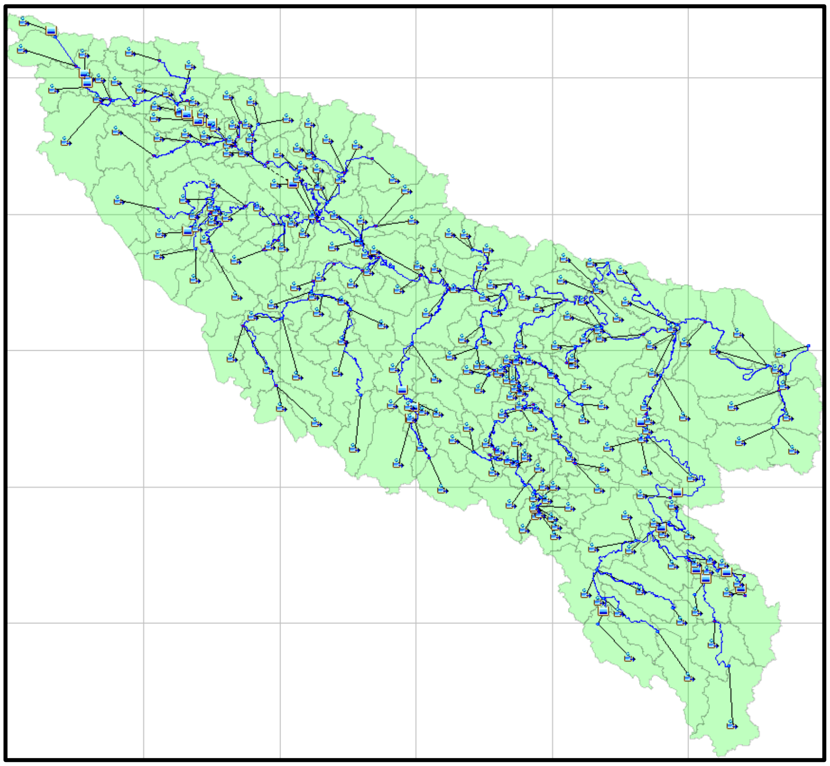
Sava River Basin Flood Study: HEC-HMS Technical Documentation Report



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INTERNATIONAL SAVA RIVER BASIN COMMISSION

US EUROPEAN COMMAND EUCOM

UNITED STATES OF AMERICA · ZAGREB · CROATIA

US Army Corps of Engineers

Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

The International Sava River Basin Commission (ISRBC) is composed of the four Sava Riparian countries, Bosnia and Herzegovina, Croatia, Serbia, and Slovenia, as the parties ratifying the Framework Agreement on the Sava River Basin (FASRB) in 2002. In addition, a Memorandum of Understanding on cooperation between the ISRBC and Montenegro was signed in December of 2013. The FASRB forms the basis for transboundary cooperation of governments, institutions, and individuals for sustainable development of the Sava River Basin (ISRBC 2016). The ISRBC, as a joint institution comprised of members from the ratifying countries, is charged with coordinating the implementation of the FASRB under a permanent Secretariat as its executive body (ISRBC 2016). The ISRBC provides political and economic stability within the area through its support of international navigation, sustainable water resources management, and hazard risk reduction within the river basin, which are the three main goals of the FASRB. The U.S. Government has an abiding interest in peaceful multilateral cooperation by the Sava River Basin nations to develop their water resources for mutual benefit, which is the underpinning goal of the relationship between the US and the ISRBC and member countries.

The ISRBC's Permanent Expert Group for Flood Prevention (PEG FP) is charged with developing a flood risk assessment methodology leading to joint identification of potential significant flood risk areas, preparation of joint flood risk and flood hazard maps, developing and implementing a flood risk management plan, and design and implementation of a joint flood forecasting and flood warning system. The overall goal of this project is to develop hydrologic and hydraulic (H&H) modeling to support these endeavors of the PEG FP.

Currently, the H&H modeling in the Sava region consists of a discontinuous collection of models developed using various software applications across multiple jurisdictional boundaries. The PEG FP desires to apply a systems-based approach to floodplain management and to develop H&H models of the Sava River Watershed that will be shared between the member nations. To aid the ISRBC and its member countries to achieve the goal of a system-wide H&H model, the U.S. Government is providing technical support through the US Army Corps of Engineers (USACE) by developing a comprehensive hydrologic model of the Sava River Basin and a hydraulic model of the Sava River. The models will be used to prepare flood inundation mapping and to support the flood forecasting system. Successful development of the joint Sava River Watershed H&H models will have a direct impact on international efforts to develop integrated flood hazard and risk maps, integrated data collection, and flood forecasting and warning systems, which will reduce vulnerability to natural, technological, and willful hazards.

The purpose of this document is to provide a general description of the hydrologic model development. The hydrologic model product includes not only a basin-wide hydrologic model, but also hydrologic models of each major tributary and mainstem basin within the Sava River Basin. USACE has developed hydrologic models for this project using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) software. All HEC-HMS models are provided to the ISRBC and member countries in HEC-HMS version 4.2.

1.1 AUTHORITY

The Humanitarian Assistance (HA) program is authorized by title 10 U.S.C., section 2561, and its projects are funded by the Overseas Humanitarian, Disaster and Civic Aid (OHDACA) Appropriation. Projects include the refurbishment of medical facilities, construction of school buildings, digging of wells, improvement of sanitary facilities, and training of host country personnel in internally displaced person and refugee repatriation operations, as well as in disaster relief and emergency response planning.

Cooperating agencies and nations participating in the Sava River modeling effort include the ISRBC, Slovenia, Croatia, Bosnia & Herzegovina, Serbia, the U.S. Army, the U.S. Department of State, and USACE.

1.2 BASIN INFORMATION

The Sava River Basin (Figure 1) is a major drainage basin of the Danube River watershed, located in southeastern Europe with a total area of approximately 97,700 km^2, which comprises about 12% of the total Danube River drainage area. The Sava River also represents the third longest tributary and the largest discharge to the Danube River at approximately 945 km long and an average discharge of 1,700 m^3/s at Belgrade, respectively. The Sava River Basin is shared among six countries: Slovenia (12% by area), Bosnia & Herzegovina (39.2% by area), Croatia (26% by area), Serbia (15.5% by area), Montenegro (7% by area), and Albania (0.2% by area). The Sava River headwaters begin in the Slovenian Alps, draining through Croatia and Bosnia and Herzegovina to the confluence with the Danube River in Serbia. The Sava River Basin represents not only an important water resource for the region as a potential flood hazard, but also hosts outstanding biological and landscape diversity and provides a substantial contribution to the local economy through its navigation capability.

The Sava River Basin has endured several major floods in its history, most recently in May 2014 when several casualties and wide spread economic damages were experienced. To reduce flooding risk for the inhabitants of the basin, several structures and systems have been implemented including an extensive levee system and complex diversion and offline flood storage area system for attenuating damaging flood waves. These flood protection features are extremely important to the livelihood of the inhabitants in the region as most of the population resides within the historical Sava floodplains, which are flat and low-lying areas highly susceptible to flooding. Without the extensive flood protection system, widespread flooding would be endured much more frequently.

Figure 1: Overview Map of the Sava River Basin

2. PRELIMINARY CONSIDERATIONS FOR MODEL DEVELOPMENT

The purpose of this section is to describe initial efforts performed as part of the hydrologic model development for the Sava River watershed. These initial tasks included: extensive data acquisition; hydrologic model development; the creation of a logical hydrologic element naming convention; the determination of possible storm event model calibration periods; and the establishment of model performance metrics.

2.1 WATCAP MODEL

In 2015, the ISRBC completed the Water and Climate Adaptation Plan (WATCAP) for the Sava River Basin. The purpose of this project was to assess the potential impacts of climate change on various water sectors such as navigation, hydropower, flood control, and irrigation. This project was funded by the World Bank and was conducted from 2012-2015. One of the products of this project was an HEC-HMS hydrologic model of the Sava River Basin. USACE utilized this model as a starting point for the development of the HEC-HMS models developed as part of this project. The WATCAP HEC-HMS model is a long-term continuous simulation model run at a daily time interval, which is much different than the type of model necessary for this project. The goal of this project is to develop a model capable of simulating flood events at an hourly time interval.

The Sava River WATCAP hydrology model was delineated by subdividing the basin at hydrologic station locations with known contributing drainage areas. A review of the original WATCAP delineation determined that using a GIS-based approach to divide the watershed would be more appropriate, and ultimately led to the development of a more refined hydrology model which better captures the magnitude, timing, and attenuation of flood events. To accomplish this, HEC-GeoHMS was used to develop delineations for the HEC-HMS models. *Section* 3 of this report details the specific HEC-GeoHMS processes used as part of the hydrologic model development. Although the original WATCAP model delineation was not adopted for this study, it provided the input parameters necessary for long-term model simulations including evapotranspiration, canopy, and initial snowmelt.

2.2 DATA ACQUISITION

The majority of hydrologic data and information used for model development was provided by the ISRBC. Any additional information needed during the development of hydrologic model development was requested through the IRSBC, who subsequently communicated with the individual member countries' experts to acquire the necessary data. A substantial amount of data was collected as part of previous modeling efforts.

Hydrologic models typically use meteorological data such as precipitation and temperature as the primary input, while hydrologic data such as observed river discharges serves as a means of calibrating the computed model discharge. Hourly and/or sub-hourly meteorologic and hydrologic time series data was necessary due to the short-term event-based simulations evaluated for the Sava River and its tributaries. Data of a higher temporal resolution made it possible to capture the changes in precipitation, hydrograph timing, and discharge magnitude needed to accurately simulate a wide range of flooding events. The effort of collecting and processing this data from the various member countries and country agencies was demanding but vital to the success of the modeling product.

In addition to meteorologic and hydrologic data, additional data was acquired that aided in the development of the hydrologic model. This information included:

- GIS-based existing basin delineations from various sources including the ISRBC and member countries
- GIS-based drainage network for major tributaries and mainstem Sava River
- GIS-based locations of available meteorologic and hydrologic stations
- Various flood reports including December 2010 and May 2014 flood events
- ISRBC hydro yearbooks
- GIS-based flood risk maps for Croatia
- GIS land cover dataset
- Information related to dams and reservoirs located in the Vrbas and Drina Watersheds
- GIS-based levee centerlines

Advanced Microwave Scanning Radiometer (AMSR-E)/Aqua Level 3 global snow water equivalent grids, which are developed by the National Aeronautics and Space Administration's (NASA) National Snow and Ice Data Center (NSIDC) in Boulder, Colorado USA, were also acquired and used to initialize the snowpack for the various calibration simulations (Tedesco et. al. 2004).

The HEC suite of software, including HEC-HMS and HEC-RAS, requires time series data inputs in a .dss format, which can stored be stored in databases and accessed through another HEC-developed program known as HEC-DSSVue. All of the gauge time series data for this project was compiled and stored into .dss format using HEC-DSSVue.

HEC-DSSVue provides the capability to view, manipulate, and perform quality control on all forms of time series data. HEC-DSSVue was developed specifically for hydrologic and hydraulic applications, and contains many tools to manipulate and perform analysis on time series data. The .dss format structure relies on a parted pathname scheme with six pathname parts, labeled A-F, delimited by slashes, "/". The six-part structure provides a descriptive method to store data and an efficient way to filter and group the data within the HEC-DSSVue software. The .dss pathname structure naming convention for this project is shown in Table 1.

Table 1: DSS Pathname Part Descriptions

Part	Description
A	Country Code: BA - Bosnia and Herzegovina; HR - Croatia; ME - Montenegro; RS - Serbia; SI - Slovenia
B	Location / Gauge Name
C	Data Parameter: Stage; Flow; Precipitation; Air Temperature
D	Date Range of Data
E	Time Interval
F	Additional User-Defined Descriptive Information: Most of the data for this project is observed data with the additional country code.

Direct interaction with the DSS database is typically performed in HEC-DSSVue. Figure 2 displays the HEC-DSSVue main window interface and Figure 3 illustrates the visualization of data plots and tables. A copy of the HEC-DSSVue file containing all of the time series data collected for this project is provided as part of the final submittal of this report.

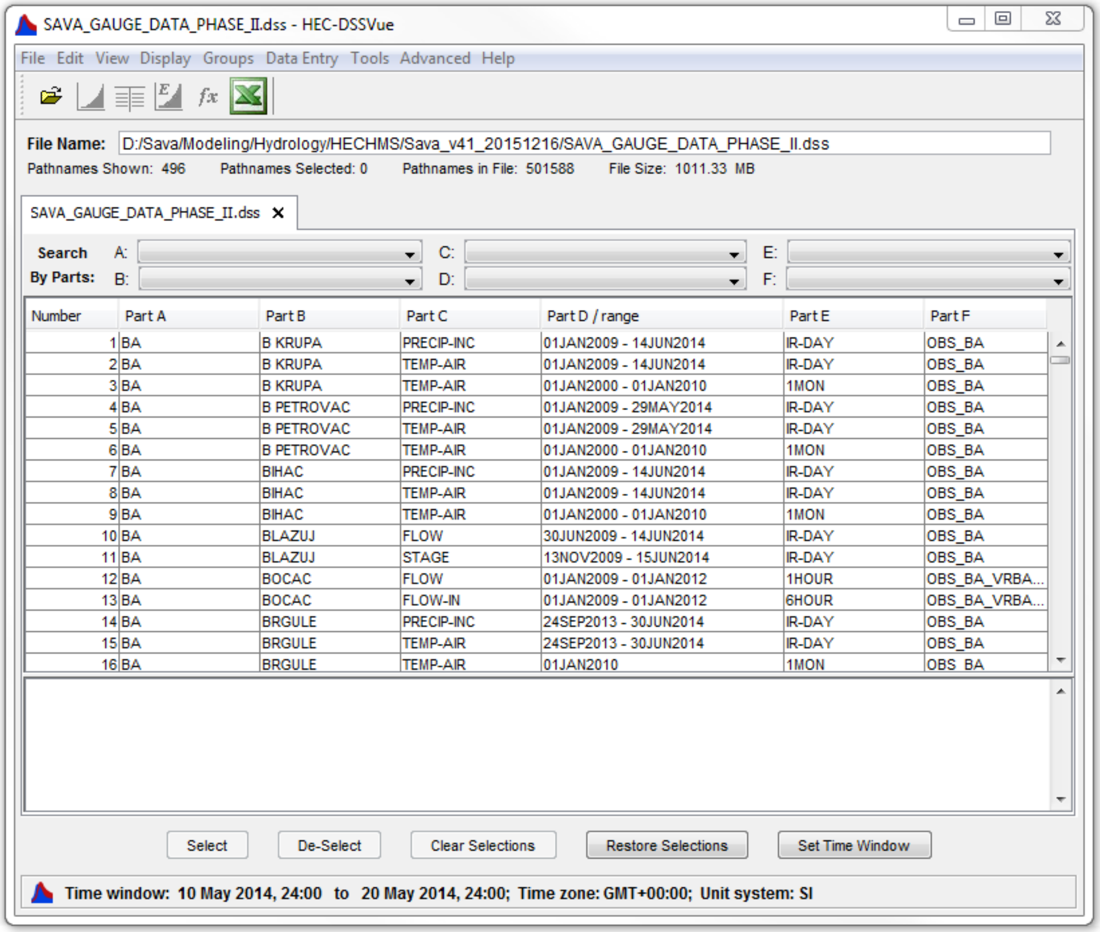
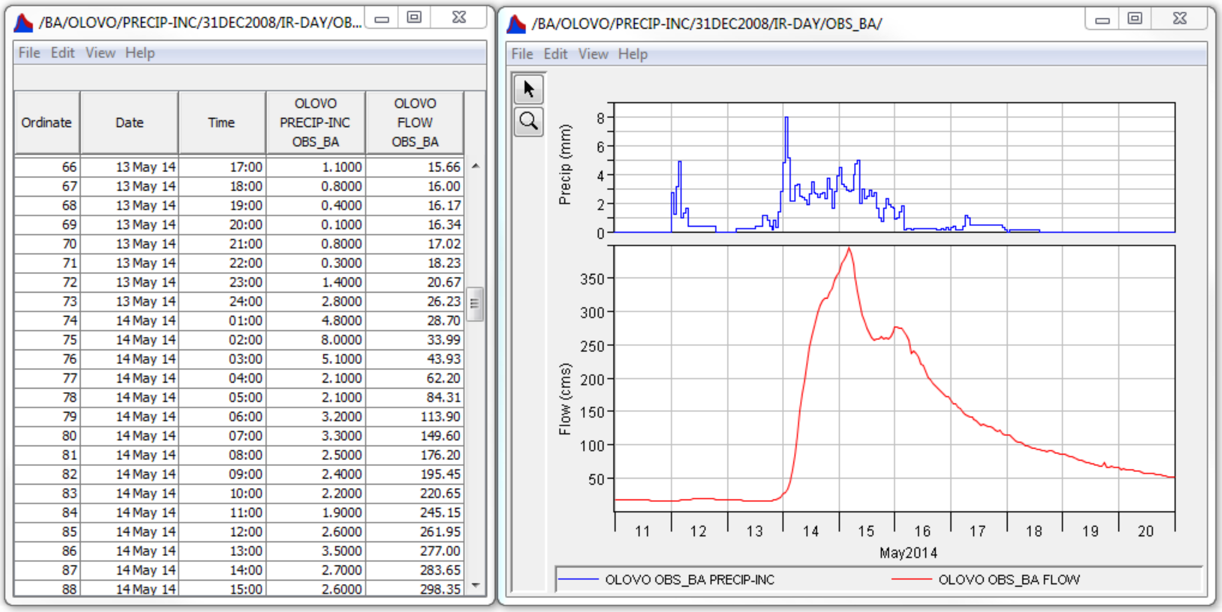


Figure 2: HEC-DSSVue Main Window Interface



Ordinate	Date	Time	OLOVO PRECIP-INC OBS_BA	OLOVO FLOW OBS_BA
66	13 May 14	17:00	1.1000	15.66
67	13 May 14	18:00	0.8000	16.00
68	13 May 14	19:00	0.4000	16.17
69	13 May 14	20:00	0.1000	16.34
70	13 May 14	21:00	0.8000	17.02
71	13 May 14	22:00	0.3000	18.23
72	13 May 14	23:00	1.4000	20.67
73	13 May 14	24:00	2.8000	26.23
74	14 May 14	01:00	4.8000	28.70
75	14 May 14	02:00	8.0000	33.99
76	14 May 14	03:00	5.1000	43.93
77	14 May 14	04:00	2.1000	62.20
78	14 May 14	05:00	2.1000	84.31
79	14 May 14	06:00	3.2000	113.90
80	14 May 14	07:00	3.3000	149.60
81	14 May 14	08:00	2.5000	176.20
82	14 May 14	09:00	2.4000	195.45
83	14 May 14	10:00	2.2000	220.65
84	14 May 14	11:00	1.9000	245.15
85	14 May 14	12:00	2.6000	261.95
86	14 May 14	13:00	3.5000	277.00
87	14 May 14	14:00	2.7000	283.65
88	14 May 14	15:00	2.6000	298.35

Figure 3: HEC-DSSVue Plot and Table Interface

2.3 HYDROLOGIC MODEL NAMING CONVENTION

Due to the size of the Sava River Basin and number of major tributaries, the effort to derive a logical hydrologic element naming convention proved challenging. A sensible naming convention allows users to manipulate the hydrologic model with greater ease, improving the functionality of the end product.

Any HEC-HMS model is composed of various basin elements. The most commonly used elements are subbasins, junctions, and reaches. The other types of elements included in the hydrologic models are sources and reservoirs. An HEC-HMS model applies precipitation to subbasin elements, transforms the precipitation into discharge hydrographs, and routes the discharge hydrographs through junction and river reach elements downstream to the basin outlet. The goal of the naming convention is to provide a logical nomenclature to define the hydrologic network that can sustain the unexpected changes that may occur throughout the future development of the model, such as choosing to combine or separate basin models. In addition, HEC-HMS limits the length of any hydrologic element name to 28 characters. Table 2 lists and describes the HEC-HMS elements used during this study.

Table 2: HEC-HMS Element Table

HEC-HMS Element	Description
Subbasin 	The subbasin is used to represent the physical watershed where precipitation is converted to runoff.
Junction 	The junction is used to combine streamflow from one or more elemets located upstream of the junction
Reach 	The reach is used to convey streamflow in the basin model from one element to another.
Source 	The source element is used to introduce flow into the basin model. The source has no inflow, and outflow from the source element is defined by the user. The source element is typically used to introduce observed flow or to make model connections from one basin model to another.
Reservoir 	The reservoir is used to model the detention and attenuation of a hydrograph caused by an impoundment of water such as a reservoir or detention pond.

Because the Sava River Basin was modeled as separate tributary and mainstem basins, a two-digit number code was assigned to each tributary and mainstem basin model. Table 3 lists these number codes and the corresponding basin. The table shows that Slovenia was originally named as one basin; however, through the model development process, the decision, in coordination with the ISRBC, was made to break the Slovenia basin into five separate basin models: Ljubljanica River; Savinja River; Krka River; and two Sava River mainstem basin models separated at the confluence between the Ljubljanica and Sava Rivers. Also, the decision was made to combine all of the Sava River mainstem local basin models into a single basin model connecting each of the tributary basin models to the combined mainstem model using source nodes. The basin numbering convention was maintained regardless of these changes to the model development in order to maintain location integrity of each HEC-HMS element within the Sava River basin.

Table 3: Tributary and Mainstem Basin Numbering Scheme

Basin	Number	Basin	Number	Basin	Number
Slovenia	01	Sava - Ilova to Una	11	Sava - Bosna to Tinja	21
Sutla	02	Una	12	Tinja	22
Sava - Sutla to Krapina	03	Sava - Una to Vrbas	13	Sava - Tinja to Drina	23
Krapina	04	Vrbas	14	Drina	24
Sava - Krapina to Kupa	05	Sava - Vrbas to Orljava	15	Sava - Drina to Bosut	25
Kupa	06	Orljava	16	Bosut	26
Sava - Kupa to Cesma	07	Sava - Orljava to Ukrina	17	Sava - Bosut to Kolubara	27
Cesma	08	Ukrina	18	Kolubara	28
Sava - Cesma to Ilova	09	Sava - Ukrina to Bosna	19	Sava - Kolubara to Mouth	29
Ilova	10	Bosna	20		

Another important consideration in naming hydrologic elements is the location of hydrologic gauging stations where observed data is available for calibration. A numbering code was developed to group HEC-HMS hydrologic elements by calibration zones, dictated by the presence of gauging stations. The final portion of the element numbering relates to its hydrologic order within the calibration zone. For elements where a hydrologic gauge exists, the name of the gauge is also included to provide the user with a clear understanding of where observed data is available for calibration.

In general, the complete naming convention is organized like this:

SCHEME

[Element Letter]_[Basin Number]_[Calibration Zone]_[Hydrologic Order within Calibration Zone]_[Gauge Name]

EXAMPLE

J_02_02_03_Rackovec – This element name tells the user that this element is a junction [J] in the Sutla River Basin [02] and is the third element hydrologically [03] within the Rakovec calibration zone [02], which is the second zone indicating that another calibration zone exists upstream in the basin.

Figure 4 shows the Sutla River basin model as an example of the naming convention applied to an entire basin model.

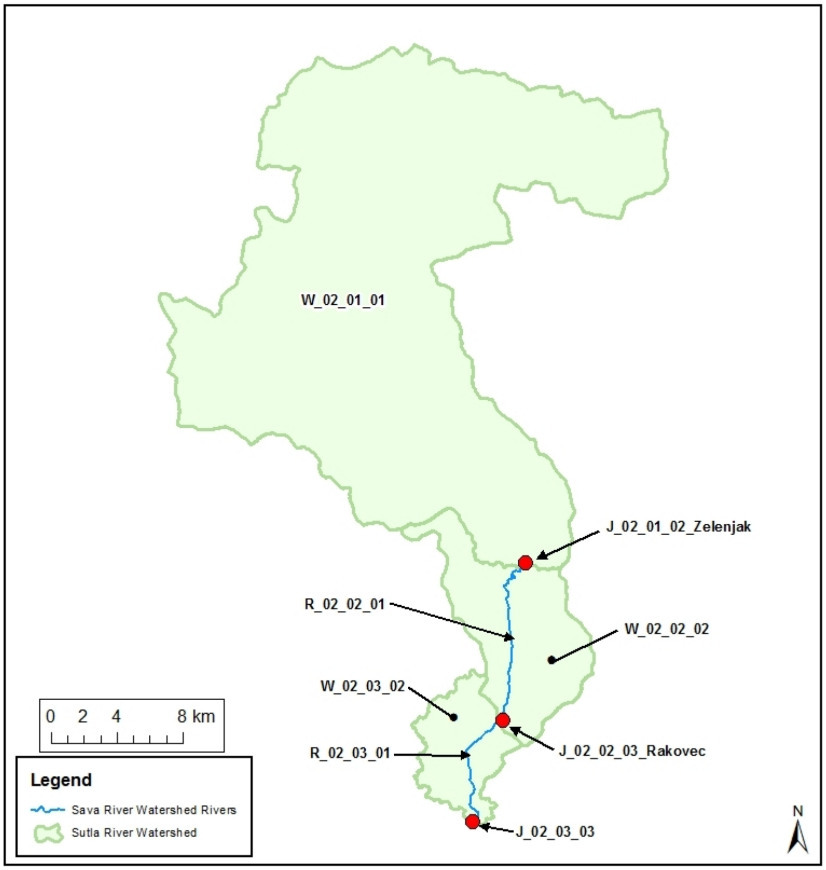


Figure 4: Sutla River Basin Naming Convention Example

2.4 MODEL CALIBRATION PERIOD DEVELOPMENT

The purpose of this project was to produce an event-based calibrated hydrologic model to support future endeavors of the ISRBC and its member countries. In order to provide this product, model simulations using hourly and/or sub-hourly computational time intervals are required. Due to the size of the watershed and large number of hydrologic stations, the ISRBC hydro yearbooks were consulted to find the larger storm events in the past 5 – 7 years in which electronic data was more readily available. The sheer size of the Sava River Basin allows for flood events to occur in certain areas of the basin while not occurring in others. Depending on the size of the storm event and how it moves through the watershed, multiple days may pass between flooding events from the upper portion to the lower portion of the Sava River basin. Consequently, large periods of hydrologic data were requested to ensure selected events were captured in all parts of the basin. The specific time periods for which hydrologic gauge data was requested are shown in Table 4.

The time windows shown below were large enough to encompass storm events as they moved through all portions of the watershed, and allowed for flexibility in using smaller, more specific time windows as necessary for the tributary and main stem hydrology models. Using smaller calibration periods enables faster simulation computation, and ultimately improves efficiency in the hydrologic model calibration process.

Table 4: Possible Calibration Periods

Start Date	End Date
5/1/2014	6/15/2014
10/1/2013	12/31/2013
10/1/2012	5/1/2013
10/1/2011	1/31/2012
9/1/2010	5/1/2011
11/1/2009	2/15/2010
1/1/2009	5/31/2009

2.5 MODEL PERFORMANCE METRICS

The development of a hydrologic model capable of performing across a wide range of flood events is the ultimate goal of this project. In order to measure the performance of model for the various calibration events, several metrics are used to demonstrate the performance of this modeling product. As a flood event-based hydrologic model, the goal is to capture simple characteristics of the runoff discharge hydrograph. The most critical characteristics of the discharge hydrograph are peak, volume, timing, and shape for this application. In order to ensure the model's ability to represent these characteristics, the following three measures are presented in Section 4 for the calibration simulations at various stream gauges.

1. Percent Difference in Peak Discharge (Q_P)

$$Q_P = \frac{Q_P^{sim} - Q_P^{obs}}{Q_P^{obs}} * 100\ (\%)$$

where Q_P^{sim} and Q_P^{obs} are simulated and observed peak discharges, respectively. This measure indicates the models ability to produce similar peak discharges for a single flood event.

2. Percent Difference in Runoff Volume (V_R)

$$V_R = \frac{V_R^{sim} - V_R^{obs}}{V_R^{obs}} * 100\ (\%)$$

where V_R^{sim} and V_R^{obs} are the simulated and observed total runoff through the simulation period, respectively. This measure indicates the models ability to accurately predict total runoff volume for a single flood event, which is critical as inflows are combined into the mainstem Sava River.

3. Nash-Sutcliffe Efficiency (NSE) coefficient

$$NSE = 1 - \frac{\sum\left(Q_n^{sim} - Q_n^{obs}\right)^2}{\sum\left(Q_n^{obs} - \overline{Q}_n^{obs}\right)^2}$$

where Q_n^{sim} and Q_n^{obs} are the simulated and observed discharges at time step *n*, respectively. $\overline{Q}_n^{obs}$ is the average observed flow. A NSE coefficient value of 1.0 indicates that model output exactly matches the observed measurements. A value of 0.70 – 0.80 is considered good; however, the goal was to attain values in the 0.85 – 0.95 range. This metric provides an overall measure of performance of the model's ability to capture all characteristics of the outflow discharge hydrographs, which incorporates peak, volume, timing, and shape.

In addition to these three metrics, calibration plots depicting the time series discharge hydrograph output versus the observed discharge hydrograph are provided in Section 4. The calibration plots provide an effective visual illustration of the performance of the model.

3. HYDROLOGIC MODEL ANALYSIS

As previously stated, separate HEC-HMS hydrology models were developed for the major Sava River tributary and mainstem basins. This approach allows for the submittal of individual tributary basin models to the ISRBC and its member countries. In addition to developing individual tributary basin models, the tributary and mainstem models are compiled into a comprehensive Sava River Basin HEC-HMS model. While this section is meant to provide an overview of the hydrologic model analysis performed during the study, section 4 contains a more detailed discussion on the hydrologic analysis for each individual tributary and mainstem model.

3.1 HYDROLOGIC MODEL BACKGROUND

The main objective of the initial phase of this project was to develop a single steady flow hydraulic model of the Sava River; however, after investigation, the team decided that an unsteady flow hydraulic model was required. In an effort to provide the inflow hydrographs necessary for the hydraulic model, a simplified hydrologic model was developed using the HEC-HMS software package. During the Water & Climate Adaptation Plan (WATCAP) for the Sava River Basin project, COWI utilized the HEC-HMS model developed during the first phase to guide the development of the COWI hydrologic model, which was designed to evaluate the hydrologic impact of future climate changes (World Bank 2015).

The HEC-HMS software was developed by USACE's Hydrologic Engineering Center (HEC) to simulate precipitation-runoff process within watershed systems (HEC 2013). The decision was made to continue the use of HEC-HMS for the second phase of this project to maintain consistency and due to the software's utilization as an industry standard tool for simulating hydrologic processes.

HEC-HMS simulates hydrologic processes through the development of a basin and meteorologic model. Through user input, the basin characteristics including soil loss, hydrograph transformation, baseflow, and river reach routing provide a hydrologic representation of the modeled basin. The meteorologic model specifies how precipitation, rainfall or snow, is applied to the basin model and also dictates evapotranspiration processes within the watershed. The basin and meteorologic model work together to define the rainfall-runoff processes within the watershed. The meteorologic model provides precipitation in the form of rain or snow as input to the basin model, while the basin model uses input loss parameters to calculate precipitation lost to storage in the watershed, precipitation infiltrating into the soils, and the subsequent amount of excess runoff precipitation. Excess precipitation is routed to the subbasin outlet as overland flow using a unit hydrograph transform (Clark Unit Hydrograph) method. Precipitation infiltrating into the soil is routed to the subbasin outlet using the recession baseflow method. Overland flow and baseflow are combined at each subbasin outlet before entering the reach network. As the combined flow is routed down through the river reach network of the basin, flow is aggregated from additional subbasins and routing reaches in hydrologic order. Further discussion of the parameters used to define the hydrologic model are described in more detail below and a summary of the various basin parameters is provided in Table 5 along with the various basin modeling methods required for HEC-HMS.

HEC-HMS allows the user to implement various methods to represent the rainfall-runoff processes of the basin of interest. Various factors contribute to the decision for each of the modeling component methods such as applicability of the method based on specific basin characteristics (such as terrain and urbanization) and availability of data supporting a specific method. Table 5 shows the specific methods chosen for this modeling study. The decision to use these methods are based on:

- Simple Canopy Method – This method is chosen for its simplicity due to a lack of available data defining the canopy. In addition, this method was used for the WATCAP study, where the parameter values for this method were reasonably assumed and calibrated.
- Deficit-Constant Soil Loss Method – This method was chosen based on the success of this method for large basin studies such as the Sava River Basin. The deficit-constant method provides the ability to simulate soil moisture characteristics throughout an event using easily derived and calibrated parameters. In addition, this method was used for the WATCAP study and is the method used for most major flood forecasting models within USACE.
- Clark Unit Hydrograph Transformation Method – This method was chosen based on its ability to be estimated using available terrain data and the successful implementation of this method across modeling studies within USACE. The parameters for this method are also fairly easy to calibrate especially in situations where discharge stations are relatively abundant such as in the Sava River Basin. In addition, this method has shown to be very effective in representing the timing and shape of flow hydrographs through varying magnitudes and volumes of floods.
- Muskingum-Cunge Reach Routing Method – This method was chosen because it primarily based on physical characteristics of the routing reaches which can be attained from the available information. This method has been widely used within USACE and provides the ability to represent the flow hydrograph translation and attenuation in situations with varying levels of floodplain storage.

Table 5: Summary of HEC-HMS Basin Model Parameters

Modeling Method	Parameter	Description
CANOPY STORAGE		
Canopy	Initial Storage	Initial storage in canopy.
	Max Storage	Maximum storage in canopy.
SOIL LOSSES		
Deficit Constant	Initial Deficit	Initial condition for the soil layer. Amount of water required to saturate the soil layer.
	Maximum Deficit	Maximum amount of water the soil layer can hold.
	Constant Loss	Percolation rate of the soil layer
	Percent Impervious Area	Percent of the subbasin that is covered by directly connected impenetrable surfaces such as concrete, rooftops, and urban development.

Modeling Method	Parameter	Description
HYDROGRAPH TRANSFORMATION		
Clark Unit Hydrograph	Time of Concentration	Travel time from the most hydrologically remote point in the subbasin to the watershed outlet.
	Storage Coefficient	Conceptual parameter representing basin's storage capacity.
BASEFLOW		
Recession Baseflow	Initial Baseflow	Baseflow at the beginning of the simulation.
	Recession Ratio	Rate at which baseflow recedes between storm events.
	Threshold Ratio	The ratio to the peak flow at which the baseflow is reset.
REACH ROUTING		
Muskingum-Cunge Routing	Length	Length of reach
	Slope	Slope of reach
	Manning's n-Values	Roughness coefficient for the channel, left overbank, and right overbank.
	Shape	Shape of the routing reach cross section. For this study, either 8-point or trapezoidal.

3.2 HYDROLOGIC MODEL DEVELOPMENT

The purpose of this section is to provide a general background on the methods and techniques used to develop all the hydrologic models for this project including geospatial preprocessing, basin and reach parameterization, and meteorologic model development. As part of the hydrologic model development the Sava River Watershed was broken into 20 separate HEC-HMS basin models, including a basin model for each of the 17 major tributaries and three for the local areas along the mainstem Sava River. A more specific discussion of the methods, analysis, and results for each tributary and mainstem basin model is provided in Section 4 of this report.

In addition to the discussion of hydrologic parameterization with Section 3 and 4 of this report, an inventory of final basin and reach parameters are provided in Appendix A.

3.2.1 GEOSPATIAL PRE-PROCESSING

The watershed delineation and drainage network were developed using the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) software. HEC-GeoHMS is a GIS tool that is a software extension to ArcInfo GIS package for personal computers (Copyright© 1996, Environmental Systems Research Institute, Inc.). The software allows the user to visualize spatial information, document watershed conditions, perform spatial analysis, and help define the structure and parameter inputs to hydrologic models. HEC-GeoHMS can be used to expediently create hydrologic model inputs that are required for rainfall-runoff simulation using HEC-HMS.

HEC-GeoHMS preprocesses the digital elevation model (DEM), which in this case was derived from the Shuttle Range Topography Mission (SRTM) digital elevation model (DEM) information collected in 2000 as a joint effort by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA). The SRTM DEM consists of grid cell resolution of 1-arc second (approximately 30m). The flow direction, flow accumulation, and stream link grids are created from the DEM and used for the generation of subbasin delineation and drainage network flowlines (Figure 5).

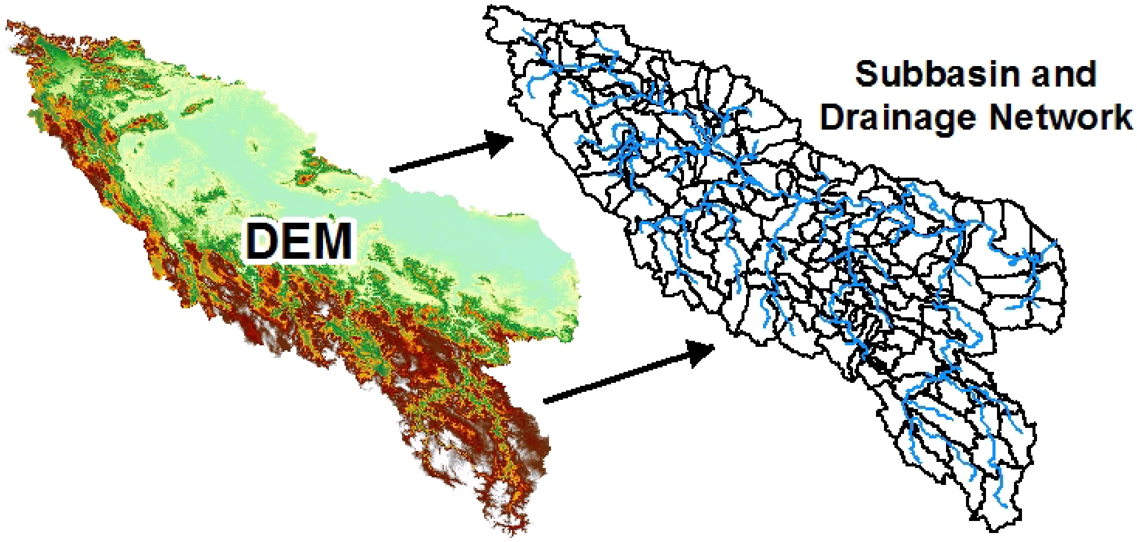


Figure 5: Illustration of the DEM Conversion to Subbasin and River Network using HEC-GeoHMS

The Sava River watershed consists of several unique features, natural and man-made, that make the delineation of the watershed more difficult. The watershed contains an extensive system of levees, dikes, diversions, and channelization, and is influenced in certain areas by the presence of karst geology throughout the basin. An accurate delineation is critical to the development of an accurate hydrologic model; as such, a considerable effort was made to utilize information provided by the member countries of the ISRBC in order to capture any hydrologically relevant features found in the Sava River basin. Several historical watershed delineations for the Sava River were available to aid in identifying these features, leading to a more accurate basin delineation to use for the hydrologic modeling effort. Using ESRI's ArcGIS Desktop, the watershed delineation was developed by incorporating the historical watershed delineations and manually digitized stream features through processes known as "walling" and "burning". "Walling" and "burning" allows the user to override existing basin boundaries and stream centerlines of the DEM/terrain in order to force the delineation and hydrologic river network to match the known basin boundaries and stream paths, respectively. Ultimately, this terrain processing produced a final DEM capable of generating a more accurate watershed delineation and drainage network. Figure 6 shows the final delineation produced by HEC-GeoHMS.

Figure 6: HEC-GeoHMS Sava River Basin Delineation and Stream Network

HEC-GeoHMS is used to generate the physical parameters of the basin such as drainage area, stream lengths, basin slopes, etc. From these physical parameters, initial estimates of unit hydrograph parameters, time of concentration (T_c) and storage coefficient (R), were developed for each subbasin. Reach routing parameters, such as reach slope and length, were also extracted from the DEM and imported into the HEC-HMS model using HEC-GeoHMS. The methods used to develop these parameters is described in more detail in the following subsections of Section 3.

3.2.2 CANOPY METHOD

Including a canopy component to subbasin elements is a way of representing the presence of vegetative interception in the landscape. Vegetation intercept precipitation, reducing the amount that arrives at the ground surface. For the Save River basin hydrology models, the simple canopy method was chosen to simulate canopy storage. This method includes 2 parameters: initial storage and maximum storage. The initial storage represents how full the canopy storage is at the beginning of the simulation by a percentage. The maximum storage represents the maximum capacity of the canopy storage in millimeters. For all events, the canopy storage is assumed to be completely full at the beginning of the simulation. Any initial storage in the watershed is accounted for using the initial deficit parameter in the soil loss method, which is explained in *Section 3.2.*3 of the report. The rate at which the canopy storage is recharged is based on the evapotranspiration rate. It should be noted that for hydrology models built in HEC-HMS version 4.0, evapotranspiration is only applied when a canopy storage method is active.

The parameter values used for the canopy method were derived from the WATCAP climate-based hydrology model. Using ArcGIS tools, a grid was developed based upon the maximum canopy storage values found in the original WATCAP basin delineation. Additional processes were run in GIS in order to take the maximum canopy storage values from the grid and transfer them to the new basins delineated as part of this project. The WATCAP report does not describe in detail how the canopy storage parameter values were developed; however, the assumption is that the values were derived from a geospatial layer or possibly through calibration to long-term simulation.

3.2.3 SOIL LOSS METHOD

The deficit constant loss rate method was chosen for simulating precipitation infiltration. The method includes four parameters: initial deficit, maximum deficit, constant rate, and percent imperviousness. Initial deficit is estimated as the soil storage capacity in millimeters prior to the storm event simulation and is related to the antecedent conditions of the basin. Maximum deficit is estimated as the maximum water holding capacity of the soil in millimeters and can be related to the soil composition, though limited to the effective rooting depth (surface active layer). Constant rate, measured in mm per hour, is representative of the soil's percolation rate and can be estimated from the saturated hydraulic conductivity is related to the soil composition.

Unfortunately, sufficient data to aid in the development of the initial values for initial deficit, maximum deficit, and constant rate was not available. Therefore, these parameters were primarily developed through calibration to observed discharge and evaluated for reasonableness. For event-based simulations, maximum deficit is not a critical parameter because this parameter provides a boundary defining the maximum amount that the soil layer can dry out over an extended period of no rain. The constant rate is normally developed during calibration. Through calibration, the constant rate across all of the subbasins in the Sava River Basin fell within a general range of 1-2 mm/hr, which was consistent across the entire watershed. Initial deficit was developed through calibration as this parameter defines the antecedent soil moisture condition at the beginning of a simulation. The initial deficit parameter proved to be highly sensitive, especially during smaller events with low precipitation volume.

The percent impervious area is defined as the area of the watershed covered by impervious surfaces directly connected to the subbasin outlet. Impervious areas are most important for areas of extreme development and for small storms where the runoff volume resulting from impervious area is significant in comparison to the event precipitation volume. The impervious area for each subbasin was estimated by using GIS to convert land use data provided by the ISRBC to a percent impervious grid. Assumptions were made regarding the percent imperviousness associated with each landuse type. Using the subbasin delineation and the percent impervious grid, the "Zonal Statistics" tool in ArcGIS was used to extract overall percent imperviousness for each subbasin. Figure 7 illustrates the percent imperviousness across the Sava River Watershed. The figure shows that as expected, outside of the larger cities, the majority of the Sava River Basin does not contain significant impervious area.

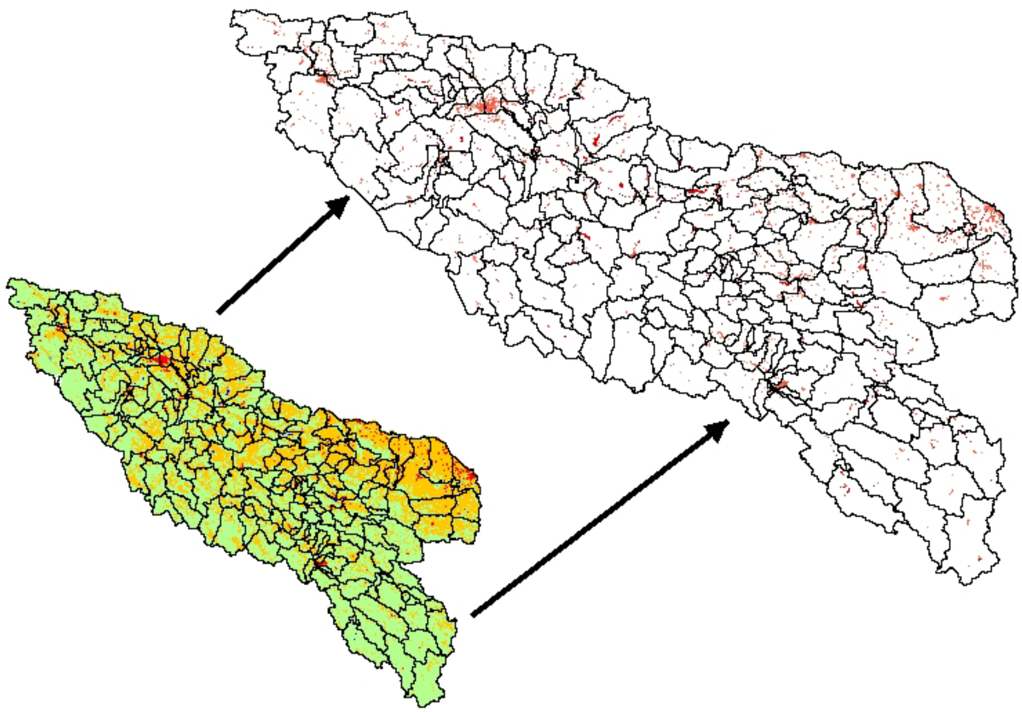


Figure 7: Illustration of Land Use Data Conversion to Imperviousness

3.2.4 HYDROGRAPH TRANSFORMATION METHOD

The Clark unit hydrograph method was the chosen rainfall-runoff transformation method. Parameters for the method include the time of concentration (T_c) and the storage coefficient (R). Time of concentration indicates the length of time necessary for surface flow to move from the subbasin divide to the outlet, while the storage coefficient represents the storage effects (attenuation) of the subbasin. The T_c was calculated using TR-55 method (USDA 1986) for calculating travel times from the hydrological distant point in each subbasin, which is related to the longest flow path, and derived per subbasin using HEC-GeoHMS. The R parameter is conceptual in nature and often estimated through calibration to historical storm events.

The TR-55 method breaks the longest flowpath, which is derived using HEC-GeoHMS, into three segments: sheet flow, shallow concentrated flow, and channel flow. The travel time for each segment is computed and combined to determine a total time of concentration for the subbasin. HEC-GeoHMS incorporates the TR-55 computation by breaking the longest flowpath into the three TR-55 segments and computes the necessary inputs (flowpath length and slope) to calculate travel time for each segment. HEC-GeoHMS also exports a Microsoft Excel Spreadsheet that can be used to manually complete the T_c computations with user-provided information such as Manning's n-value roughness factors and cross sectional geometry. The TR-55 method requires inputs in English units; therefore, the parameters for this study were converted from metric to English units before computations were made. Figure 8 is an example of the Microsoft Excel spreadsheet produced by HEC-GeoHMS, and shows the required inputs to calculate total subbasin time of concentration.

Blue - GIS defined, Green - user specified, White and yellow - calculated, Red - final result	
Watershed Name	**SAMPLE**
Watershed ID	**999**
Sheet Flow Characteristics	
Manning's Roughness Coefficient	0.015
Flow Length (ft)	100
Two-Year 24-hour Rainfall (in)	3.5
Land Slope (ft/ft)	1.3451
Sheet Flow Tt (hr)	0.00
Shallow Concentrated Flow Characteristics	
Surface Description (1 - unpaved, 2 - paved)	1
Flow Length (ft)	13000
Watercourse Slope (ft/ft)	0.25
Average Velocity - computed (ft/s)	8.07
Shallow Concentrated Flow Tt (hr)	0.45
Channel Flow Characterisitics	
Cross-sectional Flow Area (ft2)	160
Wetted Perimeter (ft)	56
Hydraulic Radius - computed (ft)	2.85
Channel Slope (ft/ft)	0.017
Manning's Roughness Coefficient	0.04
Average Velocity - computed (ft/s)	9.77
Flow Length (ft)	118958
Channel Flow Tt (hr)	3.38
Watershed Time of travel (hr)	**4.89**

Figure 8: Excerpt from the HEC-GeoHMS Time of Concentration Spreadsheet

A common ratio used to express the attenuation of a subbasin is the Clark storage relationship denoted as $R/(T_c + R)$. Greater values closer to 1.0 indicate that the subbasin has a greater capacity to attenuate runoff, in comparison with lower values which indicate a peakier, more intense basin response. Typically, the ratio is directly related basin slope, and intuitively less attenuation occurs in the steeper head waters of the watershed while more attenuation occurs in the flatter low-lying areas. Man-made structures present in the watershed may impede the flow of water and increase the attenuation of a subbasin. The computed Clark storage relationship values for each tributary and mainstem Save River basin model are presented in Section 4 of this report. The storage coefficient, R, is an estimated parameter related to the storage capacity of the subbasin and is a watershed-specific value determined through model calibration to observed storm events. The large number of hydrologic gauging stations within the Sava River Basin from which to calibrate storm events allows for more confidence in the estimation of the R storage coefficient.

3.2.5 BASEFLOW METHOD

The recession approach was chosen for the baseflow method. The primary advantage of the recession method over other baseflow methods included in HEC-HMS is that the recession method is the simplicity of the method and its ease of application. For short-term event-based model calibrations, such as those performed as part of this study, baseflow is not typically a critical hydrologic component. The recession baseflow method consists of three parameters: initial baseflow, recession constant, and threshold ratio.

Initial baseflow describes the initial baseflow for each subbasin and may be expressed as a value per area or total value, both in cubic meters per second. During calibration, initial baseflow was calibrated to observed data for each simulation. The recession constant describes the rate at which baseflow recedes between storm events. To elaborate, the recession constant parameter defines the slope of the receding limb of the baseflow hydrograph. The threshold ratio is the value at which the baseflow will reset when the current flow decreases to the ratio value as related to the peak flow of the event. For instance, if the value is set to 0.1, the baseflow will reset once the current flow decreases to 10% of the peak flow of the event. Figure 9 illustrates how the recession baseflow method contributes to the computed flow hydrograph.

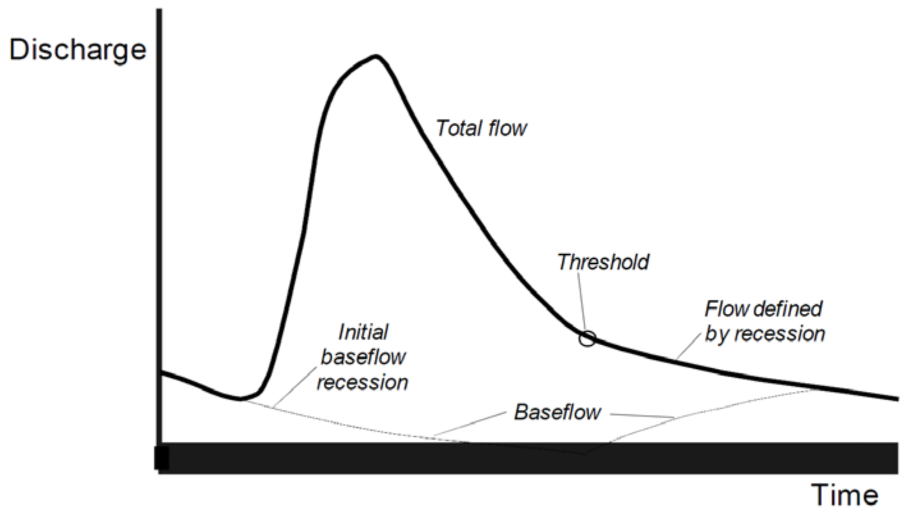


Figure 9: Illustration of Baseflow Method

3.2.6 REACH ROUTING METHOD

The Sava River Basin consists of river reaches with varying shapes, slopes and floodplain storage capacity. In an effort to represent the range of river reaches found throughout the watershed, the Muskingum-Cunge routing method was used. Routing reach geometry was expressed in both 8-point cross-sections as well as simplified trapezoidal channels. The Muskingum-Cunge routing method uses physically-based parameters such as length, slope, Manning's n-values, and cross sectional geometry to estimate the translation and attenuation of flood hydrographs through the reach. Routing reach lengths and slopes were derived directly from the SRTM DEM in HEC-GeoHMS and imported directly into the HEC-HMS hydrology models. The slopes derived from the SRTM DEM required modification during calibration, which was expected due to the low-resolution of the digital elevation model.

The 8-point cross section Muskingum-Cunge geometry is most appropriate when significant storage is found in overbank areas, and produces a better estimation of river reach attenuation. The trapezoid method uses a simple trapezoidal shaped cross section with a top-width and side-slope, and is used for reaches with limited floodplain storage. It is important to note that the quality of the SRTM DEM in certain areas limited the use of the 8-pt method where the terrain was very flat. For routing reaches in those areas with coarse terrain resolution, the trapezoid method was used.

3.2.7 METEOROLOGIC METHOD

The meteorologic model is the component of the HEC-HMS model that represents the precipitation, both rainfall and snow, and is a required component for rainfall-runoff simulations. Evapotranspiration rates are also defined within the meteorologic model.

Precipitation

Hourly precipitation and temperature data at all available meteorologic stations was acquired from the member countries of the ISRBC. Despite the relatively large number of meteorologic stations within the Sava River Watershed, areas exist within the basin where precipitation coverage is sparse due to the large size of the watershed. In an attempt to rectify the lack of observed precipitation in these areas, the Inverse Distance precipitation method was applied. The Inverse Distance method calculates subbasin average precipitation by applying and inverse distance squared weighting all available precipitation gages in the user-specified search radius. Figures are provided for each tributary and mainstem basin in Section 4 that show the coverage of precipitation stations for each basin model. Figure 10 illustrates the areas of the Sava River Watershed with less meteorological station coverage showing every station with a 25-km buffer overlaying the basin delineation. As the figure shows, a dense coverage of stations exists in the headwaters of the Sava River Watershed, the Bosna River Watershed, and the headwaters of the Drina River Watershed while there is a relative lack of stations in the middle and far downstream portions of the Sava River Watershed.

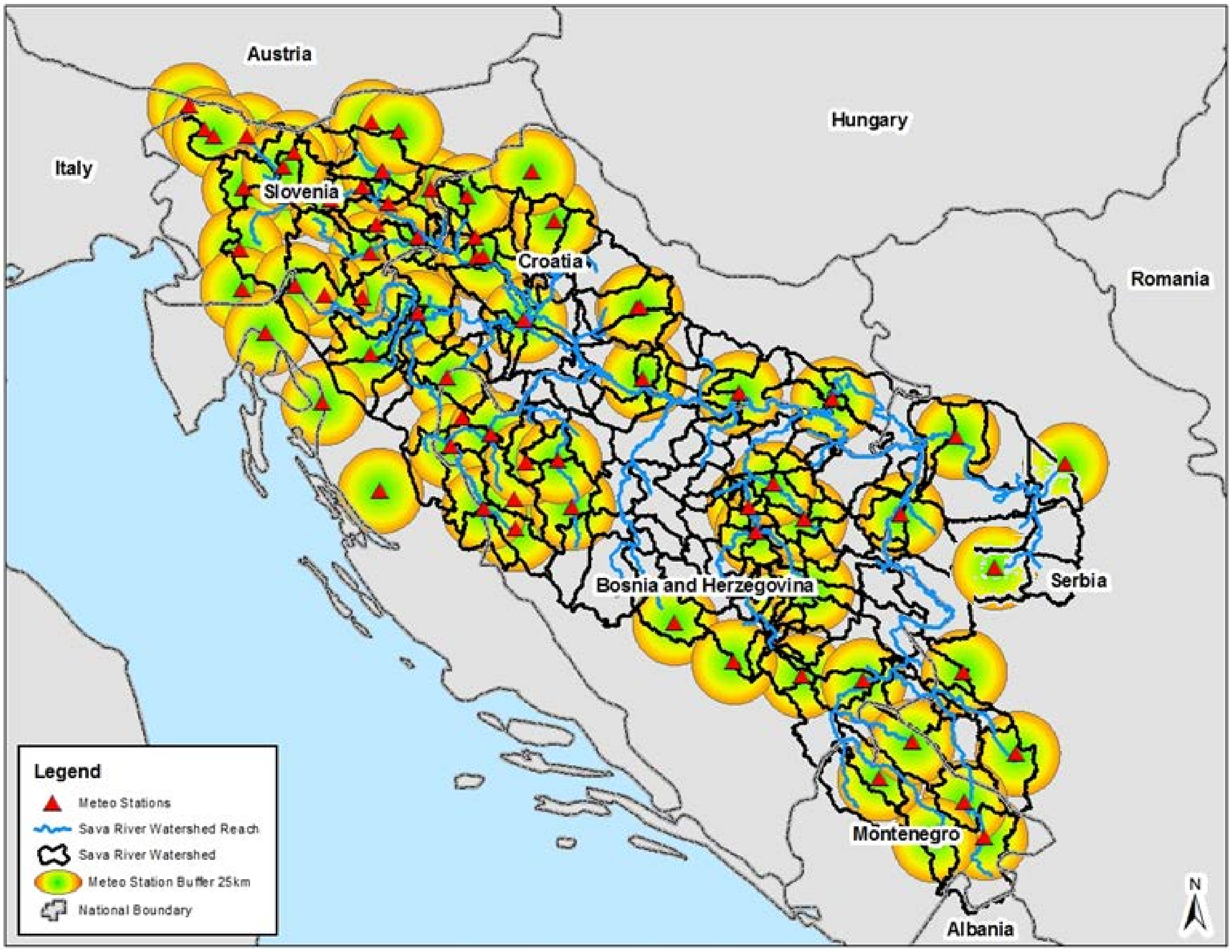


Figure 10: Sava River Basin Meteorologic Station Network Map with 25 km Buffer

The inverse distance precipitation method uses nearby precipitation gauges to assign an average precipitation to a subbasin over a specified time period. The precipitation is assigned to each subbasin through weighting based on the distance from the gauge to one or more nodes within each subbasin. For this project, a single node was defined for each subbasin and was defined by the centroid of the subbasin. The closer the gauge is to the subbasin node; the greater the precipitation in the subbasin is weighted to that gauge. This method was originally developed for real time simulations because it can automatically switch on and off when gauges start and stop reporting. This method is preferred because it provides the ability to incorporate multiple gauges where available. The method also provides the ability to input a search radius that will only use gauges within the specified search radius to ensure that distant gauges are not skewing the precipitation applied to the subbasin. For basin models without reliable precipitation coverage available, the search radius applied for the inverse distance meteorological model must be increased well above the 25 km value displayed in Figure 10. Greater search distances allow for the inclusion of metrological stations that are further away, but also increase the spatial and temporal error of the resulting station-averaged precipitation.

Evapotranspiration

The Monthly Average method was utilized to represent evapotranspiration rates in the watershed. Through the previous climate change study, COWI determined the Monthly Average ET rates based upon monthly evaporation rates collected at selected stations throughout the Sava River Basin. Once determined, the ET values were incorporated into the WATCAP model, and eventually transferred to the hydrology models developed for the current study. Evapotranspiration parameter values were transferred to the current hydrology modeling in the same fashion as canopy values, by means of developing a grid of values from the original modeling and using GIS processes to apply values to the updated hydrology model.

Evapotranspiration is not a critical component for short-term event-based simulations. ET loss rates are input as a monthly total, but HEC-HMS determines the applied rate based by dividing the monthly rate to match the computational time interval specified for the model simulation. The largest computational time interval for any simulation is 1 hour, resulting in low ET rates per simulation time step for the project. In HEC-HMS, the Monthly Average method assumes that ET does not occur during precipitation events.

Snowmelt

In addition to precipitation in the form of rainfall, the meteorological model can be configured to compute snow and snowmelt. The temperature index method in HEC-HMS was used for computing snowmelt for this project. The meteorologic model in HEC-HMS determines, at every time step, whether the precipitation falling is rainfall or snowfall based on the temperature data at nearby meteorological stations. The temperature index approach considers snowmelt as a mass-balanced process. At the beginning of a simulation, the characteristics of an initial snowpack are established through the input of various parameters. When the simulation begins, precipitation falls as either rainfall or snow. Over the course of the simulation, the falling snow either builds the snowpack or warming occurs, as defined by the representative air temperature gauge, and the snowpack melts and is converted to runoff for the specific subbasin. The temperature index method also considers the effects of rainfall on the snowpack and determines the runoff volume resulting from the melting process initiated by rain falling on the snowpack. The temperature index method uses a multitude of parameters, summarized in Table 6 and Table 7, to define the snowfall, rain on snow, and snowmelt components of the hydrological process. Available snow-related data was limited, as result the existing snow parameters defined in the WATCAP model were applied to the updated hydrology models. After evaluating the existing WATCAP parameters and consulting with snow experts at the USACE Cold Regions Research and Engineering Laboratory, finalized snowmelt parameters were established for each subbasin. Table 6 and Table 7 lists the parameters and common values used to simulate snowmelt in the Sava River basin hydrology models. Table 6 lists parameters general to the entire meteorological model, while Table 7 lists parameters specific to each subbasin.

Table 6: Snowmelt Parameters General to Entire Meteorologic Model

Parameter	Typical Value	Parameter Description
PX Temp (C°)	0 to -1	Discriminates between rain or snow based on air temp
Base Temp (C°)	0	Used to determine if melt is occurring. If air temperature is less than base temperature, then no melt occurs.
Wet Meltrate (MM/C°-day)	7.2	Describes rain on snow melt rate. Functions when rainfall is occurring and when the rainfall rate is greater than the rain rate limit.
Rain Rate Limit (MM/day)	1	Discriminates between dry and wet melt. Wet meltrate is applied if rainfall rate > rain rate limit. Otherwise meltrate is computed as if no precip is occurring.
ATI Meltrate Coef	0.98	Used when welt melt is not occurring. Coefficient is used to update the antecedent meltrate index from one time interval to the next.
ATI Meltrate Fxn	Function	Used to calculate meltrate based on antecedent temperature index
Cold Limit (MM/Day)	15	Accounts for rapid changes in temperature that snowpack undergoes during high precipitation rates.
ATI Coldrate Coef	0.4	Used to update the antecedent cold content index from one time step to the next
Water Capacity (%)	3	Defines the amount of melted water that must accumulate before it can be available from infiltration or runoff. This value is a percentage of SWE.
Groundmelt Method	Constant Value	Describes the method used to account for snow on a partially frozen or completely unfrozen ground
Groundmelt (MM/Day)	0.05	Either a constant rate or annually patterned rate

Table 7: Snowmelt Parameters Specific to Each Subbasin

Parameter	Typical Value	Parameter Description
Temp Gauge	Varies	
Lapse Rate (C°/1000M)	-1 to -6	Used in the computation of temperature in various elevation bands as lapse rate times band elevation minus gauge elevation. This parameters adjusts the temperature up and/or down for each elevation band based on the gauge temperature.
Index (MM)	Not Considered	Used to adjust precipitation between elevation bands. Typically used to account for orographic trends in precip. Not included for this project
Percent (%)	Varies	Percent area of basin represent within elevation band
Elevation (M)	Varies	Average elevation of band
Index (MM)	Not Considered	Used in conjunction with the subbasin index to adjust precipitation within bands. Not included for this project.
Initial SWE (MM)	Varies	The initial volume of water represented within the snow pack
Initial Cold Content (MM)	0	Represents the heat required to raise the snowpack temp to 0 C°. Expressed as a number equivalent to mm of frozen water. Estimated as the product of depth of snow, snow density, heat capacity of snow, C° below freezing.
Initial Liquid Water (MM)	0	Amount of liquid water held within the snowpack at the beginning of the simulation
Initial Cold Content ATI (C°)	0	The snowpack temperature at the beginning of the simulation
Initial Melt ATI (C°-Day)	0	The accumulation of degree-days since the last period of sustained temps below freezing

As previously mentioned, most parameters for the snowmelt method were established from the WATCAP model and the consultation of USACE snow experts. Initial snow-water-equivalent (SWE) values and elevation band parameters were developed through GIS processes on available data.

Determining SWE is important parameter for defining the potential runoff volume of the snowpack. Daily Advanced Microwave Scanning Radiometer (AMSR-E)/Aqua Level 3 global snow water equivalent grids were compiled from the National Aeronautics and Space Administration's (NASA) National Snow and Ice Data Center (NSIDC) in Boulder, Colorado USA (Tedesco et. al. 2004). Figure 11 illustrates the Sava River Basin superimposed over a sample of these SWE grids. The zonal statistics tool in ArcGIS was used to extract initial SWE values for each subbasin for every calibration event. Due to the low resolution (large grid size) of the SWE grids, the accuracy of this method is uncertain. However, the satellite-based SWE grids were the best available data at the time of model development.

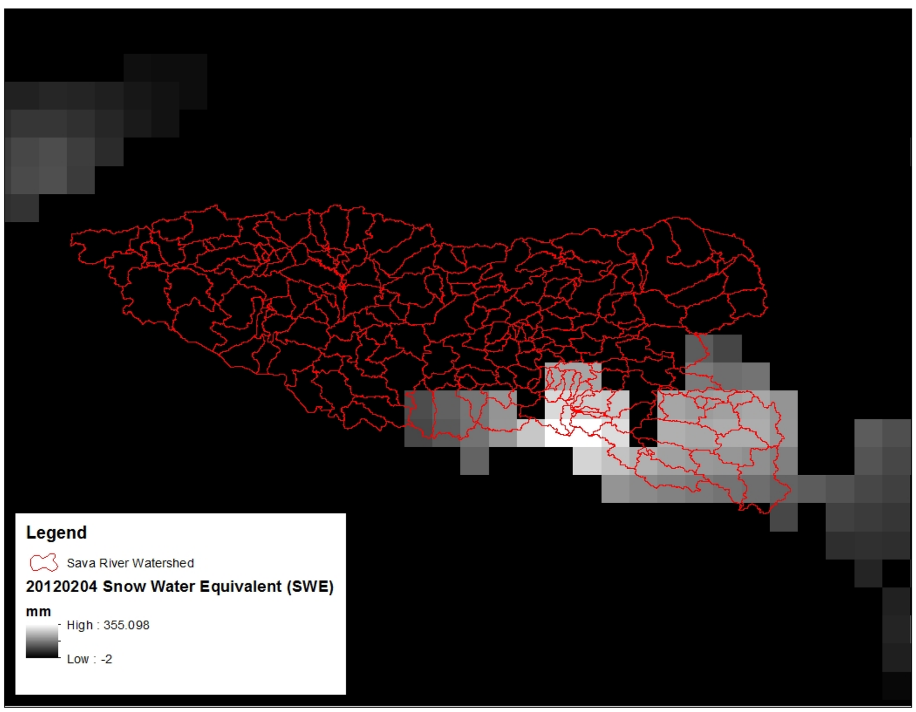


Figure 11: Sava River Basin overlaid with the (AMSR-E)/Aqua Level 3 global SWE grid

Elevation bands, which are input into the meteorological model to account for the differences in snowfall and snowpack across the range of elevations in each subbasin, were developed using the SRTM DEM as well. Elevation-area relationships were determined from the SRTM DEM by using ArcGIS tools to take area slices across the full range of elevations for each subbasin as shown in Figure 12. These elevation-area relationships were segmented at natural breakpoints in the topography to define the elevation bands for each subbasin. For most subbasins, three elevation bands were developed; however, for subbasins with less topographic relief, only one or two elevation bands were defined. For each defined elevation band, initial snowpack parameters were required to define any snowpack that may be present at the beginning of the hydrologic model simulation. The aforementioned AMSR-E SWE grids were used to define the initial SWE for each elevation band within each subbasin.

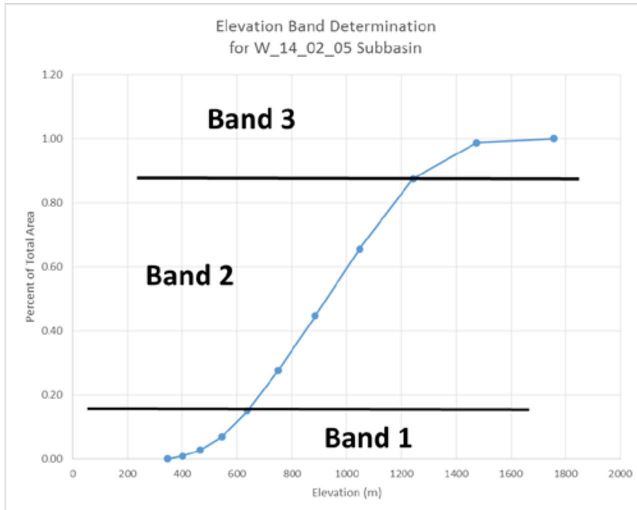


Figure 12: Percent of Total Drainage Area vs Elevation for a Sample Watershed

In general, meteorology introduces the greatest error and uncertainty to a hydrologic model due to the uncertainty and randomness that is inherent to natural phenomenon. In the reality, precipitation is highly variable spatially, temporally, and in intensity. The uncertainty associated with precipitation variability can be lessened through the use of observed meteorological stations, but never fully eliminated. Expectedly, meteorological uncertainty, both in precipitation and initial snowpack, presented the most significant challenge when performing hydrologic model calibrations for the Sava River Basin. For future recommendations, the incorporation of high resolution grid-based snow water equivalent and precipitation data, as well as the placement of additional meteorological stations in areas currently lacking observed data, will only serve to improve performance of the Sava River Basin hydrology models.

4. SPECIFIC BASIN HYDROLOGIC DISCUSSION AND ANALYSIS

This section provides the description of hydrologic modeling analysis for each specific tributary basin model. USACE evaluated the Sava River Basin by major tributary basins to the Sava River Basin. In addition, USACE evaluated the local basins along the mainstem Sava River as a separate basin model. The decision to analyze the Sava River Basin in this manner is based on the desire to provide the member countries to the ISRBC separate HEC-HMS models of the major tributary basins within the particular country's area of interest (AOI). For consistency and convenience, USACE also provides a single HEC-HMS model of the entire Sava River Basin.

This section provides specific details related to the development and limitations of each tributary and mainstem HEC-HMS model. In addition, the results for each specific model are provided and discussed within this section. The hydrologic and meteorologic stations, which provide observed data for comparison of results and input information in the form of precipitation and air temperature, respectively, are discussed for each HEC-HMS model within this section, and an inventory of all stations with available data is provided in Appendix B.

4.1 SLOVENIA WATERSHED (LJUBLJANICA, SAVINJA, KRKA, SAVA HEADWATERS AND MAINSTEM)

4.1.1 BASIN DESCRIPTION

The Slovenia Watershed contains the headwaters of the Sava River as well as several tributaries of varying size and shape including: Ljubljanica, Savinja, and Krka Rivers. The basin area is approximately 10,322 km2. The basin's topography is considered very steep with a maximum elevation in the headwaters of approximately 2850 masl and minimum elevation of approximately 126 masl.

4.1.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 8 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Slovenia Watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 1.28 mm/hr across the entire basin is expected. An average R/(T_c + R) ratio value of 0.79 indicates that a substantial amount of attenuation occurs within the watershed, likely driven by an abundance of flatter, low-lying areas in the lower reaches of the basin.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration is due to the meteorological model over-estimating (for large values) or under-estimating the precipitation (for small values) during certain events. As a result, constant loss rates are raised or lowered to physically unrealistic values to compensate for too much or too little precipitation. A range of 0.2 to 25 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is very different throughout the watershed.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 8: Slovenia Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	**Constant Rate (mm/hr)**	**T_c (hr)**	**R**	$\frac{R}{T_c + R}$	**Initial Flow (CMS/km^2)**	**Recession Constant**	**Ratio to Peak**
Representative	28	1.28	6.17	30.48	0.79	0.02	0.90	0.18
Minimum	0	0.40	0.20	0.70	0.55	0.02	0.90	0.10
Maximum	40	1.70	25.00	220.00	0.98	0.02	0.90	0.25
Standard Deviation	10	0.25	1.17	5.03	0.02	0.00	0.00	0.01

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 8 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Slovenia Watershed HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.1.3 REACH ROUTING PARAMETERS

River reach routings within the Slovenian Watershed were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the

3.2 HYDROLOGIC MODEL DEVELOPMENT section of this report. Table 9 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 9: Slovenia Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_01_01_01	31878	0.0048	Eight Point	0.03	0.07	0.07
R_01_02_01A	12442	0.0018	Eight Point	0.027	0.07	0.07
R_01_02_01B	6430	0.0058	Eight Point	0.027	0.07	0.07
R_01_03_01	22505	0.0025	Eight Point	0.027	0.07	0.07
R_01_05_01	12643	0.0027	Eight Point	0.03	0.07	0.07
R_01_05_04	24574	0.0015	Eight Point	0.035	0.07	0.07
R_01_06_01	26463	0.0005	Eight Point	0.035	0.07	0.07
R_01_13_01	8564.2	0.0006	Eight Point	0.03	0.07	0.07
R_01_08_01	42736	0.0023	Eight Point	0.03	0.07	0.07
R_01_09_01	14407	0.0017	Eight Point	0.03	0.07	0.07
R_01_13_04A	7638	0.0025	Eight Point	0.02	0.06	0.06
R_01_13_04B	8875	0.0025	Eight Point	0.02	0.06	0.07
R_01_13_04C	9544	0.0025	Eight Point	0.02	0.06	0.06
R_01_13_04D	9574	0.0025	Eight Point	0.02	0.06	0.06
R_01_13_04E	15005	0.0025	Eight Point	0.02	0.06	0.06
R_01_11_01	30951	0.0007	Eight Point	0.03	0.07	0.07
R_01_12_01	20969	0.0005	Eight Point	0.03	0.07	0.07
R_01_13_05	16644	0.0007	Eight Point	0.03	0.07	0.07
R_01_13_09	8637.8	0.0008	Eight Point	0.025	0.07	0.07

4.1.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Slovenia Watershed was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 13 illustrates the Slovenia Watershed basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 13 illustrates that the Slovenia Watershed has a reasonable number of meteorological stations covering the basin.

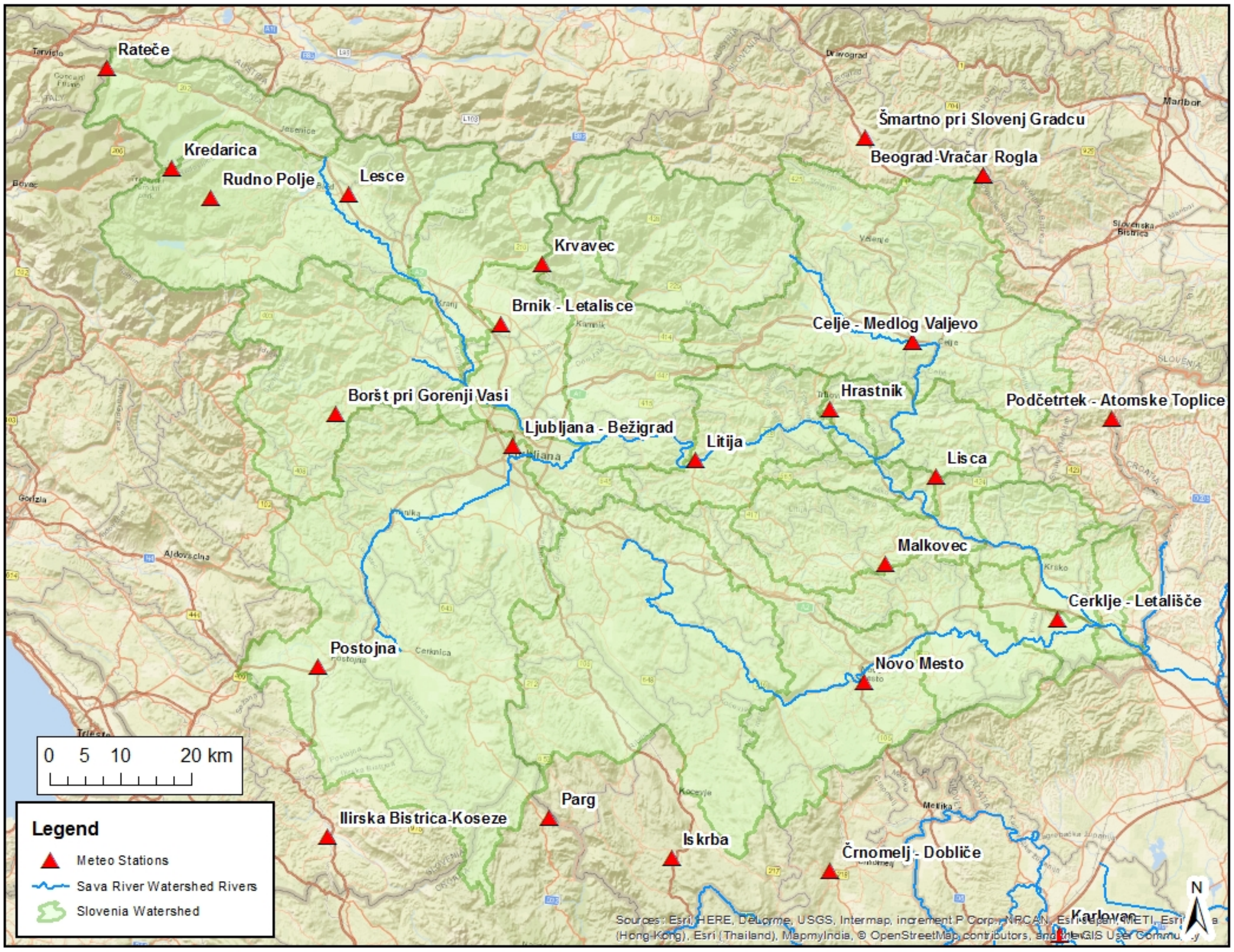


Figure 13: Meteorologic Station Map for the Slovenia Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 10 shows the average ET rates for the Slovenia River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 10: Average ET Rates for the Slovenia Watershed

Month	ET Rate (mm/month)
Jan	5.6
Feb	6.0
Mar	21.1
Apr	50.8
May	90.0
Jun	114.9
Jul	120.9
Aug	110.7
Sep	80.2
Oct	50.0
Nov	15.7
Dec	5.7

4.1.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Slovenia Watershed HEC-HMS model. Two of the most common challenges during this study were related to subbasin delineation and meteorologic data availability.

The development of the Slovenia Watershed subbasin delineation relied heavily on the SRTM DEM and a subbasin delineation ESRI shapefile provided by the ISRBC at the 1000 km^2 scale. Due to the quality of the subbasin delineation shapefile and the steep topography of the watershed, which reduces the effect of a lower quality DEM, the delineation is acceptable; however, delineation in some areas could be improved with better information such as a higher quality DEM. Based on discussions with the ISRBC, areas of karst features can influence the flow paths within the watershed and in turn, can affect the delineation. Karst issues, as it relates to subbasin delineation, were minimal and were easily modified using the subbasin delineation shapefile provided by the ISRBC.

Slovenia Watershed was divided into 5 separate HEC-HMS models (Figure 14): Ljubljanica, Savinja, and Krka Rivers and 2 Sava River sections (headwaters and mainstem). These 5 HEC-HMS models were developed as one Slovenia Watershed model and broken apart into the individual basins (Sava Mainstem 01, Sava Mainstem 02, Ljubljanica, Savinja, and Krka) after event calibrations were performed. These basins were calibrated as one Slovenia Watershed to easily develop regional parameters where gauge data was not available. For the Sava Mainstem 02 model, gauge hydrographs were used for the tributary and headwater inflows for the event runs.

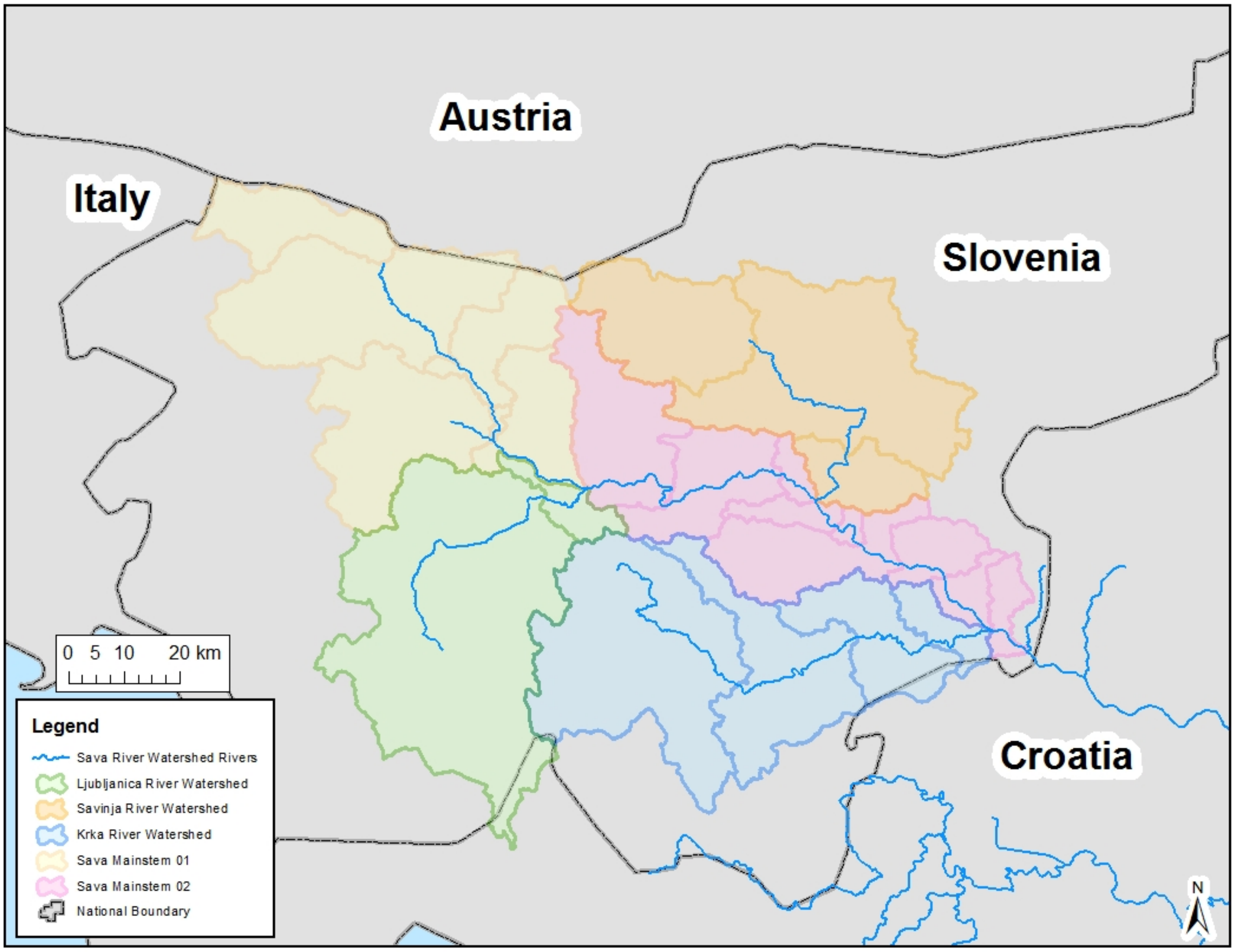


Figure 14: Breakup of Slovenia Watershed for HEC-HMS Models

The coverage of meteorologic stations for the Slovenia Watershed is exceptional for hydrologic model calibration. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred does not get or is not completely recorded at the surrounding gauges; however, with the coverage of stations for the Slovenia Watershed, the interpolation of precipitation was very accurate, especially in comparison to other areas of the Sava River Basin.

There are 7 reservoirs modeled in the Slovenia Watershed including: Moste, Mavcice, Medvode, Vrhovo, Bostanj, Blanca, and Krsko (Figure 15). Three of these structures are located in the Sava Mainstem 01 watershed (Moste, Mavcice, and Medvode) and 5 in the Sava Mainstem 02 watershed (Vrhovo, Bostanj, Blanca, and Krsko). These structures were modeled as reservoirs in the HEC-HMS models. The inputs for a reservoir in HEC-HMS include a modeling method (outflow curve, outflow structure, or specific release), storage method (elevation area or volume curve), initial condition (elevation, inflow = outflow, or storage), and geometry information for specific dam components (outlets, spillways, dam tops, and pumps). This is a simplified method for modeling reservoirs and does not include gate operations. The assumption made was that these structures act as run of river during flood events and any spillway gates would be fully open for the flood events used in the event calibrations. Most of the data was provided for the inputs but some assumptions were made. No storage curves or outflow information was provided for the reservoirs. The elevations and volumes for the active pool were provided, but to complete the elevation storage curves used in the model, storage information was needed above the active pool. To supplement the data provided, the SRTM DEM was used to calculate the elevation storage above the active pool. Another assumption made was that initial elevation for the reservoir starts at the spillway elevation. This allows for the initial conditions to be equal and any increase in flow will then be passed through the spillway.

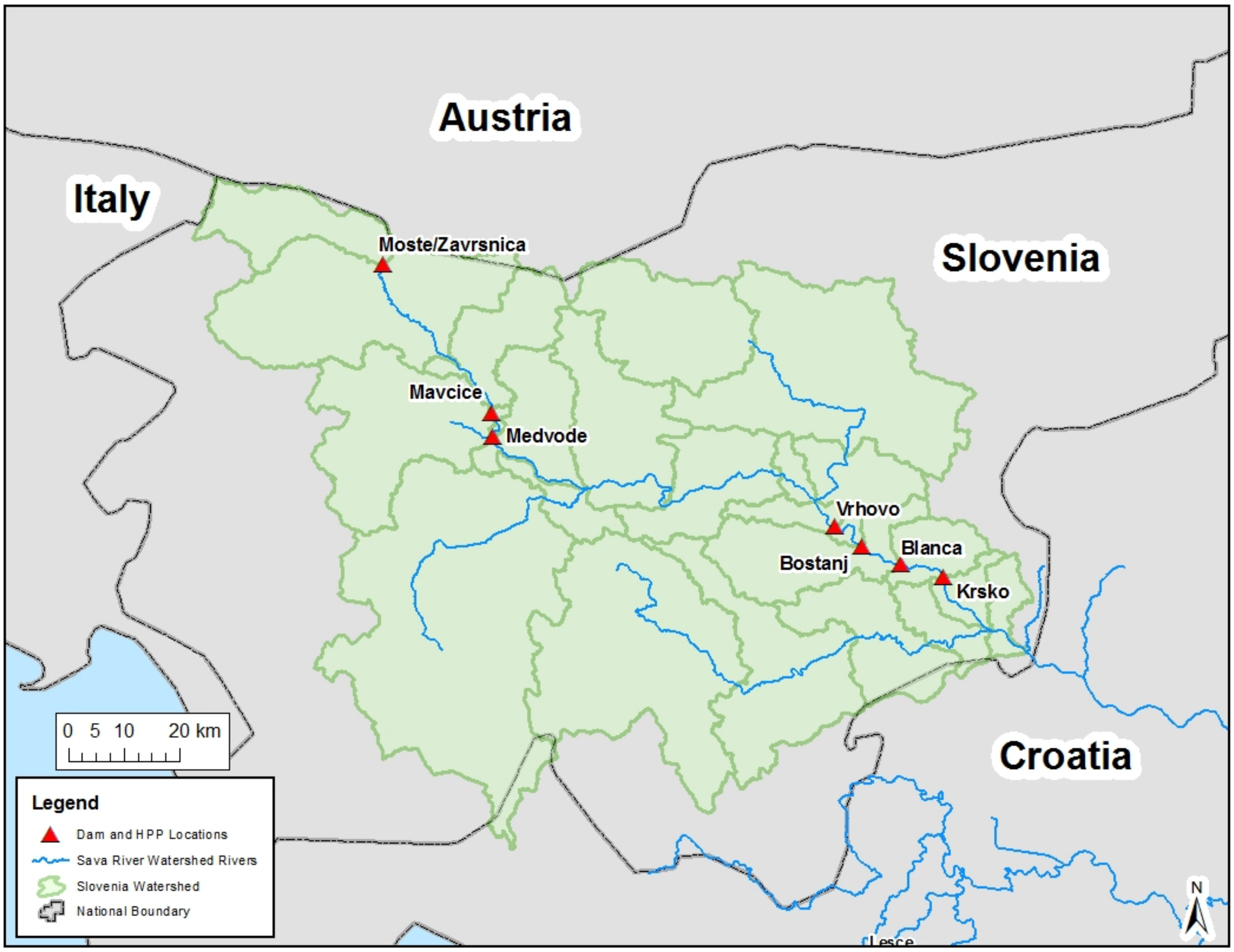


Figure 15: Reservoirs Modeled for the Slovenia Watershed

In general, other than the aforementioned minor issues, no major challenges were encountered during the Slovenia watershed HEC-HMS model development.

4.1.6 CALIBRATION RESULTS AND DISCUSSION

The Slovenia Watershed HEC-HMS model calibration quality is very good based on the performance metrics, and the model performs well across a large range of events and seasons. Figure 16 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of gauges in the basin. The calibration results at these critical, shown in Figure 17 - Figure 29, illustrate the successful calibration of the system. Data for several events on Okroglo and Litija gauge were only available in daily averages, therefore these events were calibrated based on general shape and volume rather than actual peak values. This also distorts the Nash-Sutcliffe efficiency for these events.

Figure 17 - Figure 29 and Table 11 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. In most cases, model calibration quality was dependent on the accuracy and availability of precipitation data. For some of the events (May 2009 in particular), the event calibrations were not as accurate for the headwater subbasins but as the event propagates downstream, the Catez gauge shows a rather good calibration.

The reservoirs modeled in the Slovenia Watershed may need to be updated as better data is available (updated storage curves and/or outflow data).

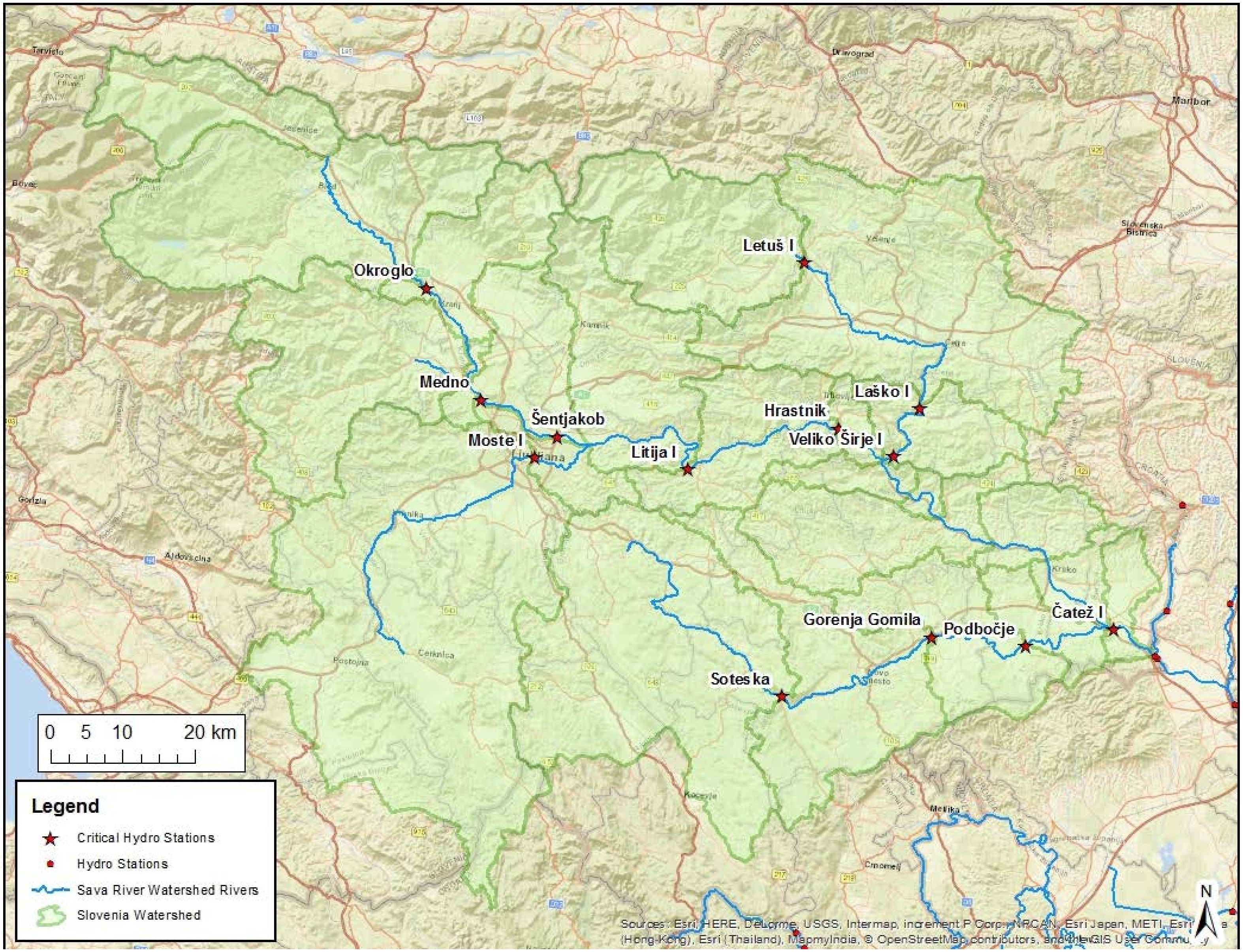


Figure 16: Hydrologic Station Map for the Slovenia Watershed

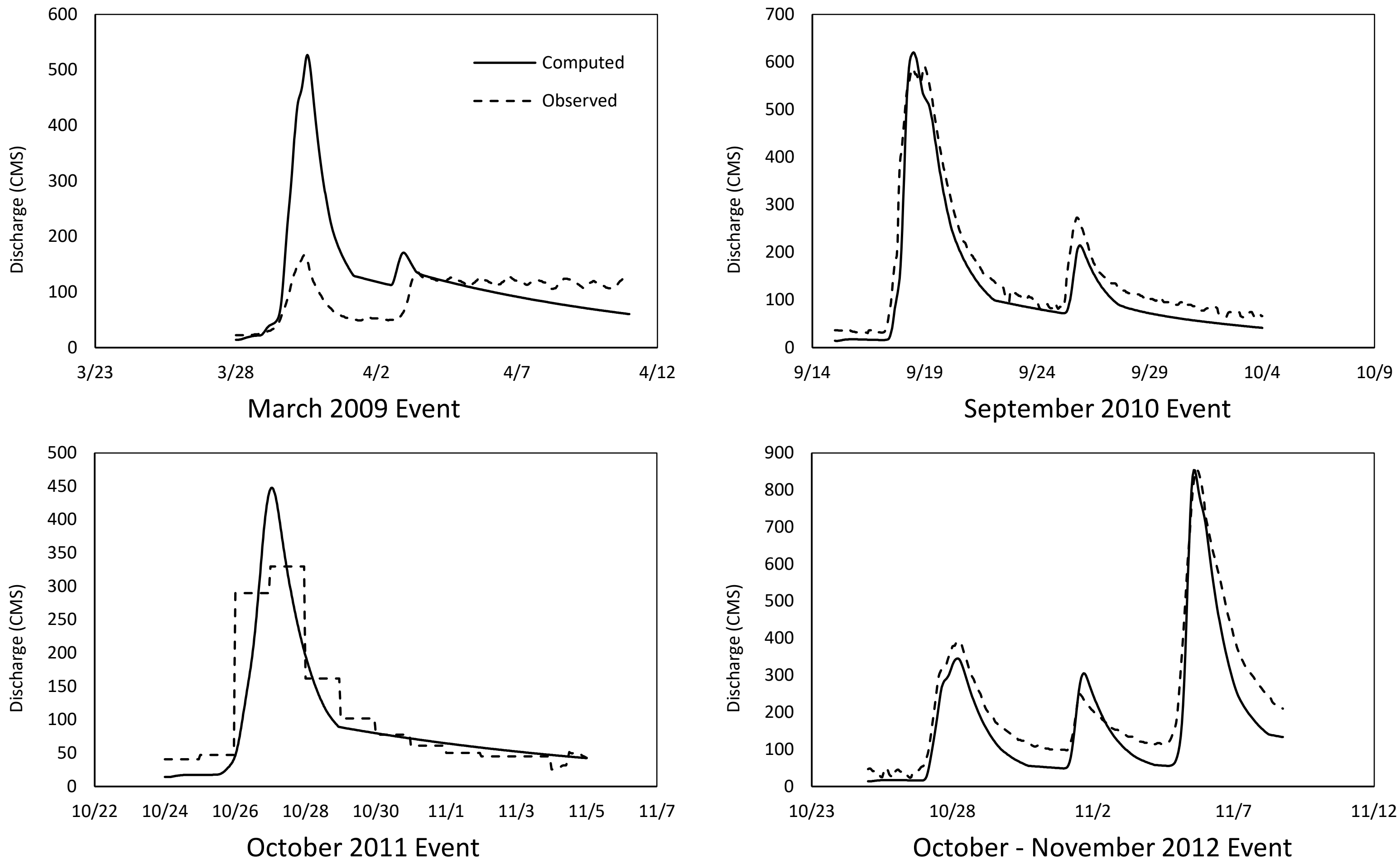


Figure 17: Calibration Plots for the Okroglo Gauge for Various Calibration Events

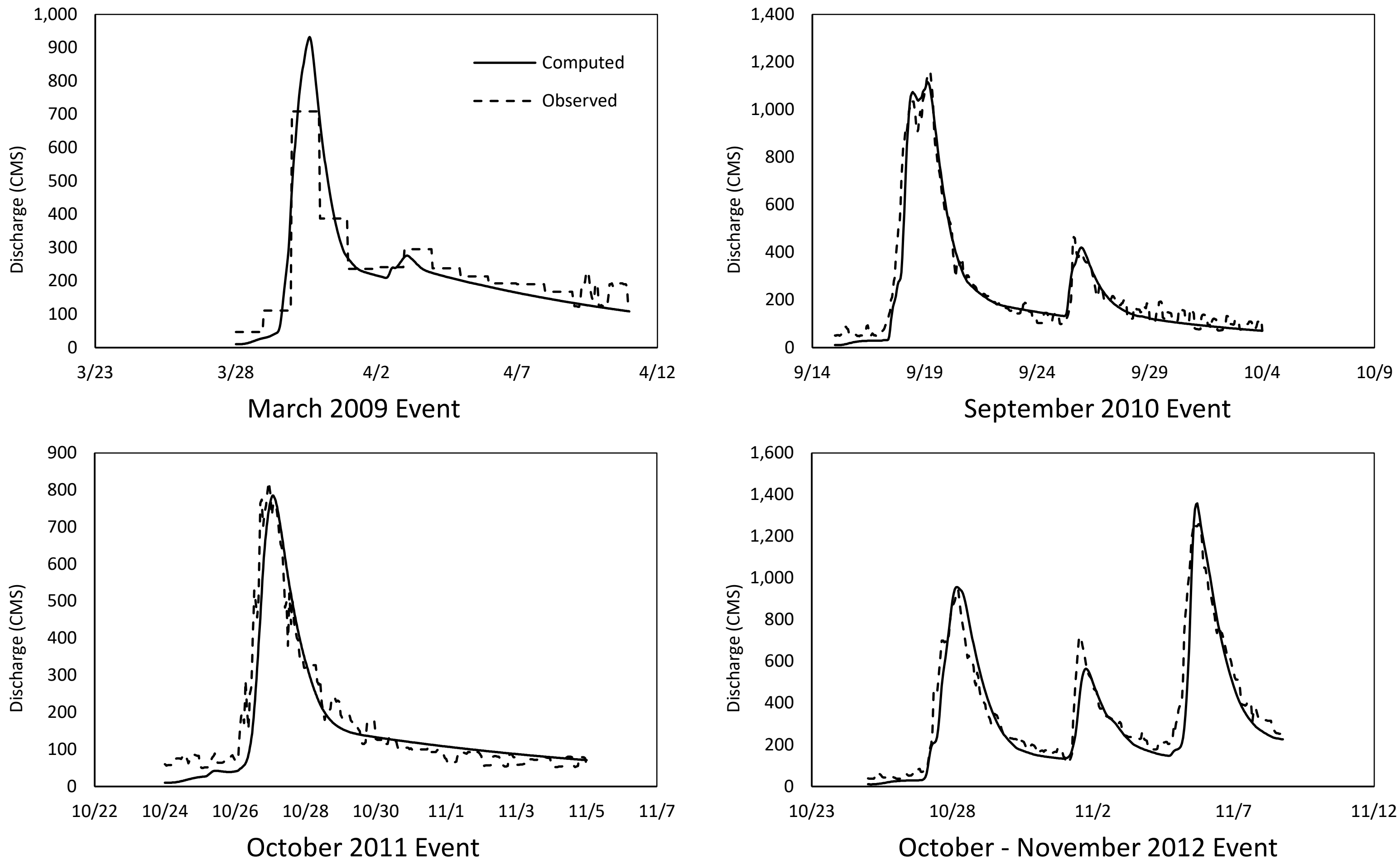


Figure 18: Calibration Plots for the Medno Gauge for Various Calibration Events

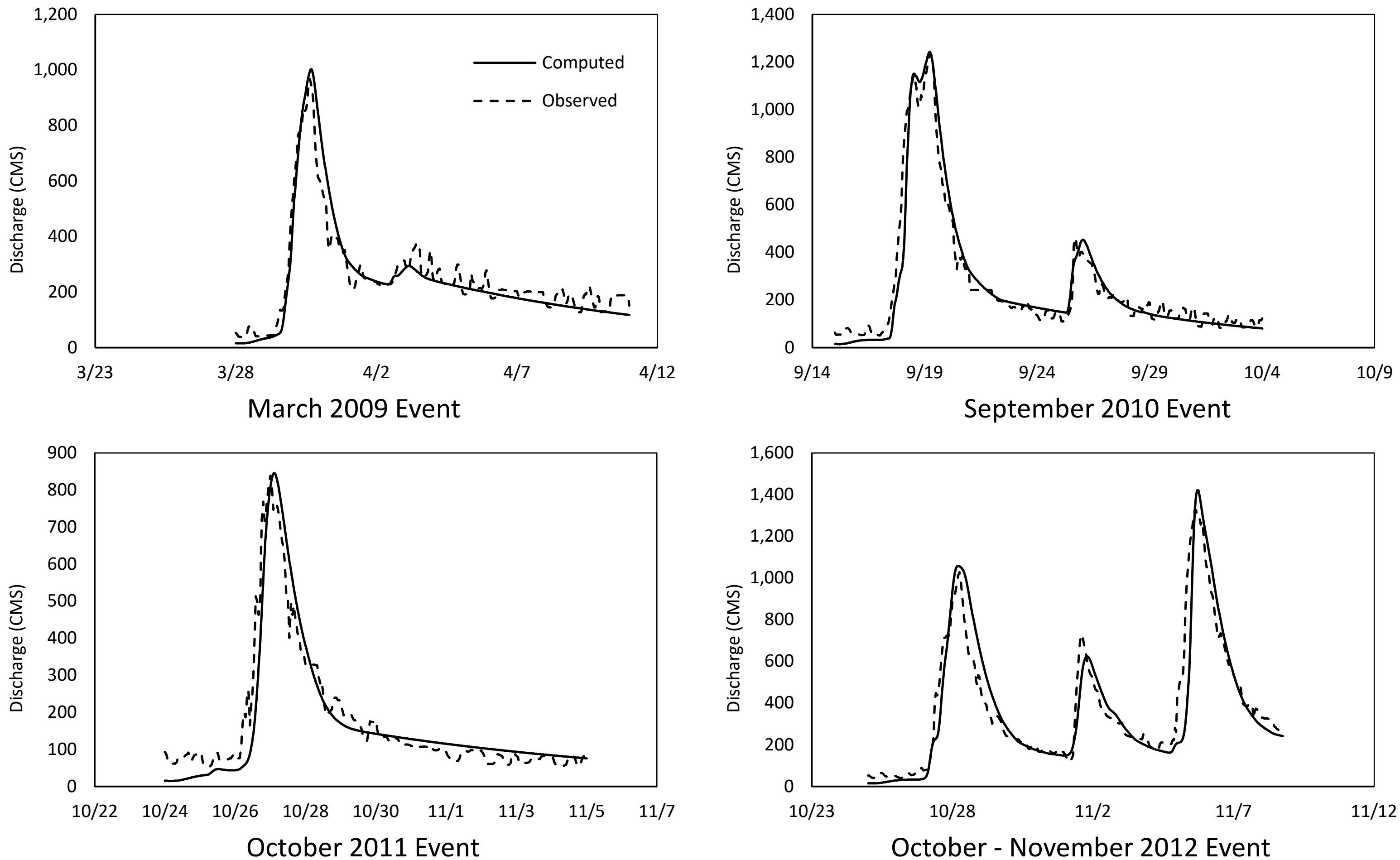


Figure 19: Calibration Plots for the Sentjakob Gauge for Various Calibration Events

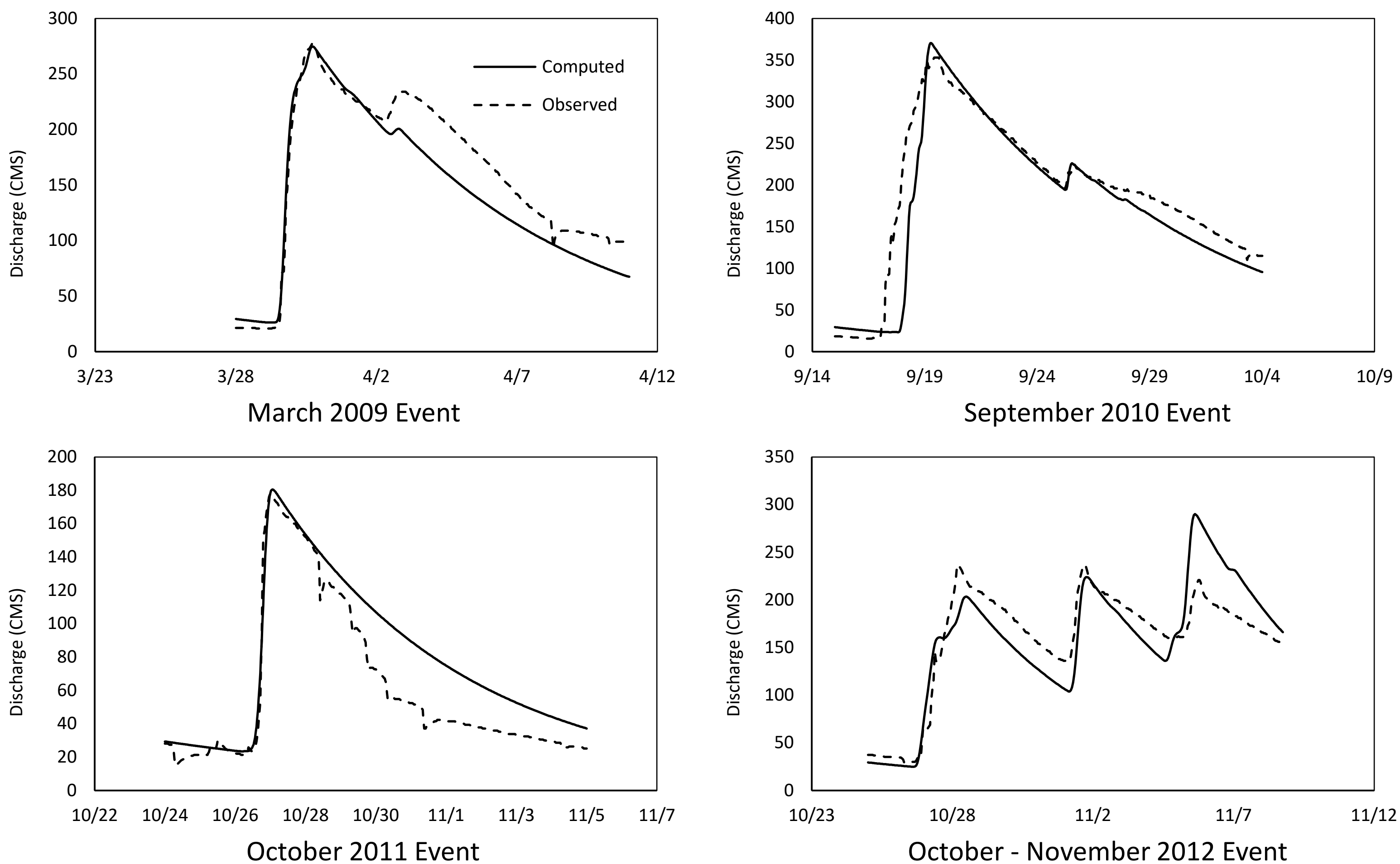


Figure 20: Calibration Plots for the Moste Gauge for Various Calibration Events

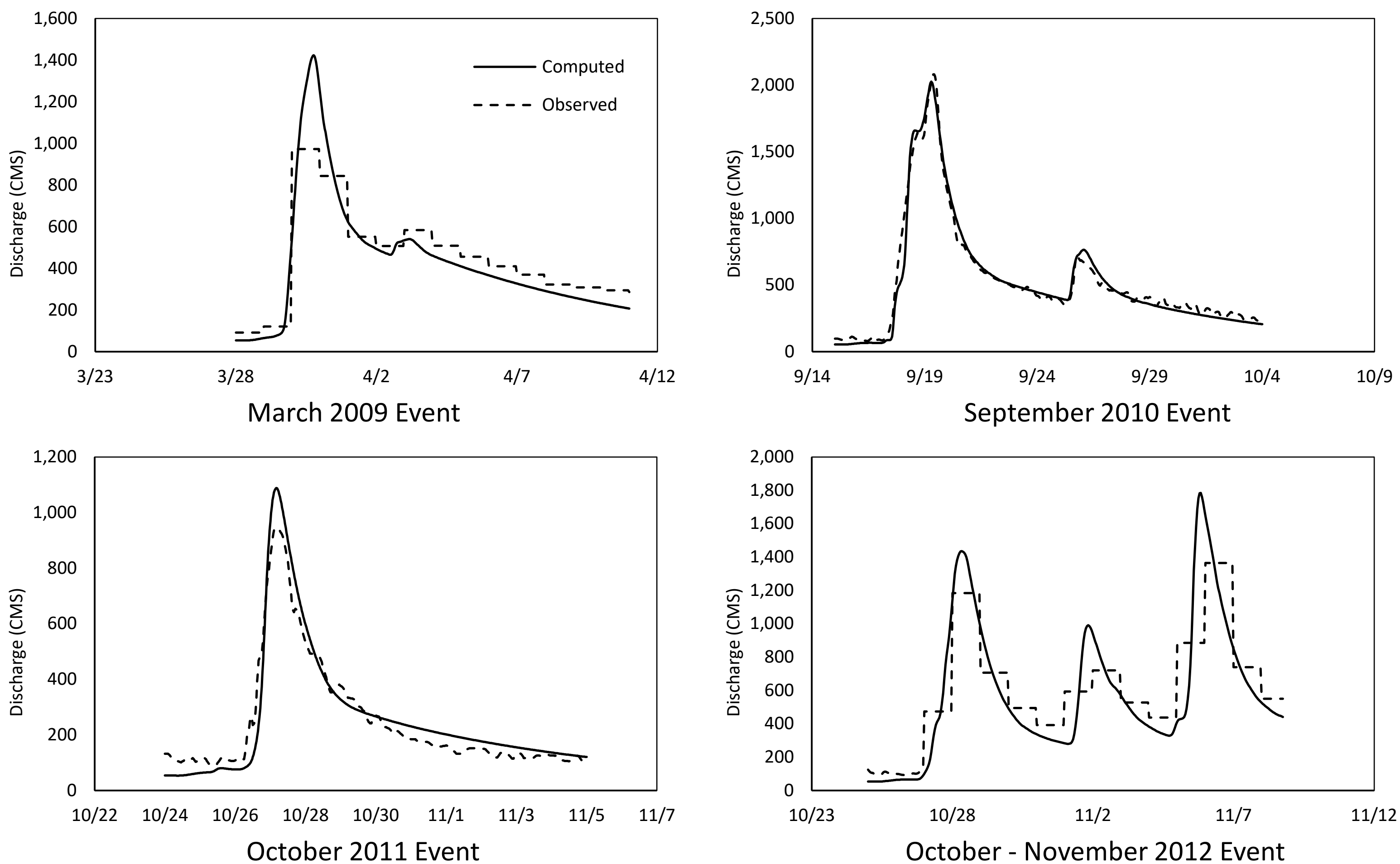


Figure 21: Calibration Plots for the Litija Gauge for Various Calibration Events

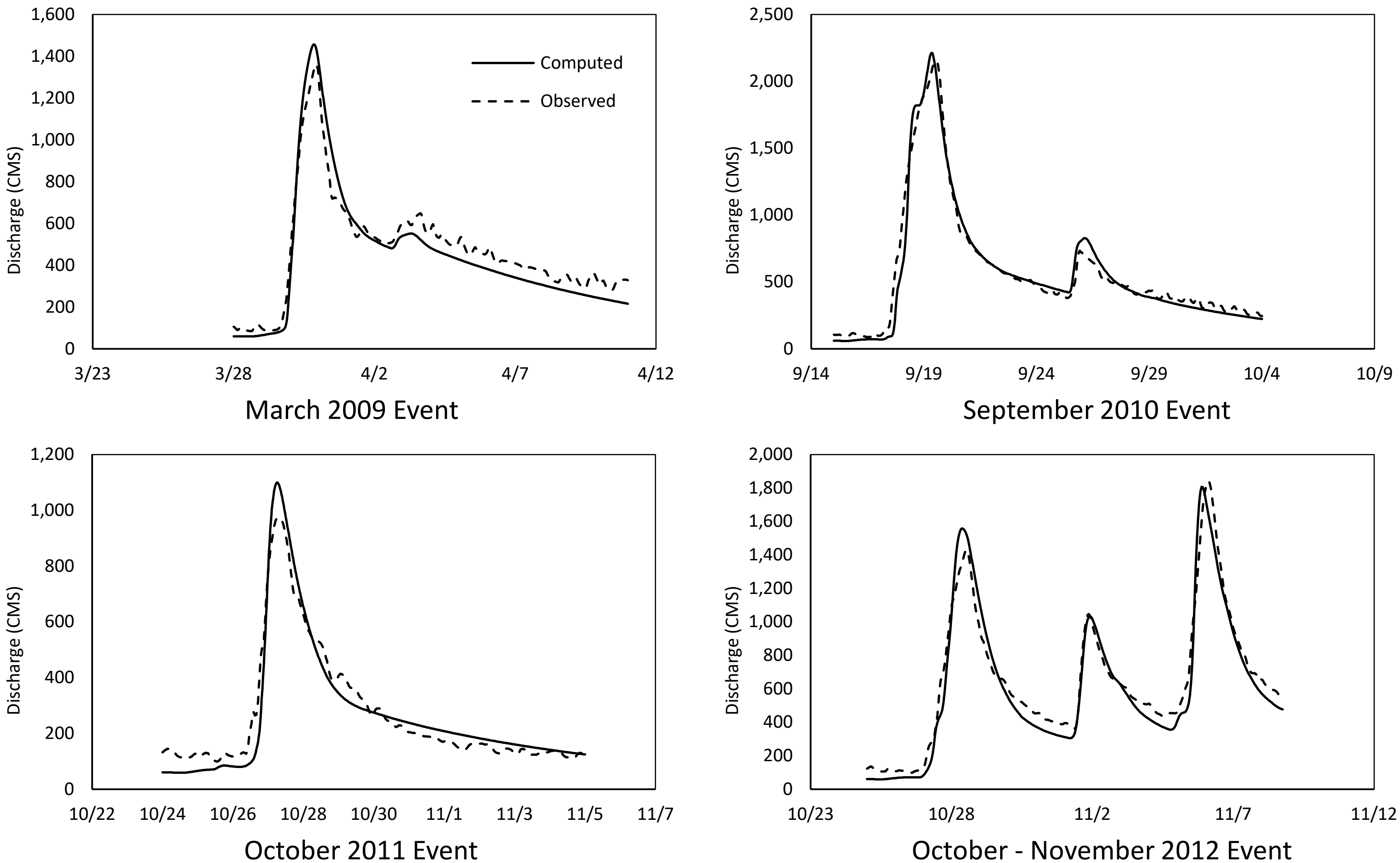


Figure 22: Calibration Plots for the Hrastnik Gauge for Various Calibration Events

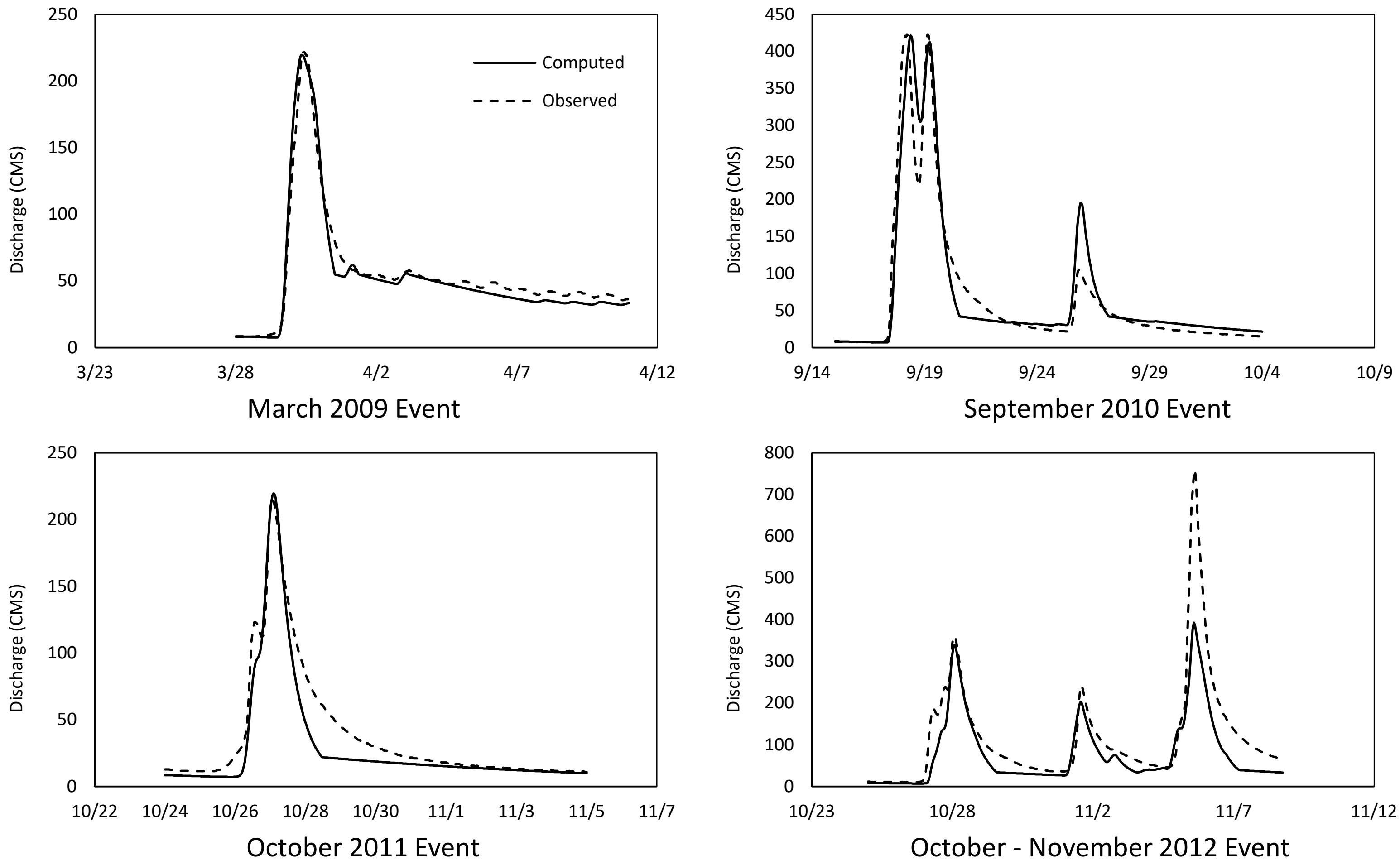


Figure 23: Calibration Plots for the Letus Gauge for Various Calibration Events

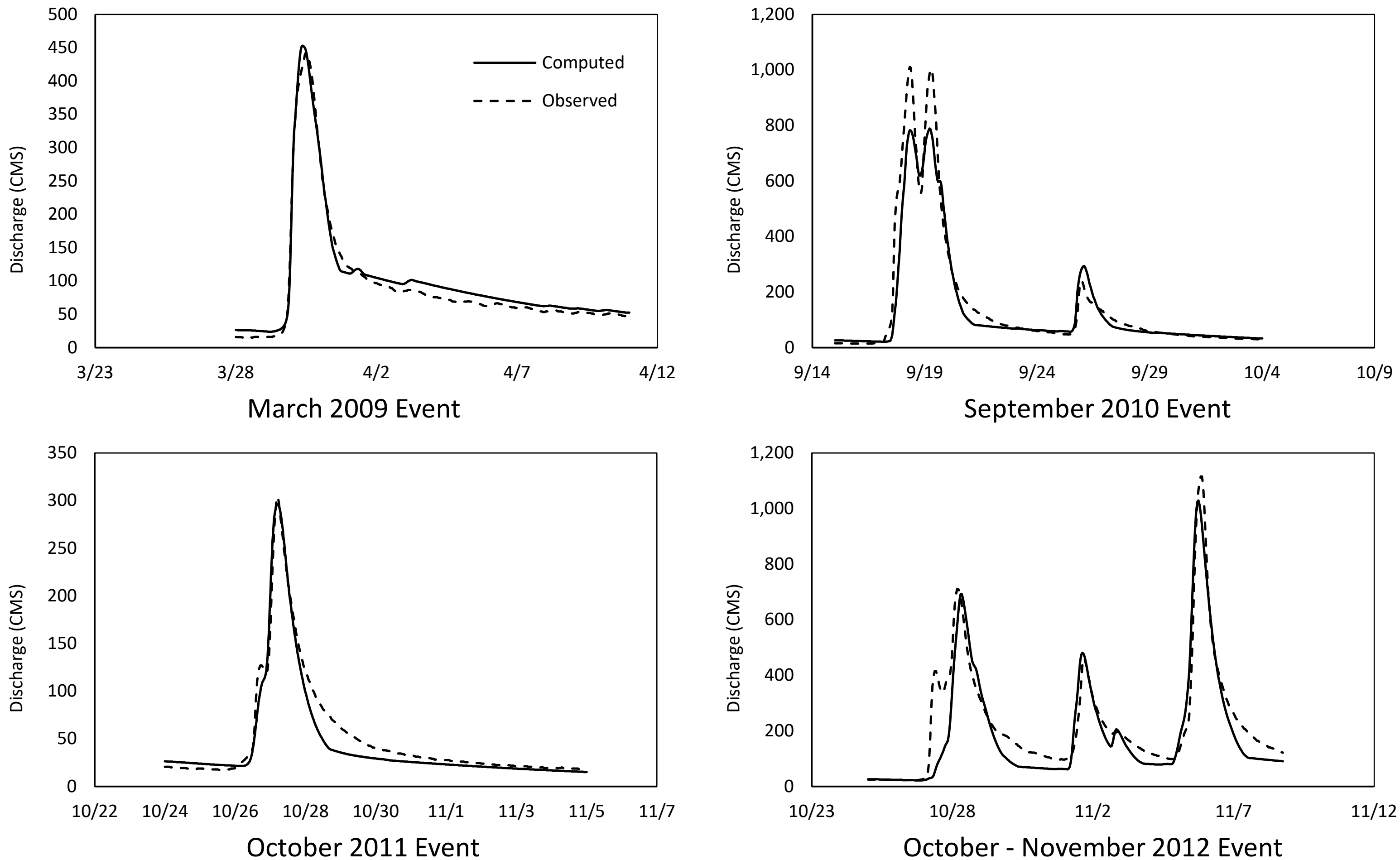


Figure 24: Calibration Plots for the Lasko Gauge for Various Calibration Events

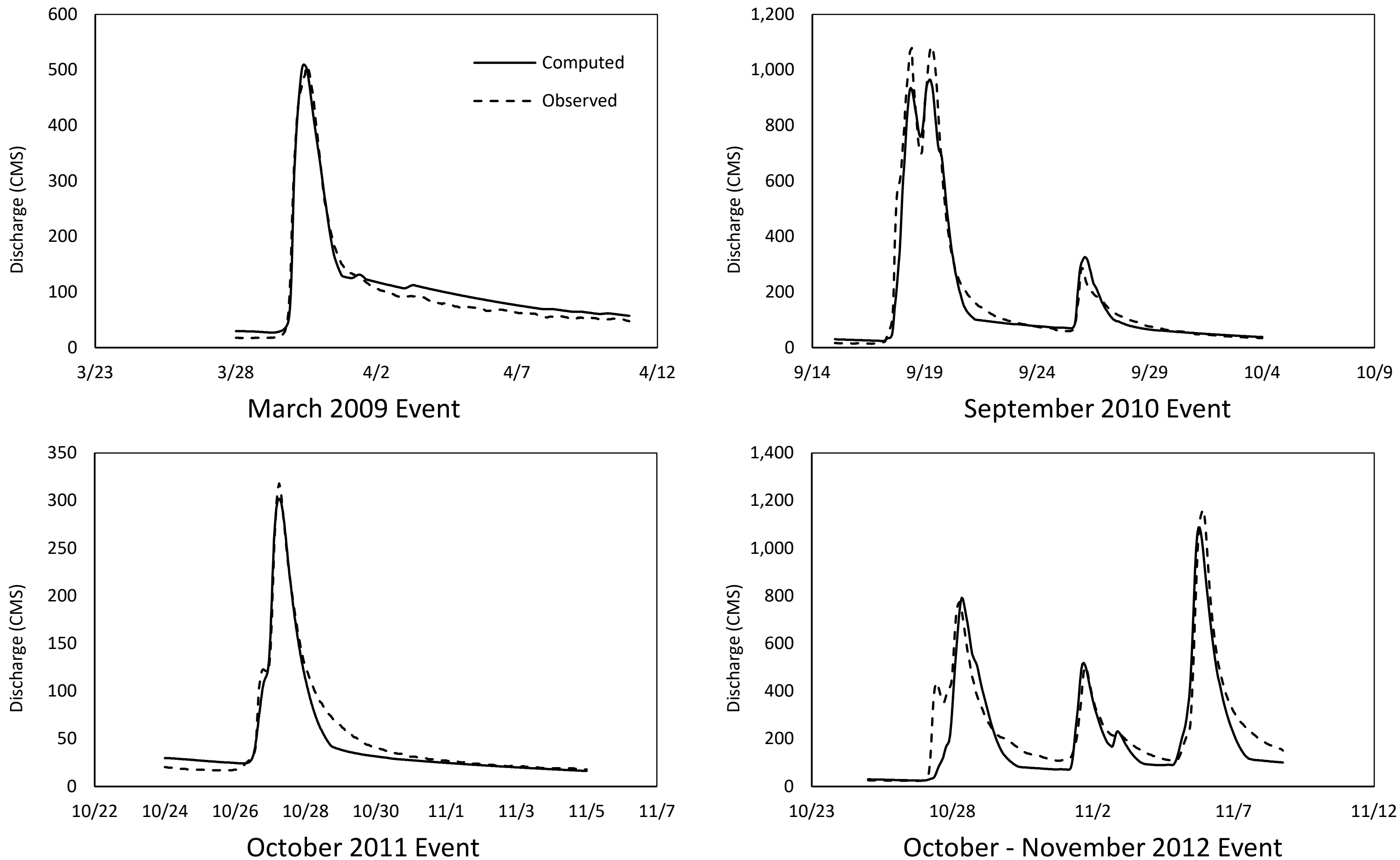


Figure 25: Calibration Plots for the Veliko Sirje Gauge for Various Calibration Events

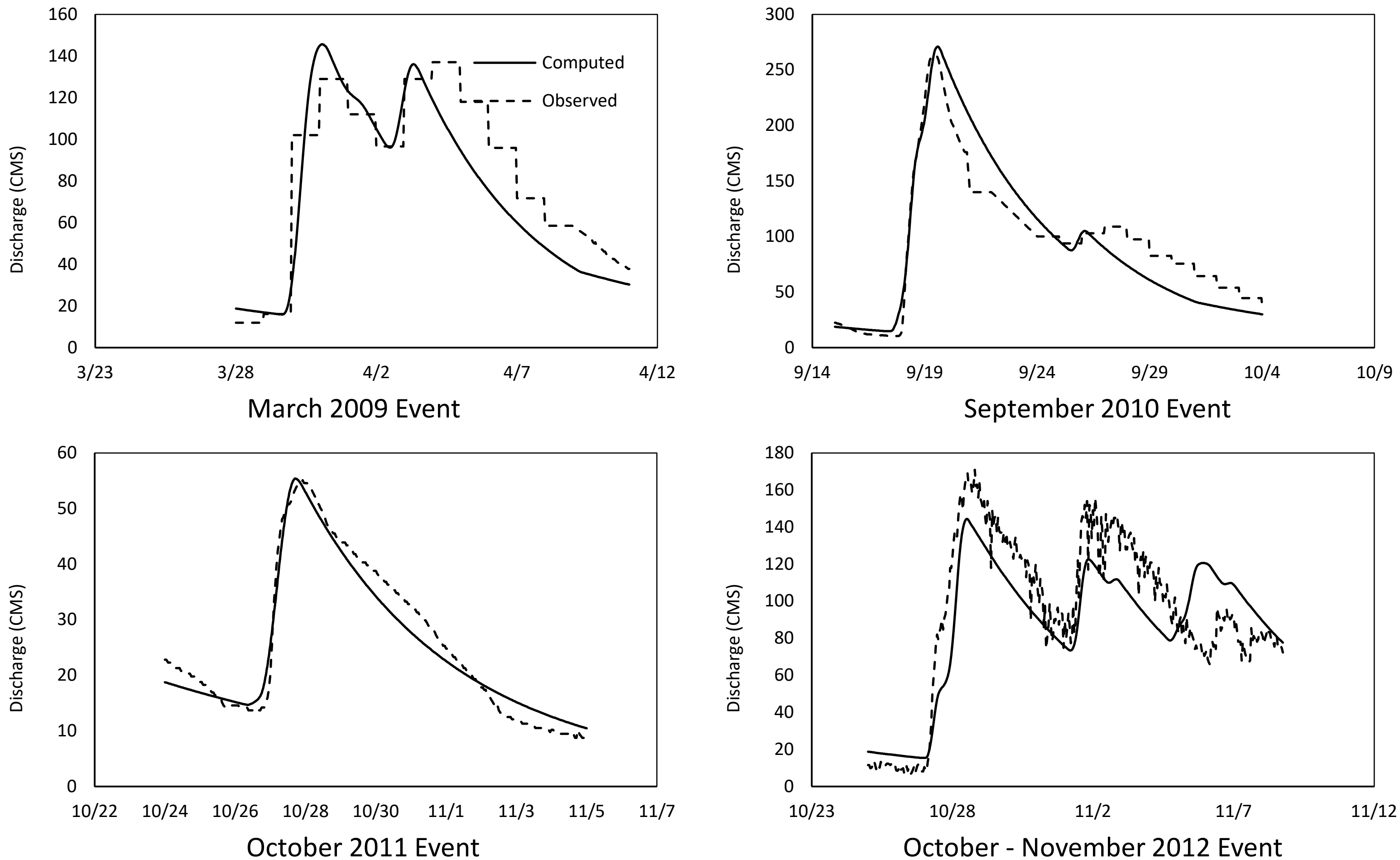


Figure 26: Calibration Plots for the Soteska Gauge for Various Calibration Events

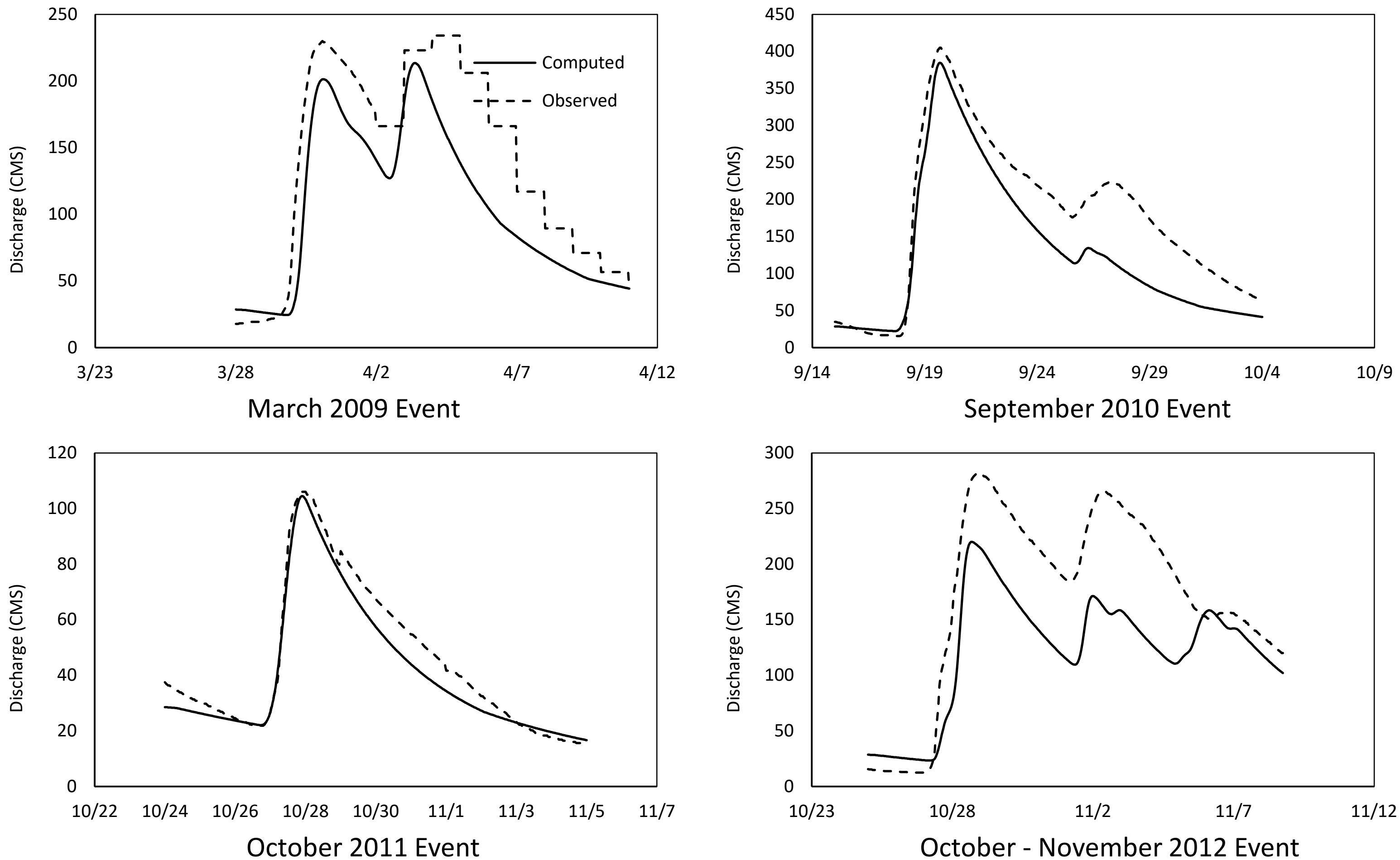


Figure 27: Calibration Plots for the Gorenja Gomila Gauge for Various Calibration Events

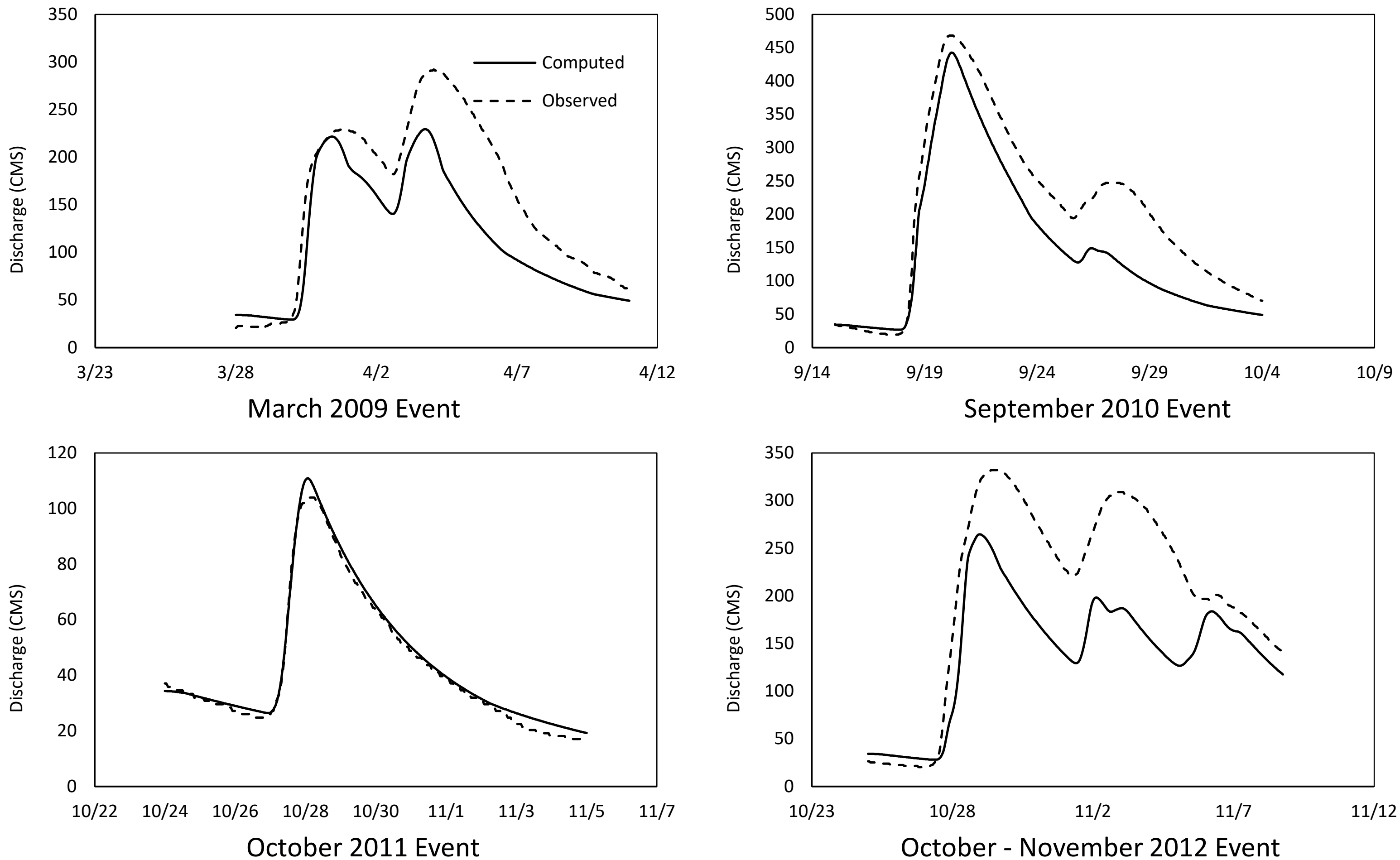


Figure 28: Calibration Plots for the Podbocje Gauge for Various Calibration Events

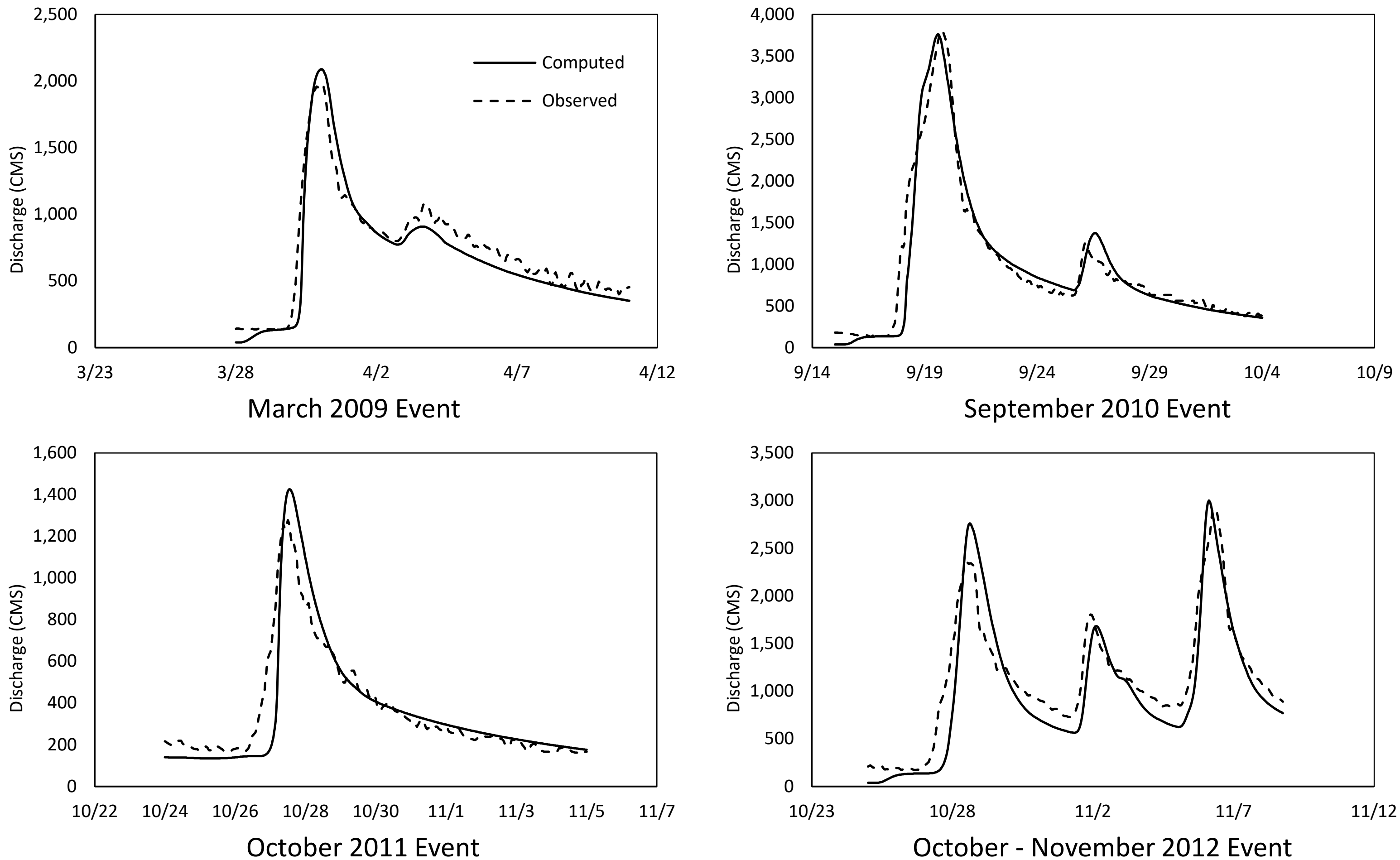


Figure 29: Calibration Plots for the Catez Gauge for Various Calibration Events

Table 11: Slovenia Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Okroglo	Mar2009	166	95	527	129	217.3%	35.7%	-6.76
	Sep2010	591	216	620	172	4.9%	-20.3%	0.91
	Oct2011*	330	93	448	83	35.7%	-10.1%	0.72
	OctNov2012	855	242	854	187	-0.1%	-22.8%	0.87
Medno	Mar2009*	709	135	932	127	31.4%	-5.7%	0.81
	Sep2010	1157	190	1116	178	-3.6%	-6.1%	0.95
	Oct2011	822	81	785	75	-4.5%	-7.5%	0.89
	OctNov2012	1263	223	1358	204	7.5%	-8.3%	0.89
Sentjakob	Mar2009	967	125	1002	120	3.7%	-3.7%	0.90
	Sep2010	1233	176	1242	175	0.7%	-1.0%	0.94
	Oct2011	839	73	846	70	0.8%	-3.5%	0.90
	OctNov2012	1330	200	1422	197	6.9%	-1.6%	0.86
Moste	Mar2009	277	105	275	94	-0.9%	-11.1%	0.87
	Sep2010	353	172	371	158	5.0%	-8.3%	0.82
	Oct2011	178	35	181	44	1.4%	27.3%	0.79
	OctNov2012	237	111	290	110	22.4%	-0.8%	0.70
Litija	Mar2009*	973	112	1423	105	46.2%	-5.5%	0.76
	Sep2010	2080	177	2025	174	-2.6%	-1.6%	0.98
	Oct2011	946	52	1089	54	15.1%	3.8%	0.93
	OctNov2012*	1365	161	1784	153	30.7%	-4.8%	0.57
Hrastnik	Mar2009	1361	108	1457	101	7.0%	-6.9%	0.91
	Sep2010	2152	180	2213	176	2.8%	-2.0%	0.97
	Oct2011	975	52	1100	51	12.8%	-1.7%	0.94
	OctNov2012	1842	158	1808	150	-1.9%	-5.3%	0.94
Letus	Mar2009	222	125	220	119	-1.1%	-5.1%	0.96
	Sep2010	423	209	421	219	-0.4%	4.8%	0.91
	Oct2011	215	74	220	57	2.1%	-23.4%	0.89
	OctNov2012	760	286	393	190	-48.3%	-33.6%	0.68
Lasko	Mar2009	443	68	453	73	2.2%	7.2%	0.98
	Sep2010	1011	156	789	138	-21.9%	-11.4%	0.92
	Oct2011	304	32	296	28	-2.6%	-11.9%	0.95
	OctNov2012	1116	178	1030	152	-7.8%	-14.9%	0.84
Veliko Sirje	Mar2009	507	66	510	72	0.5%	8.8%	0.98
	Sep2010	1083	158	965	147	-10.9%	-7.4%	0.96
	Oct2011	318	28	302	26	-5.0%	-7.1%	0.97
	OctNov2012	1162	174	1088	149	-6.4%	-14.5%	0.83
Soteska	Mar2009*	137	87	146	77	6.3%	-11.2%	0.76
	Sep2010	263	134	271	133	3.0%	-1.3%	0.85
	Oct2011	55	23	55	22	0.5%	-2.8%	0.96
	OctNov2012	171	102	144	95	-15.6%	-7.3%	0.72
Gorenja Gomila	Mar2009*	234	95	213	71	-8.8%	-25.3%	0.62
	Sep2010	405	161	384	118	-5.1%	-26.9%	0.71
	Oct2011	106	26	105	24	-1.4%	-9.8%	0.94
	OctNov2012	282	122	220	87	-22.0%	-28.6%	0.43
Podbocje	Mar2009	292	88	229	65	-21.4%	-26.4%	0.59
	Sep2010	468	155	443	114	-5.4%	-26.8%	0.75
	Oct2011	104	21	111	22	6.6%	4.0%	0.99
	OctNov2012	332	122	265	85	-20.3%	-30.7%	0.38
Catez	Mar2009	1978	87	2088	80	5.6%	-7.7%	0.90
	Sep2010	3803	155	3762	153	-1.1%	-1.3%	0.93
	Oct2011	1278	37	1426	36	11.6%	-1.9%	0.80
	OctNov2012	2921	141	3001	127	2.7%	-10.1%	0.81

*** - Observed flows are daily average**

4.2 SUTLA RIVER WATERSHED

4.2.1 BASIN DESCRIPTION

The Sutla River is a very small river that flows along the border between Slovenia and Croatia, flowing from Rogatec, Slovenia and Durmanec, Croatia southward through Podcetrtek, Slovenia and Senkovec, Croatia to its confluence with the Sava River just upstream of Zagreb, Croatia. The Sutla River basin is a relatively long and narrow basin with a basin area of approximately 600 km^2. The basin's topography is considered relatively steep with a maximum elevation in the headwaters of approximately 975 masl and minimum elevation at its confluence of approximately 125 masl.

4.2.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 12 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Sutla River watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 0.99 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.72 indicates that a reasonable amount of attenuation occurs within the watershed, likely driven by an abundance of flatter, low-lying areas in the lower reaches of the basin.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The range of constant loss rates seen during model calibration is relatively consistent which indicates the meteorologic model is properly representing precipitation volume across a wide range of events. This outcome is expected due to density of the meteorologic station coverage in the region. A range of 1.7 to 17.0 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is very different throughout the watershed.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 12: Sutla Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	20	0.99	6.73	14.39	0.72	0.01	0.90	0.13
Minimum	5	0.65	1.70	5.00	0.59	0.00	0.86	0.10
Maximum	50	1.50	17.00	35.00	0.80	0.03	0.90	0.25
Standard Deviation	18	0.19	0.78	2.97	0.08	0.01	0.00	0.02

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 12 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Sutla River HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.2.3 REACH ROUTING PARAMETERS

River reach routings within the Sutla River basin were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 13 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 13: Sutla Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_02_02_01	11794	0.0002	Eight Point	0.05	0.15	0.15
R_02_03_01	8547	0.0014	Trapezoid	0.04		

4.2.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Sutla River basin was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 30 illustrates the Sutla River basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 30 illustrates that the Sutla River Basin has a reasonable number of meteorological stations covering the basin. Although the figure shows only one station in the basin, the stations surrounding the basin provide adequate meteorologic station coverage.

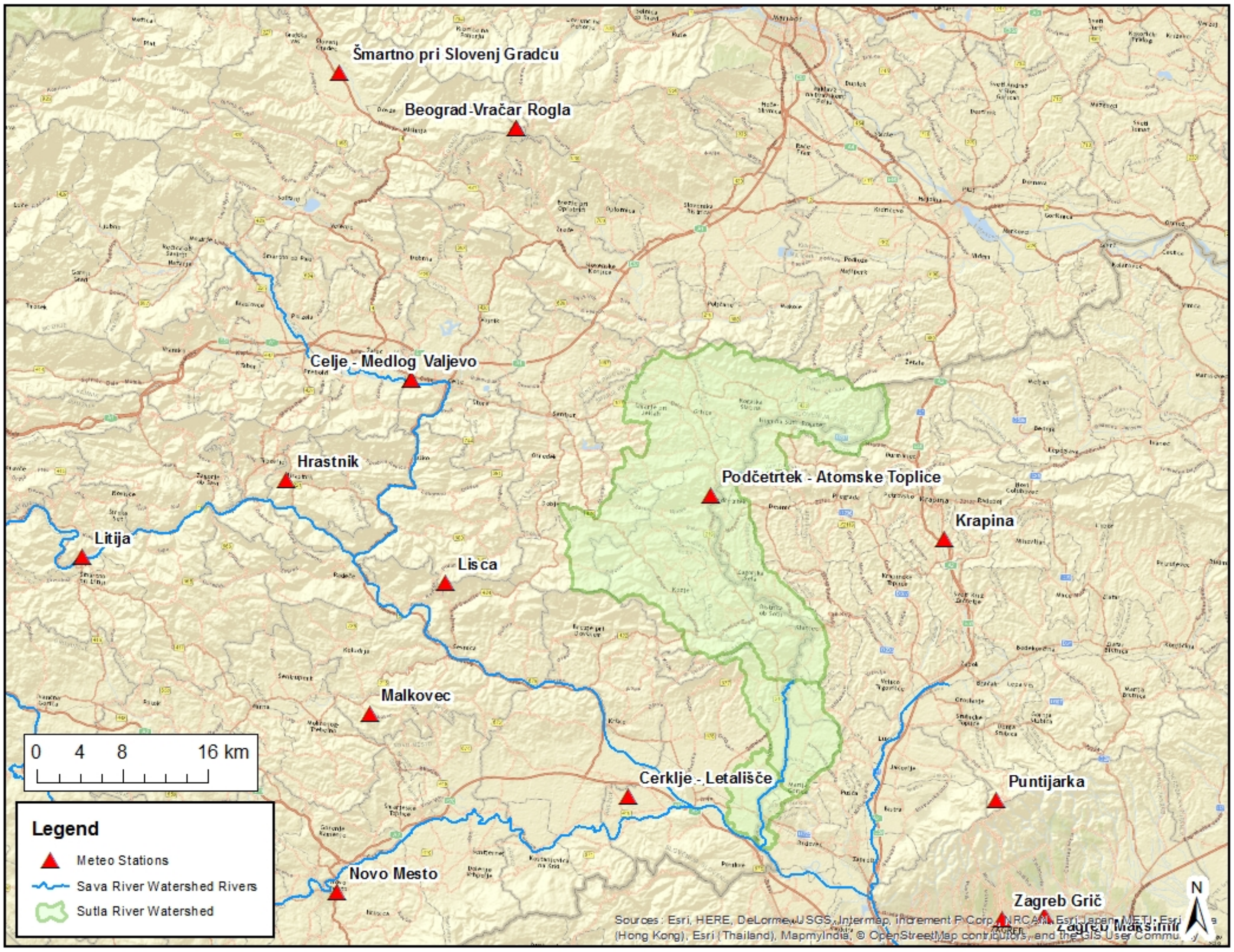


Figure 30: Meteorologic Station Map for the Sutla River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 14 shows the average ET rates for the Sutla River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 14: Average ET Rates for the Sutla River Watershed

Month	ET Rate (mm/month)
Jan	15.1
Feb	23.4
Mar	39.6
Apr	63.7
May	90.7
Jun	113.4
Jul	136.5
Aug	122.7
Sep	84.4
Oct	50.2
Nov	28.3
Dec	17.3

4.2.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Sutla River watershed HEC-HMS model. In general, the complexity of this basin is relatively low due to its size. In addition, meteorologic station density is not an issue for the Sutla River Basin, which makes the calibration process more simple and accurate. The only major recommendation that could be made for this specific basin would be to develop a higher resolution subbasin delineation if more detailed analysis is required in the future.

4.2.6 CALIBRATION RESULTS AND DISCUSSION

The Sutla River watershed HEC-HMS model calibration quality is very good based on the performance metrics, and the model performs well across a large range of events and seasons. Figure 31 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of gauges in the basin.

Figure 32 - Figure 33 and Table 15 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. In general, the calibration quality was high for all events evaluated for this basin, which implies that the precipitation was not only more accurate for this basin but also that the location of the available meteorologic stations better captured the spatial and temporal distribution of the storm event.

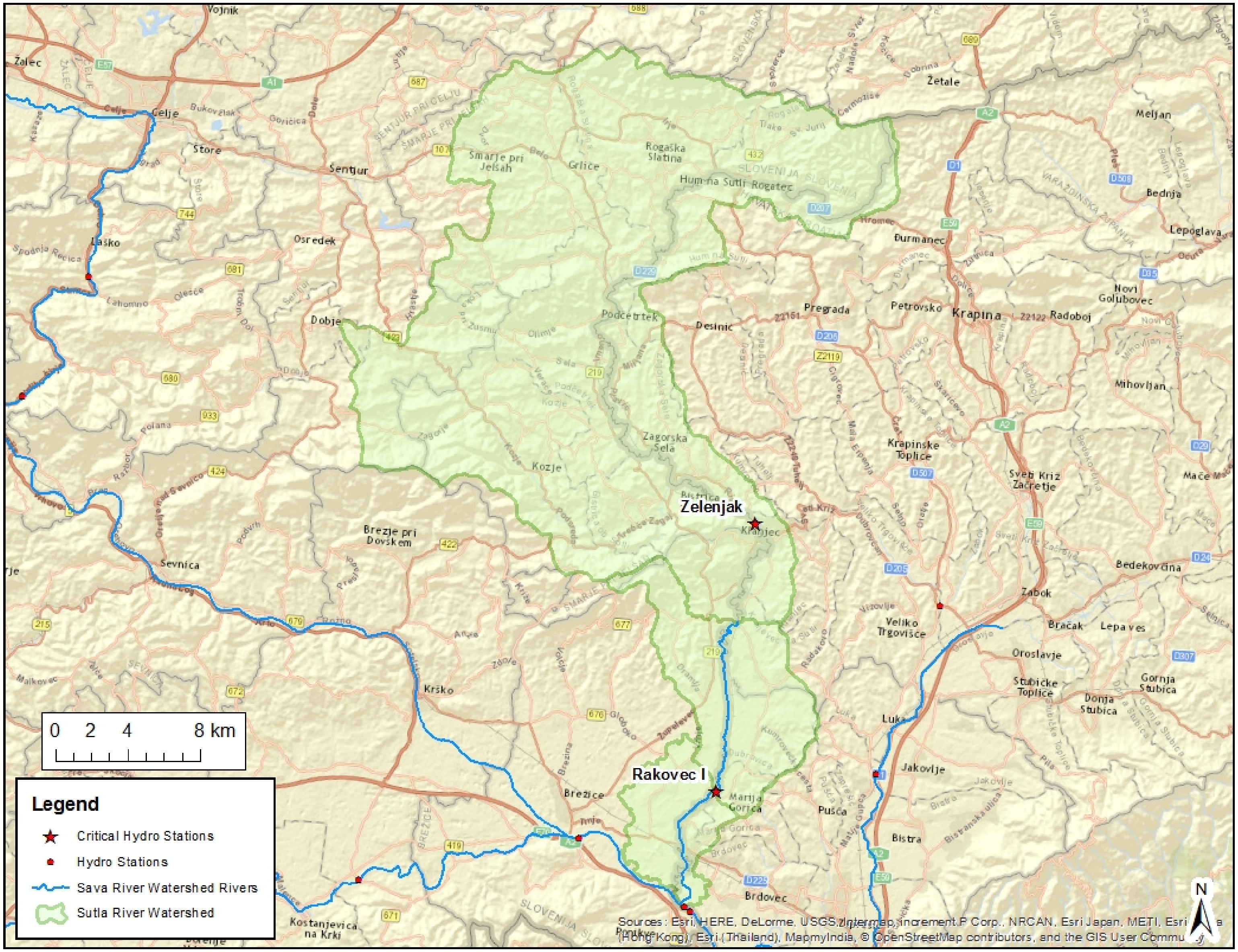


Figure 31: Hydrologic Station Map for the Sutla River Watershed

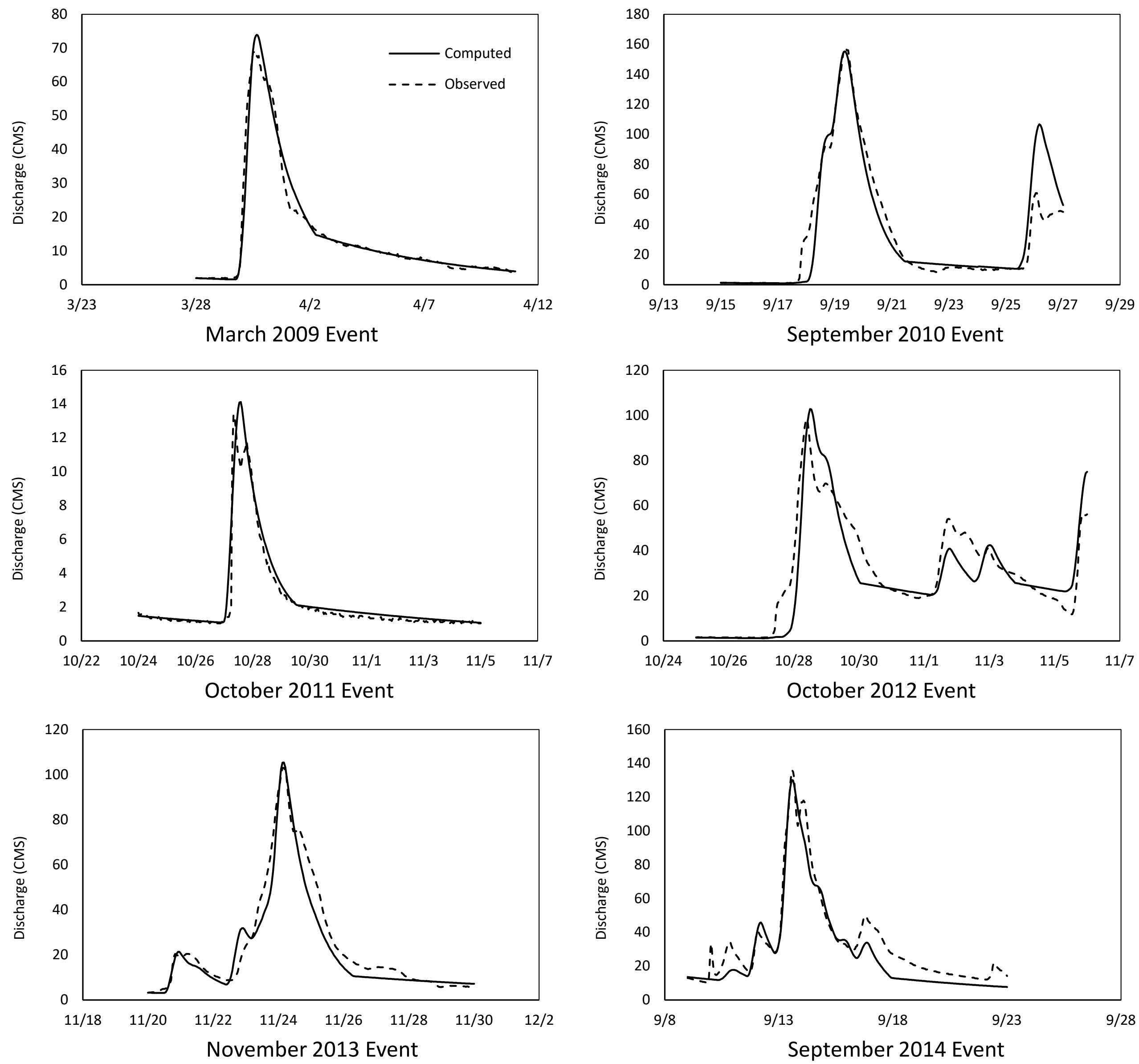


Figure 32: Calibration Plots for the Zelenjak Gauge for Various Calibration Events

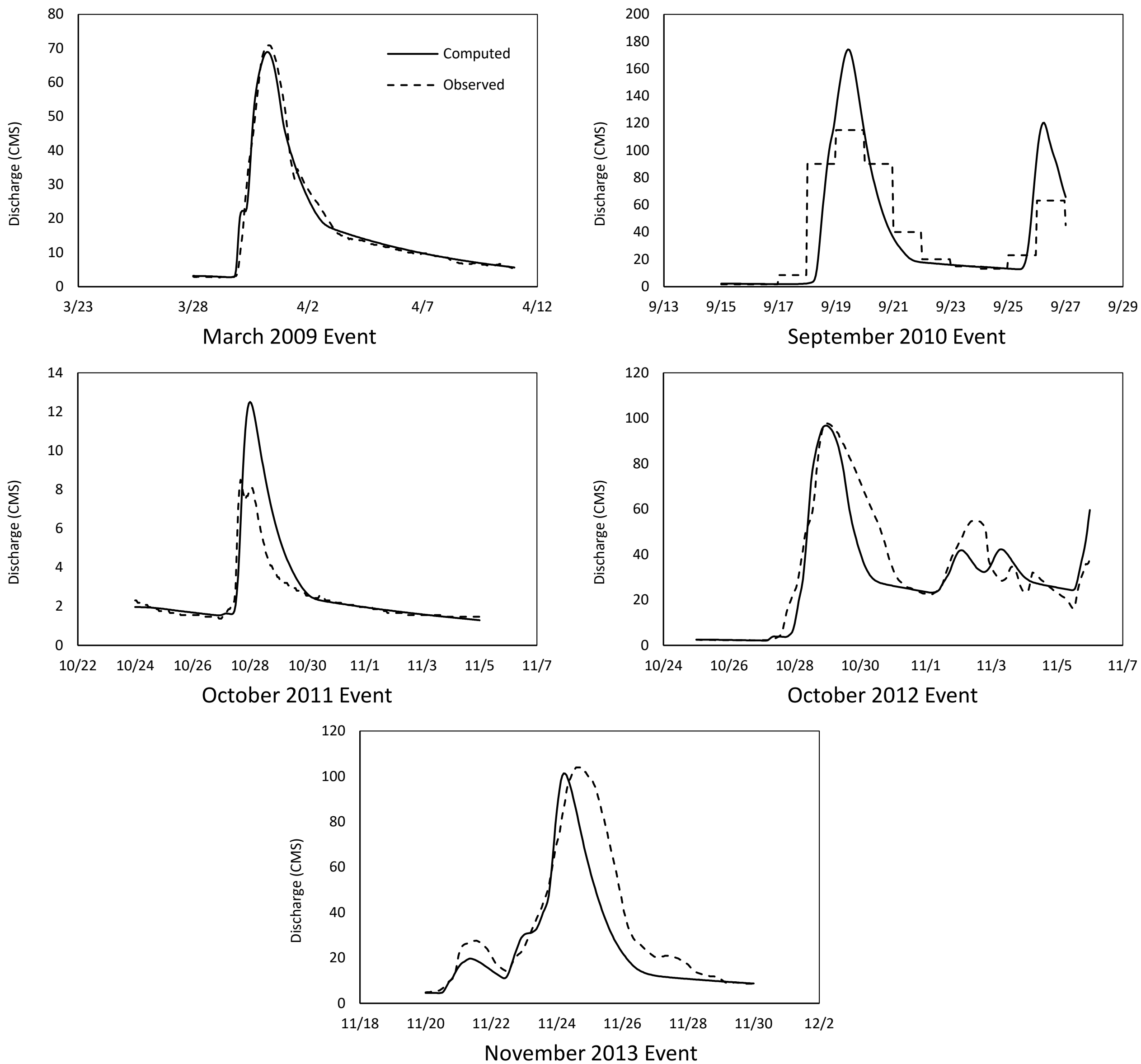


Figure 33: Calibration Plots for the Rakovec Gauge for Various Calibration Events

Table 15: Sutla River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Zelenjak	Mar 2009	69	36	74	36	7.2%	0.0%	0.974
	Sep 2010	155	50	158	55	1.9%	10.0%	0.955
	Oct 2011	13	5	14	5	7.7%	2.0%	0.925
	Oct 2012	98	78	103	73	5.1%	-6.4%	0.796
	Nov 2013	103	43	105	38	1.9%	-11.6%	0.930
	Sep 2014	136	93	130	77	-4.4%	-17.2%	0.918
Rakovec	Mar2009	71	38	69	38	-2.8%	0.0%	0.983
	Sep 2010	115	59	174	55	51.3%	-6.8%	0.584
	Oct 2011	9	5	13	5	44.4%	0.0%	0.350
	Oct 2012	98	79	97	71	-1.0%	-10.1%	0.766
	Nov 2013	104	52	101	39	-2.9%	-25.0%	0.724

4.3 KRAPINA RIVER WATERSHED

4.3.1 BASIN DESCRIPTION

The Krapina River is a relatively short river within Croatia, flowing southward from Krapina through Zabec and Kupljenovo to its confluence with the Sava River just upstream of Zagreb. The Krapina River basin is fan-shaped with a basin area of approximately 1,236 km^2. The basin's topography is considered relatively steep with a maximum elevation in the headwaters of approximately 1030 masl and minimum elevation at its confluence of approximately 100 masl.

4.3.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 16 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Krapina River watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 1.58 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.73 indicates that a substantial amount of attenuation occurs within the watershed, likely driven by an abundance of flatter, low-lying areas in the lower reaches of the basin.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The range of constant loss rates across the various calibration events is very reasonable. A range of 5.5 to 22.0 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is very different throughout the watershed.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 16: Krapina Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	28	1.58	9.7	27.9	0.73	0.004	0.90	0.11
Minimum	10	1.20	5.5	9.0	0.46	0.001	0.90	0.00
Maximum	45	2.30	22.0	60.0	0.79	0.012	0.90	0.17
Standard Deviation	16	0.42	0.7	9.0	0.09	0.004	0.00	0.04

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 16 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Krapina River HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.3.3 REACH ROUTING PARAMETERS

River reach routings within the Krapina River basin were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 17 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 17: Krapina Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_04_02_03	8868	0.0010	Trapezoid	0.040		
R_04_02_06	14362	0.0006	Trapezoid	0.040		

4.3.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Krapina River basin was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section*

3.2.7 of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 34 illustrates the Krapina River basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 34 illustrates that the Krapina River Basin has a reasonable number of meteorological stations covering the basin; however, portions of the basin are lacking sufficient coverage of meteorologic stations.

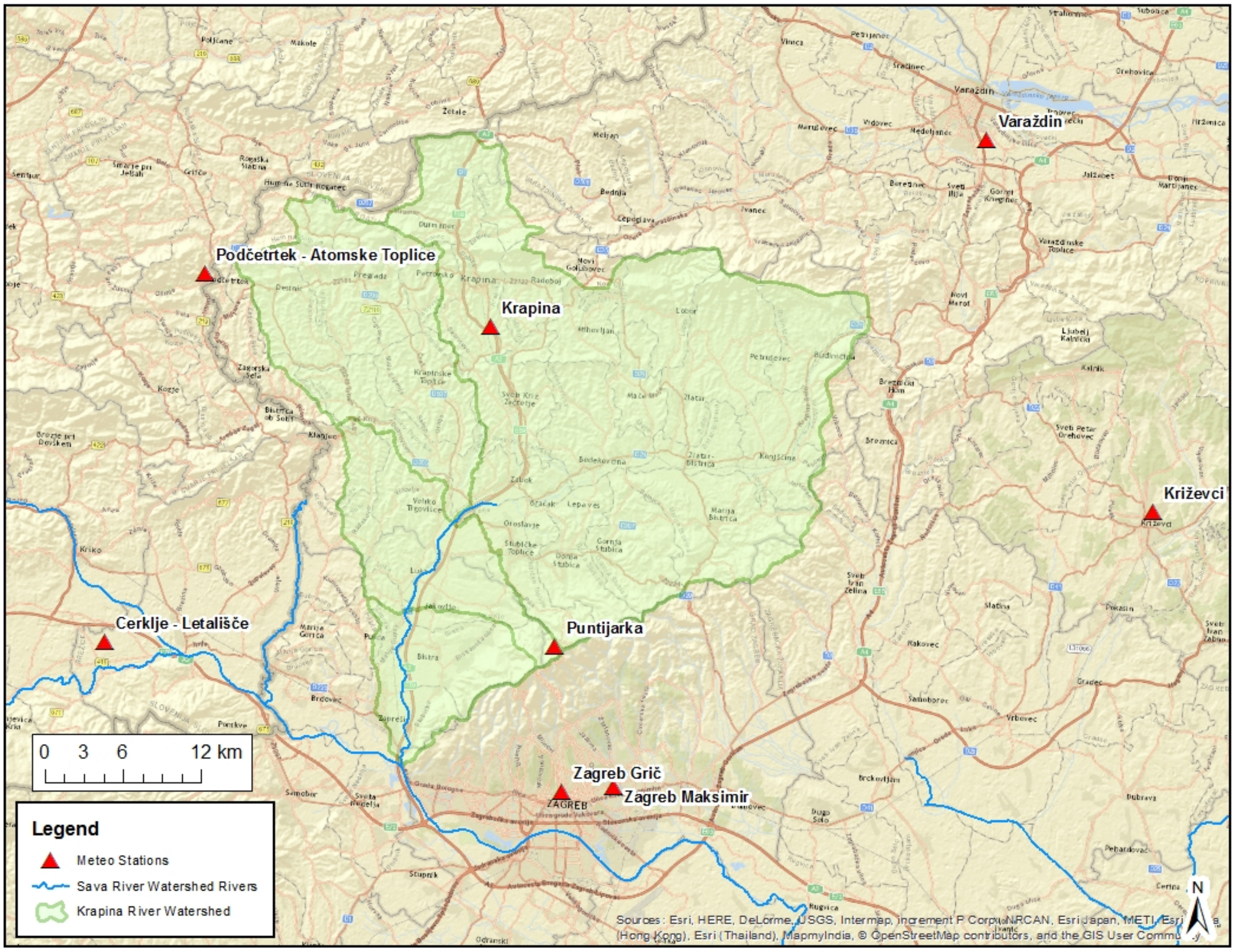


Figure 34: Meteorologic Station Map for the Krapina River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 18 shows the average ET rates for the Krapina River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 18: Average ET Rates for the Krapina River Watershed

Month	ET Rate (mm/month)
Jan	15.1
Feb	23.4
Mar	39.6
Apr	63.7
May	90.7
Jun	113.4
Jul	136.5
Aug	122.7
Sep	84.4
Oct	50.2
Nov	28.3
Dec	17.3

4.3.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Krapina River watershed HEC-HMS model. The only major challenge is related to meteorologic station coverage.

The coverage of meteorologic stations for the Krapina River basin is generally adequate for hydrologic model calibration; however, as seen in Figure 34, eastern portions of the basin lack sufficient gauge coverage. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred does not get or is not completely recorded at the surrounding gauges. In general, this was not a major limitation to the model calibration as is evident in the calibration results.

In general, other than the aforementioned minor issues, no major challenges were encountered during the Krapina River watershed HEC-HMS model development.

4.3.6 CALIBRATION RESULTS AND DISCUSSION

The Krapina River watershed HEC-HMS model calibration quality is very good based on the performance metrics, and the model performs well across a large range of events and seasons. Figure 35 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of gauges in the basin

Figure 36 - Figure 37 and Table 19 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. In general, the calibration quality was good for all calibration events evaluated, which implies that the precipitation was not only more accurate for these

events but also that the location of the available meteorologic stations better captured the spatial and temporal distribution of the storm event. In most cases, model calibration quality was dependent on the accuracy and availability of precipitation data. For the October 2012 event, the second and third peak of the event is not captured by the hydrologic model because the meteorologic stations did not capture these subsequent precipitation events.

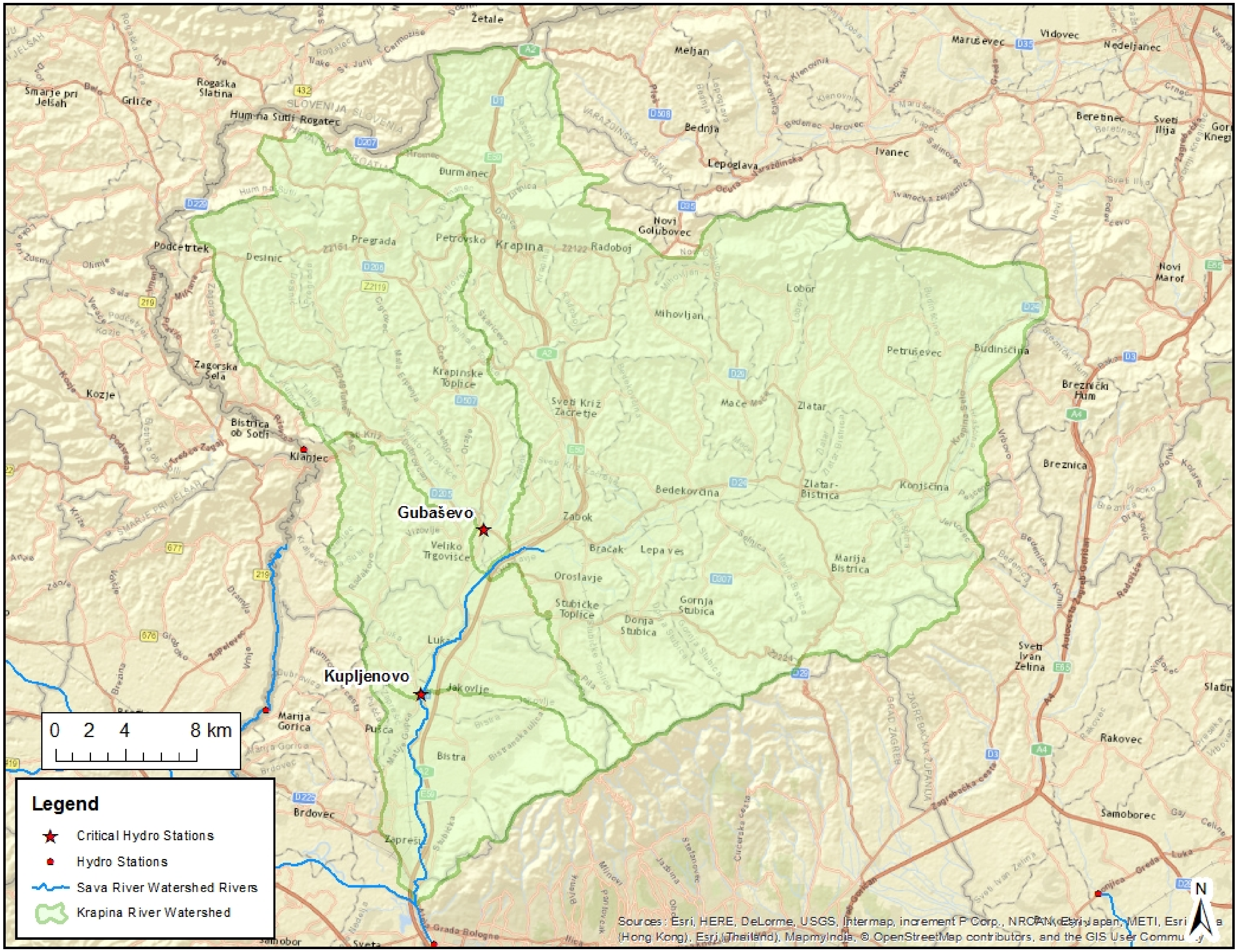


Figure 35: Hydrologic Station Map for the Krapina River Watershed

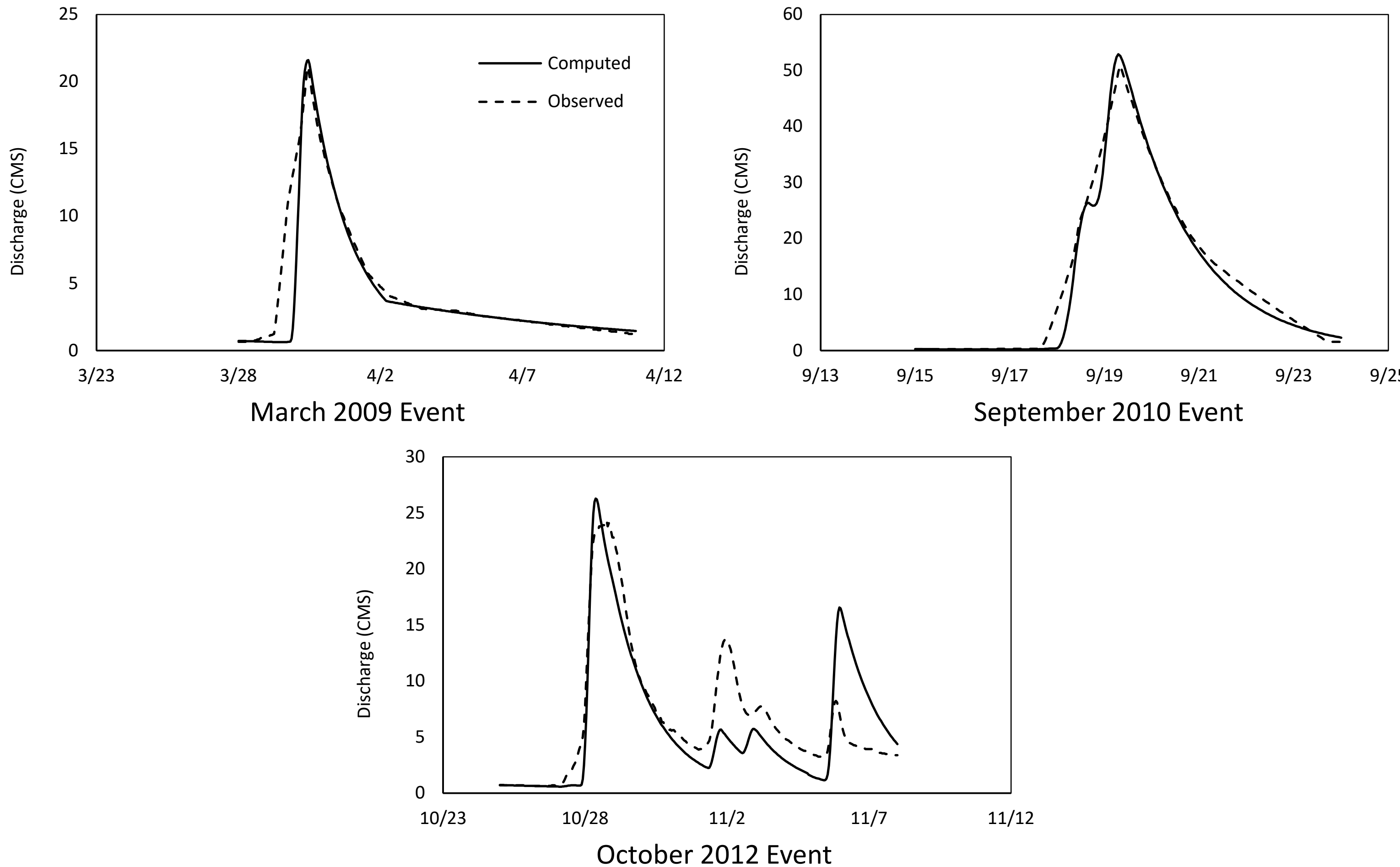


Figure 36: Calibration Plots for the Gubasevo Gauge for Various Calibration Events

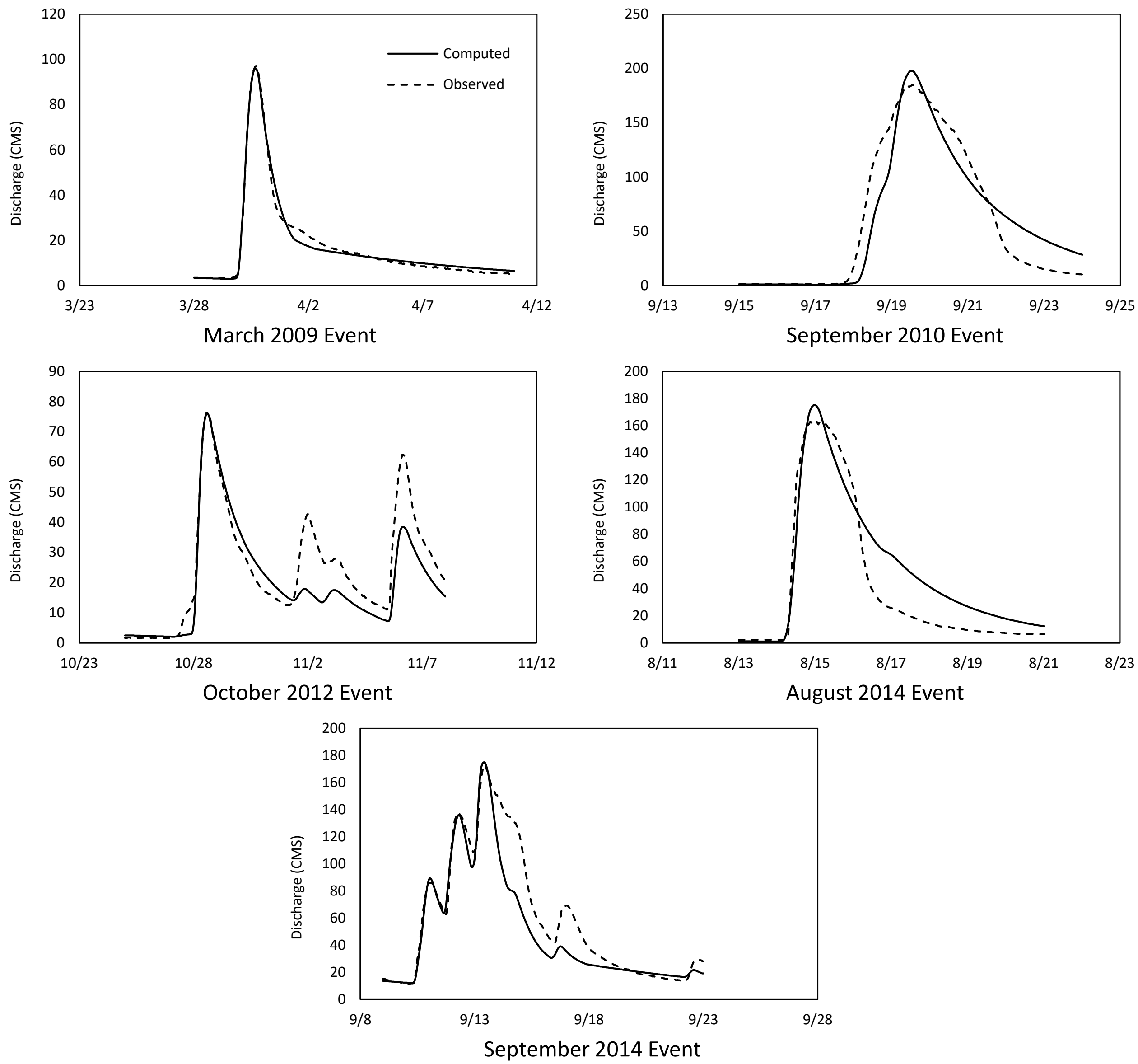


Figure 37: Calibration Plots for the Kupeljeno Gauge for Various Calibration Events

Table 19: Krapina River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Gubasevo	Mar 2009	21	23	22	21	2.4%	-9.9%	0.816
	Sep 2010	51	43	53	40	3.9%	-6.8%	0.975
	Oct 2012	24	34	26	31	7.8%	-9.1%	0.663
Kupeljeno	Mar 2009	97	18	96	19	-1.1%	0.5%	0.988
	Sep 2010	185	41	198	43	6.9%	4.9%	0.894
	Oct 2012	76	26	76	22	-0.4%	-17.7%	0.758
	Aug 2014	163	25	175	32	7.5%	26.4%	0.862
	Sep 2014	173	72	175	67	1.2%	-7.7%	0.861

4.4 KUPA RIVER WATERSHED

4.4.1 BASIN DESCRIPTION

The Kupa River is one of the largest rivers within Croatia, flowing from its headwaters on the Slovenia border to its confluence with the Sava River in Sisak. The Kupa River basin contains several tributaries of varying size and shape including Glina and Korana Rivers. The basin area is approximately 10,325 km2. The basin's topography is considered steep with a maximum elevation in the headwaters of approximately 1518 masl and minimum elevation at its confluence with the Sava River of approximately 76 masl.

4.4.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 20 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Kupa River watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 0.92 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.77 indicates that a substantial amount of attenuation occurs within the watershed, likely driven by an abundance of flatter, low-lying areas in the lower reaches of the basin.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration is due to the meteorological model over-estimating (for large values) or under-estimating the precipitation (for small values) during certain events. As a result, constant loss rates are raised or lowered to physically unrealistic values to compensate for too much or too little precipitation. A range of 2 to 90 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is very different throughout the watershed.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 20: Kupa Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	22	0.92	12.74	40.36	0.77	0.01	0.86	0.17
Minimum	0	0.30	1.00	2.00	0.55	0.01	0.85	0.15
Maximum	45	1.50	40.00	90.00	0.91	0.03	0.90	0.30
Standard Deviation	14	0.30	2.63	7.04	0.03	0.00	0.01	0.02

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 20 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Kupa River HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.4.3 REACH ROUTING PARAMETERS

River reach routings within the Kupa River basin were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 21 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 21: Kupa Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_06_06_01	99322	0.0007	Eight Point	0.025	0.07	0.07
R_06_06_03C	43365	0.0012	Eight Point	0.025	0.07	0.07
R_06_06_05	14612	0.0004	Eight Point	0.025	0.07	0.07
R_06_03_01	33551	0.0007	Eight Point	0.03	0.07	0.07
R_06_06_06	14238	0.0008	Eight Point	0.03	0.07	0.07
R_06_05_02	38512	0.0016	Eight Point	0.03	0.07	0.07
R_06_06_10	9731	0.0001	Eight Point	0.03	0.07	0.07
R_06_06_14	37930	0.0001	Eight Point	0.02	0.06	0.06
R_06_07_01	43744	0.0001	Eight Point	0.02	0.06	0.06
R_06_09_01	26366	0.0003	Eight Point	0.03	0.07	0.07
R_06_10_01	25208	0.0004	Eight Point	0.03	0.07	0.07
R_06_10_04	15981	0.0001	Eight Point	0.02	0.06	0.06
R_06_10_07	49429	0.0001	Eight Point	0.02	0.06	0.06
R_06_10_11	6050.9	0.0005	Eight Point	0.03	0.07	0.07

4.4.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Kupa River basin was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 38 illustrates the Kupa River basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 38 illustrates that the Kupa River Basin has a reasonable number of meteorological stations covering the basin, with the exception of the southern and eastern portion of the watershed, where just a few meteorological stations exist as discussed.

Figure 38: Meteorologic Station Map for the Kupa River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 22 shows the average ET rates for the Kupa River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 22: Average ET Rates for the Kupa River Watershed

Month	ET Rate (mm/month)
Jan	13.5
Feb	19.3
Mar	33.7
Apr	52.8
May	81.9
Jun	104.5
Jul	120.8
Aug	108.4
Sep	68.9
Oct	38.4
Nov	21.5
Dec	14.5

4.4.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Kupa River watershed HEC-HMS model. Two of the most common challenges during this study were related to subbasin delineation and meteorologic data availability.

The development of the Kupa River subbasin delineation relied heavily on the SRTM DEM and a subbasin delineation ESRI shapefile provided by the ISRBC at the 200 km^2 scale. Due to the quality of the subbasin delineation shapefile and the steep topography of the watershed, which reduces the effect of a lower quality DEM, the delineation is acceptable; however, delineation in some areas could be improved with better information such as a higher quality DEM. Based on discussions with the ISRBC, areas of karst features can influence the flow paths within the watershed and in turn, can affect the delineation. Karst issues, as it relates to subbasin delineation, were minimal and were easily modified using the subbasin delineation shapefile provided by the ISRBC.

The coverage of meteorologic stations for the Kupa River basin is generally adequate for hydrologic model calibration; however, as seen in Figure 38, southern and eastern portions of the basin lack sufficient gauge coverage. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred does not get or is not completely recorded at the surrounding gauges.

There are 2 reservoirs in the upstream end of the Kupa River Watershed including Gojak and Lesce (Figure 39). Gojak was not included in the HEC-HMS model because no data was provided nor could be located to develop the inputs needed for input in the model. If data is retrieved/developed for Gojak, it could be incorporated into the HEC-HMS model at a later time. Lesce was modeled as a reservoir in the HEC-HMS model. The inputs for a reservoir in HEC-HMS include a modeling method (outflow curve, outflow structure, or specific release), storage method (elevation area or volume curve), initial condition (elevation, inflow = outflow, or storage), and geometry information for specific dam components (outlets, spillways, dam tops, and pumps). This is a simplified method for modeling reservoirs and does not include gate operations. The assumption made was that these structures act as run of river during flood events and any spillway gates would be fully open for the flood events used in the event calibrations. Minimal data was provided for the inputs but some assumptions were made. No storage curves or outflow information was provided for Lesce. The SRTM DEM was used to calculate the elevation storage curve for the model. Spillway geometry was estimated based off aerial imagery of the reservoir and estimated for the input into the model. Another assumption made was that initial elevation for the reservoir starts at the spillway elevation. This allows for the initial conditions to be equal and any increase in flow will then be passed through the spillway. Verification of the dam inputs would be valuable to improve the modeling of the reservoir.

Figure 39: Reservoirs in Kupa River Watershed

In general, other than the aforementioned minor issues, no major challenges were encountered during the Kupa River watershed HEC-HMS model development.

4.4.6 CALIBRATION RESULTS AND DISCUSSION

The Kupa River watershed HEC-HMS model calibration quality is very good for some events and good at best for others based on the performance metrics, and the model performs well across a large range of events and seasons. Figure 40 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of gauges in the basin. Due to the large number of available gauges, only the gauges deemed most representative of the calibration, represented with red stars, are reported in this document. The calibration results at these critical gauges, shown in Figure 41 - Figure 50, illustrate the calibration of the system.

Figure 41 - Figure 50 and Table 23 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. In general, the calibration quality was highest for the March 2009, September 2010, and November 2013 events, which implies that the precipitation was not only more accurate for these events but also that the location of the available meteorologic stations better captured the spatial and temporal distribution of the storm event. In most cases, model calibration quality was dependent on the accuracy and availability of precipitation data. For gauges in areas of the basin with fewer available meteorological stations, such as the Glina, Veljun, and Vranovina gauges, there was a higher variability in calibration quality between storm events.

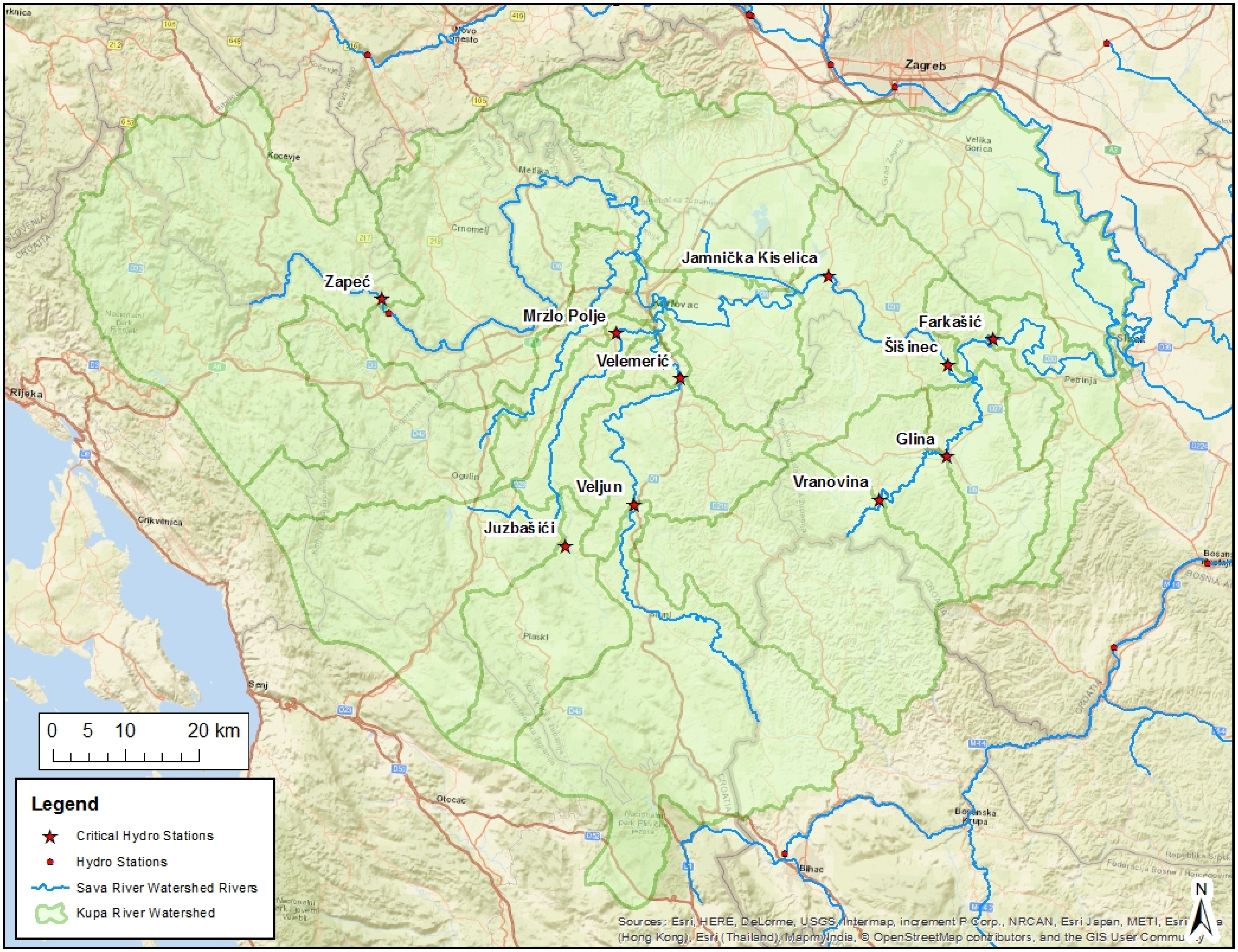


Figure 40: Hydrologic Station Map for the Kupa River Watershed

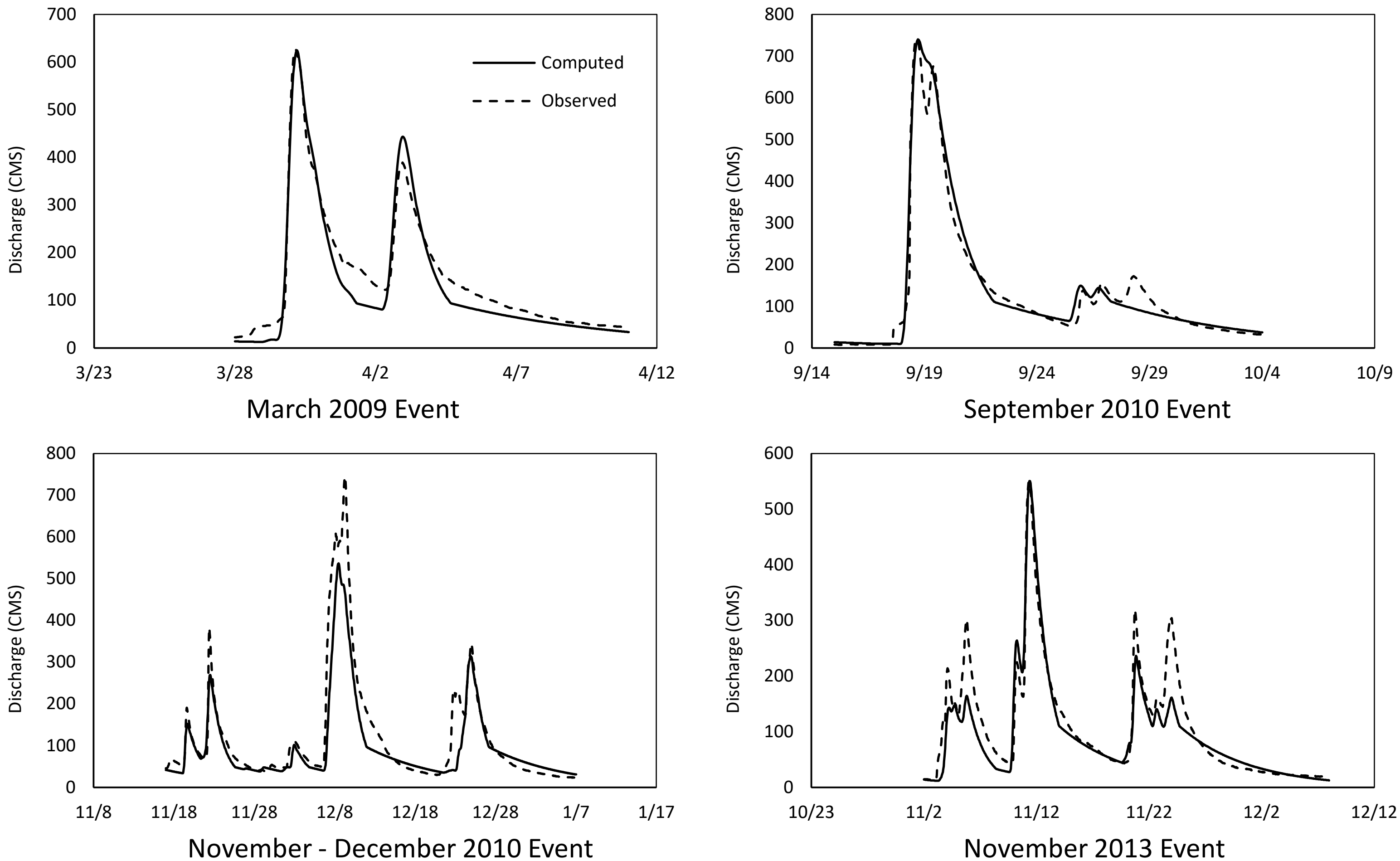


Figure 41: Calibration Plots for the Zapec Gauge for Various Calibration Events

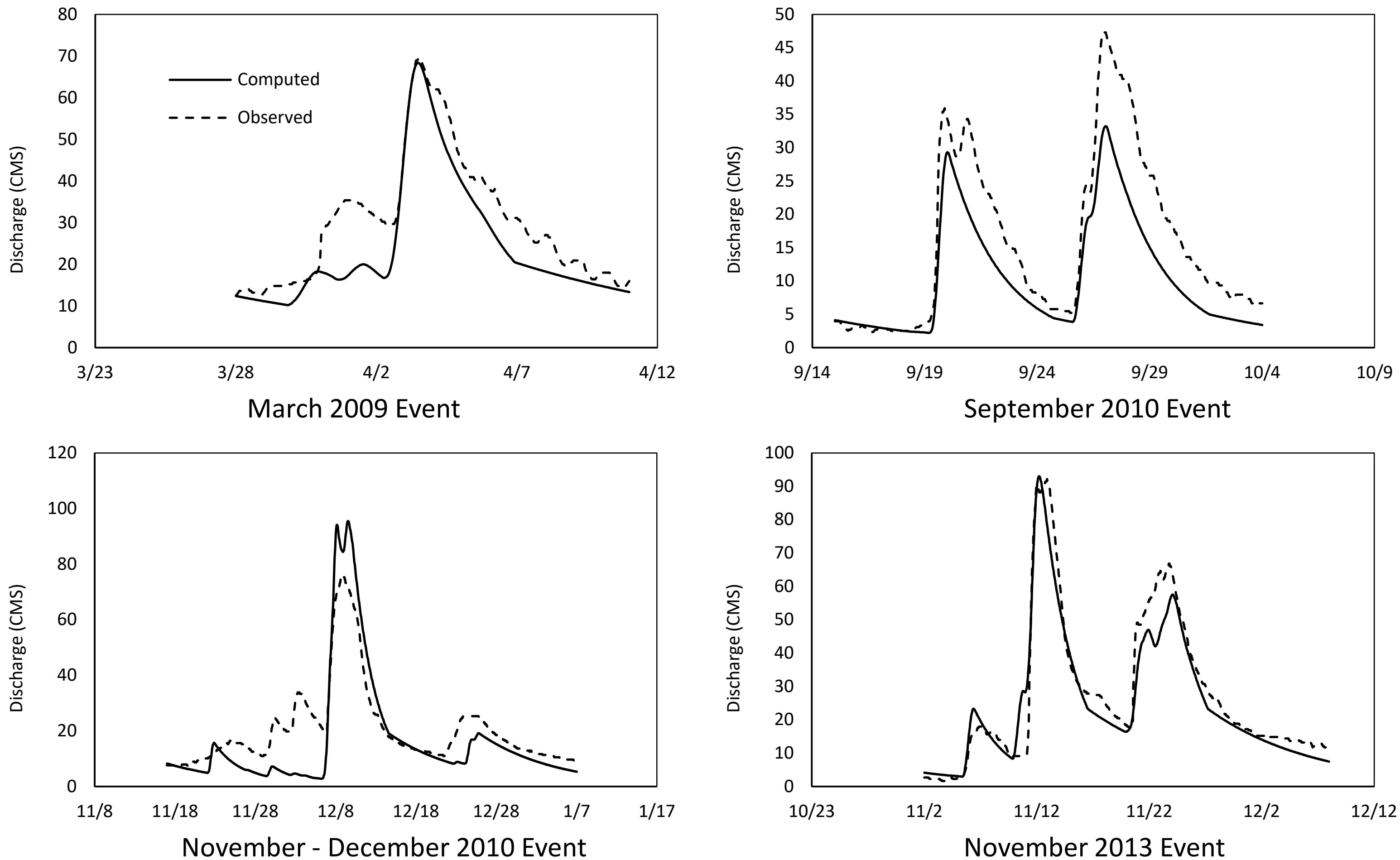


Figure 42: Calibration Plots for the Juzbasici Gauge for Various Calibration Events

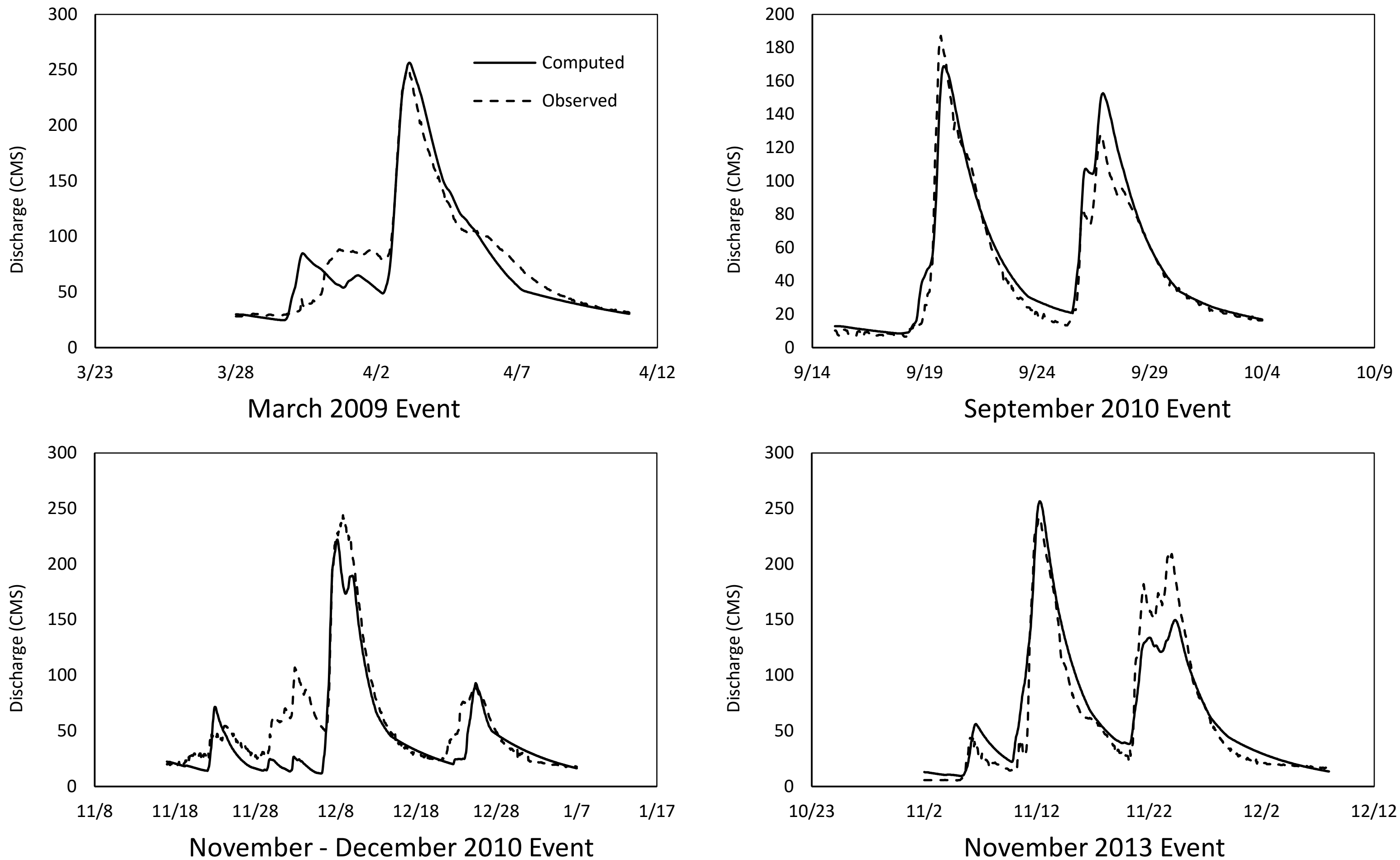


Figure 43: Calibration Plots for the Mrzlo Polje Gauge for Various Calibration Events

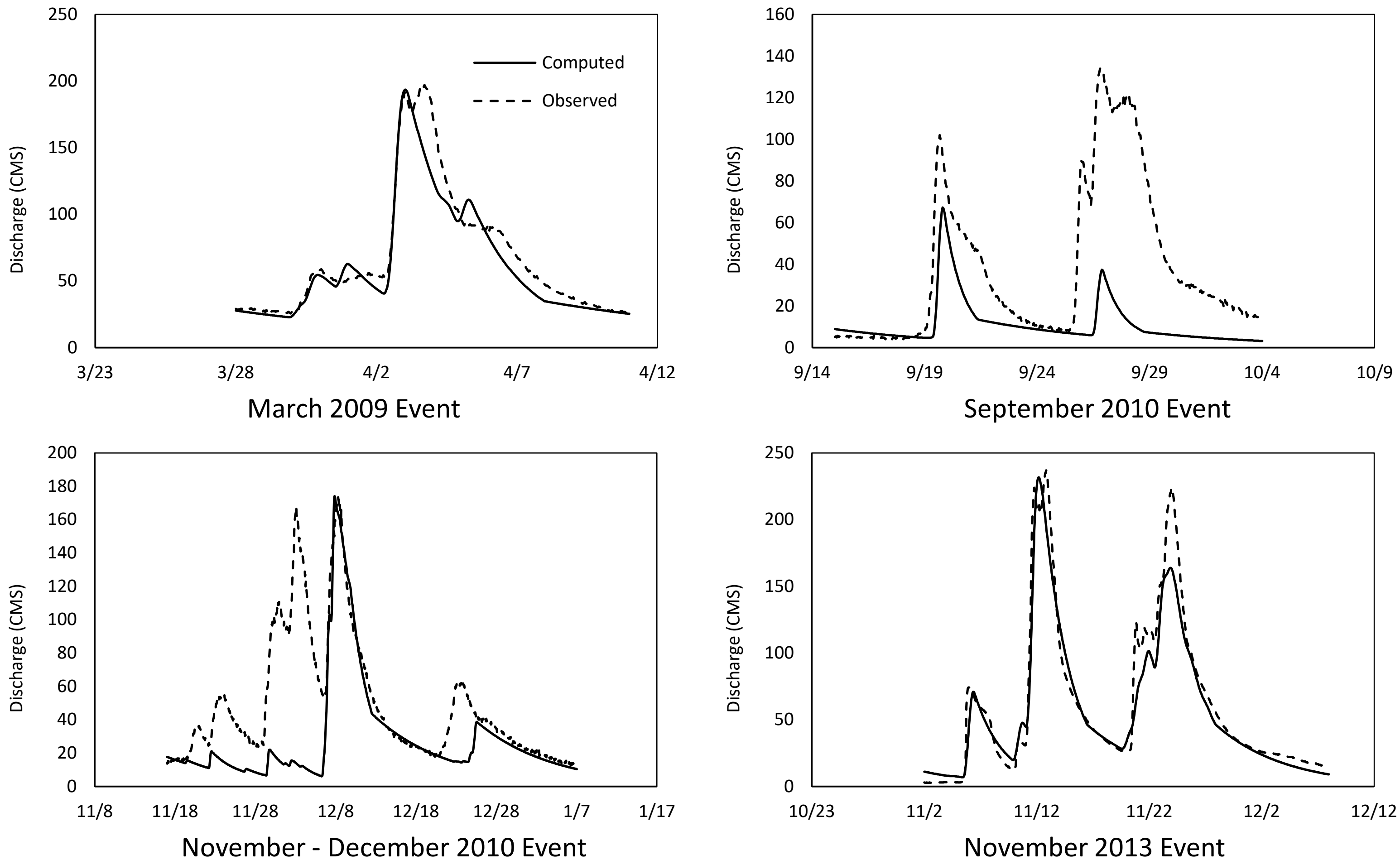


Figure 44: Calibration Plots for the Veljun Gauge for Various Calibration Events

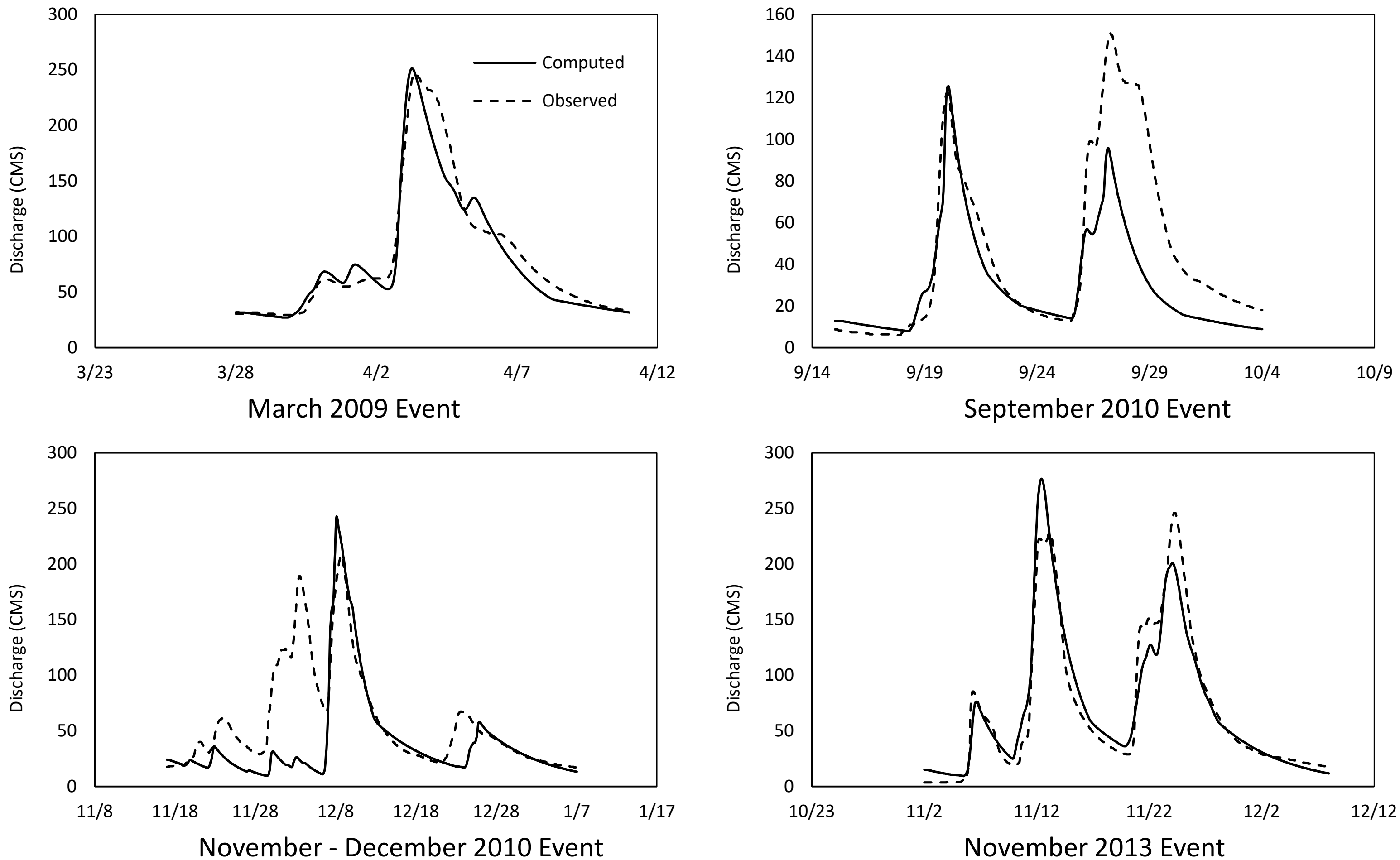


Figure 45: Calibration Plots for the Velemeric Gauge for Various Calibration Events

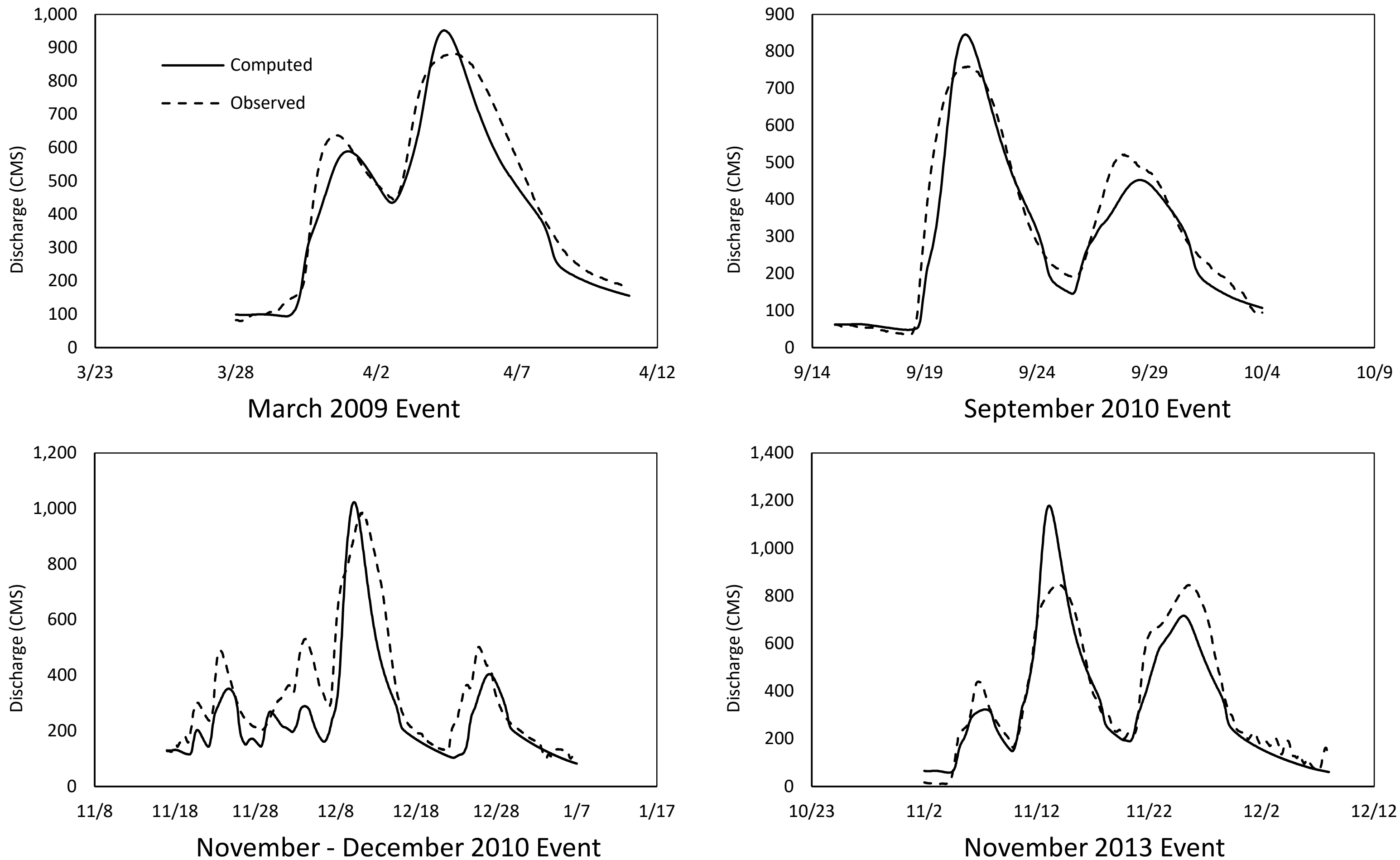


Figure 46: Calibration Plots for the Jamnicka Kiselica Gauge for Various Calibration Events

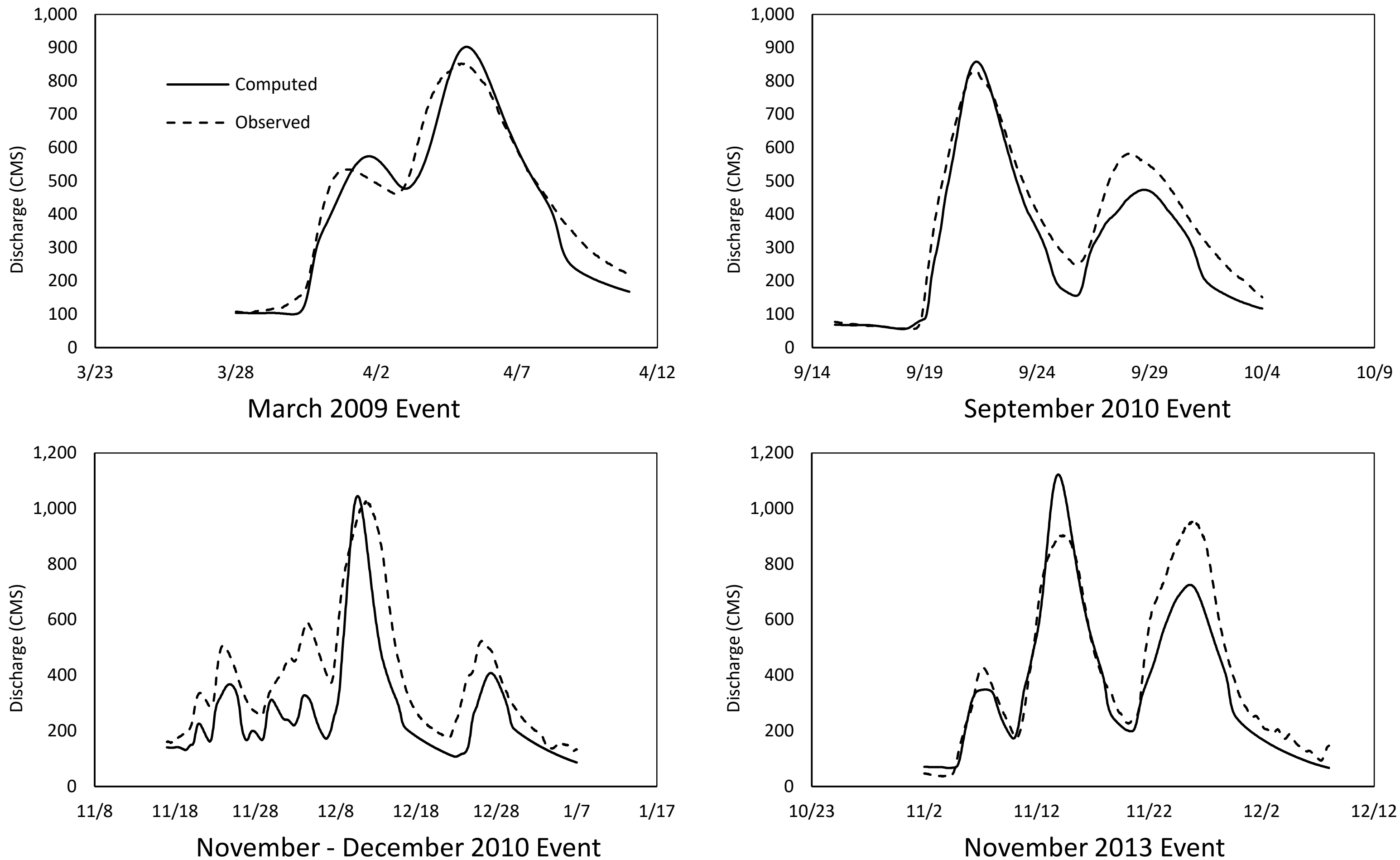


Figure 47: Calibration Plots for the Sisinec Gauge for Various Calibration Events

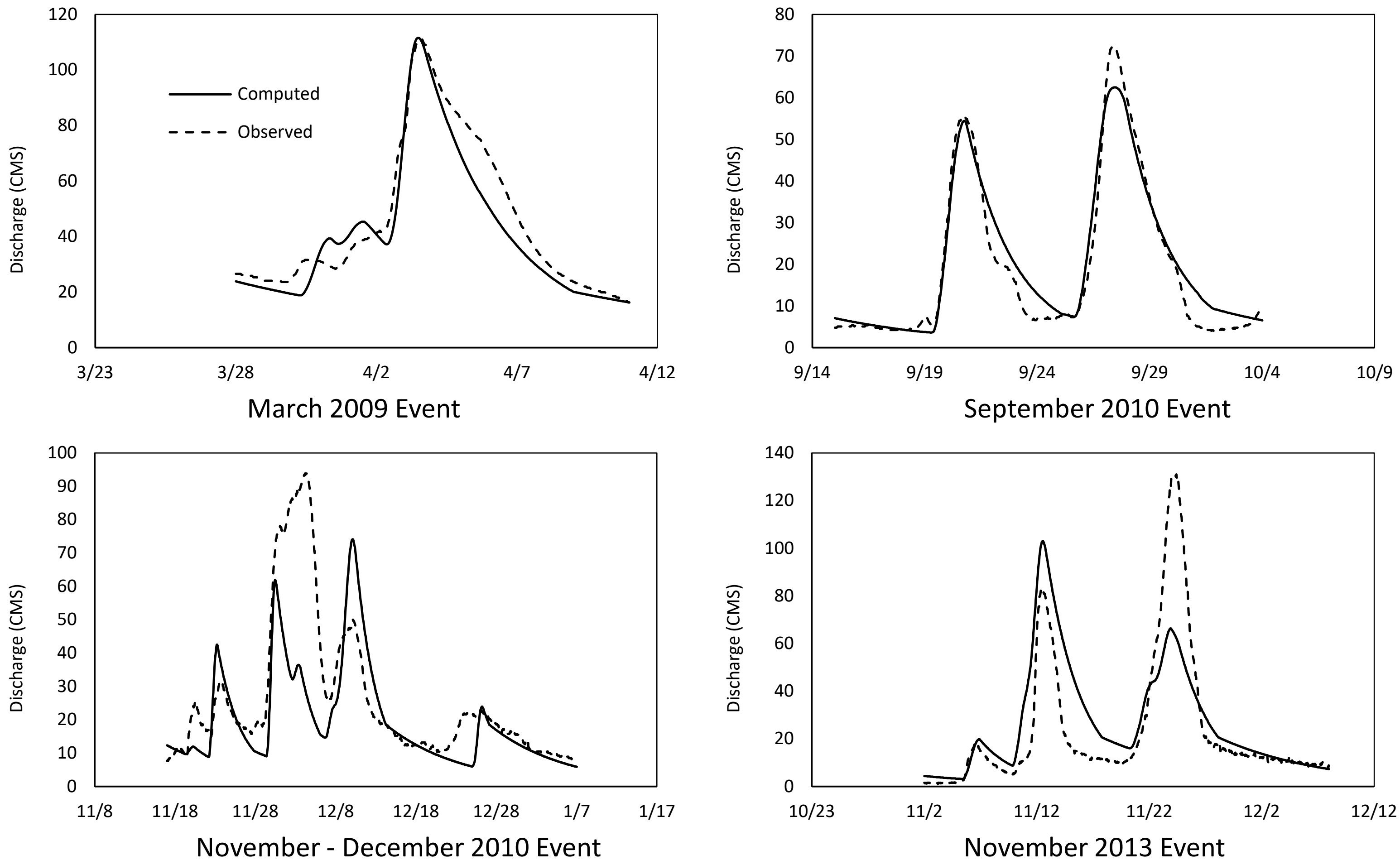


Figure 48: Calibration Plots for the Vranovina Gauge for Various Calibration Events

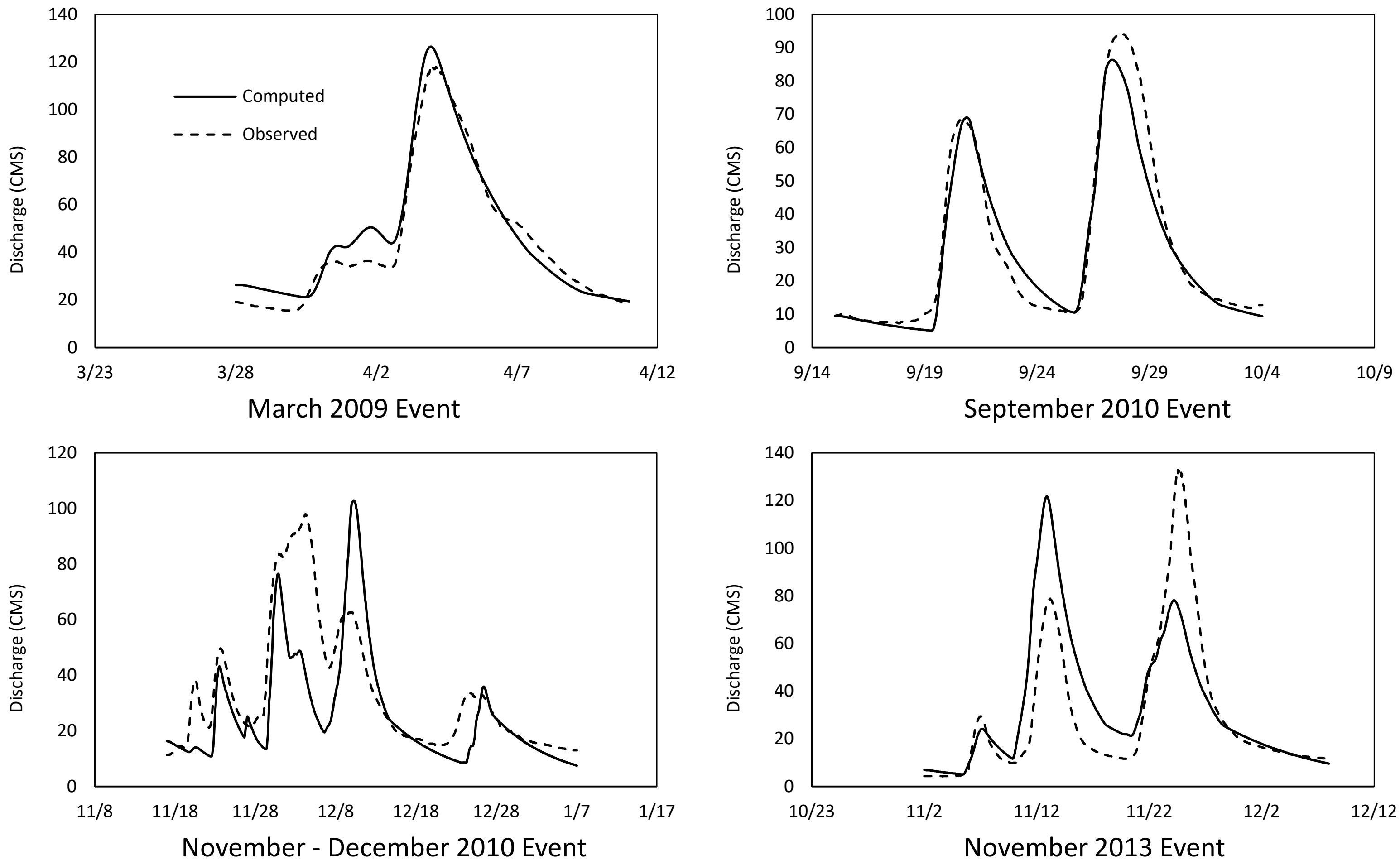


Figure 49: Calibration Plots for the Glina Gauge for Various Calibration Events

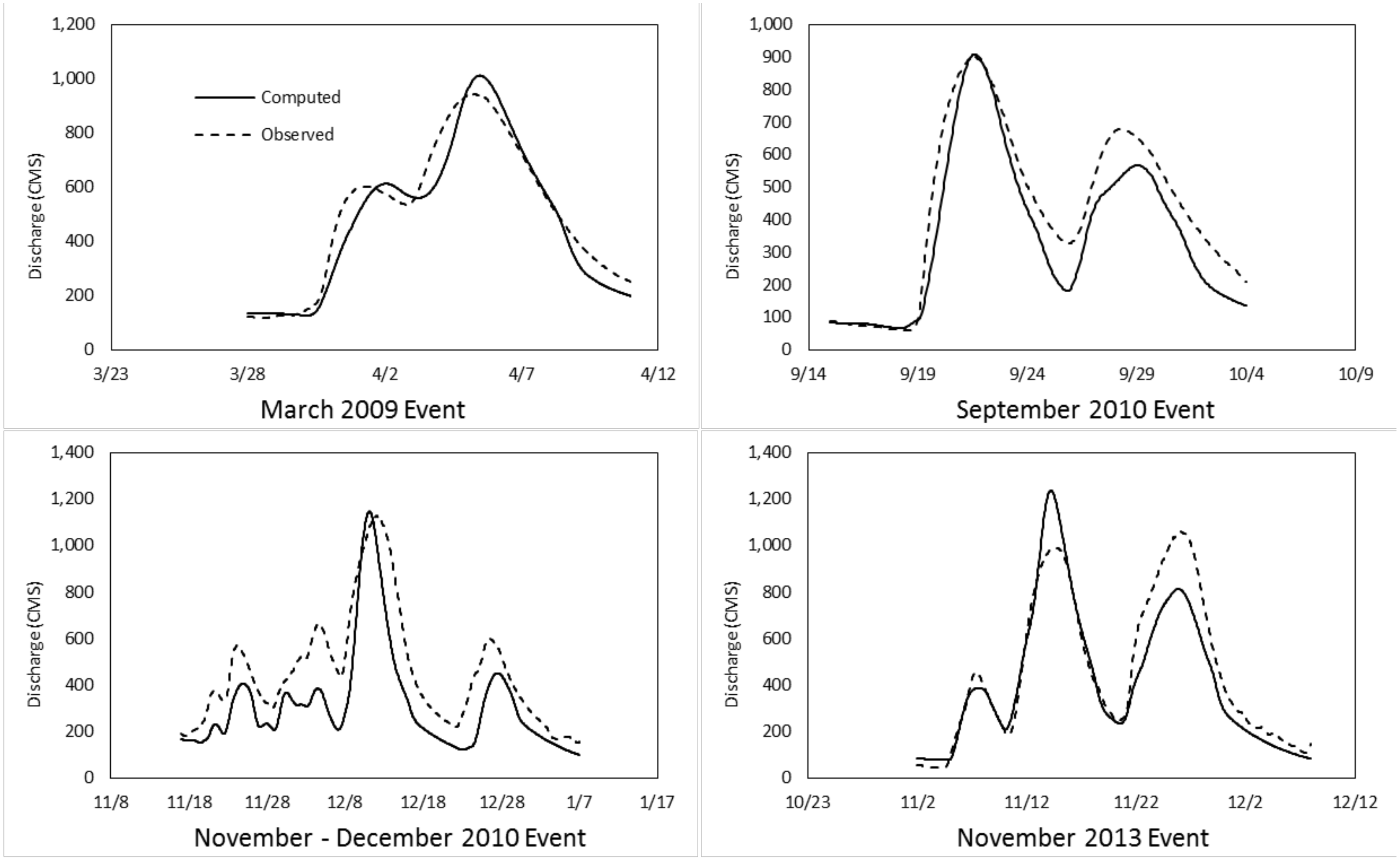


Figure 50: Calibration Plots for the Farkasic Gauge for Various Calibration Events

Table 23: Kupa River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Zapec	Mar2009	626	129	624	115	-0.3%	-11.1%	0.94
	Sep2010	739	159	740	161	0.1%	1.5%	0.96
	NovDec2010	745	379	537	308	-28.0%	-18.5%	0.82
	Nov2013	549	242	551	212	0.3%	-12.5%	0.86
Juzbasici	Mar2009	70	88	68	70	-1.9%	-20.8%	0.72
	Sep2010	47	63	33	41	-29.8%	-34.1%	0.68
	NovDec2010	76	219	96	129	25.5%	-40.9%	0.52
	Nov2013	92	209	93	189	0.9%	-9.1%	0.92
Mrzlo Polje	Mar2009	251	74	256	72	2.2%	-2.8%	0.90
	Sep2010	187	60	169	66	-9.7%	10.3%	0.93
	NovDec2010	244	198	222	155	-9.0%	-21.5%	0.77
	Nov2013	242	155	257	162	6.0%	4.3%	0.90
Veljun	Mar2009	197	74	194	67	-1.8%	-10.0%	0.91
	Sep2010	134	56	67	16	-49.8%	-70.5%	-0.28
	NovDec2010	174	196	174	113	0.1%	-42.1%	-0.02
	Nov2013	237	174	232	159	-2.2%	-8.6%	0.93
Velemeric	Mar2009	247	66	251	62	1.7%	-5.1%	0.94
	Sep2010	151	49	126	33	-16.8%	-33.4%	0.52
	NovDec2010	208	171	243	117	16.8%	-31.3%	0.13
	Nov2013	246	146	277	147	12.5%	0.2%	0.93
Jamnicka Kiselica	Mar2009	881	79	952	73	8.0%	-8.2%	0.94
	Sep2010	759	76	845	70	11.4%	-8.0%	0.92
	NovDec2010	986	213	1023	164	3.8%	-22.9%	0.70
	Nov2013	846	171	1179	157	39.4%	-8.1%	0.86
Sisinec	Mar2009	852	72	903	68	5.9%	-4.9%	0.94
	Sep2010	826	80	858	68	3.9%	-15.0%	0.90
	NovDec2010	1026	230	1045	160	1.9%	-30.6%	0.54
	Nov2013	956	173	1123	152	17.4%	-12.1%	0.86
Vranovina	Mar2009	111	62	112	56	0.5%	-9.7%	0.90
	Sep2010	72	36	63	38	-13.7%	7.8%	0.95
	NovDec2010	94	131	74	100	-21.0%	-24.3%	0.33
	Nov2013	131	86	103	95	-21.4%	11.2%	0.60
Glina	Mar2009	118	48	126	51	7.1%	6.1%	0.95
	Sep2010	94	43	86	41	-8.5%	-4.9%	0.94
	NovDec2010	98	133	103	104	5.1%	-21.6%	0.35
	Nov2013	133	83	122	93	-8.5%	11.9%	0.56
Farkasic	Mar2009	943	67	1012	64	7.3%	-5.1%	0.93
	Sep2010	907	77	908	64	0.1%	-17.5%	0.86
	NovDec2010	1127	218	1148	151	1.8%	-30.8%	0.51
	Nov2013	1061	158	1237	142	16.5%	-9.7%	0.87

4.5 CESMA RIVER WATERSHED

4.5.1 BASIN DESCRIPTION

The Cesma River is a reasonably large river within Croatia, flowing from the confluence of the Grdevica and Barna southward into the Lonja canal and the Lonjsko Polje retention area before joining the Sava River near Trebez just upstream of the Ilova-Sava River confluence. The Cesma River basin is fan-shaped with a basin area of approximately 4,267 km2. The basin's topography is considered less steep than many of the other tributary basins within the Sava River Basin with a maximum elevation in the headwaters of approximately 715 masl and minimum elevation at its confluence of approximately 60 masl.

4.5.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 24 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Cesma River watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 1.14 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.77 indicates that a substantial amount of attenuation occurs within the watershed, likely driven by an abundance of flatter, low-lying areas in the lower reaches of the basin.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration is due to the meteorological model over-estimating (for large values) or under-estimating the precipitation (for small values) during certain events. As a result, constant loss rates are raised or lowered to physically unrealistic values to compensate for too

much or too little precipitation. A range of 3.2 to 35.0 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is very different throughout the watershed.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 24: Cesma Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	**Constant Rate (mm/hr)**	**T_c (hr)**	**R**	$\frac{R}{T_c + R}$	**Initial Flow (CMS/km^2)**	**Recession Constant**	**Ratio to Peak**
Representative	15	1.14	17.1	64.2	0.77	0.0029	0.88	0.10
Minimum	0	0.00	3.2	13.1	0.46	0.0003	0.72	0.10
Maximum	40	2.25	35.0	187.9	0.91	0.0125	0.90	0.10
Standard Deviation	10	0.37	1.9	15.7	0.09	0.0032	0.00	0.00

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 24 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Cesma River HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.5.3 REACH ROUTING PARAMETERS

River reach routings within the Cesma River basin were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 25 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 25: Cesma Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_08_03_01	30423	0.0002	Eight Point	0.040	0.15	0.15
R_08_03_02	4999	0.0004	Eight Point	0.040	0.15	0.15
R_08_03_06	25412	0.0002	Eight Point	0.040	0.15	0.15
R_08_03_10	30337	0.0002	Trapezoid	0.040		
R_08_03_14	13903	0.0001	Trapezoid	0.040		
R_08_03_18	51471	0.0001	Trapezoid	0.040		

4.5.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Cesma River basin was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 51 illustrates the Cesma River basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 51 illustrates that the Cesma River Basin has a reasonable number of meteorological stations covering the basin.

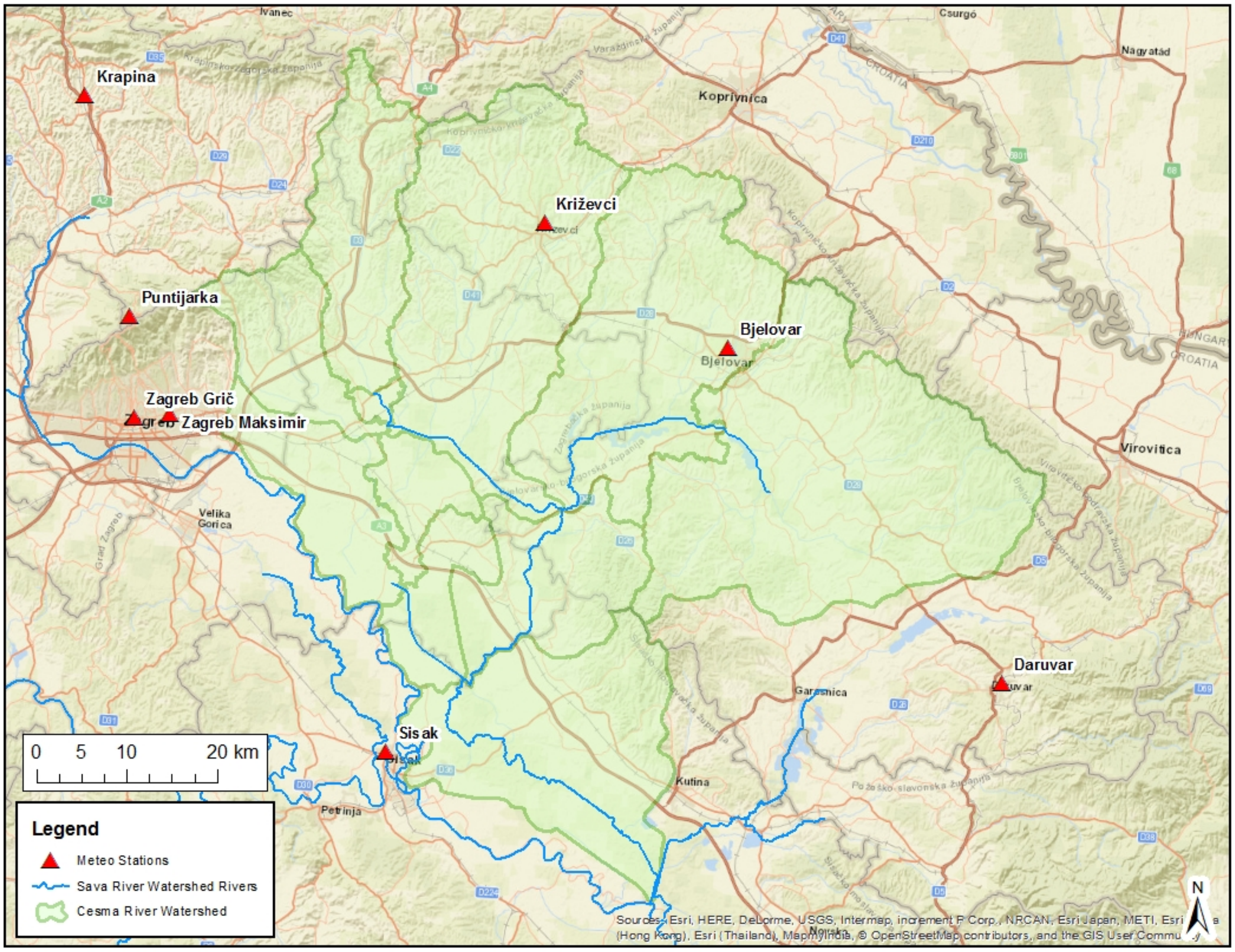


Figure 51: Meteorologic Station Map for the Cesma River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 26 shows the average ET rates for the Cesma River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 26: Average ET Rates for the Cesma River Watershed

Month	ET Rate (mm/month)
Jan	14.0
Feb	22.0
Mar	39.0
Apr	63.0
May	93.0
Jun	119.0
Jul	137.0
Aug	117.0
Sep	79.0
Oct	46.0
Nov	26.0
Dec	16.0

4.5.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Cesma River watershed HEC-HMS model. Two of the most common challenges during this study were related to downstream reach routing and meteorologic data availability.

In general, the delineation and river network produced directly from the SRTM DEM was accurate based on comparison to existing subbasin delineations provided by the ISRBC; however, intensive pre-processing of the DEM was required in the lower portions of the basin in the Lonjsko Polje retention area. In this area, the river network was manually digitized to account for the man-made Lonja canal. After pre-processing, the river network represents the main flowpath in Lonjsko Polje very well. The challenge is properly representing the flood wave attenuation resulting from the large storage capacity of the retention area. Modifications were made to the most downstream routing reach to account for attenuation based on the calibration of the Sava Mainstem 03 basin model. For future improvements, the LiDaR data being collected and the HEC-RAS model being developed later in this project should be used to improve the routing method currently incorporated in the hydrologic model.

The coverage of meteorologic stations for the Cesma River basin is generally adequate for hydrologic model calibration; however, as seen in Figure 51, additional station coverage could better represent precipitation in the basin. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred does not get or is not completely recorded at the surrounding gauges.

In general, other than the aforementioned minor issues, no major challenges were encountered during the Cesma River watershed HEC-HMS model development.

4.5.6 CALIBRATION RESULTS AND DISCUSSION

The Cesma River watershed HEC-HMS model calibration quality is very good based on the performance metrics, and the model performs well across a large range of events and seasons. Figure 52 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of gauges in the basin.

Figure 53 - Figure 55 and Table 27 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. In general, the calibration quality was relatively good for all of the calibration events, which implies that the precipitation was reasonably accurate for these events and also that the location of the available meteorologic stations captured the spatial and temporal distribution of the storm event. In most cases, model calibration quality was dependent on the accuracy and availability of precipitation data. For the November 2013 event, the second peak of the event is not captured by the hydrologic model because the meteorologic stations did not capture this second precipitation event.

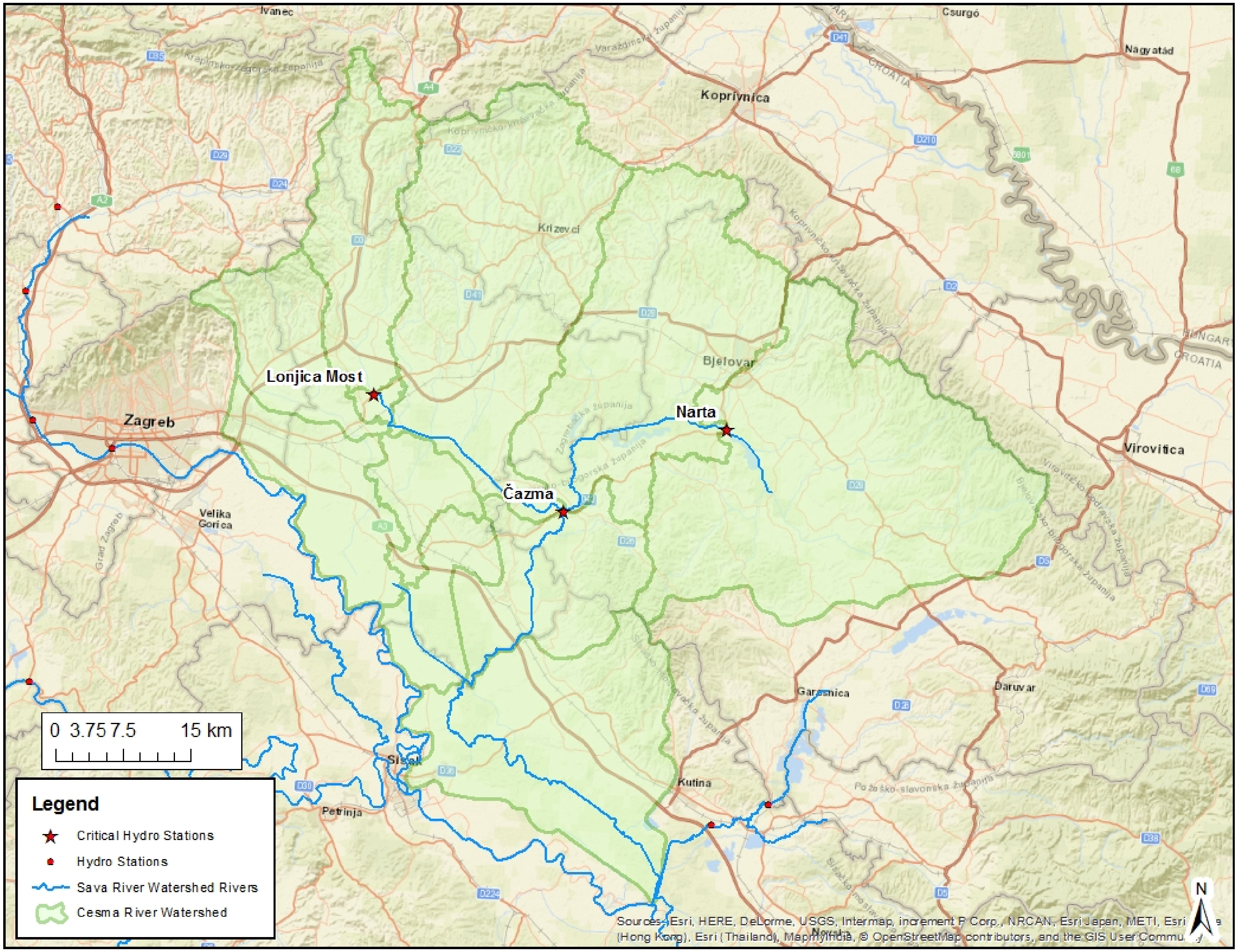


Figure 52: Hydrologic Station Map for the Cesma River Watershed

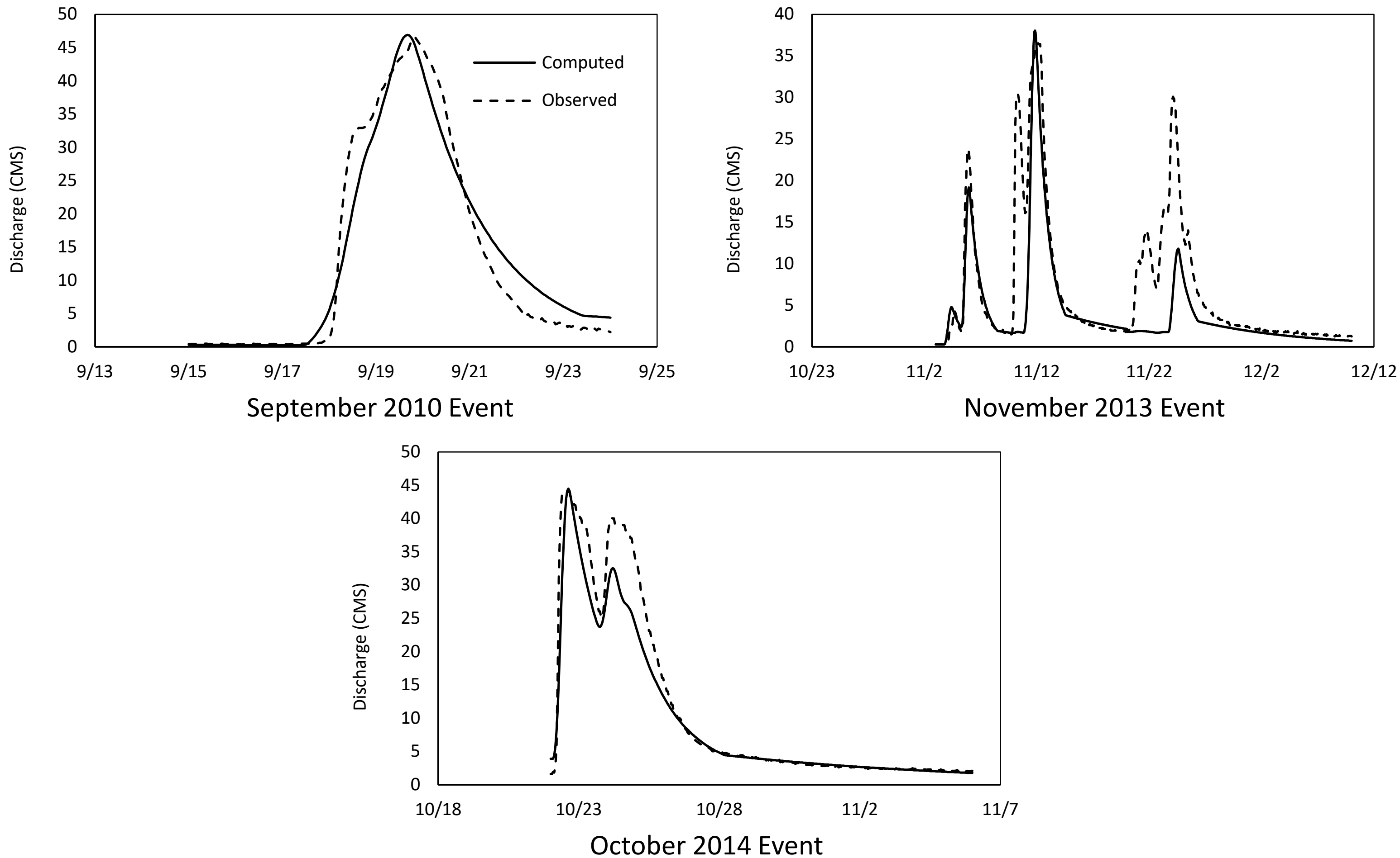


Figure 53: Calibration Plots for the Lonji Most Gauge for Various Calibration Events

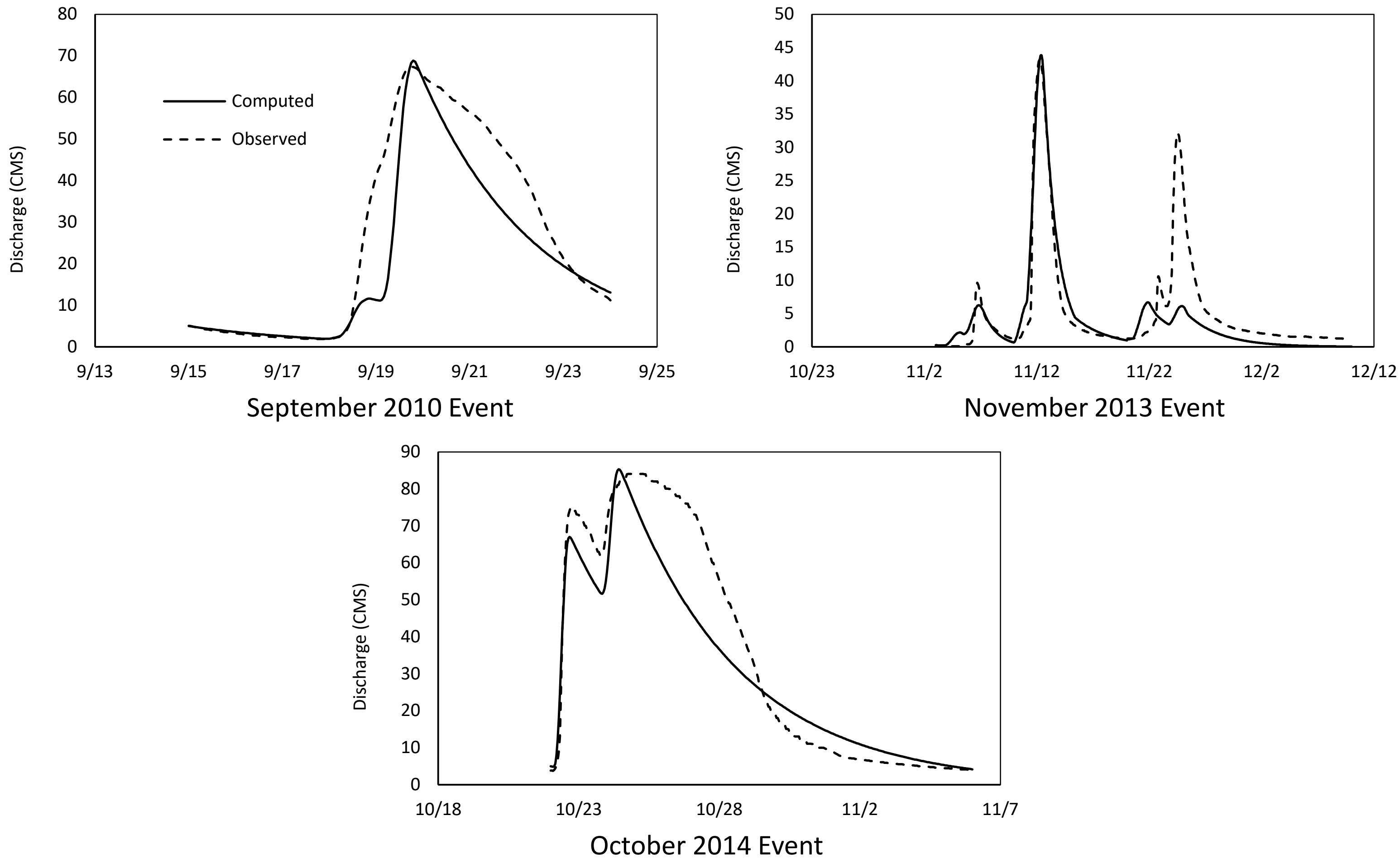


Figure 54: Calibration Plots for the Narta Gauge for Various Calibration Events

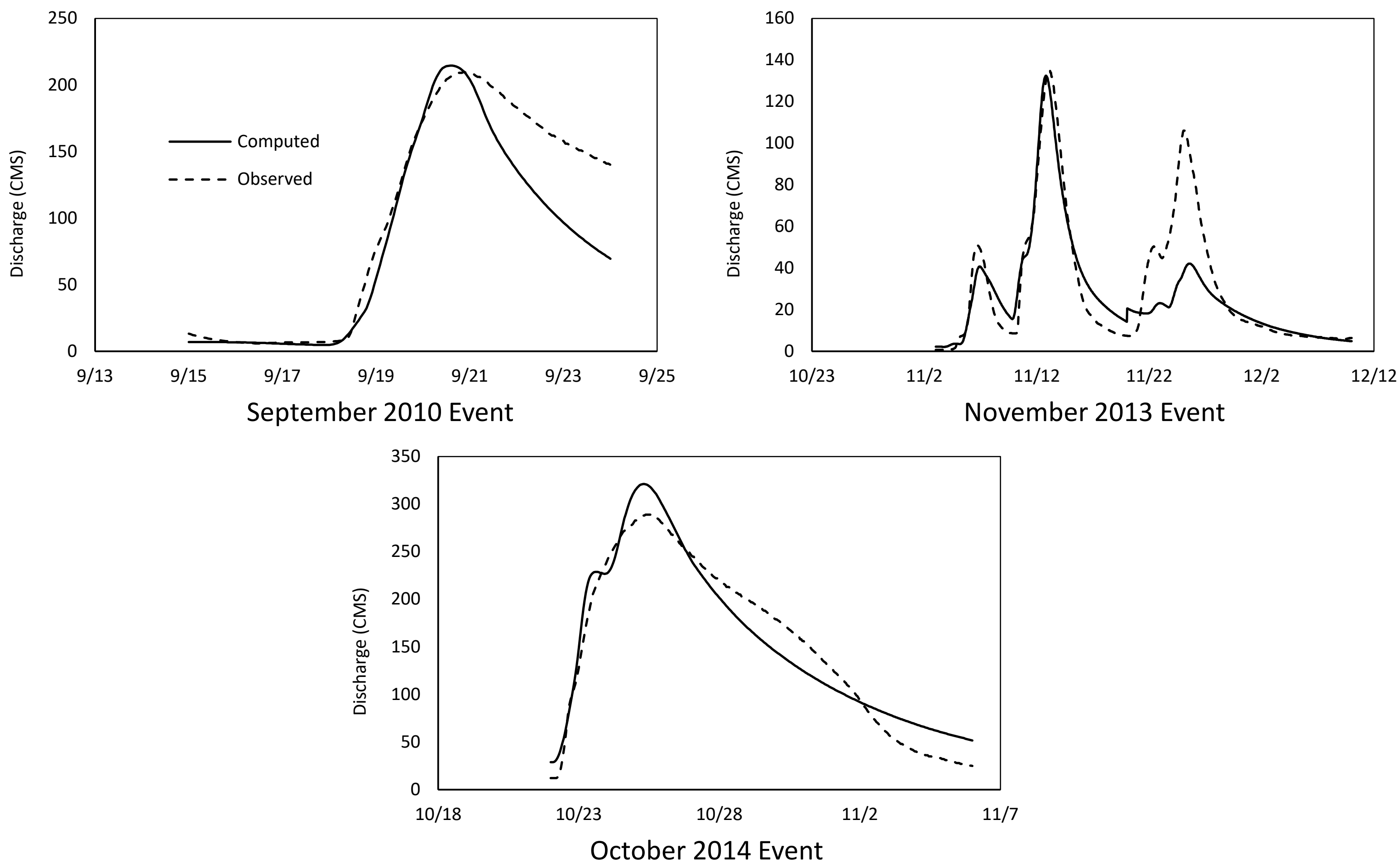


Figure 55: Calibration Plots for the Casma Gauge for Various Calibration Events

Table 27: Cesma River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Narta	Sep 2010	67	21	69	16	2.4%	-22.3%	0.801
	Nov 2013	43	9	44	10	1.4%	15.7%	0.954
	Oct 2014	84	47	85	41	1.4%	-13.6%	0.864
Lonji Most	Sep 2010	47	34	47	34	0.9%	1.6%	0.950
	Nov 2013	37	40	38	30	4.1%	-24.6%	0.612
	Oct 2014	44	47	45	40	0.9%	-14.2%	0.925
Cazma	Sep 2010	210	26	215	21	2.1%	-18.4%	0.851
	Nov 2013	135	18	132	19	-1.9%	7.4%	0.943
	Oct 2014	289	67	321	68	11.1%	0.9%	0.930

4.6 ILOVA RIVER WATERSHED

4.6.1 BASIN DESCRIPTION

The Ilova River is a relatively small river within central Croatia, flowing from Jasenas southeastward through Garesnica and several other small villages into the Opeka retention and ultimately to its confluence with the Sava River just downstream of the Ilova-Sava Confluence. The basin is relatively fan-shaped with a basin area of approximately 1,800 km^2. The basin's topography is considered relatively steep with a maximum elevation in the headwaters of approximately 1000 masl and minimum elevation at its confluence of approximately 85 masl.

4.6.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 28 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Ilova River watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 0.84 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.62 indicates that a normal amount of attenuation occurs within the watershed; however, the lower reaches of the basin experience a much greater amount of attenuation driven by an abundance of storage in the Opeka retention area.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration (specifically for the calibration events requiring a 0.0 mm/hr constant rate) is due to the meteorological model under-estimating the precipitation (for small values) during certain events. As a result, constant loss rates are lowered to physically unrealistic values to compensate for too little precipitation. A range of 4.1 to 70.0 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is very different throughout the watershed.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 28: Ilova Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	7	0.84	32.2	40.9	0.62	0.00	0.90	0.10
Minimum	0	0.00	4.1	20.0	0.22	0.00	0.90	0.10
Maximum	15	1.90	70.0	80.0	0.85	0.01	0.90	0.10
Standard Deviation	3	0.45	9.8	13.2	0.20	0.00	0.00	0.00

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 28 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Ilova River HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.6.3 REACH ROUTING PARAMETERS

River reach routings within the Ilova River basin were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 29 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 29: Ilova Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_10_02_03	24751	0.0003	Trapezoid	0.040		

4.6.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Ilova River basin was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 56 illustrates the Ilova River basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 56 illustrates that the Ilova River Basin has a limited number of meteorological stations covering the basin, which could result in inaccurate estimations of precipitation.

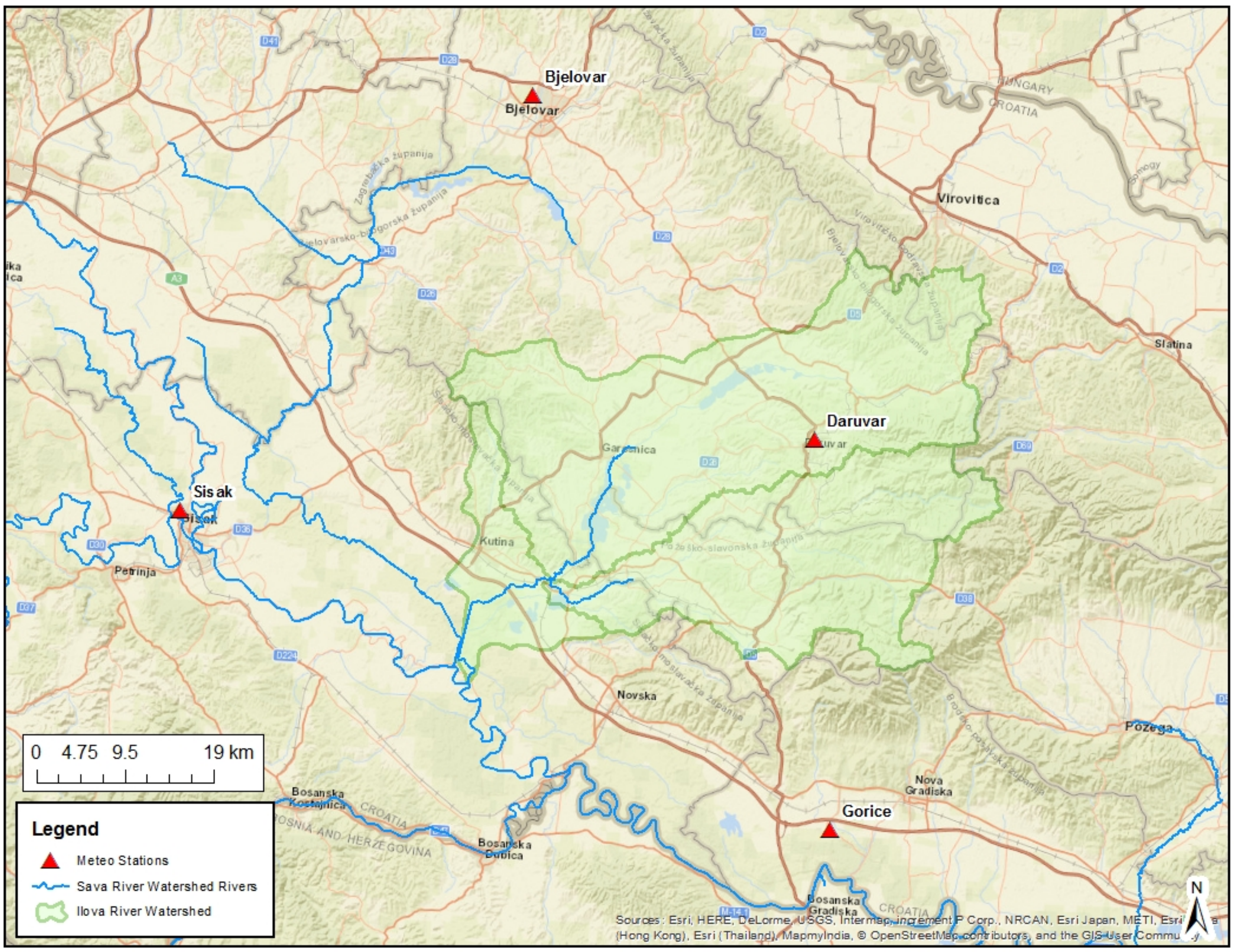


Figure 56: Meteorologic Station Map for the Ilova River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 30 shows the average ET rates for the Ilova River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the

values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 30: Average ET Rates for the Ilova River Watershed

Month	ET Rate (mm/month)
Jan	14.0
Feb	22.0
Mar	39.0
Apr	63.0
May	93.0
Jun	119.0
Jul	137.0
Aug	117.0
Sep	79.0
Oct	46.0
Nov	26.0
Dec	16.0

4.6.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Ilova River watershed HEC-HMS model. Two of the most common challenges during this study were related to downstream reach routing and meteorologic data availability.

In general, the delineation and river network produced directly from the SRTM DEM was accurate based on comparison to existing subbasin delineations provided by the ISRBC; however, intensive pre-processing of the DEM was required in the lower portions of the basin in the Opeka retention area. After pre-processing, the river network represents the main flowpath in Opeka very well; however, it appears that complex interactions at the mouth of Ilova exist, which may not be properly represented. The other challenge in this area is properly representing the flood wave attenuation resulting from the large storage capacity of the retention area. Modifications were made to the most downstream routing reach to account for attenuation based on the calibration of the Sava Mainstem 03 basin model. For future improvements, the LiDaR data being collected and the HEC-RAS model being developed later in this project should be used to improve the routing method currently incorporated in the hydrologic model.

The coverage of meteorologic stations for the Ilova River basin is generally inadequate for hydrologic model calibration, and, as seen in Figure 56, additional station coverage could better represent precipitation in the basin. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred does not get or is not completely recorded at the surrounding gauges.

In general, other than the aforementioned issues, no other major challenges were encountered during the Ilova River watershed HEC-HMS model development. In the future, the network of precipitation gauges should be expanded for this basin and/or a radar-based gridded precipitation dataset should be acquired and incorporated into the model.

4.6.6 CALIBRATION RESULTS AND DISCUSSION

The Ilova River watershed HEC-HMS model calibration quality is very good based on the performance metrics, and the model performs well across a large range of events and seasons. Figure 57 shows a map of the various hydrologic stations throughout the basin.

Figure 58 - Figure 59 and Table 31 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. In general, the calibration quality was highest for the January 2009, May 2010, and May 2014 events, which implies that the precipitation was not only more accurate for these events but also that the location of the available meteorologic stations better captured the spatial and temporal distribution of the storm event. In most cases, model calibration quality was dependent on the accuracy and availability of precipitation data. For the March 2013 event, the results show that the initial precipitation event is being overestimated using the IDW meteorologic model method.

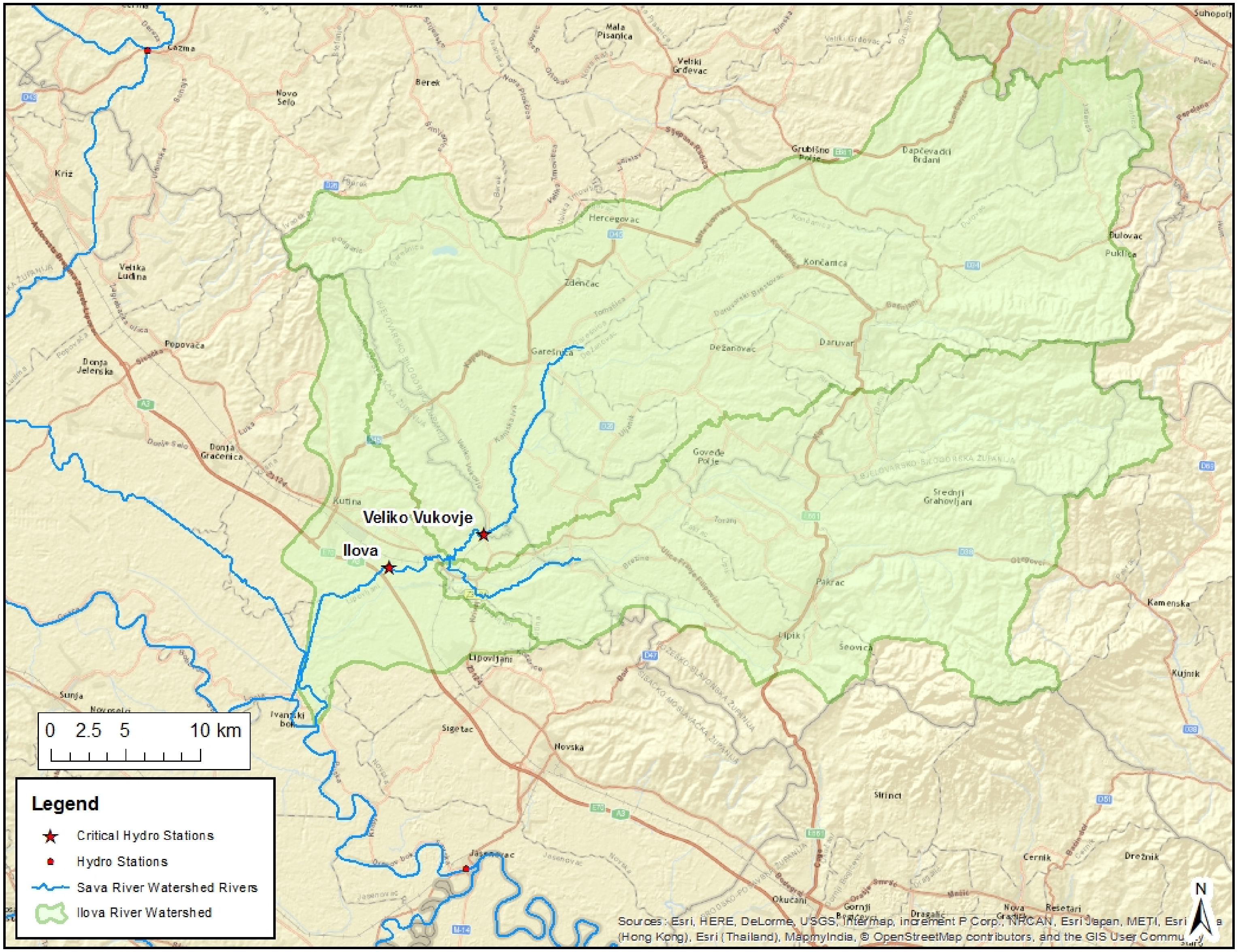


Figure 57: Hydrologic Station Map for the Ilova River Watershed

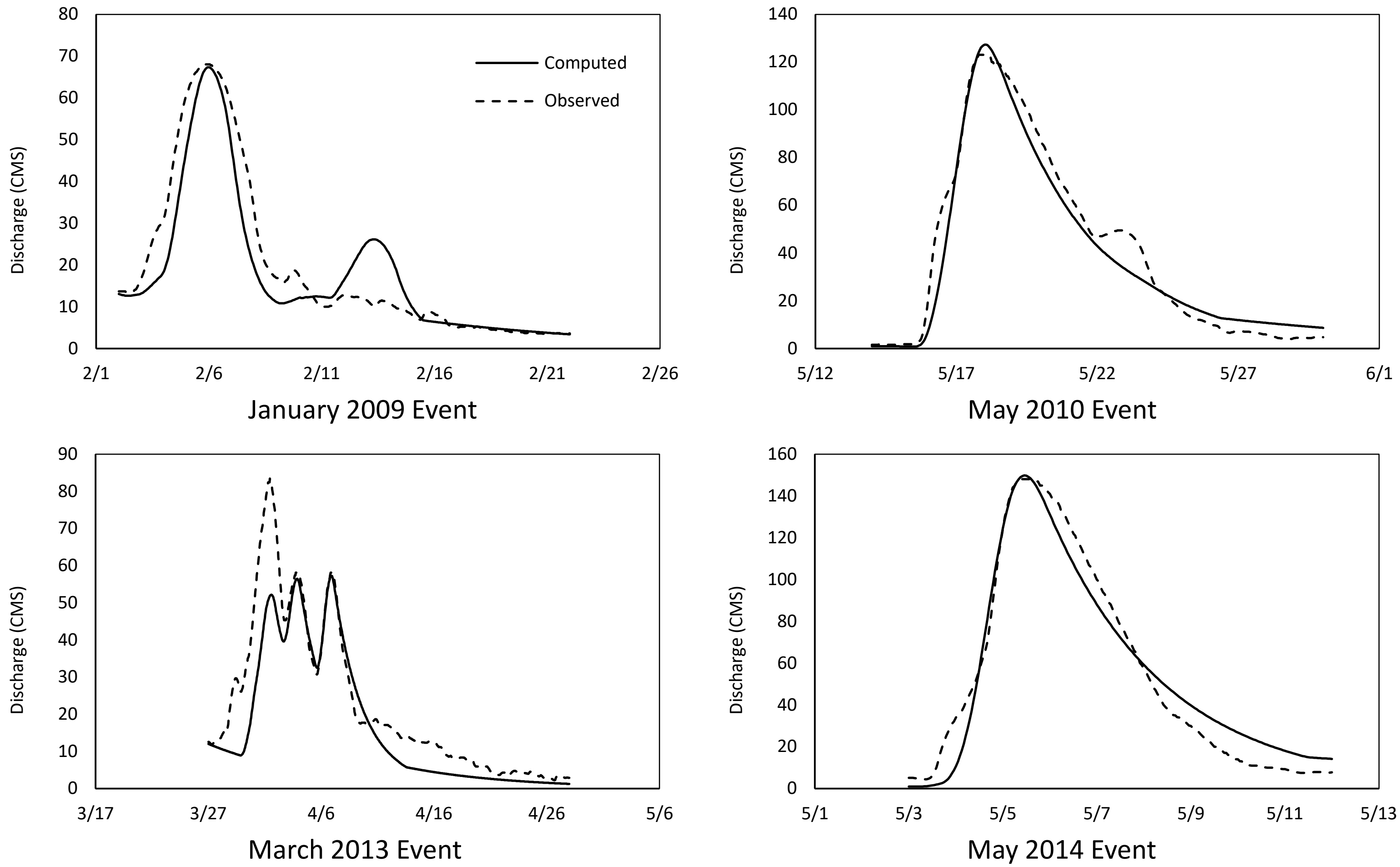


Figure 58: Calibration Plots for the Veliko Vukovje Gauge for Various Calibration Events

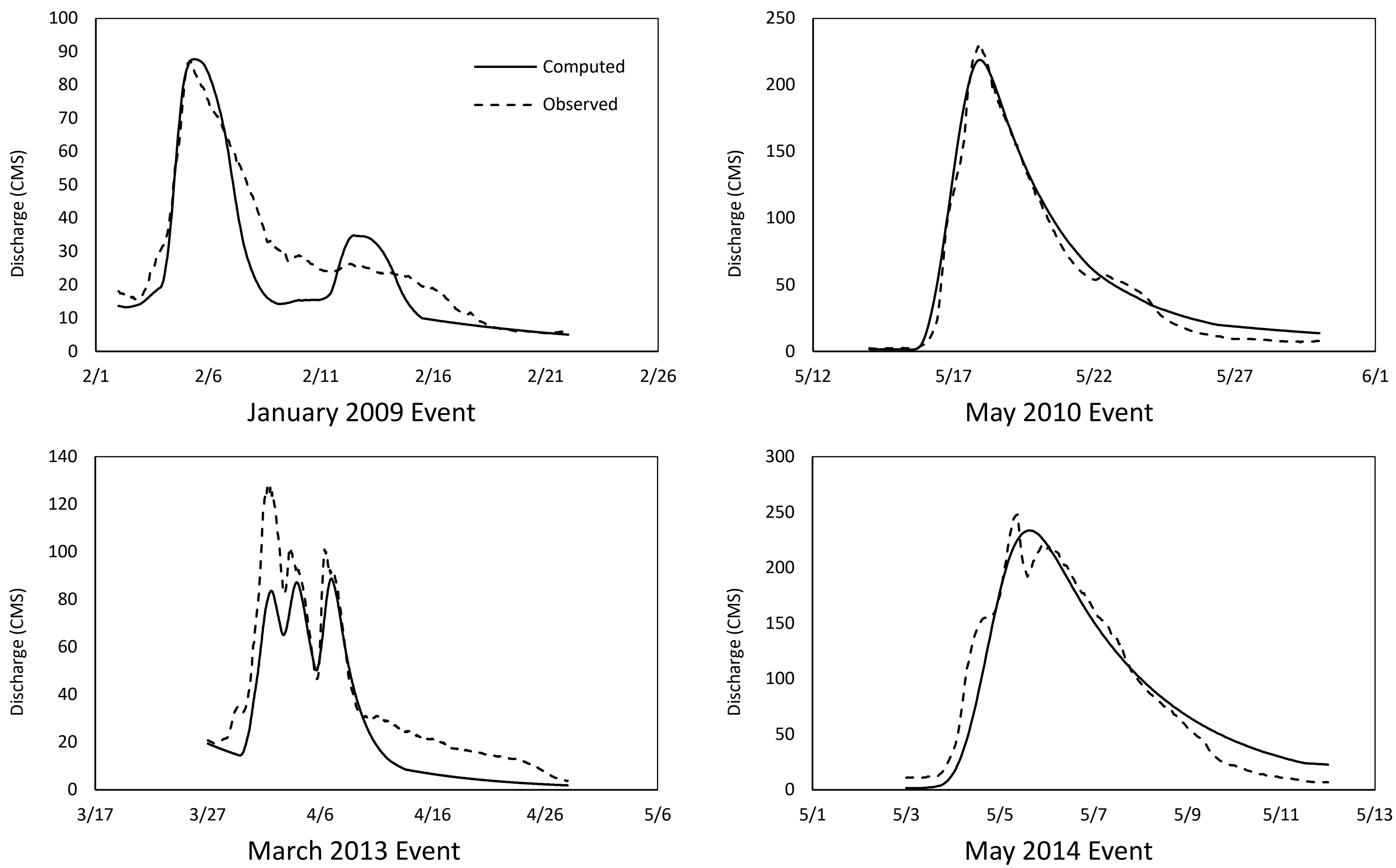


Figure 59: Calibration Plots for the Ilova Gauge for Various Calibration Events

Table 31: Ilova River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Veliko Vukovje	Jan 2009	68	34	67	31	-1.0%	-8.3%	0.859
	May 2010	123	57	127	54	3.5%	-6.2%	0.959
	Mar 2013	83	62	57	47	-31.3%	-25.0%	0.773
	May 2014	148	43	150	44	1.2%	0.8%	0.955
Ilova	Jan 2009	87	30	88	26	0.6%	-14.1%	0.825
	May 2010	229	48	219	53	-4.5%	8.9%	0.983
	Mar 2013	127	65	89	45	-30.1%	-30.8%	0.775
	May 2014	248	43	234	44	-5.8%	0.6%	0.927

4.7 UNA RIVER WATERSHED

4.7.1 BASIN DESCRIPTION

The Una River is a larger tributary to the Sava River, originating from the Vrelo Une spring on the north-eastern slopes of the Strazbenica mountain range in Croatia, flowing in a generally northward direction, as a natural border between Croatia and Bosnia until reaching a confluence with the Sava River near the small town of Jasenovac. The Una River has a total length of 214 km and a drainage area of 10,816 km2, and contains several main tributaries of varying size and shape including: the Unac, Sana, Klokot and Krusnica Rivers. The basin's topography is characterized by steep mountainous karst terrain in the headwaters to rolling hills, mixed forest, and agricultural land in the middle and lower portions of the watershed.

4.7.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 32 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Una River Watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 1.16 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.65 indicates that a normal amount of attenuation occurs within the watershed, with less attenuation in the headwaters and more attenuation in the flatter, low-lying areas of the lower reaches of the basin.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration is due to the meteorological model over-estimating (for large values) or under-estimating the precipitation (for small values) during certain events. As a result, constant loss rates are raised or lowered to physically unrealistic values to compensate for too

much or too little precipitation. A range of 1.0 to 50 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is very different throughout the watershed.

Table 32: Una Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	5	1.16	16.0	27.9	0.65	0.02	0.90	0.31
Minimum	0	0.00	1.0	1.0	0.36	0.00	0.80	0.20
Maximum	42	4.50	50.0	80.0	0.77	0.09	0.98	0.90
Standard Deviation	8	1.51	6.8	9.2	0.07	0.01	0.02	0.06

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 32 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Una River Watershed HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.7.3 REACH ROUTING PARAMETERS

River reach routings within the Una River Watershed were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 33 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 33: Una Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_12_02_01	61299	0.0050	Eight Point	0.040	0.08	0.08
R_12_03_03	54812	0.0050	Eight Point	0.038	0.08	0.08
R_12_04_01	36894	0.0014	Eight Point	0.035	0.08	0.08
R_12_04_05	39426	0.0007	Eight Point	0.035	0.08	0.08
R_12_04_06	32219	0.0008	Eight Point	0.035	0.08	0.08
R_12_04_10	29998	0.0003	Eight Point	0.035	0.08	0.08
R_12_04_14	9513	0.0001	Eight Point	0.035	0.08	0.08
R_12_04_18	9960	0.0001	Eight Point	0.035	0.08	0.08
R_12_05_01	25383	0.0010	Eight Point	0.035	0.08	0.08
R_12_06_01	24018	0.0005	Eight Point	0.035	0.08	0.08
R_12_06_04	24492	0.0005	Eight Point	0.035	0.08	0.08

4.7.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Una River Watershed was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 60 illustrates the Una River Watershed basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 60 illustrates that the Una River Watershed has a reasonable number of meteorological stations covering the basin.

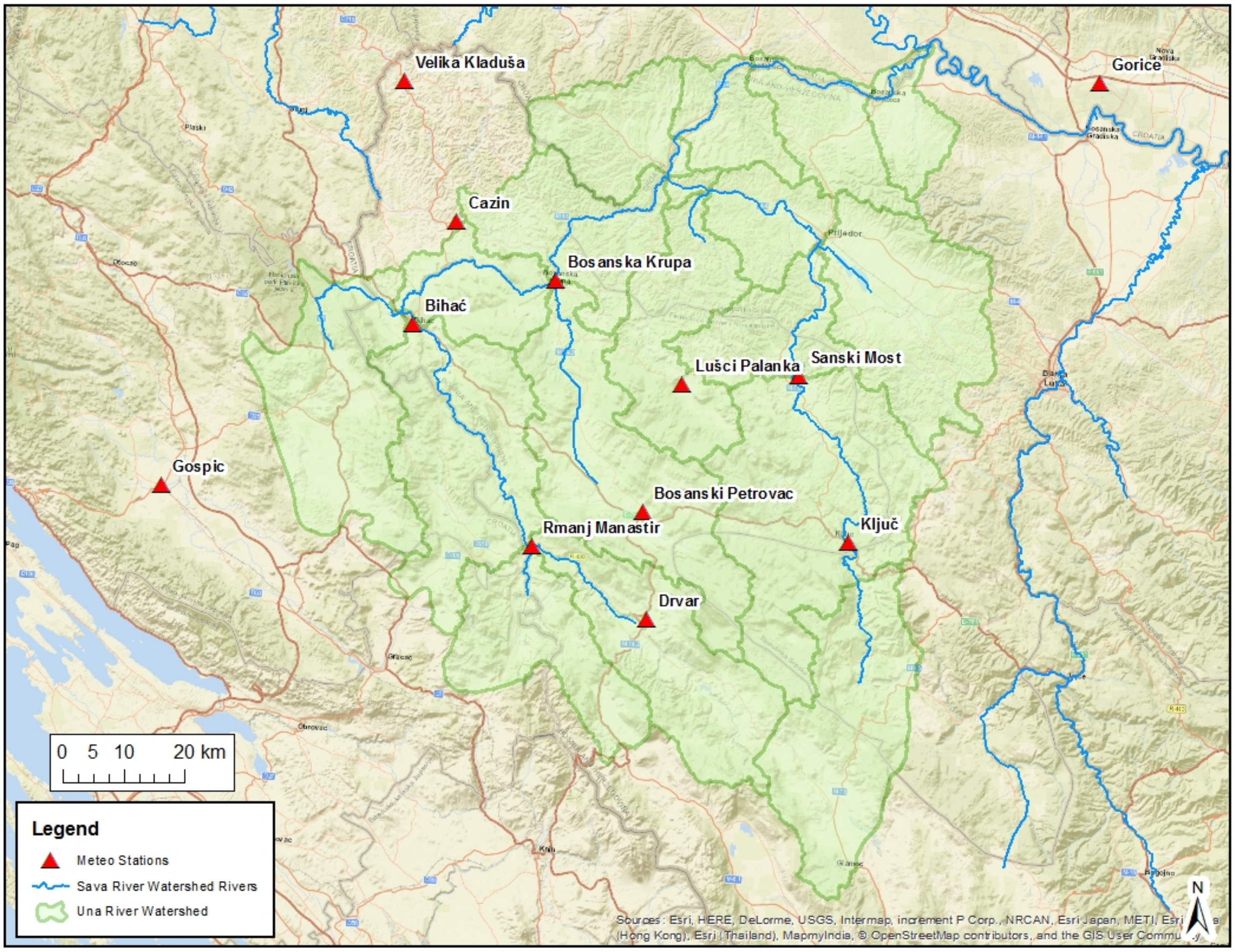


Figure 60: Meteorologic Station Map for the Una River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 34 shows the average ET rates for the Una River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 34: Average ET Rates for the Una River Watershed

Month	ET Rate (mm/month)
Jan	4.6
Feb	8.4
Mar	25.7
Apr	40.5
May	58.8
Jun	103.9
Jul	114.7
Aug	128.4
Sep	87.5
Oct	66.9
Nov	20.0
Dec	7.7

4.7.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Una River Watershed HEC-HMS model. Two of the most common challenges during this study were related to subbasin delineation and meteorologic data availability.

The development of the Una River Watershed subbasin delineation relied heavily on the SRTM DEM and a subbasin delineation ESRI shapefile provided by the ISRBC at the 1000 km^2 scale. Due to the quality of the subbasin delineation shapefile and the steep topography of the watershed, the lower resolution DEM is adequate for the purpose of hydrologic modeling. As such, the delineation is acceptable; however, there is room for improvement in certain areas, specifically those containing karst limestone features, of the basin if a higher-resolution DEM were incorporated. Based on discussions with the ISRBC, areas of karst features can influence the flow paths within the watershed and in turn, can affect the delineation. Karst issues, as it relates to subbasin delineation, were rectified using the subbasin delineation shapefile provided by the ISRBC.

The coverage of meteorologic stations for the Una River Watershed is generally adequate for hydrologic model calibration. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred is not captured by the surrounding gauges. There were no major issues with regards to meteorological or hydrological station data for the Una River basin, and the number, location, and reliability of available gages allowed for dependable model calibration results and a high degree of confidence in the hydrologic parameters developed.

4.7.6 CALIBRATION RESULTS AND DISCUSSION

As aforementioned, the Una River Watershed HEC-HMS model calibration quality is reliably accurate based on the performance metrics, and the model performs well across a large range of events and seasons. Figure 61 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of gauges in the basin. Figure 62 - Figure 67 and Table 35 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. The quality of hydrologic model calibrations is typically driven by the availability and quality of precipitation data. Model calibrations for the Una River basin benefited from a meteorological gage network capable of capturing the spatial and temporal distribution of most storm events with a reasonable accuracy.

It is important to note that in order to reduce residual errors in the hydrologic calibration process, for all events, once inflows to the hydrologic gages were calibrated, observed discharges were subsequently routed downstream. This prevented the compounding of model error and allowed for greater accuracy of hydrologic parameter development.

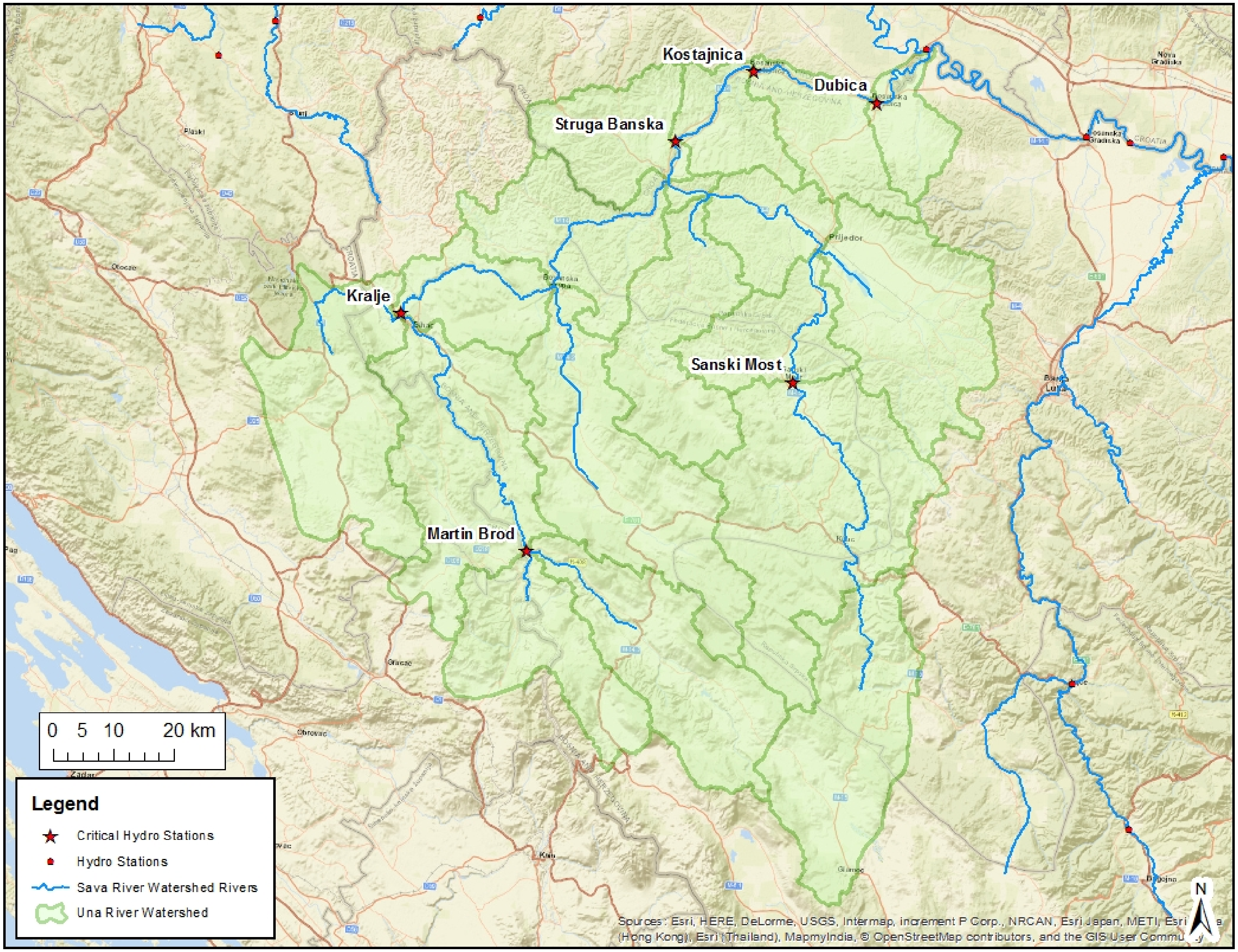


Figure 61: Hydrologic Station Map for the Una River Watershed

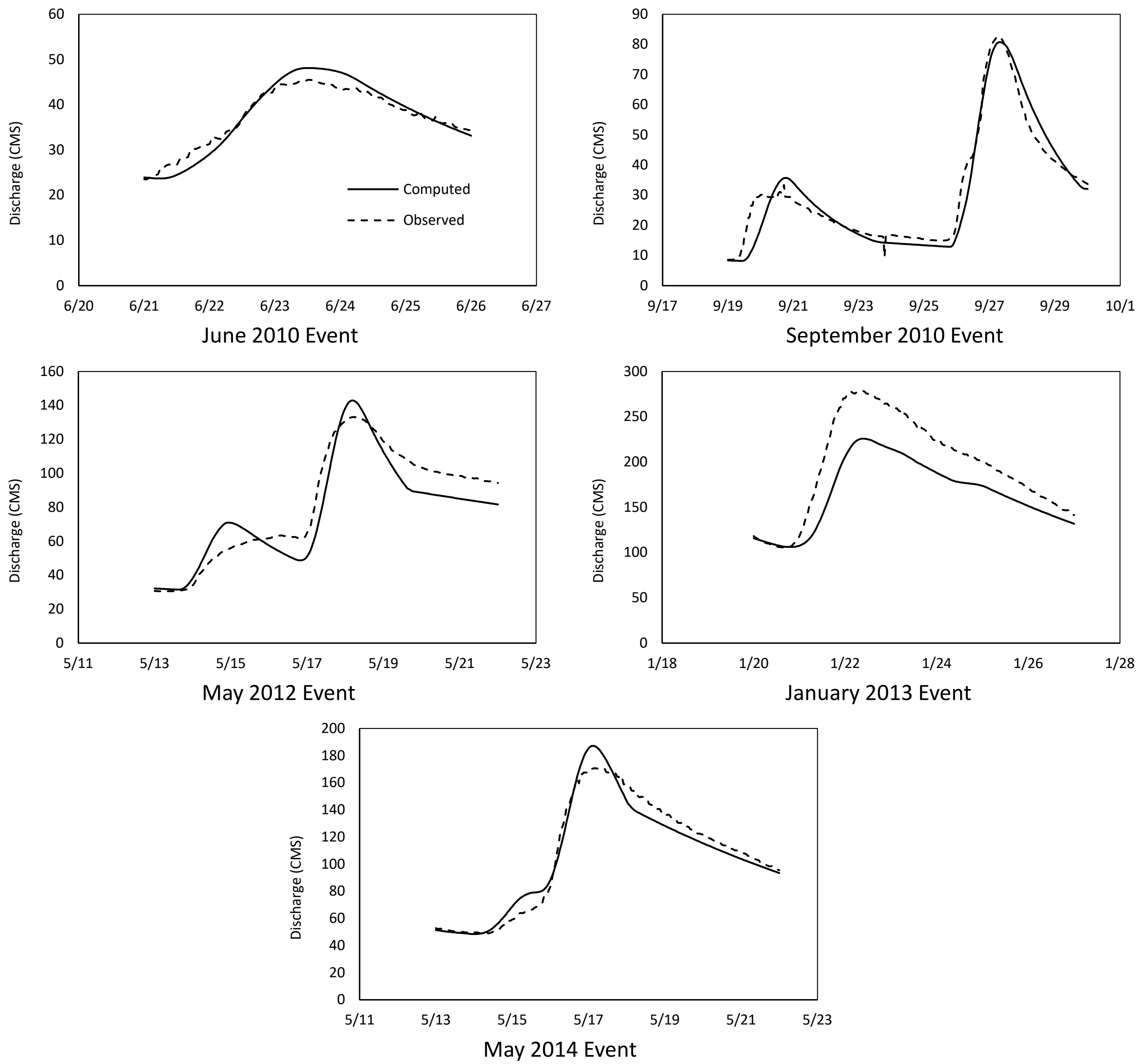


Figure 62: Calibration Plots for the Martin Brod Gauge for Various Calibration Events

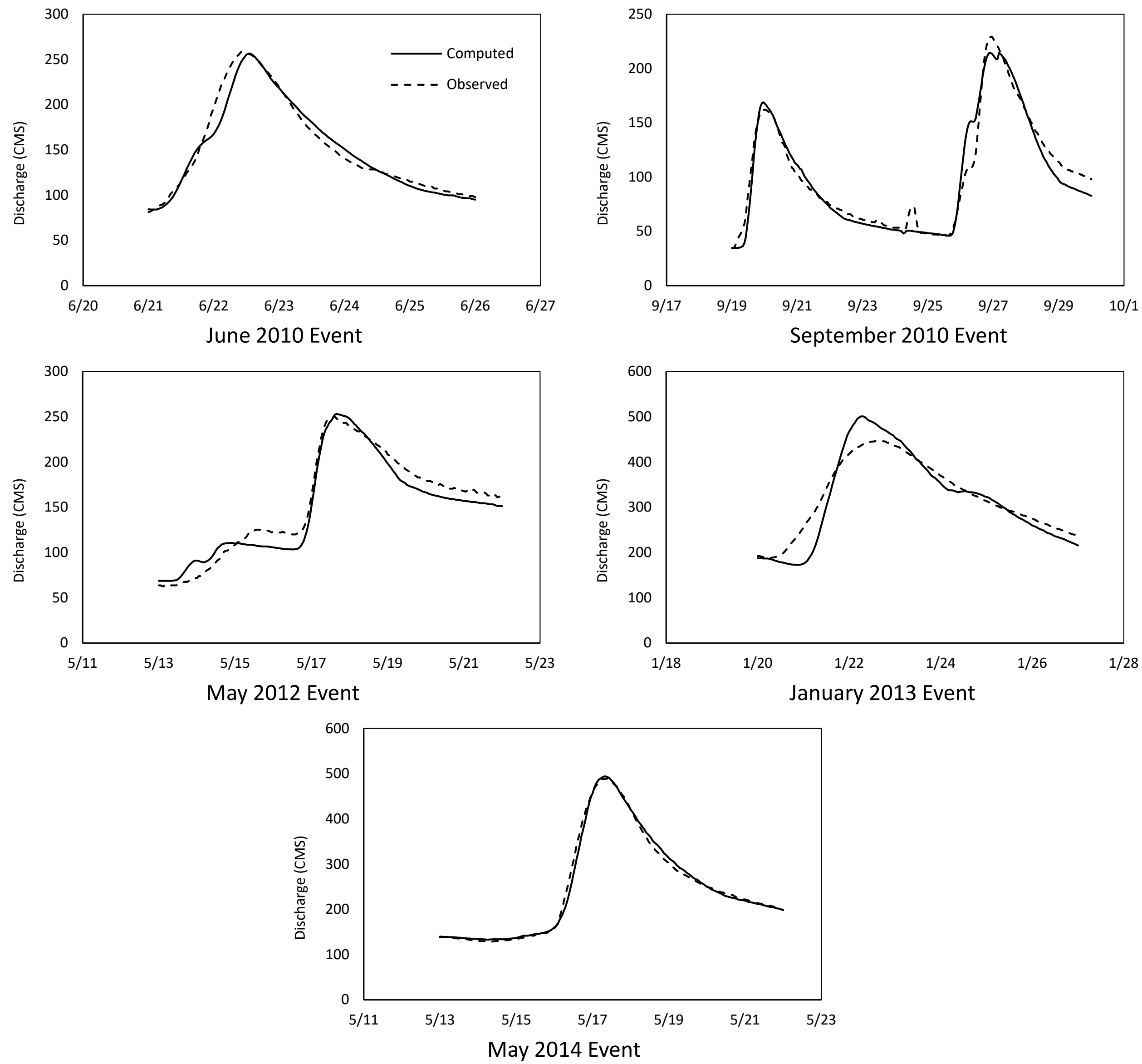


Figure 63: Calibration Plots for the Kralje Gauge for Various Calibration Events

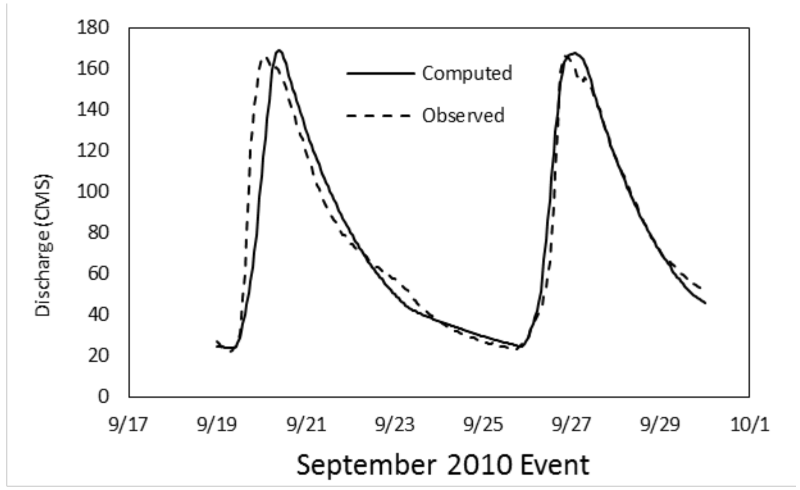


Figure 64: Calibration Plots for the Sanski Most Gauge for Various Calibration Events

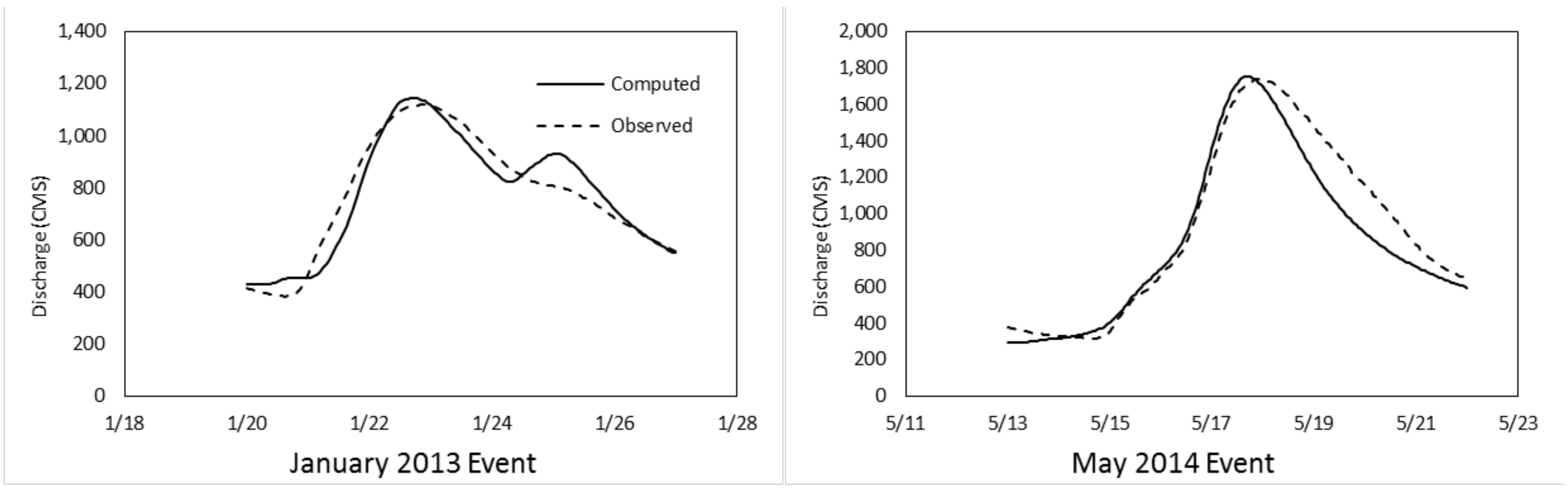


Figure 65: Calibration Plots for the Struga Banska Gauge for Various Calibration Events

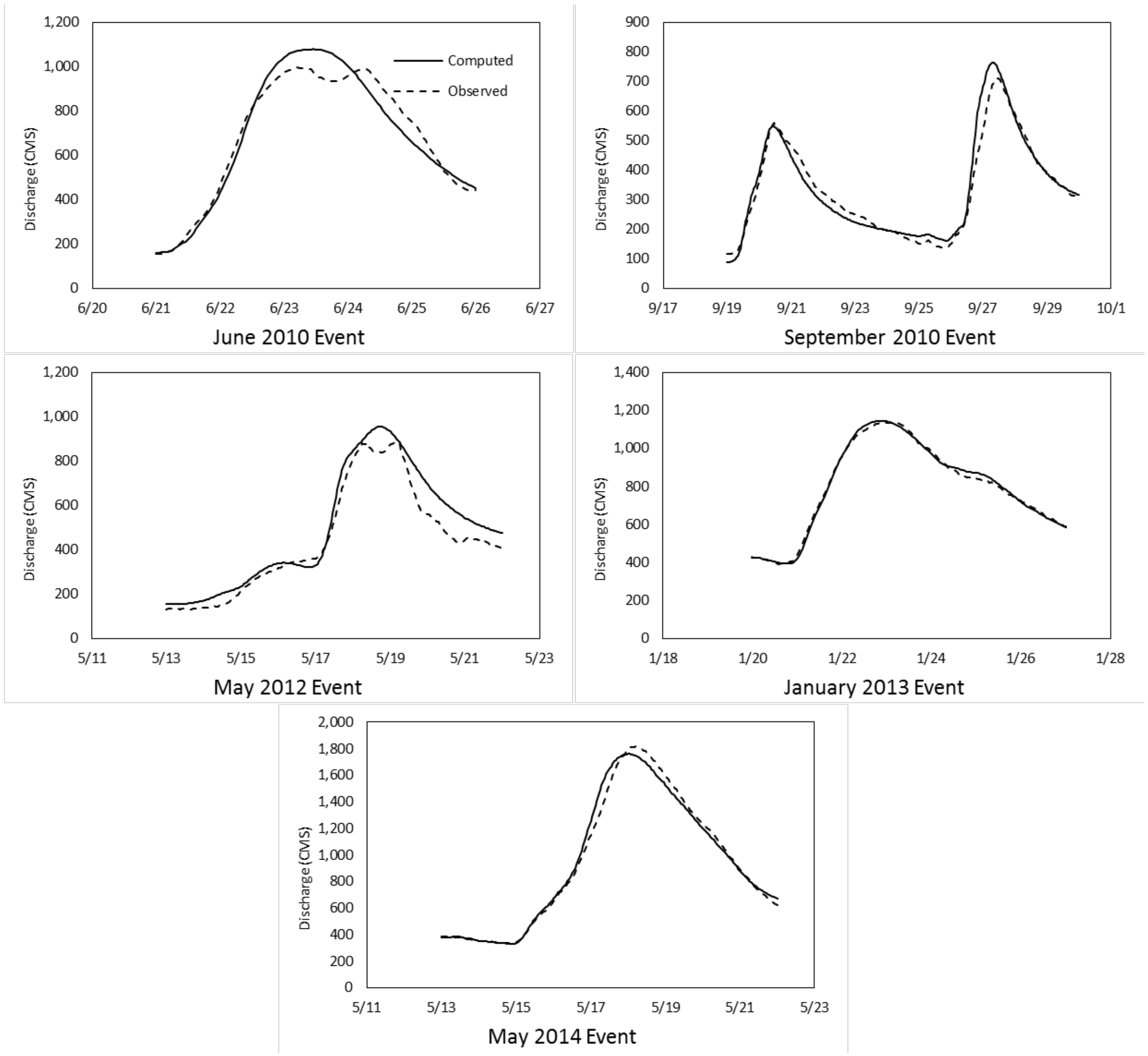


Figure 66: Calibration Plots for the Kostajnica Gauge for Various Calibration Events

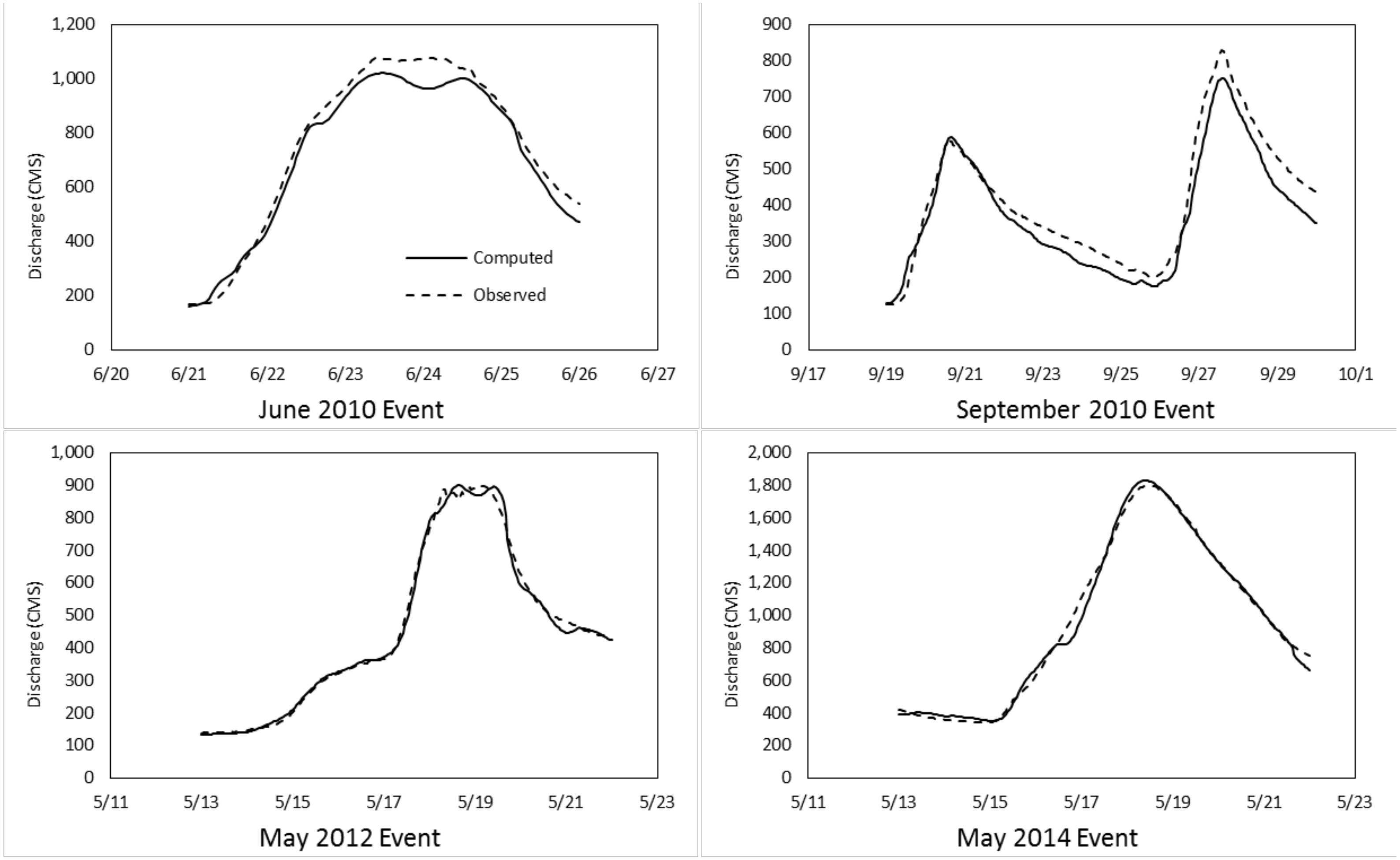


Figure 67: Calibration Plots for the Dubica Gauge for Various Calibration Events

Table 35: Una River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Martin Brod	June 2010	45.5	12.59	48.1	12.69	5.7%	0.8%	0.90
	Sep 2010	82.6	23.49	80.7	23.06	-2.3%	-1.8%	0.94
	May 2012	133.2	49.84	142.9	46.98	7.3%	-5.7%	0.88
	Jan 2013	278.7	92.46	225.8	77.97	-19.0%	-15.7%	0.55
	May 2014	170.8	65.17	187.3	64.47	9.7%	-1.1%	0.96
Kralje	June 2010	258.3	21.95	256.6	21.66	-0.7%	-1.3%	0.96
	Sep 2010	229.3	32.4	214.4	31.72	-6.5%	-2.1%	0.95
	May 2012	250	39.75	253.2	38.34	1.3%	-3.5%	0.95
	Jan 2013	446.8	65.1	501.2	63.86	12.2%	-1.9%	0.84
	May 2014	490	64.53	494.5	64.62	0.9%	0.1%	0.99
Sanski Most	Sep 2010	166.2	36.27	168.8	35.94	1.6%	-0.9%	0.91
Struga Banska	Jan 2013	1120	51.9	1143.1	50.47	2.1%	-2.8%	0.92
	May 2014	1741	76.93	1753.8	71.46	0.7%	-7.1%	0.92
Kostajnica	June 2010	998	31	1079	30.96	8.1%	-0.1%	0.95
	Sep 2010	711	33.09	763.8	33.55	7.4%	1.4%	0.94
	May 2012	890	27.05	955.6	30.24	7.4%	11.8%	0.92
	Jan 2013	1141	50.24	1144.9	50.32	0.3%	0.2%	1.00
	May 2014	1819	76.52	1760	76.63	-3.2%	0.1%	0.99
Dubica	June 2010	1077	32.87	1020.5	31.26	-5.2%	-4.9%	0.97
	Sep 2010	829	39.35	751.6	35.73	-9.3%	-9.2%	0.92
	May 2012	900	35.51	899.3	35.36	-0.1%	-0.4%	1.00
	May 2014	1794.8	75.42	1828.5	75.26	1.9%	-0.2%	0.99

4.8 VRBAS RIVER WATERSHED

4.8.1 BASIN DESCRIPTION

The Vrbas River is a major tributary to the Sava River in western Bosnia and Herzegovina with several tributaries of varying size and shape including the Ugar, Pliva and Vrbanja Rivers. The Vrbas River originates from Vranica Mountain near the town of Gornji Vakuf and flows northward until it empties into the Sava River. The most major city on the Vrbas River is Banja Luka. The drainage area of the Vrbas River is approximately 6,284 km^2, and the basin's topography is considered very steep with a maximum elevation in the headwaters of approximately 2100 masl and minimum elevation of approximately 90 masl.

4.8.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 36 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Vrbas River Watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 0.59 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.51 indicates that a normal amount of attenuation occurs within the watershed, with less attenuation in the headwaters and more attenuation in the flatter, low-lying areas of the lower reaches of the basin.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration is due to the meteorological model over-estimating (for large values) or under-estimating the precipitation (for small values) during certain events. As a result, constant loss rates are raised or lowered to physically unrealistic values to compensate for too

much or too little precipitation. A range of 4 to 60 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is very different throughout the watershed.

Table 36: Vrbas Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	**Constant Rate (mm/hr)**	**T_c (hr)**	**R**	$\frac{R}{T_c + R}$	**Initial Flow (CMS/km^2)**	**Recession Constant**	**Ratio to Peak**
Representative	13	0.59	18.7	19.1	0.51	0.05	0.90	0.37
Minimum	0	0.00	4.0	4.0	0.33	0.01	0.72	0.21
Maximum	25	1.20	60.0	50.0	0.71	0.13	0.95	0.63
Standard Deviation	7	0.43	5.5	3.2	0.08	0.00	0.02	0.00

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 36 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Vrbas River Watershed HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.8.3 REACH ROUTING PARAMETERS

River reach routings within the Vrbas River Watershed were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 37 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 37: Vrbas Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_14_02_03	3116	0.0112	0	0.035	0.08	0.08
R_14_02_04	39409	0.0050	0	0.035	0.08	0.08
R_14_02_08	12604	0.0087	0	0.035	0.08	0.08
R_14_02_11	6508	0.0088	0	0.035	0.08	0.08
R_14_02_15	15498	0.0087	0	0.035	0.08	0.08
R_14_02_18	46235	0.0027	0	0.035	0.08	0.08
R_14_02_22	86094	0.0007	0	0.035	0.08	0.08

4.8.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Vrbas River Watershed was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 68 illustrates the Vrbas River Watershed basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. It is evident from Figure 68 that the Vrbas River Watershed has a limited to insufficient number of meteorological stations covering the basin.

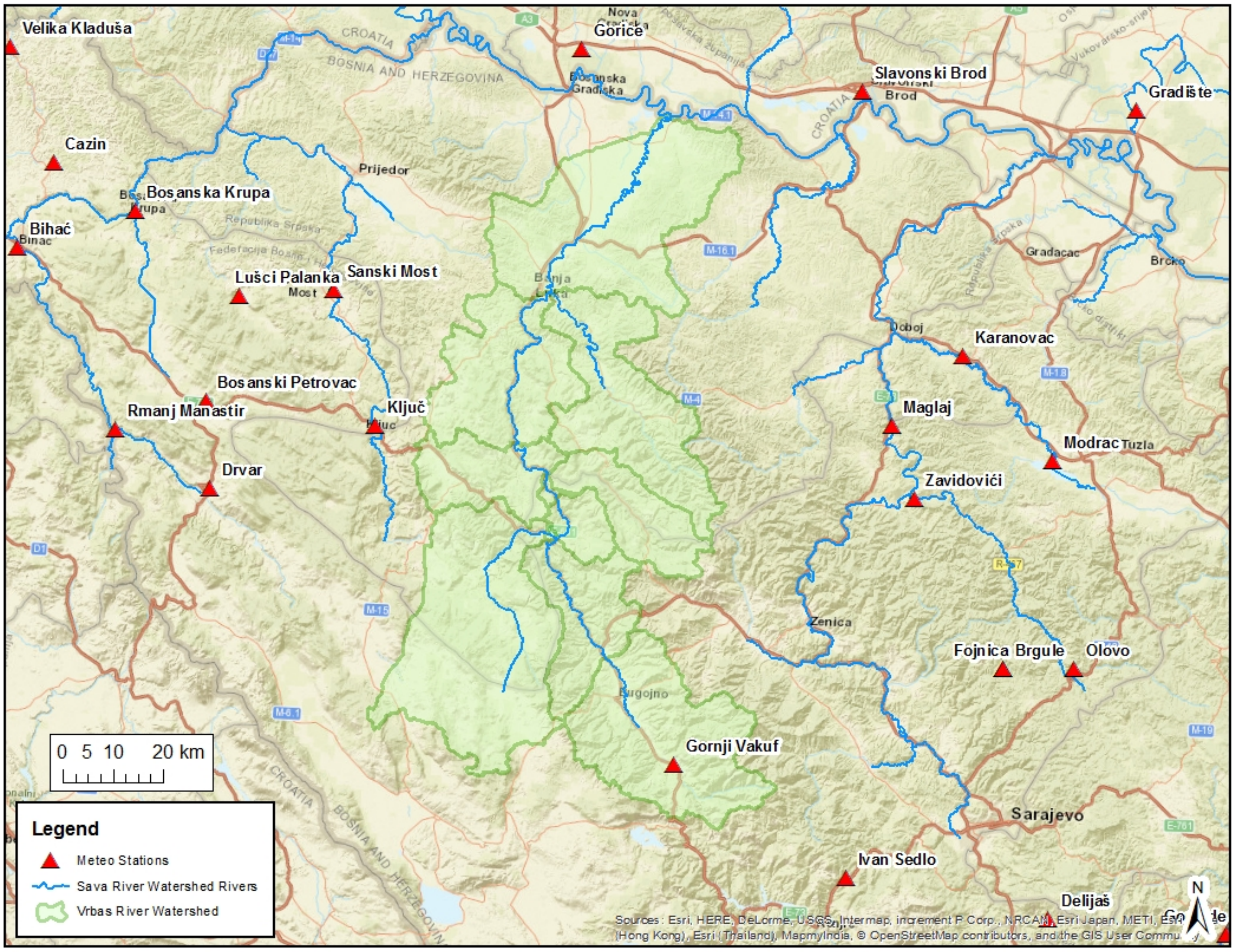


Figure 68: Meteorologic Station Map for the Vrbas River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 38 shows the average ET rates for the Vrbas River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 38: Average ET Rates for the Vrbas River Watershed

Month	ET Rate (mm/month)
Jan	1.3
Feb	4.5
Mar	18.7
Apr	40.0
May	74.8
Jun	95.2
Jul	117.6
Aug	109.2
Sep	78.5
Oct	39.4
Nov	14.5
Dec	2.9

4.8.5 BASIN SPECIFIC TOPICS

The two primary issues that caused difficulty during the hydrologic model calibration process of the Vrbas River were the lack of available precipitation gages and the incorporation of reservoir storage projects into the hydrology.

As evident from Figure 68, there is a severe absence of available precipitation gages in and around the Vrbas River watershed. The primary source of error in most hydrology models is precipitation, as such the issues with precipitation gage coverage caused high variability in many of the hydrologic parameters between different calibration events. While the inverse-distance method makes it possible to interpolate the timing and intensity of rainfall events in areas that lack precipitation gages, the further the interpolation distance the greater likelihood of significant errors. In comparison to the main stem Sava hydrology model and the other tributary models, the overall scarcity of precipitation data is more pronounced for the Vrbas River basin. However, the Vrbas River basin has meteorologic stations bounding the borders of the watershed, which provides a better situation than in other areas of the Sava River Basin.

Figure 69 shows the reservoirs that were incorporated into the Vrbas River hydrology model: Jajce I &II, and Bocac Dam. A comparison of the simulated inflow and outflow hydrographs showed Jajce I and Jajce II to not have a significant impact on the timing or magnitude of flood waves as they moved through the reservoirs. Modeling results confirmed that neither projects contained enough storage to have a sizeable effect on flood peak timing or attenuation for any of the calibration events. Bocac Dam, the larger of the reservoirs, however, did contain enough storage to have a noticeable impact on the timing and attenuation of flood flows. Data provided for the Bocac Dam included an elevation storage curve up to the normal pool, or spillway invert, as well as specifications regarding the size and number of outlet works. Additionally, observed inflow and discharge data was provided for select storm events, allowing for the dam to serve as another model calibration point. All of the storm events considered during the calibration process produced maximum pool elevations that exceeded the largest given value in the elevation-storage curve provided. To remedy this issue the provided curve was extrapolated out far enough to sufficiently cover any pool elevation experienced during the calibration events. The method of extrapolation for the elevation-storage data involved fitting the existing data to a best-fit curve and projecting out to produce storage values for all necessary elevations. Due to the error associated with an extrapolation, it is recommended that a physically-based approach be used to develop the needed storage values for pool elevations above normal pool.

With the data provided, it was only possible to perform a simply hydrologic routing of flood flows through Bocac Dam. Without operational information, it is difficult to accurately model discharge through the project using only the elevation-storage curve and specified outlet information. While the model does an adequate job of routing flood flows during large events, smaller events will likely require the incorporation of operational logic using software designed specifically for this purpose in order to more accurately reflect discharge.

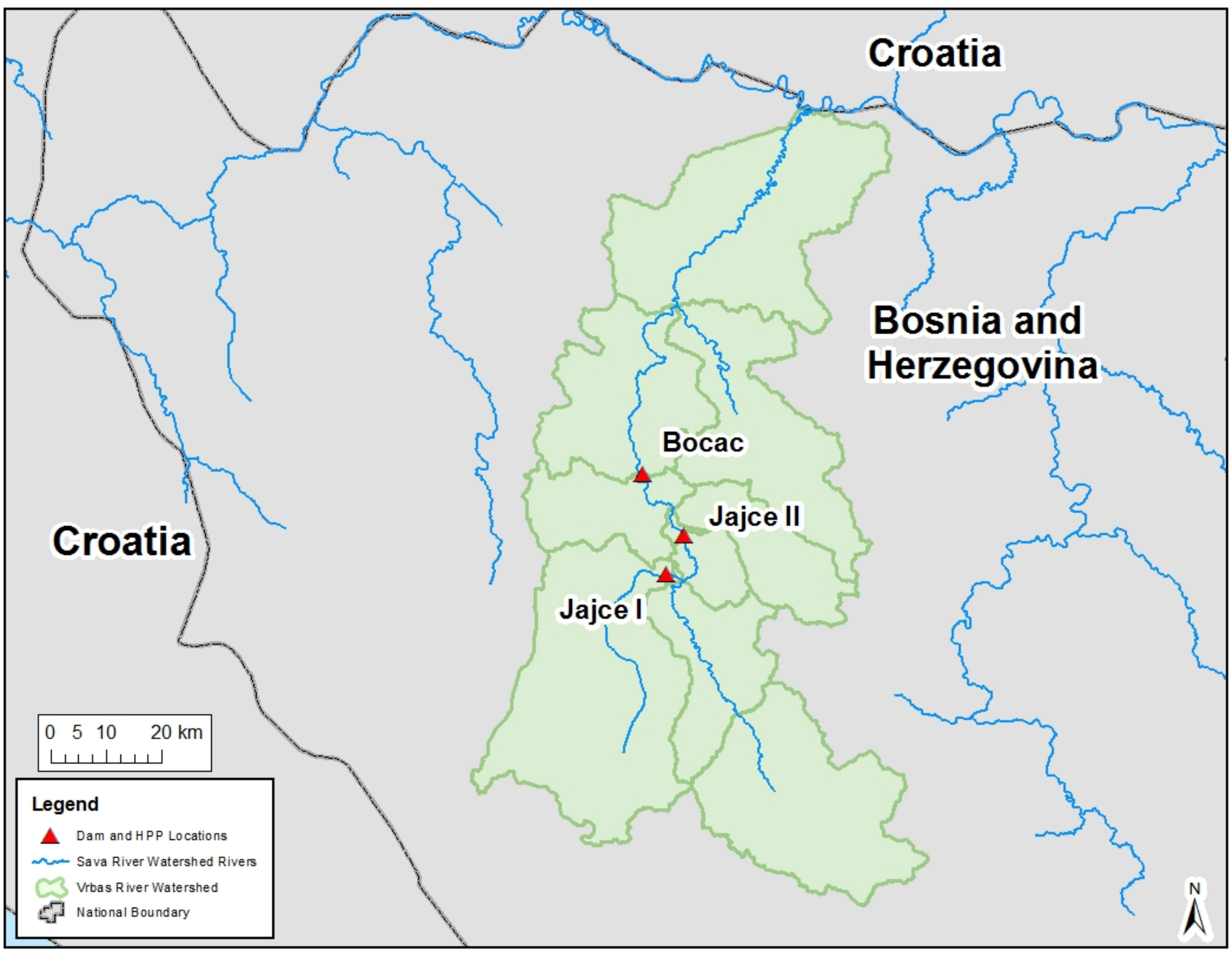


Figure 69: Reservoirs Modeled for the Vrbas River Watershed

4.8.6 CALIBRATION RESULTS AND DISCUSSION

The Vrbas River Watershed HEC-HMS model calibration quality is reasonable based upon the relative lack of nearby precipitation data. Figure 70 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of hydrologic stations in the basin. The calibration results at these locations are shown in Figure 71 - Figure 73.

Figure 71 - Figure 73 and Table 39 illustrate the quality of the calibration but also show the variability of quality between event simulations and at specific gauges. In most cases, model calibration quality was dependent on the accuracy and availability of precipitation data. As shown in Figure 70, there are no hydrologic gauging stations below Bocac Dam, an area which represents nearly 50% of the total watershed. Additional gauges downstream of Bocac Dam will improve the calibration of the Vrbas River model and produce more accurate flows into the main stem Sava River hydrology model, improving that model's performance as well.

It is important to note that in order to reduce residual errors in the hydrologic calibration process, for all events, once inflows to the hydrologic gages were calibrated, observed discharges were subsequently routed downstream. This prevented the compounding of model error and allowed for greater accuracy of hydrologic parameter development.

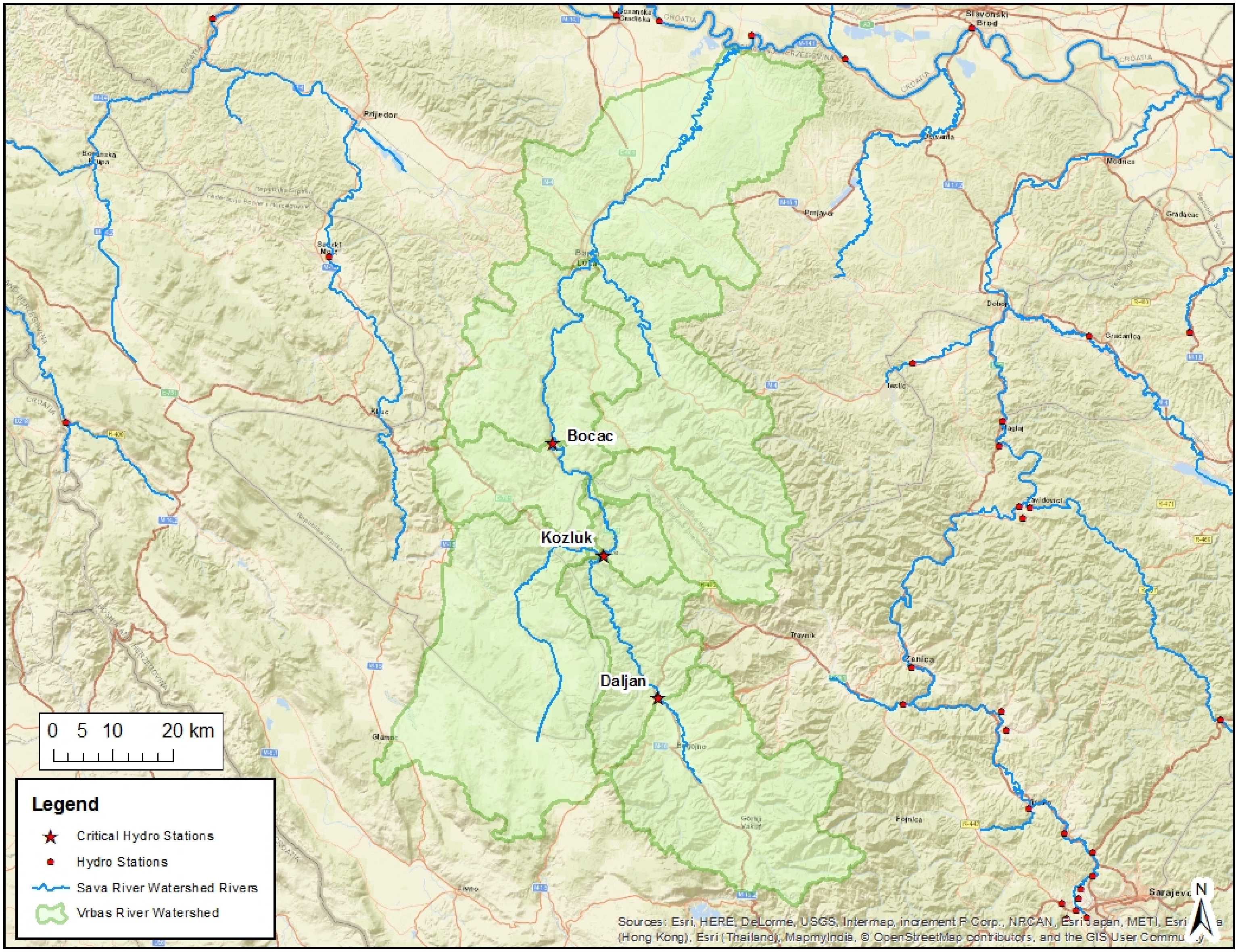


Figure 70: Hydrologic Station Map for the Vrbas River Watershed

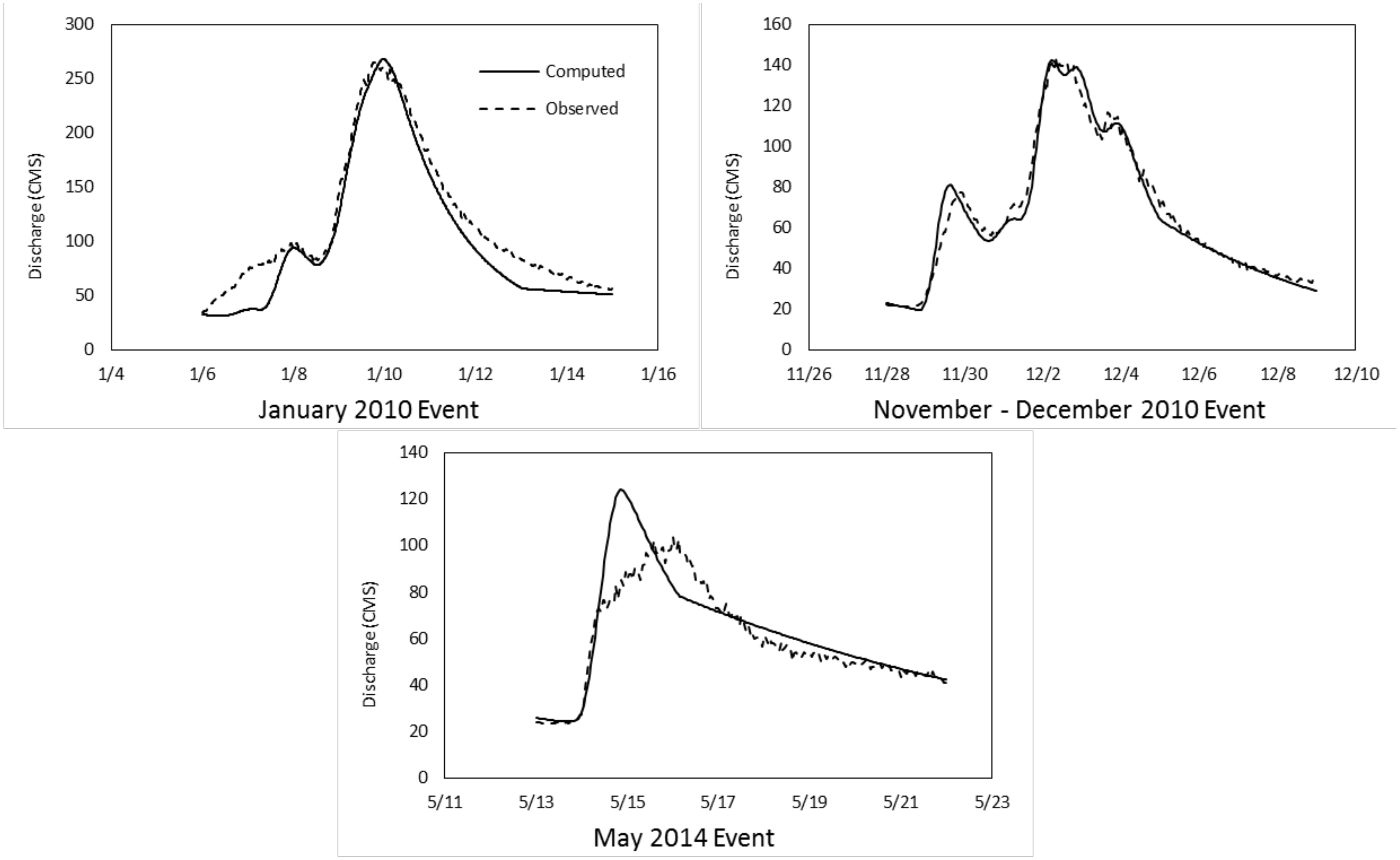


Figure 71: Calibration Plots for the Daljan Gauge for Various Calibration Events

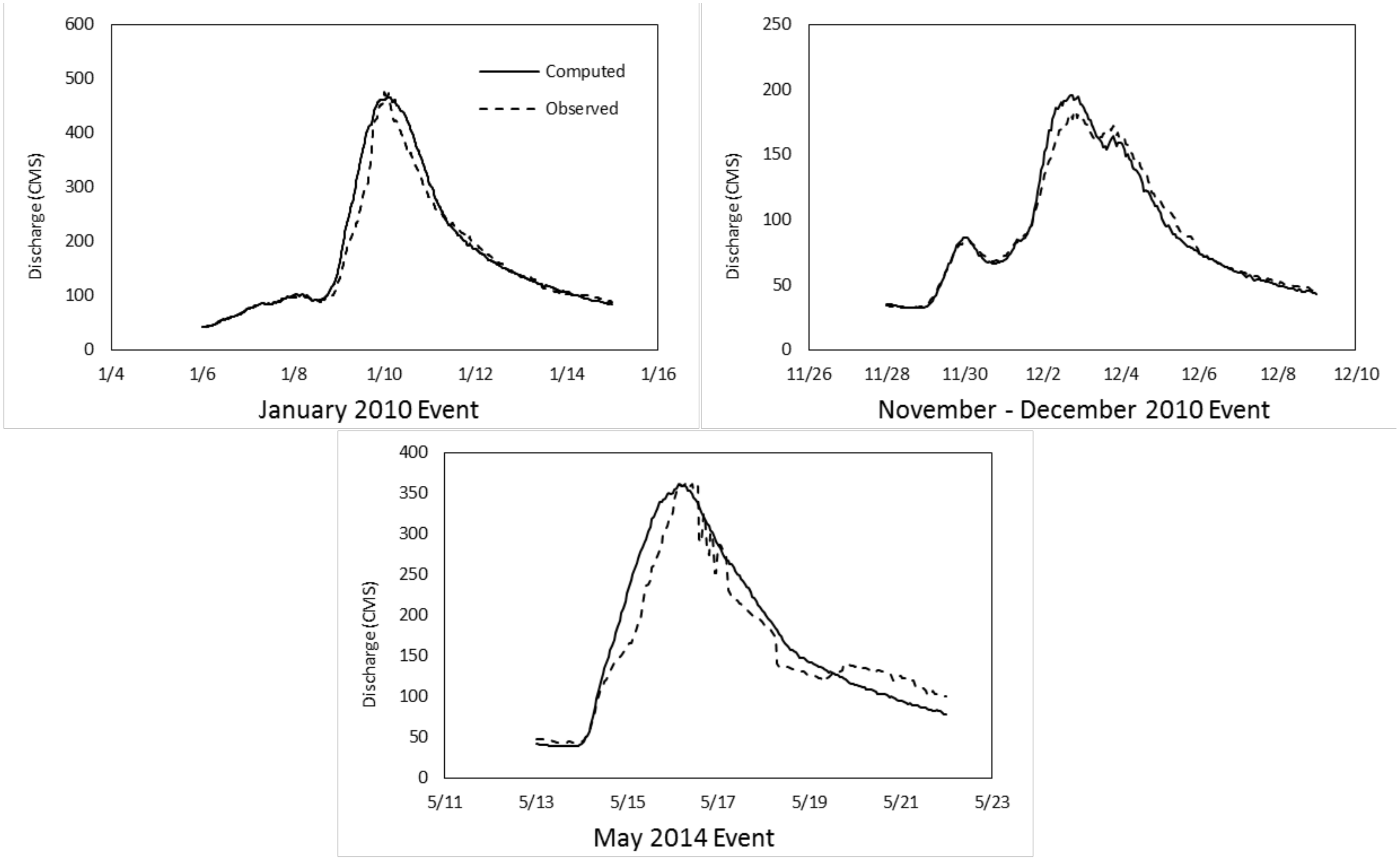


Figure 72: Calibration Plots for the Kozluk Gauge for Various Calibration Events

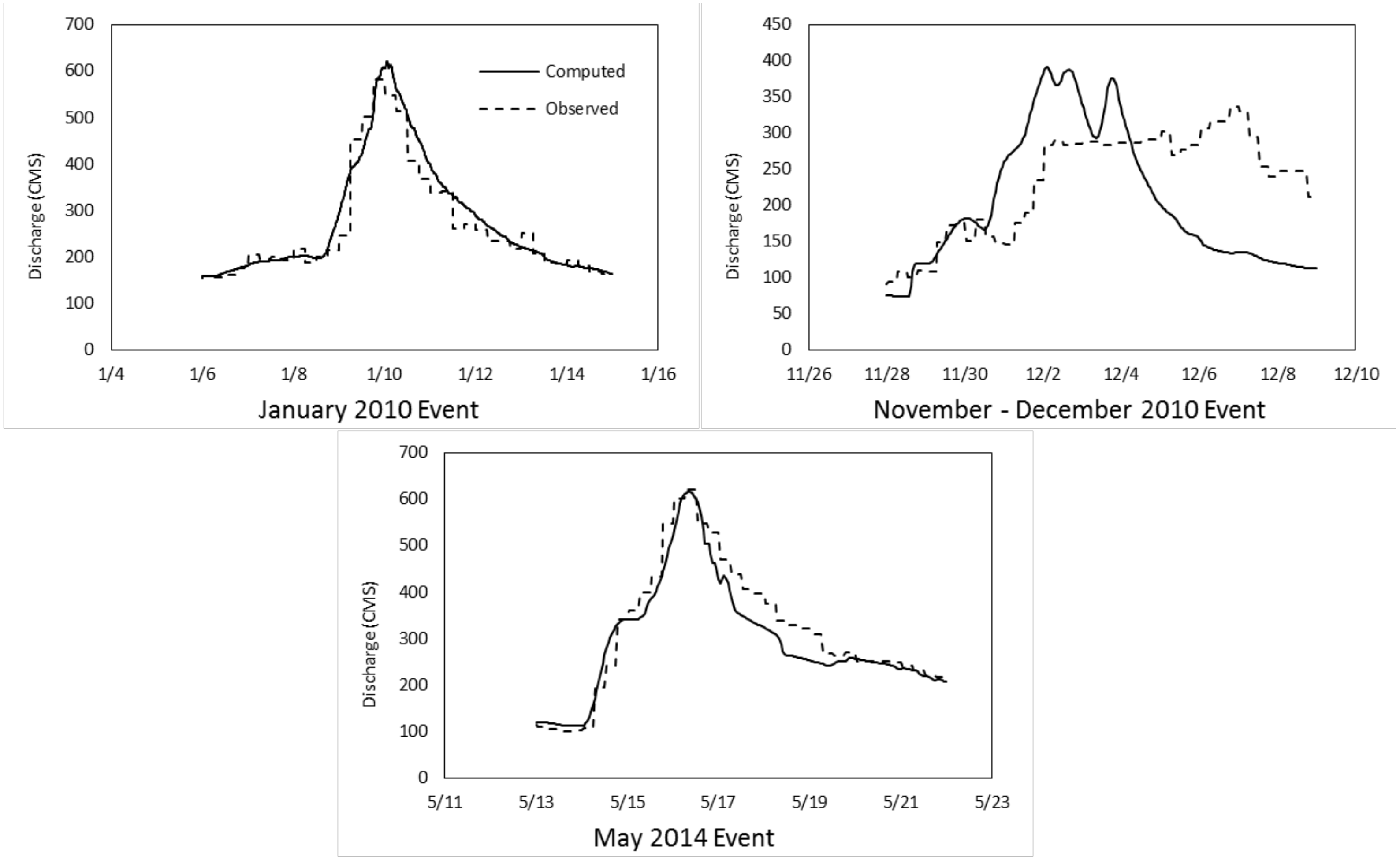


Figure 73: Calibration Plots for the Bocac Inflow Gauge for Various Calibration Events

Table 39: Vrbas River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Daljan	Jan 2010	264.8	98.57	264.8	85.95	0.0%	-12.8%	0.919
	Nov-Dec 2010	143.3	69.98	142.6	69.06	-0.5%	-1.3%	0.98
	May 2014	103.6	50.84	124.1	53.14	19.8%	4.5%	0.70
Kozluk	Jan 2010	476.6	48.49	466.1	51.18	-2.2%	5.5%	0.951
	Nov-Dec 2010	183.1	31.93	196	31.74	7.0%	-0.6%	0.97
	May 2014	364.9	46.82	361.2	46.26	-1.0%	-1.2%	0.88
Bocac Inflow (6-HR)	Jan 2010	581	57.54	621.1	59.94	6.9%	4.2%	0.92
	Nov-Dec 2010	336	61.99	391.3	54.39	16.5%	-12.3%	-1.07
	May 2014	620	68.72	616.2	64.21	-0.6%	-6.6%	0.92

4.9 ORLJAVA RIVER WATERSHED

4.9.1 BASIN DESCRIPTION

The Orljava River is one of the largest rivers within Croatia, flowing from the village of Mijaci southeastward through Pozega, Pleternica, and Luzani to its confluence with the Sava River near Slavonski Kobas. The Orljava River basin is fan-shaped with a basin area of approximately 1,620 km^2. The basin's topography is considered relatively steep with a maximum elevation in the headwaters of approximately 950 masl and minimum elevation at its confluence of approximately 80 masl.

4.9.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 40 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Orljava River watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 0.73 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.51 indicates that a normal amount of attenuation occurs within the watershed, with the steeper headwater areas of the basin consisting of less attenuation and the flatter lowlands of the basin consisting of more attenuation.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration is due to the meteorological model over-estimating (for large values) or under-estimating the precipitation (for small values) during certain events. As a result, constant loss rates are raised or lowered to physically unrealistic values to compensate for too much or too little precipitation. A range of 2.5 to 40.0 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is very different throughout the watershed.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 40: Orljava Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	10	0.73	16.3	16.3	0.51	0.01	0.90	0.22
Minimum	0	0.10	2.5	5.0	0.23	0.00	0.87	0.15
Maximum	24	1.20	40.0	40.0	0.91	0.02	0.90	0.32
Standard Deviation	8	0.31	5.5	3.7	0.20	0.01	0.00	0.05

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 40 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Orljava River HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.9.3 REACH ROUTING PARAMETERS

River reach routings within the Orljava River basin were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 41 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 41: Orljava Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_16_02_03	19304	0.0002	Trapezoid	0.040		
R_16_02_06	28922	0.0009	Trapezoid	0.040		

4.9.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Orljava River basin was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 74 illustrates the Orljava River basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 74 illustrates that the Orljava River Basin has an insufficient number of meteorological stations covering the basin, which greatly reduces the confidence in the accuracy expected from the IDW meteorologic model method.

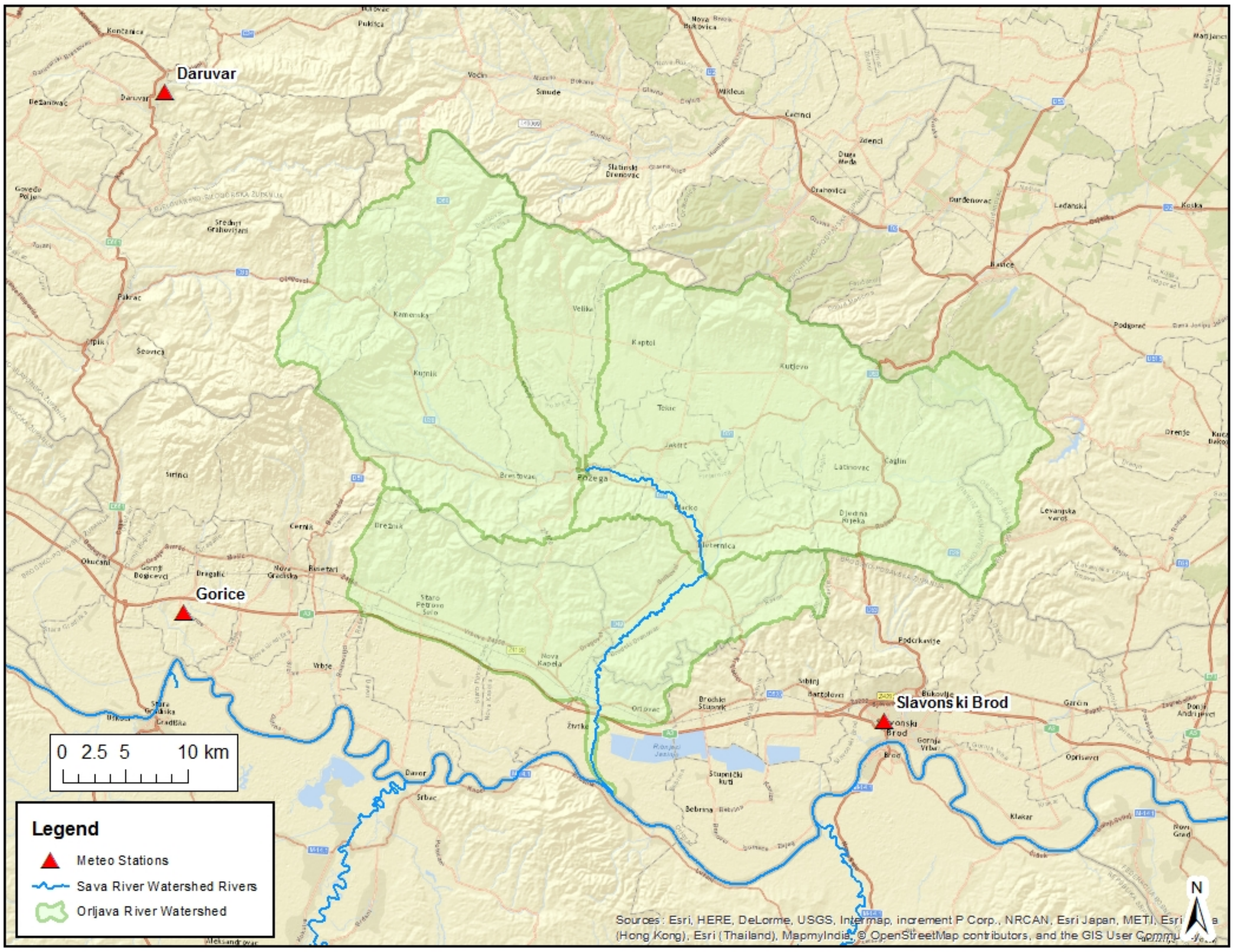


Figure 74: Meteorologic Station Map for the Orljava River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 42 shows the average ET rates for the Orljava River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 42: Average ET Rates for the Orljava River Watershed

Month	ET Rate (mm/month)
Jan	11
Feb	18
Mar	33
Apr	51
May	79
Jun	101
Jul	117
Aug	109
Sep	69
Oct	39
Nov	20
Dec	12

4.9.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Orljava River watershed HEC-HMS model. The greatest challenge during this study was related to meteorologic data availability.

The coverage of meteorologic stations for the Orljava River basin is inadequate for hydrologic model calibration; however, the results show a reasonable calibration for the selected events. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred does not get or is not completely recorded at the surrounding gauges. This limitation was not necessarily evident during the hydrologic model calibration process. In the future, the network of precipitation gauges should be expanded for this basin and/or a radar-based gridded precipitation dataset should be acquired and incorporated into the model.

In general, other than the meteorologic station issue, no major challenges were encountered during the Orljava River watershed HEC-HMS model development.

4.9.6 CALIBRATION RESULTS AND DISCUSSION

The Orljava River watershed HEC-HMS model calibration quality is very good based on the performance metrics, and the model performs well across a large range of events and seasons. This outcome is surprising considering the lack of meteorologic stations for the basin, and the same level of accuracy should not necessarily be expected for future simulations of this model. Figure 75 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of gauges in the basin.

Figure 76 - Figure 77 and Table 43 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. In general, the calibration quality was relatively good for all calibration events, which implies that the precipitation was not only more accurate for these events. In most cases, model calibration quality was dependent on the accuracy and availability of precipitation data.

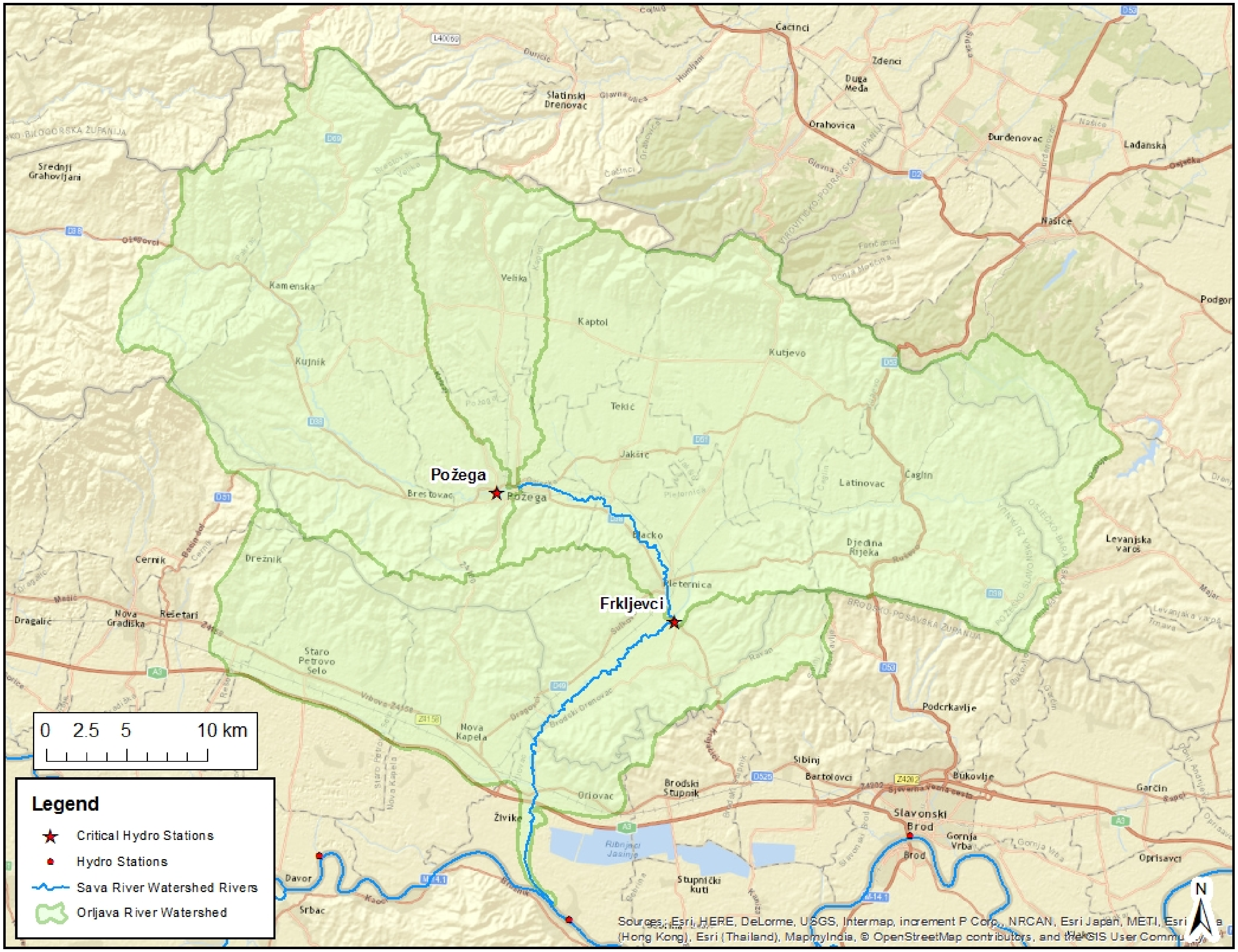


Figure 75: Hydrologic Station Map for the Orljava River Watershed

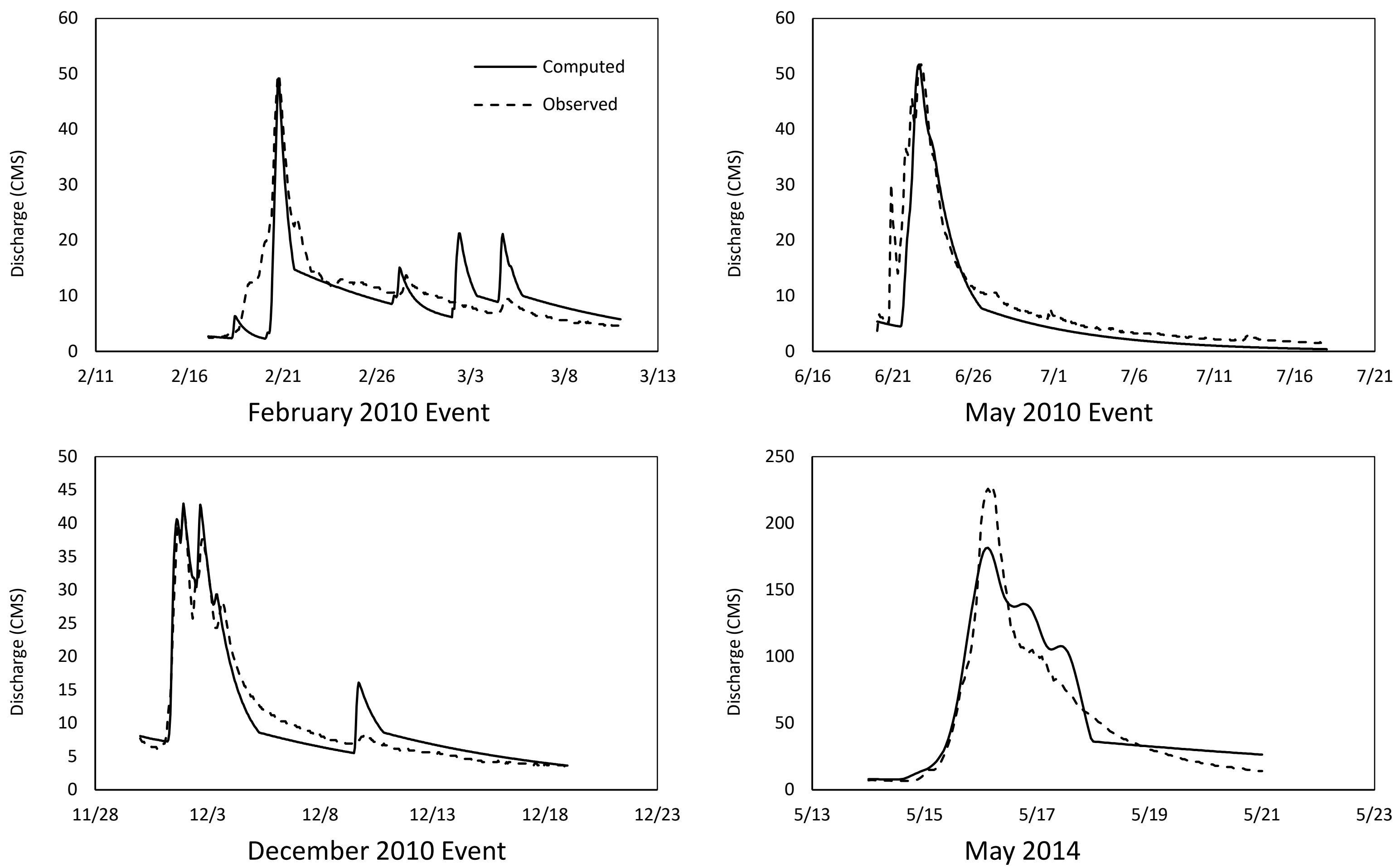


Figure 76: Calibration Plots for the Pozega Gauge for Various Calibration Events

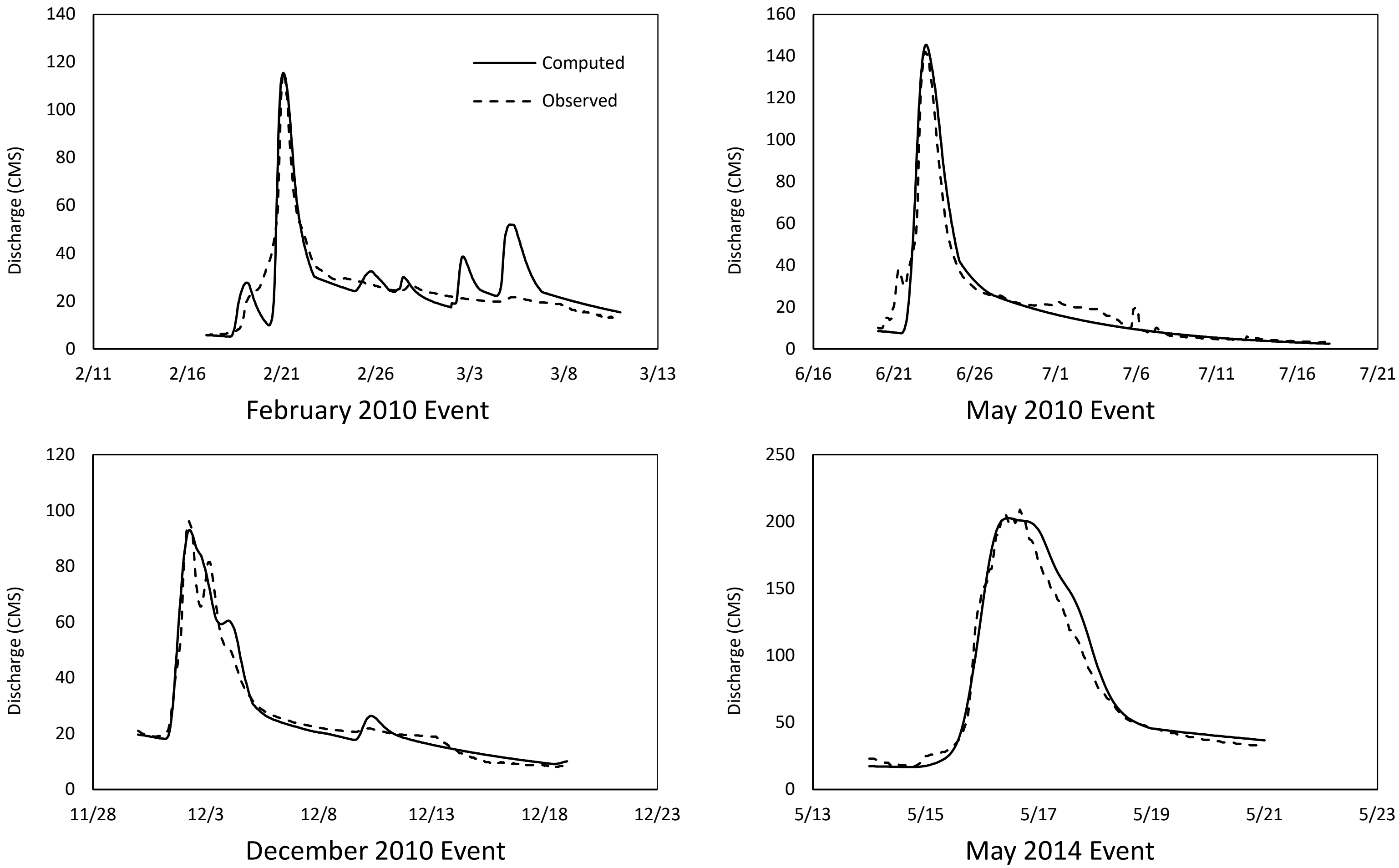


Figure 77: Calibration Plots for the Frkljevci Gauge for Various Calibration Events

Table 43: Orljava River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Pozega	Feb 2010	50	34	49	26	-1.4%	-24.7%	0.628
	May 2010	52	46	52	36	0.0%	-23.3%	0.857
	Dec 2010	42	39	43	39	3.6%	2.1%	0.930
	May 2014	227	73	182	80	-20.0%	9.3%	0.906
Frkljevci	Feb 2010	116	28	116	27	-0.4%	-4.1%	0.867
	May 2010	142	43	145	41	2.4%	-2.8%	0.928
	Dec 2010	96	34	93	35	-3.1%	2.7%	0.953
	May 2014	209	37	203	39	-3.0%	5.6%	0.968

4.10 UKRINA RIVER WATERSHED

4.10.1 BASIN DESCRIPTION

The Ukrina River is a relatively small drainage basin within Bosnia and Herzegovina, flowing from the confluence of the Lukavac and Bistrica near the village of Snjegotina Srednja northeastward to its confluence with the Sava River just upstream of Slavonski Brod. The Ukrina River basin contains several tributaries of varying size and shape including: Lukavac, Bistrica, and Vijaka Rivers. The basin area is approximately 1,503 km2. The basin's topography is considered relatively steep with a maximum elevation in the headwaters of approximately 1025 masl and minimum elevation at its confluence of approximately 80 masl.

4.10.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 44 shows the representative parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Ukrina River watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 1.5 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.80 indicates that a substantial amount of attenuation occurs within the watershed, likely driven by an abundance of flatter, low-lying areas in the lower reaches of the basin.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 44: Ukrina Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	35	1.50	5.3	21.4	0.80	0.015	0.90	0.15

4.10.3 REACH ROUTING PARAMETERS

River reach routings within the Ukrina River basin were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 45 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 45: Ukrina Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_18_01_04	25028	0.0010	Trapezoid	0.040		
R_18_01_08	67179	0.0070	Trapezoid	0.040		

4.10.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Ukrina River basin was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 78 illustrates the Ukrina River basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 78 illustrates that the Ukrina River Basin has a limited number of meteorological stations covering the basin.

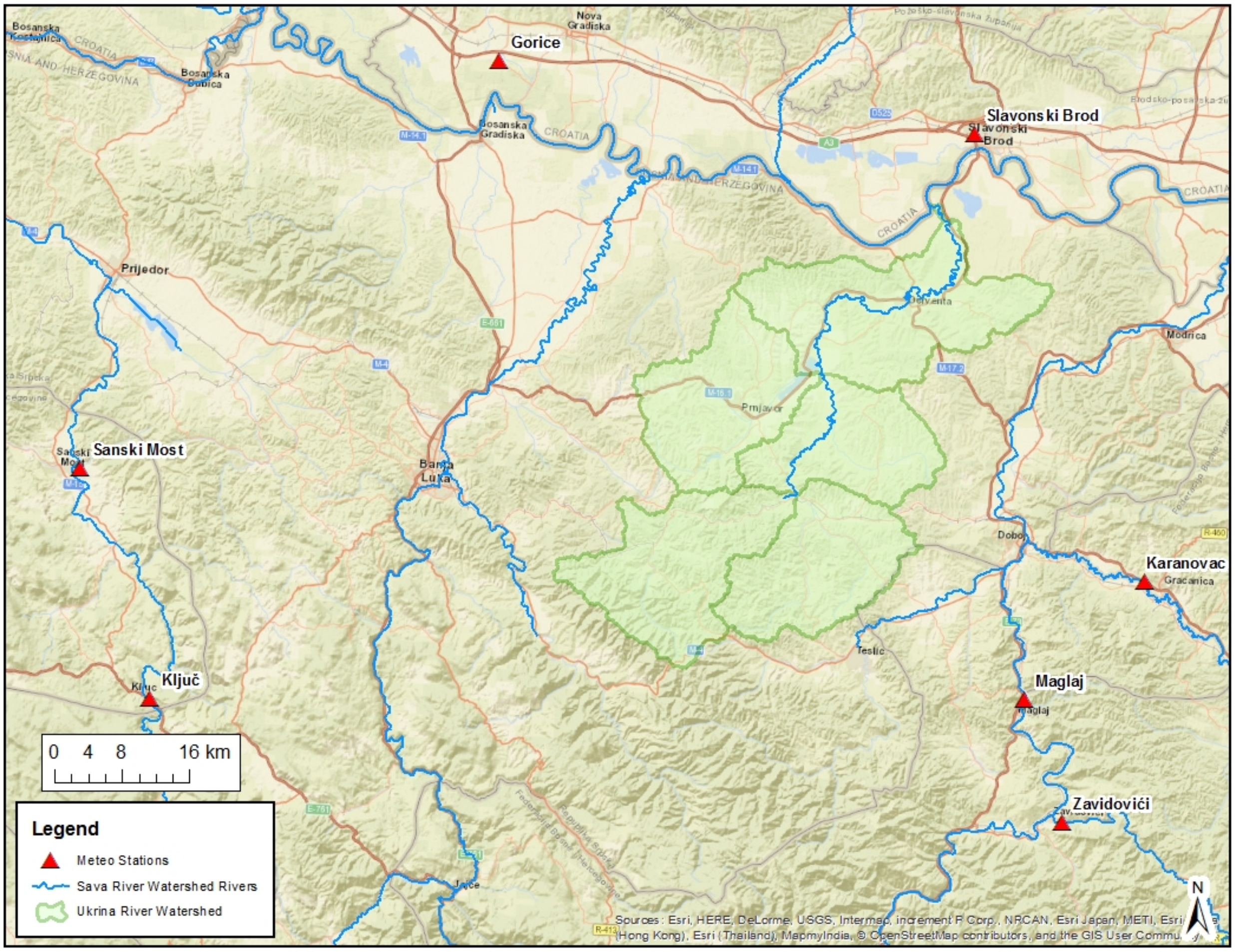


Figure 78: Meteorologic Station Map for the Ukrina River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 46 shows the average ET rates for the Ukrina River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable based on values used for other tributary basins adjacent to the Ukrina River Basin.

Table 46: Average ET Rates for the Ukrina River Watershed

Month	ET Rate (mm/month)
Jan	11.0
Feb	18.0
Mar	33.0
Apr	51.0
May	79.0
Jun	101.0
Jul	117.0
Aug	109.0
Sep	69.0
Oct	39.0
Nov	20.0
Dec	12.0

4.10.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Ukrina River watershed HEC-HMS model. Two of the most common challenges during for the Ukrina River Basin HEC-HMS model were related to observed discharge information and meteorologic data availability.

The most critical issue with hydrologic calibration of the Ukrina River Basin was the absence of any hydrologic stations providing observed discharges for calibration to events. The lack of data made it very difficult to verify the parameters used to build the HEC-HMS model for this basin; however, indirect calibration of the Ukrina River Basin was possible during the calibration of the Sava Mainstem 03 HEC-HMS model. Many of the parameters for the Ukrina hydrologic model were adjusted based on the calibration at the Slavonski Brod stream gauge located on the Sava River just downstream of the confluence between the Ukrina and Sava Rivers. This indirect calibration approach is the only means by which to calibrate this basin with the current data available; however, this approach provides a reasonable level of confidence that the delineation is at resolution necessary to derive inflows into the Sava River. In general, the Ukrina River does not provide a large inflow to the Sava River based on its smaller drainage area.

The coverage of meteorologic stations for the Ukrina River basin is generally inadequate for hydrologic model calibration (Figure 78), which reduces the confidence in the Ukrina River Basin HEC-HMS model results. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred over the Ukrina River Basin does not get or is not completely recorded at the surrounding gauges.

In general, the Ukrina River Basin hydrologic model results are inconclusive due to a lack of meteorologic and hydrologic stations within the basin; however, based on the limited influence of the inflows from the Ukrina River into the Sava River, the inadequacy of the hydrologic model does not drastically effect the results along the Sava River. As future improvements are made to the hydrologic models and more accurate results are required specifically for the Ukrina River Basin, hourly (or less) time interval recording stream gauges that rate stage to discharge and a more comprehensive meteorologic station network or a radar-based gridded precipitation data source should be incorporated to improve the confidence in the model results.

4.10.6 CALIBRATION RESULTS AND DISCUSSION

Due to the lack of hydrologic stations recording discharge within the basin, calibration results are not available for the Ukrina River Basin. As discussed in Section 4.10.5, a reasonable level of confidence in the Ukrina River Basin is provided by the indirect calibration to the Slavonski Brod stream gauge on the Sava River.

4.11 BOSNA RIVER WATERSHED

4.11.1 BASIN DESCRIPTION

The Bosna River is one of the largest rivers within Bosnia and Herzegovina, flowing from springs at the base of Mount Igman approximately 271 km northward to its confluence with the Sava River in Bosanski Samac. The Bosna River basin contains several tributaries of varying size and shape including: Fojnica, Gostovic, Krivaja, Lasva, Miljacka, Spreca, Usora, and Zeljesnica Rivers. The basin area is approximately 10,457 km2. The basin's topography is considered very steep with a maximum elevation in the headwaters of approximately 2100 masl and minimum elevation at its confluence of approximately 75 masl.

4.11.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 47 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Bosna River watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 0.66 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.75 indicates that a substantial amount of attenuation occurs within the watershed, likely driven by an abundance of flatter, low-lying areas in the lower reaches of the basin.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration is due to the meteorological model over-estimating (for large values) or under-estimating the precipitation (for small values) during certain events. As a result, constant loss rates are raised or lowered to physically unrealistic values to compensate for too

much or too little precipitation. A range of 0.6 to 38.7 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is very different throughout the watershed.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 47: Bosna Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	14	0.66	5.6	18.1	0.75	0.03	0.89	0.21
Minimum	0	0.00	0.6	0.9	0.12	0.01	0.80	0.05
Maximum	85	3.00	38.7	70.7	0.93	1.00	0.98	0.50
Standard Deviation	13	0.30	2.5	4.1	0.13	0.03	0.03	0.04

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 47 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Bosna River HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.11.3 REACH ROUTING PARAMETERS

River reach routings within the Bosna River basin were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 48 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 48: Bosna Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_20_06_03	2942	0.0027	Eight Point	0.045	0.12	0.12
R_20_06_05	559	0.0054	Eight Point	0.045	0.12	0.12
R_20_06_08	2734	0.0011	Eight Point	0.045	0.12	0.12
R_20_06_11	1295	0.0008	Eight Point	0.045	0.12	0.12
R_20_13_01	8978	0.0014	Eight Point	0.044	0.11	0.11
R_20_13_04	8361	0.0035	Eight Point	0.044	0.11	0.11
R_20_13_07	10529	0.0017	Eight Point	0.044	0.11	0.11
R_20_13_10	19512	0.0018	Eight Point	0.044	0.11	0.11
R_20_13_13	3877	0.0014	Eight Point	0.044	0.11	0.11
R_20_13_16	16477	0.0017	Eight Point	0.044	0.11	0.11
R_20_12_04	16938	0.0042	Eight Point	0.045	0.12	0.12
R_20_13_19	10731	0.0025	Eight Point	0.044	0.11	0.11
R_20_15_01	23938	0.0014	Eight Point	0.045	0.08	0.08
R_20_15_04	26877	0.0021	Eight Point	0.045	0.12	0.12
R_20_19_01	3693	0.0011	Eight Point	0.045	0.12	0.12
R_20_17_01	26028	0.0053	Eight Point	0.045	0.12	0.12
R_20_17_04	19677	0.0059	Eight Point	0.045	0.12	0.12
R_20_17_07	27853	0.0025	Eight Point	0.045	0.12	0.12
R_20_19_04	22457	0.0013	Eight Point	0.045	0.12	0.12
R_20_19_07	5503	0.0007	Eight Point	0.045	0.12	0.12
R_20_19_11	20238	0.0011	Eight Point	0.045	0.12	0.12
R_20_20_03	219	0.0046	Eight Point	0.045	0.12	0.12
R_20_20_06	7482	0.0024	Eight Point	0.045	0.12	0.12
R_20_19_12	7088	0.0021	Eight Point	0.045	0.12	0.12
R_20_19_15	5043	0.0018	Eight Point	0.045	0.12	0.12
R_20_19_19	6822	0.0012	Eight Point	0.045	0.12	0.12
R_20_19_23	4806	0.0008	Eight Point	0.045	0.12	0.12
R_20_21_04	16428	0.0013	Eight Point	0.045	0.12	0.12
R_20_21_08	48290	0.0006	Eight Point	0.045	0.12	0.12
R_20_19_24	23957	0.0005	Eight Point	0.045	0.12	0.12
R_20_19_28	30740	0.0007	Eight Point	0.045	0.12	0.12
R_20_19_31	56668	0.0007	Eight Point	0.045	0.12	0.12

4.11.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Bosna River basin was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 79 illustrates the Bosna River basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 79 illustrates that the Bosna River Basin has a reasonable number of meteorological stations covering the basin, with the exception of the western portion of the basin, where very few meteorological stations exist as discussed in Section 4.11.2.

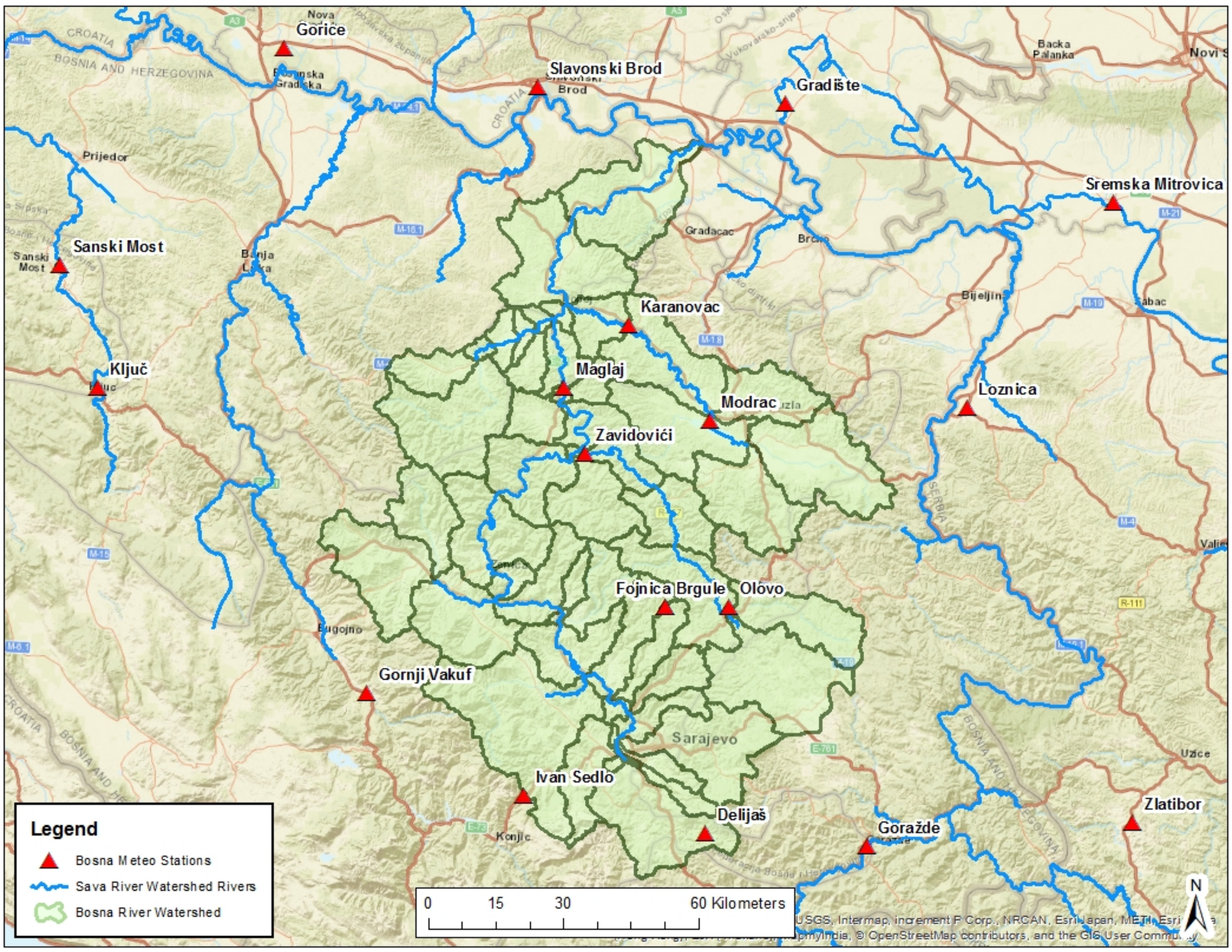


Figure 79: Meteorologic Station Map for the Bosna River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 49 shows the average ET rates for the Bosna River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the

values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 49: Average ET Rates for the Bosna River Watershed

Month	ET Rate (mm/month)
Jan	0.1
Feb	0.3
Mar	1.1
Apr	2.5
May	4.4
Jun	101.0
Jul	110.1
Aug	102.8
Sep	66.3
Oct	26.7
Nov	7.6
Dec	0.2

4.11.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Bosna River watershed HEC-HMS model. Two of the most common challenges during this study were related to subbasin delineation and meteorologic data availability.

The development of the Bosna River subbasin delineation relied heavily on the SRTM DEM and a subbasin delineation ESRI shapefile provided by the ISRBC at the 100 km^2 scale. Due to the quality of the subbasin delineation shapefile and the steep topography of the watershed, which reduces the effect of a lower quality DEM, the delineation is acceptable; however, delineation in some areas could be improved with better information such as a higher quality DEM. Based on discussions with the ISRBC, areas of karst features can influence the flow paths within the watershed and in turn, can affect the delineation. Karst issues, as it relates to subbasin delineation, were minimal and were easily modified using the subbasin delineation shapefile provided by the ISRBC.

Delineation was a challenge in the headwaters of the basin near Sarajevo. The subbasins in this area were delineated at a higher resolution than in other areas of the basin to take advantage of the numerous hydrologic gauges available in the vicinity, The drainage areas for the subsequent subbasins were smaller than the resolution of the delineation shapefile provided; therefore assumptions about the delineation boundary were made. The delineation assumptions in this area are reasonably acceptable based on the calibration results of the model; however, future improvement to this model should consider better information to verify and/or improve the delineation in this area.

The coverage of meteorologic stations for the Bosna River basin is generally adequate for hydrologic model calibration; however, as seen in Figure 79, western portions of the basin lack sufficient gauge coverage. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred does not get or is not completely recorded at the surrounding gauges. This limitation was evident during the hydrologic model calibration process where model results at the western Merdani and Kalosevici gauges did not compare as accurately to observed discharge data as the rest of the watershed for certain calibration events.

In addition to some of the issues described above, Modrac Dam lies in the headwaters of the Bosna River basin on Spreca River. Modrac Dam is primarily used for municipal drinking water supply and production of hydropower. The ISRBC requested that Modrac Dam be included in the HEC-HMS development and provided the elevation-storage curve and time-series outflow data for the dam, which was used as a source of inflow into the hydrologic network as observed data during the various calibration events.

Specific information about the outlet works of Modrac Dam was limited for this study; however, based on information provided by the ISRBC and collected through the internet, Modrac Dam consists of three overflow spillways and three low-level gated orifice outlets. A reservoir node was also included in the HEC-HMS model by deriving various physical characteristics of the dam, such as dam top, spillway, and orifice outlet elevations, spillway lengths, and orifice diameters, from information provided by the ISRBC and found on the internet.

The top of dam elevation and gated orifice outlet invert elevations were assumed to be 205 masl and 186 masl, respectively, based on the information provided in the elevation-storage curve. Aside from the information provided in the elevation-storage curve for the reservoir, all other physical characteristics for the Modrac dam were derived from photographs available in Google Earth. The spillway elevations were assumed to be 197 masl as scaled from photographs, and the spillway lengths were assumed to be 18 m long as measured within Google Earth. The areas for the gated orifice outlets were back calculated using the maximum outflow and head at the maximum outflow using the time series outflow data provided by the ISRBC. The orifice area calculated was 1.4 m^2.

This discussion shows that most of the physical parameters derived for Modrac Dam are only roughly assumed and further collection of data should be conducted to improve these assumptions. In addition, HEC-HMS is not a suitable software for simulating user-operated structures like Modrac Dam; however, this effort ensures that the HEC-HMS model is capable of providing inputs into software more suitable for simulating flow through user-operated structures.

In general, other than the aforementioned minor issues, no major challenges were encountered during the Bosna River watershed HEC-HMS model development.

4.11.6 CALIBRATION RESULTS AND DISCUSSION

The Bosna River watershed HEC-HMS model calibration quality is very good based on the performance metrics, and the model performs well across a large range of events and seasons. Figure 80 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of gauges in the basin. Due to the large number of available gauges, only the gauges deemed most representative of the calibration, represented with red stars, are reported in this document. The calibration results at these critical gauges, shown in Figure 81 - Figure 88, illustrate the successful calibration of the system.

Figure 81 - Figure 88 and Table 50 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. In general, the calibration quality was highest for the November-December 2010, February 2013, and May 2014 events, which implies that the precipitation was not only more accurate for these events but also that the location of the available meteorologic stations better captured the spatial and temporal distribution of the storm event. In most cases, model calibration quality was dependent on the accuracy and availability of precipitation data. For gauges in areas of the basin with fewer available meteorological stations, such as the Merdani and Kalosevici gauges, there was a higher variability in calibration quality between storm events.

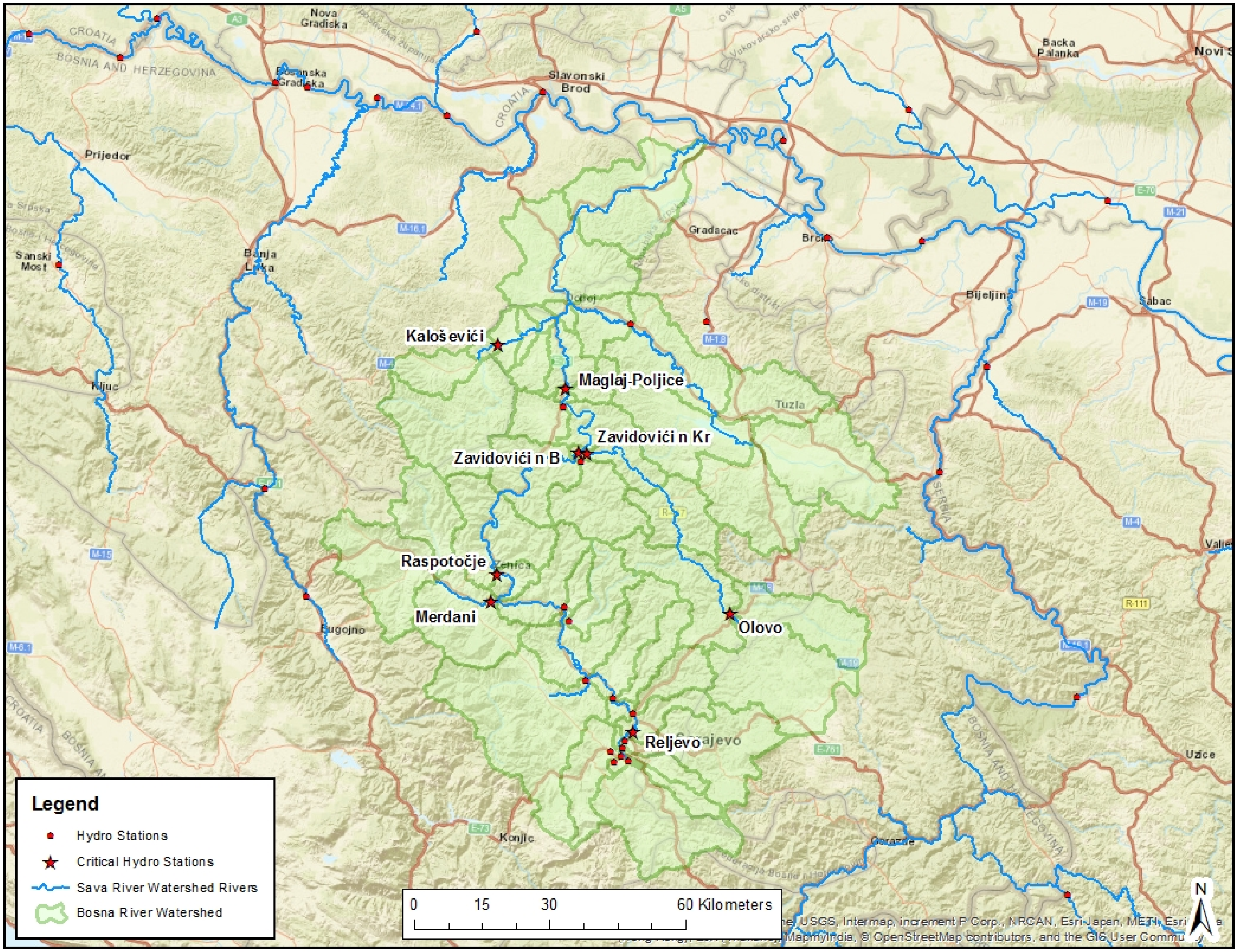


Figure 80: Hydrologic Station Map for the Bosna River Watershed

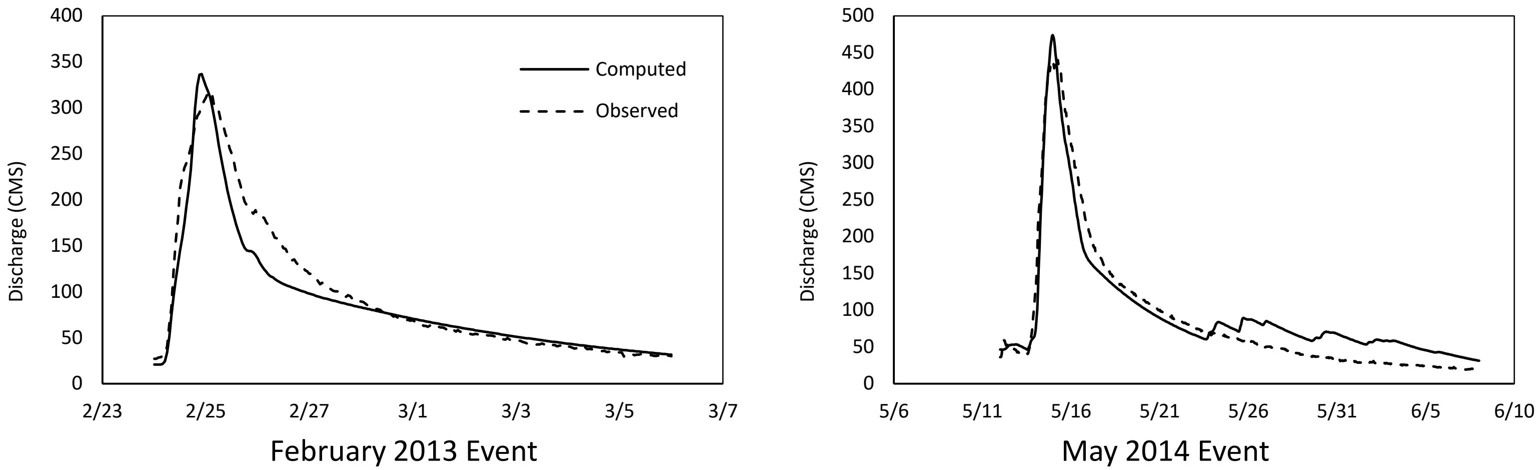


Figure 81: Calibration Plots for the Reljevo Gauge for Various Calibration Events

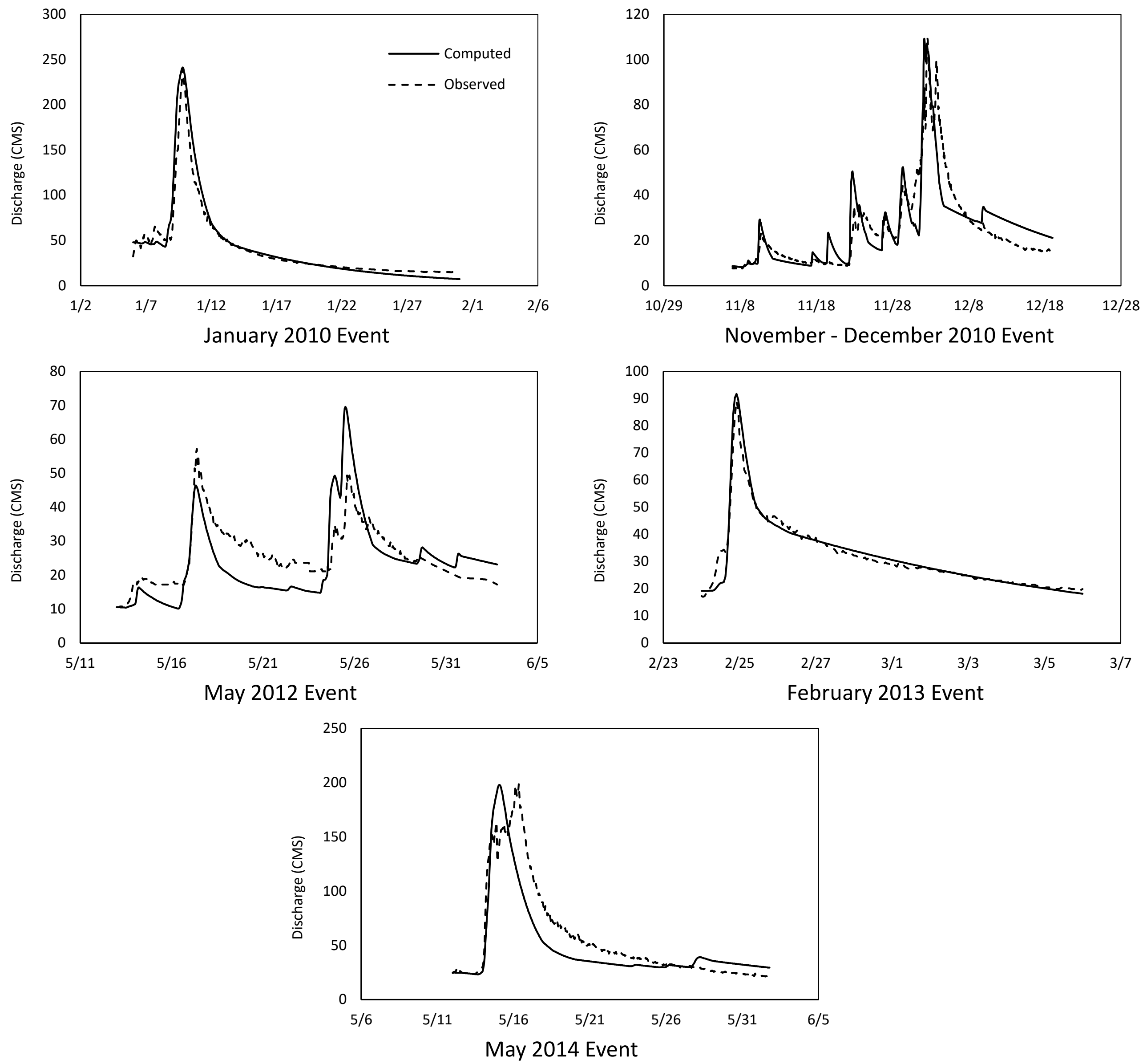


Figure 82: Calibration Plots for the Merdani Gauge for Various Calibration Events

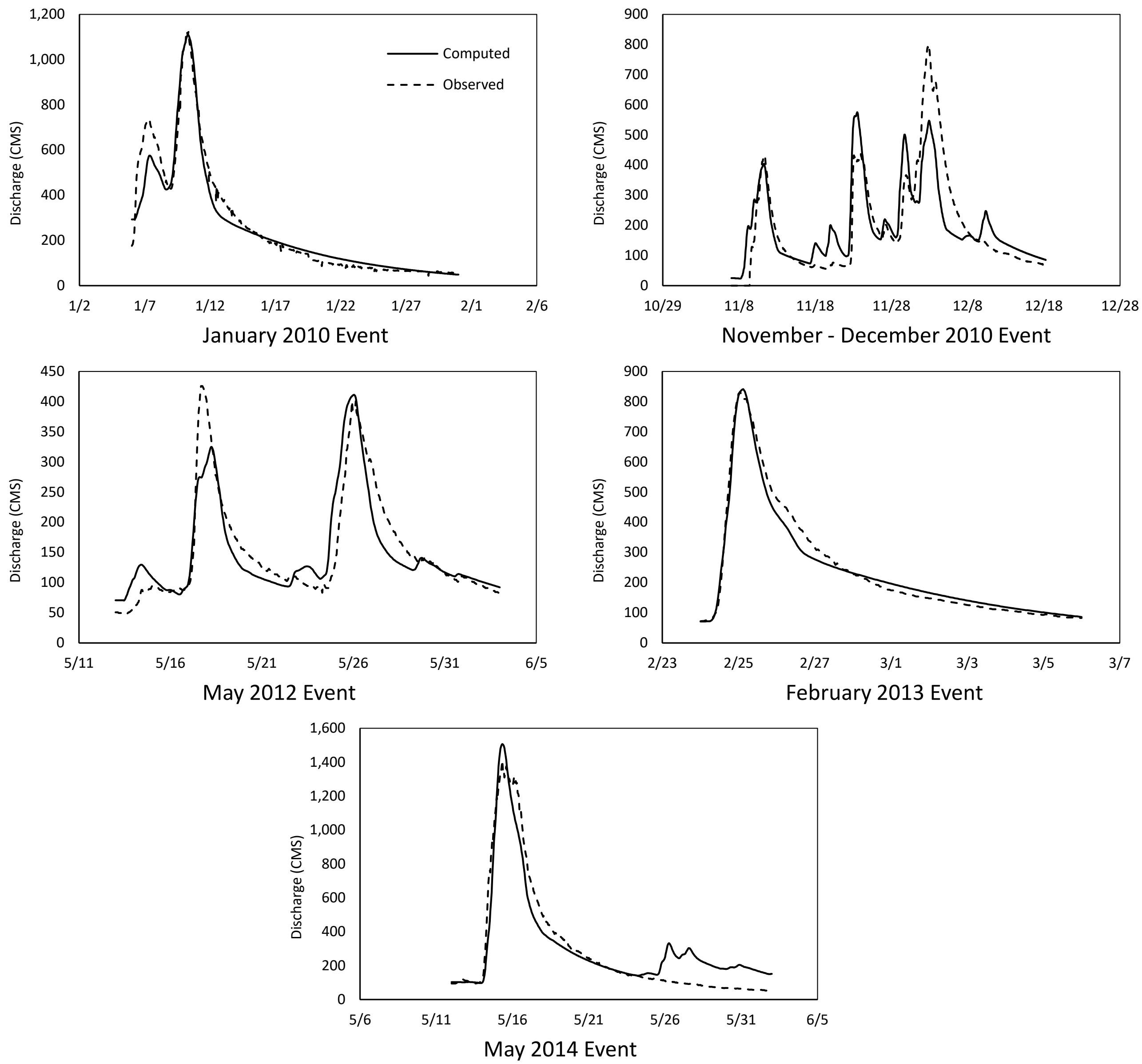


Figure 83: Calibration Plots for the Raspotocje Gauge for Various Calibration Events

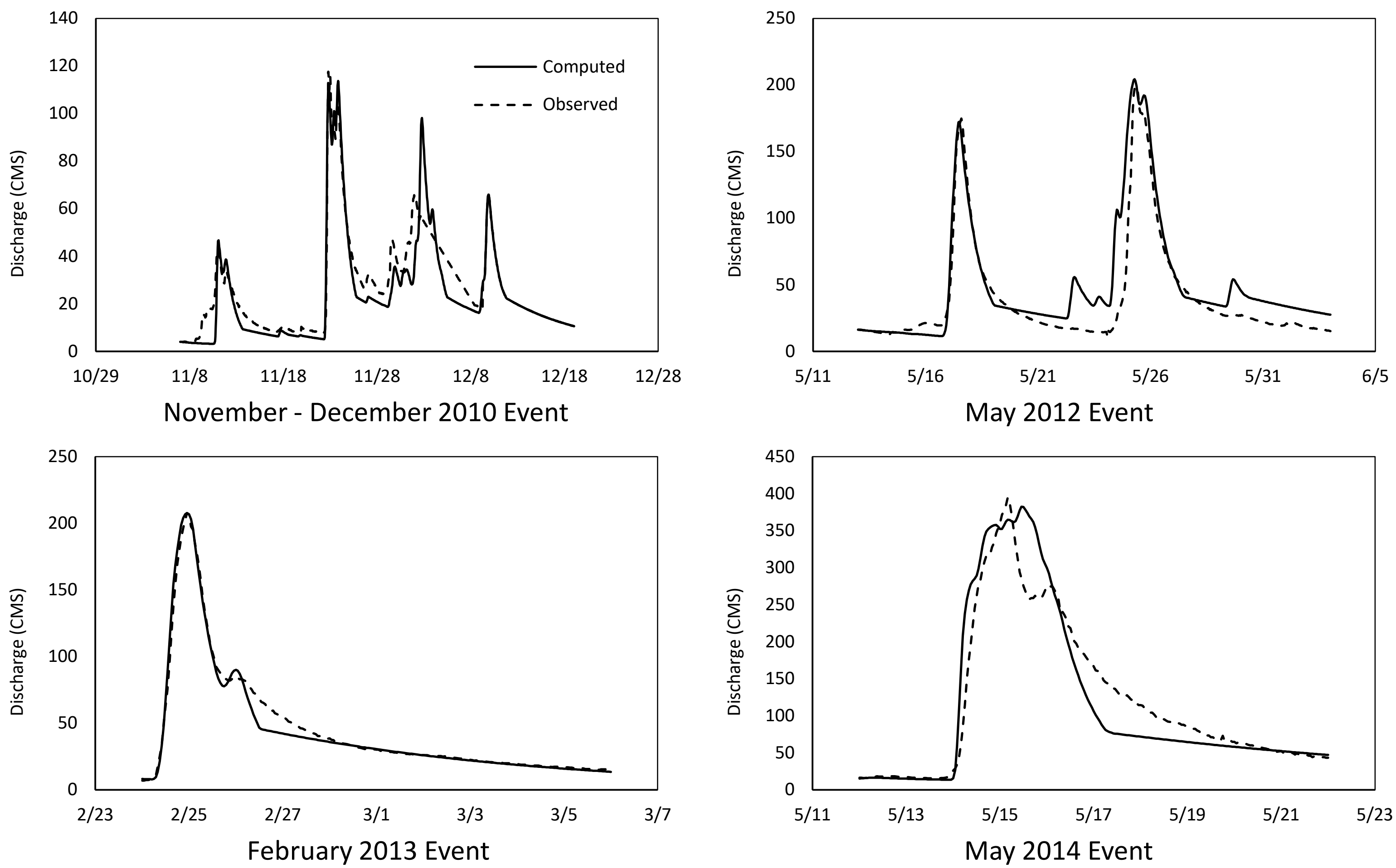


Figure 84: Calibration Plots for the Olovo Gauge for Various Calibration Events

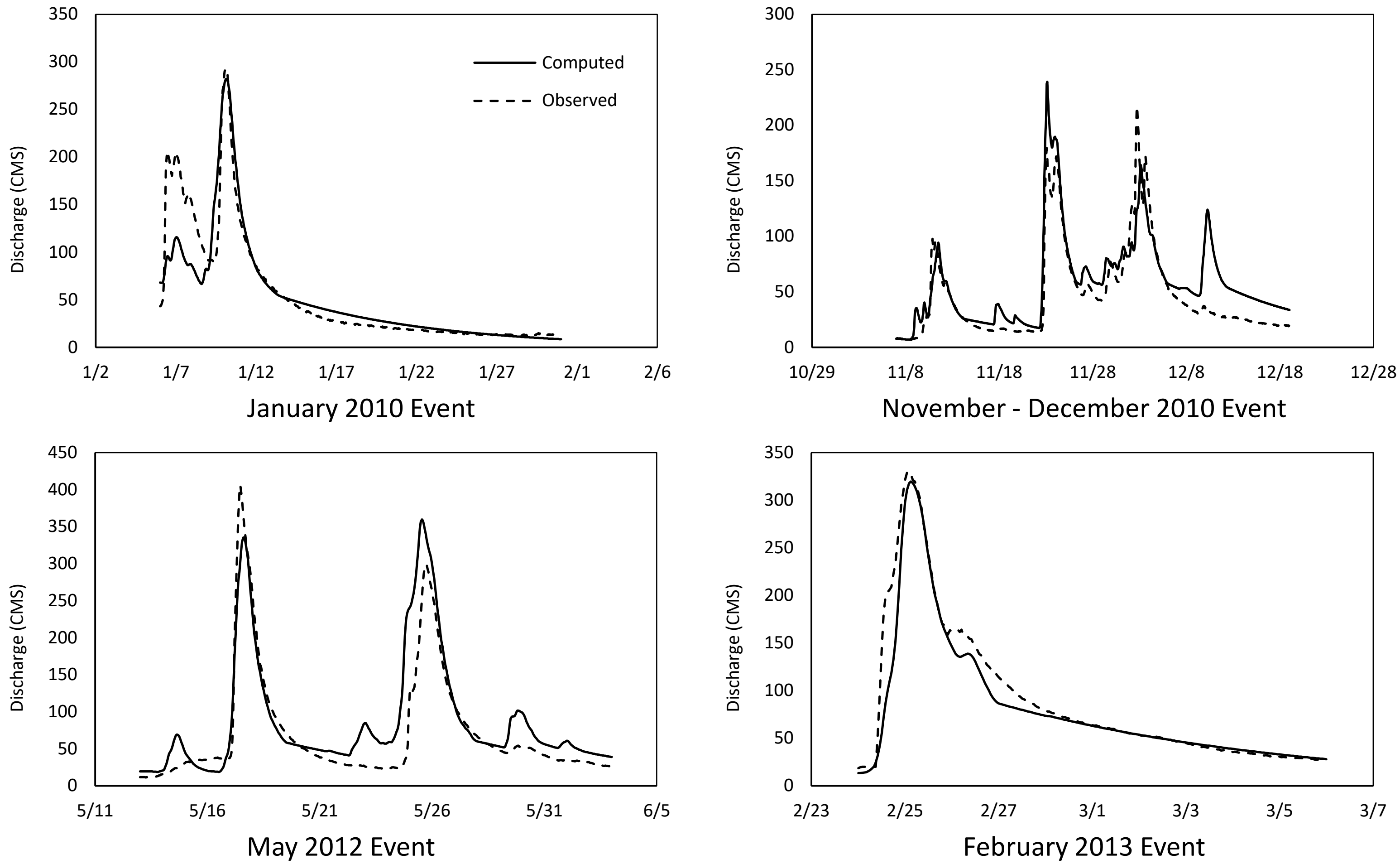


Figure 85: Calibration Plots for the Zavidovici n Kr Gauge for Various Calibration Events

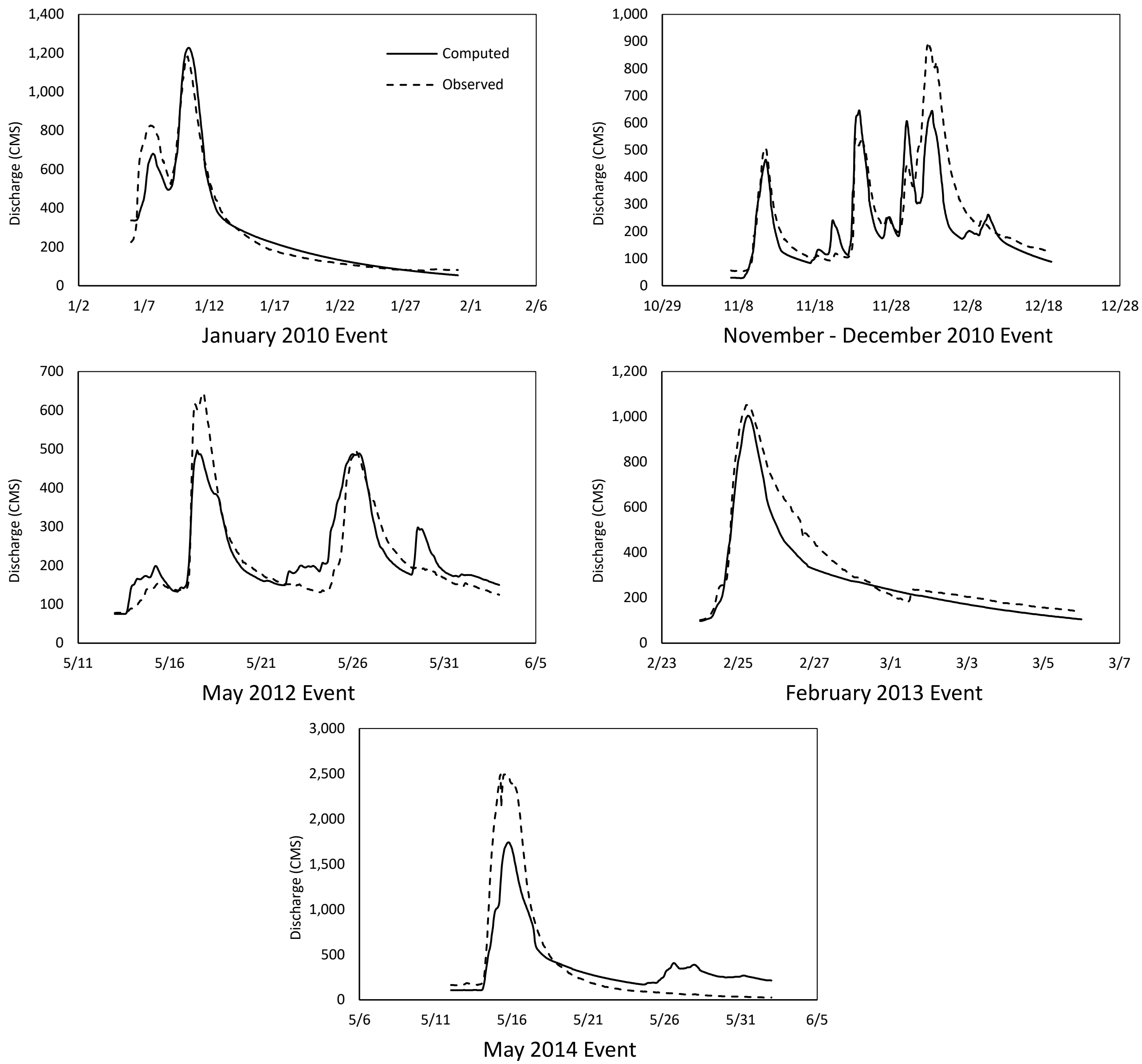


Figure 86: Calibration Plots for the Zavidovici n B Gauge for Various Calibration Events

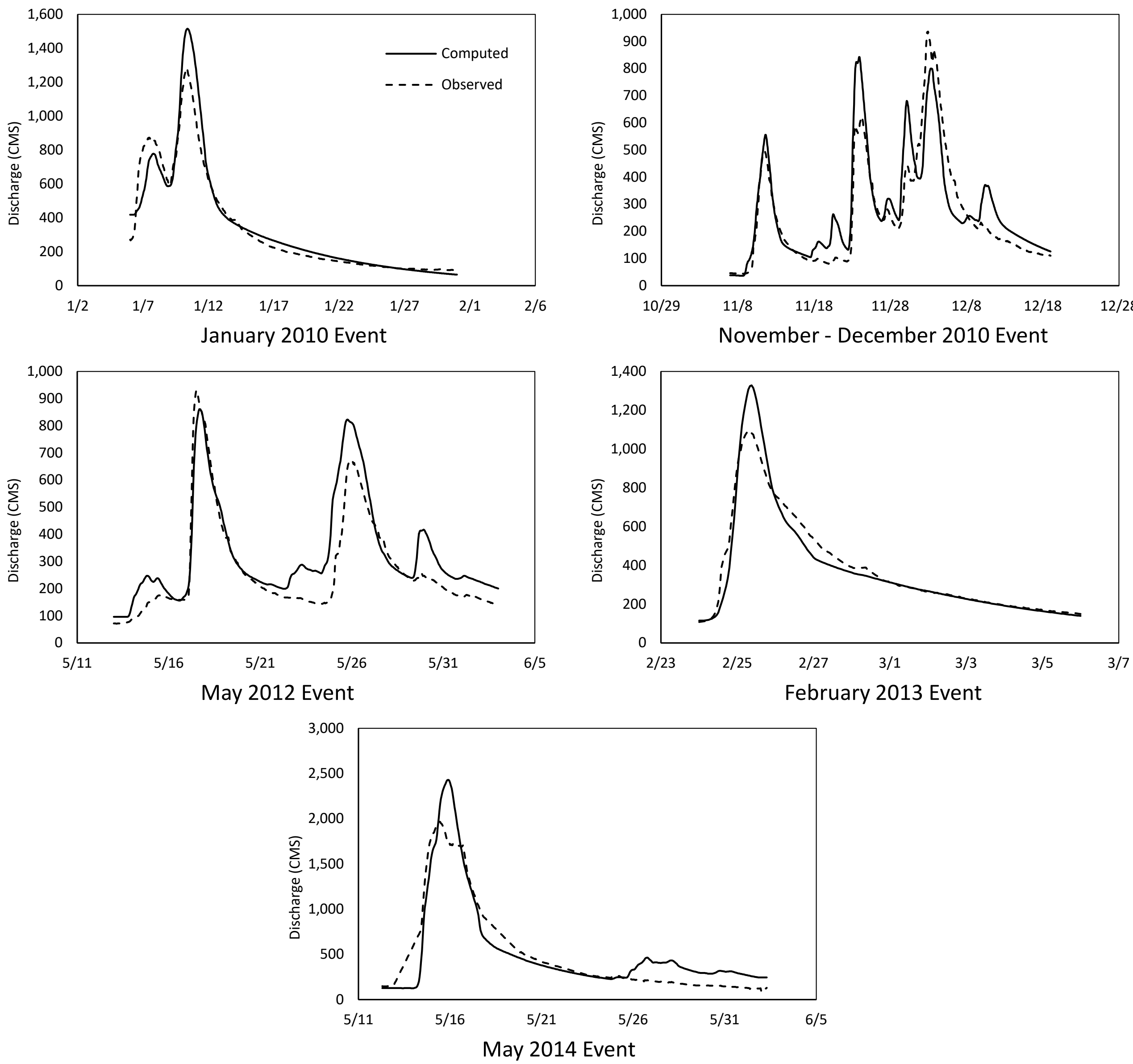


Figure 87: Calibration Plots for the Maglaj-Poljice Gauge for Various Calibration Events

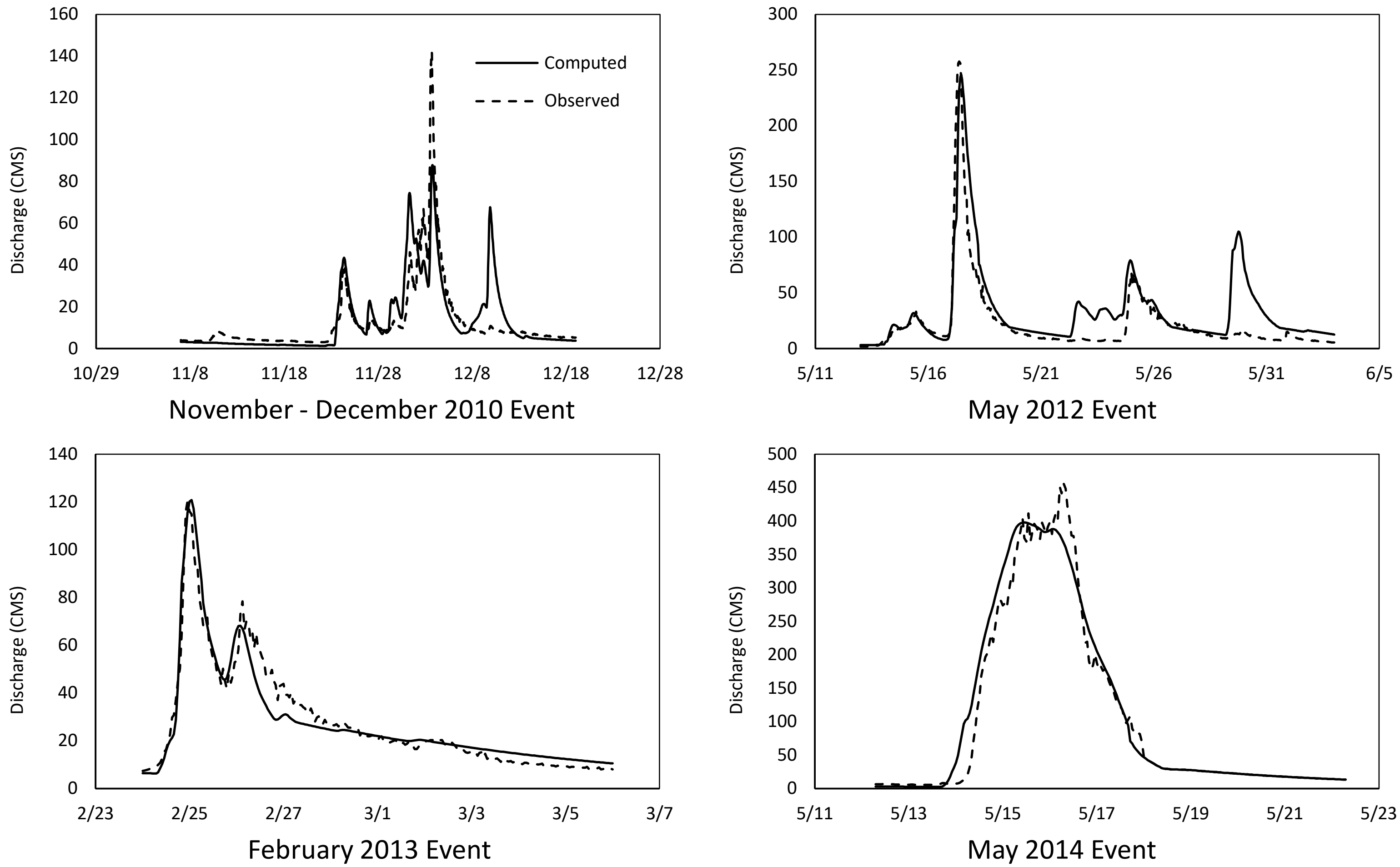


Figure 88: Calibration Plots for the Kalosevici Gauge for Various Calibration Events

Table 50: Bosna River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Reljevo	Feb 2013	317	71	339	65	6.8%	-8.2%	0.924
	May 2014	440	178	474	189	7.8%	6.0%	0.940
Merdani	Jan 2010	240	93	241	96	0.7%	2.9%	0.927
	Nov/Dec 2010	110	94	109	97	-0.4%	3.2%	0.754
	May 2012	57	48	70	45	21.7%	-6.9%	0.104
	Feb 2013	89	29	92	29	3.3%	-0.3%	0.951
	May 2014	199	117	198	106	-0.4%	-9.2%	0.780
Raspotocje	Jan 2010	1126	138	1108	132	-1.6%	-4.1%	0.949
	Nov/Dec 2010	798	236	576	171	-27.9%	-27.5%	0.694
	May 2012	426	66	411	65	-3.5%	-1.6%	0.799
	Feb 2013	833	50	841	49	1.0%	-1.4%	0.979
	May 2014	1412	134	1507	156	6.7%	16.6%	0.892
Olovo	Nov/Dec 2010	118	99	114	108	-3.4%	9.1%	0.842
	May 2012	198	90	204	112	3.0%	24.4%	0.786
	Feb 2013	208	49	208	47	0.0%	-4.1%	0.981
	May 2014	395	170	383	172	-3.0%	1.2%	0.906
Zavidovici n Kr	Jan 2010	293	79	264	68	-9.9%	-14.2%	0.786
	Nov/Dec 2010	217	115	238	131	9.7%	14.3%	0.673
	May 2012	406	87	359	108	-11.6%	24.2%	0.751
	Feb 2013	329	52	313	46	-4.8%	-11.8%	0.903
Zavidovici n B	Jan 2010	1183	126	1187	120	0.4%	-4.5%	0.928
	Nov/Dec 2010	897	188	648	162	-27.8%	-14.1%	0.672
	May 2012	643	78	494	78	-23.2%	0.5%	0.776
	Feb 2013	1052	57	1048	50	-0.3%	-11.7%	0.937
	May 2014	2493	116	2372	157	-4.9%	34.9%	0.870
Maglaj-Poljice	Jan 2010	1277	108	1446	107	13.3%	-0.3%	0.918
	Nov/Dec 2010	936	139	850	151	-9.2%	8.4%	0.757
	May 2012	931	72	836	85	-10.3%	18.0%	0.751
	Feb 2013	1096	49	1370	48	25.0%	-0.4%	0.922
	May 2014	1970	143	2438	156	23.7%	8.8%	0.859
Kalosevici	Nov/Dec 2010	142	71	88	74	-38.0%	4.2%	0.605
	May 2012	258	63	246	94	-4.7%	49.2%	0.572
	Feb 2013	120	38	121	37	0.8%	-2.6%	0.926
	May 2014	456	129	398	198	-12.7%	53.5%	0.970

4.12 TINJA RIVER WATERSHED

4.12.1 BASIN DESCRIPTION

The Tinja River is a relatively small river within Bosnia and Herzegovina, bound by the Bosna and Drina River Basins flowing northward through Srebrenik to its confluence with the Sava River near Gorice. The Tinja River basin contains several small tributaries of varying size and shape including: the Mala Tinja, Tinjica, Bukovac, Lukavac, and Lomnica Rivers. The basin area is approximately 905 km^2. The basin's topography is considered less steep with a maximum elevation in the headwaters of approximately 820 masl and minimum elevation at its confluence of approximately 75 masl.

4.12.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 51 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Tinja River watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 0.88 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.72 indicates that a reasonable amount of attenuation occurs within the watershed, likely driven by an abundance of flatter, low-lying areas in the lower reaches of the basin.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration (specifically for the calibration events requiring a 0.0 mm/hr constant rate) is due to the meteorological model under-estimating the precipitation (for small values) during certain events. As a result, constant loss rates are lowered to physically unrealistic values to compensate for too little precipitation. A range of 1.6 to 5.0 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is fairly consistent throughout the watershed.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 51: Tinja Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	14	0.88	3.3	11.3	0.72	0.00	0.90	0.10
Minimum	5	0.00	1.6	0.5	0.14	0.00	0.90	0.10
Maximum	15	1.00	5.0	19.9	0.80	0.00	0.90	0.10
Standard Deviation	1	0.04	0.2	0.2	0.19	0.00	0.00	0.00

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 51 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Tinja River HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.12.3 REACH ROUTING PARAMETERS

River reach routings within the Tinja River basin were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 52 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 52: Tinja Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_08_03_01	18947	0.0030	Trapezoid	0.040		
R_08_03_02	37285	0.0010	Trapezoid	0.040		
R_08_03_06	8865	0.0006	Trapezoid	0.040		

4.12.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Tinja River basin was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 89 illustrates the Tinja River basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 89 illustrates that the Tinja River Basin has a limited number of meteorological stations covering the basin, which could result in inaccurate estimations of precipitation.

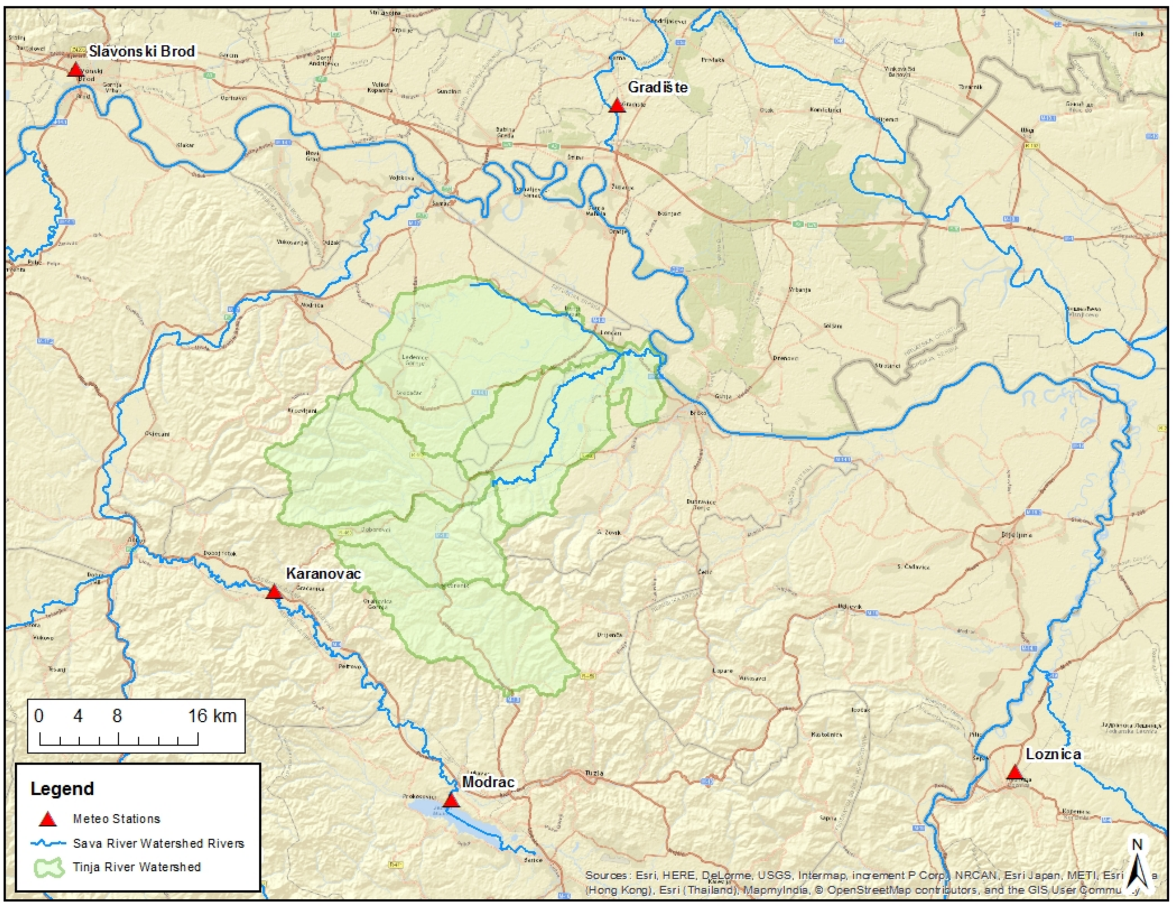


Figure 89: Meteorologic Station Map for the Tinja River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 53 shows the average ET rates for the Tinja River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the

values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 53: Average ET Rates for the Tinja River Watershed

Month	ET Rate (mm/month)
Jan	11.0
Feb	18.0
Mar	33.0
Apr	51.0
May	79.0
Jun	101.0
Jul	117.0
Aug	109.0
Sep	69.0
Oct	39.0
Nov	20.0
Dec	12.0

4.12.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Tinja River watershed HEC-HMS model. The greatest challenge during this study was related to meteorologic data availability.

The coverage of meteorologic stations for the Ilova River basin is generally inadequate for hydrologic model calibration, and, as seen in Figure 89, additional station coverage could better represent precipitation in the basin. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred does not get or is not completely recorded at the surrounding gauges. In the future, the network of precipitation gauges should be expanded for this basin and/or a radar-based gridded precipitation dataset should be acquired and incorporated into the model.

In general, other than the meteorologic station issue, no other major challenges were encountered during the Ilova River watershed HEC-HMS model development.

4.12.6 CALIBRATION RESULTS AND DISCUSSION

The Tinja River watershed HEC-HMS model calibration quality is relatively good based on the performance metrics, and the model performs well across a large range of events and seasons. Figure 90 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of gauges in the basin.

Figure 91 and Table 54 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. In general, the calibration quality is reasonable for all of the calibration events, which implies that the precipitation was relatively accurate for these events but also that the location of the available meteorologic stations better captured the spatial and temporal distribution of the storm event. The results of the calibration are actually better than would be expected considering the meteorologic station coverage; therefore, special attention should be paid to future simulations for this basin model. Ultimately, the Tinja River Basin does not dramatically influence discharges on the Sava River so limitations in this model are less significant when focused on the Sava River.

Figure 90: Hydrologic Station Map for the Tinja River Watershed

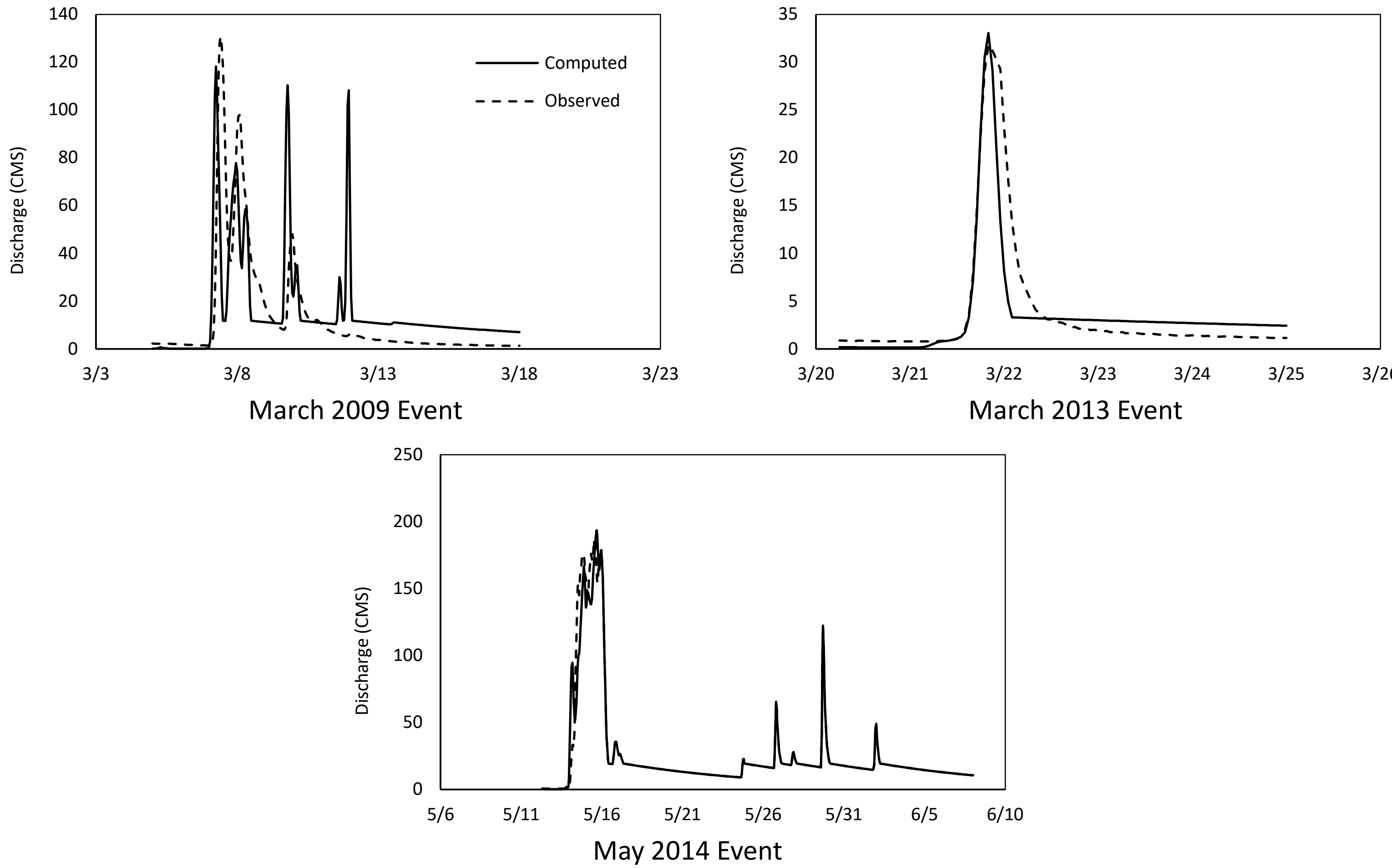


Figure 91: Calibration Plots for the Srebrenik Gauge for Various Calibration Events

Table 54: Tinja River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Srebrenik	Mar 2009	131	86	118	104	-9.6%	20.6%	0.147
	Mar 2013	32	9	33	8	3.8%	-6.7%	0.808
	May 2014	187		194		3.7%		0.936

4.13 DRINA RIVER WATERSHED

4.13.1 BASIN DESCRIPTION

The Drina River is the longest tributary to the Sava River and forms portions of the border between Bosnia and Herzegovina and Serbia. The headwaters of the Drina River are formed by the Piva and Tara Rivers originating in Montenegro. The basin area is approximately 19,713 km^2. The basin consists of numerous tributaries of varying shape and size with most of the population within the watershed residing near the Drina River where the terrain is more hospitable.

The basin's topography is considered very steep with a maximum elevation in the headwaters of approximately 2550 masl and minimum elevation of approximately 70 masl. The terrain of the Drina River Watershed is mountainous in the headwaters, especially in comparison to the lower sections of the watershed where the floodplain is very broad and flat.

4.13.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 55 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Drina River Watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 1.17 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.66 indicates that a normal amount of attenuation occurs within the watershed, with less attenuation in the headwaters and more attenuation in the flatter, low-lying areas of the lower reaches of the basin.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration is due to the meteorological model over-estimating (for large values) or under-estimating the precipitation (for small values) during certain events.

As a result, constant loss rates are raised or lowered to physically unrealistic values to compensate for too much or too little precipitation. A range of 1 to 47 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is very different throughout the watershed.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 55: Drina Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	6	1.17	11.7	23.1	0.66	0.04	0.92	0.27
Minimum	0.00	0.75	1.0	1.0	0.00	0.01	0.90	0.20
Maximum	50.00	2.50	46.9	75.0	0.75	0.25	0.98	0.55
Standard Deviation	7	0.21	0.6	1.0	0.10	0.04	0.01	0.01

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 55 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Drina River Watershed HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.13.3 REACH ROUTING PARAMETERS

River reach routings within the Drina River Watershed were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 56 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 56: Drina Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n
R_24_01_03	46301	0.0017	Trapezoidal	0.027
R_24_02_01	35277	0.0012	Trapezoidal	0.023
R_24_02_04	9547	0.0033	Trapezoidal	0.023
R_24_03_03	55550	0.0022	Trapezoidal	0.023
R_24_03_06	9990	0.0131	Trapezoidal	0.023
R_24_03_10	24960	0.0013	Trapezoidal	0.023
R_24_03_11B	92400	0.0033	Trapezoidal	0.023
R_24_03_14	45334	0.0007	Trapezoidal	0.023
R_24_03_18	15875	0.0033	Trapezoidal	0.023
R_24_03_19	13168	0.0026	Trapezoidal	0.023
R_24_03_22	19378	0.0035	Trapezoidal	0.023
R_24_03_25A	9110	0.0047	Trapezoidal	0.023
R_24_03_25B	45705	0.0007	Trapezoidal	0.023
R_24_03_29	43926	0.0005	Trapezoidal	0.023
R_24_03_33	8565	0.0007	Trapezoidal	0.023
R_24_03_36	3826	0.0058	Trapezoidal	0.023
R_24_03_37B	42800	0.0087	Trapezoidal	0.023
R_24_03_40	54336	0.0002	Trapezoidal	0.023
R_24_04_01	97875	0.0009	Trapezoidal	0.023
R_24_04_05	5137	0.0021	Trapezoidal	0.023
R_24_04_09	13034	0.0001	Trapezoidal	0.023
R_24_04_12	7971	0.0014	Trapezoidal	0.023
R_24_04_15	43744	0.0006	Trapezoidal	0.023
R_24_04_18	48615	0.0003	Trapezoidal	0.023

4.13.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Drina River Watershed was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 92 illustrates the Drina River Watershed basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 92 illustrates that the headwaters of the Drina River Watershed has a reasonable number of meteorological stations covering the basin, whereas the lower portions of the basin have a more limited gauge coverage.

Figure 92: Meteorologic Station Map for the Drina River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 57 shows the average ET rates for the Drina River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 57: Average ET Rates for the Drina River Watershed

Month	ET Rate (mm/month)
Jan	5.9
Feb	7.9
Mar	20.9
Apr	40.3
May	79.3
Jun	100.4
Jul	109.6
Aug	101.8
Sep	70.7
Oct	37.9
Nov	13.8
Dec	7.0

4.13.5 BASIN SPECIFIC TOPICS

The primary issues that caused difficulty during the hydrologic model calibration process of the Drina River were the incorporation of numerous reservoirs, problems with precipitation timing and intensity for certain storm events, and basin delineation discrepancies stemming from karst limestone features and lack of resolution in the existing delineation shapefiles provided by the ISRBC for the Drina River Basin.

The development of the Drina River Watershed subbasin delineation relied heavily on the SRTM DEM and a subbasin delineation ESRI shapefile provided by the ISRBC at the 1000 km^2 scale. Based on discussions with the ISRBC, areas of karst features can influence the flow paths within the watershed and in turn, can affect the delineation. Karst issues, as it relates to subbasin delineation, were rectified using the subbasin delineation shapefile provided by the ISRBC as well as possible. In addition to karst-related delineation issues, the existing delineation shapefile for the Drina River basin was much less resolved than for other areas of the Sava River basin; therefore, in areas of the Drina River Basin where delineation below the 1000 km^2 threshold is required, less confidence in the final delineation should be expected. Although the delineation is acceptable for this scale of study, a higher resolution DEM or better information should be incorporated to update the current delineation in future studies where more resolution is desired.

Figure 93 shows the reservoirs that were incorporated into the Drina River hydrology model, which include: Piva; Uvac; Bistrica; Kokin Brod; Potpec; Visegrad; Bajina Basta; and Zvornik reservoirs. Data provided for the reservoir projects included an elevation storage curve up to the normal pool, or spillway invert, as well as specifications regarding the size and number of outlet works. Additionally, for some projects, observed inflow and discharge data was provided for select storm events, allowing for the dam to serve as another model calibration point. Much of the inflow and discharge data for the projects was provided as daily average values, while not ideal in comparison to hourly or sub-hourly data, it was still valuable to the calibration process. The daily average observed flow values served as calibration to particularly the timing and volume of the flood event as it moved through the reservoirs. The drawback of daily average observed data is that it is very unlikely to capture the true peak value, making it difficult to know if the hydrologic model calibrations accurately simulate the maximum flow values during calibration storm events.

All of the storm events considered during the calibration process produced maximum pool elevations that exceeded the largest given value in the elevation-storage curve provided. To remedy this issue the provided curve was extrapolated out far enough to sufficiently cover any pool elevation experienced during the calibration events. The method of extrapolation for the elevation-storage data involved fitting the existing data to a best-fit curve and projecting out to produce storage values for all necessary elevations. Due to the error associated with an extrapolation, it is recommended that a physically-based approach be used to develop the needed storage values for pool elevations above normal pool.

With the data provided, it was only possible to perform a simple hydrologic routing of flood flows through the numerous reservoir projects. Without operational information, it is difficult to accurately model discharge through the project using only the elevation-storage curve and specified outlet information. While the model does an adequate job of routing flood flows during large events, smaller events will likely require the incorporation of operational logic using software designed specifically for this purpose in order to more accurately reflect discharge. The difficulty in accurately simulating flooding events without correct operational and discharge information is especially an issue for the Drina River basin, as there are multiple successive projects that may be operated as a system during these large events.

The Drina River in the upstream, western portion of the basin leading to the Visegrad Reservoir was absent of any hydrologic stations or observed flood event hydrographs. Without observed data with which to calibrate, there is significant uncertainty regarding the hydrologic parameters adopted in that portion of the Drina River basin. Adding a hydrologic station to capture observed flows, as well as utilizing Piva Dam as a point to record discharge, should allow for a more accurate model calibration and reduce the hydrologic parameter uncertainty.

Figure 93: Reservoirs Modeled for the Drina River Watershed

4.13.6 CALIBRATION RESULTS AND DISCUSSION

The Drina River Watershed HEC-HMS model calibration quality is reasonable based upon the difficulty of simulating a multi-reservoir system through elevation-storage information and specified outlet dimensions. Figure 94 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of hydrologic stations in the basin. The calibration results at these locations are shown in Figure 95 - Figure 103.

Figure 95 - Figure 103 and Table 58 illustrate the quality of the calibration but also show the variability of quality between event simulations and at specific gauges. In most cases, model calibration quality was dependent on the accuracy and availability of precipitation data. As evident in the calibration plots, precipitation error produced significant volume errors during the May 2010 event, most notably in the portion of the basin upstream of Visegrad Dam. As shown in Figure 94, there are no hydrologic gauging stations for the western tributary leading into Visegrad Dam, an area which represents a significant

portion of the total watershed area. Additional gauges in the western headwaters and observed discharge hydrographs from Piva Dam will improve the overall calibration of the Drina River model and reduce uncertainty in the applied hydrologic modeling parameters.

As aforementioned, hourly and sub-hourly observed inflow and discharge data is preferable to daily average. While it would be beneficial to record hourly or sub hourly data at all reservoirs, prioritizing downstream projects such as Zvornik Dam would serve to not only improve the calibration of the Drina River model, but also simulate more accurate discharge into the Radalj stream gauge, thus improving the performance of the main stem Sava River hydrologic and hydraulic model as well.

It is important to note that in order to reduce residual errors in the hydrologic calibration process, for all events, once inflows to the hydrologic gages were calibrated, observed discharges were subsequently routed downstream. This prevented the compounding of model error and allowed for greater accuracy of hydrologic parameter development. This method is the reason that the volume errors found in the headwaters during the 2010 event are lessened at the downstream end of the watershed. It should be noted that while calibrating the May 2014 with this method, a discrepancy was found with regards to the discharge into and out of Zvornik Dam and at the Radalj hydrologic station. For the observed data provided, the inflow is less than the outflow for Zvornik Dam by almost half, which seems improbable. In addition, the discharge out of Zvornik Dam is greater than the observed peak flow at the Radalj gauge. This is difficult to reconcile given that Zvornik Dam is upstream of the Radalj gauge. This may be due to issues with the reported data, error with the discharge ratings for either location, or backwater effects from the Sava River.

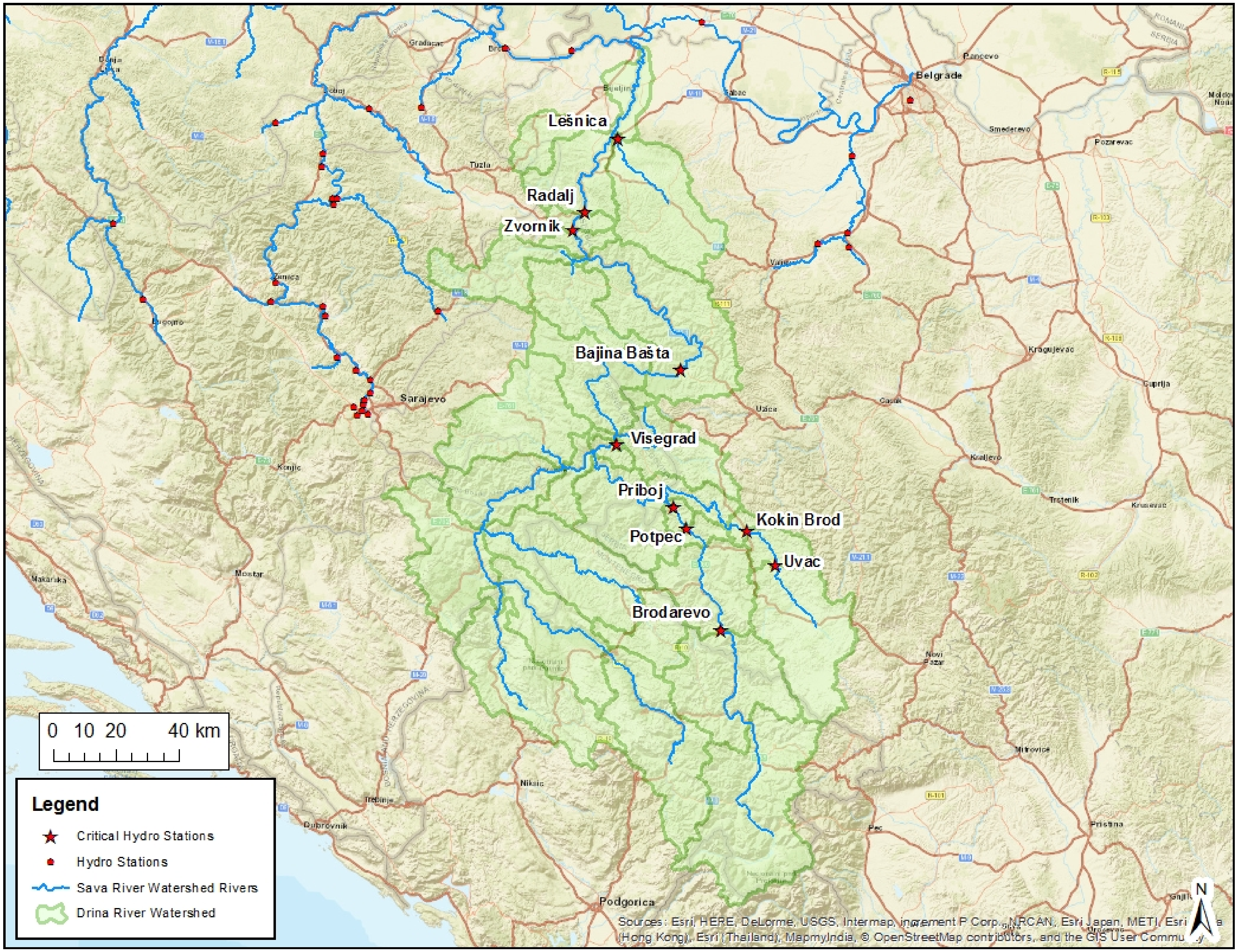


Figure 94: Hydrologic Station Map for the Drina River Watershed

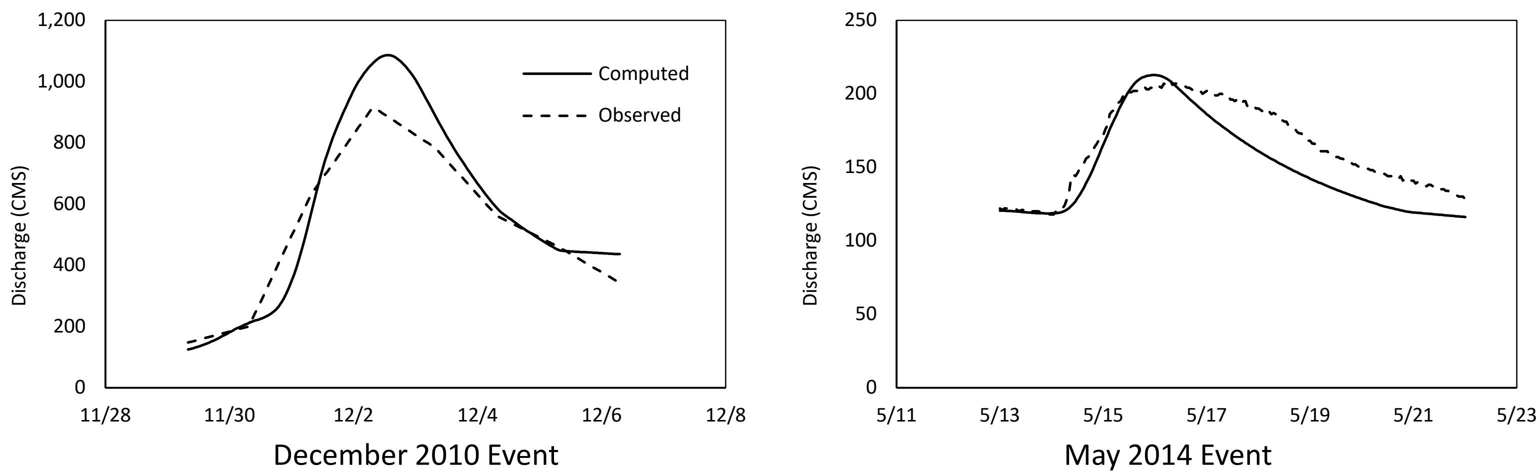


Figure 95: Calibration Plots for the Brodarevo Gauge for Various Calibration Events

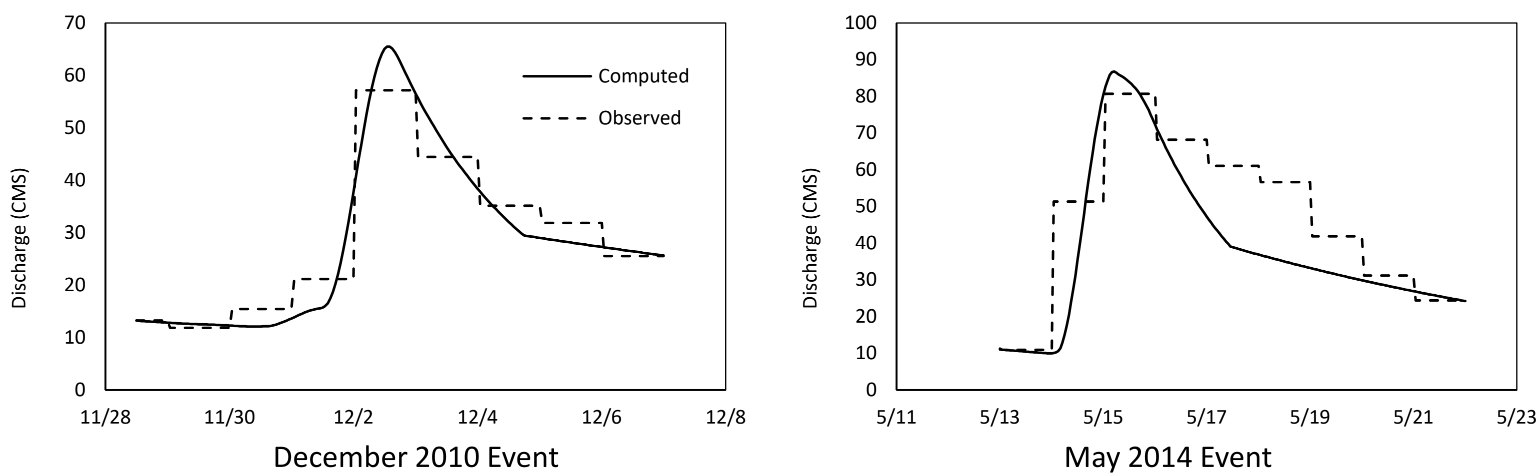


Figure 96: Calibration Plots for the Uvac Dam Inflow Gauge for Various Calibration Events

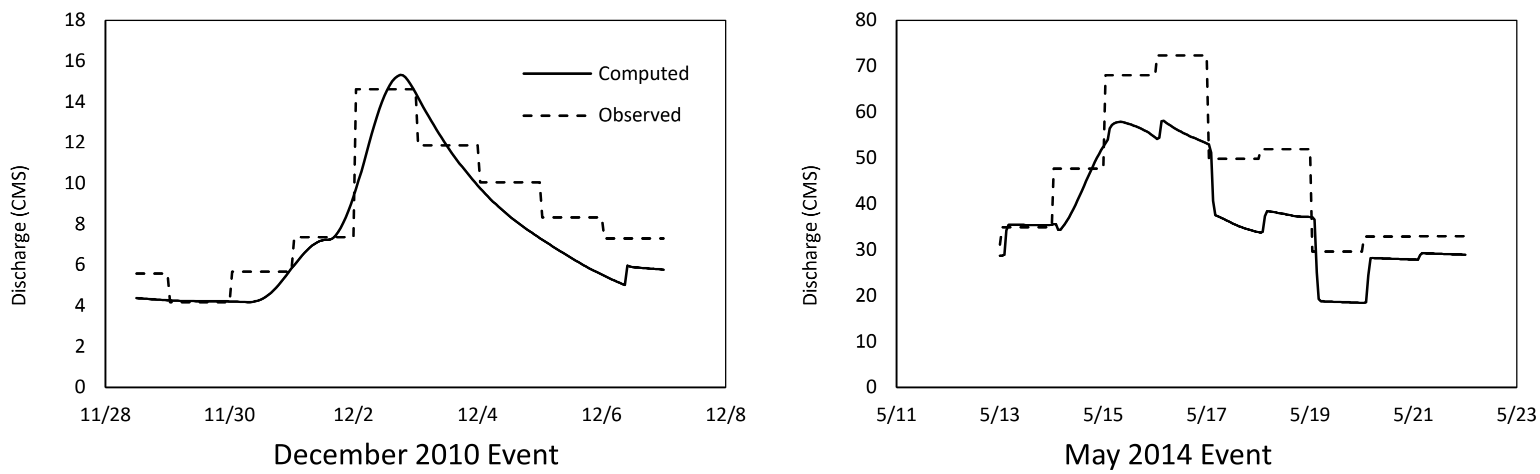


Figure 97: Calibration Plots for the Kokin Brod Gauge for Various Calibration Events

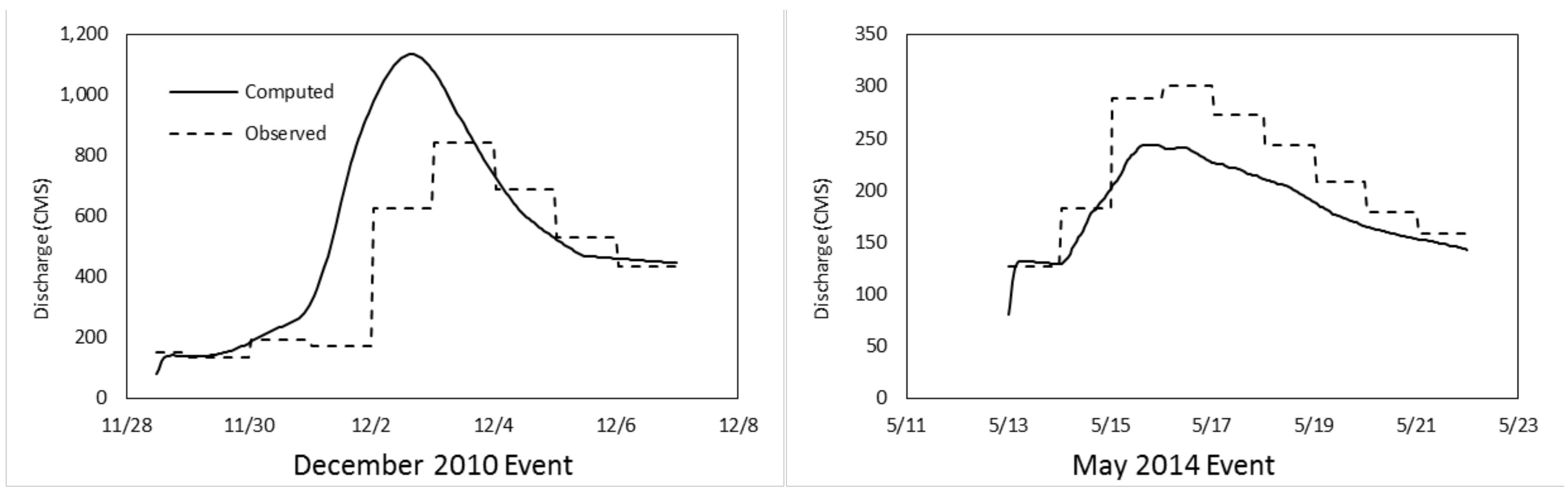


Figure 98: Calibration Plots for the Potpec Gauge for Various Calibration Events

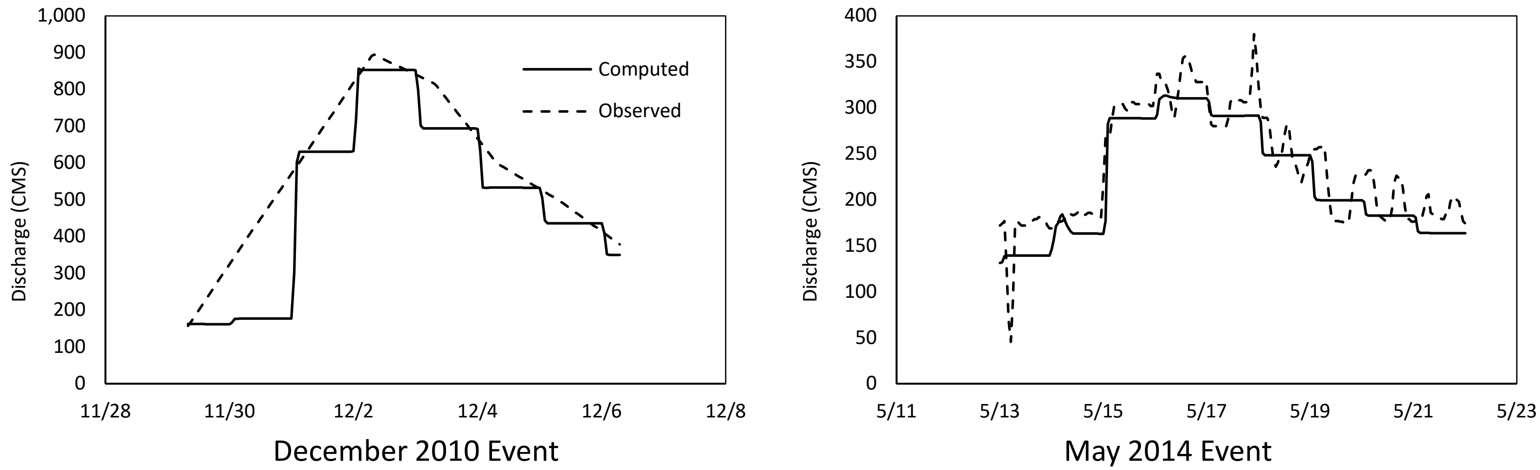


Figure 99: Calibration Plots for the Priboj Gauge for Various Calibration Events

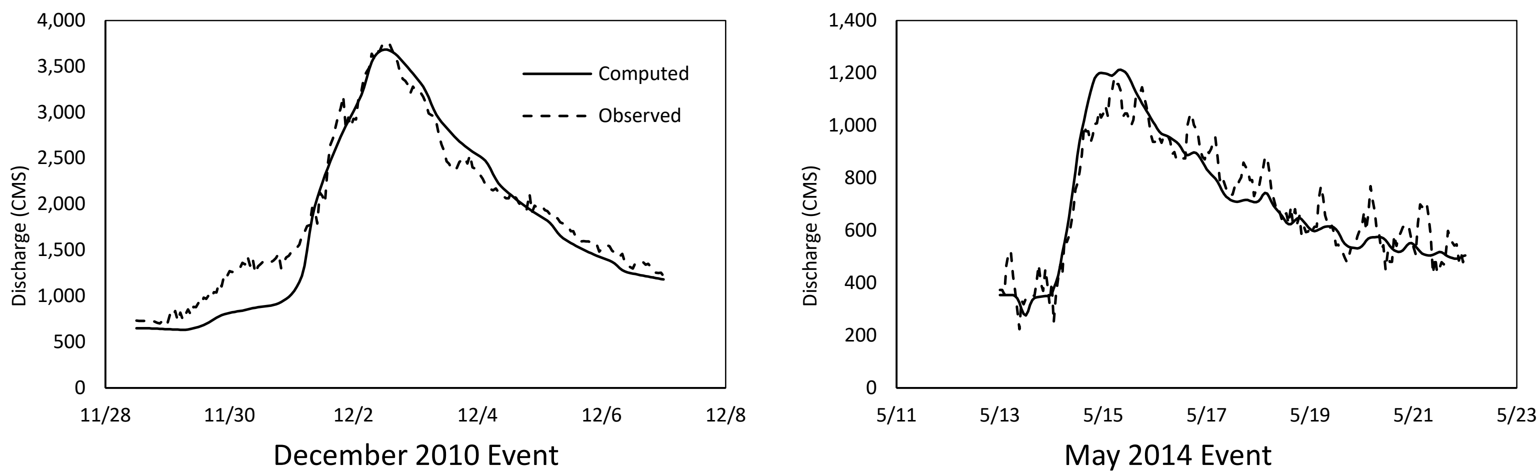


Figure 100: Calibration Plots for the Visegrad Gauge for Various Calibration Events

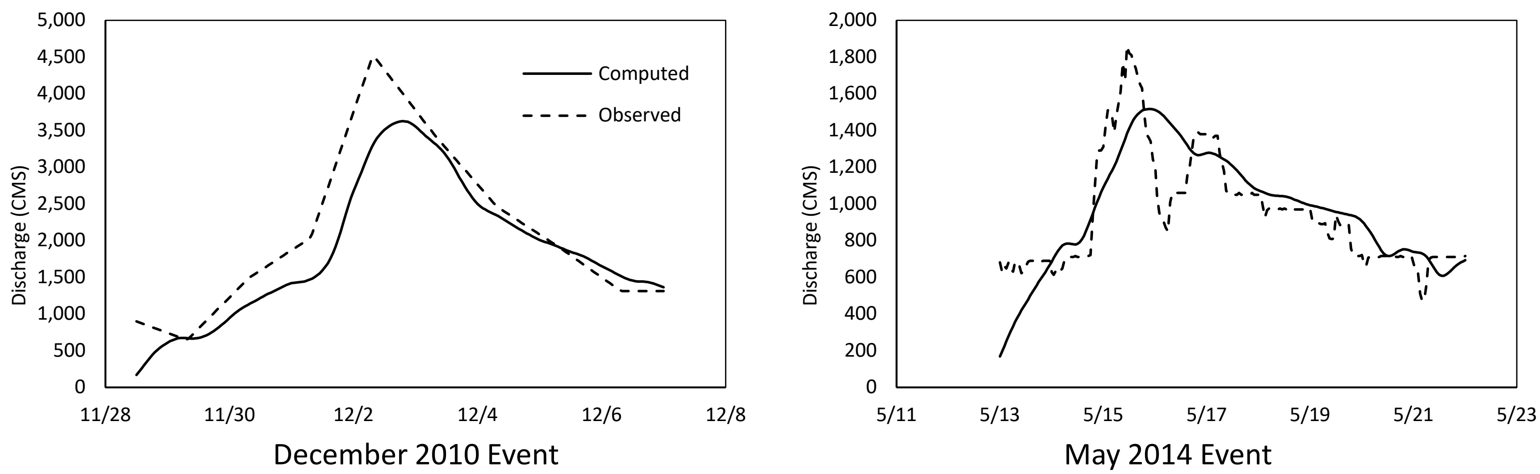


Figure 101: Calibration Plots for the Bajina Basta Gauge for Various Calibration Events

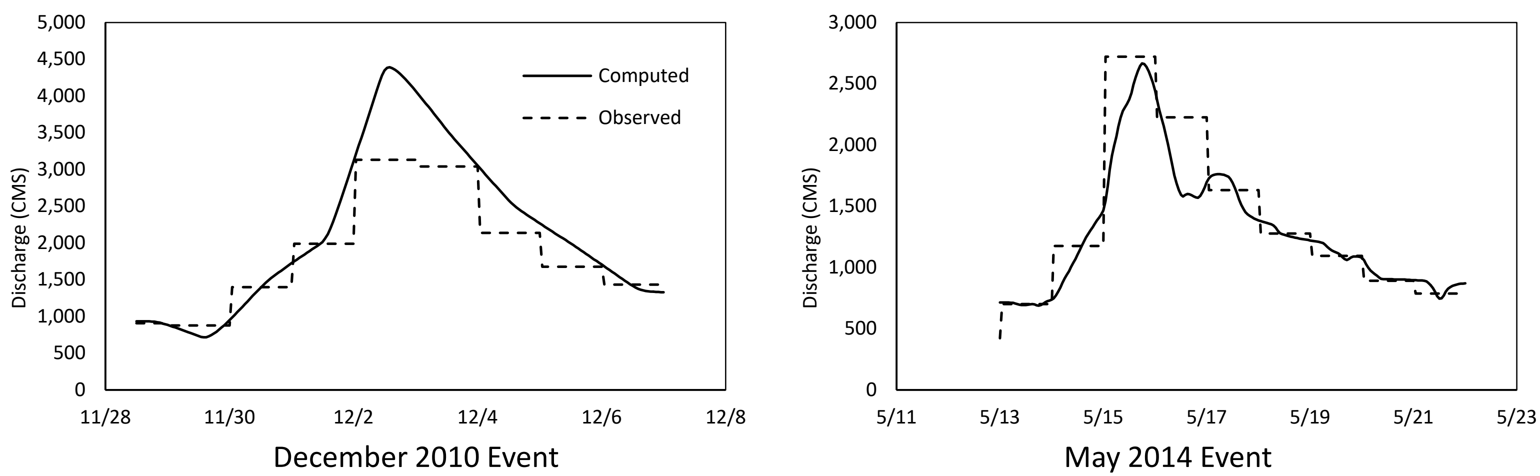


Figure 102: Calibration Plots for the Zvornik Gauge for Various Calibration Events

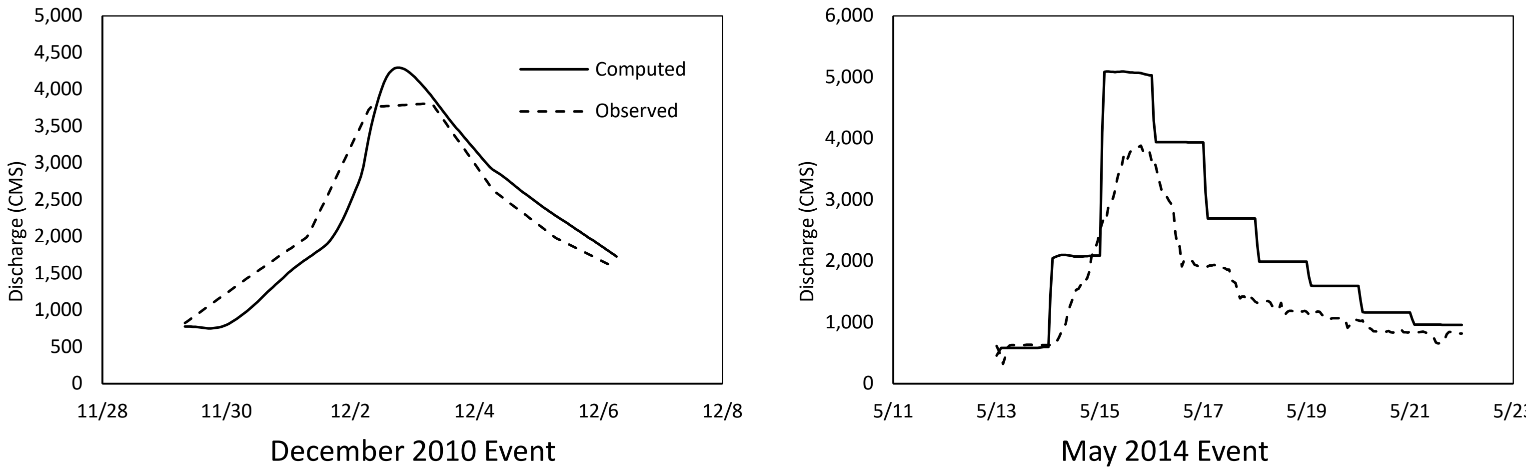


Figure 103: Calibration Plots for the Radalj Gauge for Various Calibration Events

Table 58: Drina River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Brodarevo (Daily)	Dec 2010	914.2	122.46	1086.1	143.54	18.8%	17.2%	0.854
	May 2014	209	47.75	212.8	43.63	1.8%	-8.6%	0.63
Uvac Dam (Daily)	Dec 2010	57.2	19.52	65.5	19.01	14.5%	-2.6%	0.903
	May 2014	80.7	33.39	86.7	27.49	7.4%	-17.7%	0.53
Kokin Brod (Daily	Dec 2010	14.6	4.72	15.3	4.19	4.8%	-11.2%	0.774
	May 2014	72.3	27.47	58.1	22.2	-19.6%	-19.2%	0.46
Potpec (Daily)	Dec 2010	842.9	91.26	1134.6	114.38	34.6%	25.3%	0.04
	May 2014	300.3	48.31	244	41.07	-18.7%	-15.0%	0.52
Priboj (Daily)	Dec 2010	894.3	99.38	856.6	94.13	-4.2%	-5.3%	0.67
	May 2014	380	51.4	313.5	47.98	-17.5%	-6.7%	0.79
Visegrad	Dec 2010	3743	104.77	3683.3	99.41	-1.6%	-5.1%	0.92
	May 2014	1180	41.06	1212	40.48	2.7%	-1.4%	0.87
Bajina Basta	Dec 2010	3674	100.23	3677.9	95.58	0.1%	-4.6%	0.87
	May 2014	1860	49.77	1579.4	51.84	-15.1%	4.2%	0.76
Zvornik (Daily)	Dec 2010	3131	79.83	4390.7	91.26	40.2%	14.3%	0.61
	May 2014	2720	61.84	2665	57.95	-2.0%	-6.3%	0.83
Radalj	Dec 2010	3809	82.5	4295.9	88.41	12.8%	7.2%	0.867
	May 2014	3880	67.16	5091.4	98.66	31.2%	46.9%	0.006

4.14 BOSUT RIVER WATERSHED

4.14.1 BASIN DESCRIPTION

The Bosut River is a relatively small river basin within Croatia, originating as the Bid River from the Dilj Mountain and flowing eastward through Cerna, Vinkovci, and Nijemci ultimately meeting the Sava River near Bosut. The basin area is approximately 2,803 km^2. The basin's topography is considered relatively mild with a maximum elevation in the headwaters of approximately 300 masl and minimum elevation at its confluence of approximately 60 masl.

4.14.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 59 shows the representative parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Bosut River watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 1.5 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.80 indicates that a substantial amount of attenuation occurs within the watershed, likely driven by an abundance of flatter, low-lying areas in the lower reaches of the basin.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 59: Bosut Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	35	1.50	4.9	19.5	0.80	0.001	0.90	0.10

4.14.3 REACH ROUTING PARAMETERS

River reach routings within the Bosut River basin were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 60 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 60: Bosut Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_26_01_04	8255	0.0001	Trapezoid	0.040		
R_26_01_08A	34582	0.0001	Trapezoid	0.040		
R_26_01_08B	37049	0.0002	Trapezoid	0.040		
R_26_01_08C	66751	0.0001	Trapezoid	0.040		

4.14.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Bosut River basin was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 104 illustrates the Bosut River basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 104 illustrates that the Bosut River Basin has a limited number of meteorological stations covering the basin.

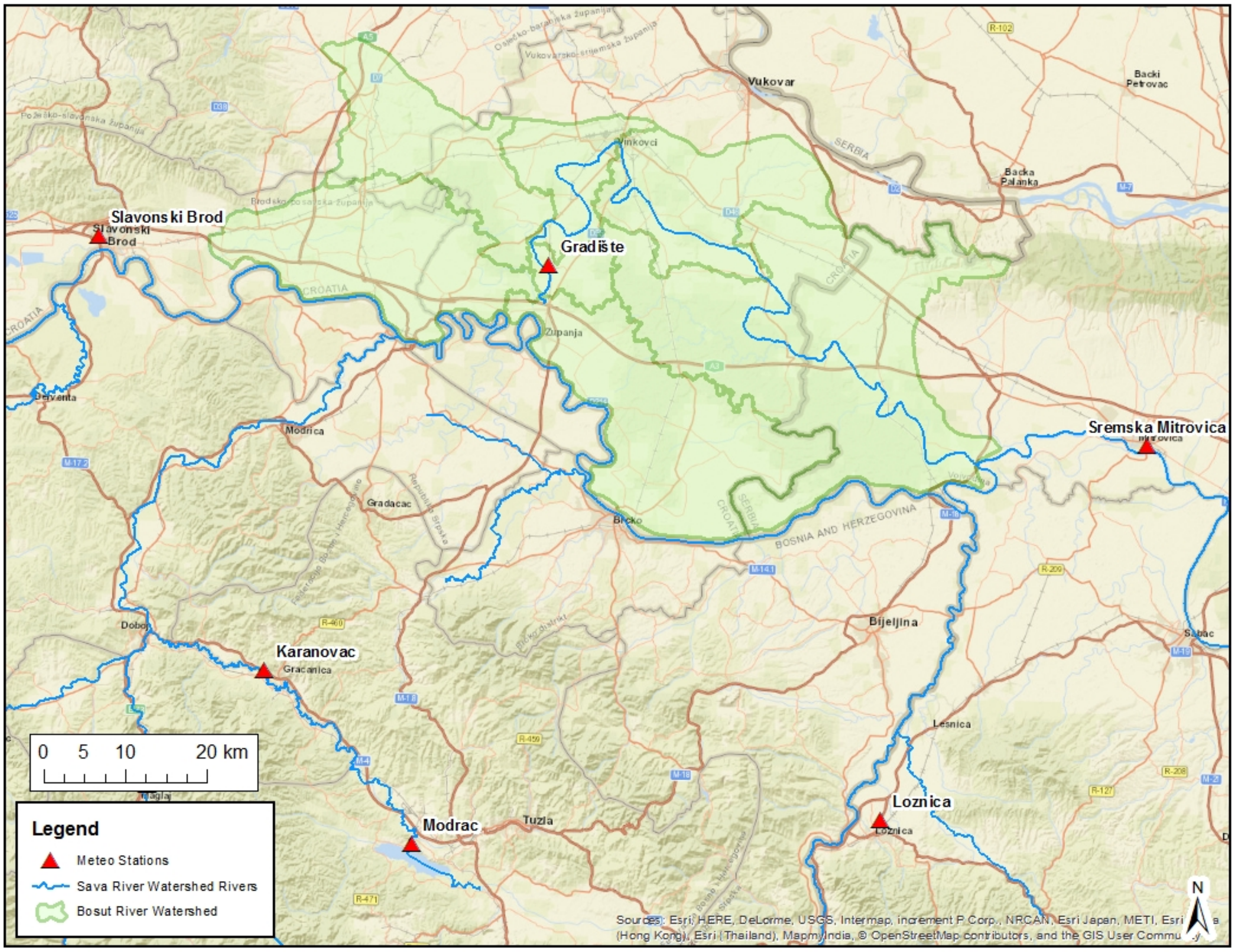


Figure 104: Meteorologic Station Map for the Bosut River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 61 shows the average ET rates for the Bosut River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable based on values used for other tributary basins adjacent to the Bosut River Basin.

Table 61: Average ET Rates for the Bosut River Watershed

Month	ET Rate (mm/month)
Jan	11.0
Feb	18.0
Mar	33.0
Apr	51.0
May	79.0
Jun	101.0
Jul	117.0
Aug	109.0
Sep	69.0
Oct	39.0
Nov	20.0
Dec	12.0

4.14.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Bosut River watershed HEC-HMS model. Two of the most common challenges during this study were related to subbasin delineation, observed discharge information, and meteorologic data availability.

The development of the Bosut River subbasin delineation relied heavily on the SRTM DEM and a subbasin delineation ESRI shapefile provided by the ISRBC at the 1000 km^2 scale. The Bosut River Basin has relatively flat topography, which makes the development of subbasin delineation using HEC-GeoHMS more difficult. The flat topography combined with the low-resolution, low-quality DEM makes it more difficult for HEC-GeoHMS to produce accurate subbasin delineations. In addition, the presence of man-made channels in the headwater of the basin appear to create complex connectivity with the Sava River. In future improvements, a high resolution DEM and better understanding of the basin flow paths can be used to develop a more accurate subbasin delineation.

After discussion with the ISRBC, two hydrologic stations were identified at Vinkovci and Nijemci. Unfortunately, a limited amount of data consisting of primarily stage time series data was made available for these gauges. Four stage versus discharge records were provided for the Nijemci gauge from which an attempt was made to develop an elevation-discharge relationship such that the time series stage data could be rated into time series discharge data. The results of this analysis were deemed unsuitable for calibration purposes. Without a reliable source of observed discharge data within the basin, a true calibration of the basin could not be completed. In future improvements, a more reliable rating of these gauges should be conducted to produce better time series discharge information so the basin model can be more accurately calibrated. An indirect calibration of the basin was made to the Sremska Mitrovica gauge on the Sava River to attain a reasonable level of confidence in the model results as it relates to inflows into the Sava River.

The coverage of meteorologic stations for the Bosut River basin is only marginally adequate for hydrologic model calibration, which reduces the confidence in the Bosut River Basin HEC-HMS model results. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred does not get or is not completely recorded at the surrounding gauges.

In general, the Bosut River Basin hydrologic model results are inconclusive due to a lack of meteorologic and hydrologic stations within the basin; however, based on the limited influence of the inflows from the Bosut River into the Sava River, the inadequacy of the hydrologic model does not drastically effect the results along the Sava River. As future improvements are made to the hydrologic models and more accurate results are required specifically for the Bosut River Basin, hourly (or less) time interval recording stream gauges that rate stage to discharge and a more comprehensive meteorologic station network or a radar-based gridded precipitation data source should be incorporated to improve the confidence in the model results. In addition, the subbasin delineation should be verified for accuracy when more accurate terrain and better information becomes available.

4.14.6 CALIBRATION RESULTS AND DISCUSSION

Due to the lack of hydrologic stations recording discharge within the basin, calibration results are not available for the Bosut River Basin. As discussed in Section 4.14.5, a reasonable level of confidence in the Bosut River Basin is provided by the indirect calibration to the Sremska Mitrovica stream gauge on the Sava River.

4.15 KOLUBARA RIVER WATERSHED

4.15.1 BASIN DESCRIPTION

The Kolubara River is the last major tributary to the Sava River, southwest of Belgrade. The basin area is approximately 3,636 km2. The basin's topography is considered steep with a maximum elevation in the headwaters of approximately 1336 masl and minimum elevation at its confluence with the Sava River of approximately 21 masl.

4.15.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 62 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Kolubara River watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 0.64 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.53 indicates that a normal amount of attenuation occurs within the watershed. However, this basin has low basin attenuation in the headwaters and higher basin attenuation in the lower portions of the basin, which is very common for basins with this type of topography.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration is due to the meteorological model over-estimating (for large values) or under-estimating the precipitation (for small values) during certain events. As a result, constant loss rates are raised or lowered to physically unrealistic values to compensate for too much or too little precipitation. Although, the constant loss rate was fairly consistent through most events with only a few of the calibration events posing a precipitation issue.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed but with the addition of more data (hydrologic and meteorological), the confidence in these parameter values could be greatly increased.

Table 62: Kolubara Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	16	0.64	24.9	22.9	0.53	0.01	0.86	0.16
Minimum	0	0.00	3.2	6.0	0.14	0.00	0.50	0.10
Maximum	30	1.25	60.0	50.0	0.80	0.04	0.91	0.65
Standard Deviation	11	0.30	5.7	10.5	0.19	0.01	0.06	0.05

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 62 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Kolubara River HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.15.3 REACH ROUTING PARAMETERS

River reach routings within the Kolubara River basin were represented using the Muskingum-Cunge and Muskingum methodology. The Muskingum-Cunge method and the techniques used to derive the routing parameters for this method are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. The Muskingum method was used in this watershed to account for the significant attenuation along the mainstem Kolubara River. This method represents reach routing using flood wave travel time through the reach and a dimensionless weighting factor. This method is described in more detail within the HEC-HMS Technical Reference Manual. Table 63 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 63: Kolubara Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n
R_28_03_06	19080	0.0007	Trapezoid	0.025

Reach	Muskingum K	Muskingum X
R_28_03_02	25	0.1

4.15.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Kolubara River basin was evaluated using the inverse distance and specified hyetograph meteorologic models within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 105 illustrates the Kolubara River basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 105 illustrates that the Kolubara River Basin has a very limited number of meteorological stations covering the basin with all available gages outside of the western portion of the watershed and none in or east of the watershed. This limited availability of meteorological data would prove to be a hindrance to the calibration of the basin as discussed in the next section. Therefore, in order to develop a more accurate calibration of the Kolubara Basin, the specified hyetograph meteorologic method was implemented using the hourly recording precipitation gauge at Valjevo.

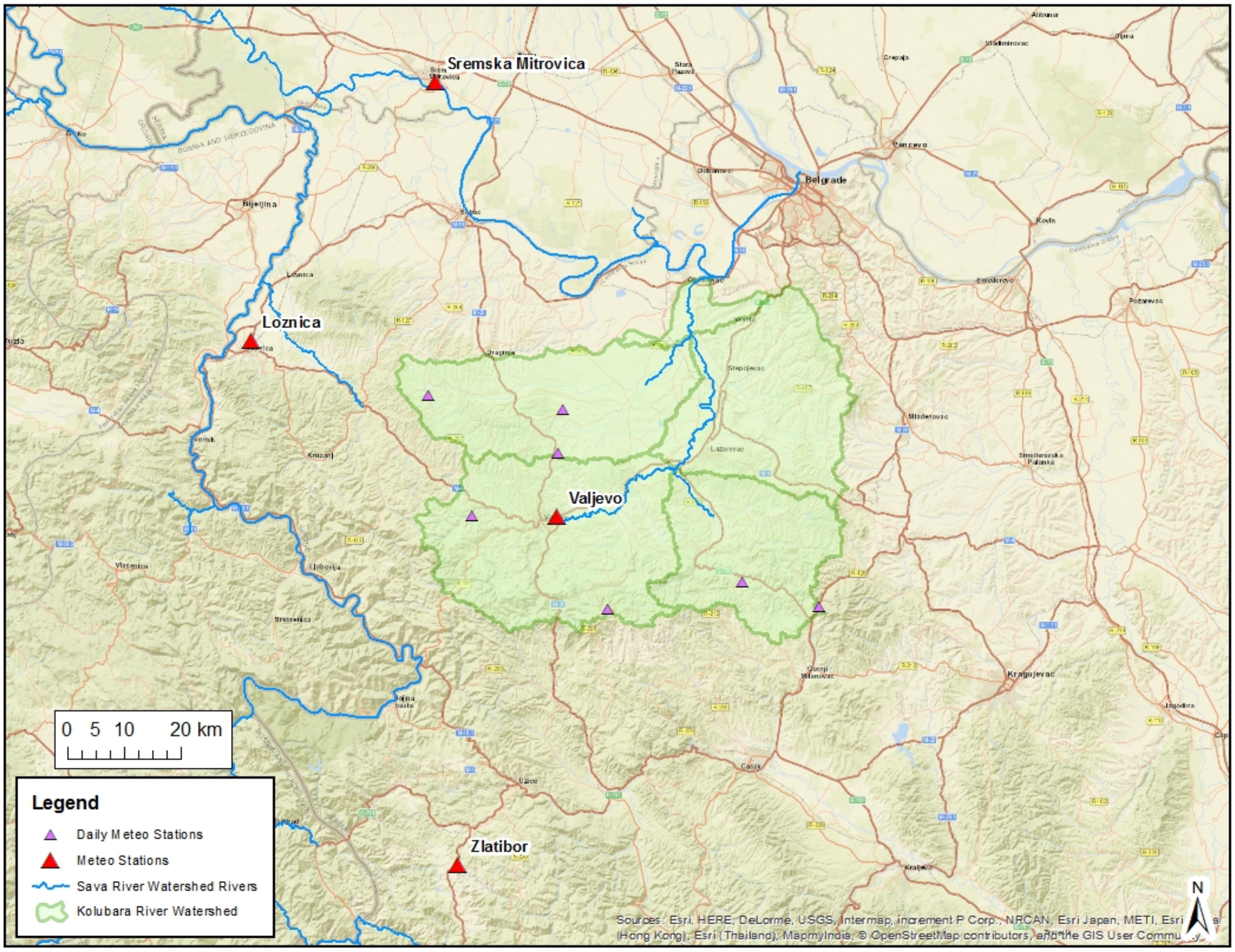


Figure 105: Meteorologic Station Map for the Kolubara River Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 64 shows the average ET rates for the Kolubara River Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 64: Average ET Rates for the Kolubara River Watershed

Month	ET Rate (mm/month)
Jan	2.3
Feb	3.7
Mar	27.4
Apr	46.0
May	89.5
Jun	115.0
Jul	123.8
Aug	111.9
Sep	81.5
Oct	48.3
Nov	14.8
Dec	5.9

4.15.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Kolubara River watershed HEC-HMS model. Two of the most common challenges during this study were related to subbasin delineation and meteorologic data availability.

The development of the Kolubara River subbasin delineation relied heavily on the SRTM DEM and a subbasin delineation ESRI shapefile provided by the ISRBC at the 1000 km^2 scale. Due to the quality of the subbasin delineation shapefile and the steep topography of the watershed, which reduces the effect of a lower quality DEM, the delineation is acceptable.

The limited coverage of meteorologic stations for the Kolubara River basin greatly hinders the quality of the hydrologic model calibration. Only one hourly recording meteorological gage is located inside the watershed. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when an insufficient number of meteorologic stations are available for this interpolation, which was the case for the Kolubara River. However, using the Valjevo Gauge and the specified hyetograph meteorologic method, a reasonable and fairly confident model calibration was achieved.

4.15.6 CALIBRATION RESULTS AND DISCUSSION

The Kolubara River watershed HEC-HMS model calibration quality is reasonably high in consideration of the lack of meteorologic stations in the region of the watershed. Figure 106 shows a map of the various hydrologic stations throughout the basin. The calibration results at these critical gauges, shown in Figure 107 - Figure 109, illustrate the calibration of the system.

Figure 107 - Figure 109 and Table 65 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. In general, the calibration quality was similar across all events evaluated. In most cases, model calibration quality was dependent on the accuracy and availability of precipitation data. More meteorological data around the Kolubara watershed would prove to be very beneficial for future improvements the model.

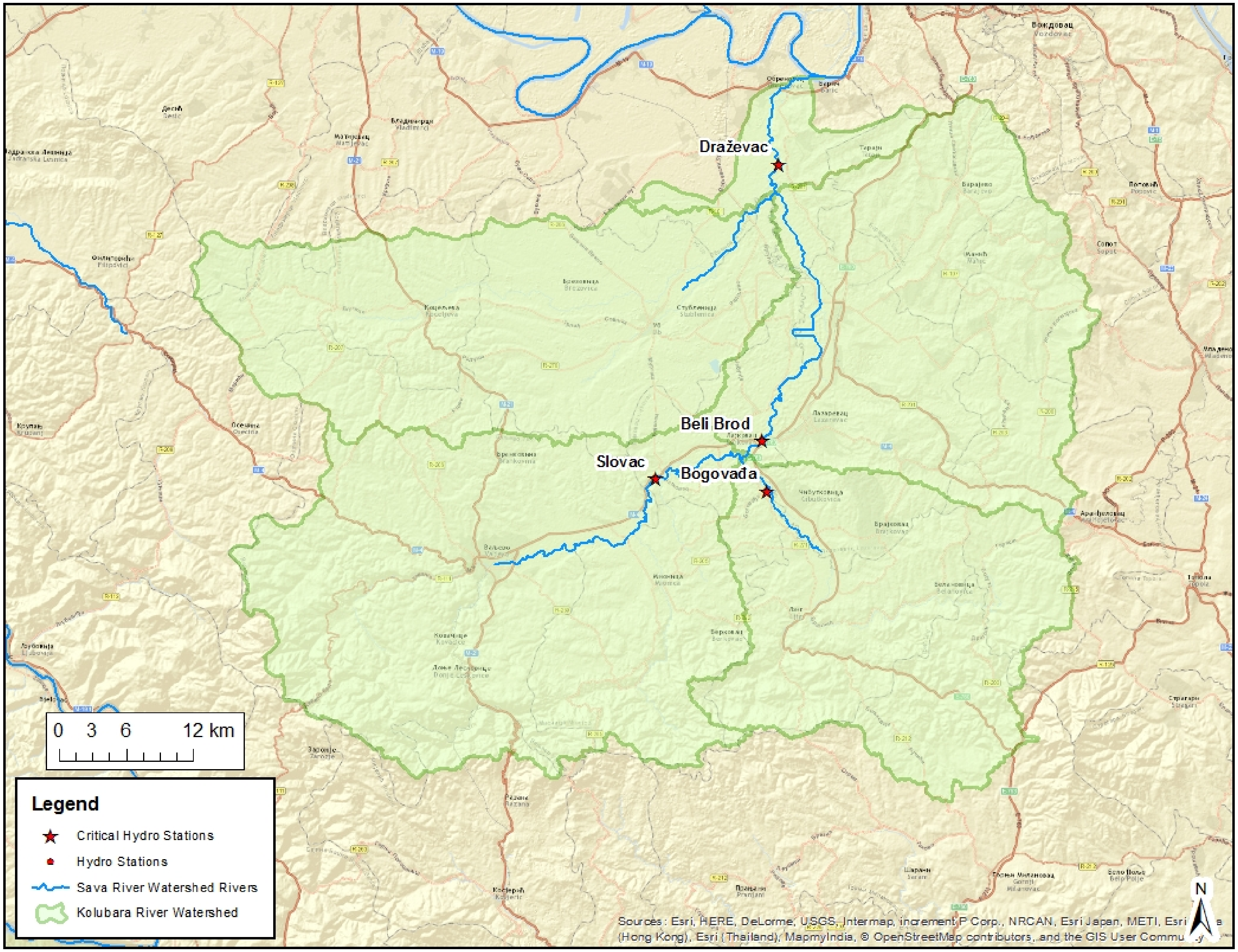


Figure 106: Hydrologic Station Map for the Kolubara River Watershed

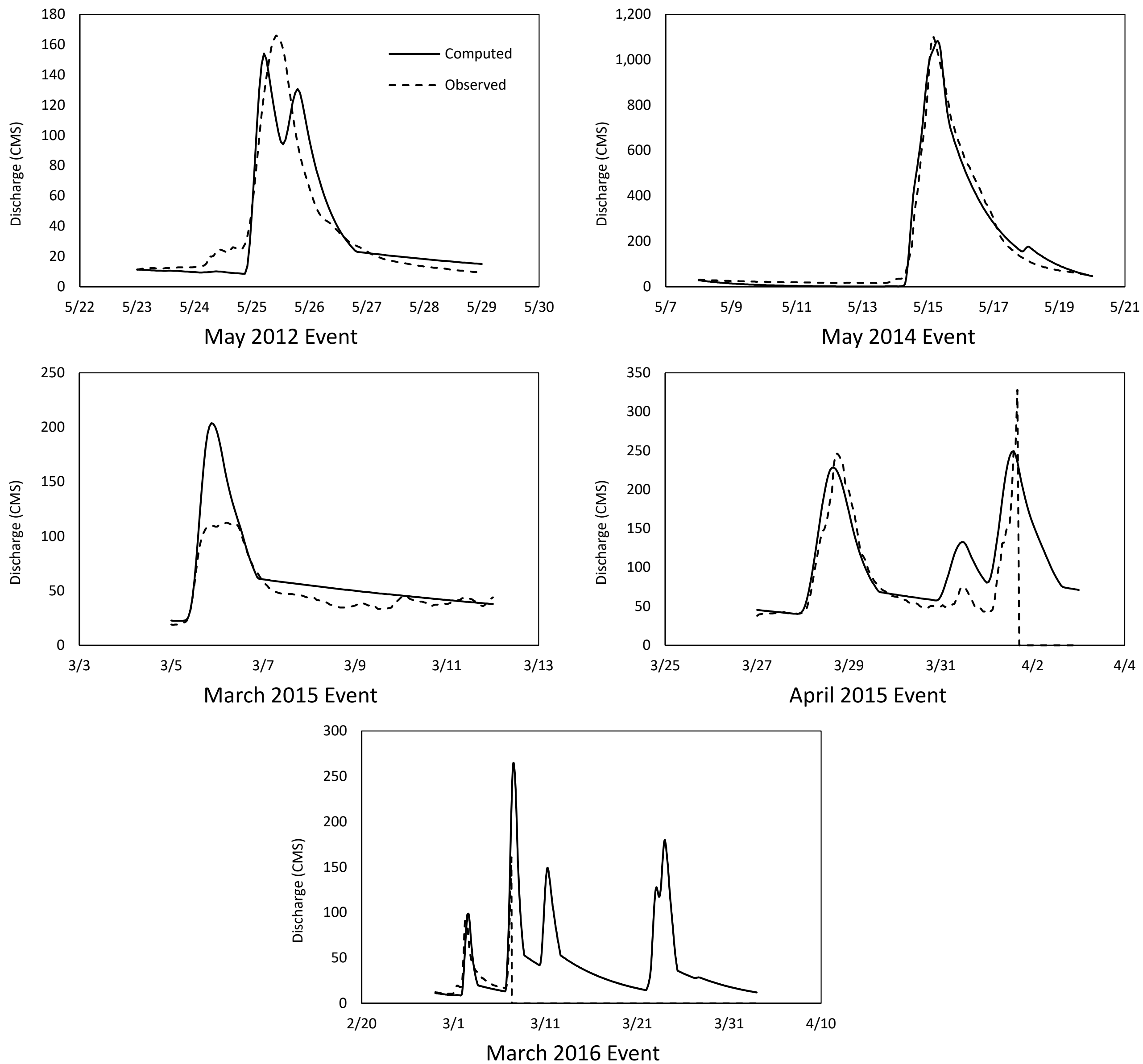


Figure 107: Calibration Plots for the Slovac Gauge for Various Calibration Events

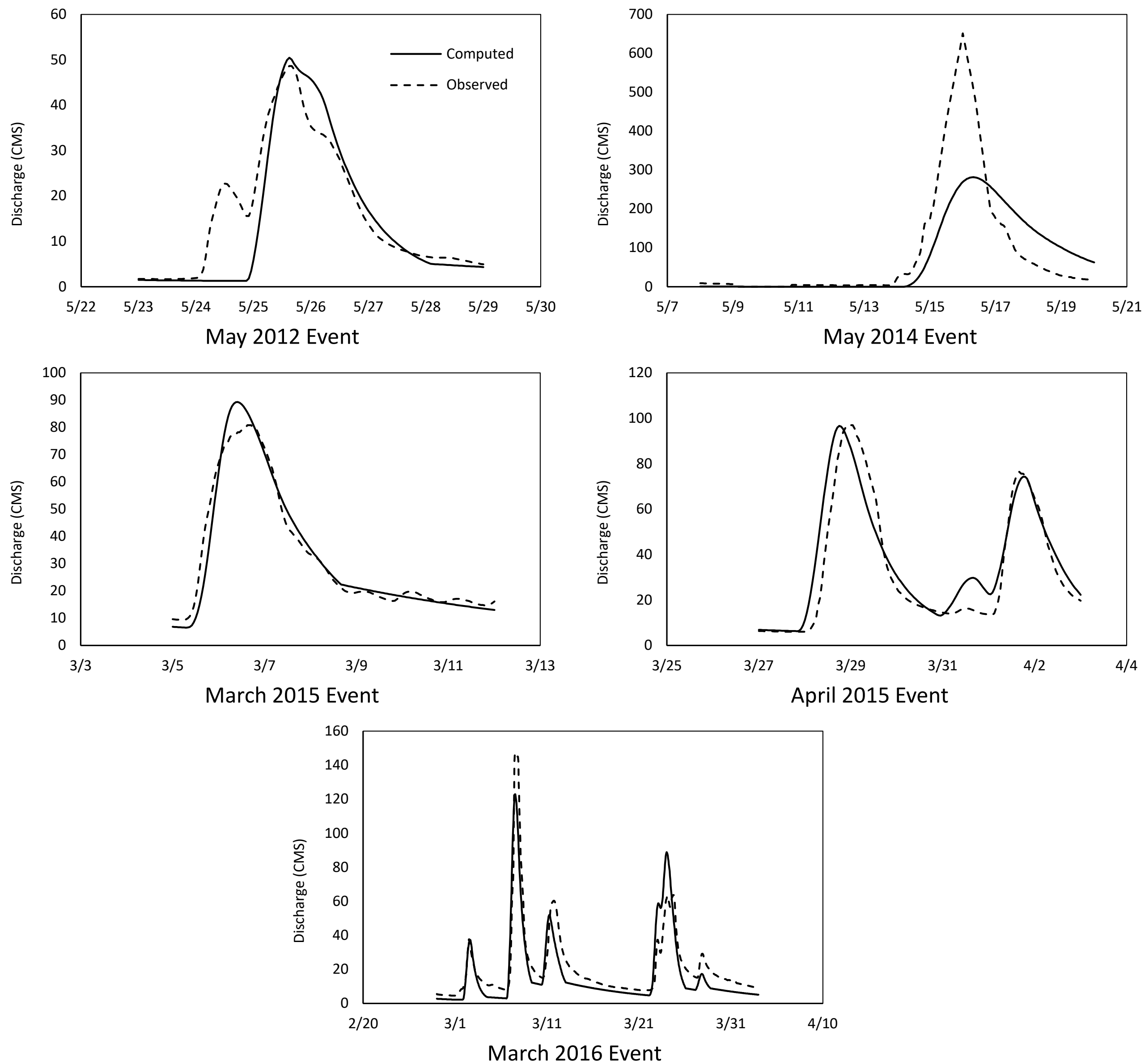


Figure 108: Calibration Plots for the Bogovada Gauge for Various Calibration Events

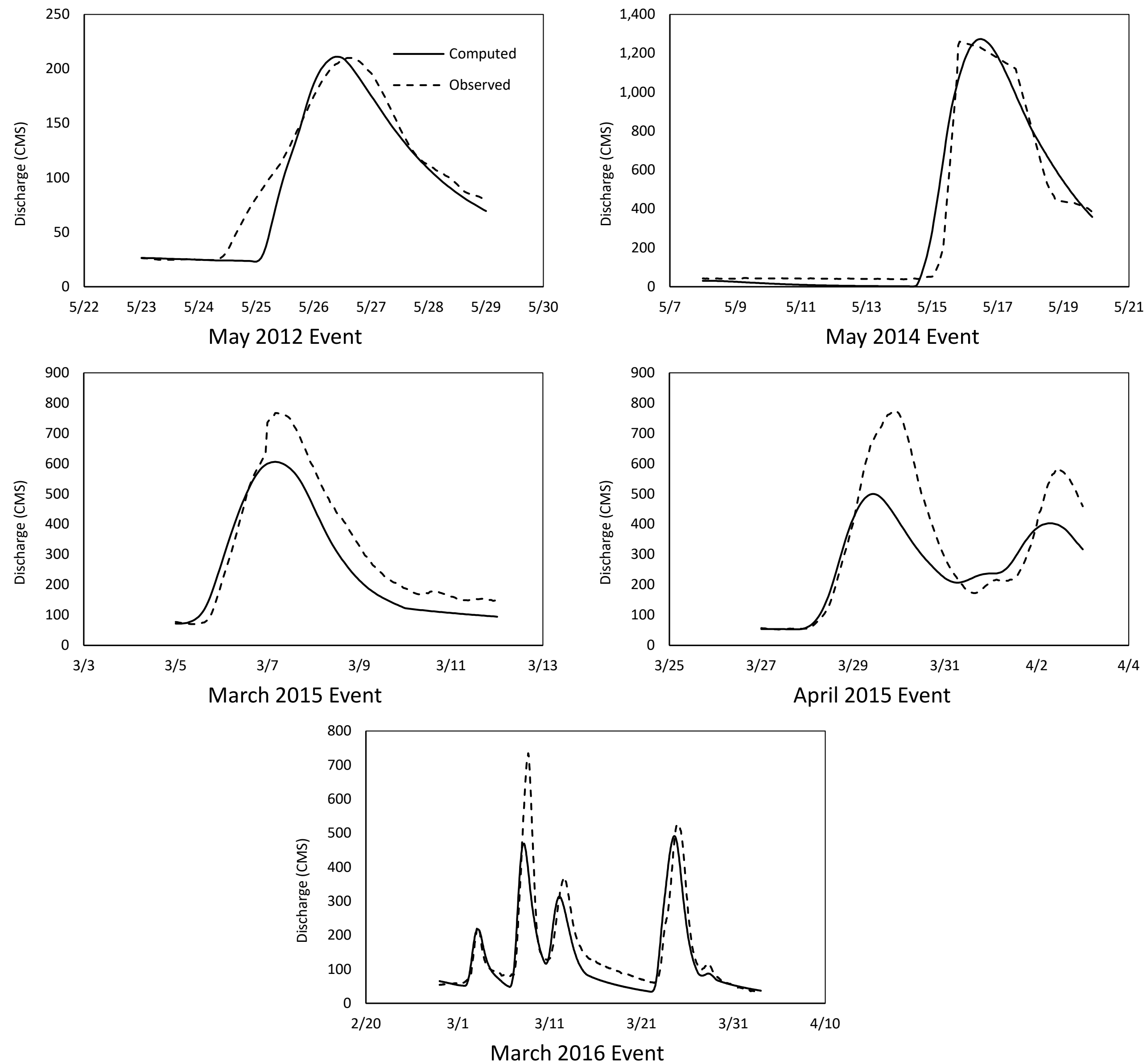


Figure 109: Calibration Plots for the Drazevac Gauge for Various Calibration Events

Table 65: Kolubara River Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed		Computed		Peak Q Percent Difference	Volume Percent Difference	Nash-Sutcliffe Efficiency
		Peak Q (CMS)	Volume (MM)	Peak Q (CMS)	Volume (MM)			
Slovac	May 2012	166	17	154	17	-7.1%	0.1%	0.82
	May 2014	1100	158	1083	156	-1.5%	-1.5%	0.98
	Mar 2015*	113	27	204	34	81.1%	24.5%	0.14
	Apr 2015**	328	38	249	103	-24.0%	171.6%	0.86
	Mar 2016**	161	19	265	119	64.5%	532.1%	0.85
Bogovada	May 2012	49	12	51	11	3.9%	-12.2%	0.72
	May 2014*	651	127	281	112	-56.8%	-11.6%	0.61
	Mar 2015	81	29	89	29	10.5%	-0.6%	0.96
	Apr 2015	97	51	97	46	-0.4%	-9.9%	0.83
	Mar 2016	147	96	123	77	-16.3%	-19.6%	0.78
Drazevac	May 2012	210	16	211	14	0.5%	-9.2%	0.91
	May 2014*	1260	102	1273	105	1.0%	3.3%	0.95
	Mar 2015*	767	56	606	45	-21.0%	-18.5%	0.83
	Apr 2015	775	95	500	83	-35.5%	-12.3%	0.78
	Mar 2016	735	134	491	110	-33.1%	-17.9%	0.77

*** Apparent Errors in Observed Dataset**

**** Incomplete Observed Dataset**

4.16 SAVA MAINSTEM 03 LOCAL WATERSHEDS

4.16.1 BASIN DESCRIPTION

The Sava Mainstem 03 basin model refers to the local subbasins adjacent to the mainstem Sava River from the confluence with the Sutla River downstream to the mouth of the Sava River in Belgrade, Serbia. The local subbasins to the mainstem Sava River compose about 12,000 km^2 of the total 97,700 km^2 Sava River Basin drainage area, which is a significant percentage of the total drainage area. The basin's topography is relatively flat consisting primarily of the broad historical Sava River floodplain area. The maximum elevation in the headwaters of the basin model is approximately 1050 masl, and the minimum elevation at its confluence is approximately 50 masl.

4.16.2 BASIN PARAMETERS

The rainfall-runoff response of the basin was defined using three components: soil loss, hydrograph transformation, and baseflow. The deficit-constant method was used to represent the soil loss characteristics within the basin. The Clark method was used to represent hydrograph transformation. The recession method was used to represent the baseflow characteristics of the basin. The methods and techniques used to derive the values for these methods are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report.

Hydrologic basin parameters are initially derived from available basin information such as soil characteristics, land use mapping, and topographic mapping; however, these initial estimations are typically finalized through a calibration process using observed hydrologic station data. For this study, limited data was available as it relates to basin parameter estimation; therefore estimation of certain parameters relied heavily on hydrologic model calibration. Provided topographic and land use information was used to derive initial estimations of transform and imperviousness parameters, respectively. Soil loss parameters were typically estimated through model calibration and reviewed to ensure values were physically reasonable.

Table 66 shows the representative, minimum, and maximum parameter values for each of these methods as well as the standard deviation of the calibrated parameter values across multiple calibration events. The representative values are based on an average of all parameters for all subbasins within the Sava Mainstem 03 watershed and indicate the general value of these parameters across the basin. For instance, an average constant rate of 1.18 mm/hr across the entire basin is expected. An average $R/(T_c + R)$ ratio value of 0.78 indicates that a substantial amount of attenuation occurs within the watershed, likely driven by an abundance of flatter, low-lying areas in the lower reaches of the basin.

In addition to representative values, the minimum and maximum values in the table show the computed ranges of values across all subbasins within the watershed for each of these parameters. The significant range of constant loss rates seen during model calibration is due to the meteorological model over-estimating (for large values) or under-estimating the precipitation (for small values) during certain events. As a result, constant loss rates are raised or lowered to physically unrealistic values to compensate for too

much or too little precipitation. A range of 0.6 to 16.0 hrs for T_c is expected because T_c is based on drainage area and slope of subbasins, which is fairly similar throughout the basin model.

In general, the values presented in the table are reasonable based on past studies and USACE's understanding of the rainfall-runoff characteristics of the watershed.

Table 66: Sava Mainstem 03 Basin Parameter Summary Table

	Soil Loss		Transform			Baseflow		
	Initial Deficit (mm)	Constant Rate (mm/hr)	T_c (hr)	R	$\frac{R}{T_c + R}$	Initial Flow (CMS/km^2)	Recession Constant	Ratio to Peak
Representative	15	1.18	5.8	22.3	0.78	0.009	0.90	0.11
Minimum	15	0.00	0.6	1.1	0.52	0.001	0.90	0.10
Maximum	30	4.00	16.0	61.5	0.82	0.103	0.95	0.33
Standard Deviation	1	0.18	2.4	8.6	0.06	0.006	0.00	0.02

In addition to representative, minimum, and maximum parameter values for each basin modeling method, Table 66 shows the standard deviation for each parameter value across the multiple calibration events. The standard deviation values are intended to show the variability seen between multiple calibration events. Initial deficit variability should be ignored because this parameter represents the antecedent soil moisture condition and is expected to have high variability. In general, the variability is an indicator of uncertainty in the model. For the Sava Mainstem 03 HEC-HMS model, the variability found in the parameter values is acceptable and typical of rainfall-runoff models developed for past studies.

4.16.3 REACH ROUTING PARAMETERS

River reach routings within the Sava Mainstem 03 basin were represented using the Muskingum-Cunge methodology. This method and the techniques used to derive the routing parameters are defined in the *3.2 HYDROLOGIC MODEL DEVELOPMENT* section of this report. Table 67 shows the reach parameter values for each reach within the basin.

The reach routing parameters used for the Muskingum-Cunge method are primarily physically based, and were derived from the DEM through the use of analysis tools found in HEC-GeoHMS. During model calibration, slight modifications may have been made to routing parameters to achieve the proper flood wave attenuation and translation to better match the computed discharge hydrographs to observed data.

Table 67: Sava Mainstem 03 Basin Reach Routing Parameter Summary Table

Reach	River Length (m)	Channel Slope (m/m)	Shape	Channel Manning's n	LOB Manning's n	ROB Manning's n
R_03_01_02	13310	0.0007	Trapezoid	0.040		
R_05_01_02	15561	0.0005	Trapezoid	0.040		
R_05_01_05A	31401	0.0005	Trapezoid	0.040		
R_05_01_05B	14972	0.0005	Trapezoid	0.040		
R_05_01_05C	39234	0.0003	Trapezoid	0.040		
R_05_01_05D	18047	0.0010	Trapezoid	0.040		
R_07_01_02	45450	0.0007	Trapezoid	0.040		
R_09_01_02	3934	0.0001	Trapezoid	0.040		
R_11_01_02B	15591	0.0001	Trapezoid	0.040		
R_13_01_02A	17785	0.0010	Trapezoid	0.040		
R_13_01_02B	15627	0.0001	Trapezoid	0.040		
R_13_01_02C	27168	0.0001	Trapezoid	0.040		
R_13_01_07	12201	0.0001	Trapezoid	0.040		
R_13_01_10	27085	0.0001	Trapezoid	0.040		
R_15_01_02	27157	0.0007	Trapezoid	0.040		
R_17_01_02	25322	0.0004	Trapezoid	0.040		
R_19_01_02	13118	0.0001	Trapezoid	0.040		
R_19_01_05	63293	0.0006	Trapezoid	0.040		
R_21_01_02	90770	0.0000	Trapezoid	0.040		
R_23_01_02	34241	0.0000	Trapezoid	0.040		
R_23_01_05	29876	0.0007	Trapezoid	0.040		
R_25_01_02	18565	0.0001	Trapezoid	0.040		
R_27_01_02	28977	0.0001	Trapezoid	0.040		
R_27_01_05	106166	0.0002	Trapezoid	0.040		
R_27_01_09	26359	0.0001	Trapezoid	0.040		
R_29_01_02	27856	0.0001	Trapezoid	0.040		

4.16.4 METEOROLOGY

Accurate meteorological information is critical to simulating runoff processes within a hydrologic model. The Sava Mainstem 03 basin was evaluated using the inverse distance meteorologic model within HEC-HMS. The function and components of the inverse distance meteorologic model are described in the *Section 3.2.7* of this report. The inverse distance method applies observed precipitation data at gauges throughout the watershed based on the distance between the meteorologic station and the centroid node of each subbasin. Figure 110 illustrates the Sava Mainstem 03 basin delineation overlaid with the meteorologic stations used to apply precipitation to the basin model. Figure 110 illustrates that the Sava

Mainstem 03 Basin has a reasonable number of meteorological stations covering the basin, with the exception of the middle and especially the lower portions of the basin model.

Figure 110: Meteorologic Station Map for the Sava Mainstem 03 Watershed

Evapotranspiration (ET) does not generally impact hydrologic model calibration performed for event-based studies; however, due to potential future applications of the hydrology model, ET was included for all modeled watersheds. Table 68 shows the average ET rates for the Sava Mainstem 03 Basin based on the evapotranspiration values computed for the WATCAP climate change model developed by COWI. Average ET rates are provided to indicate the average monthly ET values across the watershed. In actuality, ET varies across the watershed. A review of the ET values developed during the WATCAP study deemed the values to be reasonable; however, based on some of the results of the longer event simulations, further detailed development of these parameters is recommended.

Table 68: Average ET Rates for the Sava Mainstem 03 Watershed

Month	ET Rate (mm/month)
Jan	10.1
Feb	16.7
Mar	32.9
Apr	53.9
May	84.5
Jun	107.1
Jul	123.1
Aug	111.8
Sep	73.3
Oct	42.0
Nov	21.0
Dec	11.6

4.16.5 BASIN SPECIFIC TOPICS

The purpose of this section is to provide insight to unique issues encountered during the development of the Sava Mainstem 03 watershed HEC-HMS model. Two of the most common challenges during this study were related to delineation, representation of the flood protection system, and meteorologic data availability.

The development of the Sava Mainstem 03 subbasin delineation relied heavily on the SRTM DEM and a subbasin delineation ESRI shapefile provided by the ISRBC at the 1000 km^2 scale. Most of the subbasins for this model cover the flat and broad areas of the historical Sava River floodplain. HEC-GeoHMS does not perform particularly well in flat areas especially when the resolution and accuracy of the underlying DEM is low. Due to the quality of the subbasin delineation shapefiles provided, which reduces the effect of a lower quality DEM, the delineation is acceptable; however, delineation in some areas could be improved with better information such as a higher quality DEM.

Delineation was a challenge in areas where levees and other man-made artificial subbasin divides exist. This basin model includes areas with extensive artificial modifications to the landscape, especially in areas related to the flood protection system. Due to this limitation, the subbasin delineation relied heavily on the subbasin delineation ESRI shapefiles provided in order to overcome this challenge. The delineation assumptions in this area are reasonably acceptable based on the calibration results of the model; however, future improvement to this model should consider better information to verify and/or improve the delineation in this area.

One of the most critical components of the Sava River Basin is the extensive flood protection system, which drastically attenuates flood waves moving down through the basin. A description of this system and limitations related to this study are provided in detail in Section 5. Generally, the flood protection system includes lateral weirs and gated structures to divert flood waters into strategic areas behind the levees on the mainstem. In addition, large retention areas exist adjacent to the mainstem Sava River where flood waters overtake the banks of the river and are attenuated in these adjacent retention areas. For gated structures, HEC-HMS is not currently capable of simulating the operations of the gates on these structures. The Jankomir lateral weir is properly represented in the model as data was available; however, critical data was unavailable for other lateral weirs within the system. For features of the flood protection that were unable to be represented either due to software limitations or lack of data, observed discharge data was used to negate these limitations. As discussed in Section 6, the new LiDaR currently being collected and the HEC-RAS hydraulic model to be developed can be used to improve most of these limitations.

The coverage of meteorologic stations for the Sava Mainstem 03 basin is generally adequate for hydrologic model calibration; however, as seen in Figure 110, certain areas of the basin have limited or insufficient coverage of stations. In general, this was not a critical issue for this basin model because observed discharge information was relied on so heavily. Using the IDW meteorologic model method in HEC-HMS allows for the interpolation of precipitation data in this area of low meteorologic station coverage. Although, this interpolation is less effective when the precipitation that occurred does not get or is not completely recorded at the surrounding gauges. As discussed in Section 6, a more extensive network of meteorologic stations should be developed and/or radar-based gridded precipitation should be incorporated into the model.

In general, other than the aforementioned minor issues, no major challenges were encountered during the Sava Mainstem 03 watershed HEC-HMS model development.

4.16.6 CALIBRATION RESULTS AND DISCUSSION

The Sava Mainstem 03 watershed HEC-HMS model calibration quality is very good based on the performance metrics, and the model performs well across a large range of events and seasons. Figure 111 shows a map of the various hydrologic stations throughout the basin. The red points identify the location of gauges in the basin. Due to the large number of available gauges, only the gauges deemed most representative of the calibration, represented with red stars, are reported in this document. The calibration results at these critical gauges, shown in Figure 112 - Figure 123, illustrate the successful calibration of the system.

Figure 112 - Figure 123 and Table 69 illustrates the quality of the calibration but also shows the variability of quality between event simulations and at specific gauges. In general, the calibration quality was high for all events evaluated; however, it should be noted that these calibrations rely heavily on the use of observed discharge data to focus on the calibration of the local subbasins to the Sava River mainstem.

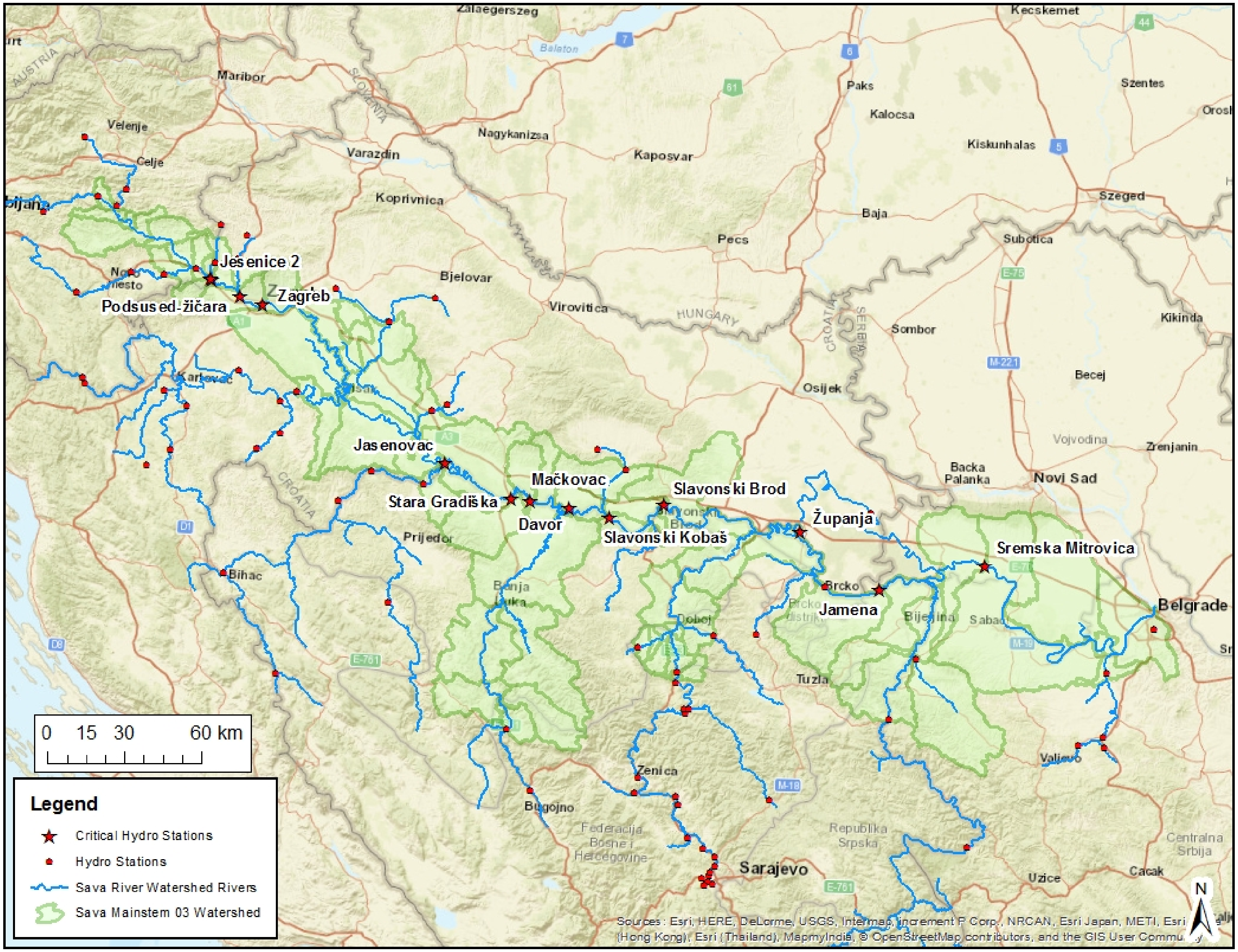


Figure 111: Hydrologic Station Map for the Sava Mainstem 03 Watershed

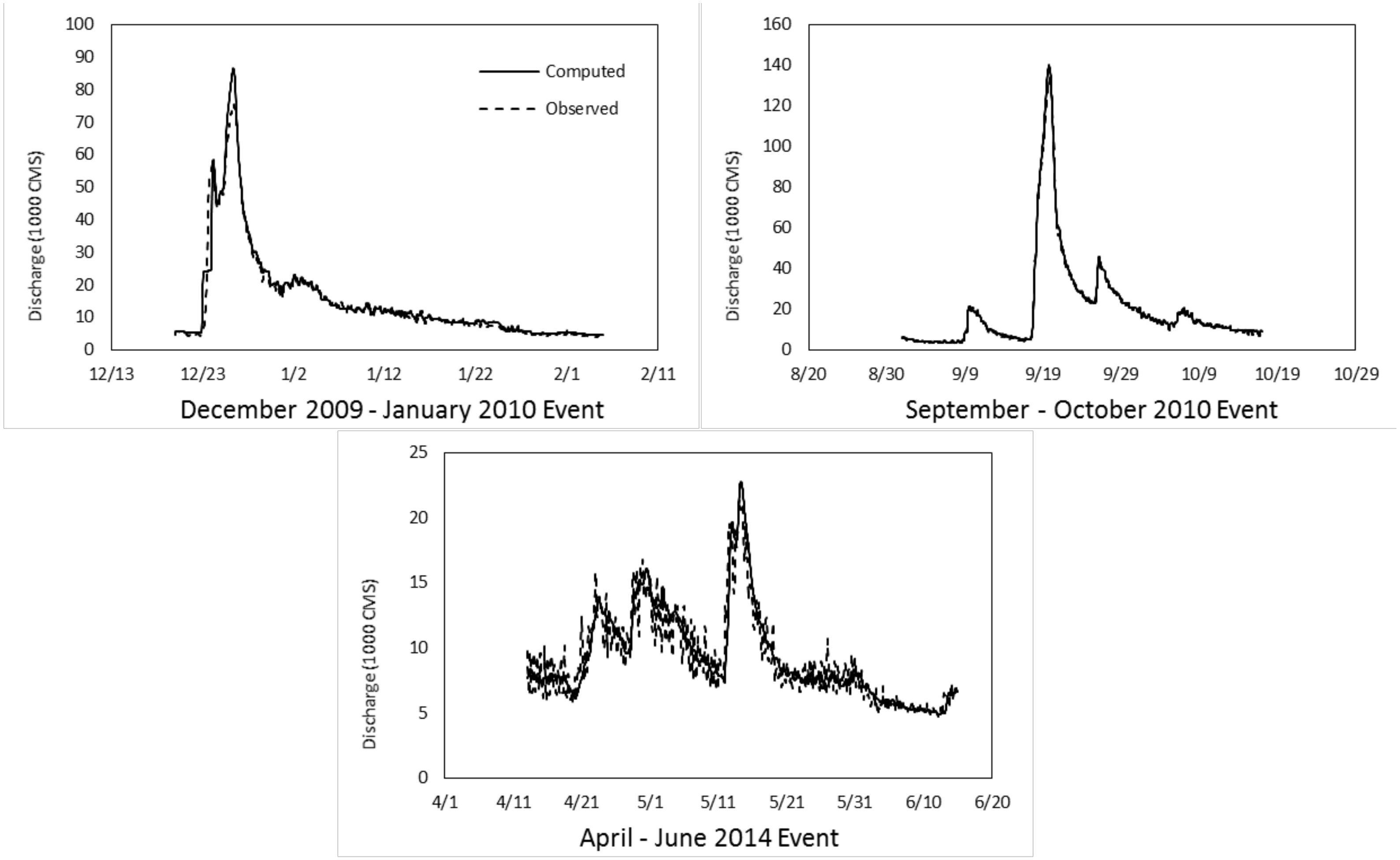


Figure 112: Calibration Plots for the Jesenice Gauge for Various Calibration Events

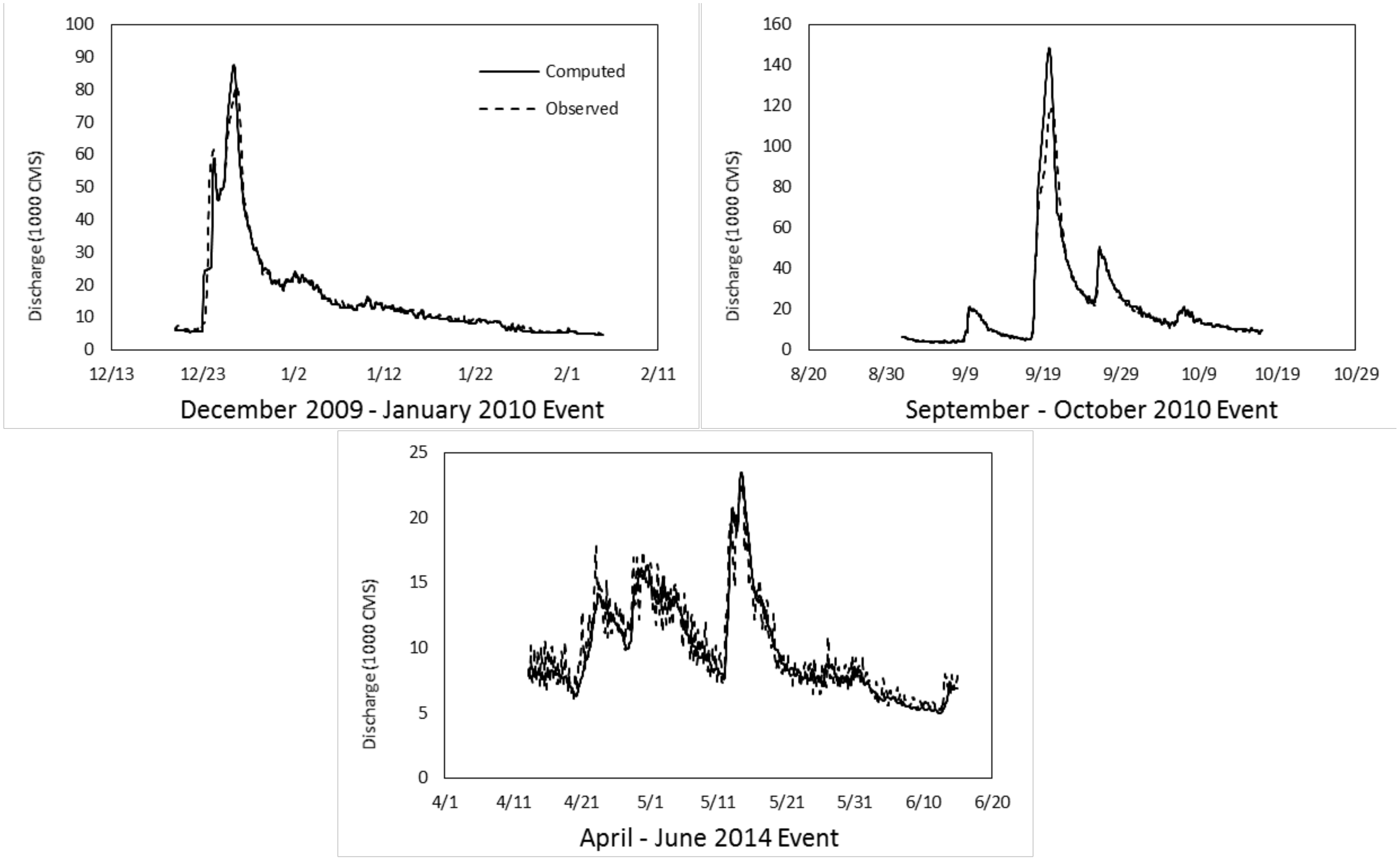


Figure 113: Calibration Plots for the Podsused Zicara Gauge for Various Calibration Events

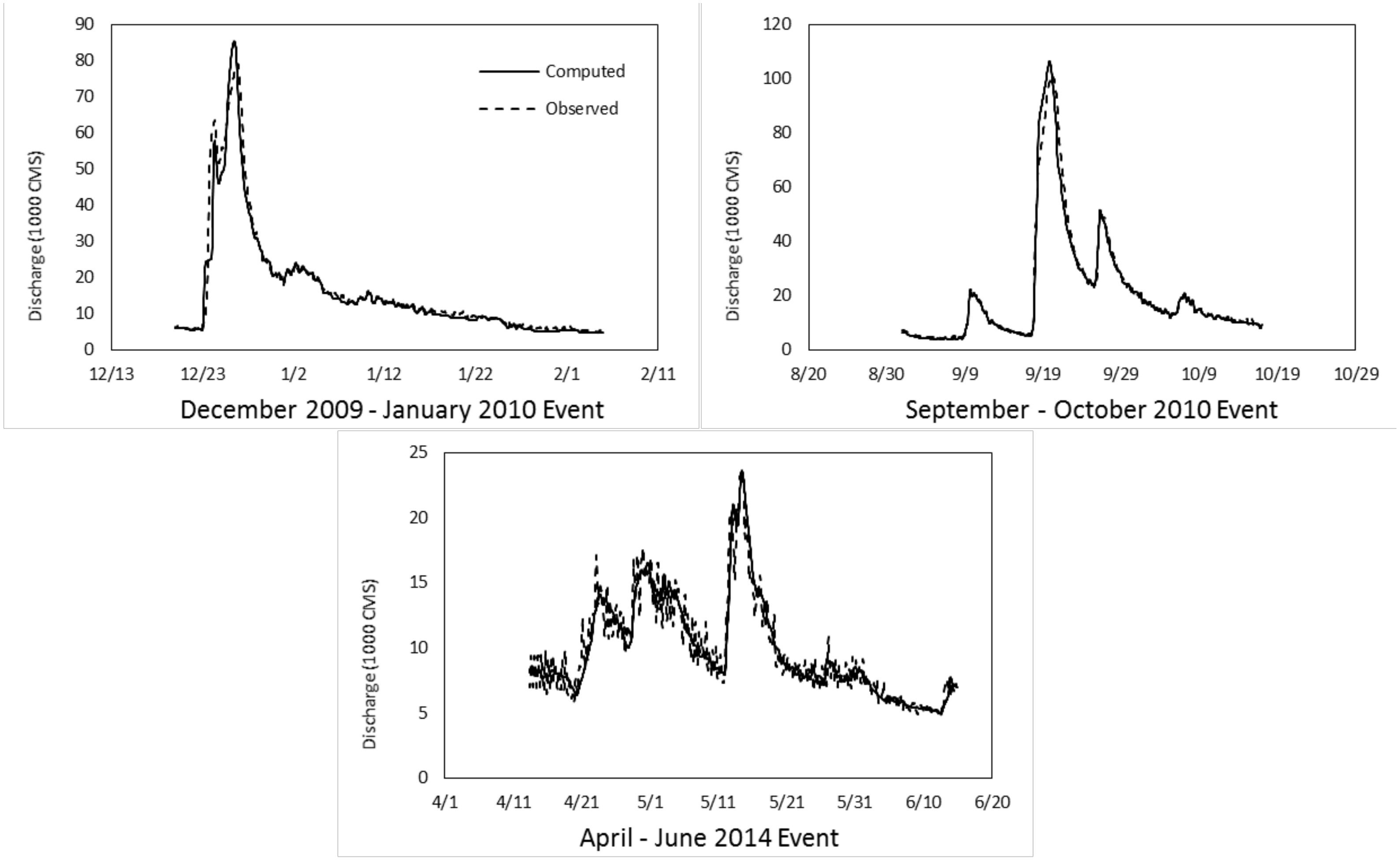


Figure 114: Calibration Plots for the Zagreb Gauge for Various Calibration Events

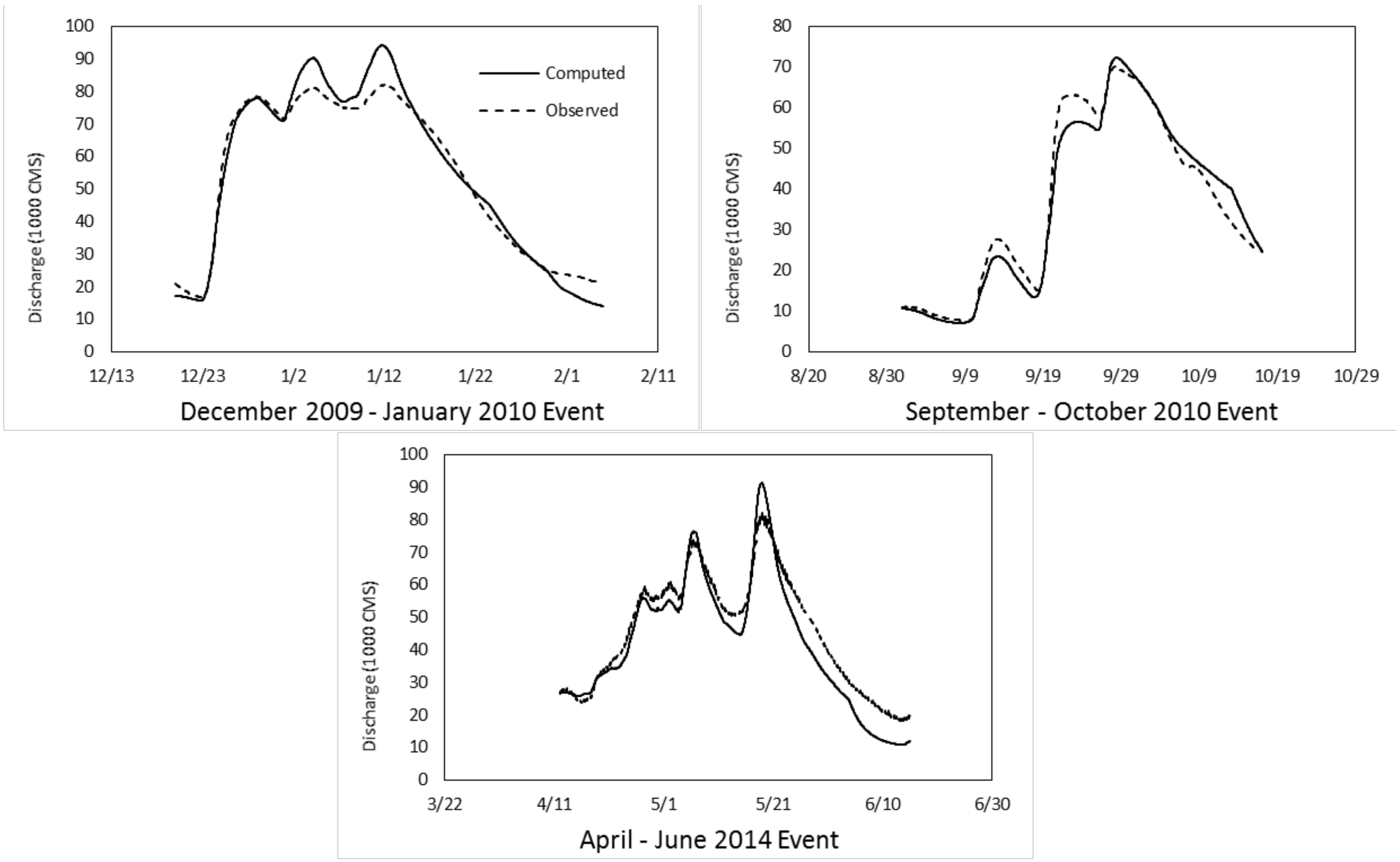


Figure 115: Calibration Plots for the Jasenovac Gauge for Various Calibration Events

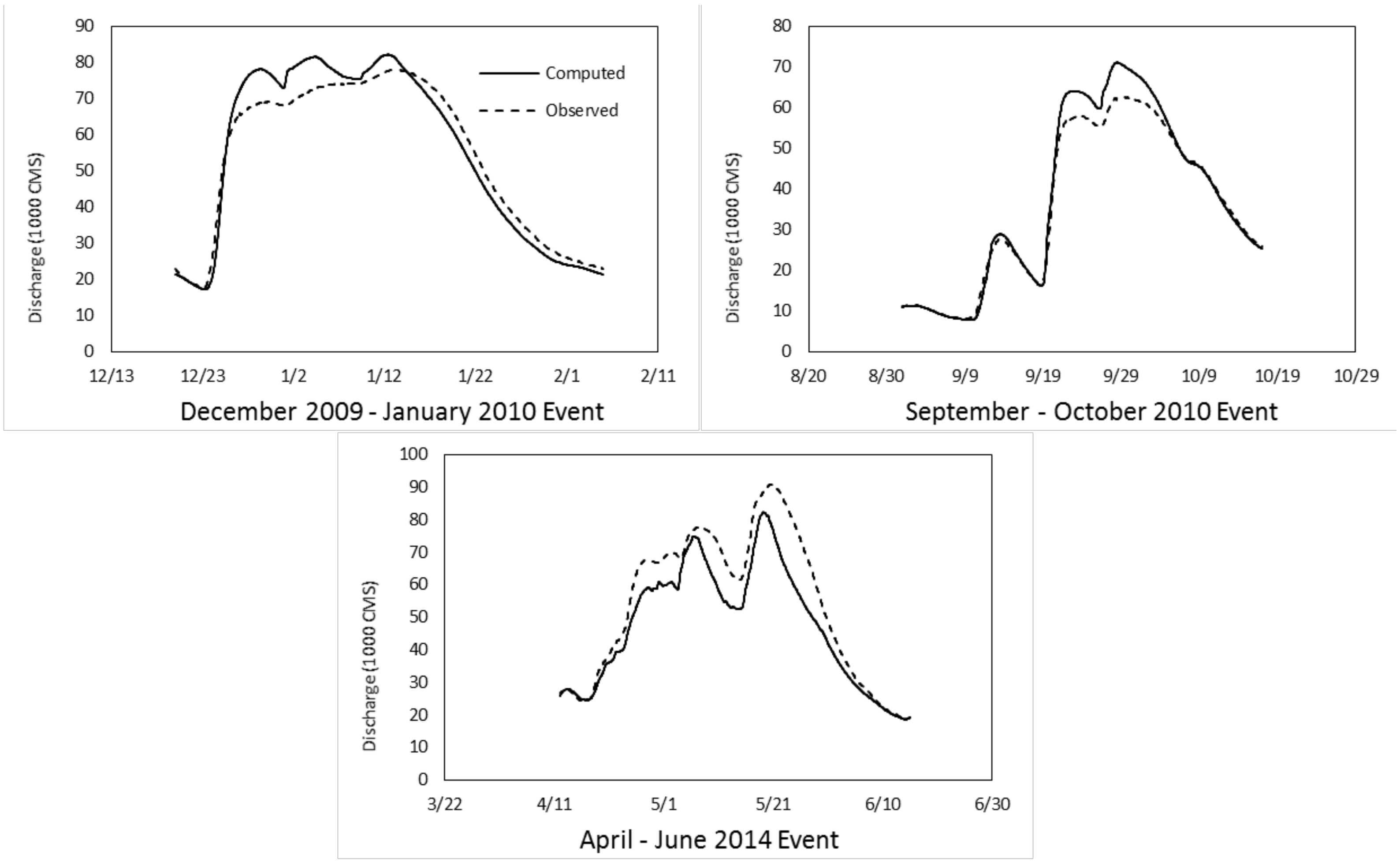


Figure 116: Calibration Plots for the Stara Gradiska Gauge for Various Calibration Events

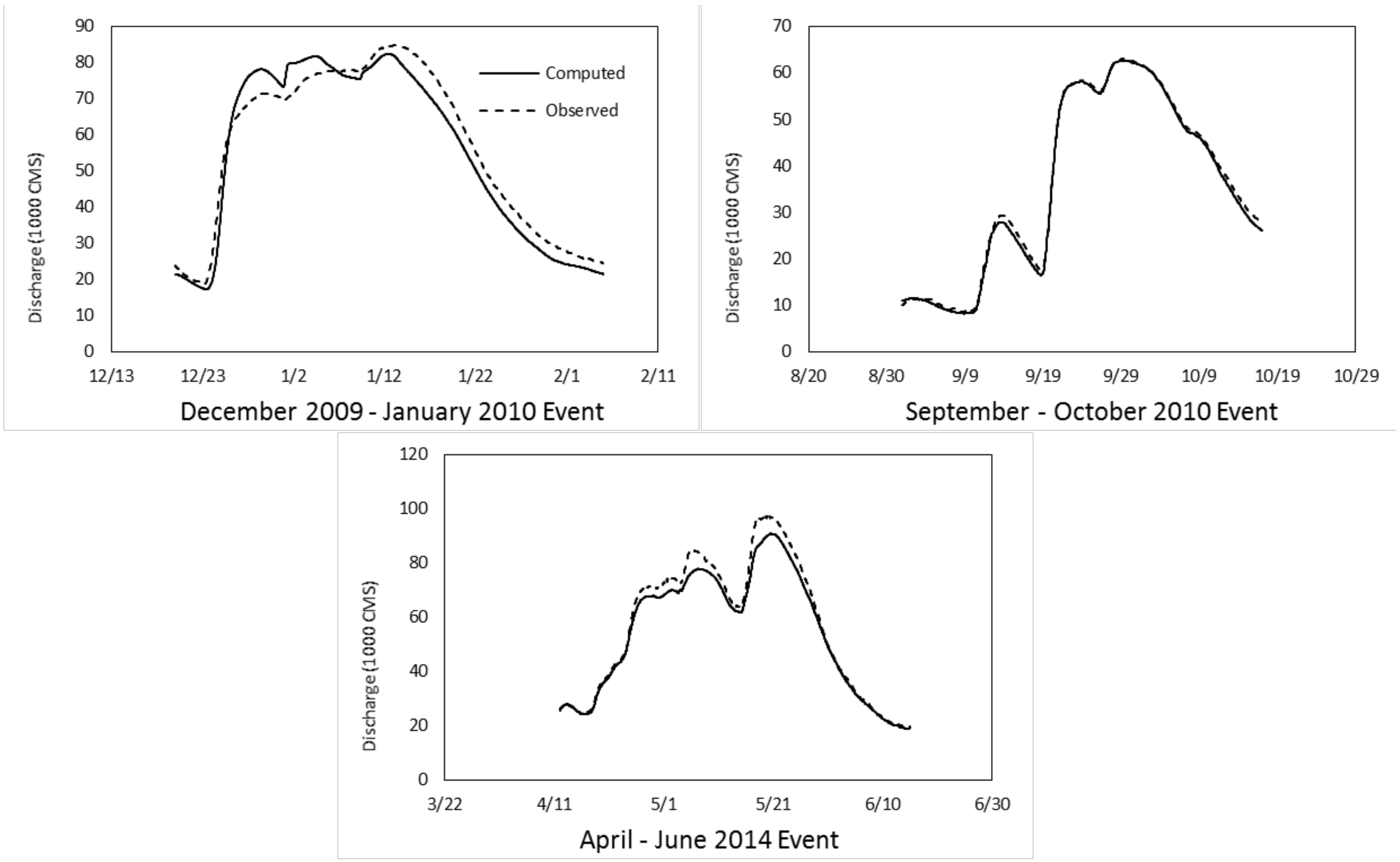


Figure 117: Calibration Plots for the Mackovac Gauge for Various Calibration Events

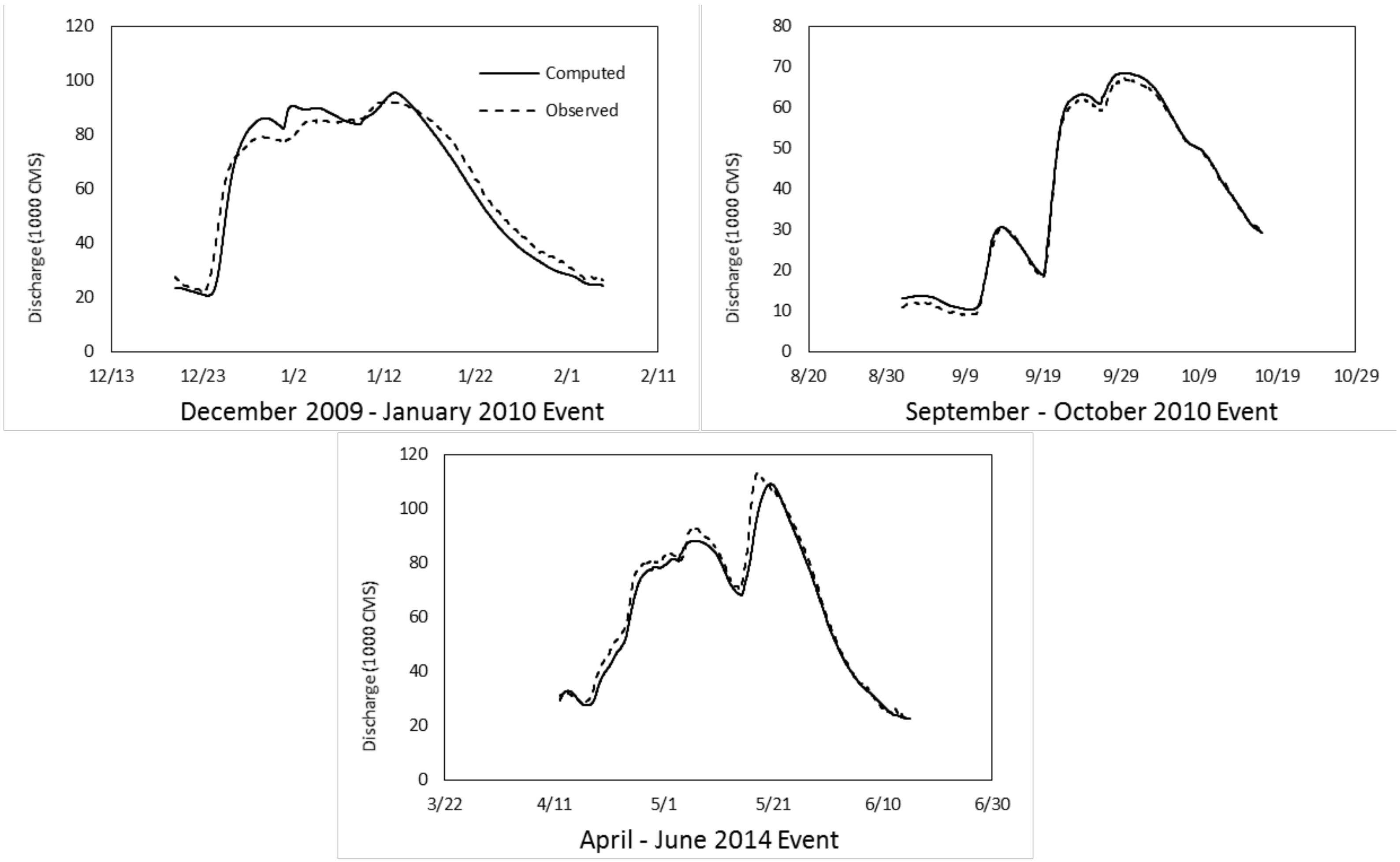


Figure 118: Calibration Plots for the Davor Gauge for Various Calibration Events

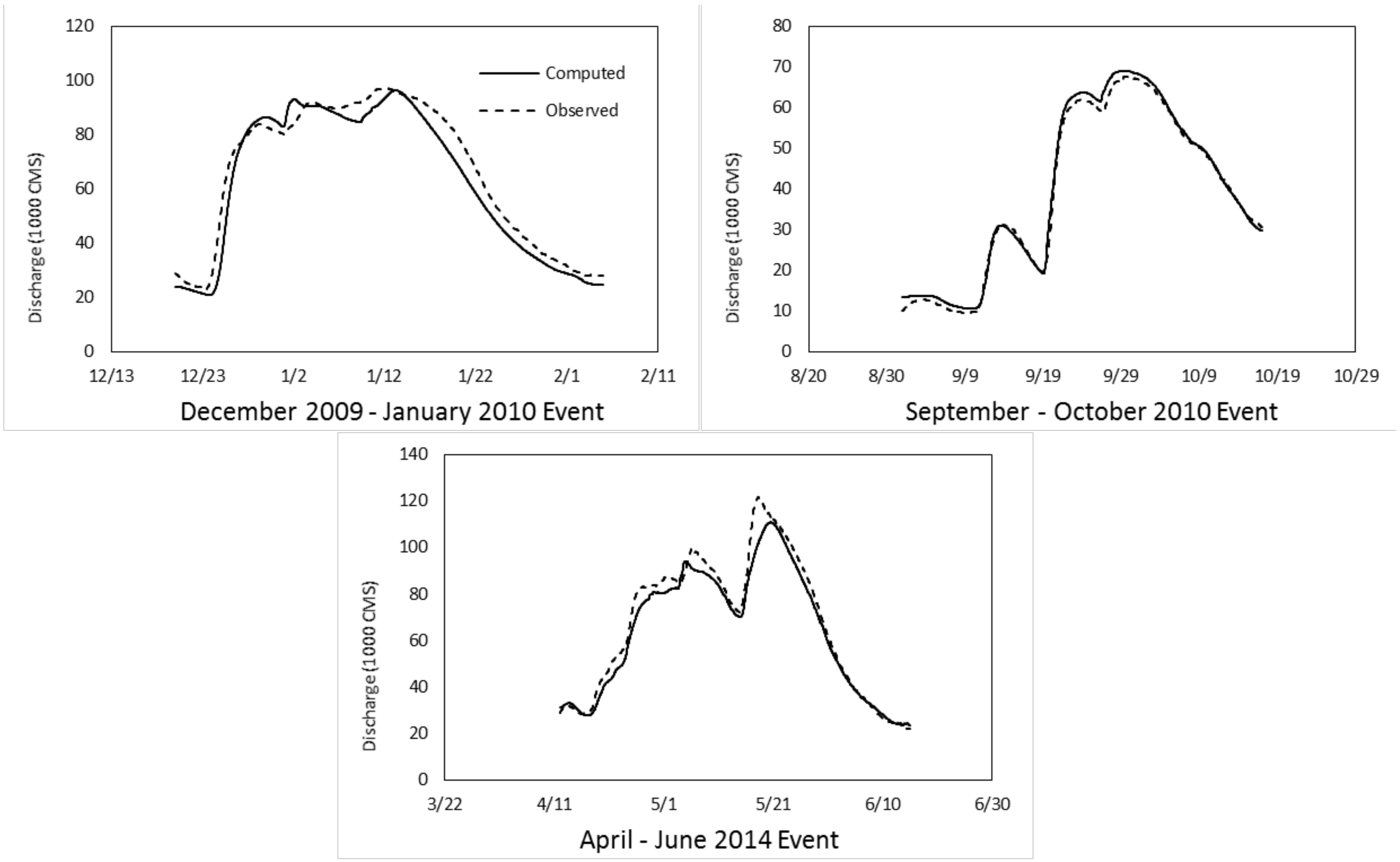


Figure 119: Calibration Plots for the Slovanski Kobas Gauge for Various Calibration Events

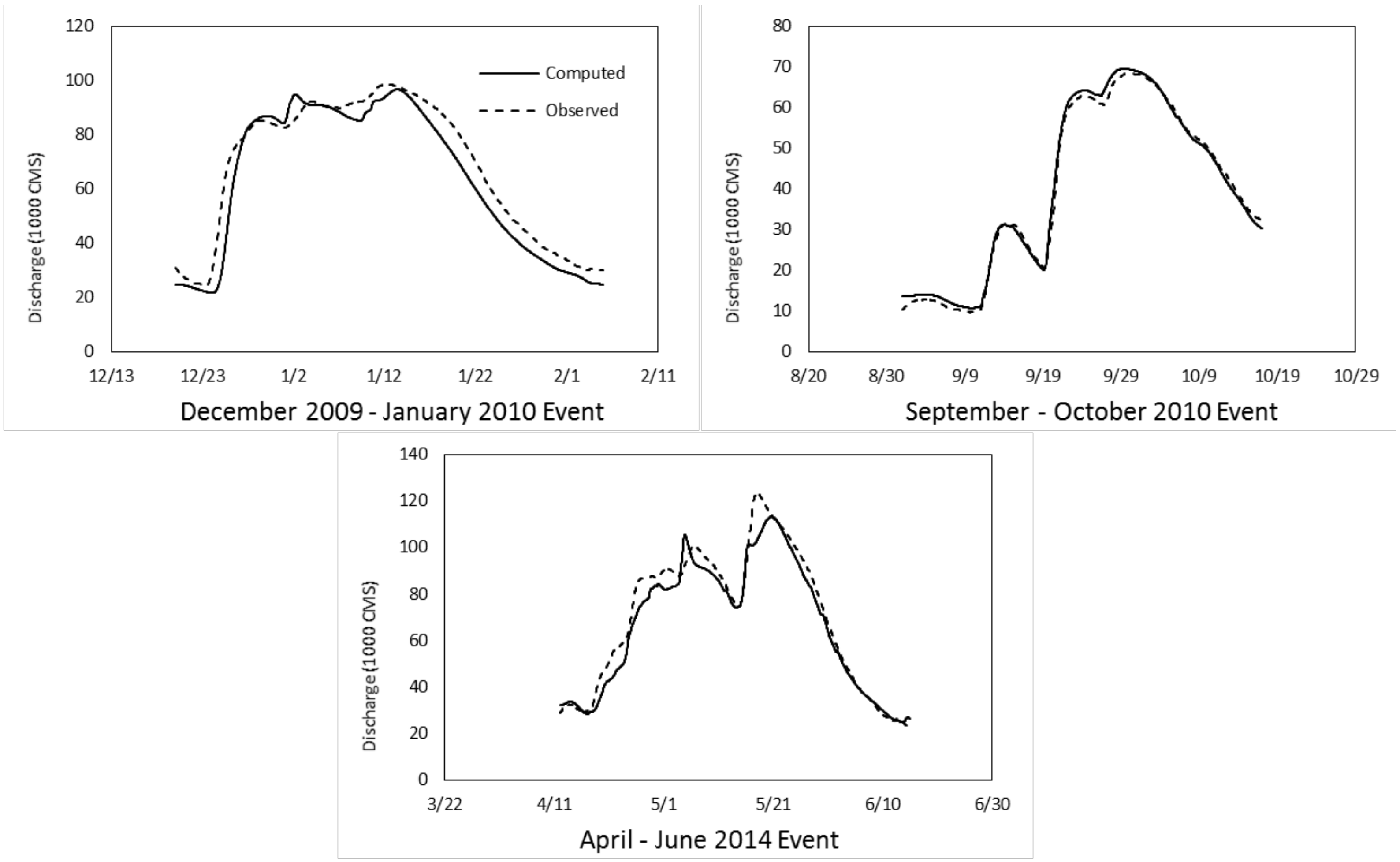


Figure 120: Calibration Plots for the Slovanski Brod Gauge for Various Calibration Events

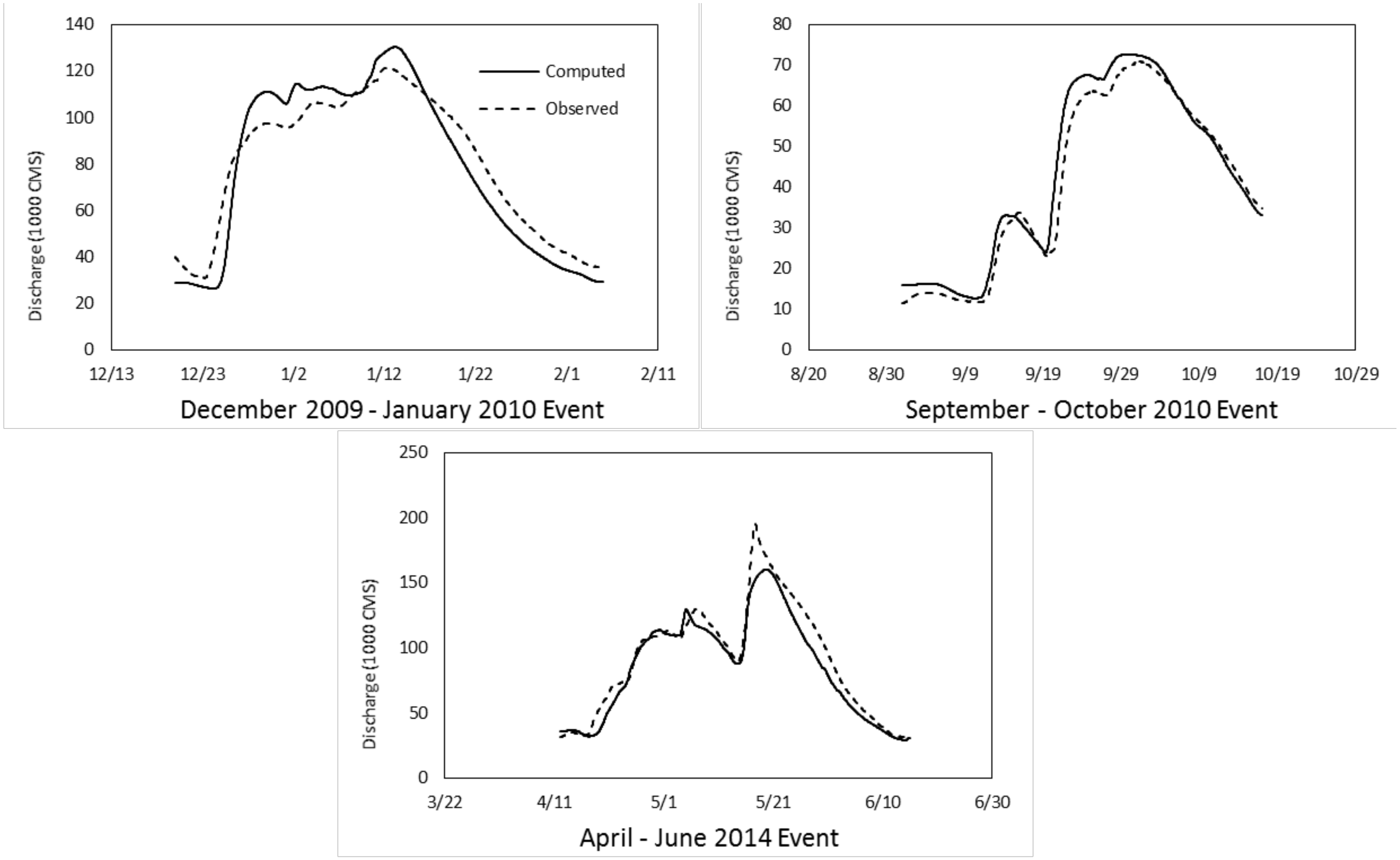
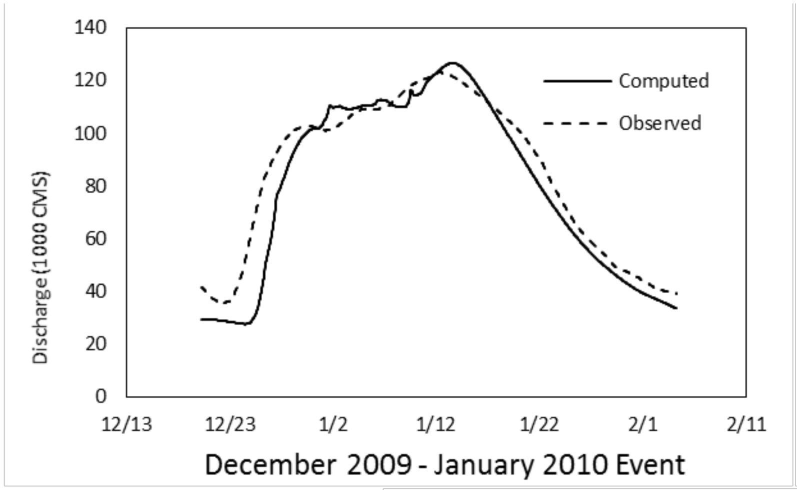
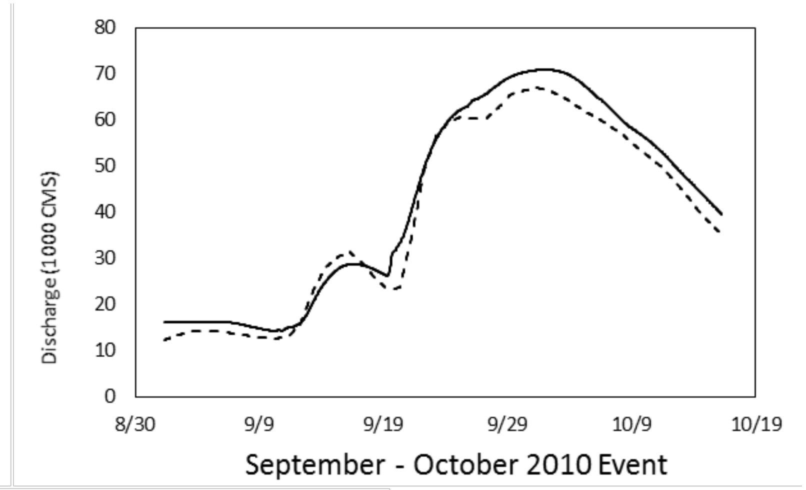


Figure 121: Calibration Plots for the Zupanja Gauge for Various Calibration Events





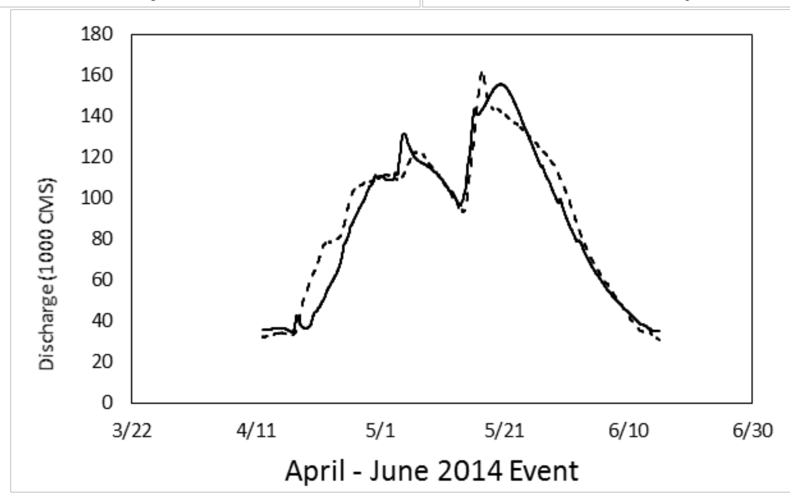


Figure 122: Calibration Plots for the Jamena Gauge for Various Calibration Events

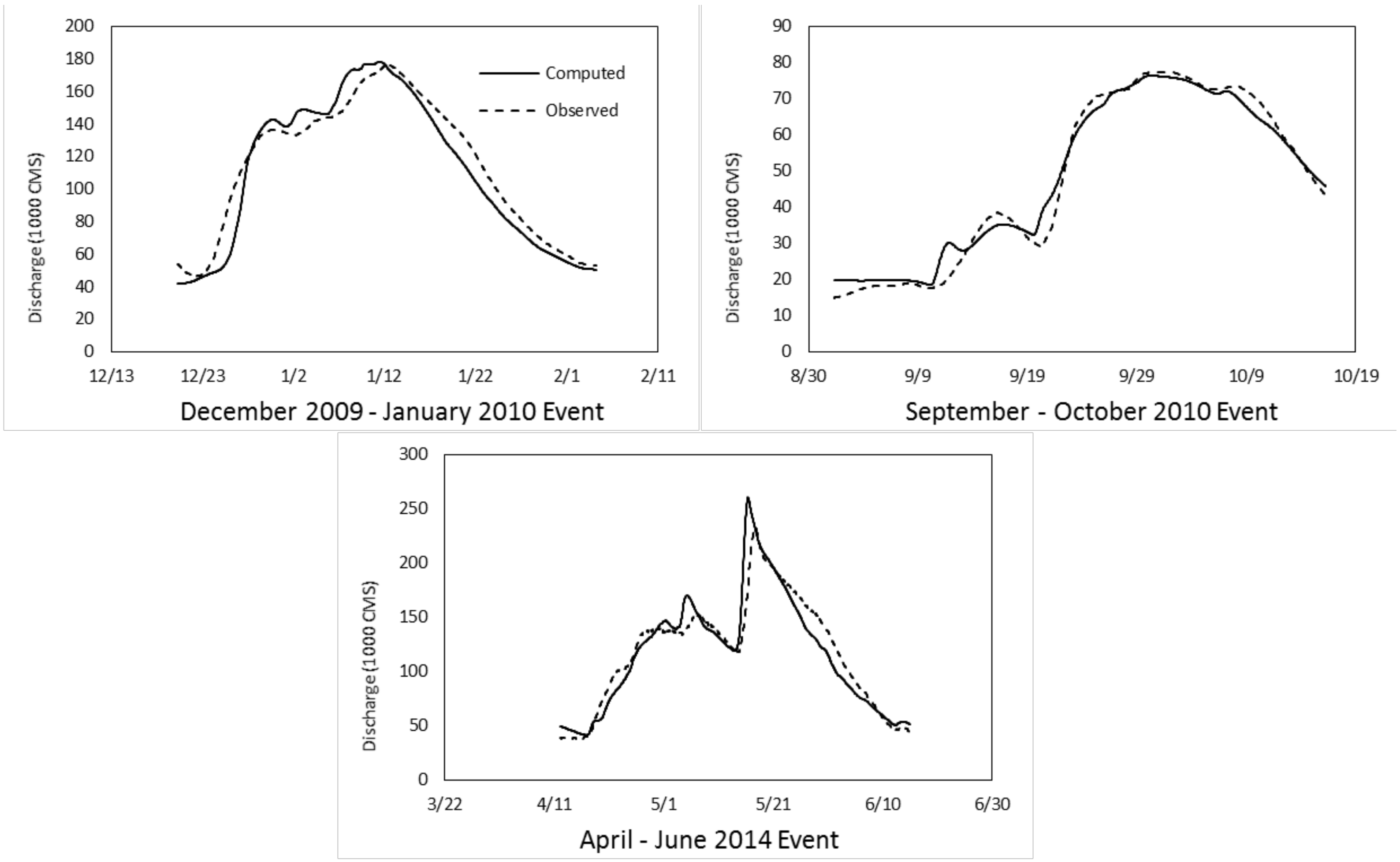


Figure 123: Calibration Plots for the Sremska Mitrovica Gauge for Various Calibration Events

Table 69: Sava Mainstem 03 Watershed HEC-HMS Model Performance Metrics

Gauge	Event	Observed Peak Q (CMS)	Computed Peak Q (CMS)	Peak Q Percent Difference	Nash-Sutcliffe Efficiency
Jesenice	Dec 2009 - Jan 2010	2135	2450	14.8%	0.950
	Sep - Oct 2010	3795	3970	4.6%	0.996
	Apr - Jun 2014	607	645	6.3%	0.818
Podsused Zicara	Dec 2009 - Jan 2010	2305	2485	7.8%	0.951
	Sep - Oct 2010	3360	4210	25.3%	0.930
	Apr - Jun 2014	646	665	2.9%	0.831
Zagreb	Dec 2009 - Jan 2010	2245	2415	7.6%	0.946
	Sep - Oct 2010	2850	3010	5.6%	0.978
	Apr - Jun 2014	656	668	1.8%	0.858
Jasenovac	Dec 2009 - Jan 2010	2320	2670	15.1%	0.961
	Sep - Oct 2010	1985	2050	3.3%	0.969
	Apr - Jun 2014	2340	2585	10.5%	0.883
Stara Gradiska	Dec 2009 - Jan 2010	2210	2325	5.2%	0.947
	Sep - Oct 2010	1770	2015	13.8%	0.967
	Apr - Jun 2014	2570	2335	-9.1%	0.846
Mackovac	Dec 2009 - Jan 2010	2400	2330	-2.9%	0.952
	Sep - Oct 2010	1785	1775	-0.6%	0.998
	Apr - Jun 2014	2765	2570	-7.1%	0.978
Davor	Dec 2009 - Jan 2010	2615	2700	3.3%	0.951
	Sep - Oct 2010	1905	1940	1.8%	0.996
	Apr - Jun 2014	3200	3090	-3.4%	0.976
Slovanski Kobas	Dec 2009 - Jan 2010	2760	2730	-1.1%	0.948
	Sep - Oct 2010	1915	1955	2.1%	0.995
	Apr - Jun 2014	3450	3135	-9.1%	0.966
Slovanski Brod	Dec 2009 - Jan 2010	2800	2740	-2.1%	0.923
	Sep - Oct 2010	1940	1970	1.5%	0.995
	Apr - Jun 2014	3495	3205	-8.3%	0.958
Zupanja	Dec 2009 - Jan 2010	3440	3690	7.3%	0.877
	Sep - Oct 2010	2010	2060	2.5%	0.962
	Apr - Jun 2014	5540	4535	-18.1%	0.931
Jamena	Dec 2009 - Jan 2010	3490	3590	2.9%	0.873
	Sep - Oct 2010	1900	2010	5.8%	0.968
	Apr - Jun 2014	4610	4405	-4.4%	0.930
Sremska Mitrovica	Dec 2009 - Jan 2010	5020	5050	0.6%	0.928
	Sep - Oct 2010	2190	2160	-1.4%	0.981
	Apr - Jun 2014	6600	7370	11.7%	0.893

5. MODEL LIMITATIONS

Limitations and uncertainty in a hydrologic model can be related to several different sources such as data accuracy and availability, knowledge uncertainty, and model method limitations. Understanding of a particular model's limitations is an important factor to ensure proper application of the model and to improve the model as new data and modeling techniques become available. The major areas of limitations and uncertainty for this hydrologic model include:

1. Meteorologic data availability and coverage
2. Subbasin and river network delineation
3. Flood attenuation characterization of flood protection systems
4. Soil loss method
5. Snow data availability
6. Reservoir regulation at various dam

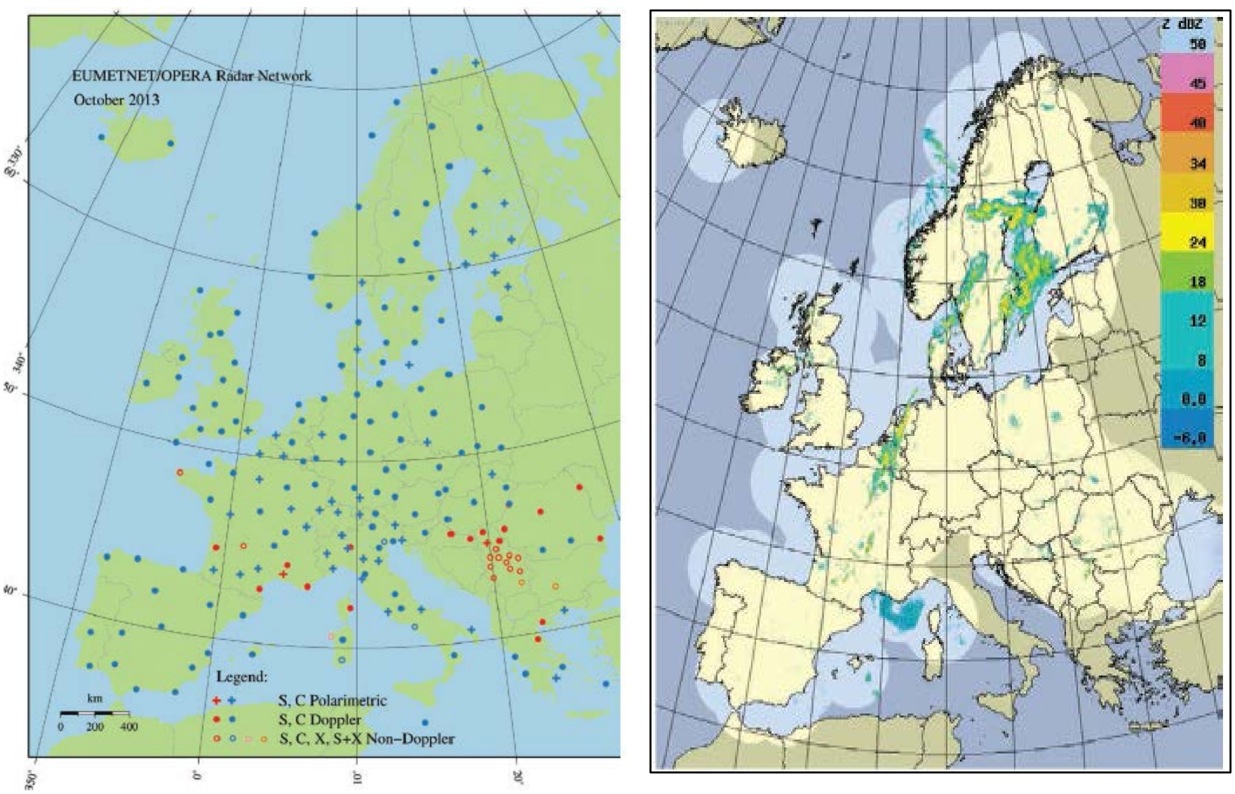
5.1 METEOROLOGIC DATA

Meteorologic inputs are typically the greatest limitation in any hydrologic model because meteorology is such a random and natural phenomenon. The ISRBC provided precipitation and air temperature time series records at an hourly or less time interval for approximately 100 meteorologic stations that span across the entire Sava River Watershed. In general, the quality and consistency of the data provided is adequate for this study; however, the density of station coverage varies dramatically across the basin as shown in Figure 10 from Section 3. Figure 10 illustrates the coverage issue with the meteorologic station network showing that the upper portion of the basin has a very detailed density of stations while the middle and especially the lower portion has an insufficient coverage of stations. The IDW meteorologic method in HEC-HMS, used to model precipitation, relies heavily on the location and density of stations because the precipitation applied at any given subbasin is computed by interpolating between measured precipitation values at these stations. If the spacing between stations is too great, a storm could pass between two stations and not be recorded at either station, which means that HEC-HMS would not register this storm and apply the proper precipitation to the subbasins between the stations. In addition, if a storm does not pass over enough stations to capture the shape and volume of the storm, the HEC-HMS model will not accurately apply precipitation to the adjacent subbasins. These inherent limitations exist for all meteorologic models relying on point stations, which is why acquiring the best available data and quality controlling this data is critical to the performance of the hydrologic model.

The two immediate solutions are increasing the density of stations in areas with limited or insufficient coverage and/or incorporating radar-based gridded precipitation data into the HEC-HMS model. For a robust flood forecasting system, incorporating both gauge- and radar-based precipitation is the best solution to create redundant data sources and to protect against one of the source data feeds failing.

Radar-based precipitation has become a standard data source for hydrologic models across the world because it solves the issue of spatial coverage of precipitation data that exists with readings at meteorologic stations. Radar-based data is measured and collected at Doppler stations, which can record precipitation for large radii around a station. Readings from a network of multiple Doppler stations can be collected and combined to cover entire areas of interest providing a continuous data source. As with any measurement, raw radar-based data possesses some level of uncertainty and must be verified and corrected to measurements made at standard single-point meteorologic stations further emphasizing the need for ground stations. In spite of this uncertainty, radar-based data, when processed through proper quality controls, provides the spatial and temporal distribution of precipitation data necessary for large, complex hydrologic models such as the Sava River Basin model.

The European National Meteorological Services Network (EUMETNET), with members from the European Union and Balkans, collaborate and produce network-wide radar mosaics through the Operational Program for Exchange of Weather Radar Information (OPERA), which could provide a source of radar-based information for all of the Sava River Basin based on Figure 124 (Huuskonen et. al. 2014)



(a) Map of European Radar Networks **(b) Sample of radar-based product**

Figure 124: OPERA radar network maps and products (Huuskonen et. al. 2014)

Figure 124 shows that the OPERA radar mosaic dataset could be a viable source of gridded precipitation for future improvements to the Sava River Basin HEC-HMS model.

5.2 SUBBASIN DELINEATION

Along with meteorological inputs, subbasin delineation accuracy and resolution is another major limitation for hydrologic modeling studies. As discussed in Section 3, the delineation for the Sava River Basin relied heavily on existing basin delineations and river networks provided by the ISRBC and its member countries. Detailed pre-processing of the SRTM DEM using the existing information was completed using HEC-GeoHMS to produce a final subbasin delineation and river network for the HEC-HMS model.

The resolution of the delineation is above adequate for the detail needed to simulate floods at the scale required for this study; therefore, it does not pose a significant limitation to the modeling product. The limitations related to the accuracy of the delineation primarily include resolution and accuracy of the SRTM DEM, man-made features in the basin such as levees, dikes, and canals, and natural phenomenon such as flat topography and karst geology. Many of these limitations were addressed by using the existing data provided and intensive processing of the DEM using aerial imagery to define these specific features that affect the development of an adequate delineation and river network. The limitations related to the delineation and river network do not create a significant effect on the accuracy of this study's modeling product; however, if more detailed analysis is desired for smaller scale studies in the future, special care should be taken to ensure the quality of the subbasin and river network delineation is adequate for the resolution of the study.

5.3 SAVA RIVER BASIN FLOOD PROTECTION SYSTEM

A complex system of flood protection measures have been incorporated into the Sava River Basin that dramatically attenuate the flood wave propagation down the mainstem Sava River protecting the extensive mainstem levees and the population protected by these levees. The flood protection system very effectively utilizes overflow weirs and gated structures to divert flood waters out of the Sava River into specific natural retention areas. The levee system along the mainstem Sava River effectively isolates the Sava River from its historical floodplain, which protects a large population of the basin that inhabit areas of the historical floodplain but also increases the risk of possible levee breaches and overtopping along the mainstem Sava River. The flood protection system allows for the levee protection needed in the basin while also opening up strategic areas of the historical floodplain for flood storage to reduce the risk of levee failure through breaching and overtopping. Figure 125 illustrates a schematic of the flood protection system.

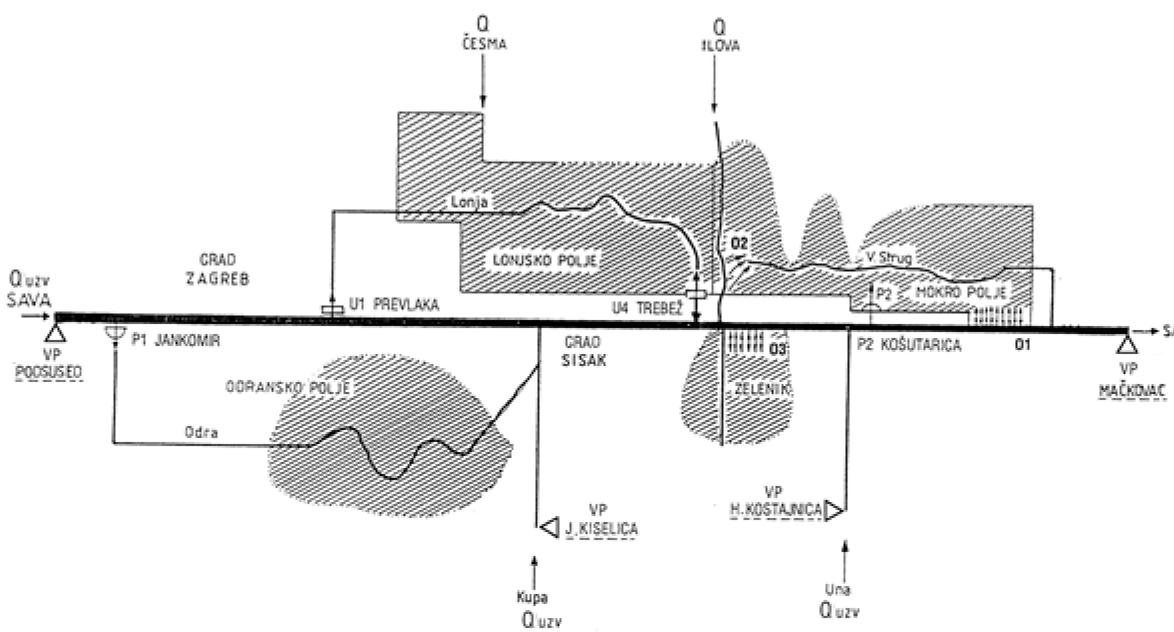


Figure 125: Sava River Flood Protection System Schematic

The flood protection system poses a modeling software and data availability limitation. HEC-HMS is not capable of handling the operation of structures like Prevlaka and Trebez Gates. For the calibration of the model, observed data for these two structures was used to properly divert flows from the mainstem Sava River. For some of the other features of the system like the overflow weirs, physical characteristics of the weirs were provided; however, HEC-HMS needs additional information in order to compute the flow diverted over these weirs like an elevation-discharge rating on the mainstem which is used to convert discharge to water surface elevation to determine head on the weir for the computation of flow over the weir using the weir equation. For the Jankomir Weir, adequate information was available and incorporated into the model. For the Palenjek and the Kosutarica Weirs, insufficient information was available to represent the flow diverted over these weirs; therefore, observed information at Sava River gauges was used to correct for this insufficiency. In addition to these man-made type features, there are two major areas where the levee orientation allows for flood waters to flow out into the natural Zelenik and Mokro Polje retention areas producing a very beneficial attenuation of the flood wave. In order to properly model these areas hydrologically, a relationship between elevation, storage, and discharge must be developed to represent the flood wave routing through these specific reaches. Currently, the necessary information and modeling is not available to develop these relationships; therefore, observed discharges were used to override the improperly computed discharges in HEC-HMS.

This flood protection system is very complex with multiple interconnections that poses a difficult hydrologic modeling problem. For now, this complexity is handled by the model through use of observed data to eliminate the deficiency in the model structure. However, in the future, the HEC-RAS hydraulic model being produced in the next step of this project and new LiDaR data currently being collected can be used to minimize these limitations.

5.4 SOIL LOSS METHOD

The hydrologic modeling developed for this project uses the deficit-constant soil loss method, which is fairly simplified conceptually. This method is commonly used for large basins within USACE because it can efficiently and relatively effectively be used for flood forecasting applications. This method requires a minimal amount of parameter inputs providing the user with flexibility and control over the model outputs. The disadvantages of this method are its ability to maintain soil moisture accounting over an extended period of time and it requires foreknowledge of current soil moisture conditions in the basin. Consequently, this method does not perform well for longer simulation periods because it is not complex enough to properly track soil moisture over a long period of time. HEC-HMS has the capability to use more complex soil loss methods such as the Soil Moisture Accounting (SMA) method; however, the inputs required to develop and calibrate this method are more extensive. If the future desire is to use this model for more long-term simulations, USACE recommends the possible inclusion of a more complex soil loss method.

5.5 SNOW DATA AVAILABILITY

The HEC-HMS model developed for this project uses the Temperature Index method as described in Section 3. This snowmelt method relies on air temperature gauges to define the snow pack across several elevation bands within each subbasin and to determine the building and melting of the snowpack throughout the simulation. This method requires a large number of parameters that were derived from the WATCAP model and through discussion with USACE snow experts. The main limitation of the snowmelt modeling is related to data availability and the resolution of the satellite-based snow-water-equivalent grids used to initialize the snowpack in the model.

Based on discussions with the ISRBC and several member countries, snowmelt is a process that effects runoff in certain portions of the Sava River basin. In future improvements to this model, a special study of the snowmelt portion should be conducted using measured snow data, which does exist but was not available for this study, in order to improve the estimation of the snowmelt method parameters. Although snowmelt is an important process in the basin, this was not a major limitation experienced during the calibration process either because calibration events did not have major snowmelt runoff or because the method used adequately represented the snowmelt characteristics in the basin.

5.6 RESERVOIR REGULATION AT DAMS

Similarly to the discussion on Prevlaka and Trebez Gates, HEC-HMS is not capable of representing the operations of gated or controlled structures. Most of the dams within the Sava River Basin are primarily used for hydropower production and water supply. For lower level flood events, the regulation at these structures can have a dramatic effect on the outflow hydrograph from these structures, which makes them important for managing the system as a whole. The ISRBC provided the locations of all dams and hydropower plants, and the subbasin delineation reflects these locations. In addition, the ISRBC gathered and provided relevant data for the dams such as observed inflow/outflow, physical characteristics, and elevation-storage relationships for the dams. The goal for this study was to incorporate the dams as well as possible based on the information provided, which for certain dams was insufficient. Because HEC-HMS is not capable of realistically representing the outflow characteristics for controlled structures, observed outflow data was used, where available, to override the HEC-HMS computed outflows. In cases where outflow data was not available, the available data was used to produce the best possible solution; although, the results should not be considered adequate. Therefore, additional data should be collected to improve the parameters used to represent these structures. USACE recommends the incorporation of a true reservoir regulation model, such as HEC-RESSIM, to properly represent the operations of these structures.

6. SUMMARY AND RECOMMENDATIONS

The Sava River and its tributaries represent a major flood risk within the Sava River Basin, which touches portions of Slovenia, Croatia, Bosnia and Herzegovina, Serbia, and Monte Negro. Recent history and a better understanding of climate change shows that this flood risk has become and will continue to be a significant risk to the welfare of the people within the Sava River Basin. This flood risk emphasizes the need for hydrologic modeling capable of simulating medium to large flood events. The hydrologic model developed through this project provides the ISRBC and its member countries with a detailed event-based hydrologic model of the entire Sava River Basin that performs well over a wide-range of flood events as shown in the previous sections of this report. In addition, individual HEC-HMS models were developed for each major tributary basin and for local subbasins to the Sava River mainstem providing the ISRBC and member countries with the ability to simulate flooding in the Sava River Basin at various scales, individual tributary basin or entire Sava River watershed. This multi-scale functionality was identified as a need by the ISRBC during the beginning phases of this project. An index map showing how each tributary and mainstem HEC-HMS model is linked together is provided in Appendix C.

The goal of this project was to provide a calibrated hydrologic model using HEC-HMS software and the best available data. The general approach to provide the best calibration included the following steps.

1. **Develop separate HEC-HMS models for each tributary basin and the mainstem local basins**.
2. **Calibrate each tributary basin model** to larger flood events using the historical stream flow and precipitation data to identify critical events with reasonable precipitation data that specifically affect the tributary basin of interest. Due to the size of the Sava River Basin, flood events can occur autonomously in certain areas of the basin while no flooding is experienced in other areas. Identifying critical events for each tributary basin provides the best opportunity to calibrate the HEC-HMS model for each tributary.
3. **Identify longer, larger events that resulted in a wide-spread flood event across large portions of the Sava River Basin.** Several events were identified, and three events were chosen: December – February 2009; September – October 2010; and April –June 2014. These events affect large portions of the watershed and also include the activation of several of the flood protection measures within the basin.
4. **Calibrate the local subbasins to the mainstem Sava River** to the three basin-wide events (described in step 3) in order to account for the long travel time and flood wave propagation through the basin. Observed stream flow data was used for the tributary inputs to produce the best possible calibration of the local subbasins to the Sava River.
5. **Combine all tributary and local mainstem HEC-HMS models into a single HEC-HMS** that covers the entire Sava River Basin.
6. **Calibrate the entire Sava River Basin HEC-HMS model** to the three basin-wide events. This final step delivers a single Sava River HEC-HMS model and also provides a verification of the individual tributary calibrations. Generally, the Sava River Basin HEC-HMS model performs well; however, the limitations of the modeling products are provided in the Section 5.

The performance metric tables and calibration plots within the Section 4 of this report shows that an above average calibration was achieved for the various hydrologic models developed over the course of this project. The percent differences in discharge hydrograph peak and volume show that these models adequately capture the general runoff characteristics of the basin while the Nash-Sutcliffe efficiencies (NSE) and calibration plots show that the hydrologic models perform well and adequately represent the overall shape and timing of the output discharge hydrographs within the basin. Table 70 shows that, generally, the maximum percent difference between observed and computed peak discharges and runoff volume totals is about +/-10% with most values being between +/-5%. The exception to this result is the Kolubara River Basin, which had very poor meteorologic station coverage. As presented in Section 4 of this report, the NSE's across the entire Sava River Basin are generally greater than 0.85 with many of the simulations resulting in values greater than 0.90. The purpose of providing these summary statistics is to provide a general indication of the hydrologic model performance. Further investigation of the Section 4 results show that there is a range of performance across various watersheds and calibration events with a few underperforming simulations, which in most cases can be attributed to the lack of meteorologic station coverage. Ultimately, the calibration results show that the hydrologic models perform very well in the representation of the runoff characteristics of the basin.

Table 70. Summary Performance Statistics across Sava River Basin HEC-HMS Model

Tributary Basin	Average Peak Discharge Percent Difference	Average Hydrograph Volume Percent Difference
Slovenia	5.3%	-7.6%
Sutla	9.9%	-5.9%
Krapina	3.5%	-2.4%
Kupa	-0.6%	-13.8%
Cesma	2.5%	-7.5%
Ilova	-8.4%	-9.3%
Una	0.9%	-2.0%
Vrbas	5.1%	-2.3%
Orljava	-2.7%	-4.4%
Ukrina	No Gauges for Analysis	
Bosna	-2.0%	6.6%
Tinja	-0.7%	7.0%
Drina	-7.5%	-6.3%
Bosut	No Gauges for Analysis	
Kolubara	-18.9%	-31.9%
Sava Mainstem Locals	Not Applicable due to Extensive Use of Observed Data for Calibration	
Combined Average	**-1.1%**	**-6.1%**

Section 5 discusses several limitations of the hydrologic models developed for this project. The major areas of limitations are meteorologic inputs and representation of the flood protection system. Other limitations and uncertainties in the modeling exist, as discussed in Section 5, and improvements can be made to mitigate or reduce some of these issues.

The basin consists of a varying coverage density of meteorologic stations with a comprehensive distribution of stations in the upstream portion of the basin and limited to insufficient distribution in the middle to downstream portions of the basin. The results of this project indicate the advantages of having a comprehensive meteorologic station network. In areas with ample station coverage, the model calibration results were more accurate and the parameter estimations between various calibration events were much more consistent. Precipitation inputs is the greatest limitation in the modeling product; therefore, USACE recommends improvements to the precipitation network. These improvements can be achieved in two ways:

1. Increasing the density of stations in areas of the basin where limited or insufficient coverage exists
2. Identifying and incorporating radar-based gridded precipitation into the hydrologic model

Based on research, radar-based gridded precipitation coverage already exists over a majority of the basin; therefore, access to this data and a mechanism to retrieve this data could to be established. In the case where this hydrologic model will be used for flood forecasting, developing access to multiple sources of precipitation inputs is the best practice in order to be prepared in case the data feed for one of the sources should fail.

The limitations related to data availability for the flood protection system can easily be solved with the incorporation of existing or new data and modeling. Gated structures such as Prevlaka and Trebez will be limitations unless improvements are made to HEC-HMS or software like HEC-RESSIM are incorporated into the system. For the other features of system such as weirs and overflow areas, these features can be better characterized using the HEC-RAS hydraulic model, which will be developed as part of this project, and high resolution LiDaR data, which is currently being collected. Therefore, USACE recommends using the future HEC-RAS model to develop the information required to better characterize the flood protection system.

Special care was taken to derive the most accurate subbasin delineation possible using existing data and the SRTM DEM for this project, and USACE believes the current delineation is sufficient for this scale of model. However, the delineation can still be improved with better data especially in the flatter areas of the basin where the DEM resolution is not precise enough to capture smaller changes in topography and areas where man-made dikes and channels create unnatural changes in the basin's flow network. In addition, if more detailed hydrologic analysis of smaller areas within the basin, such as in the area of Sarajevo, is anticipated, the current information is not sufficient to derive an accurate delineation. USACE recommends the incorporation of any higher resolution topographic information as it becomes available. When more accurate topographic information becomes available, HEC-GeoHMS can be used to pre-process the data to produce a better delineation and river network.

In addition to these recommendations, future improvements to the hydrologic model could include:

1. A more detailed analysis of snowmelt to ensure that the current method is properly representing snowmelt in the basin;
2. Development of a more complex soil loss method capable of long-term soil moisture accounting; and

3. Better incorporation of information related to the dams and hydropower plants and/or the development of a true reservoir regulation model that can adequately capture the operations of these structures.

Based on discussions with the ISRBC, the hydrologic models developed during this project should provide a vast improvement to flood modeling capability for most ISRBC member countries. The results show that the hydrologic models provided are sufficient for most flood event situations. With improved precipitation inputs, the accuracy of these hydrologic models will only improve.

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APPENDIX A: FINAL HYDROLOGIC MODEL PARAMETER TABLES

Table A - 1: Summary of Basin Hydrologic Parameters for the Sava River Basin Model

Subbasin	Soil Loss Parameters				Transform Parameters		Baseflow Parameters		
	Initial Def (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)	Tc (hr)	R (hr)	Initial Q (m^3/s per km^2)	Recession Constant	Ratio to Peak
W_01_01_01A	20	50	1.5	1.9	6.8	17.5	0.016	0.9	0.21
W_01_01_01B	20	50	1.5	1.9	9	28.5	0.016	0.9	0.19
W_01_02_02	20	50	1.5	1.6	5.4	20	0.016	0.9	0.18
W_01_02_03A	20	50	1.5	3.9	4.7	17.3	0.016	0.9	0.18
W_01_02_03B	20	50	1.5	3.9	0.2	0.7	0.016	0.9	0.18
W_01_03_02	20	50	1.6	7.2	7.2	32.3	0.016	0.9	0.18
W_01_04_01	20	30	1.3	3.1	7	160	0.016	0.9	0.16
W_01_05_02	20	50	1.5	16.2	2.5	10	0.016	0.9	0.18
W_01_05_05	20	50	1.6	3.1	7	29.8	0.016	0.9	0.18
W_01_06_02	20	50	1.6	2.6	5	20.8	0.016	0.9	0.25
W_01_07_01	20	50	0.4	0.4	8.3	12.2	0.016	0.9	0.14
W_01_08_02	20	50	0.6	3.4	4	15	0.016	0.9	0.14
W_01_09_02	20	50	0.7	0.9	3.8	15.3	0.016	0.9	0.14
W_01_10_01	20	50	1	0.9	17	108.3	0.016	0.9	0.18
W_01_11_02	20	50	0.9	1.8	16.3	70	0.016	0.9	0.18
W_01_12_02	20	50	1.1	0.8	13	68.8	0.016	0.9	0.18
W_01_13_02	20	50	1.5	3.4	1.8	8	0.016	0.9	0.18
W_01_13_06A	20	50	1.5	1.9	2.2	6.6	0.016	0.9	0.18
W_01_13_06B	20	50	1.5	1.9	0.8	2.4	0.016	0.9	0.18
W_01_13_06C	20	50	1.5	1.9	10.2	30.6	0.016	0.9	0.18
W_01_13_06D	20	50	1.5	1.9	4.2	12.6	0.016	0.9	0.18
W_01_13_06E	20	50	1.5	1.9	2.4	7.2	0.016	0.9	0.18
W_01_13_07	20	50	1.4	3.5	5.5	22	0.016	0.9	0.18

Subbasin	Soil Loss Parameters				Transform Parameters		Baseflow Parameters		
	Initial Def (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)	Tc (hr)	R (hr)	Initial Q (m^3/s per km^2)	Recession Constant	Ratio to Peak
W_01_13_10	20	50	0.9	2.3	4	16	0.016	0.9	0.18
W_02_01_01	18	75	1.1	0.8	13.5	22.5	0.0078	0.89	0.15
W_02_02_02	23	75	0.9	1.3	5	14.2	0.0169	0.9	0.12
W_02_03_02	19	75	0.9	4.2	1.7	6.5	0.0166	0.9	0.12
W_03_01_03	15	75	1	4.7	4	16.1	0.007	0.9	0.1
W_04_01_01_Gubasevo	28	75	1.58	0.5	10	31.5	0.004	0.9	0.06
W_04_02_01	24	75	1.58	1.5	17.2	45.8	0.0038	0.9	0.12
W_04_02_04	29	75	1.58	1.2	6	18	0.0038	0.9	0.12
W_04_02_07	29	75	1.58	6.5	5.5	16.2	0.0034	0.9	0.11
W_05_01_03	15	75	1	20.6	4.9	19.6	0.007	0.9	0.1
W_05_01_06A	15	75	1	28.7	4.3	20	0.007	0.9	0.1
W_05_01_06B	15	75	1	28.7	1	1.1	0.007	0.9	0.1
W_06_01_01	20	50	0.9	0.8	10.8	31.5	0.01	0.85	0.15
W_06_02_01	20	50	0.5	0.9	12	47.5	0.008	0.85	0.15
W_06_03_02	20	50	1	0.1	15.5	61.3	0.01	0.85	0.15
W_06_04_01_Juzbasici	20	50	0.8	0.3	19.8	61.8	0.01	0.85	0.15
W_06_05_03	20	50	1.2	4.6	5.3	25.5	0.01	0.85	0.15
W_06_06_02	20	50	1	1.8	13.8	80	0.01	0.85	0.15
W_06_06_03A	20	50	0.9	1.3	4	40	0.01	0.85	0.15
W_06_06_03C	20	50	0.9	1.3	4	40	0.01	0.85	0.15
W_06_06_07	20	50	1	0.7	12.8	54.3	0.01	0.85	0.15
W_06_06_08	20	50	0.9	1.6	3.2	13	0.01	0.85	0.15
W_06_06_11	20	50	0.9	19.5	2	10	0.01	0.85	0.15

Subbasin	Soil Loss Parameters				Transform Parameters		Baseflow Parameters		
	Initial Def (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)	Tc (hr)	R (hr)	Initial Q (m^3/s per km^2)	Recession Constant	Ratio to Peak
W_06_06_12	20	50	0.9	13	3	12	0.01	0.85	0.15
W_06_06_15	20	50	1.1	2.9	26.3	57.5	0.01	0.85	0.15
W_06_06_16	20	50	1	2.8	12.5	43.5	0.01	0.85	0.15
W_06_07_02	20	50	0.9	1.4	25	56.3	0.01	0.85	0.15
W_06_08_01	20	50	1.1	0.4	30	63.5	0.008	0.85	0.15
W_06_09_02	20	50	1.1	0.4	16.3	45.8	0.01	0.85	0.15
W_06_10_02	20	50	1	0.6	13.5	35	0.01	0.85	0.15
W_06_10_05	20	50	0.8	1.5	13.8	32.5	0.01	0.85	0.15
W_06_10_08	20	50	0.9	4.6	25	31.3	0.01	0.85	0.15
W_06_10_09	20	50	0.9	6.7	11	44	0.01	0.85	0.15
W_06_10_12	20	50	0.9	53.8	1	2	0.01	0.85	0.15
W_07_01_03	15	75	1	2.4	8.3	33.3	0.007	0.9	0.1
W_08_01_01	14	75	2.1	2.3	18.4	63.3	0.0034	0.72	0.1
W_08_02_01	5	75	1.8	1.3	15.7	32.3	0.0048	0.9	0.1
W_08_03_03	17	75	0.9	3.2	11.3	61.5	0.0047	0.9	0.1
W_08_03_04	17	75	0.9	4.1	3.2	17.3	0.0047	0.9	0.1
W_08_03_07	17	75	0.9	1.4	23.4	128.1	0.0047	0.9	0.1
W_08_03_08	17	75	0.9	3	21.5	118.8	0.0047	0.9	0.1
W_08_03_11	15	75	1	7.5	18.4	55.8	0.001	0.9	0.1
W_08_03_12	15	75	1	3.5	12	36.6	0.001	0.9	0.1
W_08_03_15	15	75	1	1.6	20.8	62.4	0.001	0.9	0.1
W_08_03_16	15	75	1	1.9	14.4	42.9	0.001	0.9	0.1
W_08_03_19	15	75	1	2.2	29.2	87.3	0.001	0.9	0.1

Subbasin	Soil Loss Parameters				Transform Parameters		Baseflow Parameters		
	Initial Def (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)	Tc (hr)	R (hr)	Initial Q (m^3/s per km^2)	Recession Constant	Ratio to Peak
W_09_01_03	15	75	1	14.4	0.6	2.4	0.007	0.9	0.1
W_10_01_01_VVukovje	1	75	0.78	4.9	48.8	55	0.0068	0.9	0.1
W_10_02_01	4	75	0.74	1.7	43.8	43.8	0.0038	0.9	0.1
W_10_02_04	15	75	1	8.8	4.1	24	0.001	0.9	0.1
W_11_01_03	15	75	1	3.7	4.1	16.4	0.007	0.9	0.1
W_12_01_01	5	50	0.57	0.4	33	54	0.028	0.93	0.61
W_12_01_02	5	50	0.57	0	37	55	0.028	0.93	0.62
W_12_02_02	5	50	1.53	1.1	14	35	0.034	0.95	0.29
W_12_02_03	5	50	1.53	1.6	14	34	0.034	0.95	0.28
W_12_03_01	5	50	1	0.1	20	37	0.017	0.86	0.28
W_12_03_04	5	50	1	0.5	22	37	0.017	0.86	0.3
W_12_04_02	5	50	1.37	0.1	25	49	0.017	0.92	0.25
W_12_04_03	5	50	1.37	2.1	17	26	0.017	0.92	0.25
W_12_04_07	5	50	1.37	2.9	30	45	0.017	0.9	0.25
W_12_04_08	5	50	1.37	2.1	11	26	0.017	0.92	0.25
W_12_04_11	5	50	1.37	0.1	27	37	0.018	0.92	0.25
W_12_04_12	5	50	1.37	2.3	12	23	0.017	0.92	0.25
W_12_04_15	5	50	1.37	1.4	18	35	0.017	0.92	0.25
W_12_04_16	5	50	1.37	6.3	4	4	0.017	0.92	0.25
W_12_04_19	5	50	1.37	0.5	9	20	0.017	0.9	0.25
W_12_05_02	5	50	1.62	2	5	10	0.013	0.9	0.25
W_12_06_02	5	50	0.69	1.3	7	14	0.017	0.92	0.26
W_12_06_05	5	50	3.65	2.9	3	7	0.012	0.9	0.25

Subbasin	Soil Loss Parameters				Transform Parameters		Baseflow Parameters		
	Initial Def (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)	Tc (hr)	R (hr)	Initial Q (m^3/s per km^2)	Recession Constant	Ratio to Peak
W_13_01_03	15	75	1	3.2	9.6	38.4	0.007	0.9	0.1
W_13_01_05	15	75	1	0.7	7.2	29	0.007	0.9	0.1
W_13_01_08	15	75	1	2.4	5	19.8	0.007	0.9	0.1
W_13_01_11	15	75	1	4.4	5.2	20.8	0.007	0.9	0.1
W_14_01_01	5.33	50	0.67	0.6	18	41	0.029	0.89	0.43
W_14_02_01	16.67	50	0.97	0.4	42	26	0.007	0.75	0.4
W_14_02_05	16.67	50	0.97	0.3	36	27	0.007	0.77	0.4
W_14_02_06	13.33	50	0.97	14.1	5	5	0.013	0.9	0.5
W_14_02_09	17.67	50	0.13	0.6	8	9	0.103	0.95	0.33
W_14_02_12	17.67	50	0.13	0.2	13	15	0.103	0.95	0.33
W_14_02_13	17.67	50	0.13	0.1	4	4	0.103	0.95	0.33
W_14_02_16	17.67	50	0.13	0.9	16	19	0.103	0.95	0.33
W_14_02_19	6.67	50	0.8	0.4	18	18	0.015	0.95	0.33
W_14_02_20	6.67	50	0.8	1	22	22	0.015	0.95	0.33
W_14_02_23	6.67	50	0.8	1.6	25	25	0.015	0.95	0.33
W_15_01_03	15	75	1	2.8	4.3	17.3	0.007	0.9	0.1
W_16_01_01_Pozega	5	75	0.51	0.6	8.5	21.3	0.0135	0.89	0.21
W_16_02_01	12	75	0.84	1.3	11.4	8	0.0088	0.9	0.23
W_16_02_04	12	75	0.84	0.9	31.5	18	0.0088	0.9	0.23
W_16_02_07	11	75	0.73	0.8	13.7	18	0.006	0.9	0.2
W_17_01_03	15	75	1	4.3	3.9	15.6	0.007	0.9	0.1
W_18_01_01	15	75	1	0	5.5	22	0.015	0.9	0.15
W_18_01_02	15	75	1	0.6	5.1	20.3	0.015	0.9	0.15

Subbasin	Soil Loss Parameters				Transform Parameters		Baseflow Parameters		
	Initial Def (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)	Tc (hr)	R (hr)	Initial Q (m^3/s per km^2)	Recession Constant	Ratio to Peak
W_18_01_05	15	75	1	2.6	5.2	21	0.015	0.9	0.15
W_18_01_06	15	75	1	0	4.7	18.9	0.015	0.9	0.15
W_18_01_09	15	75	1	1.8	6.2	24.7	0.015	0.9	0.15
W_19_01_03	15	75	1	20.1	4.4	17.6	0.007	0.9	0.1
W_19_01_06	15	75	1	3.8	10.5	42	0.007	0.9	0.1
W_20_01_01_Ilidza	17	75	1.1	1.2	7.5	16.7	0.0555	0.86	0.29
W_20_02_01_RimskiMst	14	75	0.4	2.1	6.5	8.3	0.621	0.92	0.29
W_20_03_01_Blazuj	27	75	1.4	1.5	6	21.3	0.019	0.88	0.23
W_20_04_01_Doglodi	13	75	0.8	8.5	4.5	17.4	0.027	0.88	0.23
W_20_05_01_ButileNM	13	75	0.5	6.3	7.3	21.9	0.027	0.88	0.25
W_20_06_01	13	75	0.7	1.5	5.3	26.3	0.021	0.88	0.25
W_20_06_06	13	75	0.7	45.3	1.8	10.8	0.021	0.88	0.25
W_20_06_09	13	75	0.7	6.7	1.6	5.5	0.027	0.88	0.25
W_20_06_12	13	75	0.7	0	1.1	3.9	0.027	0.88	0.25
W_20_07_01_Semizovac	21	75	0.7	0.1	6.9	12.5	0.02	0.86	0.23
W_20_08_01_Ilijas	21	75	0.5	0.5	10.2	16.1	0.02	0.84	0.2
W_20_09_01_VisokoNF	22	75	0.8	0.5	12.6	24.4	0.02	0.87	0.22
W_20_10_01_Obre	21	75	0.8	1	5.8	16.3	0.02	0.87	0.23
W_20_11_01_KakanjNZg	21	75	0.8	4	2.5	7.7	0.02	0.86	0.22
W_20_12_01	24	75	1.1	1.3	7.7	36	0.0232	0.93	0.3
W_20_12_02	24	75	1.1	0.4	5.8	26.6	0.0232	0.93	0.3
W_20_12_05	24	75	1.1	1.1	5.5	25.3	0.0232	0.93	0.3
W_20_13_02	19	75	0.9	2.4	4.2	13.8	0.02	0.86	0.22

Subbasin	Soil Loss Parameters				Transform Parameters		Baseflow Parameters		
	Initial Def (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)	Tc (hr)	R (hr)	Initial Q (m^3/s per km^2)	Recession Constant	Ratio to Peak
W_20_13_05	19	75	0.9	0.3	1.7	5.5	0.02	0.86	0.22
W_20_13_08	19	75	0.9	4.3	8.5	27.7	0.02	0.86	0.22
W_20_13_11	19	75	0.9	2.4	5	16.2	0.02	0.86	0.22
W_20_13_14	19	75	0.9	19.1	2.5	8.2	0.02	0.86	0.22
W_20_13_17	19	75	0.9	2.3	5.2	17	0.02	0.86	0.22
W_20_13_20	19	75	0.9	6.7	2.5	8.3	0.02	0.86	0.22
W_20_14_01_Stipovici	6	75	0.4	0.1	5	24.3	0.019	0.89	0.16
W_20_15_02	7	75	0.8	2.8	8.1	27.7	0.019	0.89	0.2
W_20_15_05	7	75	0.8	1.2	7.1	24.5	0.019	0.89	0.2
W_20_16_01	18	75	0.4	0.6	7.8	20.8	0.021	0.89	0.2
W_20_16_02	18	75	0.4	0.5	8	21.2	0.021	0.89	0.2
W_20_17_02	10	75	0.6	0	5.5	14.7	0.0125	0.88	0.17
W_20_17_05	10	75	0.6	0	3.8	10.1	0.0125	0.88	0.17
W_20_17_08	10	75	0.6	0.2	4.2	11.3	0.0125	0.88	0.17
W_20_18_01_Lijesnica	13	75	0.4	0	6.2	33.1	0.019	0.89	0.2
W_20_19_02	17	75	0.6	18.6	1.1	11	0.014	0.9	0.2
W_20_19_05	17	75	0.7	2.5	6.1	59.3	0.014	0.9	0.2
W_20_19_08	17	75	0.8	0	3.6	35.4	0.014	0.9	0.2
W_20_19_09	17	75	0.8	14.6	1.1	11.1	0.014	0.9	0.2
W_20_19_13	10	75	0.6	2.2	2.1	6.4	0.032	0.9	0.2
W_20_19_16	10	75	0.6	1.9	3.9	12.1	0.032	0.9	0.2
W_20_19_17	10	75	0.6	1	2.9	9.1	0.032	0.9	0.2
W_20_19_20	10	75	0.6	2.2	3.6	11.3	0.032	0.9	0.2

Subbasin	Soil Loss Parameters				Transform Parameters		Baseflow Parameters		
	Initial Def (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)	Tc (hr)	R (hr)	Initial Q (m^3/s per km^2)	Recession Constant	Ratio to Peak
W_20_19_21	10	75	0.6	1.5	2.3	7.3	0.032	0.9	0.2
W_20_19_25	10	75	0.6	1.4	4.3	13.4	0.032	0.9	0.2
W_20_19_26	10	75	0.6	8.9	1.7	5.3	0.033	0.9	0.2
W_20_19_29	10	75	0.6	1	7.9	24.7	0.033	0.9	0.2
W_20_19_32	10	75	0.6	3.8	8.2	25.4	0.033	0.9	0.2
W_20_20_01	16	75	0.2	1.1	6.4	7.9	0.011	0.86	0.12
W_20_20_04	16	75	0.2	0.4	15.1	18.8	0.011	0.86	0.12
W_20_20_07	16	75	0.2	0	2.7	3.3	0.011	0.86	0.12
W_20_21_01	15	75	0.5	2.2	11.7	36.2	0.0284	0.91	0.18
W_20_21_02	15	75	0.5	4.6	6.4	19.9	0.0284	0.91	0.18
W_20_21_05	15	75	0.5	5.9	7.4	22.9	0.0284	0.91	0.18
W_20_21_06	15	75	0.5	7	6.1	18.9	0.0284	0.91	0.18
W_20_21_09	15	75	0.5	4.7	11.9	36.8	0.0284	0.91	0.18
W_21_01_03	15	75	1	9.9	5.7	22.8	0.007	0.9	0.1
W_22_01_05A	10	75	0.27	2.2	3.3	1.8	0.001	0.9	0.1
W_22_01_05B	15	75	1	2.2	1.9	7.7	0.001	0.9	0.1
W_22_01_06	15	75	1	0.9	4	16.1	0.001	0.9	0.1
W_22_01_09	15	75	1	4	5	19.9	0.001	0.9	0.1
W_22_01_10	15	75	1	0.5	3.9	15.5	0.001	0.9	0.1
W_22_01_13	15	75	1	1.4	1.6	6.5	0.001	0.9	0.1
W_23_01_03	15	75	1	2.7	9.7	38.6	0.007	0.9	0.1
W_23_01_06	15	75	1	5.4	6.1	24.2	0.007	0.9	0.1
W_24_01_01	0	50	1.3	0.4	50	80	0.045	0.97	0.4

Subbasin	Soil Loss Parameters				Transform Parameters		Baseflow Parameters		
	Initial Def (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)	Tc (hr)	R (hr)	Initial Q (m^3/s per km^2)	Recession Constant	Ratio to Peak
W_24_01_04	0	50	1.3	0.3	40	63	0.045	0.98	0.43
W_24_02_02	5	50	0.6	1.4	40	35	0.0185	0.95	0.2
W_24_02_05	0	50	0.6	1.9	6.5	11	0.0185	0.95	0.2
W_24_03_01	0	50	1.25	0.2	18	42	0.0185	0.93	0.25
W_24_03_04	0	50	1.25	1.4	17	39	0.0185	0.93	0.25
W_24_03_07	0	50	1.25	0.2	13	29	0.0185	0.93	0.25
W_24_03_08	0	50	2.25	0	1	1	0.012	0.9	0.25
W_24_03_11A	0	50	1.25	0.5	6	15	0.0185	0.93	0.25
W_24_03_11B	0	50	1.25	0.5	16	38	0.0185	0.93	0.25
W_24_03_12	0	50	1.25	0.5	14	32	0.0185	0.93	0.25
W_24_03_15	0	50	1.25	0.2	16	36	0.0185	0.93	0.25
W_24_03_16	0	50	1.25	1.5	9	21	0.0185	0.9	0.25
W_24_03_20	11	50	1.3	0.8	30	53	0.011	0.95	0.25
W_24_03_23	5	50	0.75	3.8	32	44	0.016	0.95	0.34
W_24_03_26A	5	50	1.25	0.2	1	3	0.031	0.95	0.25
W_24_03_26B	5	50	1.25	0.2	3	8	0.031	0.95	0.25
W_24_03_27	25	50	1.25	2.1	1	3	0.031	0.95	0.25
W_24_03_30	5	50	1.25	0.4	12	27	0.0185	0.93	0.25
W_24_03_31	0	50	1.25	1.3	4	8	0.0185	0.93	0.25
W_24_03_34	0	50	1	2.6	1	3	0.0185	0.93	0.25
W_24_03_37A	0	50	0.25	0.3	1	2	0.0225	0.9	0.25
W_24_03_37B	0	50	0.25	0.3	9	20	0.0225	0.9	0.25
W_24_03_38	0	50	0.25	2.4	1	2	0.0225	0.9	0.25

Subbasin	Soil Loss Parameters				Transform Parameters		Baseflow Parameters		
	Initial Def (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)	Tc (hr)	R (hr)	Initial Q (m^3/s per km^2)	Recession Constant	Ratio to Peak
W_24_03_41	0	50	0.25	2	11	26	0.0225	0.9	0.25
W_24_04_02	0	50	0.75	0.8	9	20	0.012	0.9	0.25
W_24_04_03	0	50	0.75	0.3	8	18	0.012	0.9	0.25
W_24_04_06	0	50	0.75	1.6	23	52	0.012	0.9	0.25
W_24_04_07	0	50	0.75	4.3	1	2	0.012	0.9	0.25
W_24_04_10	0	50	0.75	5.4	2	5	0.012	0.9	0.25
W_24_04_13	0	50	0.1	3.2	2	4	0.012	0.9	0.25
W_24_04_16	0	50	0.1	3.4	9	20	0.012	0.9	0.25
W_24_04_19	0	50	0.1	5.8	9	20	0.012	0.9	0.25
W_24_05_01_Lesnica	0	50	0.1	1.4	16	36	0.012	0.9	0.25
W_25_01_03	15	75	1	16.5	1.4	5.5	0.007	0.9	0.1
W_26_01_01	35	75	1.5	3.1	7.1	28.5	0.001	0.9	0.1
W_26_01_02	35	75	1.5	2.9	6.6	26.4	0.001	0.9	0.1
W_26_01_05	35	75	1.5	4.4	5.6	22.4	0.001	0.9	0.1
W_26_01_06	35	75	1.5	1.7	2.4	9.4	0.001	0.9	0.1
W_26_01_09A	35	75	1.5	3.8	1.4	5.5	0.001	0.9	0.1
W_26_01_09B	35	75	1.5	3.8	2.8	11.4	0.001	0.9	0.1
W_26_01_09C	35	75	1.5	3.8	8.2	32.7	0.001	0.9	0.1
W_27_01_03	15	75	1	5.2	8.4	33.7	0.007	0.9	0.1
W_27_01_06	15	75	1	5.9	15.4	61.5	0.007	0.9	0.1
W_27_01_07	15	75	1	3.8	11.2	44.7	0.007	0.9	0.1
W_27_01_10	15	75	1	25.3	2.3	9.2	0.007	0.9	0.1
W_28_01_01_Slovac	25	75	0.6	1	20	30	0.005	0.9	0.25

Subbasin	Soil Loss Parameters				Transform Parameters		Baseflow Parameters		
	Initial Def (mm)	Max Storage (mm)	Constant Rate (mm/hr)	Impervious (%)	Tc (hr)	R (hr)	Initial Q (m^3/s per km^2)	Recession Constant	Ratio to Peak
W_28_02_01_Bogovada	29	75	0.6	0.3	15	30	0.005	0.9	0.2
W_28_03_03	30	75	0.9	1.1	15	50	0.001	0.9	0.28
W_28_03_04	30	75	0.9	3.4	15	50	0.001	0.9	0.28
W_28_03_07	30	75	0.5	5.7	3.2	12.8	0.001	0.9	0.1
W_29_01_03	15	75	1	17.3	8.3	33.2	0.007	0.9	0.1

Table A - 2: Summary of Reach Routing Parameters for the Sava River Basin Model

Reach	Length (m)	Slope (m/m)	Manning's n	XS Shape	Width (m)	Side Slope (xH:1V)	L.B. Manning's n	R.B. Manning's n	XS Table
R_01_01_01	31878	0.004768	0.035	Eight Point			0.07	0.07	R_01_01_01
R_01_02_01A	12442	0.001849	0.03	Eight Point			0.07	0.07	R10
R_01_02_01B	6430	0.005754	0.03	Eight Point			0.07	0.07	R10
R_01_03_01	22505	0.0019996	0.03	Eight Point			0.07	0.07	R30
R_01_05_01	12643	0.0026893	0.03	Eight Point			0.07	0.07	R60
R_01_05_04	24574	0.0015463	0.03	Eight Point			0.07	0.07	R2340
R_01_06_01	26463	0.0009447	0.035	Eight Point			0.07	0.07	R2400
R_01_08_01	42736	0.0023399	0.03	Eight Point			0.07	0.07	R2250
R_01_09_01	14407	0.0017352	0.03	Eight Point			0.07	0.07	R40
R_01_11_01	30951	0.00067848	0.03	Eight Point			0.07	0.07	R2490
R_01_12_01	20969	0.0005	0.03	Eight Point			0.07	0.07	R2550
R_01_13_01	8564.2	0.00058383	0.03	Eight Point			0.07	0.07	R50
R_01_13_04A	7638	0.0017	0.027	Eight Point			0.07	0.07	R70
R_01_13_04B	8875	0.000451	0.027	Eight Point			0.07	0.07	R70
R_01_13_04C	9544	0.001362	0.027	Eight Point			0.07	0.07	R70
R_01_13_04D	9574	0.001044	0.027	Eight Point			0.07	0.07	R70
R_01_13_04E	15005	0.001133	0.027	Eight Point			0.07	0.07	R70
R_01_13_05	16644	0.00072097	0.03	Eight Point			0.07	0.07	R120
R_01_13_09	8637.8	0.00081039	0.025	Eight Point			0.07	0.07	R70
R_02_02_01	11794	0.00018507	0.05	Eight Point			0.15	0.15	R_02_02_01
R_02_03_01	8547	0.001404	0.04	Trapezoid	15	4			
R_03_01_02	13310	0.0006762	0.04	Trapezoid	70	4			
R_04_02_03	8867.8	0.0010149	0.04	Trapezoid	30	4			
R_04_02_06	14362	0.00055701	0.04	Trapezoid	30	4			
R_05_01_02	15561	0.00051412	0.04	Trapezoid	85	4			
R_05_01_05A	31400.7254	0.000541	0.0267	Trapezoid	85	4			

Reach	Length (m)	Slope (m/m)	Manning's n	XS Shape	Width (m)	Side Slope (xH:1V)	L.B. Manning's n	R.B. Manning's n	XS Table
R_05_01_05B	14972.3435	0.000468	0.0267	Trapezoid	85	4			
R_05_01_05C	39234.4347	0.000255	0.0267	Trapezoid	85	4			
R_05_01_05D	18046.7777	0.001	0.0267	Trapezoid	85	4			
R_06_03_01	33551	0.00065573	0.03	Eight Point			0.07	0.07	R3210
R_06_05_02	38512	0.0016099	0.03	Eight Point			0.07	0.07	R3040
R_06_06_01	99322	0.00072492	0.025	Eight Point			0.07	0.07	R220
R_06_06_03C	43365	0.001176	0.025	Eight Point			0.07	0.07	R_06_06_03C
R_06_06_05	14612	0.00041062	0.025	Eight Point			0.07	0.07	R_06_06_05
R_06_06_06	14238	0.00084282	0.03	Eight Point			0.07	0.07	R440
R_06_06_10	9731	0.00010277	0.03	Eight Point			0.07	0.07	R210
R_06_06_14	37930	0.0001	0.025	Eight Point			0.06	0.06	R200
R_06_07_01	43744	0.0004	0.025	Eight Point			0.06	0.06	R250
R_06_09_01	26366	0.0004	0.025	Eight Point			0.07	0.07	R3360
R_06_10_01	25208	0.00043637	0.025	Eight Point			0.07	0.07	R330
R_06_10_04	15981	0.00012515	0.02	Eight Point			0.06	0.06	R3250
R_06_10_07	49429	0.0001	0.02	Eight Point			0.06	0.06	R240
R_06_10_11	6050.9	0.0004958	0.03	Eight Point			0.07	0.07	R_06_10_11
R_07_01_02	45450	0.00066006	0.04	Trapezoid	130	4			
R_08_03_01	30423	0.00019722	0.04	Eight Point			0.15	0.15	Cesma_Upper
R_08_03_02	4998.6	0.00040011	0.04	Eight Point			0.15	0.15	Cesma_Upper
R_08_03_06	25412	0.0001574	0.04	Eight Point			0.15	0.15	Cesma_Upper
R_08_03_10	30337	0.0002	0.04	Trapezoid	30	4			
R_08_03_14	13903	0.0000719	0.04	Trapezoid	15	4			
R_08_03_18	51471	0.00011657	0.04	Trapezoid	55	4			
R_09_01_02	3934.2	0.0001	0.04	Trapezoid	130	4			
R_10_02_03	24751	0.00028282	0.04	Trapezoid	20	4			

Reach	Length (m)	Slope (m/m)	Manning's n	XS Shape	Width (m)	Side Slope (xH:1V)	L.B. Manning's n	R.B. Manning's n	XS Table
R_11_01_02B	15591.3702	0.000064	0.0267	Trapezoid	120	4			
R_12_02_01	61299	0.005	0.04	Eight Point			0.08	0.08	Martin_Brod_to_Kralje
R_12_03_03	54812	0.005	0.04	Eight Point			0.08	0.08	SMost_to_J1269
R_12_04_01	36894	0.0005	0.035	Eight Point			0.08	0.08	Kralje_to_J1254
R_12_04_05	39426	0.0005	0.035	Eight Point			0.08	0.08	05_R1_Kralje
R_12_04_06	32219	0.0005	0.035	Eight Point			0.08	0.08	SMost_to_J1269
R_12_04_10	29998	0.00030002	0.035	Eight Point			0.08	0.08	05_R2_Prijedor
R_12_04_14	9512.7	0.00010512	0.035	Eight Point			0.08	0.08	05_R2_Prijedor
R_12_04_18	9960.2	0.0001004	0.035	Eight Point			0.08	0.08	05_R3_NGradNizv
R_12_05_01	25383	0.0010243	0.035	Eight Point			0.08	0.08	05_R3_NGradNizv
R_12_06_01	24018	0.0005	0.035	Eight Point			0.08	0.08	05_R4_Kostanica
R_12_06_04	24492	0.00005	0.035	Eight Point			0.08	0.08	05_R4_Kostanica
R_13_01_02A	17784.7551	0.001	0.0267	Trapezoid	130	4			
R_13_01_02B	15627.2743	0.000064	0.0267	Trapezoid	130	4			
R_13_01_02C	27168.05	0.00011	0.0267	Trapezoid	130	4			
R_13_01_07	12201	0.0001	0.04	Trapezoid	140	4			
R_13_01_10	27085	0.0001	0.04	Trapezoid	170	4			
R_14_02_03	3115.8	0.0112332	0.035	Eight Point			0.08	0.08	Vrbas_R890
R_14_02_04	39409	0.005	0.035	Eight Point			0.08	0.08	Vrbas_R890
R_14_02_08	12604	0.006	0.035	Eight Point			0.08	0.08	Vrbas_R3910
R_14_02_11	6507.8	0.0063001	0.035	Eight Point			0.08	0.08	Vrbas_R3910
R_14_02_15	15498	0.006	0.035	Eight Point			0.08	0.08	Vrbas_R4000
R_14_02_18	46235	0.00027252	0.035	Eight Point			0.08	0.08	Vrbas_R3890
R_14_02_22	86094	0.00007318	0.035	Eight Point			0.08	0.08	Vrbas_R3890
R_15_01_02	27157	0.00073647	0.04	Trapezoid	170	4			
R_16_02_03	19304	0.00015022	0.04	Trapezoid	10	4			

Reach	Length (m)	Slope (m/m)	Manning's n	XS Shape	Width (m)	Side Slope (xH:1V)	L.B. Manning's n	R.B. Manning's n	XS Table
R_16_02_06	28922	0.00089896	0.04	Trapezoid	15	4			
R_17_01_02	25322	0.00039491	0.04	Trapezoid	175	4			
R_18_01_04	25028	0.001	0.04	Trapezoid	15	4			
R_18_01_08	67179	0.007	0.04	Trapezoid	20	4			
R_19_01_02	13118	0.0001	0.04	Trapezoid	175	4			
R_19_01_05	63293	0.00063198	0.04	Trapezoid	180	4			
R_20_06_03	2942.3	0.002719	0.045	Eight Point			0.12	0.12	R5860
R_20_06_05	559.41	0.0053628	0.045	Eight Point			0.12	0.12	R5860
R_20_06_08	2733.8	0.0010974	0.045	Eight Point			0.12	0.12	R5860
R_20_06_11	1294.6	0.00077241	0.045	Eight Point			0.12	0.12	R5860
R_20_12_04	16937.6	0.0042493	0.045	Eight Point			0.12	0.12	R5060
R_20_13_01	8977.92	0.0014271	0.044	Eight Point			0.112	0.112	R5760
R_20_13_04	8360.7	0.0035029	0.044	Eight Point			0.112	0.112	R5660
R_20_13_07	10529.38	0.0017384	0.044	Eight Point			0.112	0.112	R5560
R_20_13_10	19512.06	0.0018293	0.044	Eight Point			0.112	0.112	R5480
R_20_13_13	3876.78	0.0014164	0.044	Eight Point			0.112	0.112	R5460
R_20_13_16	16477.26	0.0016663	0.044	Eight Point			0.112	0.112	R5360
R_20_13_19	10730.72	0.0024733	0.044	Eight Point			0.112	0.112	R5020
R_20_15_01	23937.876	0.0013916	0.045	Eight Point			0.08	0.08	R4980
R_20_15_04	26876.688	0.0020859	0.045	Eight Point			0.12	0.12	R4880
R_20_17_01	26028	0.005302	0.045	Eight Point			0.12	0.12	R5270
R_20_17_04	19677	0.0059461	0.045	Eight Point			0.12	0.12	R5320
R_20_17_07	27853	0.0025491	0.045	Eight Point			0.12	0.12	R5160
R_20_19_01	3692.8	0.0010832	0.045	Eight Point			0.12	0.12	R4860
R_20_19_04	22457	0.0012913	0.045	Eight Point			0.12	0.12	R4780
R_20_19_07	5502.8	0.00072691	0.045	Eight Point			0.12	0.12	R4780

Reach	Length (m)	Slope (m/m)	Manning's n	XS Shape	Width (m)	Side Slope (xH:1V)	L.B. Manning's n	R.B. Manning's n	XS Table
R_20_19_11	20238	0.0011365	0.045	Eight Point			0.12	0.12	R4780
R_20_19_12	7087.6	0.0021164	0.045	Eight Point			0.12	0.12	R6420
R_20_19_15	5043.2	0.0017846	0.045	Eight Point			0.12	0.12	R6480
R_20_19_19	6822.3	0.0011726	0.045	Eight Point			0.12	0.12	R6460
R_20_19_23	4806.1	0.00083227	0.045	Eight Point			0.12	0.12	R610
R_20_19_24	23957	0.0005009	0.045	Eight Point			0.12	0.12	R4440
R_20_19_28	30740	0.00007482	0.045	Eight Point			0.12	0.12	R4300
R_20_19_31	56668	0.00006882	0.045	Eight Point			0.12	0.12	R5860
R_20_20_03	219.07	0.0045647	0.045	Eight Point			0.12	0.12	R6370
R_20_20_06	7481.8	0.0024058	0.045	Eight Point			0.12	0.12	R6370
R_20_21_04	16428	0.0012783	0.045	Eight Point			0.12	0.12	R4460
R_20_21_08	48290	0.00062125	0.045	Eight Point			0.12	0.12	R4560
R_21_01_02	90770	0.00003305	0.04	Trapezoid	195	4			
R_22_01_05B	18946.75	0.003008	0.04	Trapezoid	10	4			
R_22_01_08	37285	0.00099235	0.04	Trapezoid	10	4			
R_22_01_12	8865.3	0.000564	0.04	Trapezoid	15	4			
R_23_01_02	34241	0.00001	0.04	Trapezoid	250	4			
R_23_01_05	29876	0.00066943	0.04	Trapezoid	250	4			
R_24_01_03	46301	0.0026133	0.04	Trapezoid	20	3			
R_24_02_01	35277	0.0018426	0.035	Trapezoid	20	3			
R_24_02_04	9547.3	0.005	0.035	Trapezoid	20	3			
R_24_03_03	55550	0.0032583	0.035	Trapezoid	15	3			
R_24_03_06	9989.8	0.0196201	0.035	Trapezoid	15	3			
R_24_03_10	24960	0.0019231	0.035	Trapezoid	20	3			
R_24_03_11B	92400	0.005	0.035	Trapezoid	20	3			
R_24_03_14	45334	0.0011029	0.035	Trapezoid	25	3			

Reach	Length (m)	Slope (m/m)	Manning's n	XS Shape	Width (m)	Side Slope (xH:1V)	L.B. Manning's n	R.B. Manning's n	XS Table
R_24_03_18	15875	0.005	0.035	Trapezoid	25	3			
R_24_03_19	13168	0.0039489	0.035	Trapezoid	20	3			
R_24_03_22	19378	0.005212	0.035	Trapezoid	20	3			
R_24_03_25A	9110	0.007	0.035	Trapezoid	20	3			
R_24_03_25B	45705	0.001	0.035	Trapezoid	20	3			
R_24_03_29	43926	0.00072849	0.035	Trapezoid	25	3			
R_24_03_33	8565	0.0010508	0.035	Trapezoid	20	3			
R_24_03_36	3825.8	0.0086256	0.035	Trapezoid	20	3			
R_24_03_37B	42800	0.013	0.035	Trapezoid	10	3			
R_24_03_40	54336	0.00034968	0.035	Trapezoid	20	3			
R_24_04_01	97875	0.0013384	0.035	Trapezoid	25	3			
R_24_04_05	5136.7	0.0031149	0.035	Trapezoid	10	3			
R_24_04_09	13034	0.00015345	0.035	Trapezoid	25	3			
R_24_04_12	7970.8	0.0021328	0.035	Trapezoid	25	3			
R_24_04_15	43744	0.00008687	0.035	Trapezoid	25	3			
R_24_04_18	48615	0.00004731	0.035	Trapezoid	25	3			
R_25_01_02	18565	0.0001	0.04	Trapezoid	250	4			
R_26_01_04	8255.2	0.0001	0.04	Trapezoid	15	4			
R_26_01_08A	34582	0.0001	0.04	Trapezoid	40	4			
R_26_01_08B	37049	0.000162	0.04	Trapezoid	40	4			
R_26_01_08C	66751	0.000075	0.04	Trapezoid	40	4			
R_27_01_02	28977	0.00013804	0.04	Trapezoid	260	4			
R_27_01_05	106166	0.00018838	0.04	Trapezoid	350	4			
R_27_01_09	26359	0.0001	0.04	Trapezoid	350	4			
R_28_03_02	44573	0.001	0.03	Trapezoid	15	2			
R_28_03_06	19080	0.00068134	0.025	Trapezoid	30	4			

Reach	Length (m)	Slope (m/m)	Manning's n	XS Shape	Width (m)	Side Slope (xH:1V)	L.B. Manning's n	R.B. Manning's n	XS Table
R_29_01_02	27856	0.0001	0.04	Trapezoid	425	4			

Reach	Storage-Discharge Function	Subreaches	Initial Condition
R_11_01_02A	Zelenik	1	Inflow = Outflow

APPENDIX B: HYDROLOGIC AND METEOROLOGIC STATION INVENTORY INFORMATION

Figure B - 1: Locations of Hydrologic Stations used in HEC-HMS Model

Table B - 1: Hydrologic Station Inventory

Code	Name	Latitude (DD)	Longitude (DD)	Elevation (m)	Country	Responsibility	River	Time Step
2	Okroglo	46.25627	14.32436	355.7	SI	ARSO Ljubljana	Sava	1 hour
3	Medno	46.12253	14.44050	300.273	SI	ARSO Ljubljana	Sava	5 min
4	Šentjakob	46.08405	14.58247	268.185	SI	ARSO Ljubljana	Sava	10 min
5	Litija I	46.05565	14.82296	230.444	SI	ARSO Ljubljana	Sava	1 hour
6	Hrastnik	46.12186	15.09080	193.85	SI	ARSO Ljubljana	Sava	30 min
7	Čatež I	45.89315	15.61001	137.279	SI	ARSO Ljubljana	Sava	1 hour
8	Jesenice na Dolenjskem	45.86048	15.69246	129.433	SI	ARSO Ljubljana	Sava	30 min
45	Moste I	46.05545	14.54447	281.29	SI	ARSO Ljubljana	Ljubljanica	10 min
63	Letuš I	46.32624	15.00442	313.444	SI	ARSO Ljubljana	Savinja	10 min
66	Laško I	46.15397	15.23356	215.025	SI	ARSO Ljubljana	Savinja	10 min
67	Veliko Širje I	46.09200	15.19236	189.957	SI	ARSO Ljubljana	Savinja	30 min
82	Soteska	45.77967	15.02397	167.59	SI	ARSO Ljubljana	Krka	10 min
83	Gorenja Gomila	45.86746	15.28563	148.82	SI	ARSO Ljubljana	Krka	10 min
84	Podbočje	45.86484	15.45536	146.32	SI	ARSO Ljubljana	Krka	30 min
94	Rakovec I	45.92083	15.70528	139.21	SI	ARSO Ljubljana	Sutla	1 hour
98	Radenci II	45.46497	15.09663	175.25	SI	ARSO Ljubljana	Kolpa	1 hour
102	Jesenice 2	45.86229	15.68800	132.754	HR	DHMZ Zagreb	Sava	1 hour
104	Podsused-žičara	45.80743	15.83869	119.134	HR	DHMZ Zagreb	Sava	1 hour
106	Zagreb	45.78449	15.95331	112.26	HR	DHMZ Zagreb	Sava	1 hour
115	Jasenovac	45.26671	16.90743	86.82	HR	DHMZ Zagreb	Sava	1 hour
116	Stara Gradiška	45.15017	17.25003	85.467	HR	DHMZ Zagreb	Sava	1 hour
117	Mačkovac	45.14471	17.34165	83.645	HR	DHMZ Zagreb	Sava	1 hour
118	Davor	45.12862	17.53874	82.59	HR	DHMZ Zagreb	Sava	1 hour
119	Slavonski Kobaš	45.09885	17.73774	82.69	HR	DHMZ Zagreb	Sava	1 hour
120	Slavonski Brod	45.15287	18.00504	81.8	HR	DHMZ Zagreb	Sava	1 hour
122	Županja	45.07351	18.68661	76.277	HR	DHMZ Zagreb	Sava	1 hour

Code	Name	Latitude (DD)	Longitude (DD)	Elevation (m)	Country	Responsibility	River	Time Step
123	Gunja	44.88067	18.81665	74.324	HR	DHMZ Zagreb	Sava	1 hour
139	Zelenjak	46.05478	15.72000	162.46	HR	DHMZ Zagreb	Sutla	1 hour
142	Kupljenovo	45.93472	15.81750	128.877	HR	DHMZ Zagreb	Krapina	1 hour
145	Gubaševo	46.02011	15.85567	137.375	HR	DHMZ Zagreb	Horvatska	1 hour
148	Zapeć	45.48247	15.08111	180.1	HR	DHMZ Zagreb	Kupa	1 hour
154	Jamnička Kiselica	45.54857	15.85752	100.794	HR	DHMZ Zagreb	Kupa	1 hour
155	Šišinec	45.44853	16.07717	94.81	HR	DHMZ Zagreb	Kupa	1 hour
156	Farkašić	45.48326	16.15290	93.847	HR	DHMZ Zagreb	Kupa	1 hour
163	Veljun	45.25233	15.54542	139.104	HR	DHMZ Zagreb	Korana	1 hour
164	Velemerić	45.41072	15.61106	112.953	HR	DHMZ Zagreb	Korana	1 hour
170	Juzbašići	45.19547	15.43114	185.511	HR	DHMZ Zagreb	Donja Mrežnica	1 hour
171	Mrzlo Polje	45.46081	15.49514	113.967	HR	DHMZ Zagreb	Donja Mrežnica	1 hour
175	Vranovina	45.27736	15.97086	118.476	HR	DHMZ Zagreb	Glina	1 hour
176	Glina	45.33628	16.08322	106.628	HR	DHMZ Zagreb	Glina	1 hour
180	Struga Banska	45.11268	16.39368	111.907	HR	DHMZ Zagreb	Una	1 hour
181	Kostajnica	45.22225	16.54885	103.196	HR	DHMZ Zagreb	Una	1 hour
182	Dubica	45.18563	16.80942	94.17	HR	DHMZ Zagreb	Una	1 hour
183	Lonjica Most	45.85408	16.31974	103.77	HR	DHMZ Zagreb	Lonja	1 hour
185	Narta	45.83887	16.82187	103.365	HR	DHMZ Zagreb	Česma	1 hour
187	Čazma	45.74909	16.59759	97.112	HR	DHMZ Zagreb	Česma	1 hour
188	Veliko Vukovje	45.46898	16.90817	98.651	HR	DHMZ Zagreb	Ilova	1 hour
189	Ilova	45.44591	16.82884	93.942	HR	DHMZ Zagreb	Ilova	1 hour
190	Požega	45.33630	17.66686	143.976	HR	DHMZ Zagreb	Orljava	1 hour
193	Frkljevci	45.26800	17.81220	111.928	HR	DHMZ Zagreb	Orljava	1 hour
196	Nijemci	45.14194	19.03776	75.76	HR	DHMZ Zagreb	Bosut	1 hour

Code	Name	Latitude (DD)	Longitude (DD)	Elevation (m)	Country	Responsibility	River	Time Step
209	Martin Brod	44.49569	16.13476	310.3	BA	AVP Sava Sarajevo	Una	1 hour
213	Kralje	44.83458	15.84600	208.84	BA	AVP Sava Sarajevo	Una	1 hour
225	Sanski Most	44.76646	16.66631	156.04	BA	AVP Sava Sarajevo	Sana	1 hour
229	Daljan	44.12927	17.40244	516.41	BA	AVP Sava Sarajevo	Vrbas	1 hour
230	Kozluk	44.33999	17.27357	342.51	BA	AVP Sava Sarajevo	Vrbas	1 hour
238	Vrelo Bosne	43.82134	18.26860	491.78	BA	AVP Sava Sarajevo	Bosna	1 hour
239	Rimski Most/Plandište	43.83402	18.28622	489.04	BA	AVP Sava Sarajevo	Bosna	1 hour
242	Reljevo	43.88600	18.31920	478.46	BA	FHMZ Sarajevo	Bosna	1 hour
247	Raspotočje	44.18958	17.92694	312.62	BA	AVP Sava Sarajevo	Bosna	1 hour
250	Zavidovići n B	44.43802	18.13999	200.72	BA	AVP Sava Sarajevo	Bosna	1 hour
253	Maglaj-Poljice	44.56517	18.09946	164.8	BA	AVP Sava Sarajevo	Bosna	1 hour
257	Ilidža	43.82464	18.30917	495.93	BA	AVP Sava Sarajevo	Željeznica	1 hour
261	Blažuj	43.84336	18.25648	502.46	BA	AVP Sava Sarajevo	Zujevina	1 hour
262	Doglodi	43.85166	18.29069	487.36	BA	AVP Sava Sarajevo	Dobrinja	1 hour
266	Butile n/M	43.86613	18.29457	483.85	BA	AVP Sava Sarajevo	Miljacka	1 hour
267	Semizovac	43.92130	18.31670	470.5	BA	AVP Sava Sarajevo	Ljubina	1 hour
269	Ilijaš	43.94954	18.25793	438.89	BA	AVP Sava Sarajevo	Misoča	1 hour
272	Visoko n/F	43.98431	18.18267	412.66	BA	AVP Sava Sarajevo	Fojnica	1 hour
273	Obre	44.10107	18.13019	395.74	BA	AVP Sava Sarajevo	Trstionica	1 hour
274	Kakanj n/Zg	44.12932	18.11792	386.03	BA	AVP Sava Sarajevo	Zgošća	1 hour
276	Merdani	44.13469	17.91250	357.59	BA	AVP Sava Sarajevo	Lašva	1 hour
277	Stipovići	44.42051	18.14719	214.08	BA	AVP Sava Sarajevo	Gostović	1 hour
278	Olovo	44.12639	18.57468	527.2	BA	AVP Sava Sarajevo	Krivaja	1 hour
280	Zavidovići n Kr	44.43610	18.16269	204.31	BA	AVP Sava Sarajevo	Krivaja	1 hour
283	Liješnica	44.52630	18.09430	173.37	BA	AVP Sava Sarajevo	Lješnica	1 hour
285	Kaloševići	44.64677	17.90422	177.63	BA	AVP Sava Sarajevo	Usora	1 hour
290	Karanovac	44.69610	18.27375	150.05	BA	AVP Sava Sarajevo	Spreča	1 hour
296	Srebrenik	44.70726	18.48597	172.84	BA	AVP Sava Sarajevo	Tinja	1 hour

Code	Name	Latitude (DD)	Longitude (DD)	Elevation (m)	Country	Responsibility	River	Time Step
306	Jamena	44.87828	19.08364	72.44	RS	RHMZ Belgrad	Sava	1 hour
307	Sremska Mitrovica	44.96704	19.60205	72.22	RS	RHMZ Belgrad	Sava	1 hour
311	Bajina Bašta	43.97517	19.54192	211.47	RS	RHMZ Belgrad	Drina	1 hour
312	Radalj	44.41927	19.14825	129.47	RS	RHMZ Belgrad	Drina	1 hour
313	Brodarevo	43.23311	19.71976	489.24	RS	RHMZ Belgrad	Lim	1 hour
315	Priboj	43.58137	19.52390	380.79	RS	RHMZ Belgrad	Lim	1 hour
320	Lešnica	44.63274	19.27445	103.47	RS	RHMZ Belgrad	Jadar	1 hour
324	Slovac	44.33966	20.08096	121.59	RS	RHMZ Belgrad	Kolubara	1 hour
325	Beli Brod	44.37070	20.19968	99.32	RS	RHMZ Belgrad	Kolubara	1 hour
326	Draževac	44.59334	20.21553	71.24	RS	RHMZ Belgrad	Kolubara	1 hour
332	Bogovađa	44.33047	20.20618	109.43	RS	RHMZ Belgrad	Ljig	1 hour
337	Rakovica	44.75128	20.44705	83.22	RS	RHMZ Belgrad	Topčiderska reka	1 hour

Figure B - 2: Locations of Meteorologic Stations used in the HEC-HMS Model

Table B - 2: Meteorologic Station Inventory - Precipitation

Code	Name	Latitude (DD)	Longitude (DD)	Elevation (m)	Country	Responsibility	Type	Basin	Time Step
1	Ljubljana - Bežigrad	46.06558	14.51237	299	SI	ARSO Ljubljana	Automatic	Sava	30 min
3	Litija	46.06645	14.84527	272	SI	ARSO Ljubljana	Automatic	Sava	30 min
5	Malkovec	45.95341	15.20500	400	SI	ARSO Ljubljana	Automatic	Sava	30 min
6	Lisca	46.06786	15.28498	943	SI	ARSO Ljubljana	Automatic	Sava	30 min
7	Hrastnik	46.14391	15.08329	290	SI	ARSO Ljubljana	Automatic	Sava	30 min
12	Rateče	46.49709	13.71290	864	SI	ARSO Ljubljana	Automatic	Sava	30 min
14	Kredarica	46.37877	13.84894	2514	SI	ARSO Ljubljana	Automatic	Sava	30 min
15	Lesce	46.36531	14.17443	515	SI	ARSO Ljubljana	Automatic	Sava	30 min
20	Rudno Polje	46.34641	13.92387	1344	SI	ARSO Ljubljana	Automatic	Sava	30 min
28	Boršt pri Gorenji Vasi	46.08720	14.18531	530	SI	ARSO Ljubljana	Automatic	Sava	30 min
31	Krvavec	46.29778	14.53861	1740	SI	ARSO Ljubljana	Automatic	Kamniška Bistrica	30 min
32	Brnik - Letalisce	46.21754	14.47276	364	SI	ARSO Ljubljana	Automatic	Kamniška Bistrica	30 min
34	Postojna	45.76615	14.19280	533	SI	ARSO Ljubljana	Automatic	Ljubljanica	30 min
44	Celje - Medlog	46.23659	15.22579	242	SI	ARSO Ljubljana	Automatic	Savinja	30 min
53	Novo Mesto	45.80208	15.18206	220	SI	ARSO Ljubljana	Automatic	Krka	30 min
54	Cerklje - Letališče	45.89897	15.52328	154	SI	ARSO Ljubljana	Automatic	Krka	30 min
62	Podčetrtek - Atomske Toplice	46.15703	15.59747	202	SI	ARSO Ljubljana	Automatic	Sutla	30 min
65	Črnomelj - Dobliče	45.56007	15.14615	157	SI	ARSO Ljubljana	Automatic	Kupa	30 min
66	Iskrba	45.56124	14.85810	540	SI	ARSO Ljubljana	Automatic	Kupa	10 min
70	Rogla	46.45312	15.33146	1492	SI	ARSO Ljubljana	Automatic	Drava	30 min
71	Šmartno pri Slovenj Gradcu	46.48955	15.11122	444	SI	ARSO Ljubljana	Automatic	Drava	30 min
73	Ilirska Bistrica-Koseze	45.55329	14.23576	415	SI	ARSO Ljubljana	Automatic	Adriatic Sea	30 min

Code	Name	Latitude (DD)	Longitude (DD)	Elevation (m)	Country	Responsibility	Type	Basin	Time Step
87	Puntijarka	45.91667	15.96667	988	HR	DHMZ Zagreb	Automatic	Sava	1 hour
88	Zagreb Grič	45.81667	15.98333	157	HR	DHMZ Zagreb	Automatic	Sava	1 hour
89	Zagreb Maksimir	45.82194	16.03361	123	HR	DHMZ Zagreb	Automatic	Sava	1 hour
91	Gorice	45.22361	17.27833	135	HR	DHMZ Zagreb	Automatic	Sava	1 hour
92	Slavonski Brod	45.16667	18.00000	88	HR	DHMZ Zagreb	Automatic	Sava	1 hour
93	Krapina	46.13333	15.88333	202	HR	DHMZ Zagreb	Automatic	Krapina	1 hour
94	Parg	45.60000	14.63333	863	HR	DHMZ Zagreb	Automatic	Kupa	1 hour
95	Karlovac	45.50000	15.56667	110	HR	DHMZ Zagreb	Automatic	Kupa	1 hour
98	Sisak	45.50000	16.36667	98	HR	DHMZ Zagreb	Automatic	Kupa	1 hour
99	Ogulin	45.26667	15.23333	328	HR	DHMZ Zagreb	Automatic	Kupa	1 hour
102	Križevci	46.03333	16.55000	155	HR	DHMZ Zagreb	Automatic	Lonja	1 hour
103	Bjelovar	45.91983	16.82044	141	HR	DHMZ Zagreb	Automatic	Lonja	1 hour
104	Daruvar	45.60000	17.23333	161	HR	DHMZ Zagreb	Automatic	Ilova	1 hour
106	Gradište	45.15000	18.70000	97	HR	DHMZ Zagreb	Automatic	Bosut	1 hour
107	Varaždin	46.28278	16.36389	167	HR	DHMZ Zagreb	Automatic	Drava	1 hour
113	Gospic	44.55056	15.37306	564	HR	DHMZ Zagreb	Automatic	Adriatic Sea	1 hour
124	Rijeka	45.33694	14.44278	120	HR	DHMZ Zagreb	Automatic	Adriatic Sea	1 hour
125	Senj	44.99250	14.90333	26	HR	DHMZ Zagreb	Automatic	Adriatic Sea	1 hour
135	Cazin	44.96771	15.94933	375	BA	AVP Sava Sarajevo	Automatic	Kupa	1 hour
136	Velika Kladuša	45.17092	15.82127	140	BA	AVP Sava Sarajevo	Automatic	Kupa	1 hour
137	Bihać	44.81090	15.87244	246	BA	AVP Sava Sarajevo	Automatic	Una	1 hour
138	Bosanska Krupa	44.88921	16.16401	150	BA	AVP Sava Sarajevo	Automatic	Una	1 hour
139	Bosanski Petrovac	44.55465	16.37169	670	BA	AVP Sava Sarajevo	Automatic	Una	1 hour
141	Drvar	44.39580	16.39191	465	BA	AVP Sava Sarajevo	Automatic	Una	1 hour
142	Rmanj Manastir	44.49357	16.14705	322	BA	AVP Sava Sarajevo	Automatic	Una	1 hour

Code	Name	Latitude (DD)	Longitude (DD)	Elevation (m)	Country	Responsibility	Type	Basin	Time Step
145	Ključ	44.52563	16.79977	250	BA	AVP Sava Sarajevo	Automatic	Una	1 hour
146	Lušci Palanka	44.74600	16.43926	431	BA	AVP Sava Sarajevo	Automatic	Una	1 hour
147	Sanski Most	44.76730	16.67929	158	BA	AVP Sava Sarajevo	Automatic	Una	1 hour
149	Gornji Vakuf	43.94036	17.58917	670	BA	AVP Sava Sarajevo	Automatic	Vrbas	1 hour
159	Maglaj	44.56556	18.10491	173	BA	AVP Sava Sarajevo	Automatic	Bosna	1 hour
161	Delijaš	43.68393	18.53716	925	BA	AVP Sava Sarajevo	Automatic	Bosna	1 hour
162	Brgule	44.13369	18.40553	1125	BA	AVP Sava Sarajevo	Automatic	Bosna	1 hour
163	Fojnica	43.9713	17.90854	658	BA	AVP Sava Sarajevo	Automatic	Bosna	1 hour
164	Olovo	44.13810	18.58324	530	BA	AVP Sava Sarajevo	Automatic	Bosna	1 hour
165	Zavidovići	44.43611	18.16779	211	BA	AVP Sava Sarajevo	Automatic	Bosna	1 hour
166	Modrac	44.51090	18.51382	183	BA	AVP Sava Sarajevo	Automatic	Bosna	1 hour
167	Karanovac	44.69614	18.27888	158	BA	AVP Sava Sarajevo	Automatic	Bosna	1 hour
170	Goražde	43.66540	18.98178	345	BA	AVP Sava Sarajevo	Automatic	Drina	1 hour
175	Ivan Sedlo	43.74679	18.03114	890	BA	AVP J. more Mostar	Automatic	Adriatic Sea	1 hour
177	Sremska Mitrovica	44.96667	19.63333	82	RS	RHMZ Belgrad	Automatic	Sava	1 hour
178	Zlatibor	43.72392	19.71312	1028	RS	RHMZ Belgrad	Automatic	Drina	1 hour
179	Loznica	44.55000	19.23333	121	RS	RHMZ Belgrad	Automatic	Drina	1 hour
182	Sjenica	43.29423	20.10895	1038	RS	RHMZ Belgrad	Automatic	Drina	1 hour
183	Valjevo	44.27544	19.91256	176	RS	RHMZ Belgrad	Automatic	Kolubara	1 hour
184	Beograd-Vračar	44.79839	20.46484	132	RS	RHMZ Belgrad	Automatic	Danube	1 hour
185	Berane	42.85000	19.88333	691	ME	ZHMS Podgorica	Automatic	Drina	1 day
186	Bijelo Polje	43.03330	19.73330	606	ME	ZHMS Podgorica	Automatic	Drina	1 hour
187	Kolašin	42.83330	19.51670	944	ME	ZHMS Podgorica	Automatic	Drina	1 hour
188	Žabljak	43.15000	19.11670	1450	ME	ZHMS Podgorica	Automatic	Drina	1 hour
189	Pljevlja	43.35000	19.35000	784	ME	ZHMS Podgorica	Automatic	Drina	1 hour

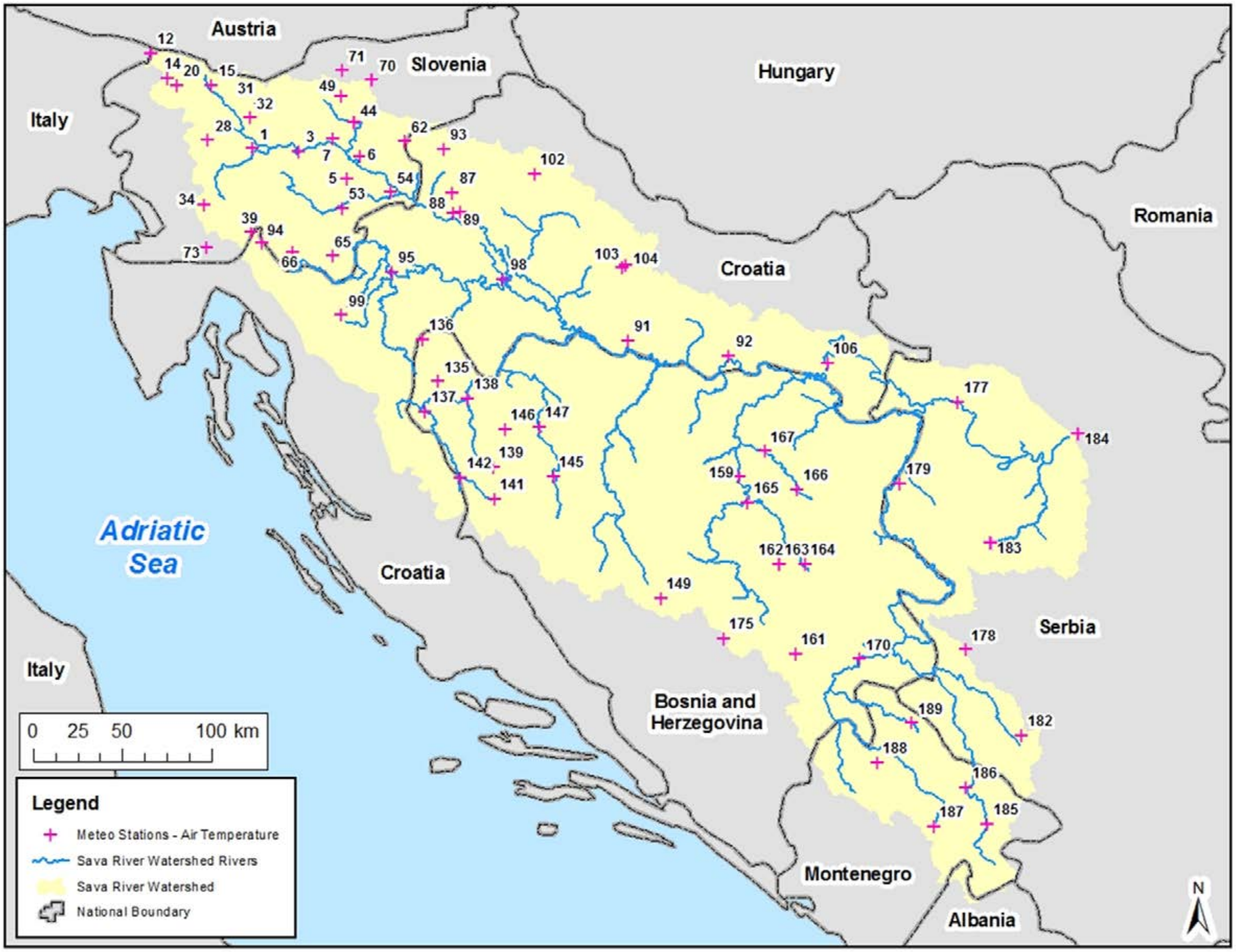

Figure B - 3: Locations of Meteorologic Stations with Available Air Temperature Data

Table B - 3: Meteorologic Station Inventory – Air Temperature

Code	Name	Latitude (DD)	Longitude (DD)	Elevation (m)	Country	Responsibility	Time Step	Used (Y/N)
1	Ljubljana - Bežigrad	46.06558	14.51237	299	SI	ARSO Ljubljana	30 min	Y
3	Litija	46.06645	14.84527	272	SI	ARSO Ljubljana	30 min	N
5	Malkovec	45.95341	15.20500	400	SI	ARSO Ljubljana	30 min	N
6	Lisca	46.06786	15.28498	943	SI	ARSO Ljubljana	30 min	Y
7	Hrastnik	46.14391	15.08329	290	SI	ARSO Ljubljana	30 min	Y
12	Rateče	46.49709	13.71290	864	SI	ARSO Ljubljana	30 min	N
14	Kredarica	46.37877	13.84894	2514	SI	ARSO Ljubljana	30 min	N
15	Lesce	46.36531	14.17443	515	SI	ARSO Ljubljana	30 min	Y
20	Rudno Polje	46.34641	13.92387	1344	SI	ARSO Ljubljana	30 min	N
28	Boršt pri Gorenji Vasi	46.08720	14.18531	530	SI	ARSO Ljubljana	30 min	Y
31	Krvavec	46.29778	14.53861	1740	SI	ARSO Ljubljana	30 min	N
32	Brnik - Letalisce	46.21754	14.47276	364	SI	ARSO Ljubljana	30 min	Y
34	Postojna	45.76615	14.19280	533	SI	ARSO Ljubljana	30 min	N
39	Babno Polje	45.64545	14.54961	754	SI	ARSO Ljubljana	1 day	N
44	Celje - Medlog	46.23659	15.22579	242	SI	ARSO Ljubljana	30 min	N
49	Velenje	46.36064	15.11671	388	SI	ARSO Ljubljana	1 day	Y
53	Novo Mesto	45.80208	15.18206	220	SI	ARSO Ljubljana	30 min	Y
54	Cerklje - Letališče	45.89897	15.52328	154	SI	ARSO Ljubljana	30 min	Y
62	Podčetrtek - Atomske Toplice	46.15703	15.59747	202	SI	ARSO Ljubljana	30 min	Y
65	Črnomelj - Dobliče	45.56007	15.14615	157	SI	ARSO Ljubljana	30 min	N
66	Iskrba	45.56124	14.85810	540	SI	ARSO Ljubljana	10 min	Y
70	Rogla	46.45312	15.33146	1492	SI	ARSO Ljubljana	30 min	N
71	Šmartno pri Slovenj Gradcu	46.48955	15.11122	444	SI	ARSO Ljubljana	30 min	N
73	Ilirska Bistrica-Koseze	45.55329	14.23576	415	SI	ARSO Ljubljana	30 min	N

Code	Name	Latitude (DD)	Longitude (DD)	Elevation (m)	Country	Responsibility	Time Step	Used (Y/N)
87	Puntijarka	45.91667	15.96667	988	HR	DHMZ Zagreb	1 hour	Y
88	Zagreb Grič	45.81667	15.98333	157	HR	DHMZ Zagreb	1 hour	Y
89	Zagreb Maksimir	45.82194	16.03361	123	HR	DHMZ Zagreb	1 hour	Y
91	Gorice	45.22361	17.27833	135	HR	DHMZ Zagreb	1 hour	Y
92	Slavonski Brod	45.16667	18.00000	88	HR	DHMZ Zagreb	1 hour	Y
93	Krapina	46.13333	15.88333	202	HR	DHMZ Zagreb	1 hour	Y
94	Parg	45.60000	14.63333	863	HR	DHMZ Zagreb	1 hour	N
95	Karlovac	45.50000	15.56667	110	HR	DHMZ Zagreb	1 hour	N
98	Sisak	45.50000	16.36667	98	HR	DHMZ Zagreb	1 hour	Y
99	Ogulin	45.26667	15.23333	328	HR	DHMZ Zagreb	1 hour	N
102	Križevci	46.03333	16.55000	155	HR	DHMZ Zagreb	1 hour	Y
103	Bjelovar	45.59139	17.21000	141	HR	DHMZ Zagreb	1 hour	Y
104	Daruvar	45.60000	17.23333	161	HR	DHMZ Zagreb	1 hour	N
106	Gradište	45.15000	18.70000	97	HR	DHMZ Zagreb	1 hour	Y
135	Cazin	44.96771	15.94933	375	BA	AVP Sava Sarajevo	1 hour	Y
136	Velika Kladuša	45.17092	15.82127	140	BA	AVP Sava Sarajevo	1 hour	Y
137	Bihać	44.81090	15.87244	246	BA	AVP Sava Sarajevo	1 hour	Y
138	Bosanska Krupa	44.88921	16.16401	150	BA	AVP Sava Sarajevo	1 hour	N
139	Bosanski Petrovac	44.55465	16.37169	670	BA	AVP Sava Sarajevo	1 hour	N
141	Drvar	44.39580	16.39191	465	BA	AVP Sava Sarajevo	1 hour	Y
142	Rmanj Manastir	44.49357	16.14705	322	BA	AVP Sava Sarajevo	1 hour	N
145	Ključ	44.52563	16.79977	250	BA	AVP Sava Sarajevo	1 hour	Y
146	Lušci Palanka	44.74600	16.43926	431	BA	AVP Sava Sarajevo	1 hour	N
147	Sanski Most	44.76730	16.67929	158	BA	AVP Sava Sarajevo	1 hour	Y

Code	Name	Latitude (DD)	Longitude (DD)	Elevation (m)	Country	Responsibility	Time Step	Used (Y/N)
149	Gornji Vakuf	43.94036	17.58917	670	BA	AVP Sava Sarajevo	1 hour	Y
159	Maglaj	44.56556	18.10491	173	BA	AVP Sava Sarajevo	1 hour	Y
161	Delijaš	43.68393	18.53716	925	BA	AVP Sava Sarajevo	1 hour	Y
162	Brgule	44.13369	18.40553	1125	BA	AVP Sava Sarajevo	1 hour	N
163	Fojnica	43.97134	17.90854	658	BA	AVP Sava Sarajevo	1 hour	Y
164	Olovo	44.13810	18.58324	530	BA	AVP Sava Sarajevo	1 hour	Y
165	Zavidovići	44.43611	18.16779	211	BA	AVP Sava Sarajevo	1 hour	Y
166	Modrac	44.51090	18.51382	183	BA	AVP Sava Sarajevo	1 hour	Y
167	Karanovac	44.69614	18.27888	158	BA	AVP Sava Sarajevo	1 hour	Y
170	Goražde	43.66540	18.98178	345	BA	AVP Sava Sarajevo	1 hour	Y
175	Ivan Sedlo	43.74679	18.03114	890	BA	AVP J. more Mostar	1 hour	Y
177	Sremska Mitrovica	44.96667	19.63333	82	RS	RHMZ Belgrad	1 hour	N
178	Zlatibor	43.72392	19.71312	1028	RS	RHMZ Belgrad	1 hour	Y
179	Loznica	44.55000	19.23333	121	RS	RHMZ Belgrad	1 hour	Y
182	Sjenica	43.29423	20.10895	1038	RS	RHMZ Belgrad	1 hour	N
183	Valjevo	44.27544	19.91256	176	RS	RHMZ Belgrad	1 hour	N
184	Beograd-Vračar	44.79839	20.46484	132	RS	RHMZ Belgrad	1 hour	N
185	Berane	42.85000	19.88333	691	ME	ZHMS Podgorica	1 day	N
186	Bijelo Polje	43.03330	19.73330	606	ME	ZHMS Podgorica	1 hour	N
187	Kolašin	42.83330	19.51670	944	ME	ZHMS Podgorica	1 hour	Y
188	Žabljak	43.15000	19.11670	1450	ME	ZHMS Podgorica	1 hour	Y
189	Pljevlja	43.35000	19.35000	784	ME	ZHMS Podgorica	1 hour	N

APPENDIX C: HEC-HMS MODEL KEY MAP

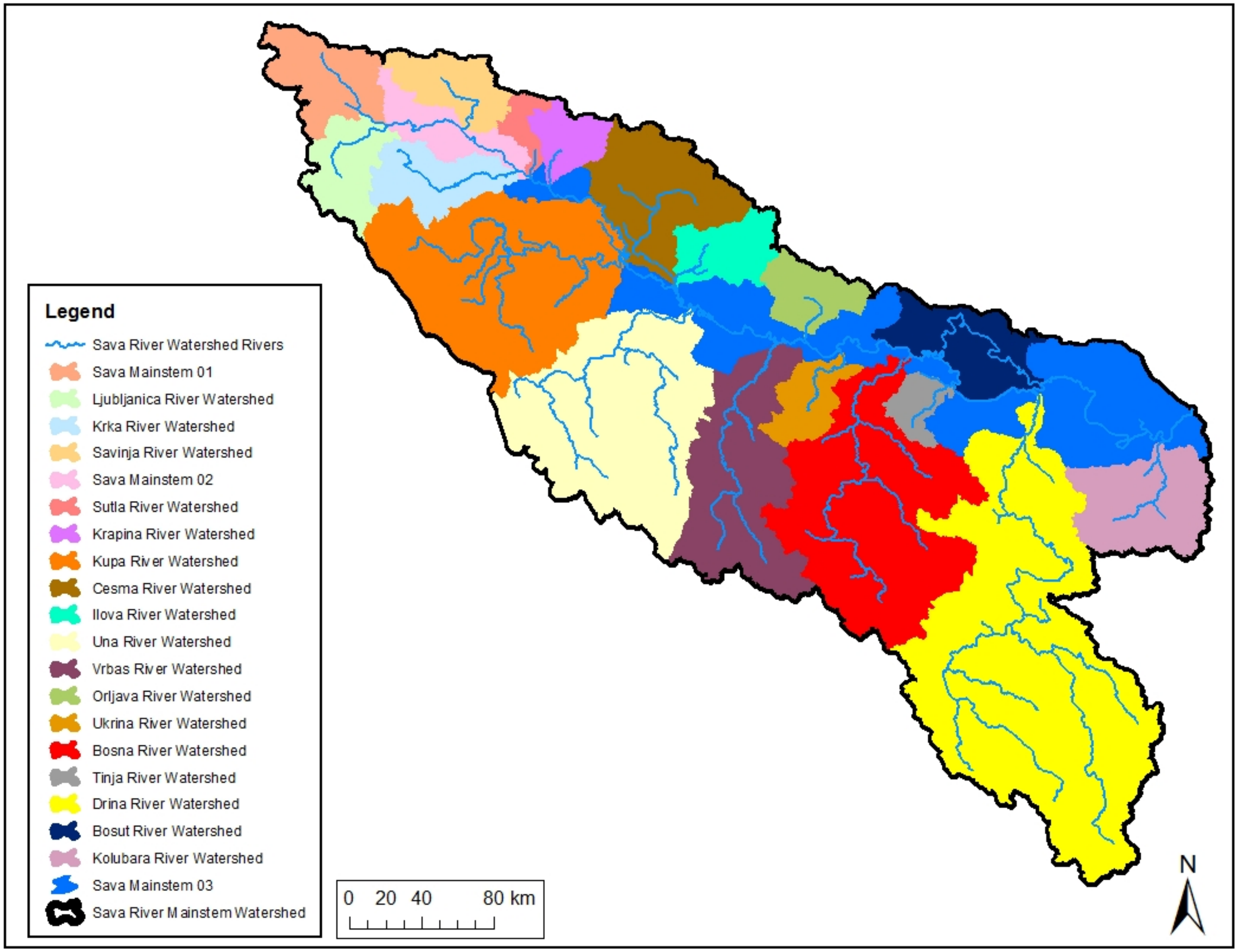

Figure C - 1: Sava River Watershed HEC-HMS Calibration Model Key Map