038   | 0.038   | 0.038   | 0.038   |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| <b>VR-807</b>                         |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 5       | 3       | 2       | 5       | 3       | 2       | 1       |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.38    | 0.23    | 0.1     | 0.03    | 0.03    | 0.03    | 0.03    |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| <b>MC-801 and NC-808</b>              |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 5       | 3       | 2       | 5       | 3       | 2       | 1       |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.228   | 0.138   | 0.060   | 0.018   | 0.018   | 0.018   | 0.018   |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| <b>USGS</b>                           |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 4.2     | 2.52    | 1.68    | 4.2     | 2.52    | 1.68    | 0.84    |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.243   | 0.147   | 0.064   | 0.019   | 0.019   | 0.019   | 0.019   |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| <b>SB-802</b>                         |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 5.45    | 3.27    | 2.18    | 5.45    | 3.27    | 2.18    | 1.09    |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.388   | 0.235   | 0.102   | 0.031   | 0.031   | 0.031   | 0.031   |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| <b>WOMP</b>                           |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 3.65    | 2.19    | 1.46    | 3.65    | 2.19    | 1.46    | 0.73    |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.399   | 0.242   | 0.105   | 0.032   | 0.032   | 0.032   | 0.032   |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| <b>Event G</b>                        |         |         |         |         |         |         |         |
| <b>SC-804</b>                         |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 7.1     | 4.26    | 2.84    | 7.1     | 4.26    | 2.84    | 1.42    |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.483   | 0.292   | 0.127   | 0.038   | 0.038   | 0.038   | 0.038   |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| <b>VR-807</b>                         |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 5       | 3       | 2       | 5       | 3       | 2       | 1       |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.38    | 0.23    | 0.1     | 0.03    | 0.03    | 0.03    | 0.03    |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| <b>MC-801 and NC-808</b>              |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 6.65    | 3.99    | 2.66    | 6.65    | 3.99    | 2.66    | 1.33    |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.228   | 0.138   | 0.060   | 0.018   | 0.018   | 0.018   | 0.018   |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |

**Table 5-5 Continued Calibrated Parameters for Hydrologic Soil Groups**

| Hydrologic Soil Group                 | A       | B       | C       | A/D     | B/D     | C/D     | D       |
|---------------------------------------|---------|---------|---------|---------|---------|---------|---------|
| <b>USGS</b>                           |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 10      | 6       | 4       | 10      | 6       | 4       | 2       |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.243   | 0.147   | 0.064   | 0.019   | 0.019   | 0.019   | 0.019   |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| <b>SB-802</b>                         |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 1.5     | 0.9     | 0.6     | 1.5     | 0.9     | 0.6     | 0.3     |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.388   | 0.235   | 0.102   | 0.031   | 0.031   | 0.031   | 0.031   |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| <b>WOMP</b>                           |         |         |         |         |         |         |         |
| Initial Infiltration $F_o$ (in/hr)    | 4.5     | 2.7     | 1.8     | 4.5     | 2.7     | 1.8     | 0.9     |
| Asymptotic Infiltration $F_c$ (in/hr) | 0.399   | 0.242   | 0.105   | 0.032   | 0.032   | 0.032   | 0.032   |
| Decay Coefficient $k$ (1/sec)         | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |

Similar to the calibrated infiltration parameters, XP-SWMM parameters that were not adjusted during the calibration process (i.e., percent impervious, roughness coefficients, and depression storage) can all be calculated for a specific land use classification. A complete table of XP-SWMM model parameters and the base value for each land use classification and hydrologic soil group to be used in design event simulations is included in [Appendix F](#). The initial infiltration parameters given in [Appendix F](#) are different from those listed in [Table 5-5](#). This is because the initial infiltration parameters used in the design events were modified from the calibrated parameters following the methodology discussed earlier in this section. This provides a consistent way for municipalities or developers to select the appropriate model parameter values prior to redevelopment and accurately simulate the impacts of the development in the watershed. For example, consider an existing agricultural parcel that is 0 percent impervious. A developer proposing to redevelop that parcel to a commercial facility would look up the percent impervious for “Retail and Other Commercial” land use in [Appendix F](#) of 75.7 percent, and use that value to model the change in impervious area of the proposed redevelopment. Similarly, the developer would revise the roughness coefficients and depression storage to reflect the new land use using values from [Appendix F](#). This method will eliminate uncertainty from the current method that most developers use to model proposed redevelopment in the watershed by attempting to select the appropriate curve number. A more detailed discussion of how to modify the model for future conditions is included in [Appendix G](#).

## 5.2 Validation Results

Following an extensive calibration process where the XP-SWMM model was calibrated to two separate storm events, the model was validated by comparing calibrated model results to observed data from two independent events. Additionally the calibrated model results were compared to the 1992 flood of record at the USGS gage, the discharge frequency curve, USGS regression equations, USGS transfer method analysis, various municipal models, and flows calculated for the Dakota County DFIRM.

### 5.2.1 Validation Events

Results from the calibrated XP-SWMM model were validated by comparing calibrated model results to observed data from two independent events of similar magnitude, Event A where 4.3 inches occurred during July 5-9, 2000, and Event C where 3.7-inches occurred during June 2-7, 2002. The events selected for validation, and agreed on by the ITR committee, both occurred during summer months. Event D calibrated initial infiltration values were used for both validation events because the August calibration event most accurately approximated a similar time of the year as the validation events (Event A—July and Event C—June). Precipitation and base flow values for both events were calculated following the methodology used to calculate inputs for the calibration events as described in [Section 4.2.2.1](#) and [Section 4.4](#).

Complete validation event results are included in [Figures 5-19 through 5-32](#). The validation events were not calibrated so it is expected that simulated results will not fit the observed data as well as the calibration event simulations because assumptions regarding the initial conditions of the model were made rather than calibrated. The modeled results generally follow the trends of the observed hydrographs at the seven monitoring stations, and at most gages predict a peak water surface elevation slightly higher than observed. However, at some monitoring stations the validation results provide a good match of the observed data. At station VR-807, located in the southern portion of Farmington, both Event A and Event C model results closely follow the observed data. Event C model results do not provide a good fit for the data at station SC-804, which is the furthest upstream gage. However, this could be a result of uncertainty in the data at this gage since the simulated results closely approximate the observed data at VR-807 located 6,650 feet downstream, or could reflect the uncertainty in assuming that the initial infiltration for Event C is the same as Event D.

Similar to the calibration events, statistics were calculated for the validation events to quantify how well modeled results fit observed data. Complete validation event statistics are included in [Table 5-6](#) and [Table 5-7](#).

**Table 5-6 Event A XP-SWMM Model Validation Statistics**

| <b>Monitoring Station</b> | <b><math>E_f</math></b> | <b>Z</b> | <b><math>r^2</math></b> |
|---------------------------|-------------------------|----------|-------------------------|
| SC-804                    | -0.58                   | 0.66     | 0.84                    |
| VR-807                    | 0.84                    | 0.31     | 0.88                    |
| NC-808                    | 0.80                    | 0.49     | 0.80                    |
| MC-801                    | 0.87                    | 0.50     | 0.89                    |
| USGS                      | 0.79                    | 0.65     | 0.81                    |
| SB-802                    | 0.46                    | 0.81     | 0.53                    |
| WOMP                      | -0.32                   | 0.66     | 0.71                    |

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\* Event A validation statistics were calculated for 7/5/00 to 7/13/00

**Table 5-7 Event C XP-SWMM Model Validation Statistics**

| <b>Monitoring Station</b> | <b><math>E_f</math></b> | <b>Z</b> | <b><math>r^2</math></b> |
|---------------------------|-------------------------|----------|-------------------------|
| SC-804                    | -1.55                   | 0.97     | 0.56                    |
| VR-807                    | 0.84                    | 0.51     | 0.85                    |
| NC-808                    | 0.61                    | 0.36     | 0.84                    |
| MC-801                    | 0.66                    | 0.57     | 0.81                    |
| USGS                      | 0.68                    | 0.65     | 0.87                    |
| SB-802                    | -0.57                   | 0.74     | 0.93                    |
| WOMP                      | 0.72                    | 0.26     | 0.82                    |

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\* Event C validation statistics were calculated for 6/2/02 to 6/9/02

Overall, the validation model statistics indicate that the validation events approximate the observed data at the majority of the monitoring stations. Therefore, the validation events support the conclusion that the XP-SWMM model is appropriately calibrated and adequately predicts water surface elevations at the seven monitoring stations located throughout the watershed.

## 5.2.2 Historical Analysis

The 1992 precipitation event resulted in the flood of record at the USGS station, and was significantly larger than the storm events selected for calibrating and validating the model. The 1992



event had a duration of 10 hours and a basin-weighted average precipitation of 5.3 inches, which corresponds to a point precipitation total of 6.2 inches. Using this point precipitation total and extrapolating data from TP-40, indicates the 1992 event has a return interval of approximately 1,100 years according to the U.S. COE, July 1998 report.

The calibrated model was used to evaluate the 1992 event and predicted flows were compared to observed flow data. Simulation results and observed data for this event are shown in [Figure 5-33](#). The flow curves are similar, however the peak flow rate of 5,029 cfs from the calibrated XP-SWMM model is less than the peak flow rate of 6,570 cfs calculated from the rating curve at the station. The simulation does an accurate job of matching flow rates that were measured in the field where uncertainty in the flow reading is not introduced by calculating from a rating curve.

Comparison to the 1992 event was not a detailed validation due to the lack of available precipitation data. Precipitation totals used for this simulation were GTR from monitoring stations located within the study area. However, a map published by the Minnesota State Climatology Office indicates that the precipitation used for this analysis may underestimate the total precipitation over the duration of the event. Isohyets from the Minnesota State Climatology Office are shown over the study area in [Figure 5-34](#). A sensitivity analysis showed that if the precipitation used to simulate the 1992 event were increased by 20 percent the calibrated model would produce peak flows similar to what was observed at the USGS monitoring station. This is not an unreasonable increase given the magnitude of isohyets in the map from the Minnesota State Climatology Office in Figure 5-34 are approximately 20 percent larger than the GTR recorded at the weather stations around the Vermillion River watershed.

### **5.2.3 1998 Discharge Frequency Curve and Infiltration Methodology**

The 1 percent probability (100-year) peak flow rate at the USGS monitoring station was compared to the discharge frequency curve that was developed by the U.S. COE as part of the July 1998 report and updated with data from 1998-2007 as shown in [Figure 5-35](#). The peak flow rate predicated by the XP-SWMM model for the 100-year, 4-day precipitation event at the USGS station was 3,364 cfs, which was less than the flow rate, estimated using the frequency curve at 4,940 cfs

Following direction from the ITR Committee, a detailed assessment of the validity of the Hortonian infiltration method, the infiltration methodology agreed upon by the ITR Committee at the beginning of the analysis, was conducted to verify that the XP-SWMM model was not over estimating infiltration that occurred during the long duration, low intensity storm events. This section describes

the analysis. The results indicate that the maximum infiltration volume parameter (which sets the total infiltration capacity for a single storm event) slightly influences flow rates during the design events and does not affect the calibration results, therefore it was incorporated into the model.

For a given storm event, the infiltration rate will vary with time. At the beginning of the storm, the initial infiltration rate is the maximum infiltration that can occur because the top soil is typically drier and full of air spaces. As the storm event continues, the infiltration rate will gradually decrease as the air space in the soil fills with water. According to Hortonian infiltration theory, during long duration storms the infiltration rate will reach a constant minimum infiltration rate, the soils hydraulic conductivity. The calibrated XP-SWMM model uses the Horton equation to simulate this variation of infiltration rate with time. However, if the soil becomes completely saturated (i.e., the groundwater table is at the ground surface), infiltration may be significantly reduced and could potentially cease. Under the direction of the ITR Committee, this process was investigated to determine if: (1) this phenomenon occurred in the Vermillion River watershed, and (2) it would have a significant impact on the peak flow rates so that the calibrated XP-SWMM model results would match the discharge frequency curve at the USGS station near Empire.

#### **5.2.3.1 Horton Infiltration**

Horton infiltration input parameters include, asymptotic infiltration capacity or hydraulic conductivity ( $F_c$ ), initial infiltration capacity ( $F_o$ ), and the decay coefficient ( $k$ ). Unique infiltration values were assigned to each hydrologic soil group. The initial infiltration coefficient and asymptotic infiltration parameters were modified as part of the calibration process. Sensitivity analysis showed the decay coefficient did not have a significant impact on the results and was not modified as part of the calibration process. A composite initial infiltration and asymptotic infiltration parameter were calculated by taking an area weighted average based on the percentage of each soil group in each watershed. This method does not limit the total volume of water that can be infiltrated during a storm event.

#### **5.2.3.2 Maximum Infiltration Volume**

At the beginning of a storm event, infiltration is governed by the Horton equation until all of the available voids in the soil fill with water, and water can no longer move downward due to a high water table or low permeable layer. When this occurs infiltration may be significantly reduced and could potentially cease, which would in turn cause more of the remaining precipitation to become

surface runoff. The amount of infiltrated water that can be stored in the soil profile can be estimated based on the specific yield of the soil and the depth to the groundwater table.

The depth to the groundwater table was determined by using the November 2008 results from the calibrated Twin Cities Metropolitan Area Groundwater Flow Model that was completed for the Metropolitan Council to predict water availability and how pumping rates affect adjacent wells (Metropolitan Council, December 2008). The depth to the groundwater table was calculated by subtracting the groundwater elevation obtained from the Met Council groundwater model from the surface elevation determined by Dakota and Scott County LiDAR data, and is shown on [Figure 5-36](#). The specific yield of the soils in the Vermillion River watershed was obtained from the DNR online data deli. Multiplying the depth to groundwater and soils specific yield results in an estimate of the maximum infiltration capacity (i.e., the amount of water that can be stored in the soil profile under completely saturated conditions) for each watershed. The analysis results summarized in [Figure 5-37](#) illustrate that the low/wetland areas and areas adjacent to the streams have the potential to become completely saturated during a large storm event. However, the average depth of water that can be stored in the soil profile between the groundwater table and the ground surface upstream from the USGS station is about 117 inches, which is significantly larger than the 8.3 inches of precipitation that would occur during the 100-year, 4-day rainfall event. However, there are small areas near the southeast corner of Farmington where the depth to groundwater is less than 6 inches. The area where shallow groundwater occurs is small enough that it does not significantly influence the downstream flows. Therefore limiting the infiltration volume to the available storage in the soil does not impact the peak flow rate at the USGS station, because the soils capacity to store water is significantly larger than the total amount of rainfall that occurs during the 100-year, 4-day event. However, because the peak flow rates are slightly impacted near Farmington due to localized shallow groundwater, the maximum infiltration parameter was incorporated into the XP-SWMM model.

The maximum infiltration parameter slightly influences flow rates during the design events, but does not affect the calibration results, because the infiltration limit used in the XP-SWMM model does not limit infiltration during precipitation events of smaller magnitude or duration.

#### **5.2.4 Historically Adjusted Discharge Frequency Curve**

As noted above, the peak flow rate of 3,494 cfs predicated by the XP-SWMM model for the 100-year, 4-day precipitation event at the USGS station is less than the flow rate estimated using the frequency curve at 4,940 cfs. However, the 100-year precipitation event may not necessarily produce the 100-year flow for large watersheds. Therefore, the discharge frequency curve was reviewed to

verify that it accurately predicted the 100-year flow at the USGS monitoring station and to investigate why the model results are lower than the curve presented in the July 1998, U.S. COE report. As described below, a historical adjustment to the largest historical event lowers the discharge frequency curve.

The 1992 event resulted in the flood of record at the USGS gage and produced the highest flow rates in the discharge frequency curve. The 1992 event peak flow rate is considered a statistical high outlier based on the methodology in Bulletin 17B (U.S.G.S., 1982) (industry standard discharge frequency methodology) and shown in [Figure 5-35](#). Bulletin 17B (U.S.G.S., 1982) and the U.S. COE's Engineering and Design Manual *Hydrologic Frequency Analysis* (EM 1110-2-1415) indicate:

“...values that are determined to be high outliers are weighted by the historical adjustment equations. Therefore, for any flood peak(s) to be weighted as high outlier(s), either historical information must be available or the probable occurrence of the event(s) estimated must be based on flood information at nearby sites. If it is not possible to obtain any information that weights the high outlier(s) over a longer period than that of the systematic record, then the outlier(s) should be retained as part of the systematic record.”

Adjusting the weight of the 1992 event based on the length of the systematic record of 66 years (1942-2007) modifies the discharge frequency curve for the larger flood events as shown in [Figure 5-38](#). Using the adjusted curve the 1 percent probable flood (or 100-year flood) flow at the USGS would be estimated at 4,334 cfs. The 100-year flow at the USGS gage from the calibrated model (3,364 cfs) is located within the 95 percent confidence intervals of the adjusted discharge frequency curve.

Since handling high outliers requires an estimation of the probable occurrence of the flood event one alternative to using the systematic record length (66 years) could be to use the estimated rainfall frequency to establish the historic period to assign to the flow event. As discussed in [Section 5.2.2](#), the historic period would be about 1,100 years. Adjusting the weight of the 1992 event based on the historic period of 1,100 years modifies the discharge frequency curve for the larger flood events even more than that shown in [Figure 5-38](#), and would yield a 1 percent probable flood (or 100-year flood) flow at the USGS station estimated at 3,450 cfs as shown in [Figure 5-39](#).

The historically adjusted discharge frequency curves indicate that the XP-SWMM model predicted 100-year flow rate at the USGS monitoring station is within the range of expected probability.

### 5.2.5 USGS Regression Equations

In order to verify the historically adjusted discharge frequency curve in [Figure 5-38](#), the 100-year flow rates were calculated using the USGS regression equations. The estimated 100- year discharge based on the drainage basin characteristics and the USGS regression equations would be about 3,186 cfs with a standard error of the estimate of 54 percent. [Figure 5-40](#) shows the calibrated XP-SWMM model results, and the discharge frequency curve calculated using USGS regression equations. Both the 100-year and 10-year flows from the calibrated XP-SWMM model plot with good correlation to the USGS regression curve. Results from this analysis indicate that the XP-SWMM model is reasonably estimating the 100-year flow rate at the USGS monitoring station.

### 5.2.6 USGS Transfer Method

Because of the uncertainty in flow rates from the frequency curve (discussed in [Section 5.2.4](#)), the USGS transfer method was used to provide an additional comparison for modeled flow rates. The USGS regression analysis results were compared to estimated discharges from four other gages using the gage transfer method as described in *Techniques for Estimating the Magnitude and Frequency of Floods in Minnesota* (Guetzkow, L.C., 1977). [Figure 5-41](#) shows the locations of the gages used for the transfer method analysis relative to the USGS gage. The transfer method suggests the 100-year discharge should range between 2,100-4,000 cfs. The 100-year flow predicted by the XP-SWMM model of 3,494 cfs is within the range of flow rates predicted by the gage transfer method. Complete results from the transfer method analysis are included in [Table 5-8](#).

**Table 5-8     Transfer Method Analysis Results**

| Transfer Gage                                      | 100-Year Flow (cfs) |
|----------------------------------------------------|---------------------|
| East Branch Blue Earth River near Bricelyn, MN     | 2,881               |
| Cannon River below Sabre Lake near Kilkenny, MN    | 4,041               |
| East Fork DesMoines River near Ceylon, MN          | 2,141               |
| South Branch Yellow Medicine River at Minneota, MN | 3,137               |

[Figure 5-42](#) compares the results from the discharge frequency curve analysis, USGS regression equation, gage transfer method, and calibrated XP-SWMM results on the same plot. Similar to previous analysis results, the gage transfer analysis indicates that the XP-SWMM model is adequately predicting the 100-year flow rate at the USGS monitoring station.

### 5.2.7 Municipal Models

The calibrated 100-year model peak flow results at standard locations were compared to various city models obtained from municipalities prior to developing the final calibrated XP-SWMM model. Subwatersheds for the XP-SWMM model were developed based on subwatersheds from municipal SWMP as described in [Section 4.2.1.1](#). This facilitates a direct comparison between the various models because they use similar upstream drainage areas. However, the municipal models are uncalibrated, which in some cases, results in a large difference between peak flow rates when compared with the XP-SWMM model. Additionally, municipal models use point precipitation distributions that are not spatially adjusted for upstream drainage area and vary from the 4-day frequency based distribution used in the XP-SWMM model. The precipitation distribution has a significant impact on the 100-year peak flow results and results in differing predicted peak flows between municipal models and the calibrated XP-SWMM model. [Table 5-9](#) compares the 100-year results from the calibrated XP-SWMM model to various municipal models and the Dakota County DFIRM.

### 5.2.8 Dakota County DFIRM Flows

The calibrated XP-SWMM 100-year model peak flows were also compared to flows calculated for the Dakota County DFIRM study at standard locations. USGS regression equations were used to calculate flows in tributaries to the Vermillion River for the Dakota County DFIRM. DFIRM flows for the Vermillion River were obtained from the MWH HEC-HMS model, which was based on the U.S. COE HEC-1 model calibrated to the 1998 frequency curve. However, as discussed in [Section 5.2.4](#) the unadjusted frequency curve over predicted flows in the Vermillion River, which explains why the calibrated XP-SWMM model results along the Vermillion River, are less than the flows calculated for the DFIRM study. A complete comparison of calibrated XP-SWMM model and DFIRM flows is included in [Table 5-9](#).

## 5.3 Municipal Standards

The drainage area was calculated to each municipal standard location to determine the appropriate precipitation distribution. As described in [Section 4.2.2.3](#) the point distribution was adjusted based on methodology presented in TP-40 (National Weather Service, 1961). Standard locations were divided into four groups based on upstream drainage area and the appropriate precipitation was assigned based on upstream drainage area as shown in [Figure 5-43](#).



Following the extensive validation process, the 1-, 2-, 10-, 50-, and 100-year events were evaluated using the calibrated XP-SWMM model, and the peak flow rates and total runoff volume were determined at each of the 61 standard locations agreed on by the ITR Committee. Peak flow results at standard locations are included in [Table 5-10](#) and [Figure 5-44](#) through [Figure 5-48](#). [Appendix H](#) describes the methodology of how the peak flow rate and runoff volume were determined at each standard location.

West of Empire Township the peak flow rates in the Vermillion River increase as the tributary area increases. However, east of Empire Township the peak flow rates in the Vermillion River do not increase as the tributary area increases, because the peaks of the subwatersheds located in the eastern portion of the watershed are not aligning with the maximum peak flows generated upstream. This trend along with attenuation of the hydrograph as it is routed downstream results in the peak flow rate at the WOMP station (225-square mile drainage area, 3,789 cfs) to be only slightly larger than the peak flow rate at the USGS station (115-square mile drainage area 3,494 cfs), despite the large increase in tributary area. For similar reasons, the peak flow rate along the Vermillion River is located between the WOMP and USGS stations at VR-17, not at the downstream end of the watershed.

Similarly, the total volume of water passing through each standard location was determined for the 1-, 2-, 10-, 50-, and 100-year events. The total volume at standard locations only accounts for the volume of runoff generated by the design events; base flow in the Vermillion River was not included as part of the volume calculations. For a given precipitation amount the total runoff volume is directly related to tributary area. This trend is observed at each standard location in the Vermillion River watershed. However, as discussed in [Section 4.2.2](#) the precipitation amount varies based on drainage area, and is not constant for each standard location. This can result in a volume standard at one location that is larger than the next downstream location. An example of this is the two volume standards located on the Vermillion River between Vermillion and Vermillion Township. The volume standards at this location are larger than the next downstream volume standard. Total runoff volume results at standard locations are included in [Table 5-11](#) and [Figure 5-49](#) through [Figure 5-53](#).

**Table 5-9 Calibrated XP-SWMM Model and Previous Model Peak Flow Rates at Standard Locations**

| XP-SWMM Node | XP-SWMM Link | Reach                                         | Upstream Municipality | Downstream Municipality | XP-SWMM 100-Year Peak Flow (cfs) <sup>1</sup> | Previously Calculated 100-Year Flow (cfs) <sup>2</sup> | Previous Model Description                       |
|--------------|--------------|-----------------------------------------------|-----------------------|-------------------------|-----------------------------------------------|--------------------------------------------------------|--------------------------------------------------|
| N-1261       | L-1442       | County Ditch 12                               | New Market Twp.       | Eureka Twp              | 315                                           |                                                        |                                                  |
| ECreek-2     | L-1351       | East Branch South Creek                       | Lakeville             | Farmington              | 364                                           | 716                                                    | SCS100y24hr from Farmington HydroCAD model.      |
| MCreek-20    | L-1595       | Middle Creek                                  | Lakeville             | Farmington              | 603                                           | 1,318                                                  | SCS 100y24hr Farmington HydroCAD model           |
| MCreek-1a    | L-201        | Middle Creek                                  | Farmington            | Empire Twp.             | 862                                           | 1,061                                                  | 100y24hr event from Farmington HydroCAD          |
| NBranch-2    | L-1233       | North Branch Vermillion River                 | Empire Twp.           | Vermillion Twp.         | 496                                           | 667                                                    | Dakota County DFIRM - USGS Regression Equations  |
| L-1583       | L-1580       | North Creek                                   | Farmington            | Empire Twp.             | 1,381                                         | 1,203                                                  | 100y24hr event Farmington HydroCAD model         |
| NCreek-9     | L-1584       | North Creek                                   | Lakeville             | Farmington              | 1,149                                         | 1051 <sup>3</sup>                                      | 100y24hr Farmington HydroCAD                     |
| SBranch-26   | L-1121       | South Branch Vermillion River                 | Erueka Twp.           | Castle Rock Twp.        | 327                                           | 232                                                    | Dakota County DFIRM - USGS Regression Equations  |
| SBranch-9    | L-1599       | South Branch Vermillion River                 | Castle Rock Twp.      | Empire Twp.             | 699                                           | 1,421                                                  | Dakota County DFIRM - USGS Regression Equations  |
| SBranch-8    | L-305        | South Branch Vermillion River                 | Empire Twp.           | Vermillion Twp.         | 698                                           | 1,421                                                  | Dakota County DFIRM - USGS Regression Equations  |
| SCreek-2     | L-830        | South Creek                                   | Lakeville             | Farmington              | 1,144                                         | 1,555                                                  | SCS100y24hr event from Farmington HydroCAD model |
| Trib1-20     | L-1022       | Tributary 1                                   | Hampton Twp.          | Vermillion Twp.         | 386                                           | 535                                                    | Dakota County DFIRM - USGS Regression Equations  |
| Trib1-13     | L-992        | Tributary 1                                   | Vermillion Twp.       | Marshan Twp.            | 373                                           | 1,390                                                  | Dakota County DFIRM - USGS Regression Equations  |
| Trib1-3      | L-979        | Tributary 1                                   | Marshan Twp.          | Hastings                | 540                                           | 1,280                                                  | Dakota County DFIRM - USGS Regression Equations  |
| MCreek-3     | L-202        | Tributary 1 to Middle Creek                   | Farmington            | Empire Twp.             | 105                                           | 24                                                     | 100y24hr event Farmington HydroCAD               |
| NCreek-25    | Link19       | Tributary 1 to North Creek                    | Apple Valley          | Lakeville               | 80                                            | 77                                                     | 100yr flow from bonestroo HydroCAD model         |
| SBranch-5    | L-1078       | Tributary 1 to South Branch Vermillion River  | Hampton               | Hampton Twp.            | 341                                           | 323                                                    | Dakota County DFIRM - USGS Regression Equations  |
| SBranch-3    | L-1072       | Tributary 1 to South Branch Vermillion River  | Hampton Twp.          | Vermillion Twp.         | 403                                           |                                                        |                                                  |
| SCreek-11    | L-131        | Tributary 1 to South Creek                    | New Market Twp.       | Eureka Twp.             | 383                                           |                                                        |                                                  |
| SCreek-10    | L-1345       | Tributary 1 to South Creek                    | Lakeville             | Eureka Twp.             | 337                                           |                                                        |                                                  |
| SCreek-8     | L-1344       | Tributary 1 to South Creek                    | Erueka Twp.           | Lakeville               | 194                                           |                                                        |                                                  |
| SCreek-6     | L-1339       | Tributary 1 to South Creek                    | Lakeville             | Farmington              | 447                                           | 879                                                    | SCS100y24hr event from Farmington HydroCAD model |
| NCreek-24    | L-1167       | Tributary 1A to North Creek                   | Apple Valley          | Lakeville               | 27                                            |                                                        |                                                  |
| Trib1-12     | L-392        | Tributary 1C                                  | Vermillion Twp.       | Marshan Twp.            | 60                                            | 227                                                    | Dakota County DFIRM - USGS Regression Equations  |
| Trib1-2      | L-1220       | Tributary 1D                                  | Marshan Twp.          | Hastings                | 187                                           |                                                        |                                                  |
| Trib1-18     | L-378        | Tributary 1E                                  | Hampton Twp.          | Vermillion Twp.         | 210                                           |                                                        |                                                  |
| CD12-12      | L-1623       | Tributary 2 to County Ditch 12                | New Market            | New Market Twp.         | 231                                           | 208                                                    | 100y24hr event Elko New Market HydroCAD          |
| SBranch-10   | L-301        | Tributary 2 to South Branch Vermillion River  | Empire Twp.           | Castle Rock Twp.        | 253                                           | 52                                                     | Dakota County DFIRM - USGS Regression Equations  |
| N-990        | L-1104       | Tributary 3 to South Branch Vermillion River  | Hampton Twp.          | Hampton                 | 133                                           |                                                        |                                                  |
| SBranch-14   | L-294        | Tributary 3 to South Branch Vermillion River  | Hampton               | Hampton Twp.            | 541                                           | 550                                                    | Dakota County DFIRM - USGS Regression Equations  |
| SBranch-13   | L-1532       | Tributary 3 to South Branch Vermillion River  | Hampton Twp.          | Castle Rock Twp.        | 614                                           | 550                                                    | Dakota County DFIRM - USGS Regression Equations  |
| SBranch-6    | L-295        | Tributary 3C to South Branch Vermillion River | Hampton               | Hampton Twp.            | 234                                           |                                                        |                                                  |
| NCreek-7     | L-215        | Tributary 4 to North Creek                    | Empire Twp.           | Farmington              | 281                                           | 1051 <sup>3</sup>                                      | 100y24hr Farmington HydroCAD                     |
| Trib6-6      | L-1547       | Tributary 6                                   | Castle Rock Twp.      | Empire Twp.             | 40                                            | 76                                                     | SCS100y24hr event from Farmington HydroCAD       |
| MCreek-18    | L-1200       | Tributary 6 to Middle Creek                   | Lakeville             | Farmington              | 436                                           | 843                                                    | SCS 100y24hr event from Farmington HydroCAD      |
| SBranch-4    | L-310        | Tributary 6 to South Branch Vermillion River  | Hampton Twp.          | Vermillion Twp.         | 90                                            |                                                        |                                                  |
| Trib6-3      | L-1675       | Tributary 6A                                  | Farmington            | Empire Twp.             | 81                                            | 40                                                     | SCS100y24hr event Farmington HydroCAD            |
| MCreek-15    | L-1589       | Tributary 6A to Middle Creek                  | Lakeville             | Farmington              | 353                                           | 655                                                    | SCS100y24hr event from Farmington HydroCAD model |
| TribC-10     | L-340        | Tributary C2                                  | Coates                | Vermillion Twp.         | 428                                           |                                                        |                                                  |
| TribC-8      | L-346        | Tributary C2                                  | Rosemount             | Vermillion Twp.         | 289                                           |                                                        |                                                  |
| TribC-5      | L-352        | Tributary C2                                  | Vermillion Twp.       | Nininger Twp.           | 233                                           |                                                        |                                                  |
| VRTribF-14   | L-322        | Tributary F                                   | Vermillion Twp.       | Vermillion              | 153                                           |                                                        |                                                  |
| VRTribG-16   | L-320        | Tributary G                                   | Vermillion Twp.       | Vermillion              | 299                                           |                                                        |                                                  |
| VRTribH-22   | L-257        | Tributary H                                   | Empire Twp.           | Vermillion Twp.         | 191                                           |                                                        |                                                  |
| VRTribR-47   | L-1500       | Tributary R                                   | Elko                  | New Market Twp.         | 26                                            | 35                                                     | 100y24hr event Elko New Market HydroCAD          |
| VR-31        | L-179        | Vermillion River                              | Farmington            | Empire Twp.             | 2,152                                         | 4712 <sup>4</sup>                                      | Dakota County DFIRM                              |
| N-1288       | L-1473       | Vermillion River                              | New Market Twp.       | Eureka Twp              | 451                                           | 429 <sup>4</sup>                                       | Dakota County DFIRM                              |
| VR-34        | L-1413       | Vermillion River                              | Eureka Twp.           | Farmington              | 956                                           |                                                        |                                                  |

Table 5-9 Calibrated XP-SWMM Model and Previous Model Peak Flow Rates at Standard Locations

| XP-SWMM Node | XP-SWMM Link | Reach            | Upstream Municipality | Downstream Municipality | XP-SWMM 100-Year Peak Flow (cfs) <sup>1</sup> | Previously Calculated 100-Year Flow (cfs) <sup>2</sup> | Previous Model Description |
|--------------|--------------|------------------|-----------------------|-------------------------|-----------------------------------------------|--------------------------------------------------------|----------------------------|
| VR-32        | L-1317       | Vermillion River | Farmington            | Empire Twp.             | 2,199                                         |                                                        |                            |
| VR-30        | L-225        | Vermillion River | Empire Twp.           | Farmington              | 3,330                                         | 4712 <sup>4</sup>                                      | Dakota County DFIRM        |
| VR-29        | L-1302       | Vermillion River | Farmington            | Empire Twp.             | 3,378                                         | 4712 <sup>4</sup>                                      | Dakota County DFIRM        |
| VR-24        | L-581        | Vermillion River | Empire Twp.           | Vermillion Twp.         | 3,479                                         | 5834 <sup>4</sup>                                      | Dakota County DFIRM        |
| VR-17        | L-319        | Vermillion River | Vermillion Twp.       | Vermillion              | 3,916                                         |                                                        |                            |
| VR-15        | L-324        | Vermillion River | Vermillion            | Vermillion Twp.         | 3,907                                         |                                                        |                            |
| VR-8         | L-1039       | Vermillion River | Vermillion Twp.       | Marshan Twp.            | 3,691                                         |                                                        |                            |
| VR-7         | L-1034       | Vermillion River | Marshan Twp.          | Nininger Twp.           | 3,686                                         | 7823 <sup>4</sup>                                      | Dakota County DFIRM        |
| VR-6         | L-1031       | Vermillion River | Nininger Twp.         | Hastings                | 3,754                                         | 7823 <sup>4</sup>                                      | Dakota County DFIRM        |
| VR-5         | L-1029       | Vermillion River | Nininger Twp.         | Hastings                | 3,753                                         |                                                        |                            |
| VR-1         | WOMP         | Vermillion River | Hastings              | NA                      | 3,789                                         | 8424 <sup>4</sup>                                      | Dakota County DFIRM        |

<sup>1</sup> Calibrated 100-year flow rates are from the 4-day duration design event. Design events of smaller duration are nested within the 4-day distribution used to calculate 100-year flow rates.

<sup>2</sup> Peak flow rates are uncalibrated; With the exception of the Dakota County Vermillion River Mainstem flows that were based on the 1998 MWH HEC-HMS model.

<sup>3</sup> Flow rate from Hydro CAD model includes the area upstream of Ncreek-7 & Ncreek-9

<sup>4</sup> DFIRM flow rates along the mainstem of the Vermillion River were based on HEC-HMS model completed in 2002 by MWH. The HEC-HMS model was origionally based on a HEC-1 model calibrated to the discharge-frequency curve completed in 1998 by the COE

**Table 5-10 Peak Flow Rates at Standard Locations**

| XP-SWMM Node           | XP-SWMM Link | Reach                                         | Upstream Municipality | Downstream Municipality | Upstream Tributary Area (sq mi) | 100 Year Peak Flow (cfs) <sup>1</sup> | 50 Year Peak Flow (cfs) <sup>1</sup> | 10 Year Peak Flow (cfs) <sup>1</sup> | 2 Year Peak Flow (cfs) <sup>1</sup> | 1 Year Peak Flow (cfs) <sup>1</sup> |
|------------------------|--------------|-----------------------------------------------|-----------------------|-------------------------|---------------------------------|---------------------------------------|--------------------------------------|--------------------------------------|-------------------------------------|-------------------------------------|
| N-1261                 | L-1442       | County Ditch 12                               | New Market Twp.       | Eureka Twp              | 12.1                            | 315                                   | 285                                  | 226                                  | 147                                 | 111                                 |
| CD12-8                 | L-1448       | County Ditch 12                               | New Market            | New Market Twp.         | 2.4                             | 226                                   | 214                                  | 183                                  | 113                                 | 70                                  |
| ECreek-2               | L-1351       | East Branch South Creek                       | Lakeville             | Farmington              | 0.9                             | 364                                   | 318                                  | 212                                  | 106                                 | 86                                  |
| MCreek-20              | L-1595       | Middle Creek                                  | Lakeville             | Farmington              | 2.4                             | 603                                   | 459                                  | 345                                  | 180                                 | 119                                 |
| MCreek-1a              | L-201        | Middle Creek                                  | Farmington            | Empire Twp.             | 11.5                            | 862                                   | 730                                  | 459                                  | 141                                 | 104                                 |
| NBranch-2              | L-1233       | North Branch Vermillion River                 | Empire Twp.           | Vermillion Twp.         | 6.2                             | 496                                   | 391                                  | 225                                  | 89                                  | 44                                  |
| NCreek-2               | L-1580       | North Creek                                   | Farmington            | Empire Twp.             | 20.5                            | 1,381                                 | 1,147                                | 754                                  | 318                                 | 193                                 |
| NCreek-9               | L-1584       | North Creek                                   | Lakeville             | Farmington              | 16.9                            | 1,149                                 | 949                                  | 642                                  | 362                                 | 268                                 |
| SBranch-26             | L-1121       | South Branch Vermillion River                 | Eureka Twp.           | Castle Rock Twp.        | 1.9                             | 327                                   | 266                                  | 161                                  | 66                                  | 36                                  |
| SBranch-9              | L-1599       | South Branch Vermillion River                 | Castle Rock Twp.      | Empire Twp.             | 27.1                            | 699                                   | 621                                  | 397                                  | 108                                 | 36                                  |
| SBranch-8              | L-305        | South Branch Vermillion River                 | Empire Twp.           | Vermillion Twp.         | 27.5                            | 698                                   | 620                                  | 396                                  | 105                                 | 35                                  |
| SCreek-2               | L-830        | South Creek                                   | Lakeville             | Farmington              | 15.5                            | 1,144                                 | 984                                  | 694                                  | 394                                 | 312                                 |
| Trib1-20               | L-1022       | Tributary 1                                   | Hampton Twp.          | Vermillion Twp.         | 1.5                             | 386                                   | 314                                  | 196                                  | 106                                 | 75                                  |
| Trib1-13               | L-992        | Tributary 1                                   | Vermillion Twp.       | Marshan Twp.            | 8.7                             | 373                                   | 288                                  | 149                                  | 71                                  | 47                                  |
| Trib1-3                | L-979        | Tributary 1                                   | Marshan Twp.          | Hastings                | 19.2                            | 540                                   | 453                                  | 290                                  | 144                                 | 95                                  |
| MCreek-3               | L-202        | Tributary 1 to Middle Creek                   | Farmington            | Empire Twp.             | 0.8                             | 105                                   | 90                                   | 64                                   | 34                                  | 23                                  |
| NCreek-25 <sup>2</sup> | Link19       | Tributary 1 to North Creek                    | Apple Valley          | Lakeville               | 7.6                             | 80                                    | 80                                   | 77                                   | 55                                  | 45                                  |
| SBranch-5              | L-1078       | Tributary 1 to South Branch Vermillion River  | Hampton               | Hampton Twp.            | 0.5                             | 341                                   | 309                                  | 186                                  | 117                                 | 101                                 |
| SBranch-3              | L-1072       | Tributary 1 to South Branch Vermillion River  | Hampton Twp.          | Vermillion Twp.         | 2.0                             | 403                                   | 339                                  | 218                                  | 101                                 | 59                                  |
| SCreek-11              | L-131        | Tributary 1 to South Creek                    | New Market Twp.       | Eureka Twp.             | 0.6                             | 383                                   | 349                                  | 246                                  | 157                                 | 123                                 |
| SCreek-10              | L-1345       | Tributary 1 to South Creek                    | Lakeville             | Eureka Twp.             | 1.2                             | 337                                   | 290                                  | 185                                  | 99                                  | 60                                  |
| SCreek-8               | L-1344       | Tributary 1 to South Creek                    | Eureka Twp.           | Lakeville               | 2.8                             | 194                                   | 156                                  | 95                                   | 41                                  | 20                                  |
| SCreek-6               | L-1339       | Tributary 1 to South Creek                    | Lakeville             | Farmington              | 3.9                             | 447                                   | 343                                  | 210                                  | 80                                  | 52                                  |
| NCreek-24 <sup>2</sup> | L-1167       | Tributary 1A to North Creek                   | Apple Valley          | Lakeville               | 5.8                             | 27                                    | 27                                   | 27                                   | 27                                  | 27                                  |
| Trib1-12               | L-392        | Tributary 1C                                  | Vermillion Twp.       | Marshan Twp.            | 0.5                             | 60                                    | 49                                   | 28                                   | 12                                  | 6                                   |
| Trib1-2                | L-1220       | Tributary 1D                                  | Marshan Twp.          | Hastings                | 4.7                             | 187                                   | 150                                  | 86                                   | 34                                  | 17                                  |
| Trib1-18               | L-378        | Tributary 1E                                  | Hampton Twp.          | Vermillion Twp.         | 0.8                             | 210                                   | 172                                  | 96                                   | 43                                  | 21                                  |
| CD12-12                | L-1623       | Tributary 2 to County Ditch 12                | New Market            | New Market Twp.         | 1.6                             | 231                                   | 202                                  | 139                                  | 89                                  | 70                                  |
| SBranch-10             | L-301        | Tributary 2 to South Branch Vermillion River  | Empire Twp.           | Castle Rock Twp.        | 2.0                             | 253                                   | 238                                  | 178                                  | 124                                 | 102                                 |
| N-990                  | L-1104       | Tributary 3 to South Branch Vermillion River  | Hampton Twp.          | Hampton                 | 0.3                             | 133                                   | 108                                  | 65                                   | 31                                  | 19                                  |
| SBranch-14             | L-294        | Tributary 3 to South Branch Vermillion River  | Hampton               | Hampton Twp.            | 2.6                             | 541                                   | 443                                  | 268                                  | 135                                 | 95                                  |
| SBranch-13             | L-1532       | Tributary 3 to South Branch Vermillion River  | Hampton Twp.          | Castle Rock Twp.        | 4.7                             | 614                                   | 512                                  | 320                                  | 134                                 | 83                                  |
| SBranch-6              | L-295        | Tributary 3C to South Branch Vermillion River | Hampton               | Hampton Twp.            | 0.5                             | 234                                   | 213                                  | 143                                  | 87                                  | 64                                  |
| NCreek-7               | L-215        | Tributary 4 to North Creek                    | Empire Twp.           | Farmington              | 0.8                             | 281                                   | 213                                  | 130                                  | 52                                  | 28                                  |
| Trib6-6                | L-1547       | Tributary 6                                   | Castle Rock Twp.      | Empire Twp.             | 0.4                             | 40                                    | 30                                   | 25                                   | 19                                  | 15                                  |
| MCreek-18              | L-1200       | Tributary 6 to Middle Creek                   | Lakeville             | Farmington              | 1.2                             | 436                                   | 371                                  | 242                                  | 110                                 | 66                                  |
| SBranch-4              | L-310        | Tributary 6 to South Branch Vermillion River  | Hampton Twp.          | Vermillion Twp.         | 0.3                             | 90                                    | 74                                   | 44                                   | 19                                  | 11                                  |
| Trib6-3                | L-1675       | Tributary 6A                                  | Farmington            | Empire Twp.             | 0.2                             | 81                                    | 66                                   | 39                                   | 19                                  | 11                                  |
| MCreek-15              | L-1589       | Tributary 6A to Middle Creek                  | Lakeville             | Farmington              | 0.8                             | 353                                   | 284                                  | 178                                  | 77                                  | 44                                  |
| TribC-10               | L-340        | Tributary C2                                  | Coates                | Vermillion Twp.         | 2.5                             | 428                                   | 365                                  | 243                                  | 137                                 | 97                                  |
| TribC-8                | L-346        | Tributary C2                                  | Rosemount             | Vermillion Twp.         | 4.6                             | 289                                   | 221                                  | 137                                  | 62                                  | 36                                  |
| TribC-5                | L-352        | Tributary C2                                  | Vermillion Twp.       | Nininger Twp.           | 6.3                             | 233                                   | 195                                  | 128                                  | 62                                  | 39                                  |

**Table 5-10 Peak Flow Rates at Standard Locations**

| XP-SWMM Node                                                                                                                                                                               | XP-SWMM Link | Reach            | Upstream Municipality | Downstream Municipality | Upstream Tributary Area (sq mi) | 100 Year Peak Flow (cfs) <sup>1</sup> | 50 Year Peak Flow (cfs) <sup>1</sup> | 10 Year Peak Flow (cfs) <sup>1</sup> | 2 Year Peak Flow (cfs) <sup>1</sup> | 1 Year Peak Flow (cfs) <sup>1</sup> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|------------------|-----------------------|-------------------------|---------------------------------|---------------------------------------|--------------------------------------|--------------------------------------|-------------------------------------|-------------------------------------|
| VRTribF-14                                                                                                                                                                                 | L-322        | Tributary F      | Vermillion Twp.       | Vermillion              | 1.0                             | 153                                   | 126                                  | 72                                   | 29                                  | 15                                  |
| VRTribG-16                                                                                                                                                                                 | L-320        | Tributary G      | Vermillion Twp.       | Vermillion              | 1.9                             | 299                                   | 270                                  | 190                                  | 116                                 | 85                                  |
| VRTribH-22                                                                                                                                                                                 | L-257        | Tributary H      | Empire Twp.           | Vermillion Twp.         | 2.5                             | 191                                   | 147                                  | 94                                   | 56                                  | 34                                  |
| VRTribR-47                                                                                                                                                                                 | L-1500       | Tributary R      | Elko                  | New Market Twp.         | 0.5                             | 26                                    | 16                                   | 14                                   | 12                                  | 11                                  |
| VR-45                                                                                                                                                                                      | L-1495       | Vermillion River | Elko                  | New Market Twp.         | 3.0                             | 336                                   | 309                                  | 234                                  | 116                                 | 76                                  |
| VR-31                                                                                                                                                                                      | L-179        | Vermillion River | Farmington            | Empire Twp.             | 62.0                            | 2,152                                 | 1,802                                | 1,153                                | 546                                 | 343                                 |
| N-1288                                                                                                                                                                                     | L-1473       | Vermillion River | New Market Twp.       | Eureka Twp              | 4.6                             | 451                                   | 395                                  | 238                                  | 97                                  | 59                                  |
| VR-34                                                                                                                                                                                      | L-1413       | Vermillion River | Eureka Twp.           | Farmington              | 37.9                            | 956                                   | 677                                  | 314                                  | 129                                 | 81                                  |
| VR-32                                                                                                                                                                                      | L-1317       | Vermillion River | Farmington            | Empire Twp.             | 61.7                            | 2,199                                 | 1,841                                | 1,180                                | 560                                 | 349                                 |
| VR-30                                                                                                                                                                                      | L-225        | Vermillion River | Empire Twp.           | Farmington              | 95.7                            | 3,330                                 | 2,713                                | 1,662                                | 713                                 | 458                                 |
| VR-29                                                                                                                                                                                      | L-1302       | Vermillion River | Farmington            | Empire Twp.             | 97.9                            | 3,378                                 | 2,746                                | 1,683                                | 726                                 | 468                                 |
| VR-24                                                                                                                                                                                      | L-581        | Vermillion River | Empire Twp.           | Vermillion Twp.         | 116.4                           | 3,479                                 | 2,816                                | 1,709                                | 634                                 | 416                                 |
| VR-17                                                                                                                                                                                      | L-319        | Vermillion River | Vermillion Twp.       | Vermillion              | 163.9                           | 3,916                                 | 3,149                                | 1,770                                | 661                                 | 434                                 |
| VR-15                                                                                                                                                                                      | L-324        | Vermillion River | Vermillion            | Vermillion Twp.         | 166.5                           | 3,907                                 | 3,137                                | 1,752                                | 655                                 | 432                                 |
| VR-8                                                                                                                                                                                       | L-1039       | Vermillion River | Vermillion Twp.       | Marshan Twp.            | 178.3                           | 3,691                                 | 2,975                                | 1,578                                | 614                                 | 408                                 |
| VR-7                                                                                                                                                                                       | L-1034       | Vermillion River | Marshan Twp.          | Nininger Twp.           | 179.6                           | 3,686                                 | 2,966                                | 1,549                                | 614                                 | 408                                 |
| VR-6                                                                                                                                                                                       | L-1031       | Vermillion River | Nininger Twp.         | Hastings                | 197.5                           | 3,754                                 | 3,023                                | 1,565                                | 617                                 | 410                                 |
| VR-5                                                                                                                                                                                       | L-1029       | Vermillion River | Nininger Twp.         | Hastings                | 197.9                           | 3,753                                 | 3,020                                | 1,563                                | 617                                 | 410                                 |
| VR-1                                                                                                                                                                                       | WOMP         | Vermillion River | Hastings              | NA                      | 225.3                           | 3,789                                 | 3,101                                | 1,575                                | 613                                 | 439                                 |
| <sup>1</sup> Calibrated flow rates are from the 4-day duration design event. Design events of smaller duration are nested within the 4-day distribution used to calculate peak flow rates. |              |                  |                       |                         |                                 |                                       |                                      |                                      |                                     |                                     |
| <sup>2</sup> Apple Valley flow rates are agreed on by Apple Valley, Lakeville, and the VRWJPO. Inflows were not adjusted as part of the calibration process.                               |              |                  |                       |                         |                                 |                                       |                                      |                                      |                                     |                                     |

**Table 5-11 Total Runoff Volume at Standard Locations**

| XP-SWMM Node           | XP-SWMM Link | Reach                                         | Upstream Municipality | Downstream Municipality | Upstream Tributary Area (sq mi) | Baseflow (cfs) | 100 Year Volume (ac-ft) <sup>1</sup> | 50 Year Volume (ac-ft) <sup>1</sup> | 10 Year Volume (ac-ft) <sup>1</sup> | 2 Year Volume (ac-ft) <sup>1</sup> | 1 Year Volume (ac-ft) <sup>1</sup> |
|------------------------|--------------|-----------------------------------------------|-----------------------|-------------------------|---------------------------------|----------------|--------------------------------------|-------------------------------------|-------------------------------------|------------------------------------|------------------------------------|
| N-1261                 | L-1442       | County Ditch 12                               | New Market Twp.       | Eureka Twp              | 12.1                            | 0              | 1,292                                | 1,049                               | 640                                 | 286                                | 174                                |
| CD12-8                 | L-1448       | County Ditch 12                               | New Market            | New Market Twp.         | 2.4                             | 0              | 401                                  | 335                                 | 216                                 | 105                                | 65                                 |
| ECreek-2               | L-1351       | East Branch South Creek                       | Lakeville             | Farmington              | 0.9                             | 0              | 144                                  | 121                                 | 78                                  | 38                                 | 24                                 |
| MCreek-20              | L-1595       | Middle Creek                                  | Lakeville             | Farmington              | 2.4                             | 0              | 452                                  | 375                                 | 246                                 | 116                                | 74                                 |
| MCreek-1a              | L-201        | Middle Creek                                  | Farmington            | Empire Twp.             | 11.5                            | 0              | 2,110                                | 1,758                               | 1,141                               | 528                                | 331                                |
| NBranch-2              | L-1233       | North Branch Vermillion River                 | Empire Twp.           | Vermillion Twp.         | 6.2                             | 0              | 480                                  | 369                                 | 195                                 | 58                                 | 26                                 |
| NCreek-2               | L-1580       | North Creek                                   | Farmington            | Empire Twp.             | 20.5                            | 0              | 9,819                                | 9,411                               | 8,663                               | 6,494                              | 5,573                              |
| NCreek-9               | L-1584       | North Creek                                   | Lakeville             | Farmington              | 16.9                            | 0              | 9,114                                | 8,825                               | 8,291                               | 6,346                              | 5,483                              |
| SBranch-26             | L-1121       | South Branch Vermillion River                 | Eureka Twp.           | Castle Rock Twp.        | 1.9                             | 0              | 181                                  | 140                                 | 76                                  | 24                                 | 10                                 |
| SBranch-9              | L-1599       | South Branch Vermillion River                 | Castle Rock Twp.      | Empire Twp.             | 27.1                            | 0              | 2,320                                | 1,796                               | 939                                 | 275                                | 115                                |
| SBranch-8              | L-305        | South Branch Vermillion River                 | Empire Twp.           | Vermillion Twp.         | 27.5                            | 0              | 2,367                                | 1,833                               | 960                                 | 282                                | 118                                |
| SCreek-2               | L-830        | South Creek                                   | Lakeville             | Farmington              | 15.5                            | 0              | 1,915                                | 1,611                               | 1,029                               | 545                                | 372                                |
| Trib1-20               | L-1022       | Tributary 1                                   | Hampton Twp.          | Vermillion Twp.         | 1.5                             | 0              | 150                                  | 119                                 | 67                                  | 24                                 | 12                                 |
| Trib1-13               | L-992        | Tributary 1                                   | Vermillion Twp.       | Marshan Twp.            | 8.7                             | 0              | 811                                  | 638                                 | 354                                 | 124                                | 61                                 |
| Trib1-3                | L-979        | Tributary 1                                   | Marshan Twp.          | Hastings                | 19.2                            | 0              | 1,219                                | 935                                 | 499                                 | 170                                | 88                                 |
| MCreek-3               | L-202        | Tributary 1 to Middle Creek                   | Farmington            | Empire Twp.             | 0.8                             | 0              | 184                                  | 157                                 | 105                                 | 54                                 | 35                                 |
| NCreek-25 <sup>2</sup> | Link19       | Tributary 1 to North Creek                    | Apple Valley          | Empire Twp.             | 7.6                             | 0              | NA                                   | NA                                  | NA                                  | NA                                 | NA                                 |
| SBranch-5              | L-1078       | Tributary 1 to South Branch Vermillion River  | Hampton               | Hampton Twp.            | 0.5                             | 0              | 71                                   | 58                                  | 36                                  | 17                                 | 11                                 |
| SBranch-3              | L-1072       | Tributary 1 to South Branch Vermillion River  | Hampton Twp.          | Vermillion Twp.         | 2.0                             | 0              | 204                                  | 162                                 | 94                                  | 36                                 | 20                                 |
| SCreek-11              | L-131        | Tributary 1 to South Creek                    | New Market Twp.       | Eureka Twp.             | 0.6                             | 0              | 92                                   | 76                                  | 49                                  | 24                                 | 15                                 |
| SCreek-10              | L-1345       | Tributary 1 to South Creek                    | Lakeville             | Eureka Twp.             | 1.2                             | 0              | 157                                  | 129                                 | 79                                  | 34                                 | 20                                 |
| SCreek-8               | L-1344       | Tributary 1 to South Creek                    | Eureka Twp.           | Lakeville               | 2.8                             | 0              | 381                                  | 308                                 | 183                                 | 74                                 | 39                                 |
| SCreek-6               | L-1339       | Tributary 1 to South Creek                    | Lakeville             | Farmington              | 3.9                             | 0              | 577                                  | 477                                 | 301                                 | 144                                | 91                                 |
| NCreek-24 <sup>2</sup> | L-1167       | Tributary 1A to North Creek                   | Apple Valley          | Lakeville               | 5.8                             | 0              | NA                                   | NA                                  | NA                                  | NA                                 | NA                                 |
| Trib1-12               | L-392        | Tributary 1C                                  | Vermillion Twp.       | Marshan Twp.            | 0.5                             | 0              | 31                                   | 23                                  | 12                                  | 3                                  | 1                                  |
| Trib1-2                | L-1220       | Tributary 1D                                  | Marshan Twp.          | Hastings                | 4.7                             | 0              | 233                                  | 171                                 | 82                                  | 21                                 | 9                                  |
| Trib1-18               | L-378        | Tributary 1E                                  | Hampton Twp.          | Vermillion Twp.         | 0.8                             | 0              | 83                                   | 65                                  | 35                                  | 11                                 | 5                                  |
| CD12-12                | L-1623       | Tributary 2 to County Ditch 12                | New Market            | New Market Twp.         | 1.6                             | 0              | 279                                  | 234                                 | 153                                 | 79                                 | 51                                 |
| SBranch-10             | L-301        | Tributary 2 to South Branch Vermillion River  | Empire Twp.           | Castle Rock Twp.        | 2.0                             | 0              | 142                                  | 110                                 | 60                                  | 24                                 | 14                                 |
| N-990                  | L-1104       | Tributary 3 to South Branch Vermillion River  | Hampton Twp.          | Hampton                 | 0.3                             | 0              | 38                                   | 31                                  | 18                                  | 7                                  | 3                                  |
| SBranch-14             | L-294        | Tributary 3 to South Branch Vermillion River  | Hampton               | Hampton Twp.            | 2.6                             | 0              | 239                                  | 188                                 | 105                                 | 38                                 | 20                                 |
| SBranch-13             | L-1532       | Tributary 3 to South Branch Vermillion River  | Hampton Twp.          | Castle Rock Twp.        | 4.7                             | 0              | 449                                  | 353                                 | 198                                 | 71                                 | 37                                 |
| SBranch-6              | L-295        | Tributary 3C to South Branch Vermillion River | Hampton               | Hampton Twp.            | 0.5                             | 0              | 64                                   | 52                                  | 32                                  | 14                                 | 8                                  |
| NCreek-7               | L-215        | Tributary 4 to North Creek                    | Empire Twp.           | Farmington              | 0.8                             | 0              | 125                                  | 102                                 | 64                                  | 26                                 | 13                                 |
| Trib6-6                | L-1547       | Tributary 6                                   | Castle Rock Twp.      | Empire Twp.             | 0.4                             | 0              | 58                                   | 47                                  | 30                                  | 12                                 | 7                                  |
| MCreek-18              | L-1200       | Tributary 6 to Middle Creek                   | Lakeville             | Farmington              | 1.2                             | 0              | 212                                  | 174                                 | 112                                 | 47                                 | 27                                 |
| SBranch-4              | L-310        | Tributary 6 to South Branch Vermillion River  | Hampton Twp.          | Vermillion Twp.         | 0.3                             | 0              | 31                                   | 24                                  | 14                                  | 5                                  | 2                                  |
| Trib6-3                | L-1675       | Tributary 6A                                  | Farmington            | Empire Twp.             | 0.2                             | 0              | 65                                   | 54                                  | 29                                  | 10                                 | 6                                  |
| MCreek-15              | L-1589       | Tributary 6A to Middle Creek                  | Lakeville             | Farmington              | 0.8                             | 0              | 129                                  | 106                                 | 68                                  | 28                                 | 16                                 |
| TribC-10               | L-340        | Tributary C2                                  | Coates                | Vermillion Twp.         | 2.5                             | 0              | 219                                  | 176                                 | 104                                 | 49                                 | 33                                 |
| TribC-8                | L-346        | Tributary C2                                  | Rosemount             | Vermillion Twp.         | 4.6                             | 0              | 360                                  | 282                                 | 159                                 | 65                                 | 40                                 |
| TribC-5                | L-352        | Tributary C2                                  | Vermillion Twp.       | Nininger Twp.           | 6.3                             | 0              | 479                                  | 375                                 | 209                                 | 84                                 | 52                                 |
| VRTribF-14             | L-322        | Tributary F                                   | Vermillion Twp.       | Vermillion              | 1.0                             | 0              | 72                                   | 55                                  | 28                                  | 8                                  | 4                                  |
| VRTribG-16             | L-320        | Tributary G                                   | Vermillion Twp.       | Vermillion              | 1.9                             | 0              | 133                                  | 103                                 | 57                                  | 22                                 | 13                                 |
| VRTribH-22             | L-257        | Tributary H                                   | Empire Twp.           | Vermillion Twp.         | 2.5                             | 0              | 224                                  | 173                                 | 93                                  | 30                                 | 13                                 |



**Table 5-11 Total Runoff Volume at Standard Locations**

| XP-SWMM Node | XP-SWMM Link | Reach            | Upstream Municipality | Downstream Municipality | Upstream Tributary Area (sq mi) | Baseflow (cfs) | 100 Year Volume (ac-ft) <sup>1</sup> | 50 Year Volume (ac-ft) <sup>1</sup> | 10 Year Volume (ac-ft) <sup>1</sup> | 2 Year Volume (ac-ft) <sup>1</sup> | 1 Year Volume (ac-ft) <sup>1</sup> |
|--------------|--------------|------------------|-----------------------|-------------------------|---------------------------------|----------------|--------------------------------------|-------------------------------------|-------------------------------------|------------------------------------|------------------------------------|
| VRTribR-47   | L-1500       | Tributary R      | Elko                  | New Market Twp.         | 0.5                             | 0              | 69                                   | 57                                  | 36                                  | 17                                 | 11                                 |
| VR-45        | L-1495       | Vermillion River | Elko                  | New Market Twp.         | 3.0                             | 0              | 423                                  | 348                                 | 218                                 | 102                                | 63                                 |
| VR-31        | L-179        | Vermillion River | Farmington            | Empire Twp.             | 62.0                            | 10             | 7,051                                | 5,749                               | 3,515                               | 1,630                              | 1,032                              |
| N-1288       | L-1473       | Vermillion River | New Market Twp.       | Eureka Twp              | 4.6                             | 0              | 635                                  | 521                                 | 324                                 | 147                                | 89                                 |
| VR-34        | L-1413       | Vermillion River | Eureka Twp.           | Farmington              | 37.9                            | 1              | 3,876                                | 3,095                               | 1,819                               | 764                                | 455                                |
| VR-32        | L-1317       | Vermillion River | Farmington            | Empire Twp.             | 61.7                            | 10             | 6,984                                | 5,691                               | 3,475                               | 1,610                              | 1,018                              |
| VR-30        | L-225        | Vermillion River | Empire Twp.           | Farmington              | 95.7                            | 16             | 17,782                               | 15,854                              | 12,532                              | 8,236                              | 6,687                              |
| VR-29        | L-1302       | Vermillion River | Farmington            | Empire Twp.             | 97.9                            | 16             | 18,316                               | 16,312                              | 12,818                              | 8,382                              | 6,793                              |
| VR-24        | L-581        | Vermillion River | Empire Twp.           | Vermillion Twp.         | 116.4                           | 30             | 20,785                               | 18,281                              | 13,924                              | 8,876                              | 6,909                              |
| VR-17        | L-319        | Vermillion River | Vermillion Twp.       | Vermillion              | 163.9                           | 39             | 23,962                               | 20,664                              | 15,093                              | 9,187                              | 7,044                              |
| VR-15        | L-324        | Vermillion River | Vermillion            | Vermillion Twp.         | 166.5                           | 39             | 24,126                               | 20,790                              | 15,159                              | 9,210                              | 7,058                              |
| VR-8         | L-1039       | Vermillion River | Vermillion Twp.       | Marshan Twp.            | 178.3                           | 58             | 23,987                               | 20,585                              | 14,928                              | 9,078                              | 6,991                              |
| VR-7         | L-1034       | Vermillion River | Marshan Twp.          | Nininger Twp.           | 179.6                           | 58             | 24,044                               | 20,626                              | 14,945                              | 9,082                              | 6,993                              |
| VR-6         | L-1031       | Vermillion River | Nininger Twp.         | Hastings                | 197.5                           | 58             | 24,897                               | 21,263                              | 15,267                              | 9,204                              | 7,070                              |
| VR-5         | L-1029       | Vermillion River | Nininger Twp.         | Hastings                | 197.9                           | 58             | 24,937                               | 21,294                              | 15,285                              | 9,212                              | 7,075                              |
| VR-1         | WOMP         | Vermillion River | Hastings              | NA                      | 225.3                           | 50             | 26,508                               | 22,509                              | 15,950                              | 9,492                              | 7,258                              |

<sup>1</sup> Total volume is the runoff volume generated by the design event only; base flow is not included in the total volume calculation. See Appendix G for further discussion of volume calculations.

<sup>2</sup> Apple Valley flows were not adjusted as part of the calibration process and entered as constant inflows, not as a runoff hydrograph.

**Figure 5-1. Event D Calibration Results (SC-804)**

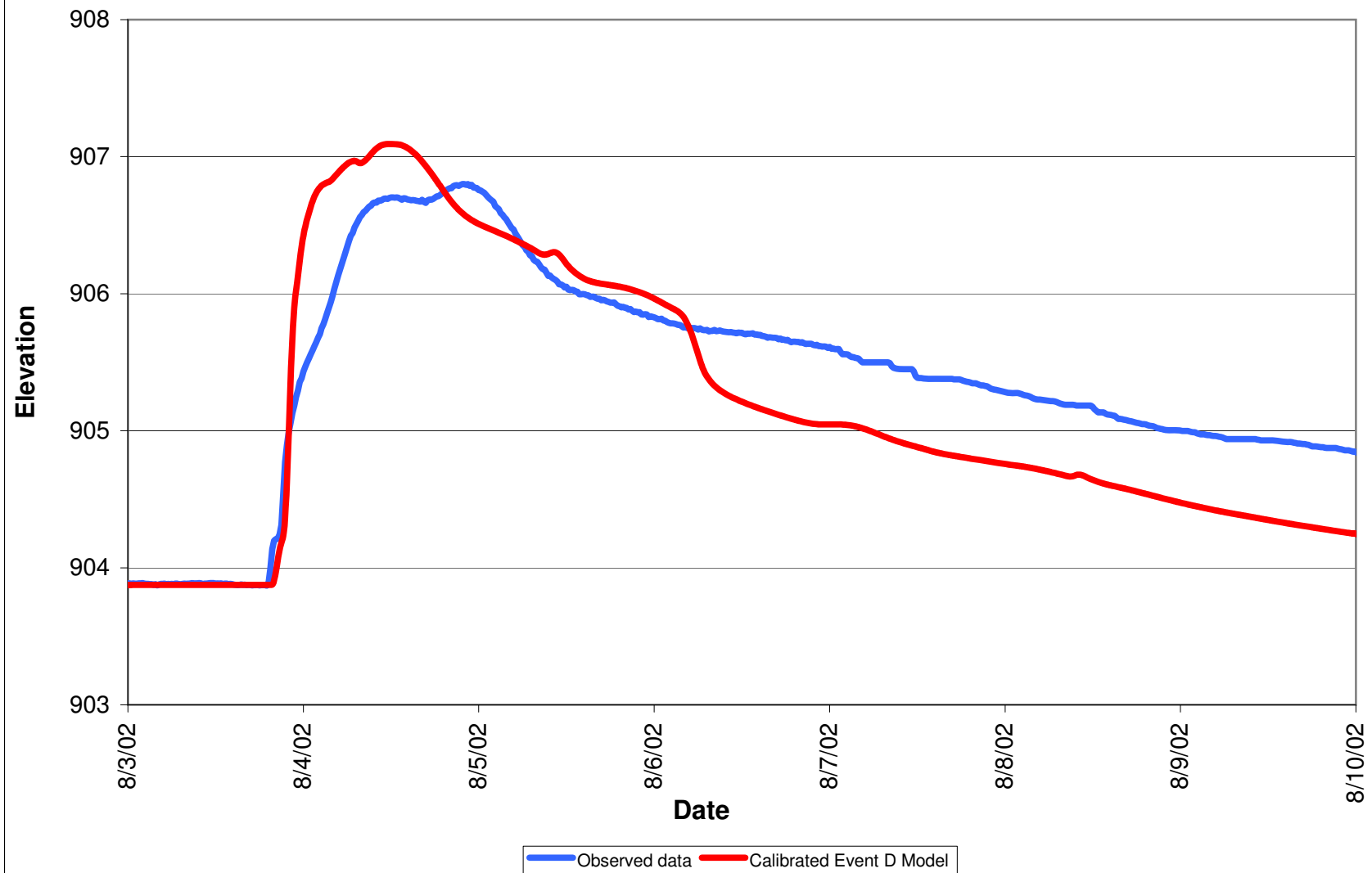
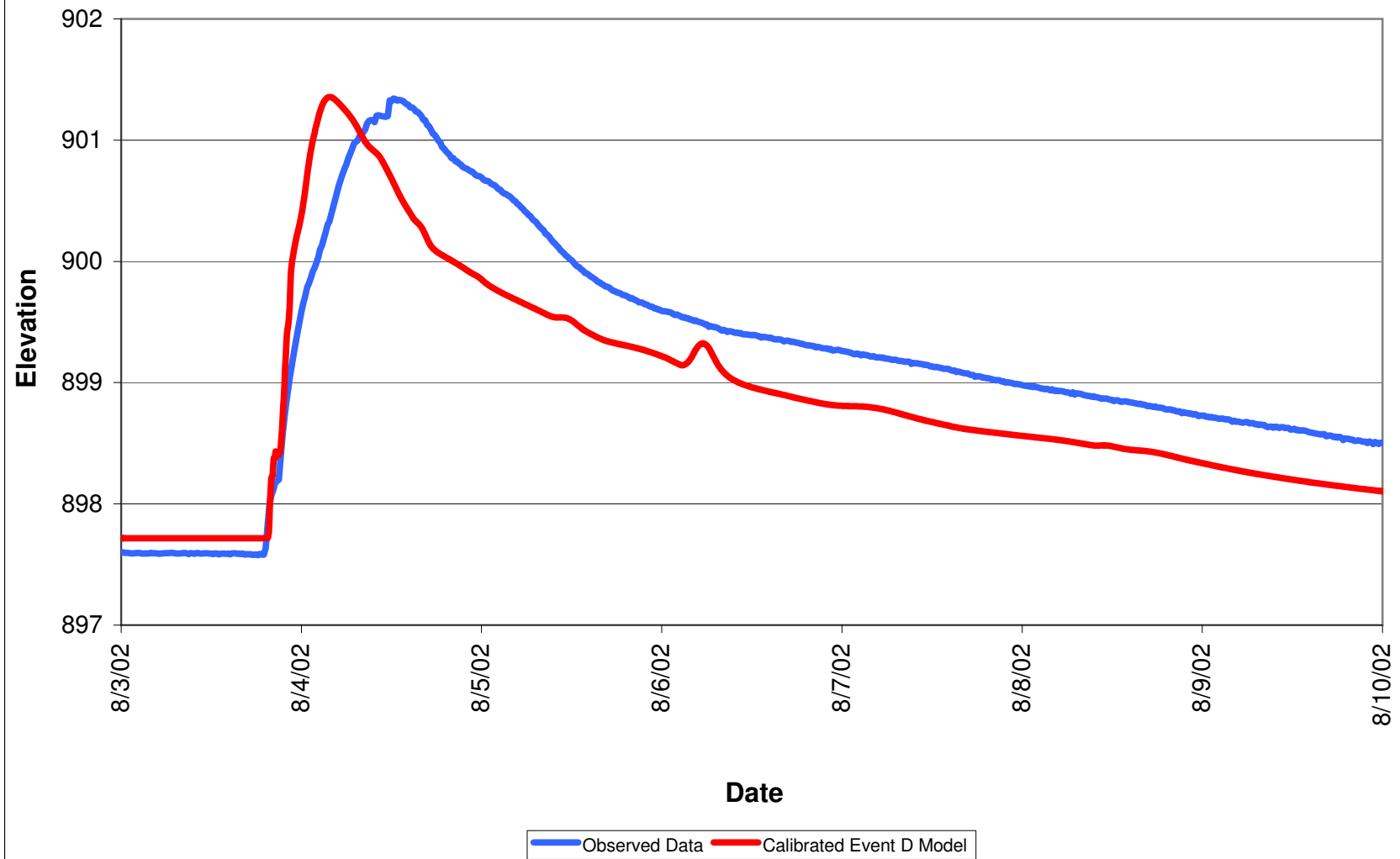
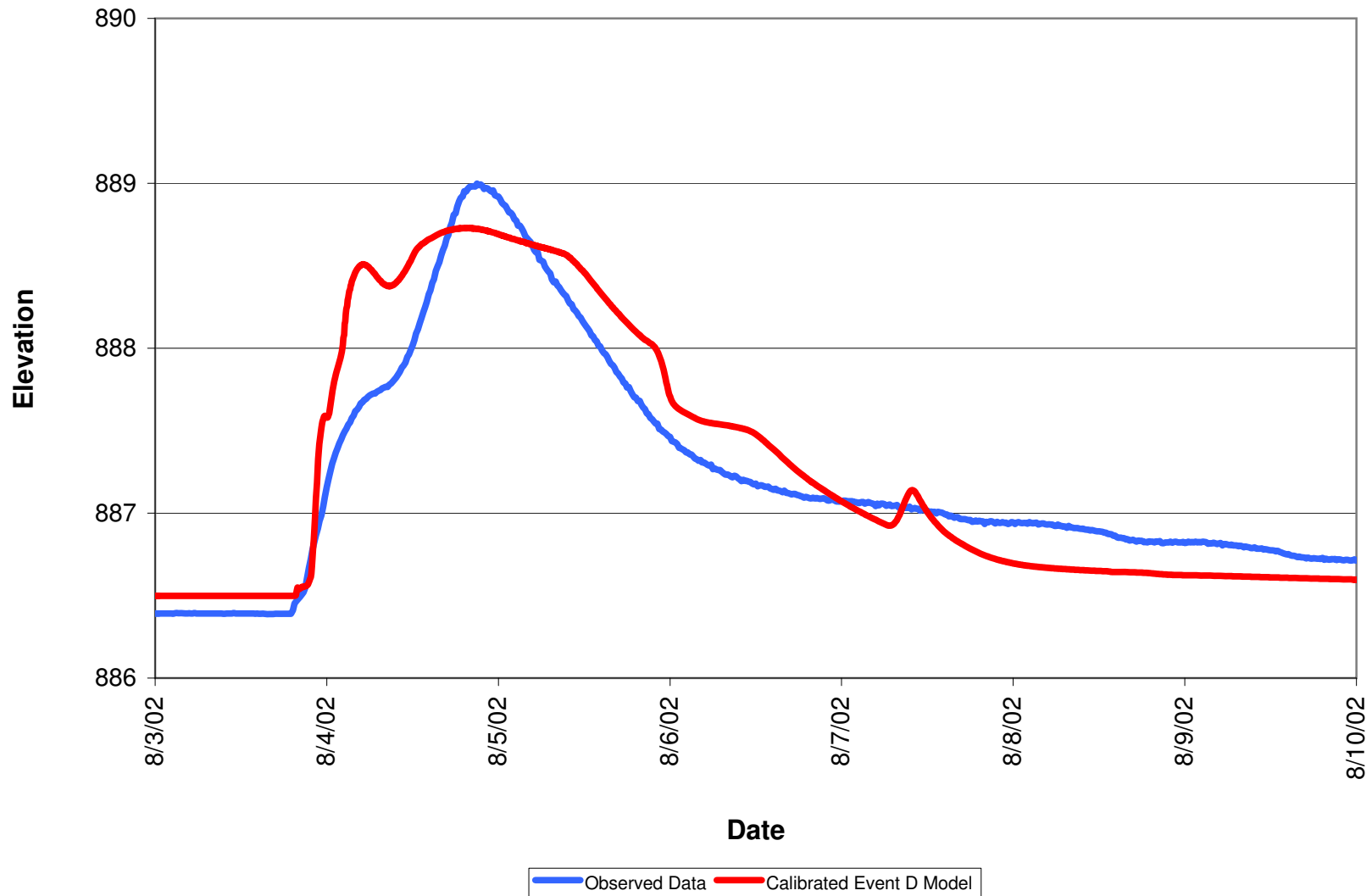


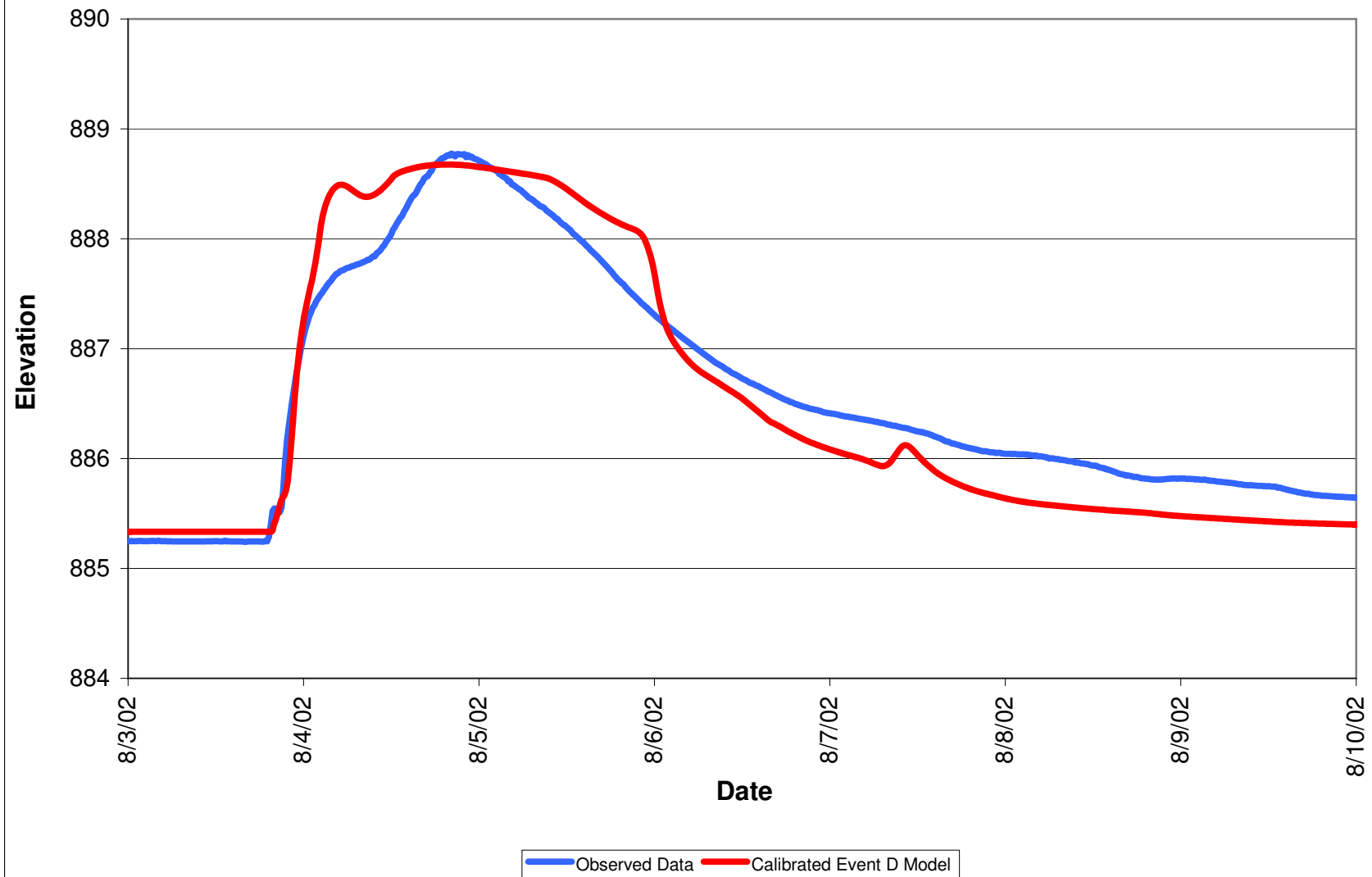
Figure 5-2. Event D Calibration Results (VR-807)



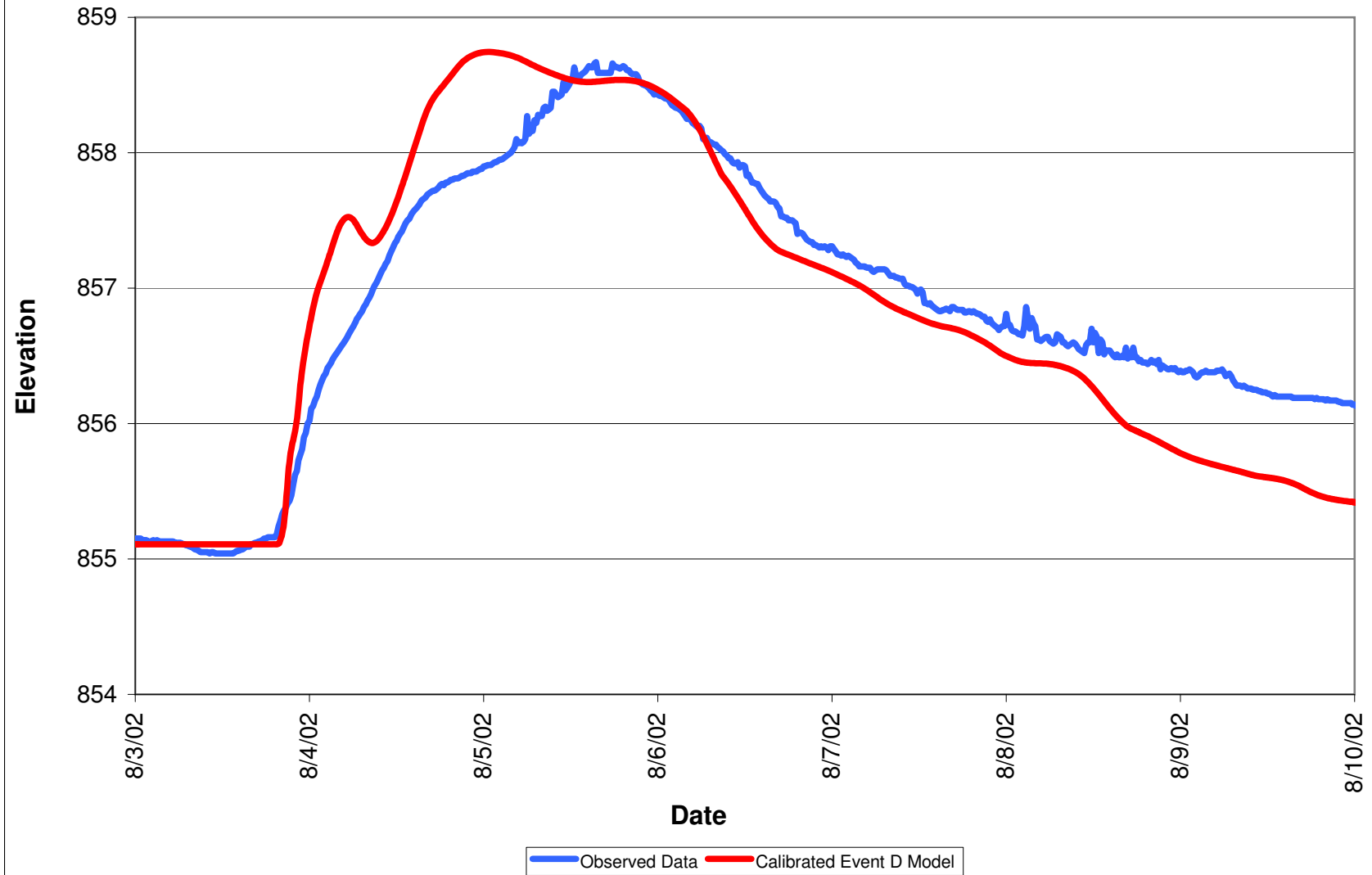
**Figure 5-3. Event D Calibration Results (NC-808)**



**Figure 5-4. Event D Calibration Results (MC-801)**



**Figure 5-5. Event D Calibration Results (USGS)**





**Figure 5-6. Event D Calibration Results (SB-802)**

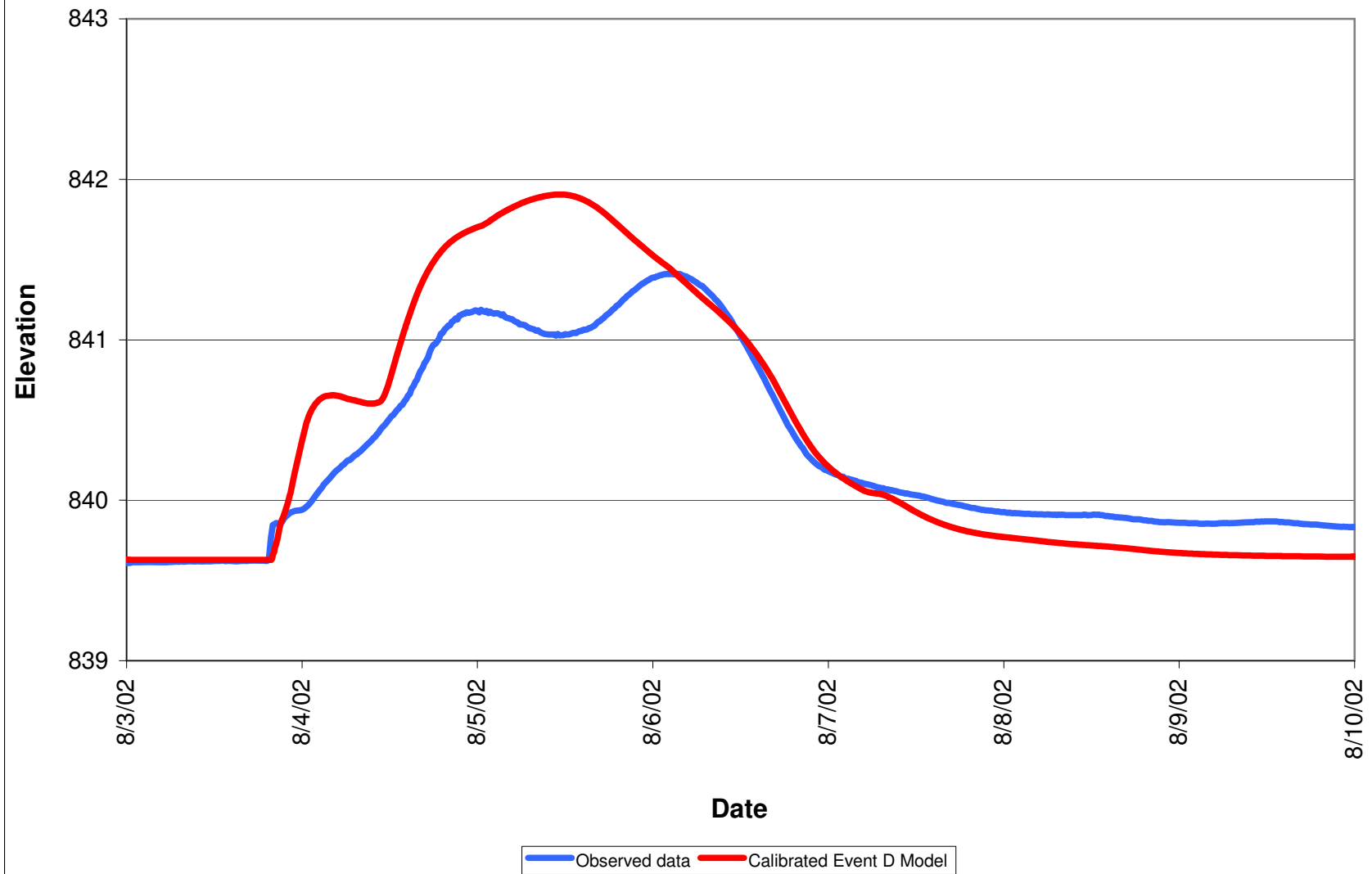


Figure 5-7. Event D Calibration Results (WOMP)

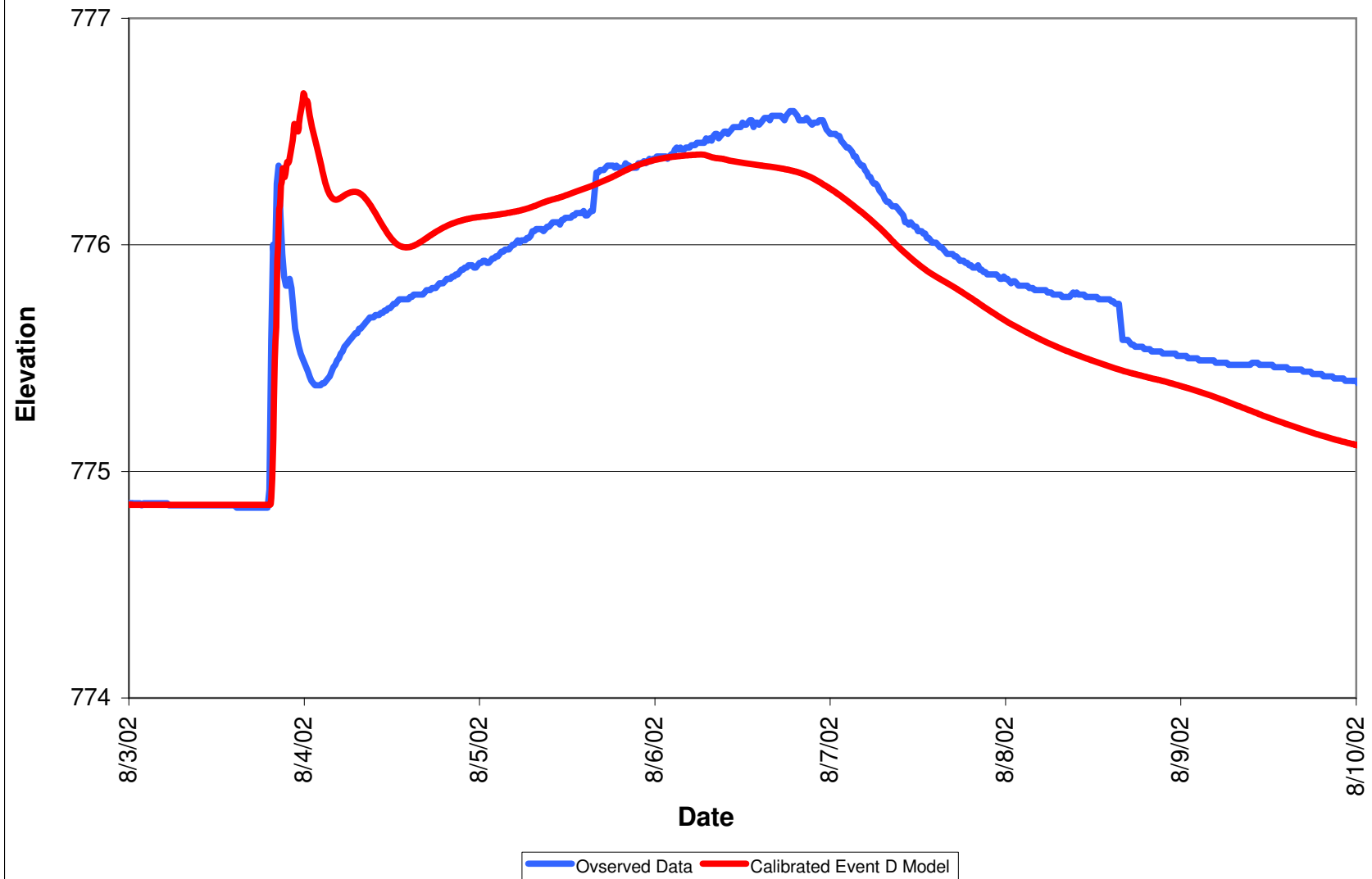
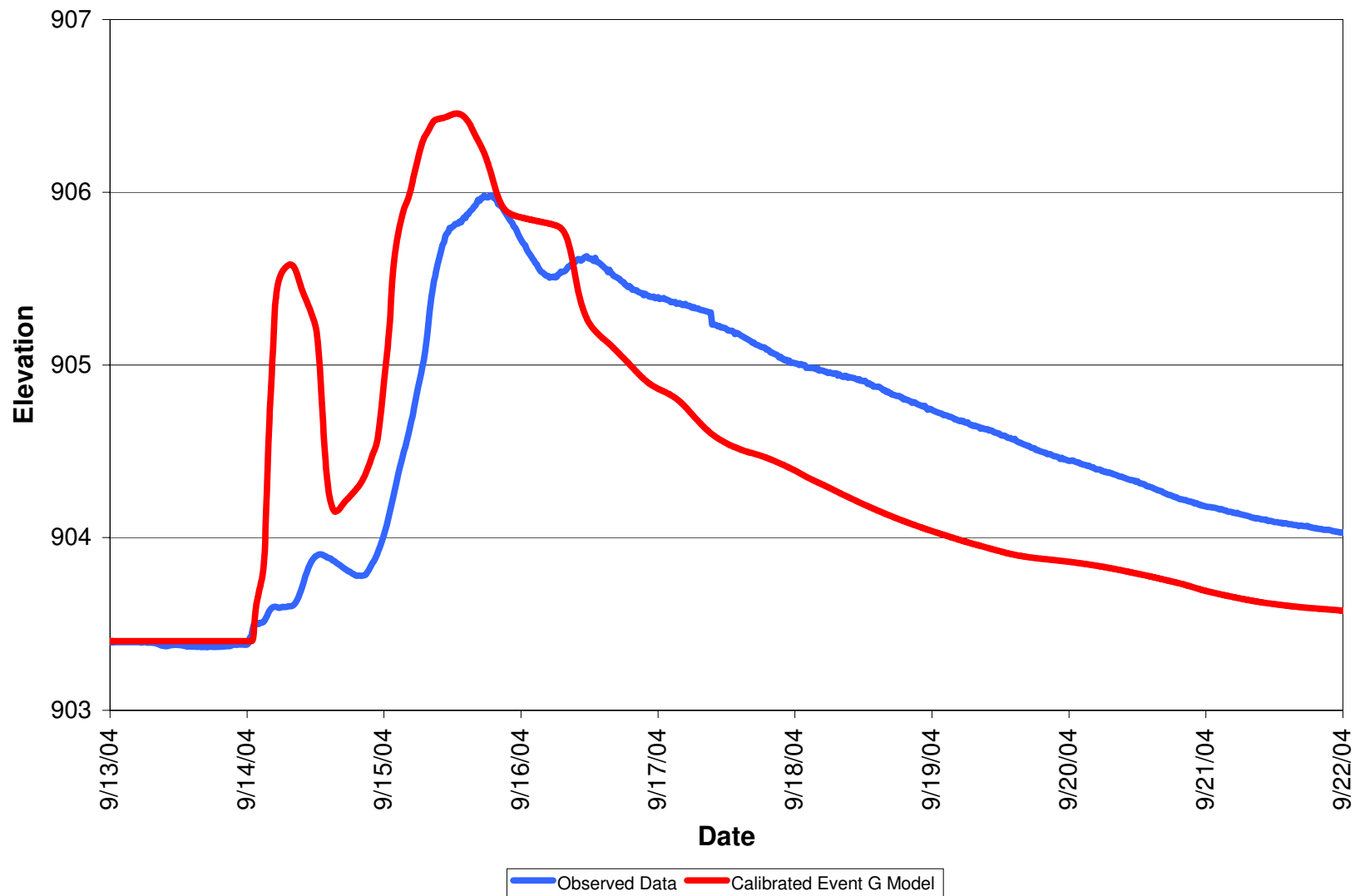


Figure 5-8. Event G Calibration Results (SC-804)



**Figure 5-9. Event G Calibration Results (VR-807)**

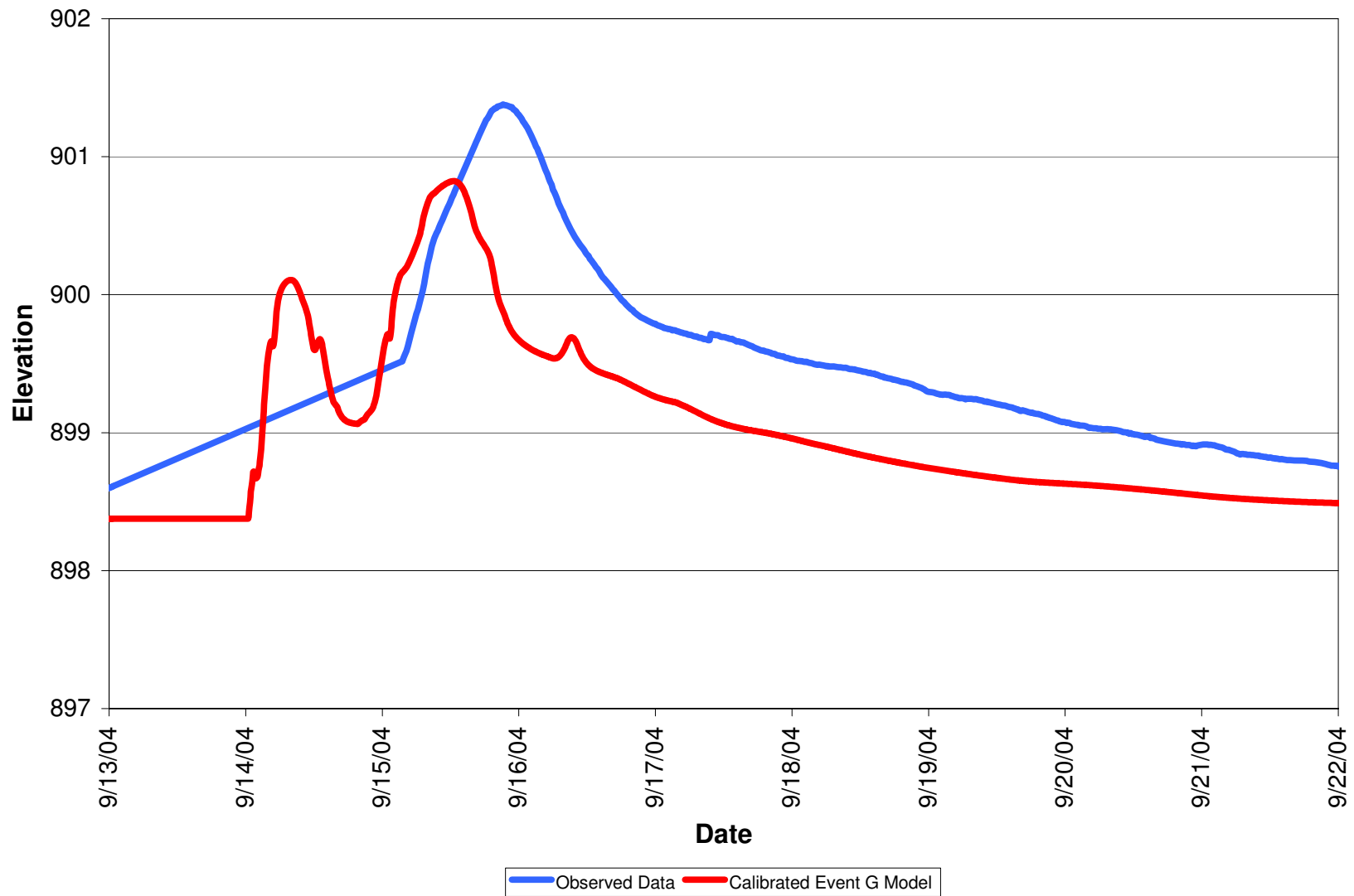


Figure 5-10. Event G Calibration Results (NC-808)

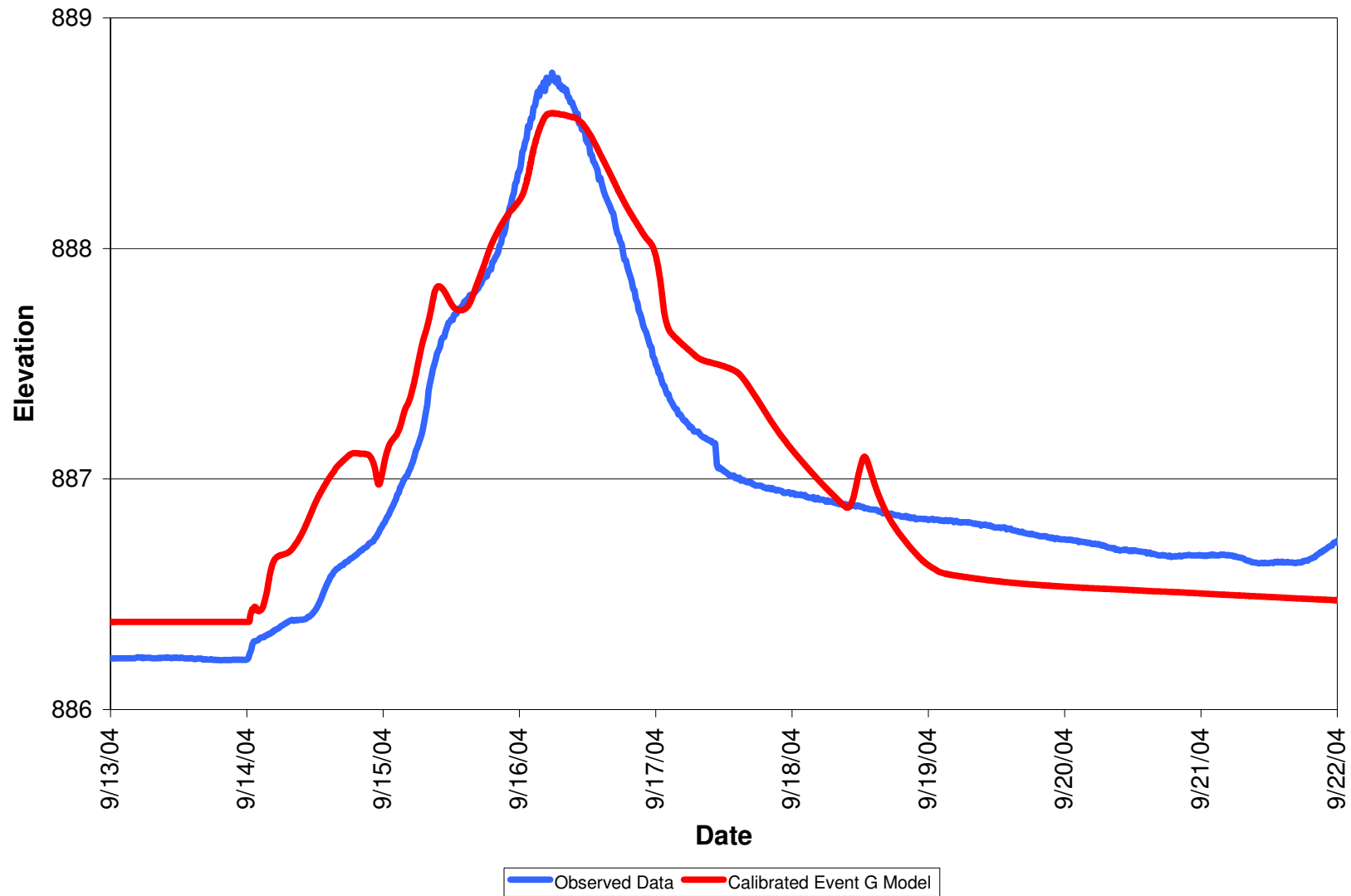
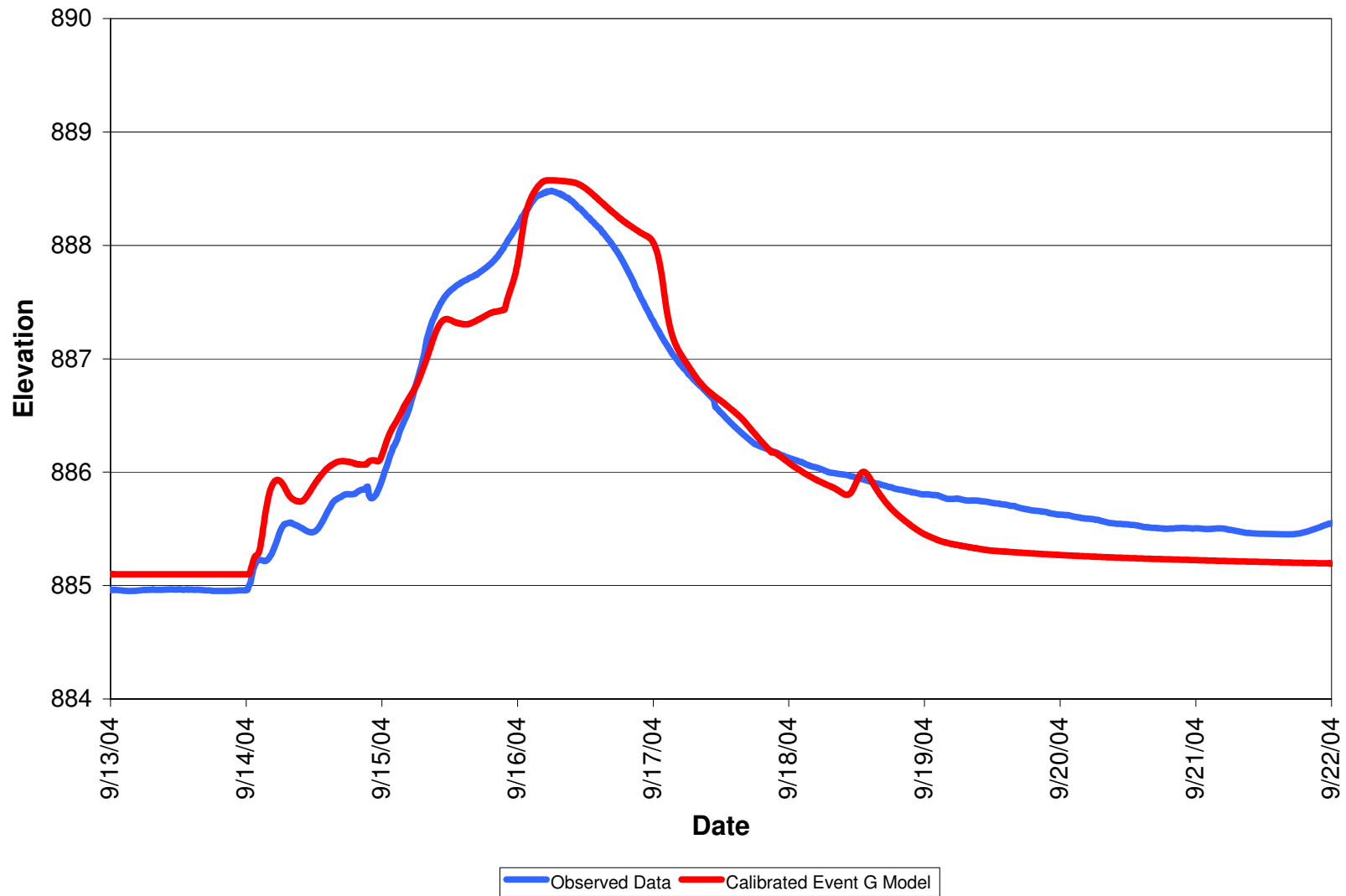
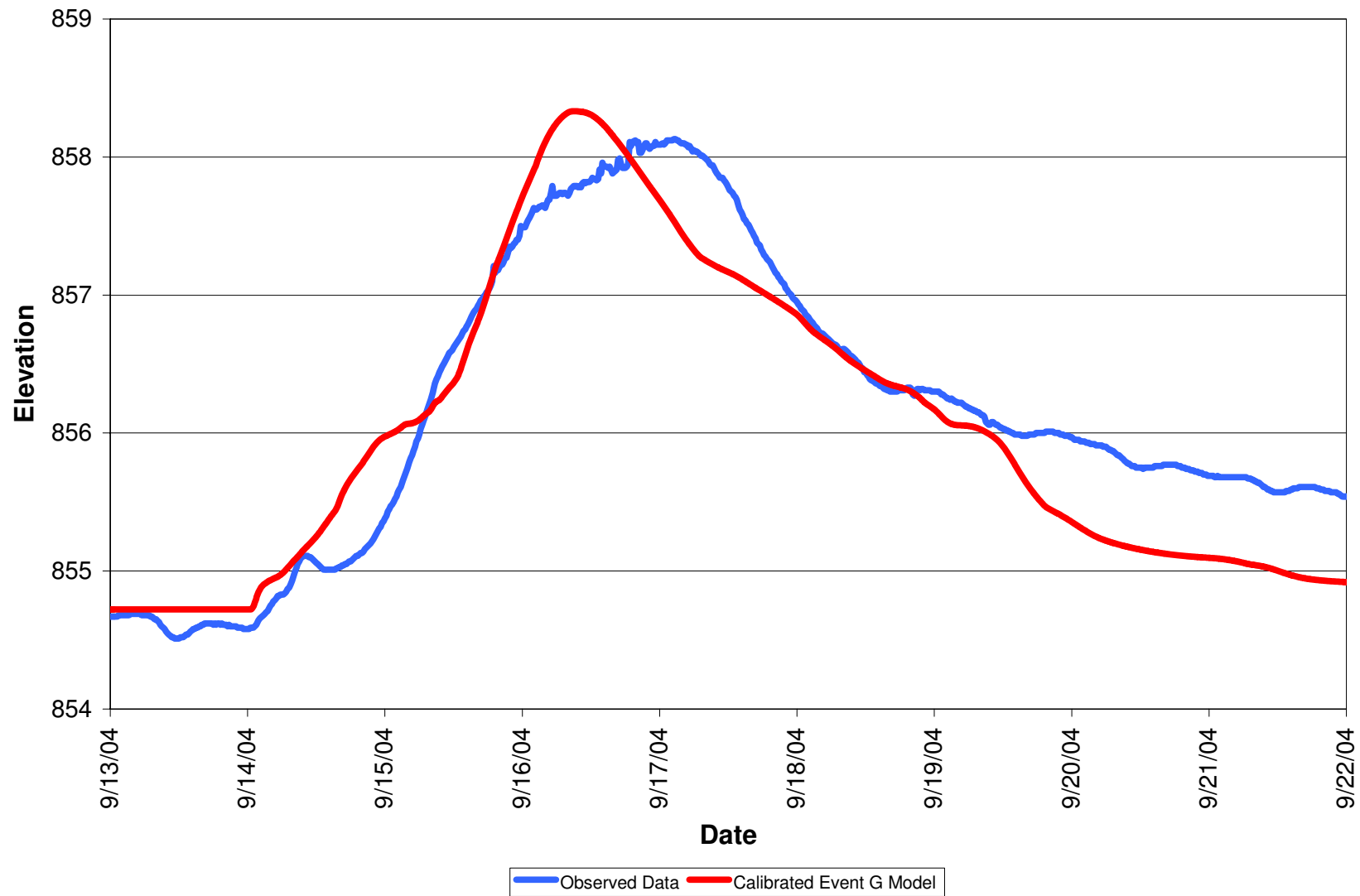


Figure 5-11. Event G Calibration Results (MC-801)



**Figure 5-12. Event G Calibration Results (USGS)**





**Figure 5-13. Event G Calibration Results (SB-802)**

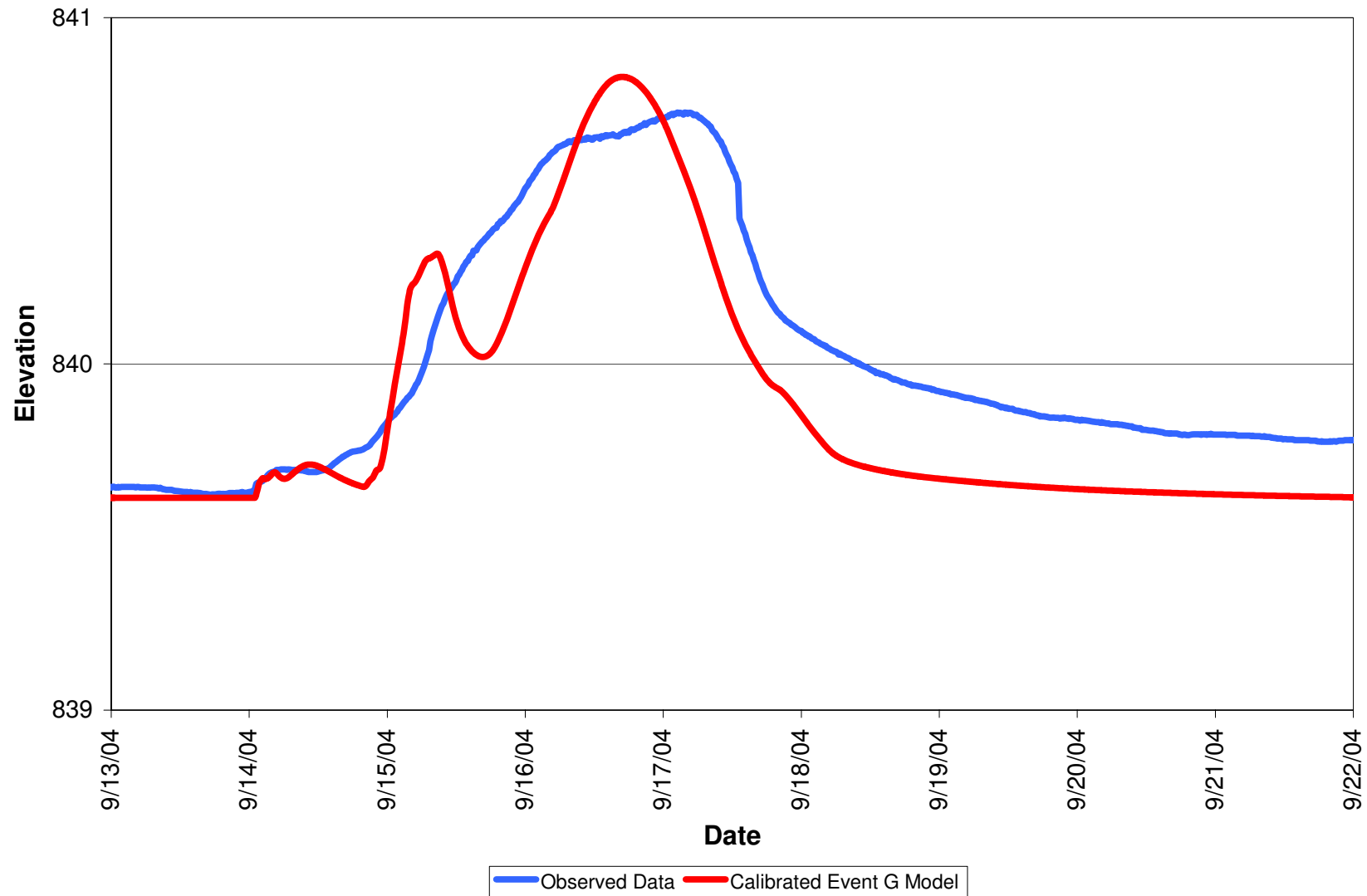
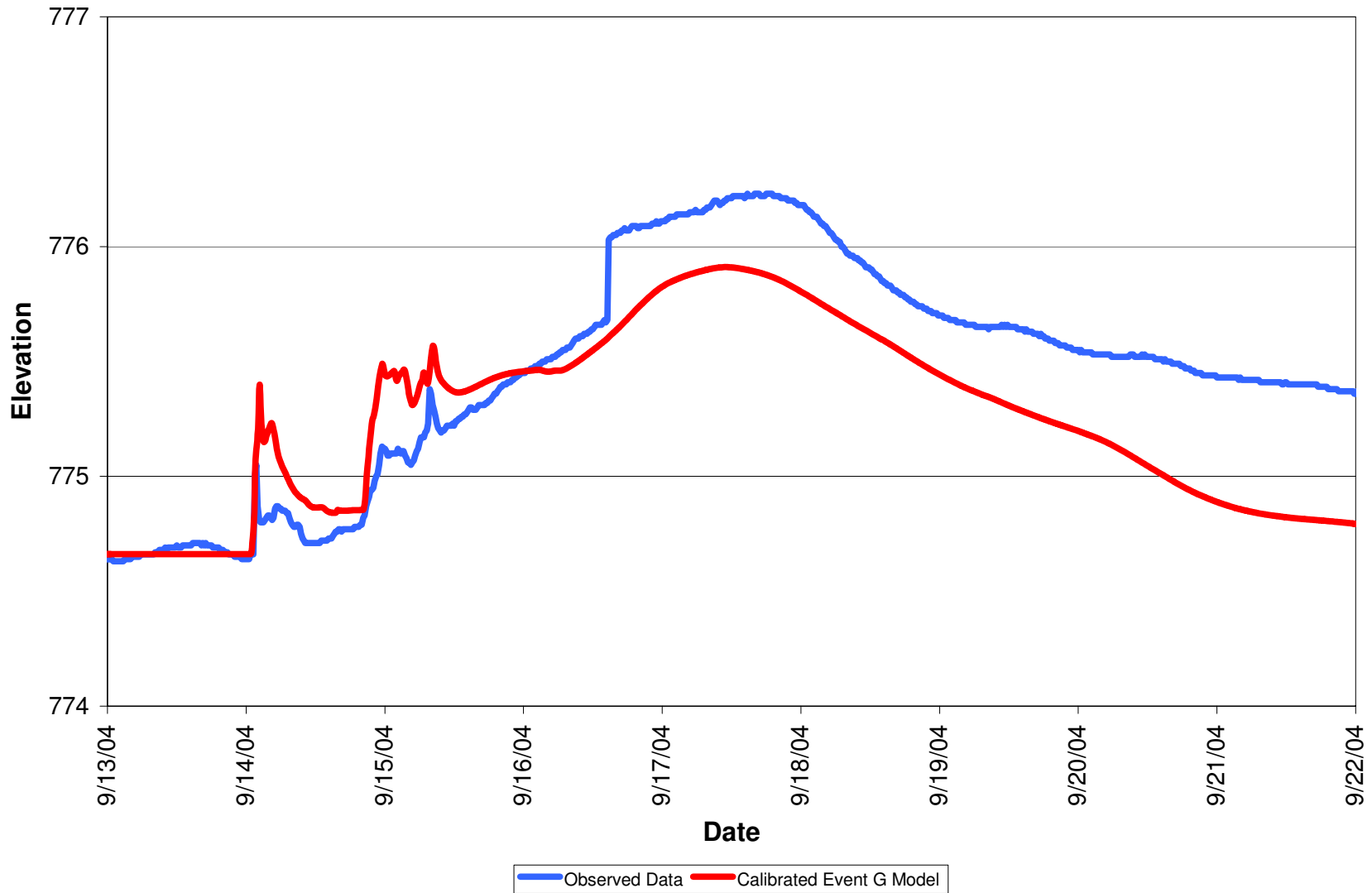
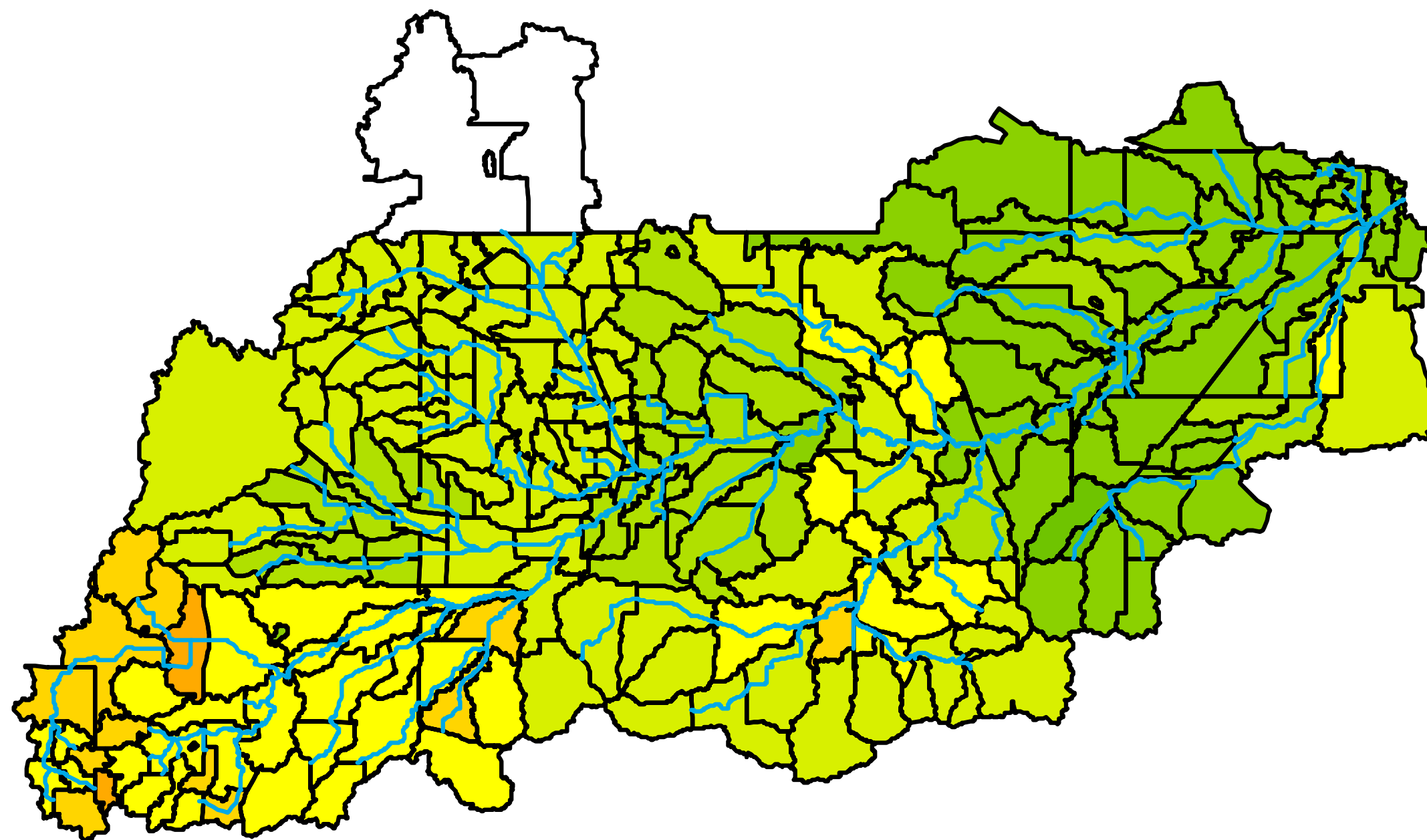


Figure 5-14. Event G Calibration Results (WOMP)





## Legend

-  Vermillion River & Tributaries
-  Vermillion River Subwatersheds

## Event D: Initial Infiltration (in/hr)

-  1.5 - 2.0
-  2.0 - 2.5
-  2.5 - 3
-  3.0 - 3.5
-  3.5 - 4.0
-  4.0 - 4.5
-  4.5 - 5.0

The Apple Valley watersheds were not calibrated.  
100-year inflows used in the XP-SWMM model were  
agreed on by the Cities of Apple Valley and Lakeville.

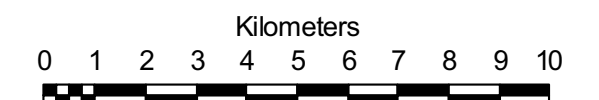
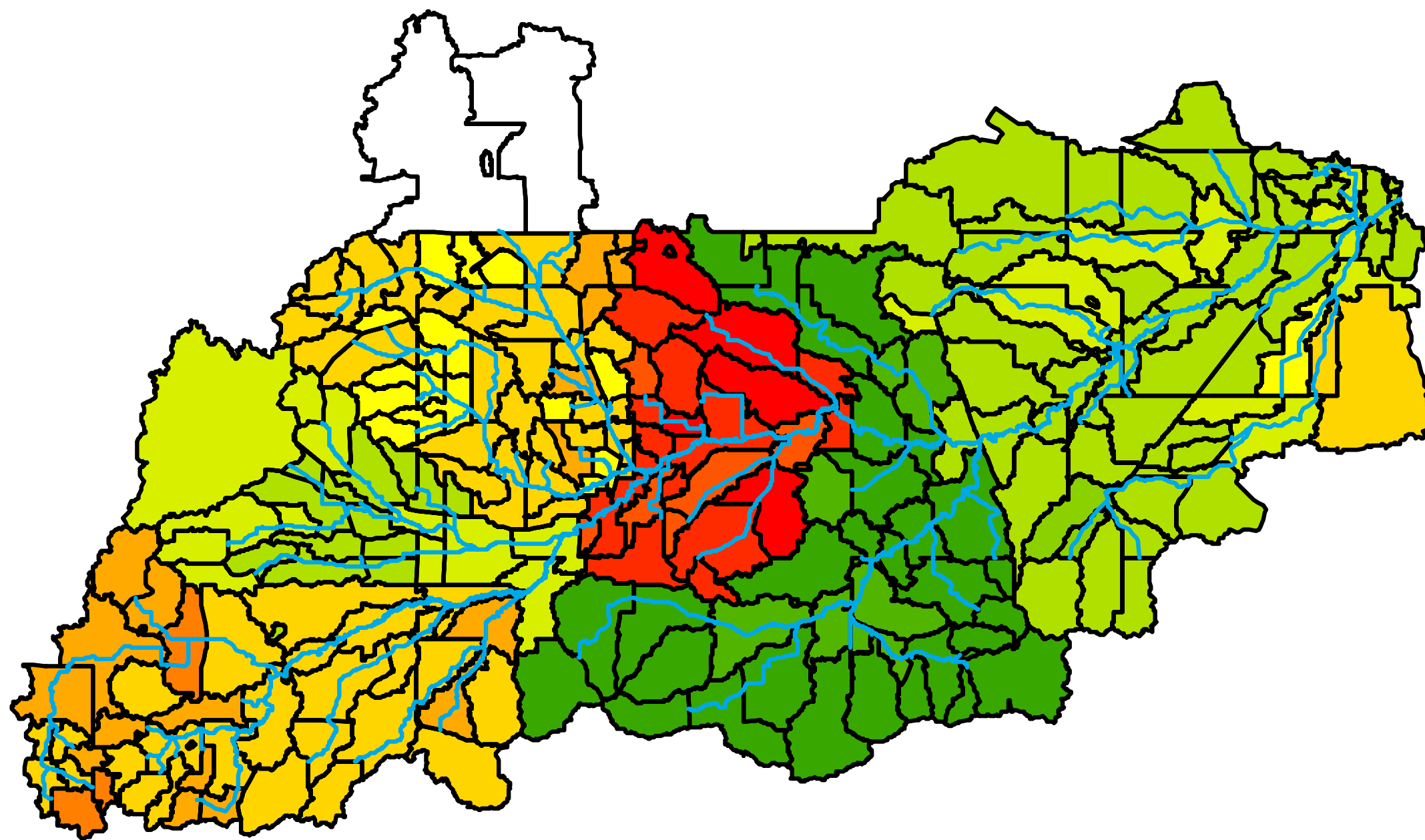


Figure 5-15

EVENT D CALIBRATED INITIAL INFILTRATION  
VRWJPO Hydrologic Model  
Vermillion River Watershed

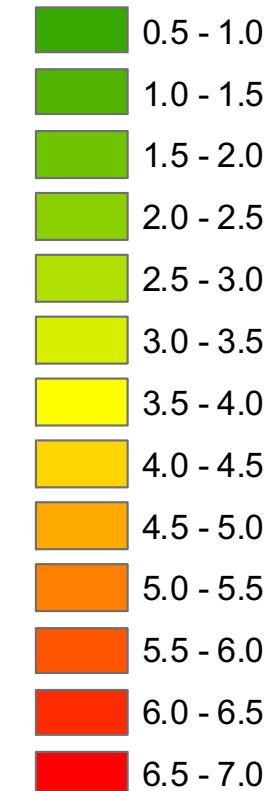


## Legend

 Vermillion River Subwatersheds

 Vermillion River & Tributaries

## Event G: Initial Infiltration (in/hr)



The Apple Valley watersheds were not calibrated. 100-year inflows used in the XP-SWMM model were agreed on by the Cities of Apple Valley and Lakeville.

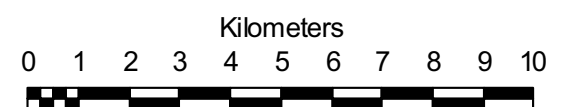
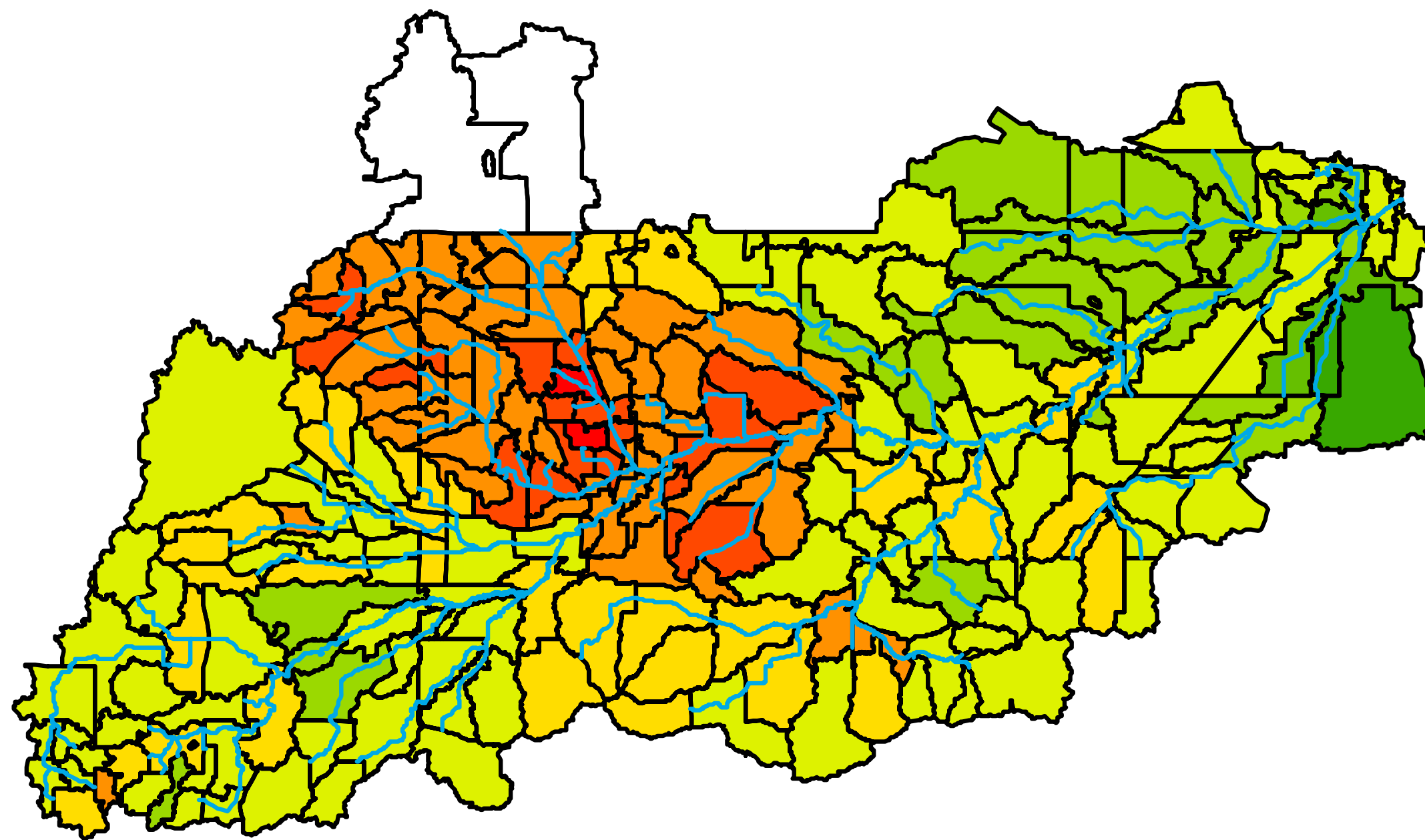


Figure 5-16

EVENT G CALIBRATED INITIAL INFILTRATION  
VRWJPO Hydrologic Model  
Vermillion River Watershed

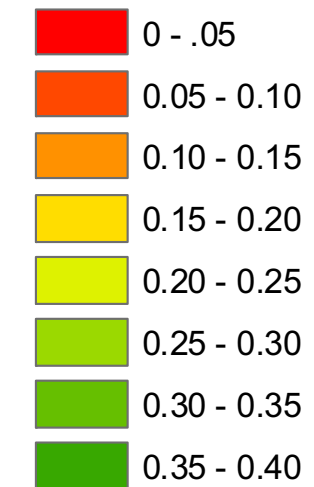


## Legend

 Vermillion River Subwatersheds

 Vermillion River & Tributaries

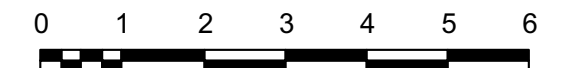
## Asymptotic Infiltration (in/hr)



The Apple Valley watersheds were not calibrated.  
100-year inflows used in the XP-SWMM model were  
agreed on by the Cities of Apple Valley and Lakeville.



Miles



Kilometers

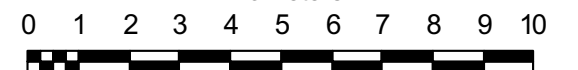
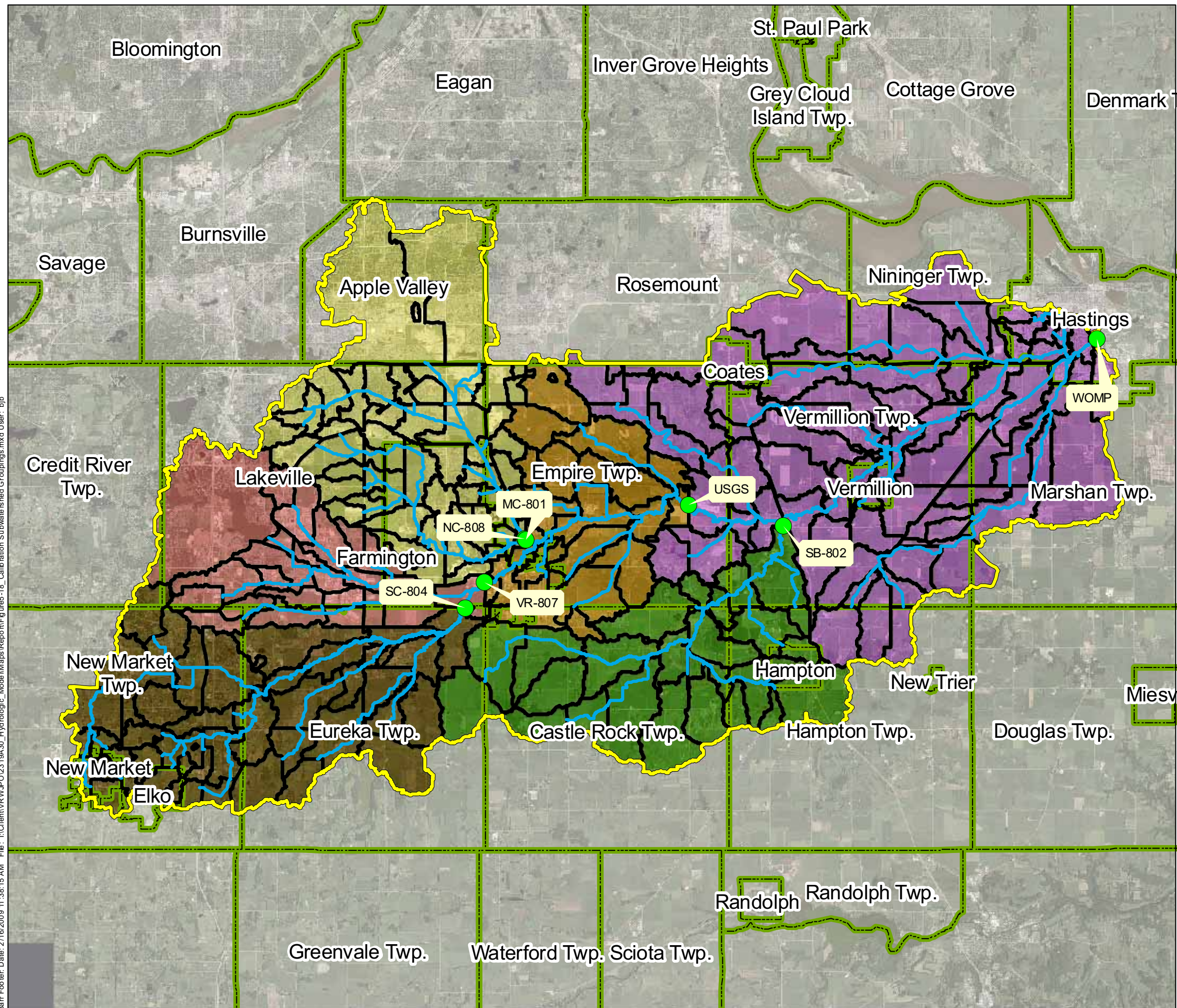


Figure 5-17

CALIBRATED ASYMPTOTIC INFILTRATION  
VRWJPO Hydrologic Model  
Vermillion River Watershed



Barr Footer: Date: 2/16/2009 11:38:15 AM File: I:\Client\VRW\PO2319\30\_Hydrologic\_Model\Maps\Report\Figure5-18\_Calibration Subwatershed Groupings.mxd User: bjb



**Legend**

- Stream Monitoring Station
- Stream
- ▭ Vermillion River Study Area
- ▭ Municipal Boundaries
- Vermillion River Subwatersheds**
  - ▭ SC-804 Calibration Area
  - ▭ VR-807 Calibration Area
  - ▭ NC-808 & MC-801 Calibration Area
  - ▭ USGS Calibration Area
  - ▭ SB-802 Calibration Area
  - ▭ WOMP Calibration Area

Subwatershed groupings have similar calibration scale factors.

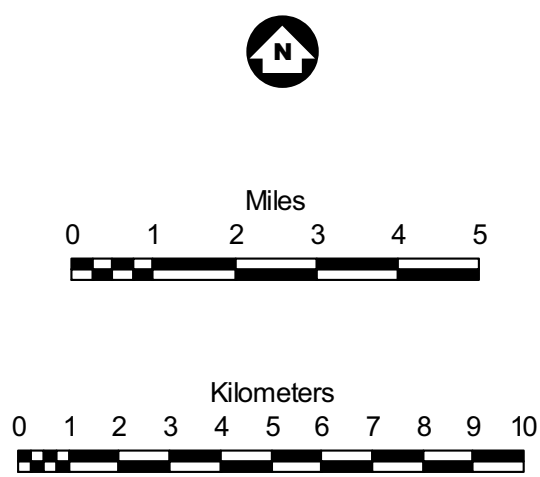
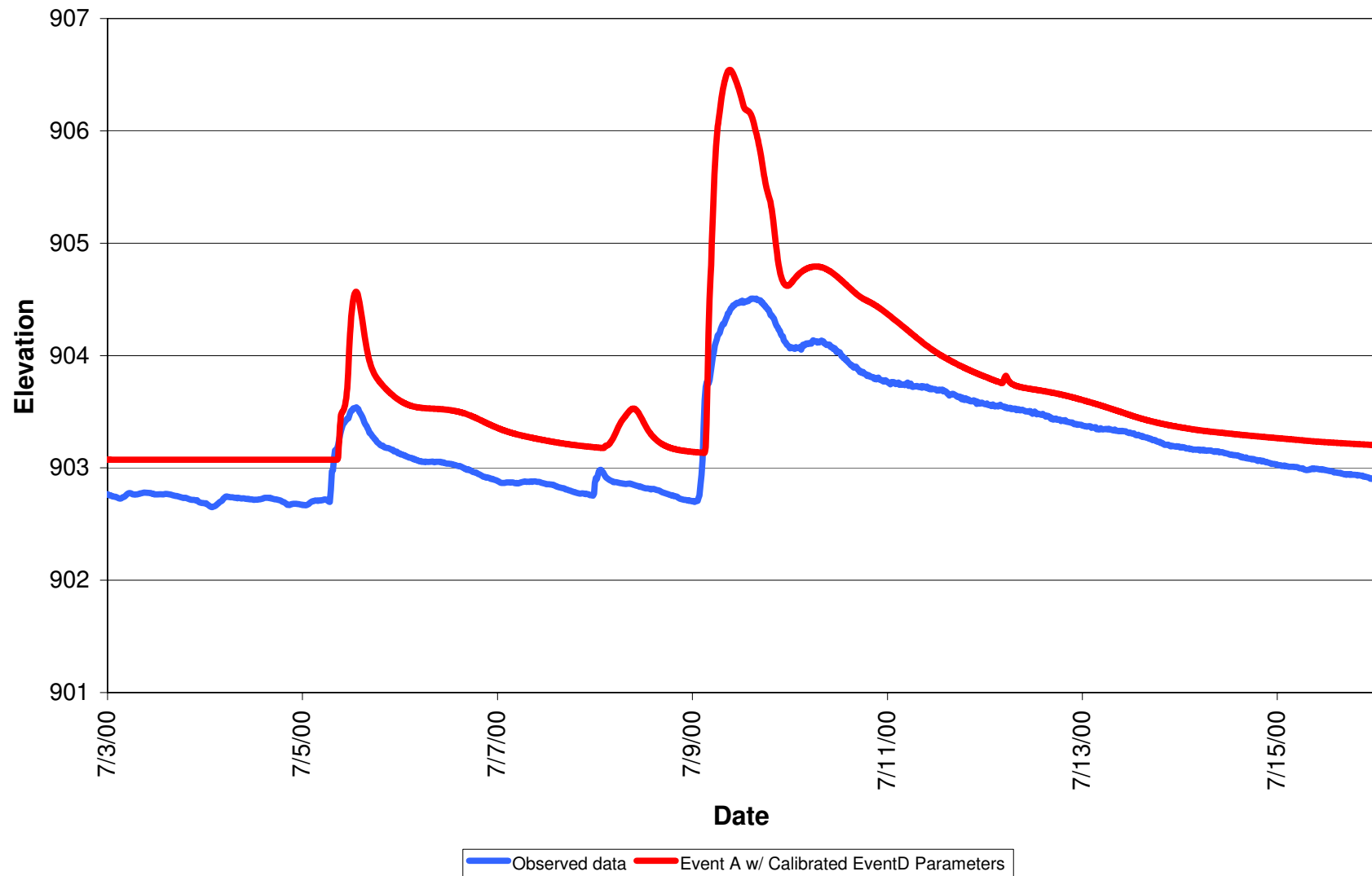


Figure 5-18  
CALIBRATION SUBWATERSHED GROUPINGS  
VRWJPO Hydrologic Model  
Vermillion River Watershed



**Figure 5-19. Event A Validation Results (SC-804)**





**Figure 5-20. Event A Validation Results (VR-807)**

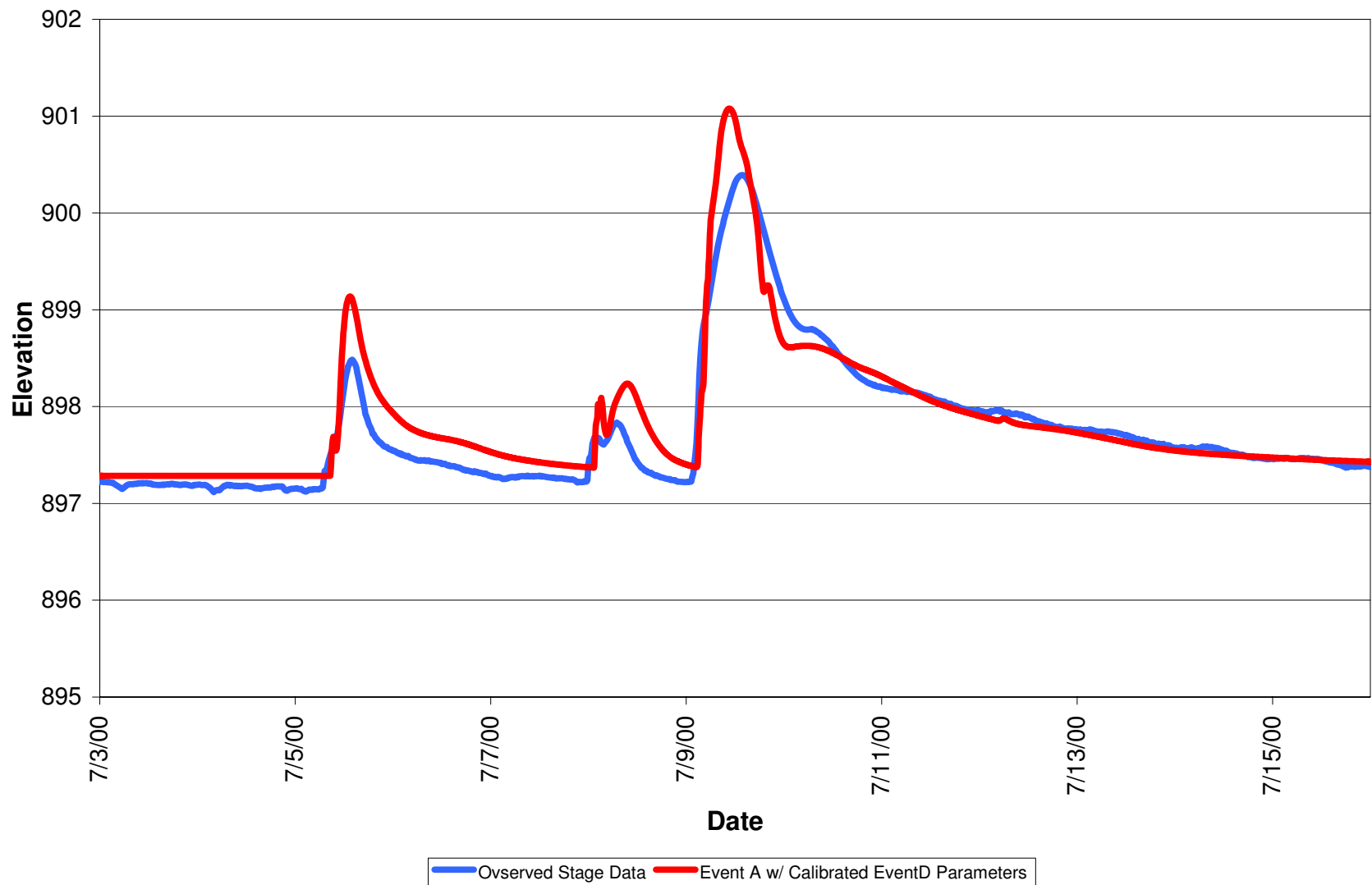


Figure 5-21. Event A Validation Results (NC-808)

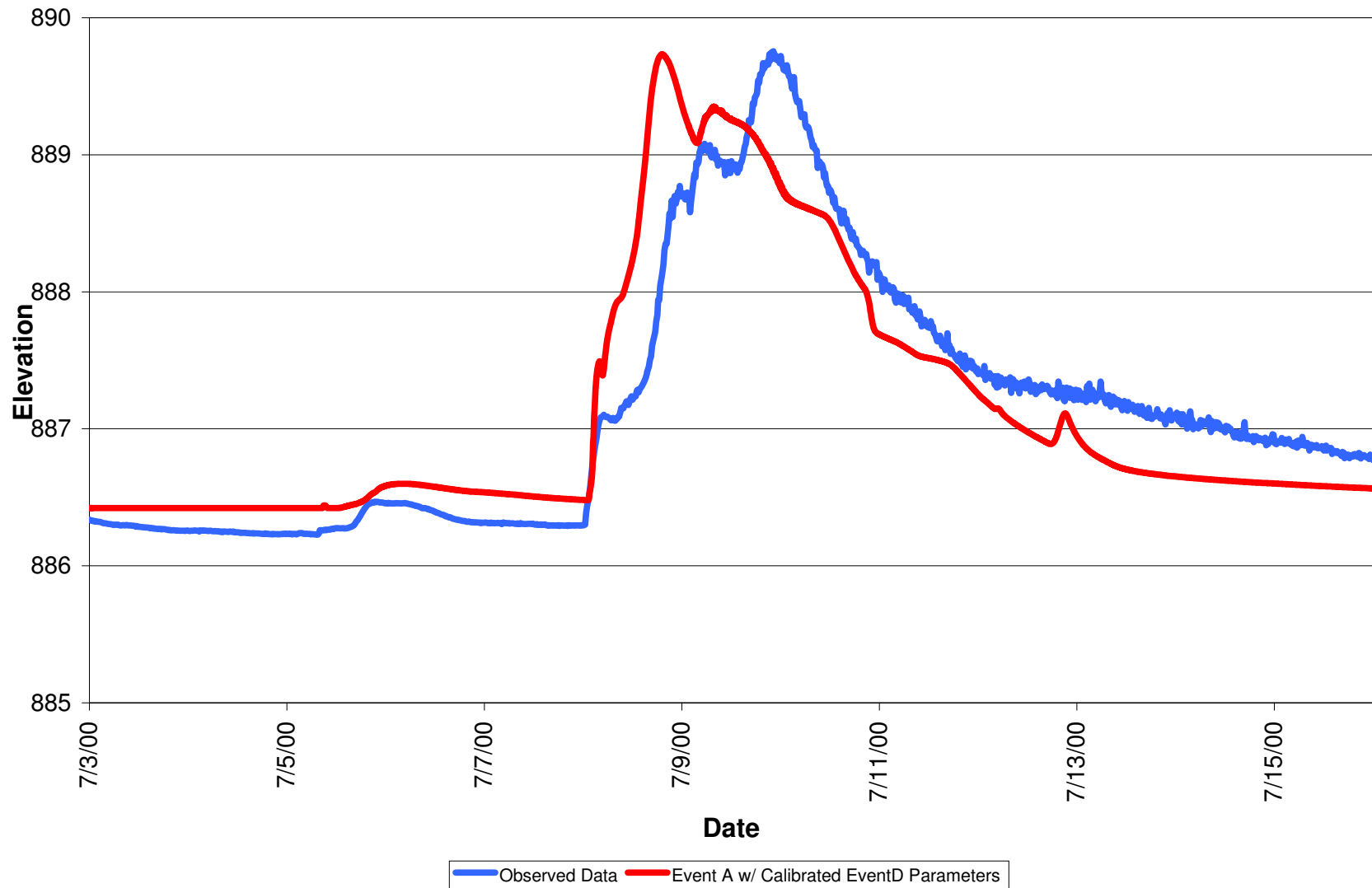
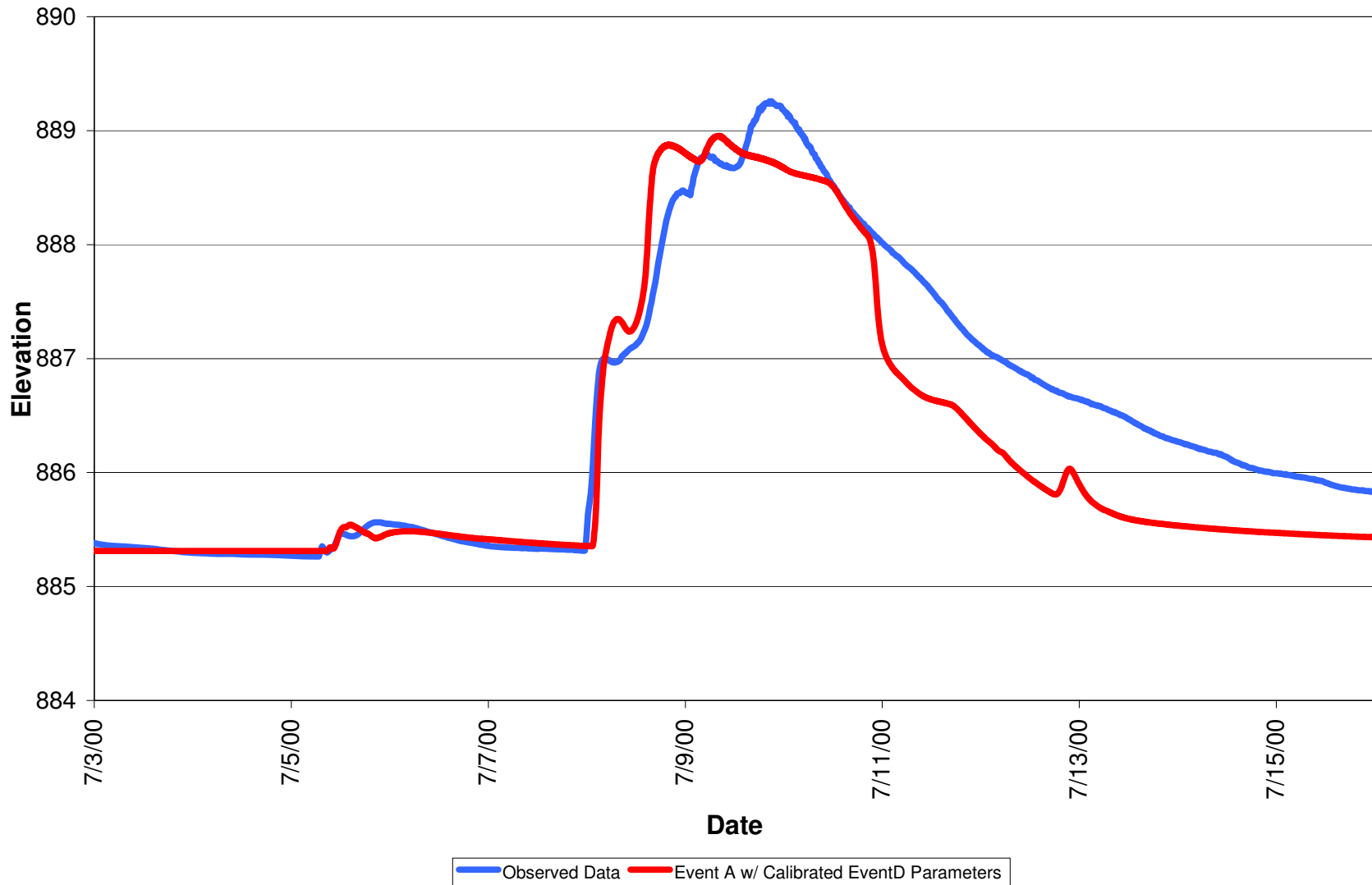
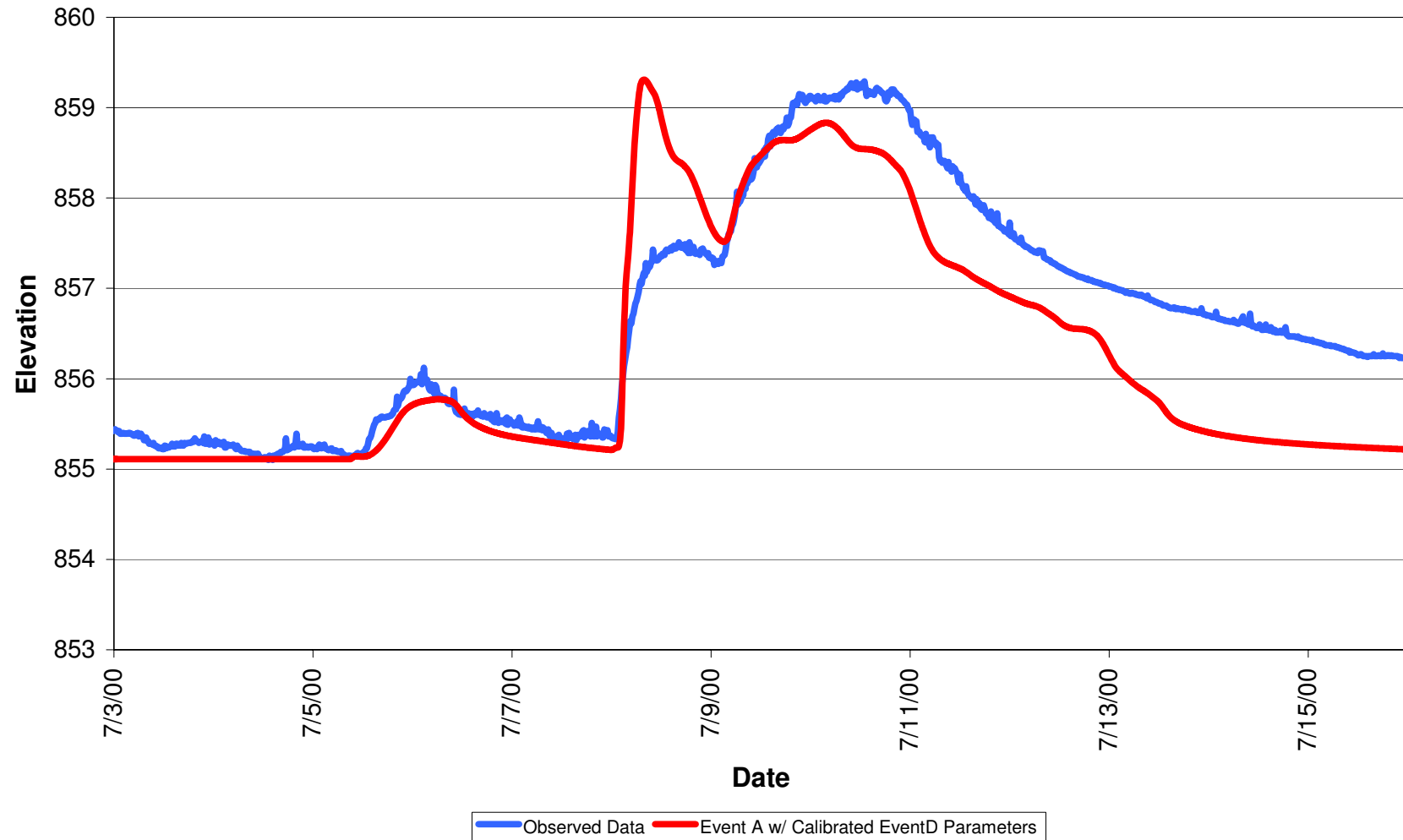


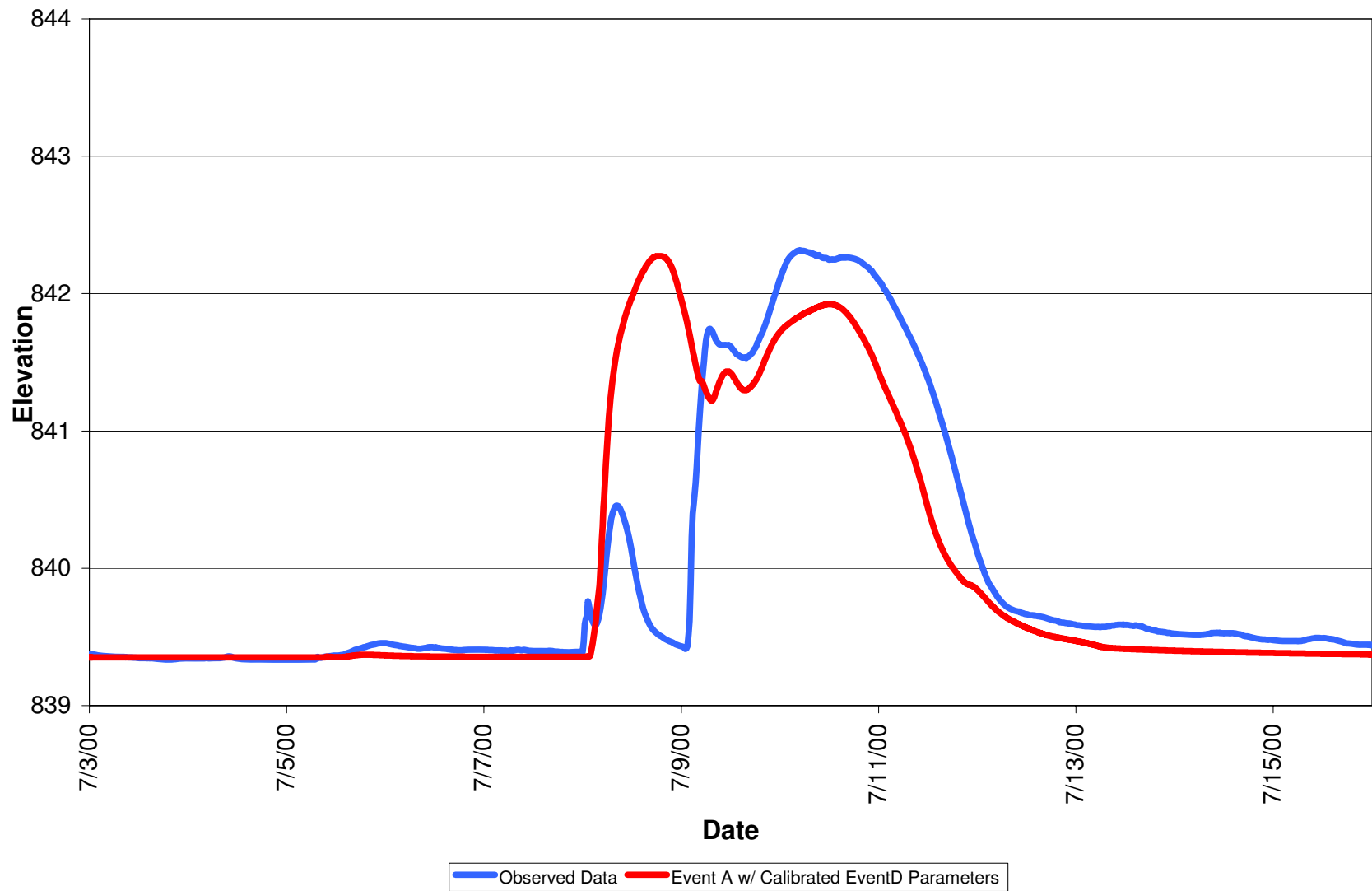
Figure 5-22. Event A Validation Results (MC-801)



**Figure 5-23. Event A Validation Results (USGS)**



**Figure 5-24. Event A Validation Results (SB-802)**



**Figure 5-25. Event A Validation Results (WOMP)**

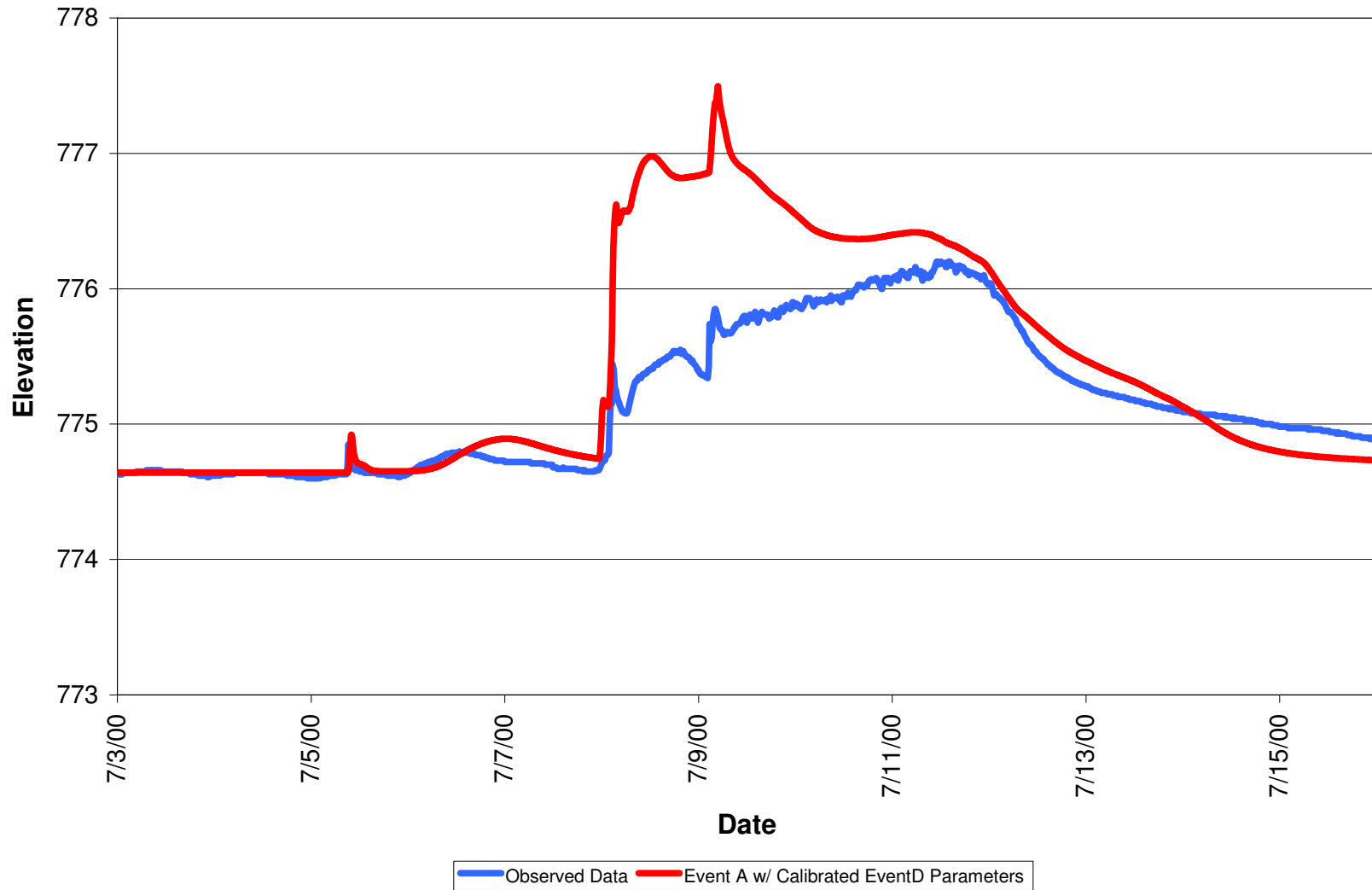


Figure 5-26. Event C Validation Results (SC-804)

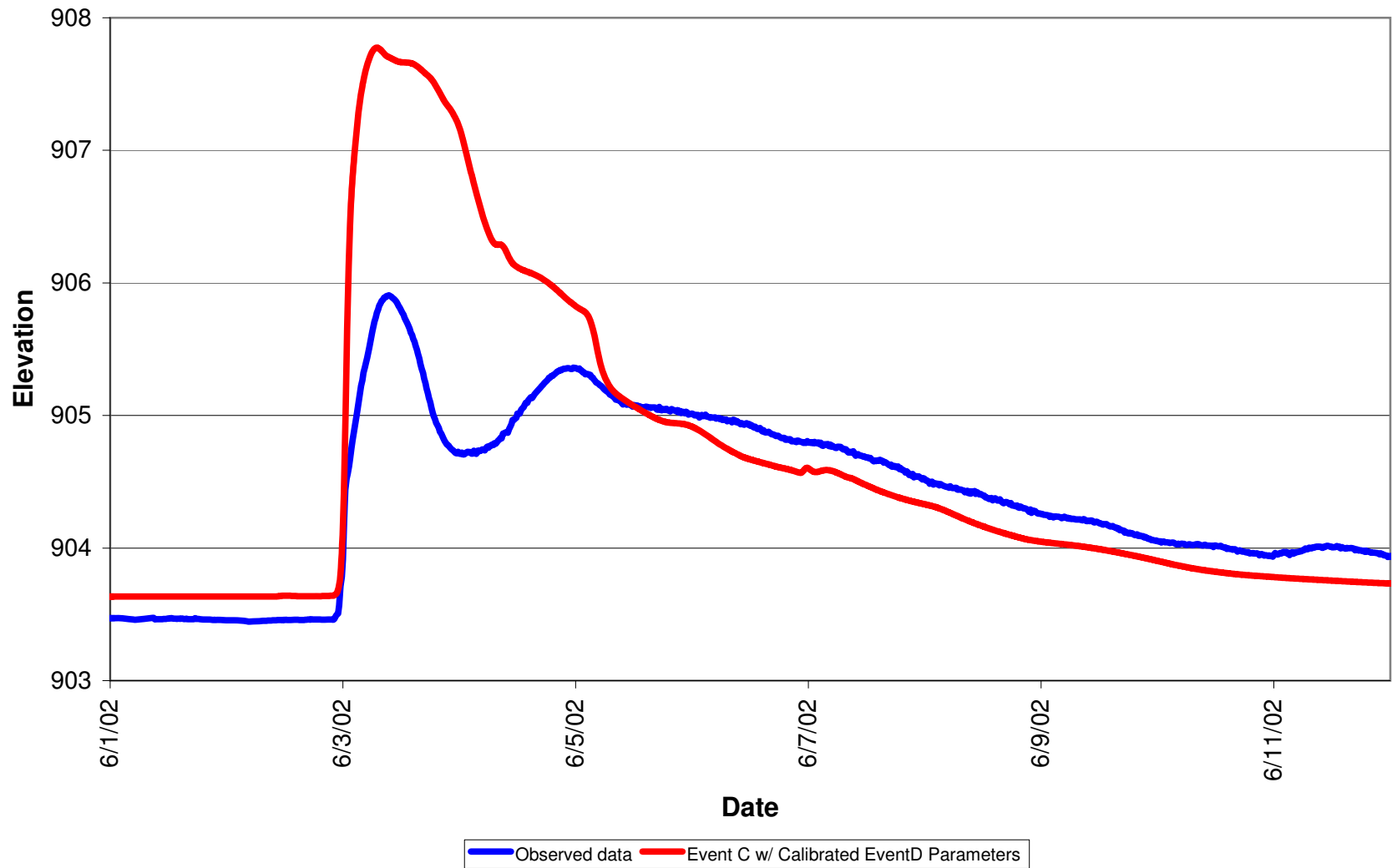




Figure 5-27. Event C Validation Results (VR-807)

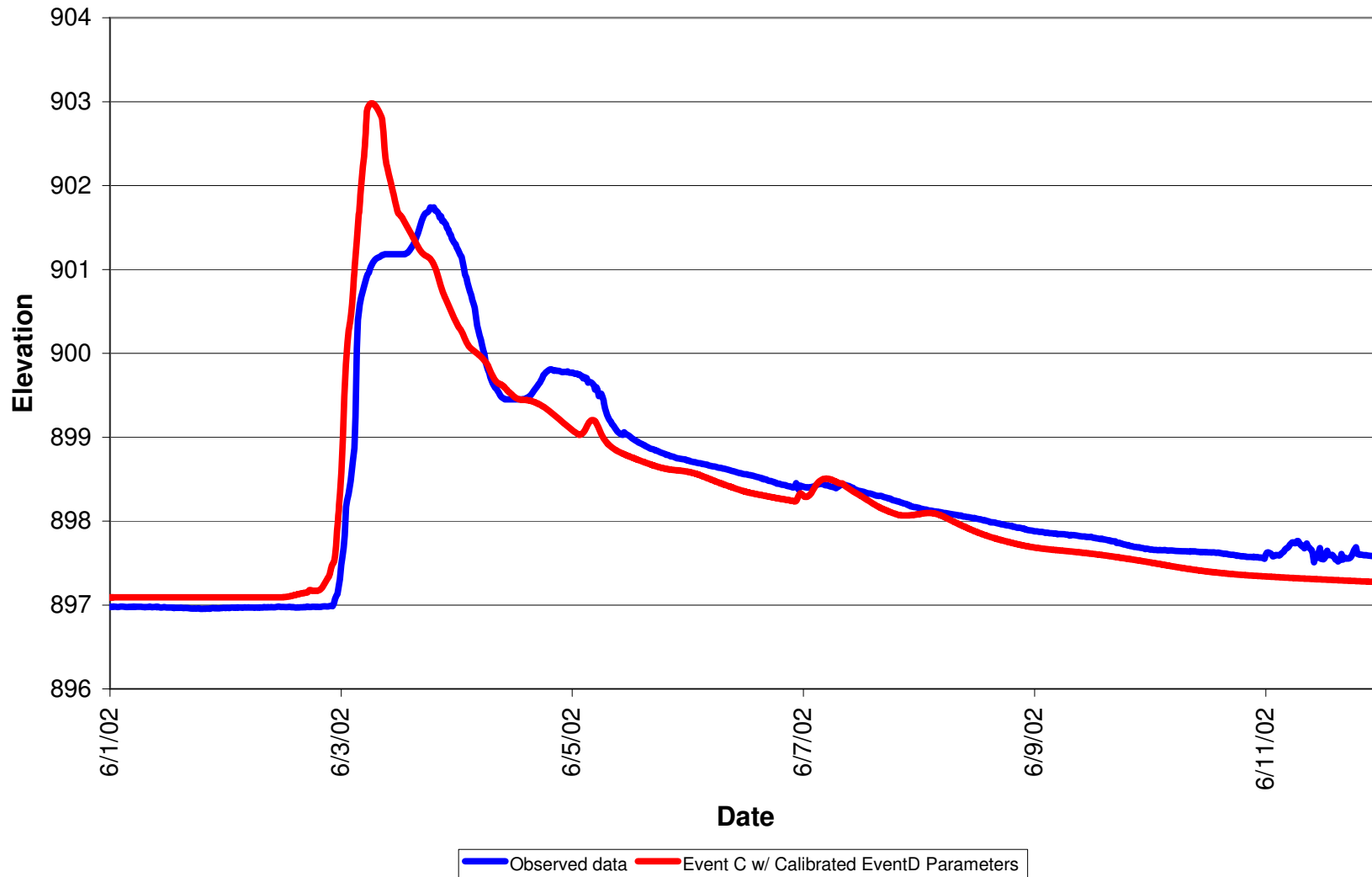


Figure 5-28. Event C Validation Results (NC-808)

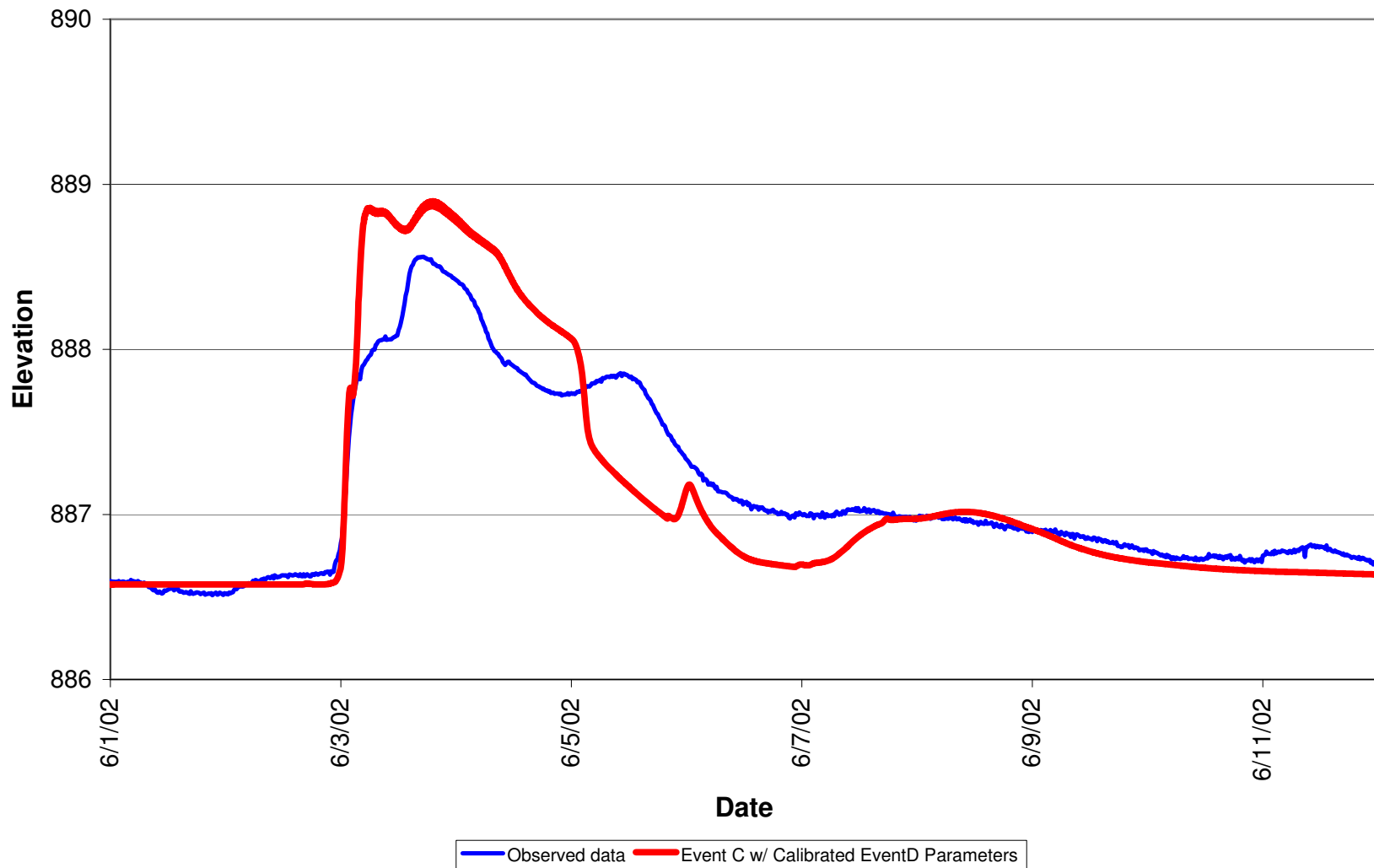


Figure 5-29. Event C Validation Results (MC-801)

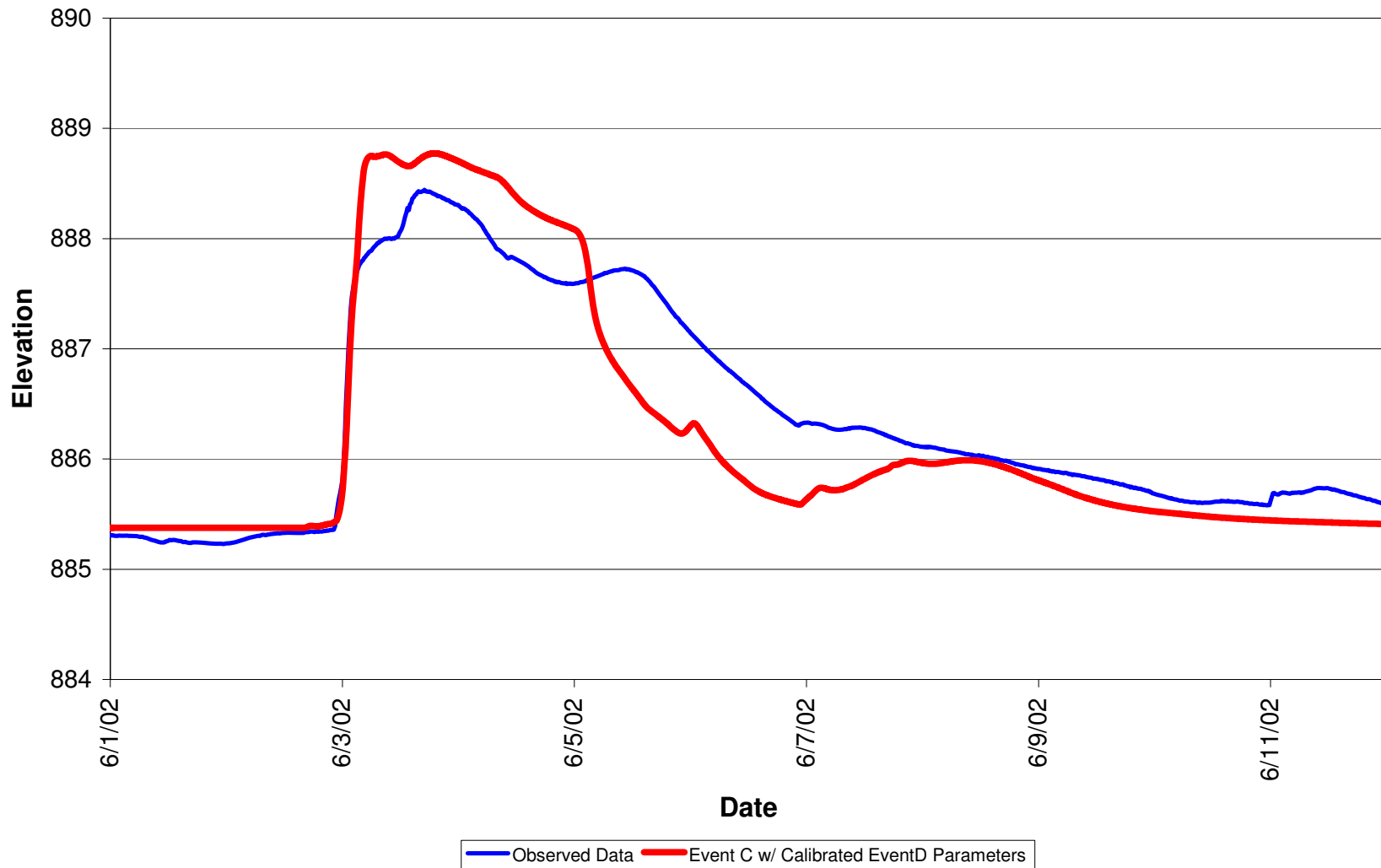


Figure 5-30. Event C Validation Results (USGS)

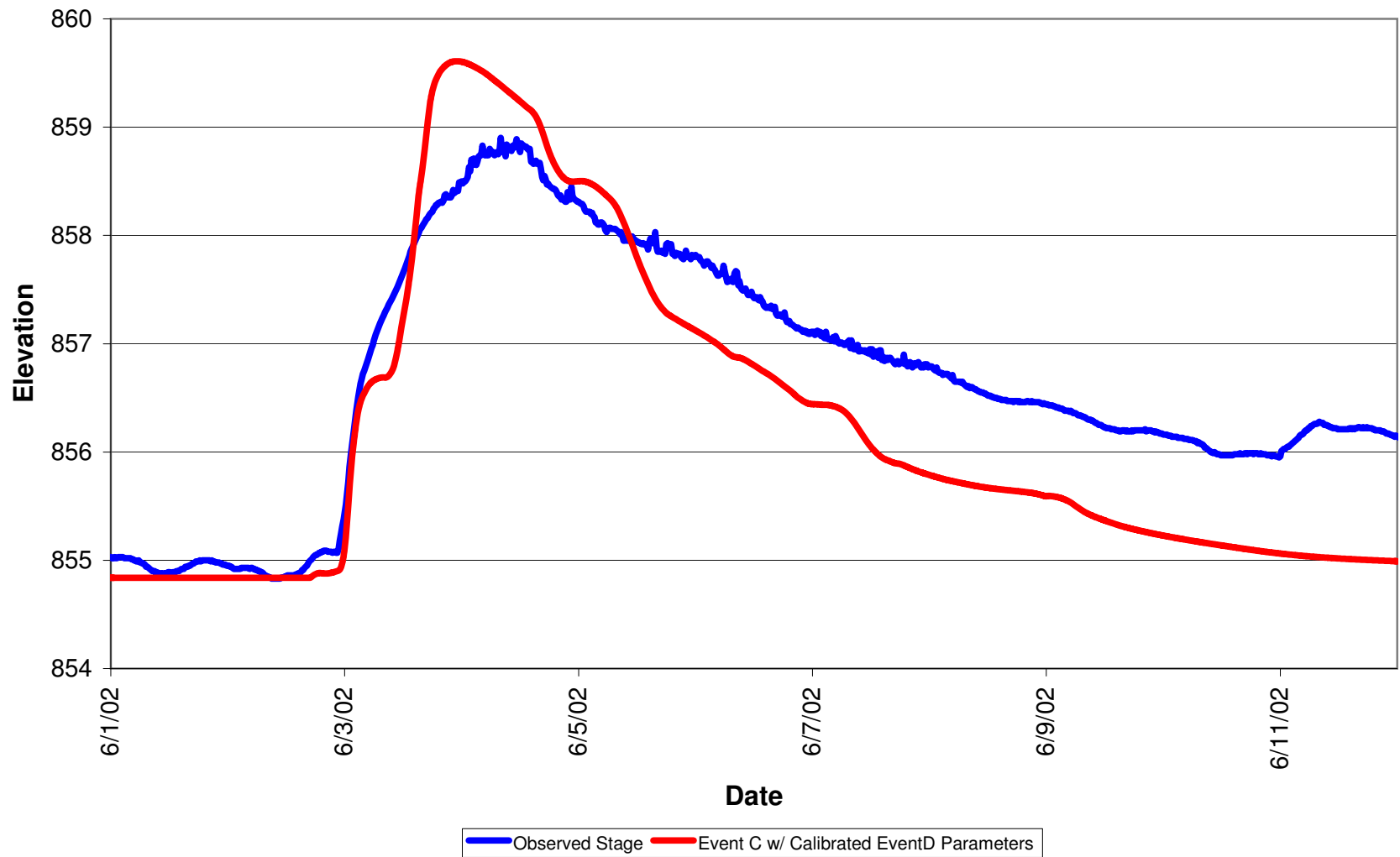


Figure 5-31. Event C Validation Results (SB-802)

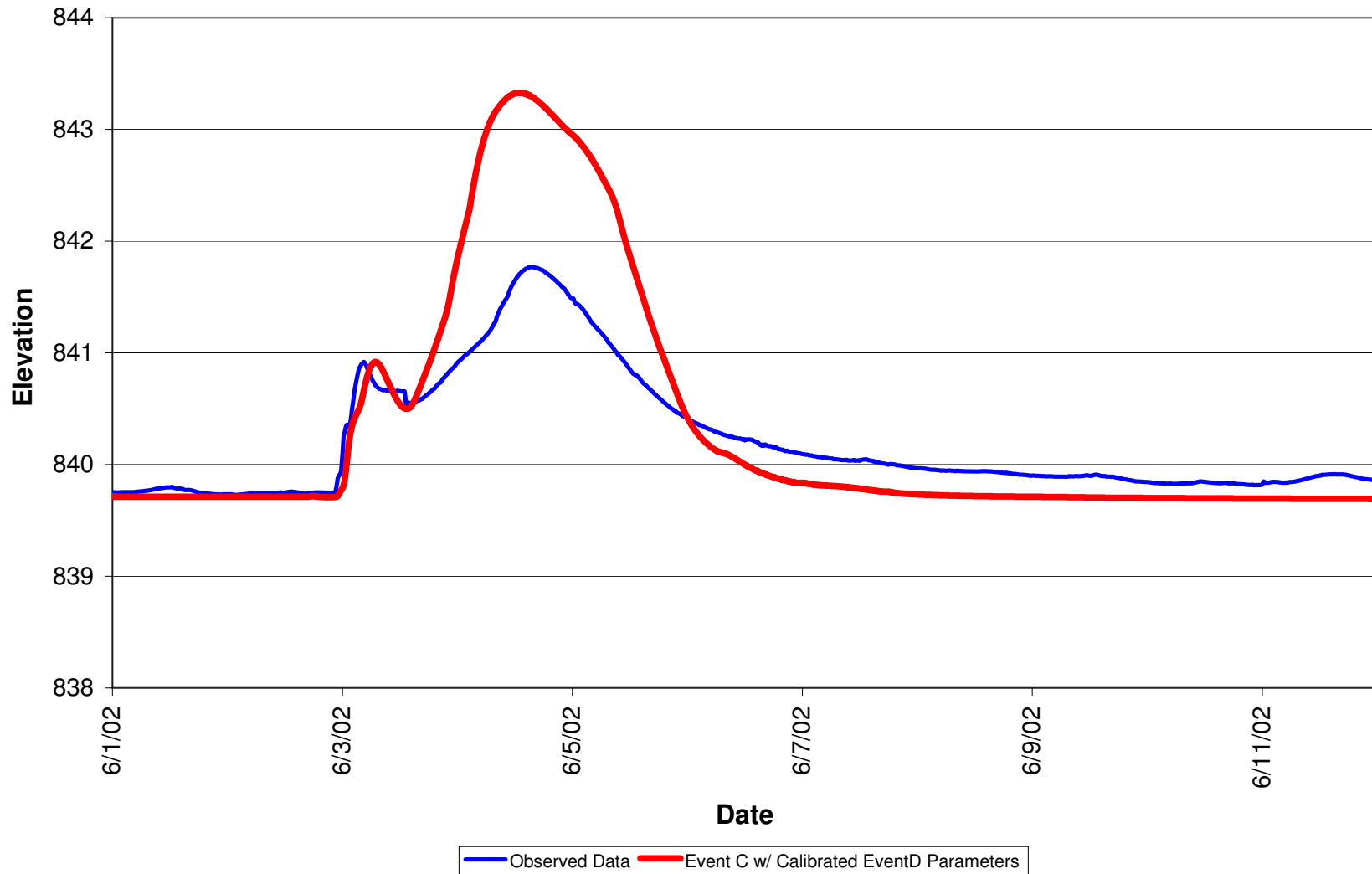


Figure 5-32. Event C Validation Results (WOMP)

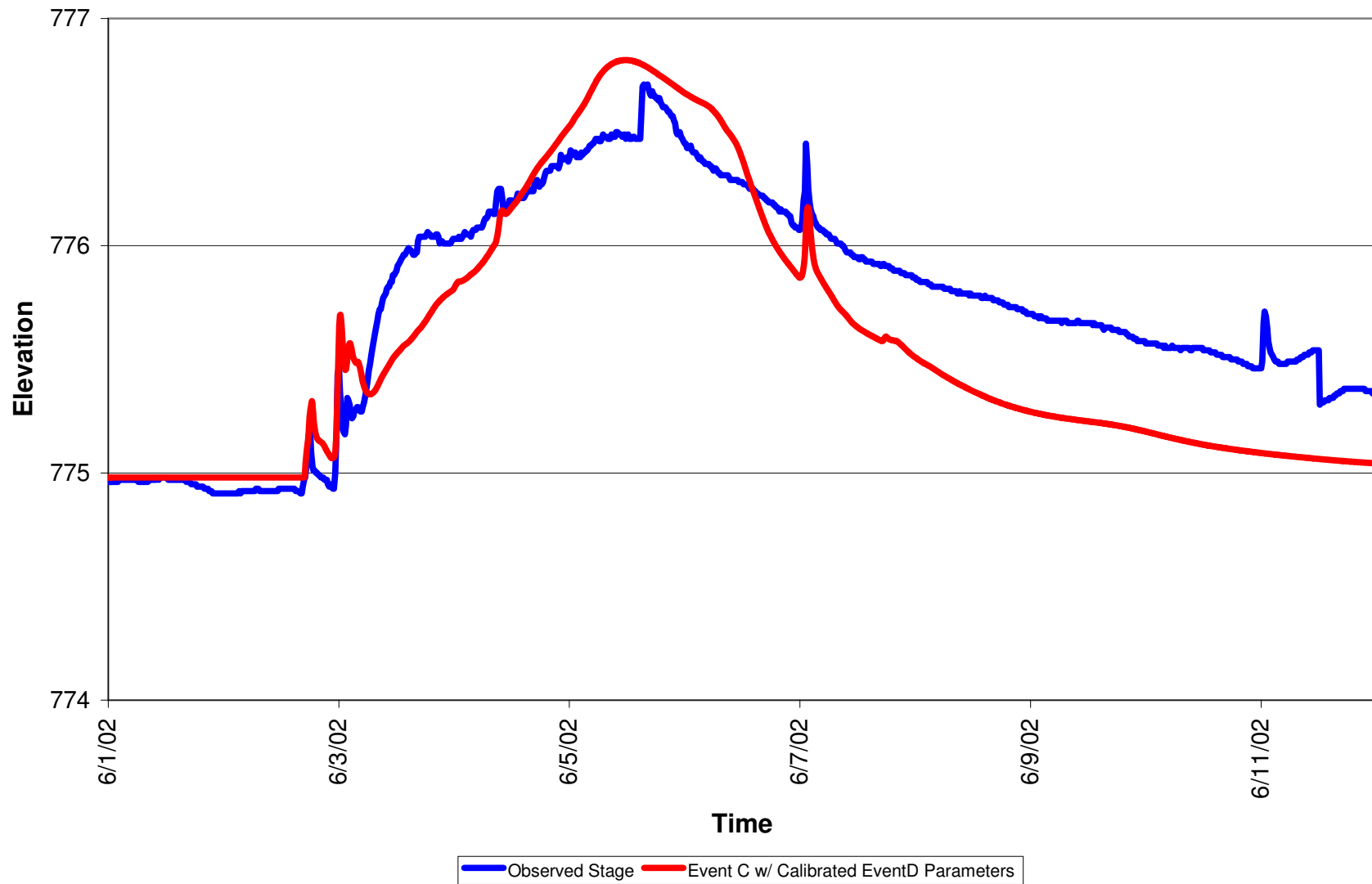
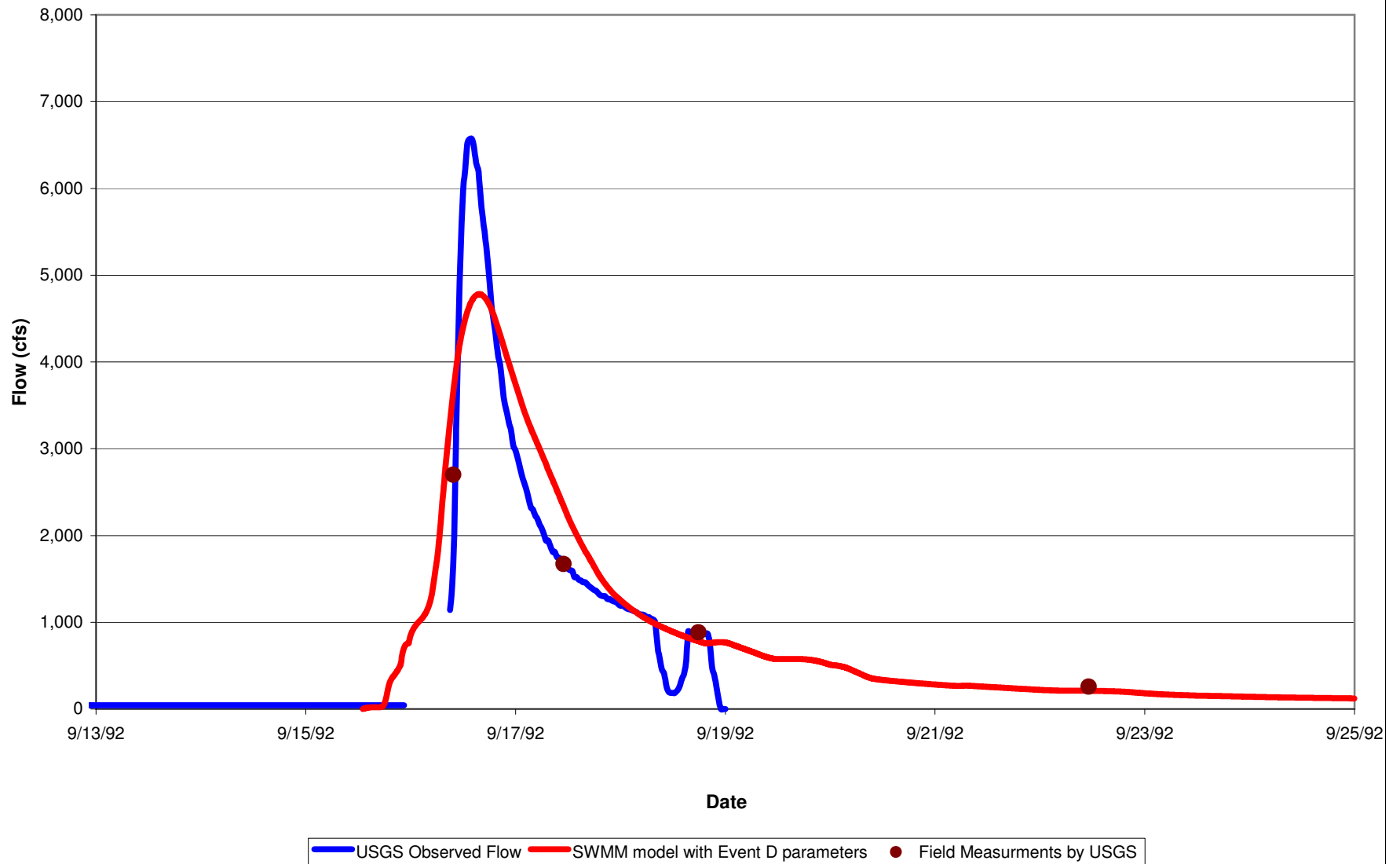
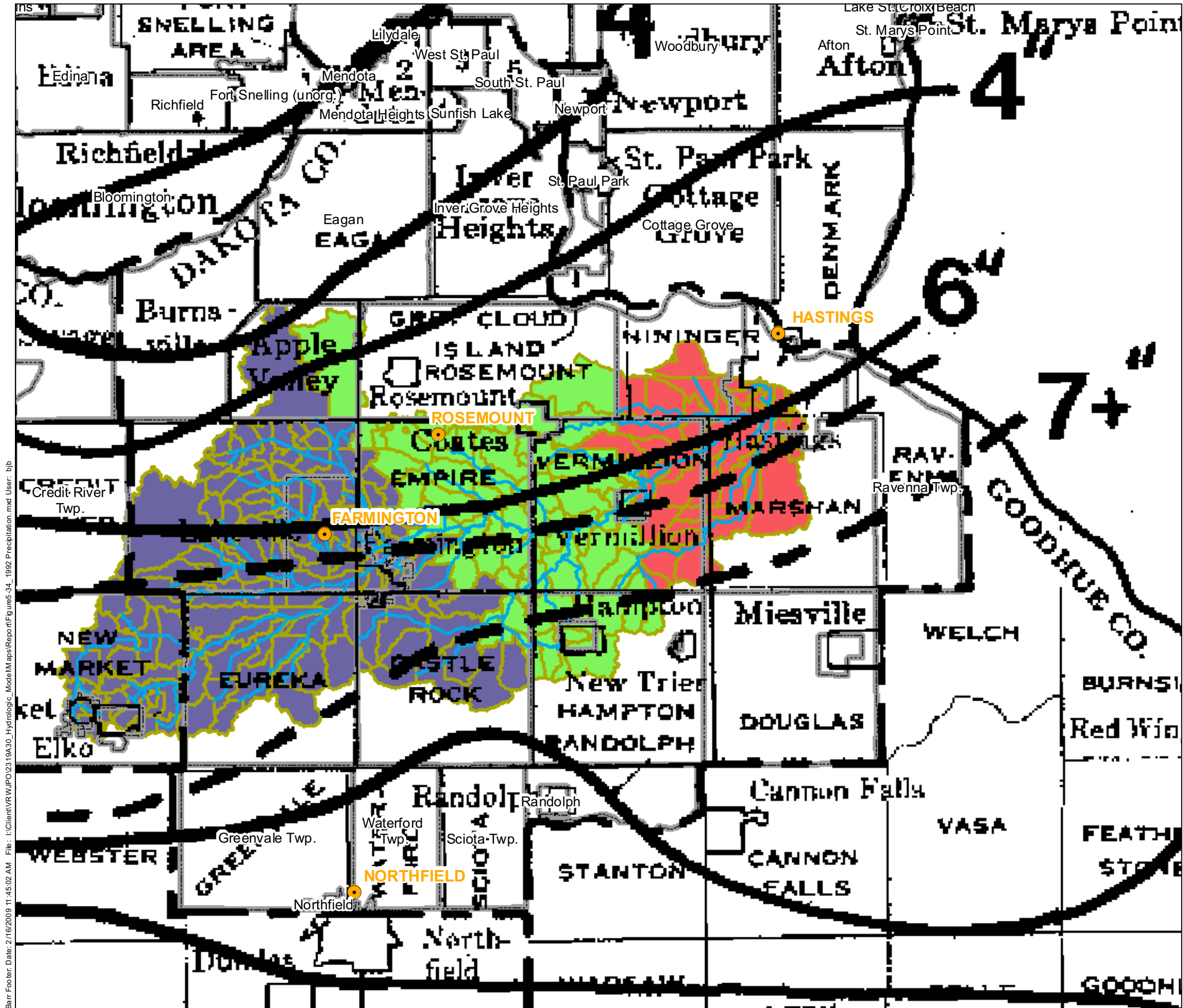


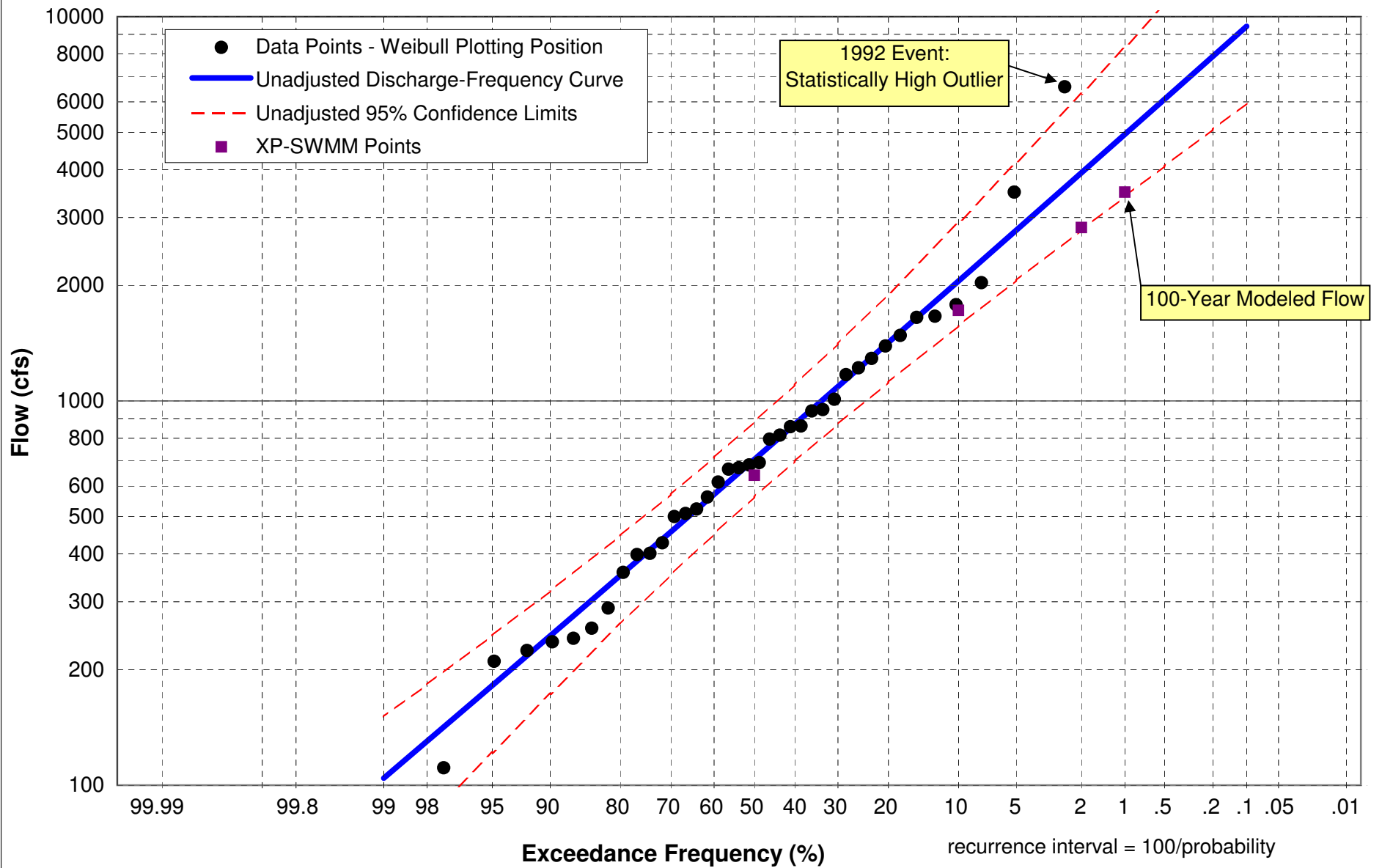
Figure 5-33. Reconstitution of the September 16, 1992 Storm Event  
at the USGS Gage







**Figure 5-35. Unadjusted USGS Discharge Frequency Curve**  
*Annual Instantaneous Peaks (Record: 1942-1945, 1974-2007)*



plot date: 4/7/2009

file: FreqCurves\_ver209\_UNADJUSTED.xls

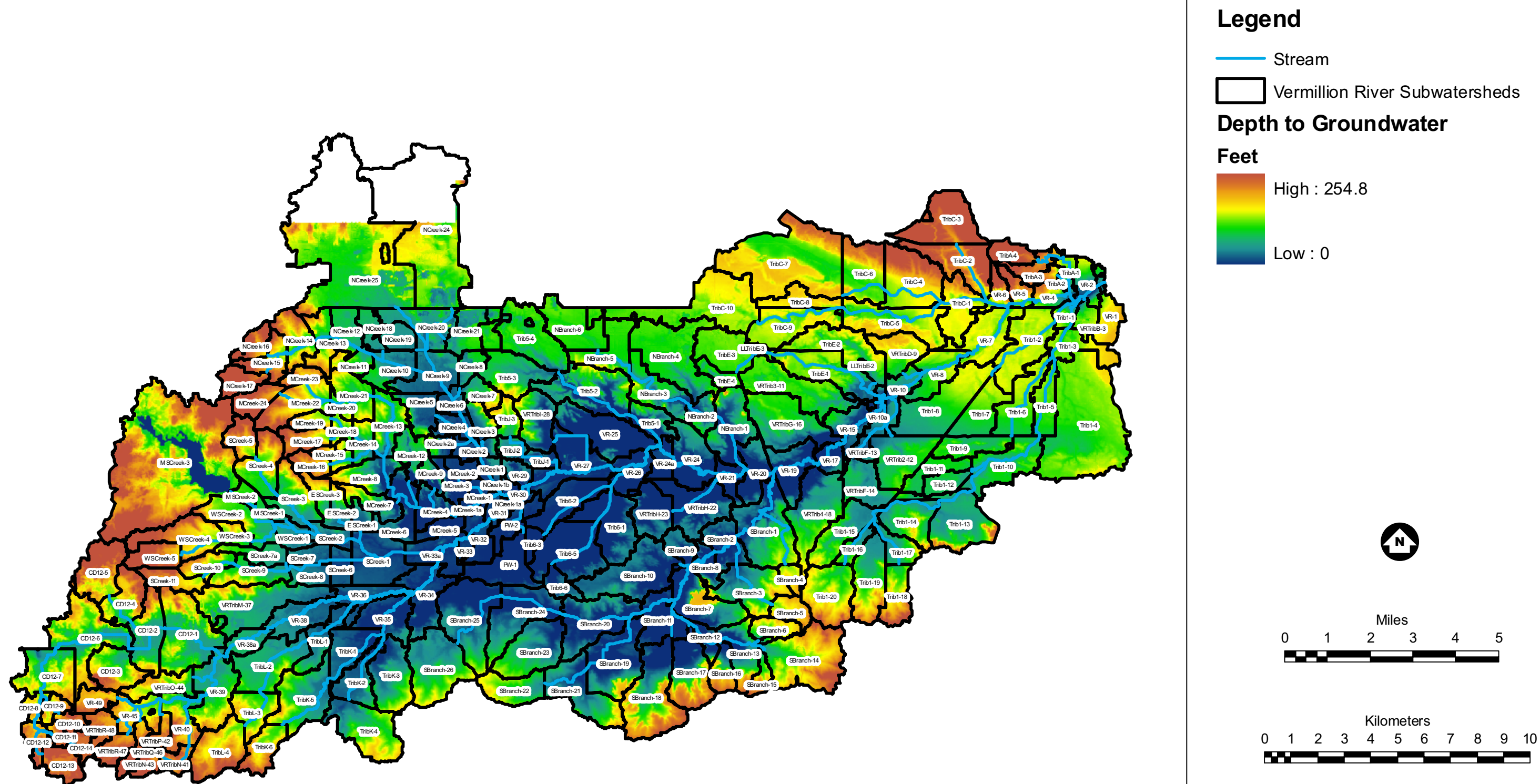


Figure 5-36

DEPTH TO GROUNDWATER  
VRWJPO Hydrologic Model  
Vermillion River Watershed



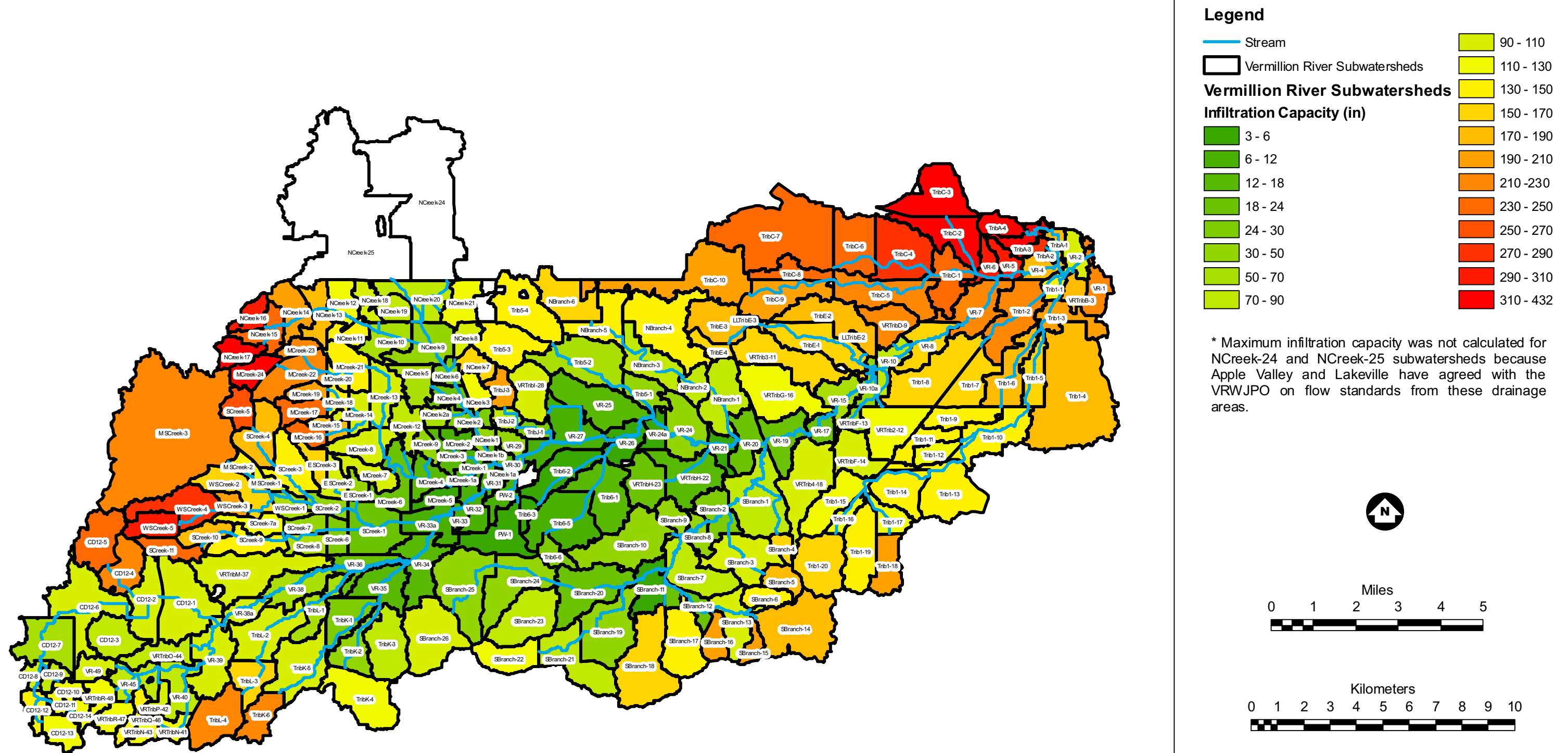
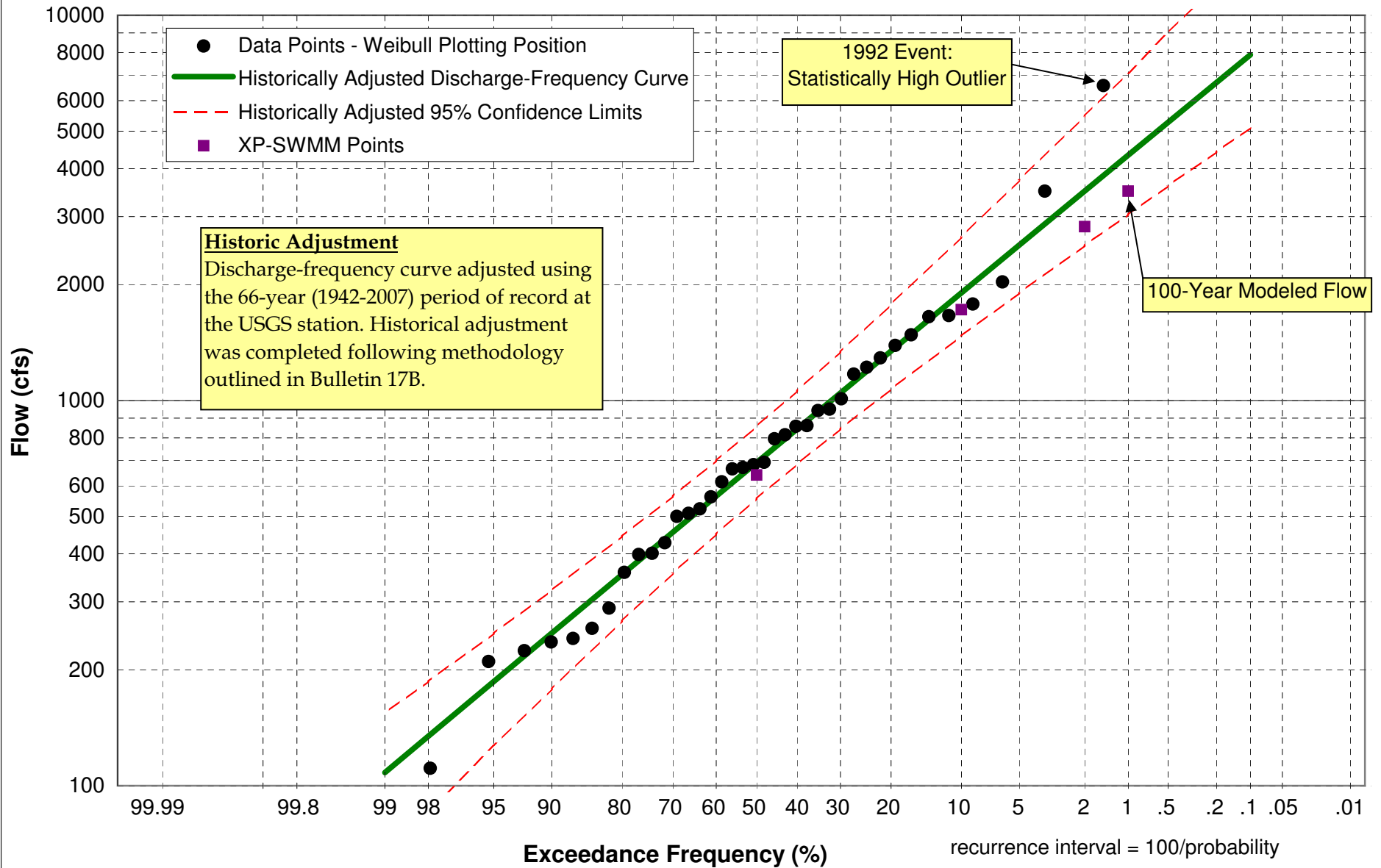


Figure 5-37

SUBWATERSHED INFILTRATION CAPACITY  
VRWJPO Hydrologic Model  
Vermillion River Watershed

**Figure 5-38. Historically Adjusted USGS Discharge Frequency Curve  
Based on Period of Record**

*Annual Instantaneous Peaks (Record: 1942-1945, 1974-2007)*

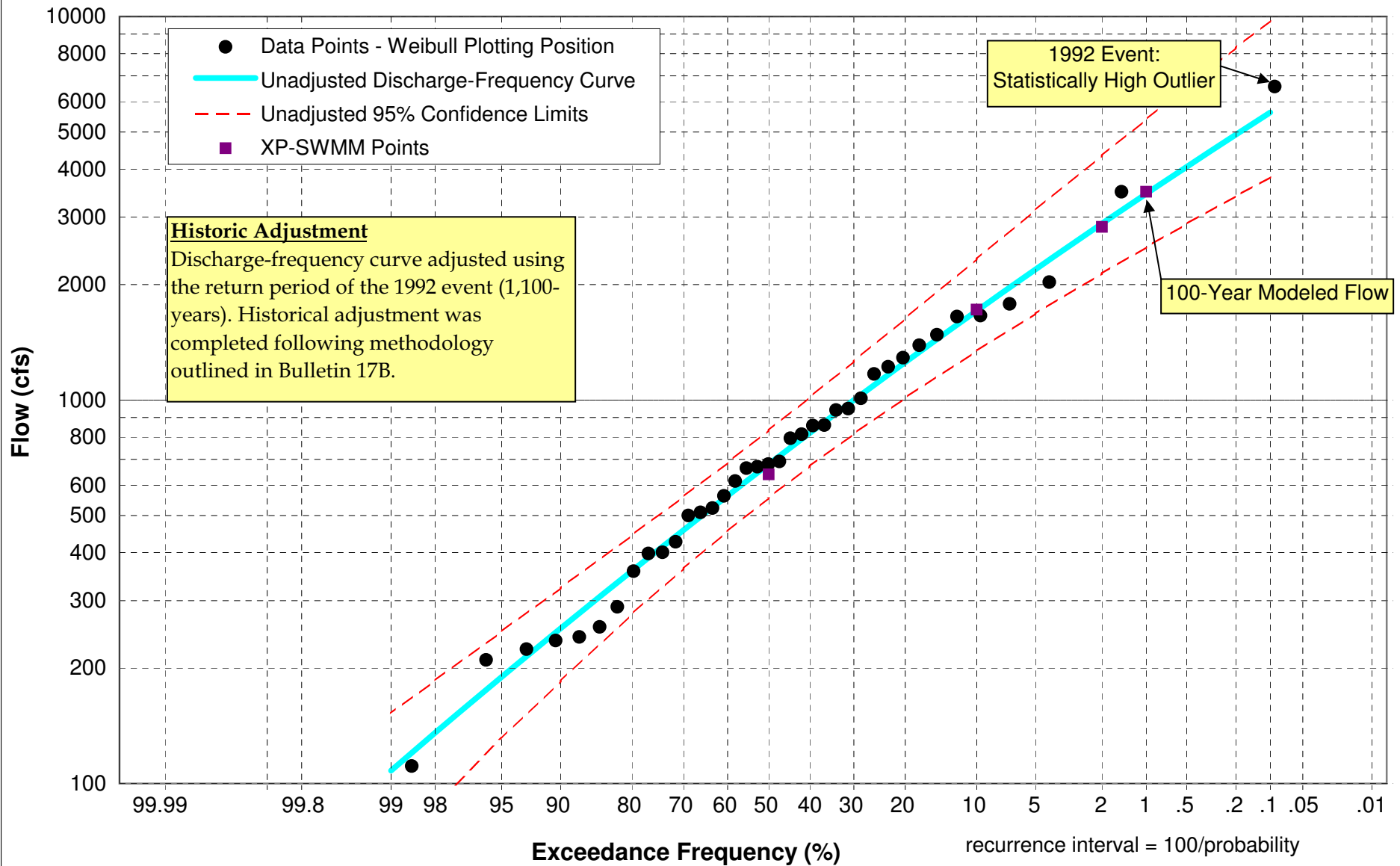


plot date: 4/7/2009

file: FreqCurves\_ver209\_66 HISTORIC ANALYSIS.xls

**Figure 5-39. Historically Adjusted USGS Discharge Frequency Curve  
Based on Precipitation Return Period**

*Annual Instantaneous Peaks (Record: 1942-1945, 1974-2007)*

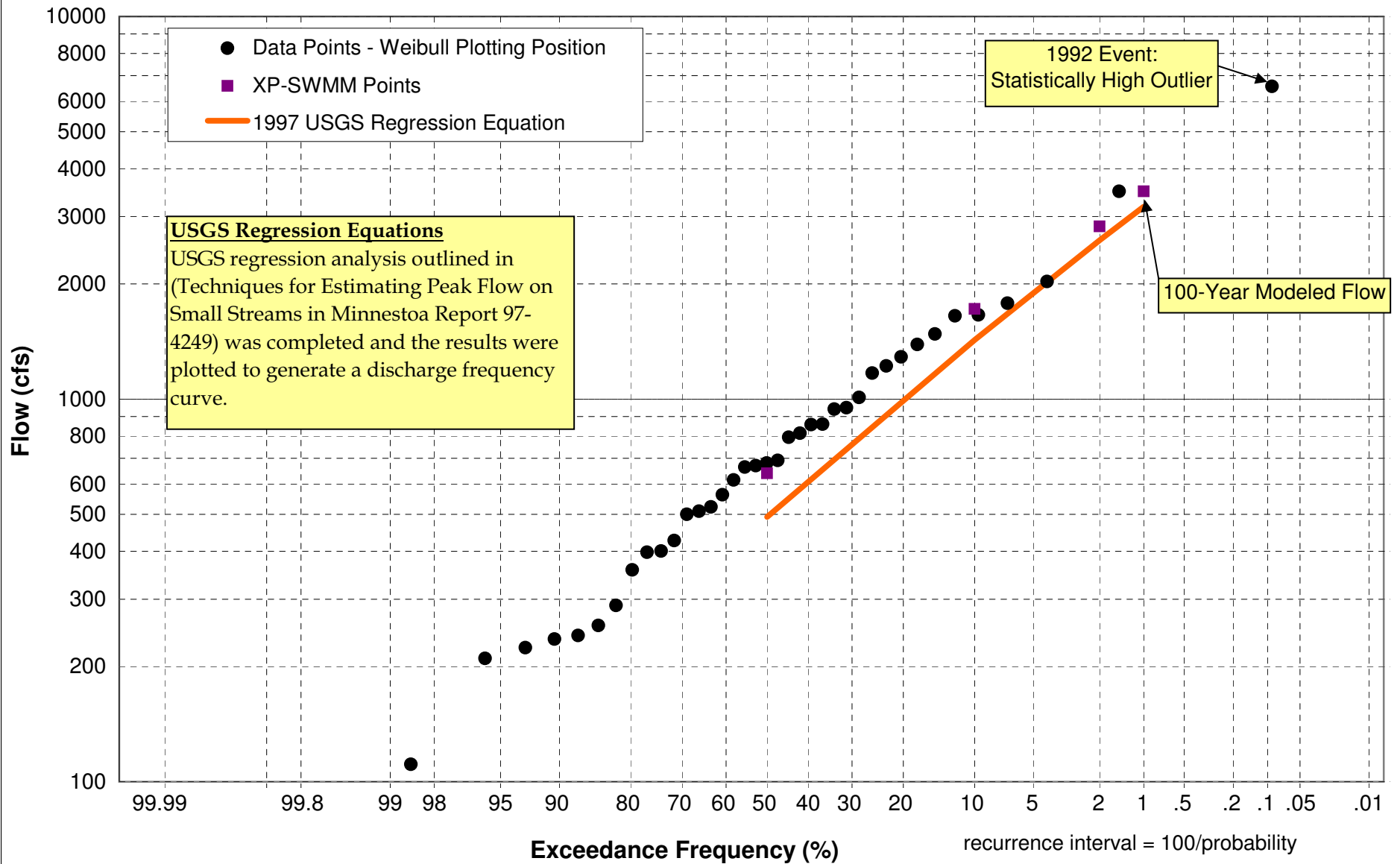


plot date: 4/7/2009

file: FreqCurves\_ver209\_1100 HISTORIC ANALYSIS.xls

**Figure 5-40. USGS Regression Equation Generated Discharge Frequency Curve  
at the USGS Station**

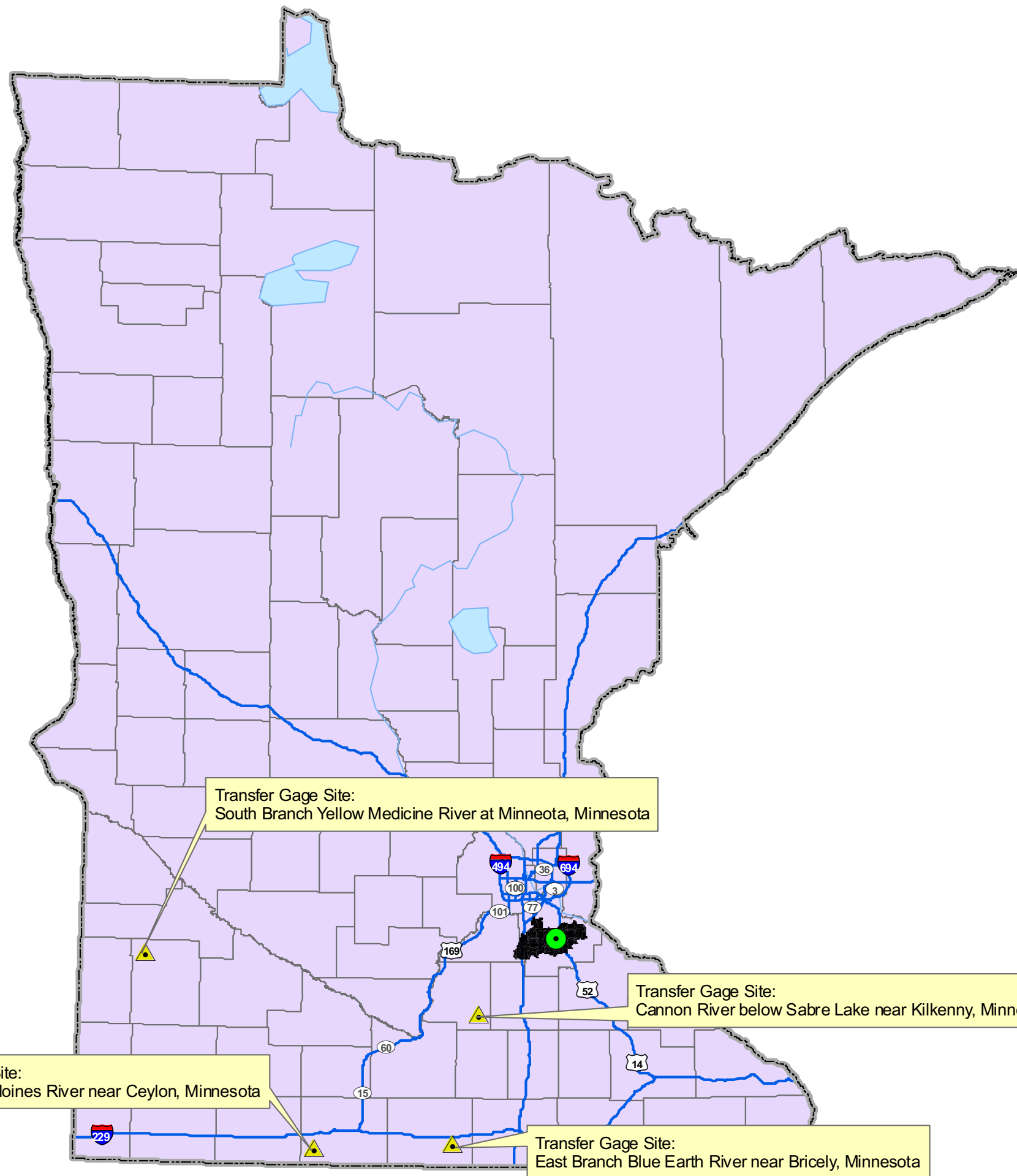
*Annual Instantaneous Peaks (Record: 1942-1945, 1974-2007)*



plot date: 4/7/2009

file: FreqCurves\_ver209\_USGS REGRESSION ANALYSIS.xls





## Legend

-  Vermillion River Study Area
-  USGS Station
-  Transfer Gages
-  State Boundary
-  Minnesota County Boundaries
-  Major Rivers
-  Major Lakes

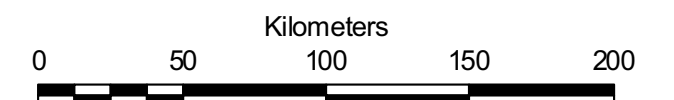
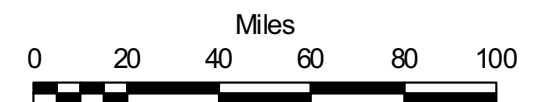
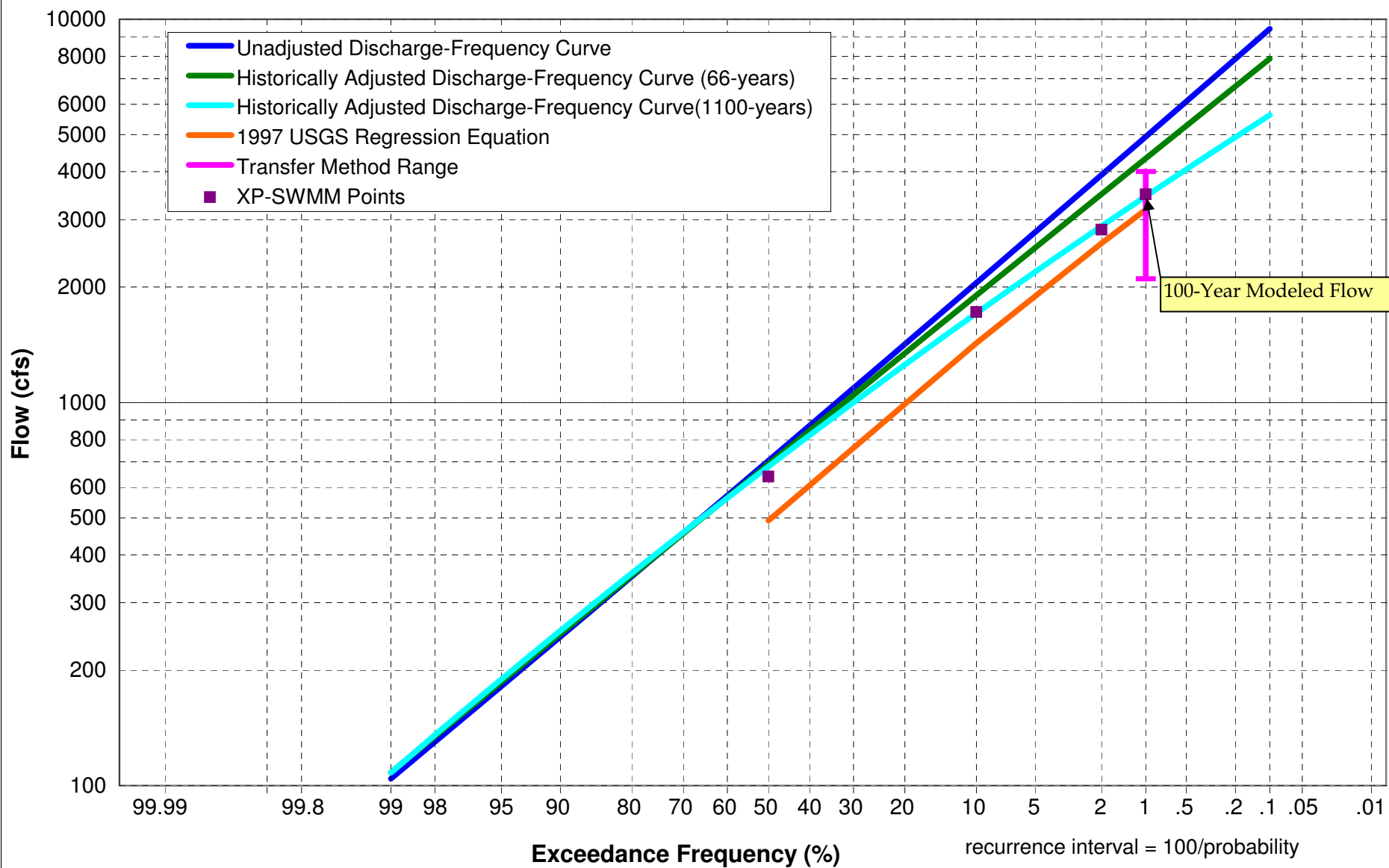


Figure 5-41

TRANSFER METHOD GAGE LOCATIONS  
VRWJPO Hydrologic Model  
Vermillion River Watershed

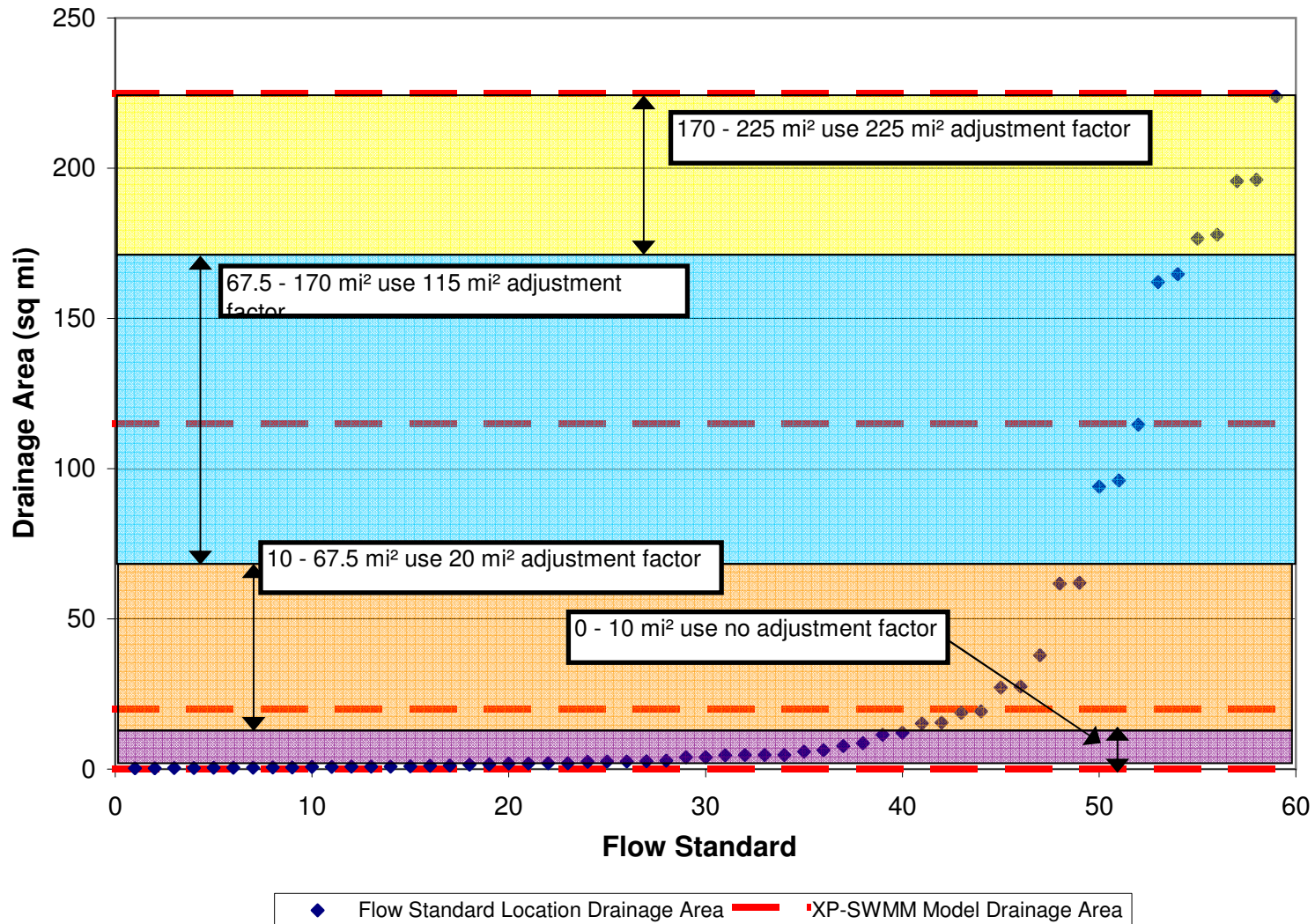
**Figure 5-42. Discharge Frequency Curve Summary at the USGS Station**  
*Annual Instantaneous Peaks (Record: 1942-1945, 1974-2007)*

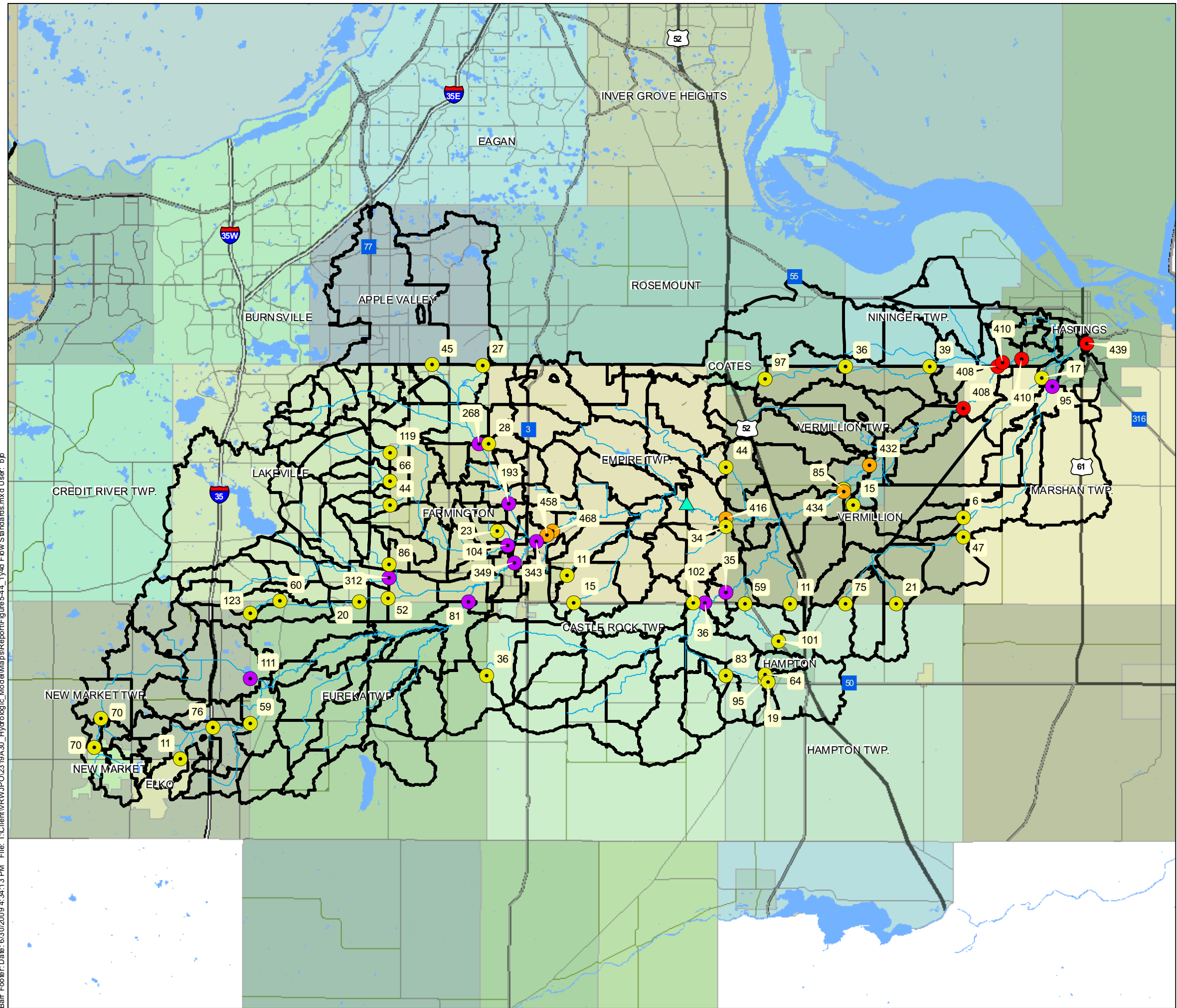


plot date: 4/7/2009

file: FreqCurves\_ver209\_SUMMARY\_Reduced Fo.xls

**Figure 5-43. Standard Locations Spatial Precipitation Adjustment Grouping**





# Legend

## Standard Locations

## Tributary Drainage Area

- 0-10 square miles
- 10-67.5 square miles
- 67.5-170 square miles
- 170-225 square miles
- ▲ USGS Station (420 cfs)

SWMM Links

Watersheds

Lakes

Peak flow rates listed in units of cfs.

Community Boundaries Source:  
Metropolitan Council, Updated as of 07/01/2005.

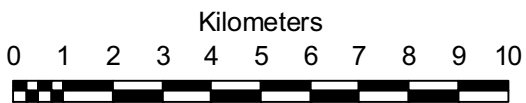
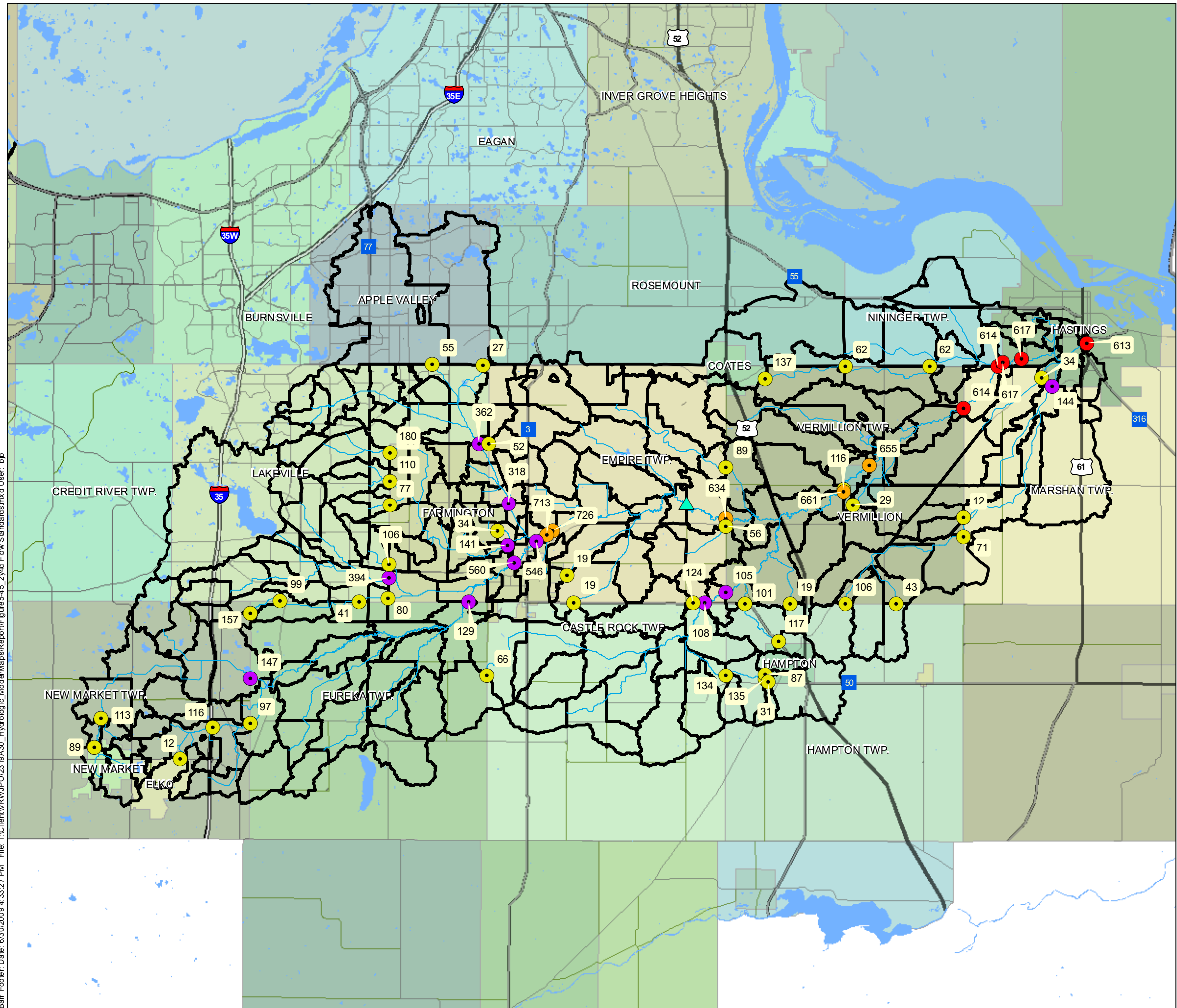


Figure 5-44

COMMUNITY FLOW STANDARDS  
1 Year 4 Day Peak Flow  
Vermillion River Hydrologic Model  
Vermillion River Watershed





## Legend

### Standard Locations

### Tributary Drainage Area

- 0-10 square miles
- 10-67.5 square miles
- 67.5-170 square miles
- 170-225 square miles
- ▲ USGS Station (640 cfs)

— SWMM Links

□ Watersheds

■ Lakes

Peak flow rates listed in units of cfs.

Community Boundaries Source:  
Metropolitan Council, Updated as of 07/01/2005.

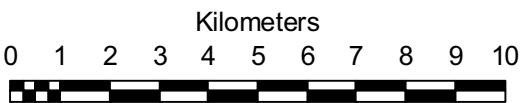
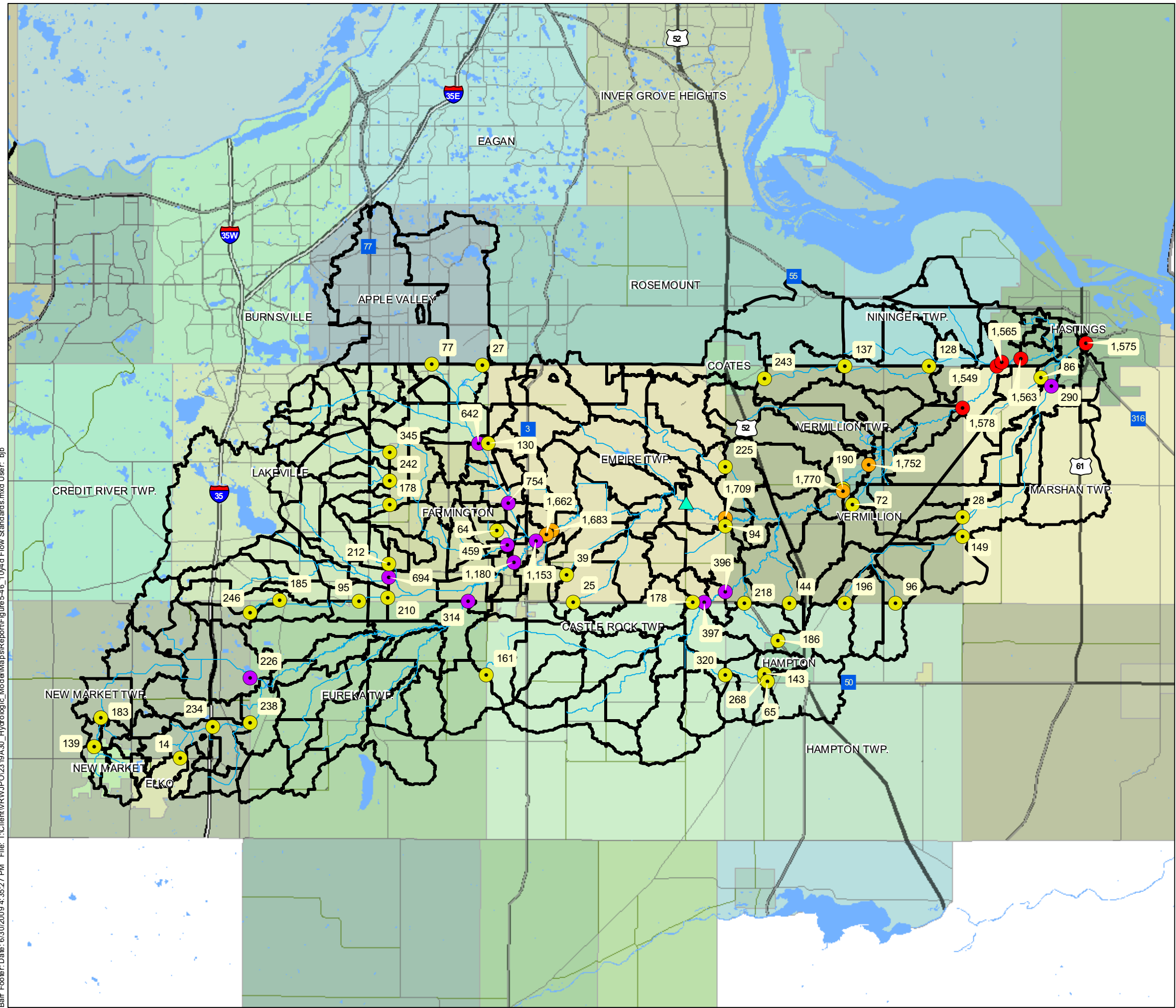


Figure 5-45

COMMUNITY FLOW STANDARDS  
2 Year 4 Day Peak Flow  
Vermillion River Hydrologic Model  
Vermillion River Watershed

Barr Footer: Date: 6/30/2009 4:35:27 PM File: I:\Client\VRW\JPO\2319A30\_Hydrologic\_Model\Maps\Report\Figure5-46\_10y4d Flow Standards.mxd User: bjb



## Legend

### Standard Locations

### Tributary Drainage Area

- 0-10 square miles
- 10-67.5 square miles
- 67.5-170 square miles
- 170-225 square miles
- ▲ USGS Station (1,721 cfs)

— SWMM Links

□ Watersheds

■ Lakes

Peak flow rates listed in units of cfs.

Community Boundaries Source:  
Metropolitan Council, Updated as of 07/01/2005.

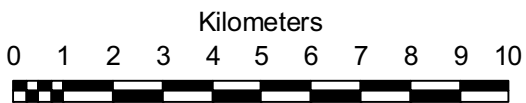
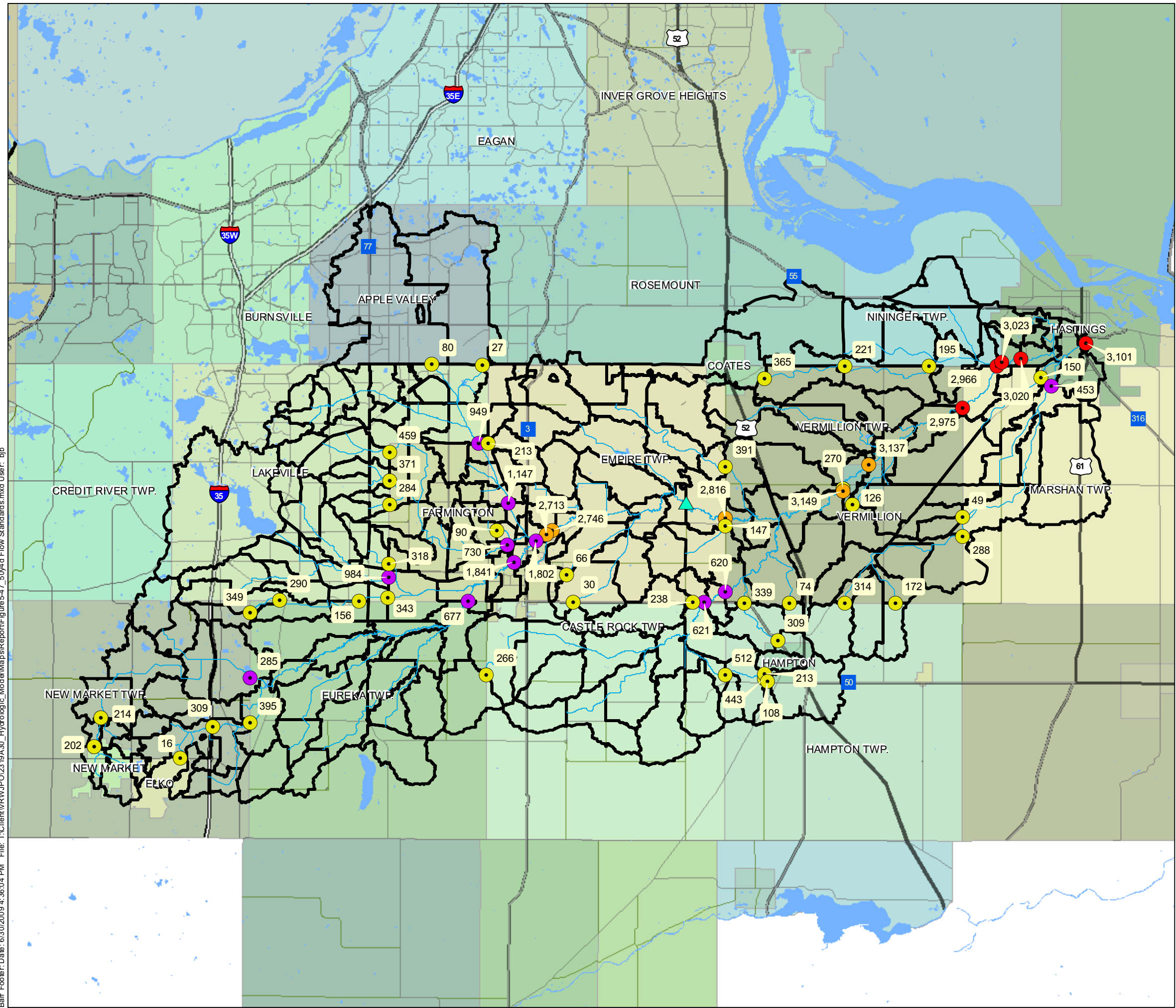


Figure 5-46

COMMUNITY FLOW STANDARDS  
10 Year 4 Day Peak Flow  
Vermillion River Hydrologic Model  
Vermillion River Watershed





## Legend

### Standard Locations

### Tributary Drainage Area

- 0-10 square miles
- 10-67.5 square miles
- 67.5-170 square miles
- 170-225 square miles
- ▲ USGS Station (2,826 cfs)

— SWMM Links

□ Watersheds

■ Lakes

Peak flow rates listed in units of cfs.

Community Boundaries Source:  
Metropolitan Council, Updated as of 07/01/2005.

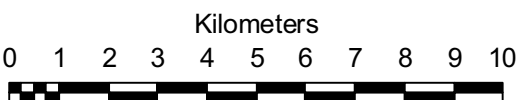
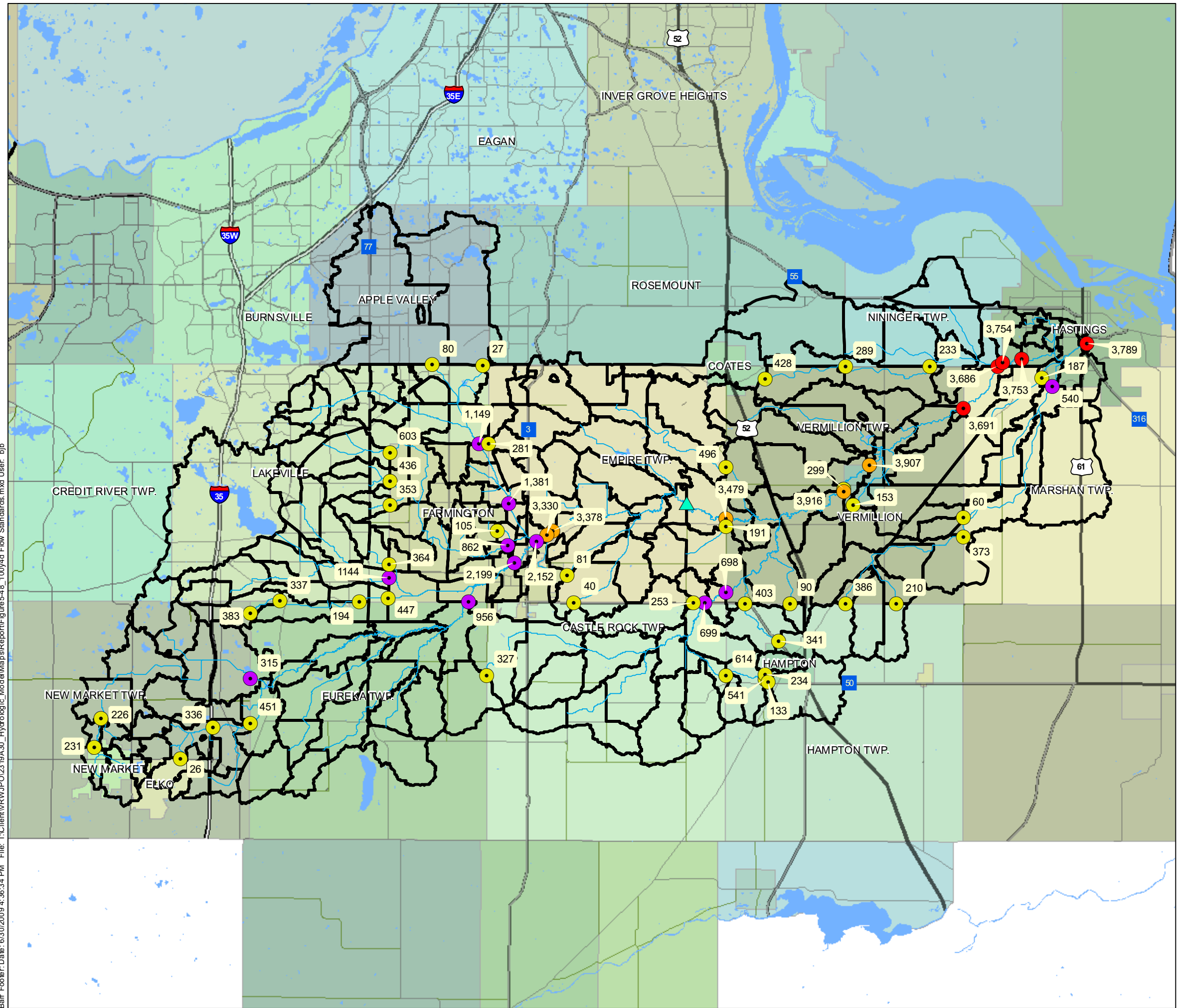


Figure 5-47

COMMUNITY FLOW STANDARDS  
50 Year 4 Day Peak Flow  
Vermillion River Hydrologic Model  
Vermillion River Watershed





# Legend

## Standard Locations

### Tributary Drainage Area

- 0-10 square miles
- 10-67.5 square miles
- 67.5-170 square miles
- 170-225 square miles
- USGS Station (3,494 cfs)

SWMM Links

Watersheds

Lakes

Peak flow rates listed in units of cfs.

Community Boundaries Source:  
Metropolitan Council, Updated as of 07/01/2005.

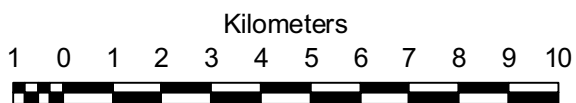
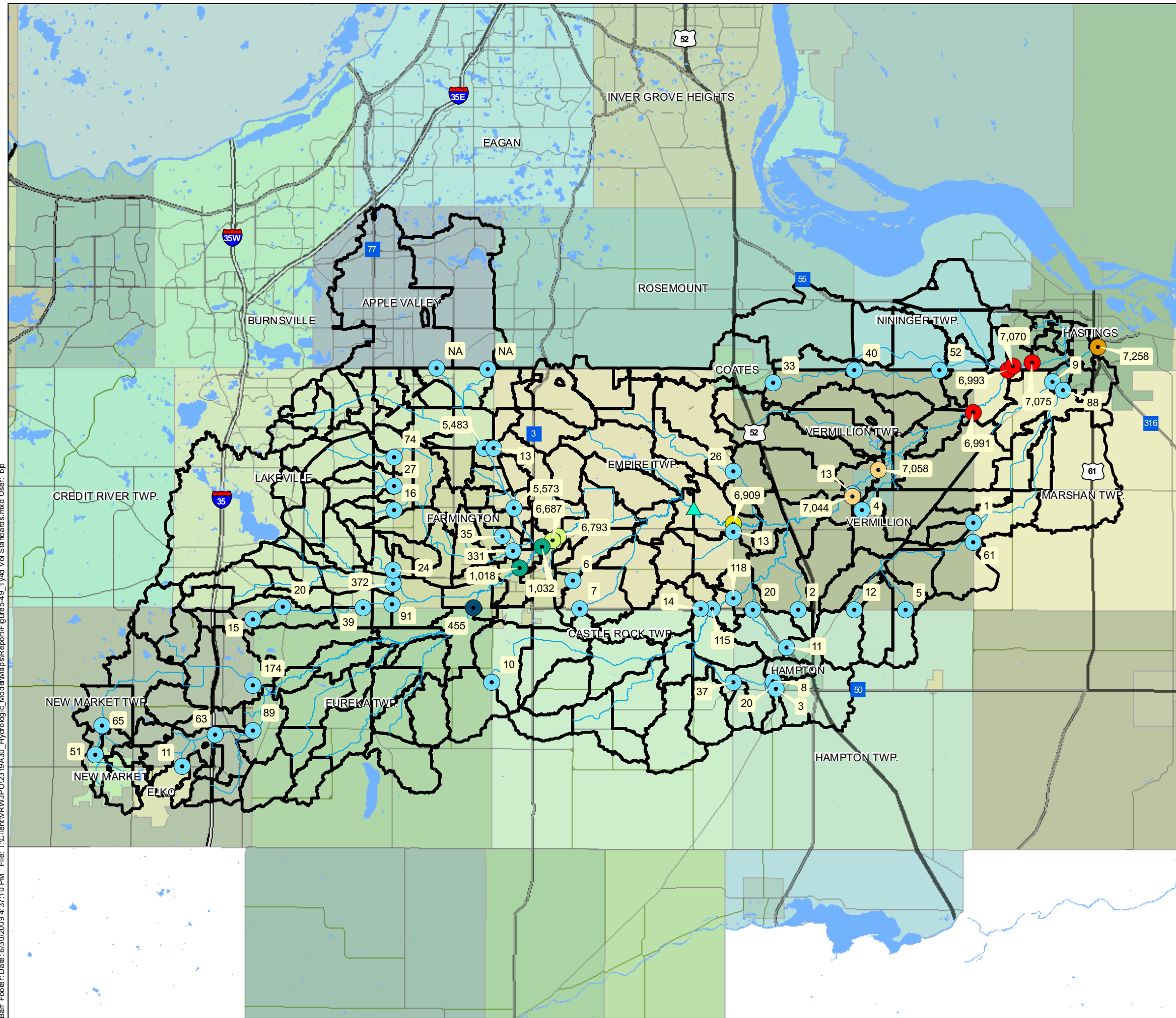


Figure 5-48

COMMUNITY FLOW STANDARDS  
100 Year 4 Day Peak Flow  
Vermillion River Hydrologic Model  
Vermillion River Watershed



## Legend

### Standard Locations

#### Baseflow

- 0 cfs
- 1 cfs
- 10 cfs
- 16 cfs
- 30 cfs
- 39 cfs
- 50 cfs
- 58 cfs
- USGS Station (6,908 ac-ft)

SWMM Links

Watersheds

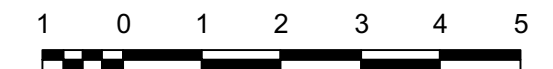
Lakes

Runoff volumes listed in units of ac-ft.

Community Boundaries Source:  
Metropolitan Council, Updated as of 07/01/2005.



Miles



Kilometers

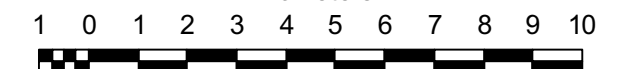
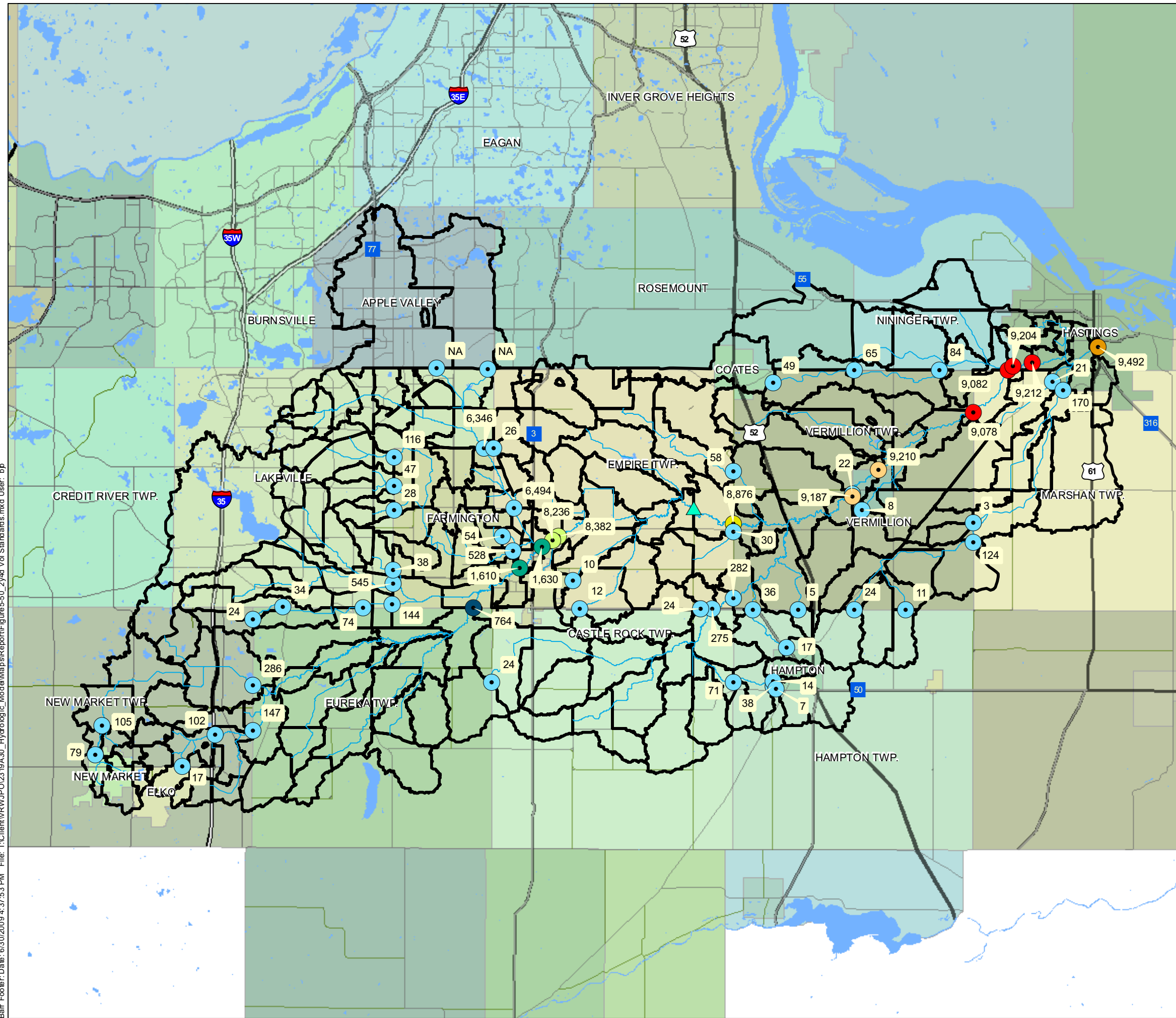


Figure 5-49

COMMUNITY VOLUME STANDARDS  
1 Year 4 Day Runoff Volume  
Vermillion River Hydrologic Model  
Vermillion River Watershed





### Legend

#### Standard Locations

##### Baseflow

- 0 cfs
- 1 cfs
- 10 cfs
- 16 cfs
- 30 cfs
- 39 cfs
- 50 cfs
- 58 cfs
- USGS Station (8,873 ac-ft)
- SWMM Links
- Watersheds
- Lakes

Runoff volumes listed in units of ac-ft.

Community Boundaries Source:  
Metropolitan Council, Updated as of 07/01/2005.

Miles

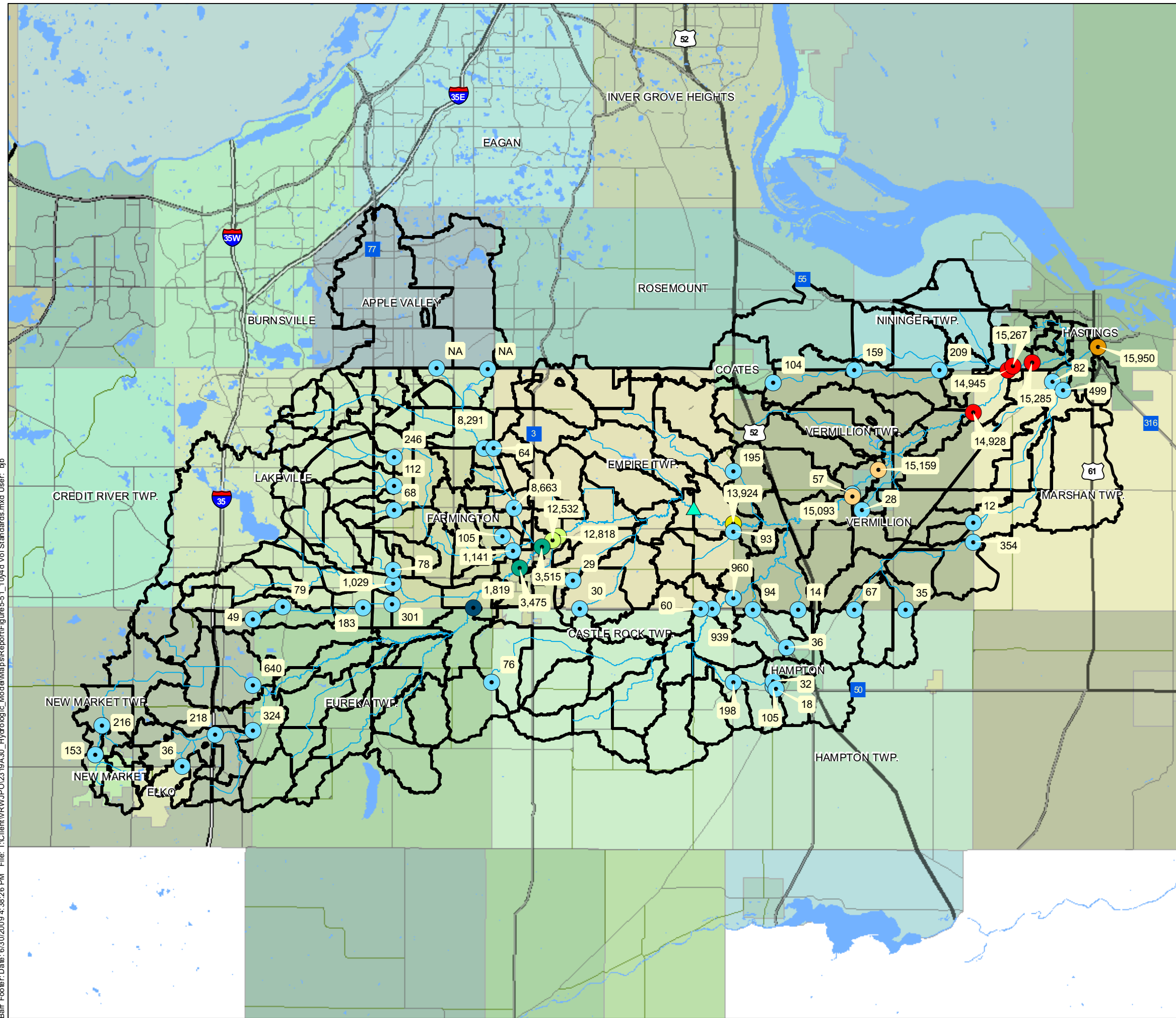
1 0 1 2 3 4 5

Kilometers

1 0 1 2 3 4 5 6 7 8 9 10

Figure 5-50

COMMUNITY VOLUME STANDARDS  
2 Year 4 Day Runoff Volume  
Vermillion River Hydrologic Model  
Vermillion River Watershed



## Legend

### Standard Locations

#### Baseflow

- 0 cfs
- 1 cfs
- 10 cfs
- 16 cfs
- 30 cfs
- 39 cfs
- 50 cfs
- 58 cfs
- USGS Station (13,907 ac-ft)

SWMM Links

Watersheds

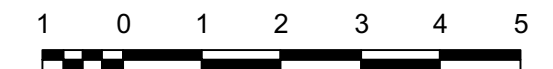
Lakes

Runoff volumes listed in units of ac-ft.

Community Boundaries Source:  
Metropolitan Council, Updated as of 07/01/2005.



Miles



Kilometers

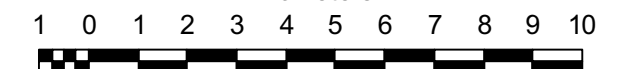
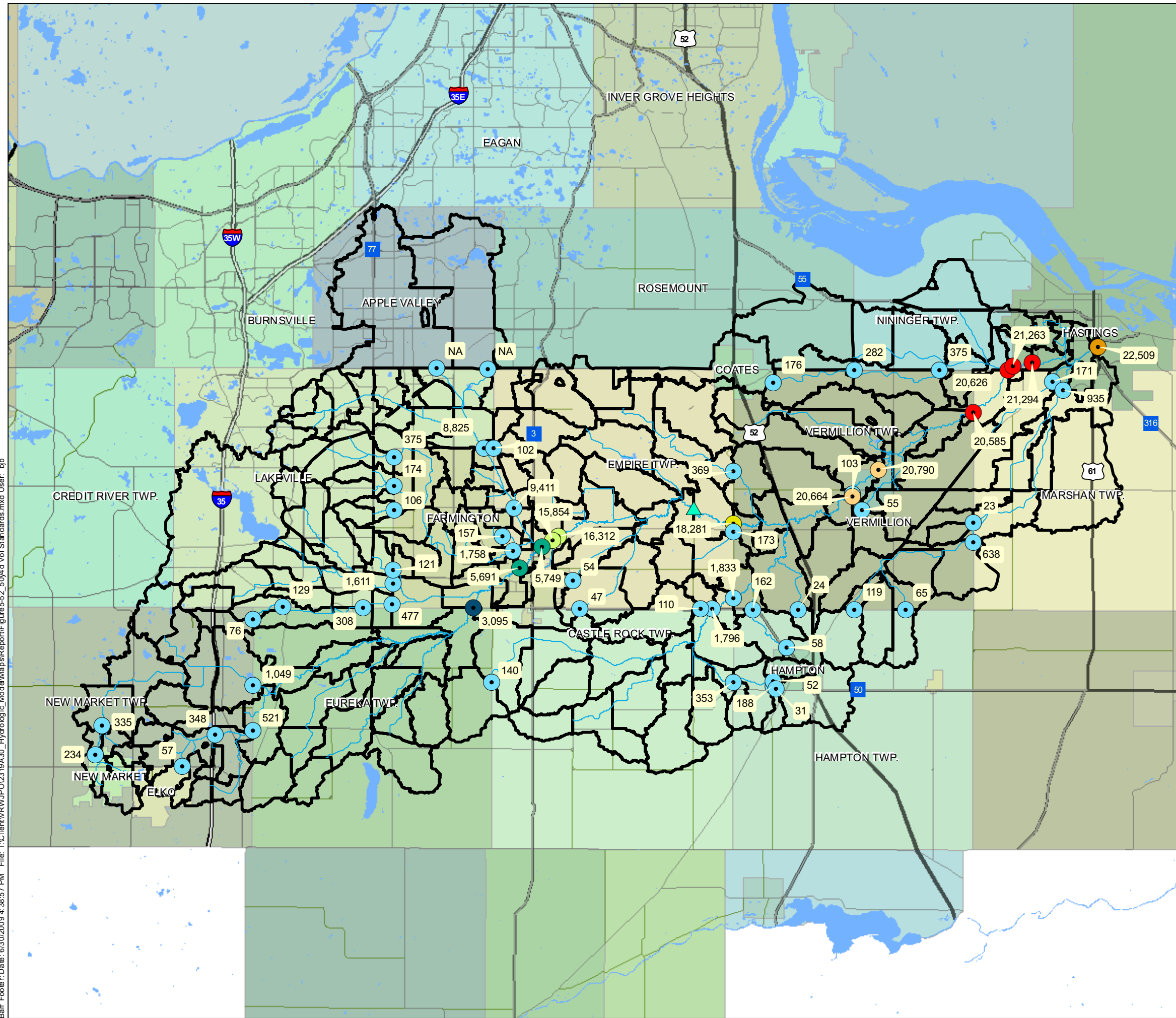


Figure 5-51

COMMUNITY VOLUME STANDARDS  
10 Year 4 Day Runoff Volume  
Vermillion River Hydrologic Model  
Vermillion River Watershed





## Legend

### Standard Locations

#### Baseflow

- 0 cfs
- 1 cfs
- 10 cfs
- 16 cfs
- 30 cfs
- 39 cfs
- 50 cfs
- 58 cfs
- USGS Station (18,240 ac-ft)

SWMM Links

Watersheds

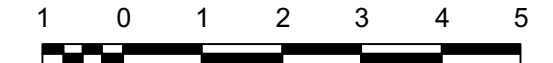
Lakes

Runoff volumes listed in units of ac-ft.

Community Boundaries Source:  
Metropolitan Council, Updated as of 07/01/2005.



Miles



Kilometers

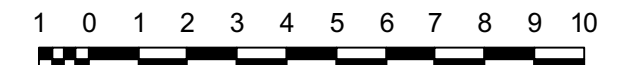
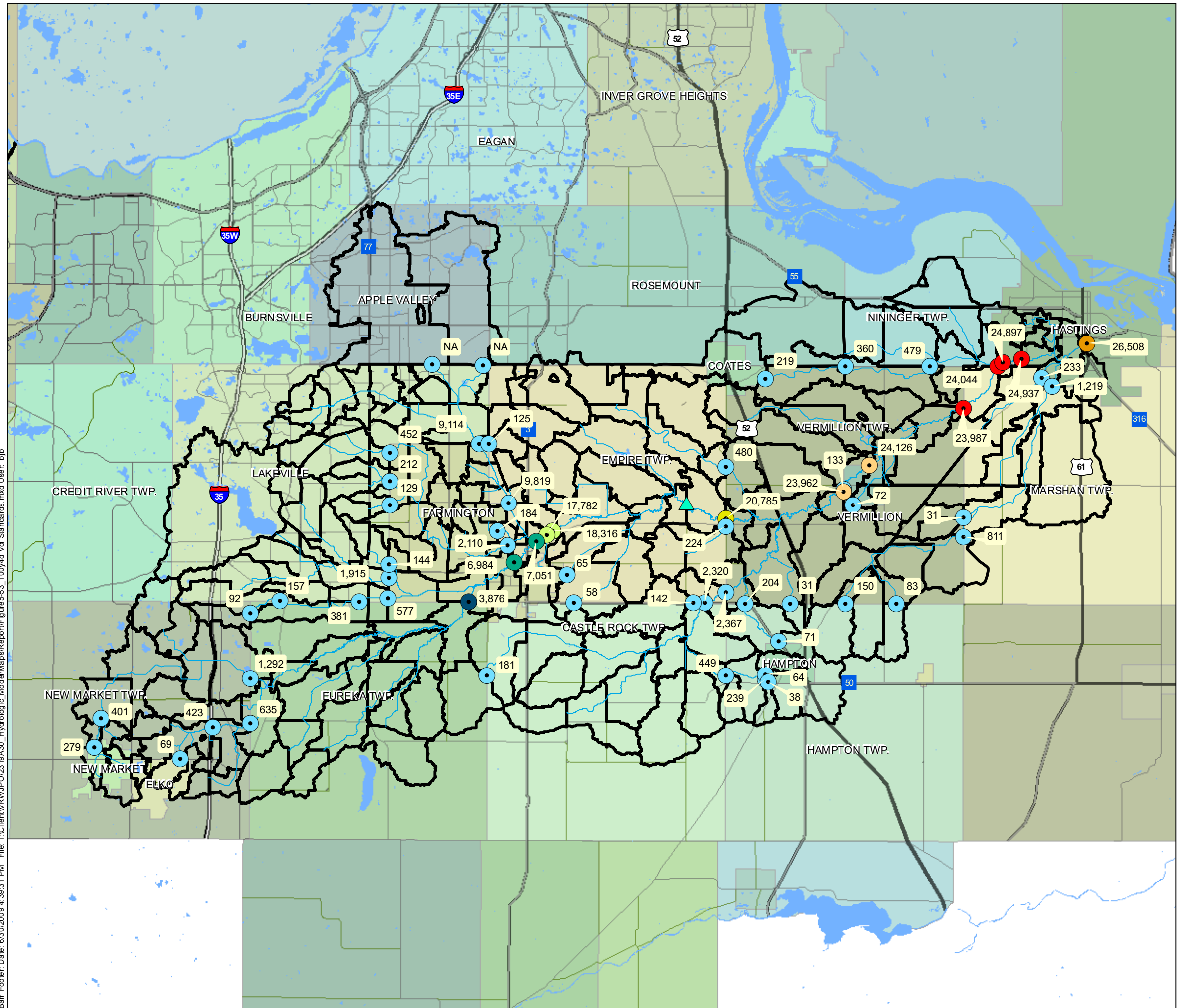


Figure 5-52

COMMUNITY VOLUME STANDARDS  
50 Year 4 Day Runoff Volume  
Vermillion River Hydrologic Model  
Vermillion River Watershed

Barr Footer: Date: 6/30/2009 4:39:31 PM File: I:\Client\VRW\JPO\2319A30\_Hydrologic\_Model\Maps\Report\Figure5-53\_100y4d Vd Standards.mxd User: bjb



## Legend

### Standard Locations

#### Baseflow

- 0 cfs
- 1 cfs
- 10 cfs
- 16 cfs
- 30 cfs
- 39 cfs
- 50 cfs
- 58 cfs
- USGS Station (20,728 ac-ft)

SWMM Links

Watersheds

Lakes

Runoff volumes listed in units of ac-ft.

Community Boundaries Source:  
Metropolitan Council, Updated as of 07/01/2005.



Miles



Kilometers

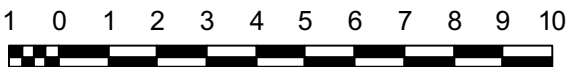


Figure 5-53

COMMUNITY VOLUME STANDARDS  
100 Year 4 Day Runoff Volume  
Vermillion River Hydrologic Model  
Vermillion River Watershed

## 6.0 Recommendations

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During this study, several issues were identified related to the overall implementation of the results and should be considered in the future. This section briefly describes these issues.

During the calibration process, it was discovered that the rating curves that were developed at Dakota County SWCD monitoring station locations were developed using observations collected during low flow conditions. The absence of high flow observations for the rating curves requires interpolation of high flow rates based on rough approximations during large precipitation events, and introduces uncertainty into the calculated high flows. It is recommended that the Dakota County SWCD attempt to collect high flow measurements to revise the rating curves within the Vermillion River watershed. This would reduce the uncertainty associated with interpolating high flows on the rating curves for the watershed gaging stations.

The calibrated XP-SWMM model was developed for the specific application of aiding the VRWJPO in regulating development throughout the watershed. Municipalities within the watershed have inquired about how this study will impact current FEMA studies ([Appendix I](#)). While the flow rates from the calibrated model were compared to flow rates used in previous FEMA studies, the intended application of this model was not to update current FEMA studies at this time. Therefore, the calibrated XP-SWMM model was not submitted to the IAHR. Additionally, submission of the XP-SWMM model to the IAHR for further review was not part of the scope for this study, but may be included in a future project. Since the revised flows rates are in some cases significantly lower than the flow rates in the DFIRM, processing the update with FEMA may be beneficial to local landowners and county floodplain coordinators. Therefore, the ITR Committee recommends the VRWJPO consider this request at a later date.

The inflows from Apple Valley were part of a previous modeling effort that was agreed on by Apple Valley, Lakeville, and the VRWJPO. The calibrated XP-SWMM model does not include these subwatersheds, but only incorporates the discharges into the calibrated model. This results in accurately predicting peak flow rates at standard locations, but does not provide the VRWJPO a tool to regulate the change total volume discharged at the Apple Valley-Lakeville standard locations due to development in the Apple Valley subwatersheds. It is recommended the VRWJPO obtain a copy of the model used to determine inflows from Apple Valley to use as a baseline for future development. This would allow the VRWJPO to regulate the total volume discharged due to development in Apple Valley with the same level of detail as the rest of the contributing watershed.



## 7.0 References

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