# Final

## Hydrologic Modeling Report for Volume Depletion Approach Study

**Prepared for:**

**California State Water Resources Control Board**

**Division of Water Rights**

**March 31, 2014**

**Prepared by:**

**Stetson Engineers Inc.**

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# 1 Background

On September 28, 2010, the State Water Resources Control Board (State Water Board or SWRCB) adopted the Policy for Maintaining Instream Flows in Northern California Coastal Streams (Policy; SWRCB, 2010). The Policy establishes guidelines for evaluating the potential impacts of water diversion projects on stream hydrology and biological resources. Appendix A of the Policy contains two sets of approaches for evaluating the cumulative impacts of a proposed project. One of these two approaches, known as the volume depletion approach and described in Policy Section A.1.8.3, was proposed during the Policy adoption meetings. In Policy Section 10.4.1, the State Water Board requires that a study be completed to assess the regional protectiveness of Section A.1.8.3 within five years of the Policy adoption date. The purpose of this project is to complete the required study to assess the regional protectiveness of the alternative approach known as the Volume Depletion Approach.

On June 11, 2012, the State Water Board Division of Water Rights (Division) and Stetson Engineers Inc. (Stetson) executed a contract (No. 11-130-300; Contract) to perform the Volume Depletion Approach Study (Study). This report describes the hydrologic modeling work conducted for this study in accordance with Task 4 of the Contract Scope of Work.

The Volume Depletion Approach guidelines described in Policy Section A.1.8.3 apply to water right applicants located upstream of anadromous habitat. This study focuses on how potential diversions in headwaters areas of watersheds affect downstream habitat. Three study basins representative of the Policy area were selected in order to evaluate the regional protectiveness of the alternative guidelines.

Field work was conducted in the three study basins from October 2012 through April 2013. Habitat and streamflow data were collected to support the protectiveness analysis. The protectiveness analysis will use results from the hydrologic models described in this report to evaluate how various impaired flow scenarios affect downstream habitat. Model results will be used in the protectiveness analysis to determine: (1) available flow at potential points of diversion at locations upstream of habitat; (2) seasonal unimpaired flow quantities at the upper limits of anadromy; and (3) impaired flow at habitat POIs. In each model, unimpaired flow was estimated at:

- Potential points of diversion (PODs) at headwaters
- Existing PODs
- Upper limits of anadromy (ULAs)
- Habitat points of interest (POIs)
- Flow measurement locations

Each model was calibrated using the flow data collected in this study, as well as with available data collected by other parties.

# 2 Study Basins and Model Overview

In fall 2012, Stetson selected three study basins to include in the Study in consultation with State Water Board staff. From October 2012 through May 2013, Stetson completed field work in these study basins. Data were collected to support the hydrologic modeling and habitat protectiveness analysis.

## 2.1 Study Basins

The three study basins are Maacama Creek in Sonoma County, Upper Sonoma Creek in Sonoma County and Walker Creek in Marin County.

Fig. 1 shows the locations of the three study basins within the Policy area and Figs. 2 through 4 show the locations of the study sites within the three study basins. Overall, the field study included 17 study sites, listed in Table 1. Stetson installed dataloggers to measure stream stage at 15 of these sites. Stream stage and discharge were measured in each study basin in order to provide field calibration data for hydrologic models of the study basins. Habitat sites are classified as Class I sites, or Points of Interest (POIs). In general, both habitat data and streamflow data were collected at POIs. Field sites that are upstream of anadromous habitat are classified as Class II or III streams. At these locations, only streamflow data were collected for the field study. More information about stream class of the field sites may be found in the Field Study Report (Appendix A of the Final Study Report).

The majority of dataloggers were installed in October or November of 2012 and removed in May 2013, providing about one winter season of data. The dataloggers recorded pressure and temperature at 10-minute intervals. Periodically, stream discharge was measured in the field in order to relate discharge to stream stage. The raw datalogger pressure readings were corrected for barometric pressure, elevation differences and sensor shifts. Rating curves were then created using the discharge-stage measurements, and the corrected stage data were transformed into hourly time series. These hourly time series were used as calibration data in the hydrologic models described in this report.

**Table 1 - List of Study Basins and Study Sites**

| Study Site ID | Study Location | Drainage Area (sq mi) | Streamflow Gage | Habitat Survey |
|---|---|---|---|---|
| Maacama Creek | | | | |
| MC1 | Little Ingalls Creek | 0.4 | X | |
| MC2 | Ingalls Creek | 2.3 | X | X |
| MC3 | McDonnell Cr below Ingalls Cr | 5.2 | X | X |
| MC4 | Briggs Cr above Maacama Cr[1] | 12.4 | X | |
| MC5 | Maacama Cr below Briggs Cr | 23.2 | X | X |
| Sonoma Creek | | | | |
| SC1 | Headwaters Sonoma Creek | 0.6 | X | |
| SC2 | Unnamed trib to Sonoma Creek | 0.2 | X | |
| SC3 | Malm Fork | 0.5 | X | |
| SC4 | Upper Sonoma Cr above Bear Cr | 3.8 | X | X |
| SC5 | Lower Bear Cr | 1.9 | X | X |
| SC6 | Sonoma Cr near Highway 12 | 8.2 | X | X |
| Walker Creek | | | | |
| WC1 | Upper Salmon Cr | 0.3 | X | |
| WC2 | Middle Salmon Cr[2] | 1.6 | | X |
| WC3 | Unnamed trib to Walker Cr at Walker Ranch | 0.2 | X | |
| WC4 | Walker Cr[3,4] | 12.3 | | X |
| WC5 | Unnamed trib to Walker Cr d/s Walker Ranch | 0.3 | X | |
| WC6 | Frink Cyn, lower | 3.2 | X | X |

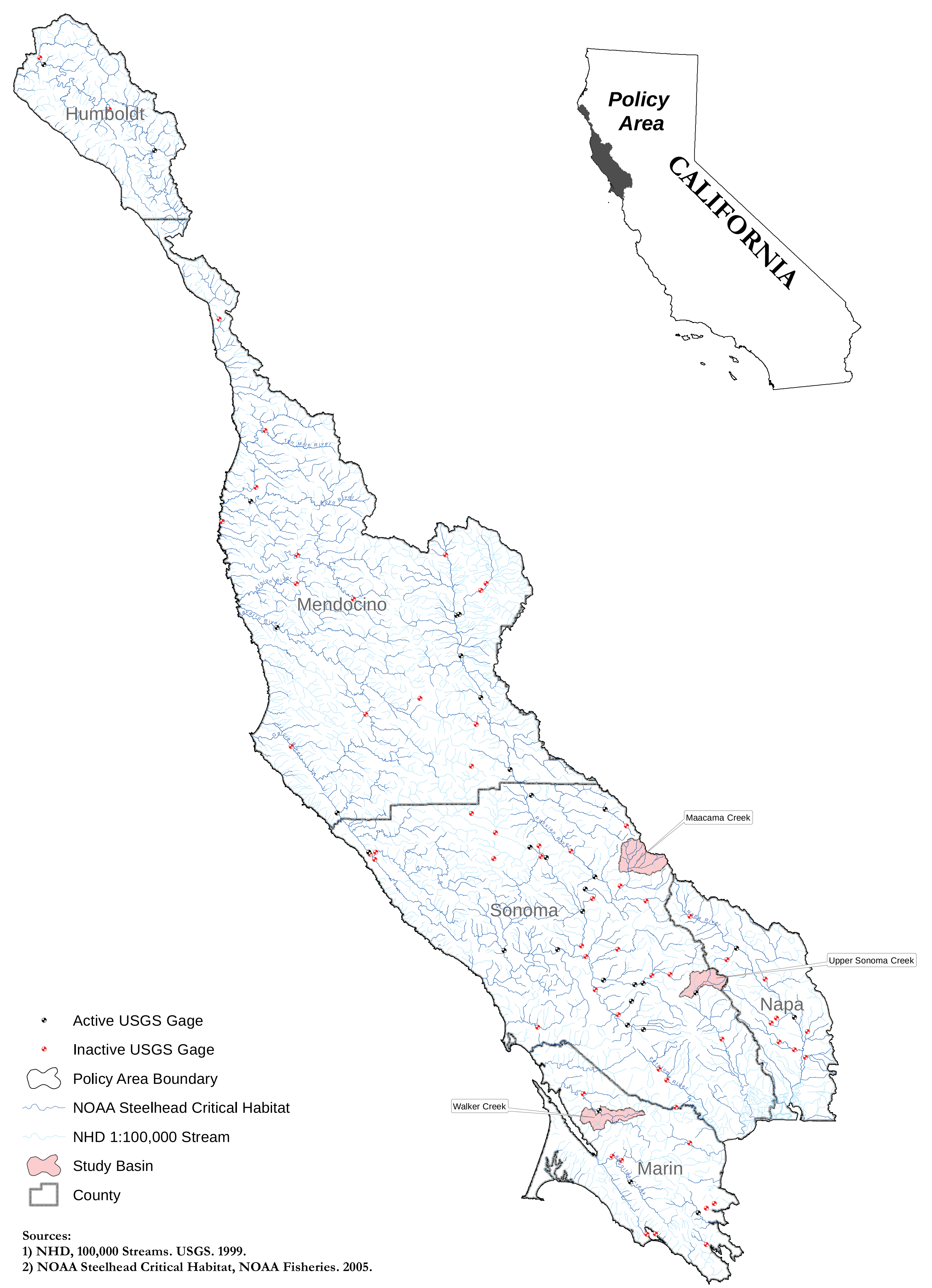
Notes:

[1] Flow measurement only; no habitat data were collected.

[2] Habitat survey only; flow was measured nearby at gage WC1.

[3] Habitat survey only; flow was measured nearby at USGS gage No. 11460750

[4] Drainage area at the gage does not include the 19 square miles ($mi^2$) of land regulated by Soulajule Reservoir. The drainage area shown (12.3 $mi^2$) represents the drainage area on Salmon Creek, Arroyo Sausal below Soulajule Reservoir, Verde Canyon and Walker Creek.




Sources:
1) NHD, 100,000 Streams. USGS. 1999.
2) NOAA Steelhead Critical Habitat, NOAA Fisheries. 2005.

# VOLUME DEPLETION APPROACH STUDY BASINS

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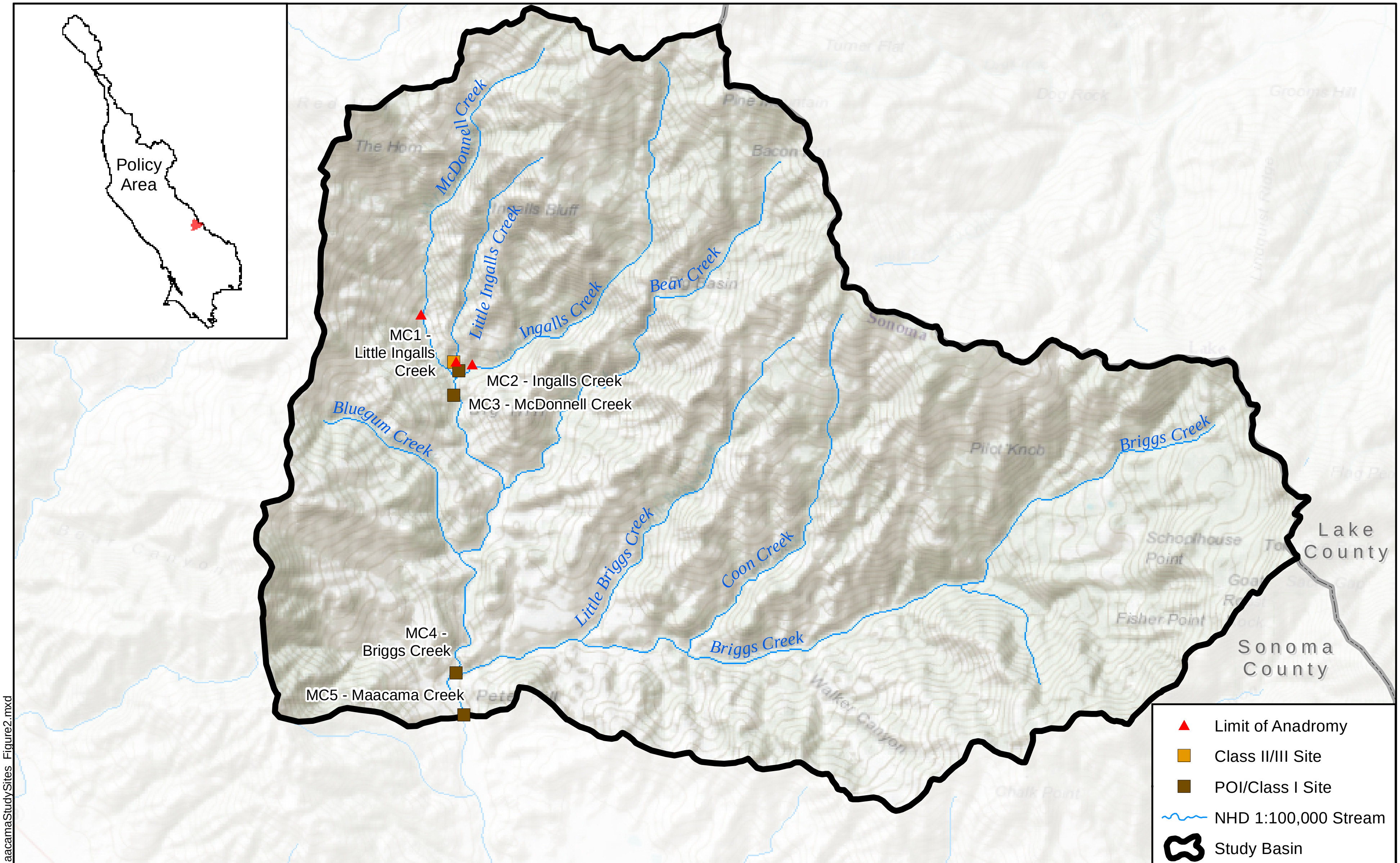
FIGURE 1




# MAP OF MAACAMA CREEK WATERSHED AND STUDY SITES

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Source:
NHD, 100,000 Streams. USGS. 1999.

N

0 0.5 1 Miles

FIGURE 2

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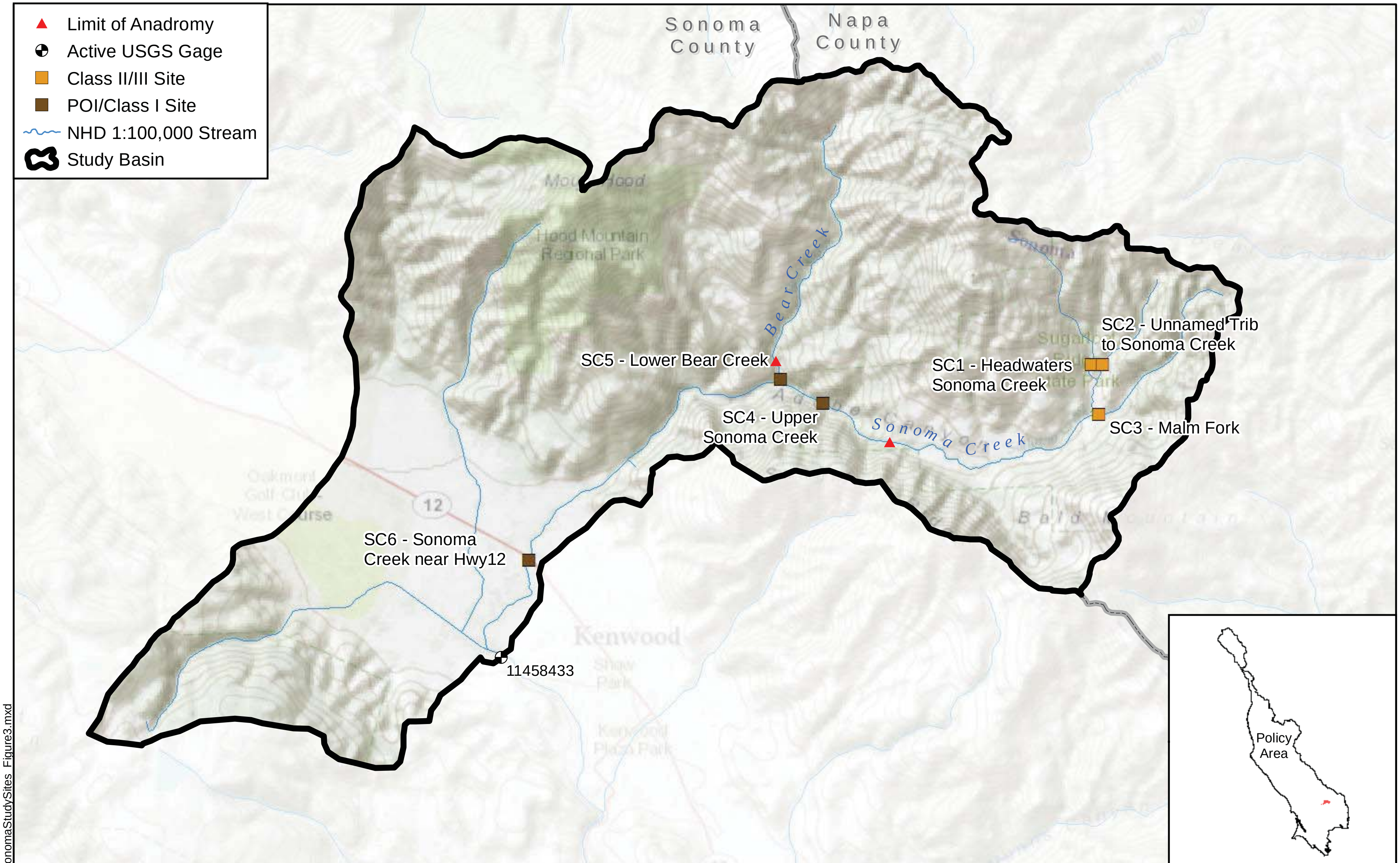


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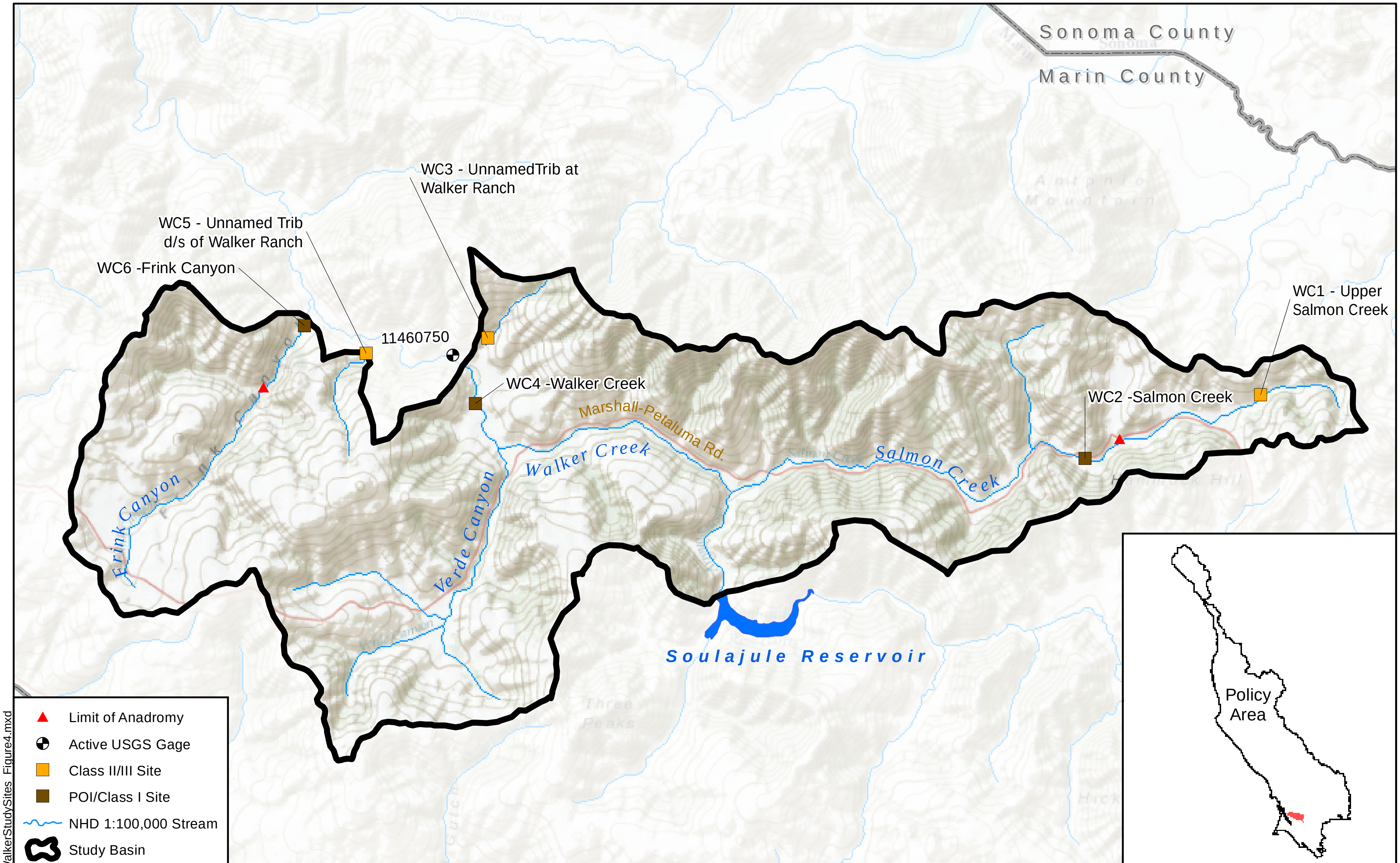
# MAP OF SONOMA CREEK WATERSHED AND STUDY SITES

Source:
NHD, 100,000 Streams. USGS. 1999.

FIGURE 3




# MAP OF WALKER CREEK WATERSHED AND STUDY SITES

Source:
NHD, 100,000 Streams. USGS. 1999.

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FIGURE 4

## 2.2 HSPF Model Overview

This report describes the preparation of hydrologic models of the three study basins using the Hydrologic Simulation Program - Fortran (HSPF) developed by Hydrocomp and Aquaterra and supported and distributed by the US Environmental Protection Agency (Bicknell et al, 2001).

HSPF is a software program (model) that simulates hydrologic processes in land segments and stream channels in response to input meteorological time series. HSPF is available as part of the Better Assessment Science Integrating point and Nonpoint Sources (BASINS) software system, available via free download from the US Environmental Protection Agency (EPA, 2013). WinHSPF version 2.3 was utilized to run the HSPF simulation for a continuous 10-year period. Model inputs were hourly precipitation and evaporation time series and land segment and reach parameters. Model outputs were flow time series.

The model setup was calibrated by adjusting land segment parameters for each of the three watersheds to provide the most accurate estimate of unimpaired flow when compared to the available gaged flows. The Model-Independent Parameter Estimation (PEST) software program developed by John Doherty (Doherty, 2004) was used for auto-calibration of parameters in combination with manual calibration to minimize observed and simulated stream flow differences and to match hydrograph shape.

## 2.3 Model Simulation Period

All three models were simulated for the period from October 2003 through the end of April 2013. In addition, in all three models, the simulation was run from October 2002 through September 2003 in order to establish appropriate antecedent soil moisture conditions at the beginning of the model period in October 2003. All three models were run on an hourly time step.

# 3 Meteorological Data

HPSF requires two types of meteorological time series data as input to the model: precipitation and potential evapotranspiration. The models and corresponding input data used an hourly time step. Data from multiple weather networks were used in this study. The data and sources are described below.

## 3.1 Precipitation

Precipitation data were obtained from regional, state-wide and national weather networks. The stations used in the model are listed in Table 2 and shown in Fig. 5. In most cases, hourly data were available for at least one station in close proximity to each study basin. Each study basin was assigned two precipitation stations.

The raw precipitation records were checked for errors and missing data. Missing data were flagged and then estimated using data from nearby stations.

Some stations contained 'accumulated' errors, where a missing period is followed by a precipitation value that is flagged as accumulated over the missing period. The missing period was filled by distributing the accumulated amount over each day in the accumulation period according to distribution of rainfall during the same period at a nearby gage.

Missing values were estimated from the precipitation records at a nearby station. The rainfall amount at the main station was determined using the ratio of the long-term average rainfall at the main station to the long-term average rainfall at the alternate station:

$$P_{main} = P_{alt} \frac{LTA_{main}}{LTA_{alt}}$$

where $P_{main}$ = estimated precipitation amount at the main station,
$P_{alt}$ = observed precipitation amount at the alternate station,
$LTA_{main}$ = long-term average precipitation at the main station and
$LTA_{alt}$ = long-term average precipitation at the alternate station.

Long-term average precipitation, given for each station in Table 3, was obtained from a raster grid GIS coverage of precipitation from the PRISM Climate Group (PRISM, 2012).

At the Calistoga and Glen Ellen stations, only daily data were available. In these cases, the daily time series was checked and any missing values were filled with data from nearby stations. Then, each filled daily record was disaggregated to hourly using the observed hourly rainfall distribution at nearby stations. This disaggregation was completed in the WDMUtil software program (Version 2.27), distributed with BASINS.

Data from the Bennett Valley and Windsor stations, part of the California Irrigation Management Information System (CIMIS, 2013), were used to fill data records used in the model; however, the CIMIS precipitation records were not directly used by the models.

The filled precipitation records are included in Appendix B-1.

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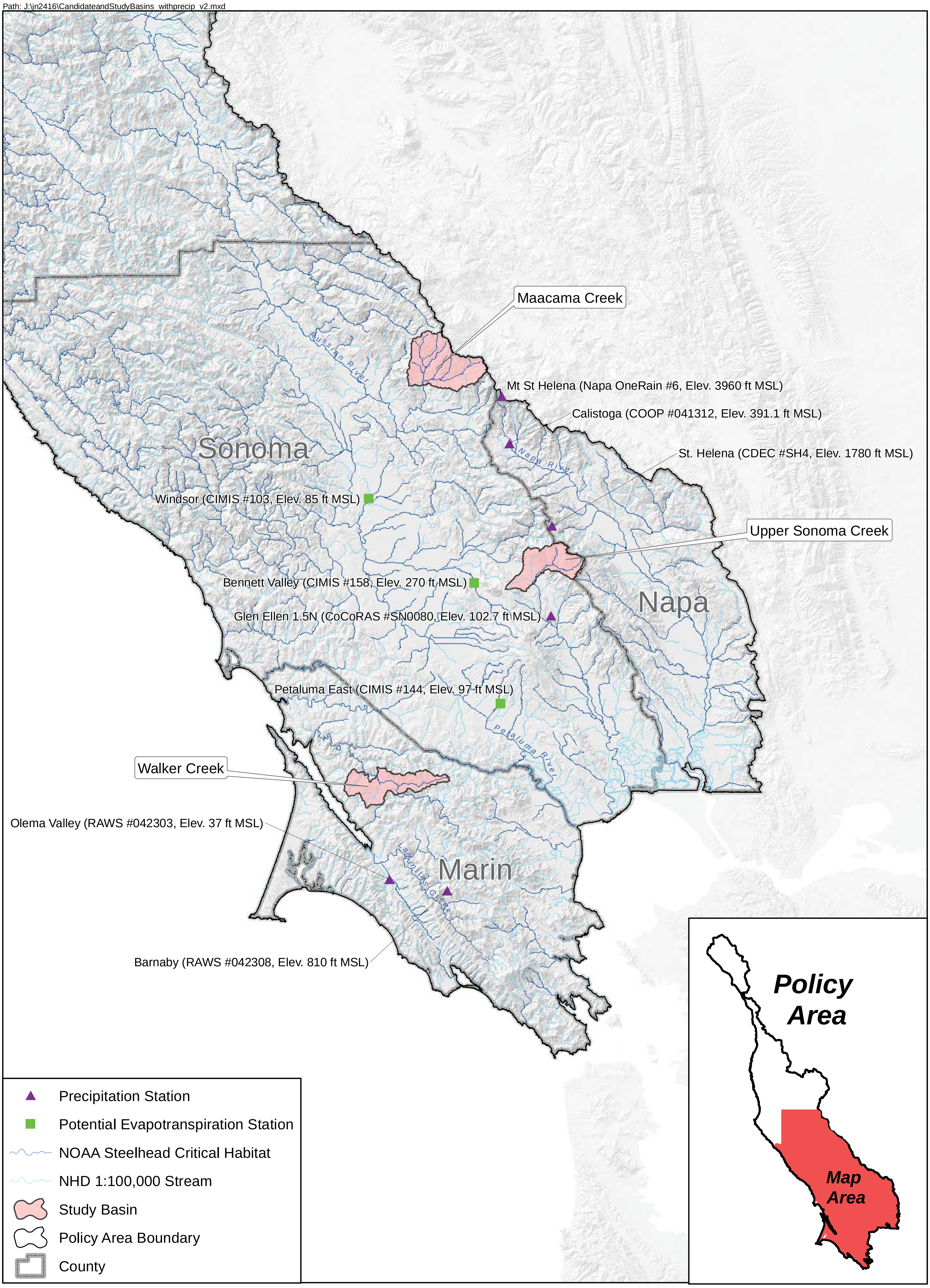


# METEOROLOGICAL STATIONS USED IN STUDY BASIN HYDROLOGIC MODELS



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Sources:
1) NHD, 100,000 Streams. USGS. 1999.
2) NOAA Steelhead Critical Habitat, NOAA Fisheries. 2005.

FIGURE 5

**Table 2 - Summary of Precipitation Data Used in HSPF Models**

| Study Basin | Station Name | Network ID | Start Date | End Date | Source | Elevation (ft) | Avg Ann Precip from PRISM (in/yr) | Data Resolution |
|---|---|---|---|---|---|---|---|---|
| Maacama | Mt. St. Helena | 6 | 10/1/2003 | 4/30/2013 | (1) | 3,960 | 57.5 | Hourly |
| | Calistoga | 041312 | 10/1/2003 | 4/30/2013 | (2) | 391 | 39.6 | Daily* |
| Sonoma | Saint Helena 4 WSW | SH4 | 10/1/2002 | 4/30/2013 | (3) | 1,741 | 45.5 | Hourly |
| | Glen Ellen 1.5 | SN0080 | 10/1/2003 | 4/30/2013 | (4) | 103 | 33.7 | Daily* |
| Walker | Barnaby | 042308 | 10/1/2002 | 4/30/2013 | (5) | 810 | 43.8 | Hourly |
| | Olema Valley | 042303 | 10/1/2007 | 4/30/2013 | (5) | 37 | 33.9 | Hourly |

Notes:
Start and end dates are those of the data series used in the model; additional data may be available at stations prior to and after those dates.
An asterisk (*) indicates that data at that station were only available in daily format, but were then disaggregated to hourly using the hourly pattern from a nearby station.
Sources:
(1) Napa OneRain (Napa County, 2013)
(2) Western Regional Climate Center (WRCC), Cooperative Network Station (WRCC, 2013a)
(3) California Data Exchange Center (CDEC) (DWR, 2013)
(4) National Climatic Data Center (NCDC), Community Collaborative Rain, Hail & Snow Network (CoCoRAS) (NCDC, 2013)
(5) Western Regional Climate Center (WRCC), Remote Automatic Weather Station Network (WRCC, 2013b)

## 3.2 Potential Evapotranspiration

Potential evapotranspiration (PET) data were obtained from the CIMIS network for stations near the study basins (CIMIS, 2013). Each study basin hydrologic model was assigned the station in closest proximity, listed in Table 3 and shown in Fig. 5. The Maacama Creek hydrologic model was assigned the Windsor station (#103); Sonoma Creek was assigned the Bennett Valley station (#158); and Walker Creek was assigned the Petaluma East station (#144). Data were obtained for the period 10/1/2002 through 4/30/2013.

Each station's record contained some missing records, which were filled using available data from nearby stations. If data were missing at all three stations, supplemental data were obtained for two additional stations in the area, Santa Rosa (#83) and Oakville (#77). Windsor, Bennett Valley, Petaluma East and Santa Rosa are in the same evapotranspiration (ET) zone, Zone 5 (CIMIS, 1999), meaning they are subject to similar evapotranspiration quantities. Accordingly, no adjustment was made when filling data between these stations (i.e. if Windsor was missing a value, the available value at Bennett Valley was used without any modification). However, the Oakville Station is in ET Zone 8, so an adjustment ratio was used when filling from this station. The ratio was based on the average annual ET in Zones 5 and 8, which are 43.9 and 49.4 inches, respectively. The filled PET records are included in Appendix B-1.

**Table 3 - Summary of Potential Evapotranspiration Data Used in HSPF Models**

| Study Basin | Station Name and ID | Start Date | End Date | Elevation (ft) | Avg Ann Precip from PRISM (in/yr) | Data Resolution |
|---|---|---|---|---|---|---|
| Maacama | Windsor, #103 | 10/1/2002 | 4/30/2013 | 85 | 36.1 | Hourly |
| Sonoma | Bennett Valley, # 158 | 10/1/2002 | 4/30/2013 | 270 | 33.8 | Hourly |
| Walker | Petaluma East, #144 | 10/1/2002 | 4/30/2013 | 97 | 27.3 | Hourly |

Source: All data from California Irrigation Management Information System (CIMIS, 2013). Start and end dates are those of the data series used in the model; additional data may be available at stations prior to and after those dates.

# 4 Land Segments and Reaches

In addition to precipitation and evaporation inputs, HSPF requires a description of the watershed. The watershed area is represented as land segments; the stream channels are represented as reaches. Precipitation and evaporation occur on the surface of the land segments, changing the soil moisture conditions on and within the land. The changing soil moisture conditions may result in water leaving the land and entering the reaches (runoff). This runoff moves through the reaches to the watershed outlet.

The stream channels were divided into reaches based on locations that will be analyzed in the protectiveness analysis. Reach end point locations include:

- Existing PODs. For the three study basins, existing PODs were reviewed in the SWRCB electronic Water Rights Information Management System (eWRIMS) database. Reach end points were defined at existing POD locations on Class II and Class III streams in the study basins so that diversions could be simulated at these locations in the protectiveness analysis.
- ULAs. In evaluating the guidelines in Section A.1.8.3, it is critical to know the unimpaired flow at the ULAs, as the maximum cumulative diversion is based on a percentage of the unimpaired flow at the ULAs. Reach end points were defined at the ULAs of each study basin.
- Habitat POIs. Reach end points were defined at all habitat POIs so that potential cumulative impacts could be assessed at these locations.
- Flow measurement locations. Reach end points were defined at all field study flow measurement sites and available flow data locations so that the flow data could be used to calibrate the hydrologic models.

The alternative guidelines in Section A.1.8.3 will be evaluated in the protectiveness analysis using a range of diversion scenarios, including a “distributed” case which analyzes the impacts of diversions throughout the headwaters of each study basin. For the three hydrologic models, potential headwater POD locations were defined at the upstream ends of streams as delineated in the National Hydrography Dataset (NHD) 1:24,000 stream coverage.

The watershed areas were divided into land segments based on elevation. A land segment was defined for every 200 feet (ft) change in elevation. The area of each land segment contributing to each reach and each potential headwater POD was measured in the GIS.

## 4.1 Maacama Creek Reaches and Land Segments

The Maacama Creek model (Fig. 6) has 17 land segments that range in elevation from 200 ft. to 3,600 ft. mean sea level (MSL). There are nine headwaters locations where flow is estimated. There are reach outlet points for each of the five field study locations (MC1 - MC5). There is also a reach outlet for Bear Creek, which was simulated but does not have any associated field data. The downstream limit of the model is the most downstream POI located at MC5. An existing POD is located in the headwaters of McDonnell Creek, upstream of gage MC3.

## 4.2 Sonoma Creek Reaches and Land Segments

The Sonoma Creek model (Fig. 7) has 13 land segments that range in elevation from 200 ft. to 2,800 ft MSL. There are 11 headwaters locations, as well as six reach outlet points for each of the six field study locations (SC1 - SC6). The downstream limit of the model is at the USGS gage on Sonoma Creek (#11458433). Reaches were also created for Rattlesnake Canyon and a tributary near the USGS gage. Two existing PODs are located at the outlet point of the Rattlesnake Canyon reach. Another existing POD is on the Bear Creek headwaters.

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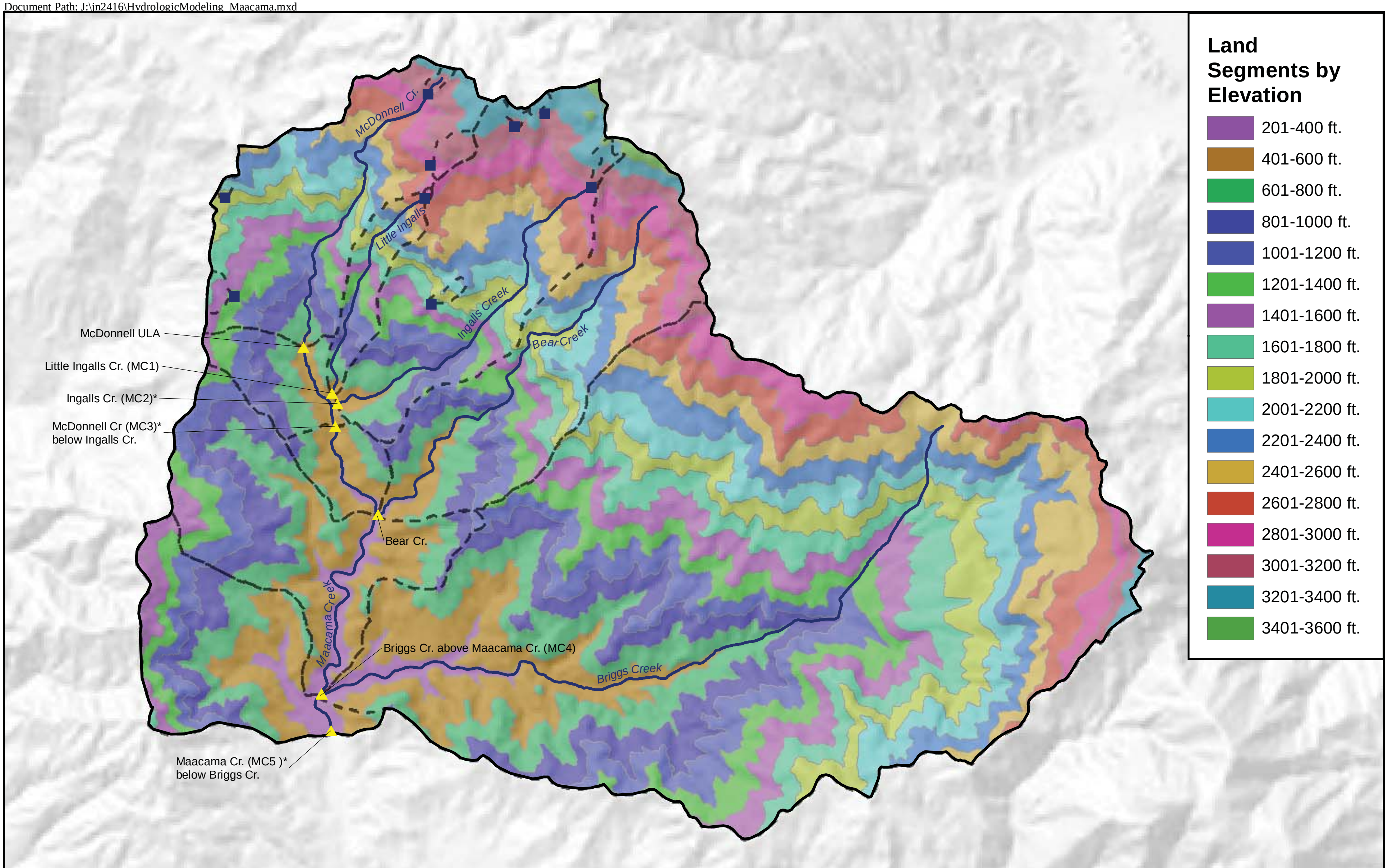


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Reach Outlet Point (*indicates calibration location)
Headwaters Outlet Point
Reach
Reach Drainage Area

# MAACAMA CREEK WATERSHED REACHES AND LAND SEGMENTS

N

0 0.5 1 Mile

FIGURE 6

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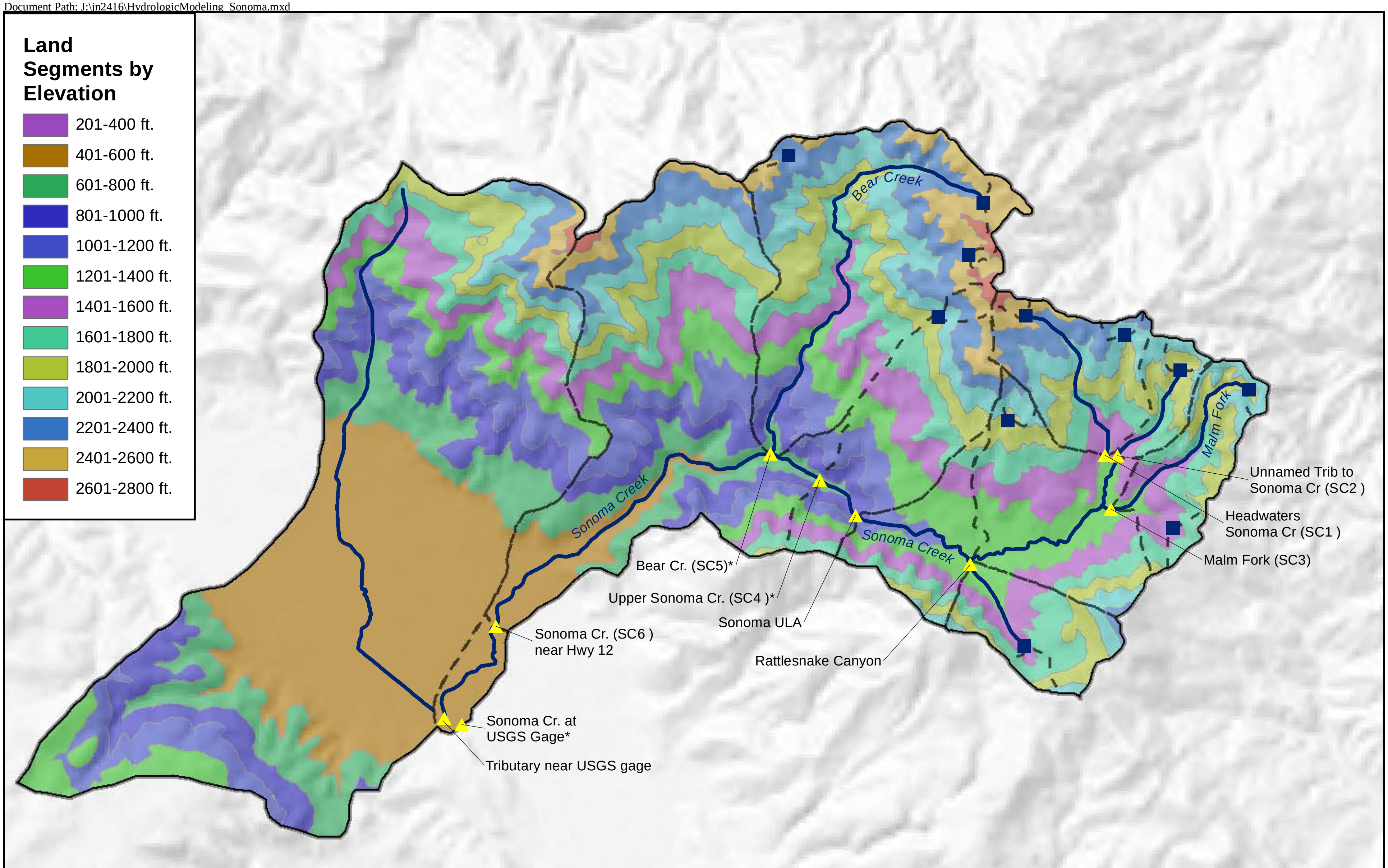


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Reach Outlet Point (* indicates calibration location)

Headwaters Outlet Point

Reach

Reach Drainage Area

**SONOMA CREEK WATERSHED**
**REACHES AND LAND SEGMENTS**

N

0 0.5 1 Mile

FIGURE 7

## 4.3 Walker Creek Reaches and Land Segments

The Walker Creek model (Fig. 8) has seven land segments that range in elevation from 0 ft. to 1,400 ft. MSL. There are five headwaters locations. Reaches were defined at the six field study locations (WC1 - WC6). In addition, reaches were defined at important confluences, such as where Salmon Creek and Arroyo Sausal meet to form Walker Creek, and where Verde Canyon joins Walker Creek. There are no existing PODs on the Class II or Class III streams; however there is a pending POD on a tributary to Salmon Creek, upstream of WC2.

The downstream limit of simulation for Walker Creek is at the USGS gage (#11460750) near site WC4. Frink Canyon was simulated only above the gage at field site WC6. The area between site WC6 and its confluence with Walker Creek was not simulated since no additional flow or habitat data were collected there.

The model area does not include Soulajule Reservoir or any of its contributing area. Walker Creek model results were only used for Frink Canyon (above WC6), Salmon Creek (above WC2) and the unnamed tributary at Walker Ranch (above WC3).

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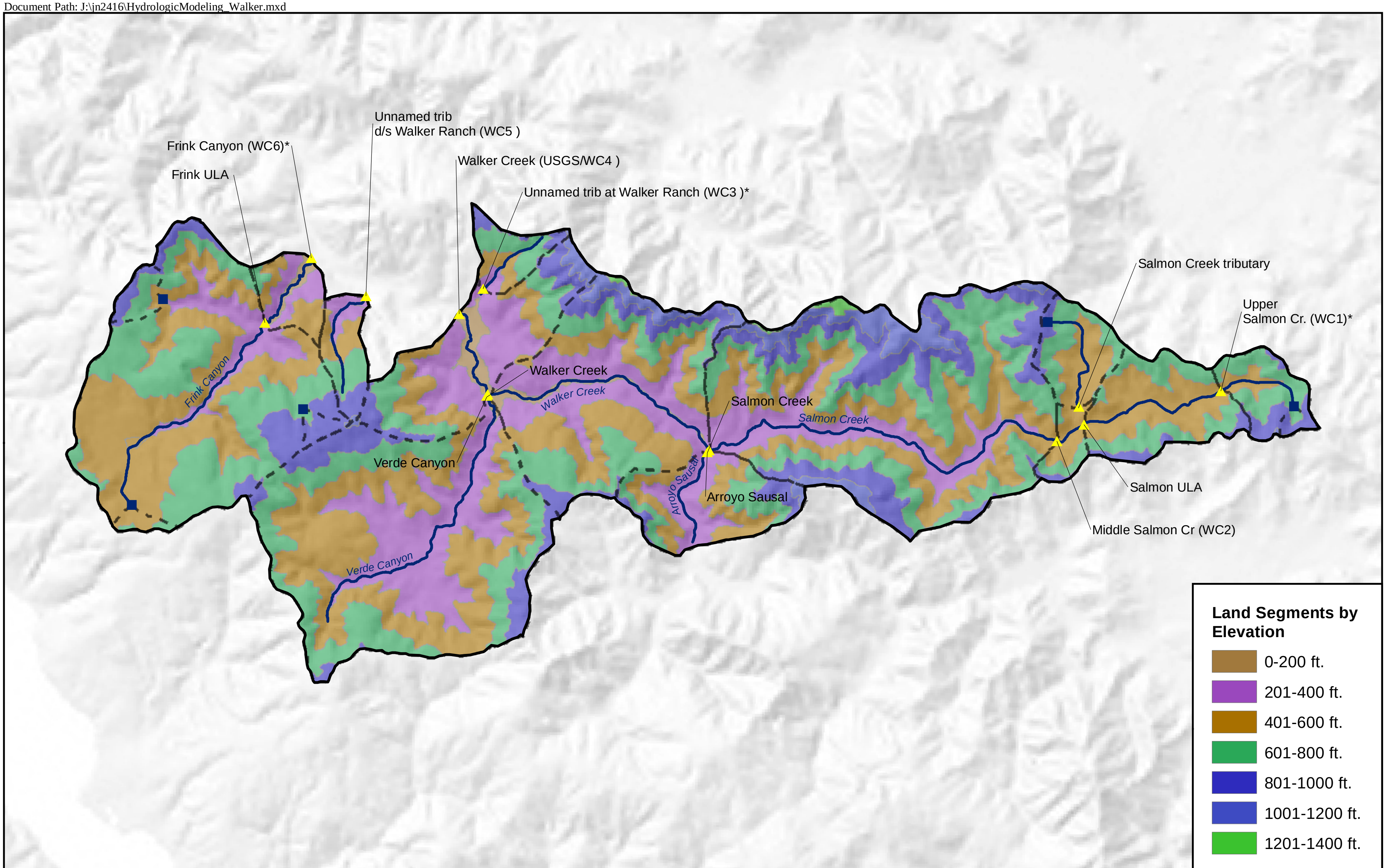


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- ▲ Reach Outlet Point (* indicates calibration location)
- ■ Headwaters Outlet Point
- Reach
- Reach Drainage Area

# WALKER CREEK WATERSHED REACHES AND LAND SEGMENTS

N

0 0.5 1 Mile

FIGURE 8

# 5 Calibration and Results

The HSPF model of each study basin was calibrated to produce estimates of streamflow that match the observed data using an iterative procedure of HSPF parameter estimation and evaluation. The calibration data, parameters, and techniques used are described below.

## 5.1 Flow Data for Calibration

Model calibration for each study basin was completed using streamflow data collected for this study and by other parties:

- Maacama Creek: Streamflow data collected by Stetson at the five field study sites (MC1 - MC5) were used for calibration. In addition, data collected for a previous study (Deitch and Kondolf, 2012) were provided for use in this study (M. Deitch, pers. comm., "Gage Data from Maacama Creek", January 28, 2013). The flow measurements collected by Stetson generally cover the period from November 2012-April 2013. The flow measurements collected for the previous study cover the period from October 2003 through August 2005.
- Sonoma Creek: Streamflow data collected by Stetson at the six field study sites (SC1 - SC6) were used for calibration. In addition, data collected by the USGS at the gage at Kenwood (#11458433) were used for calibration. Hourly time series were computed from the USGS 15-minute records. Flow measurements collected by Stetson cover the period from November 2012-April 2013. The USGS records are available for October 2008 through April 2013.
- Walker Creek: Flow measurements collected by Stetson at the four flow gage study sites (WC1, WC3, WC5 and WC6)[1] were used for calibration. Streamflow measurements at the USGS gage (#11460750) were used for estimating flows in the watershed, but this gage data was not directly used for calibration. Field data collected by Stetson covers the period from November 2012-April 2013.

Table 4 lists the existing diversions in each study basins as documented in the SWRCB eWRIMS database (2013). The study basins were selected to have relatively few diversions:

- Maacama Creek: There is only one existing POD in the study area on Class II or III streams, A020901 on the McDonnell Creek headwaters. All other existing PODs are on Briggs Creek with a total max direct diversion rate of 1.85 cfs. These diversions reduce the observed streamflow at MC4, particularly in the fall when storage is filling. The downstream gage at MC5 (POI and calibration point) is also impacted.
- Sonoma Creek: There are relatively few diversions in this basin, most of which are located in the lower part of the watershed. There are three existing PODs in the study area on Class II or III streams, S000118 and S015983 on Rattlesnake Creek and A028978 on the Bear Creek headwaters.
- Walker Creek: There are relatively few diversions on Walker Creek and Salmon Creek and there are no existing PODs on Class II or III streams. There are many diversions on the Arroyo Sausal tributary upstream of the Soulajule Reservoir; however, this area is not modeled so these PODs are not included in Table 4.

The model of each study basin was calibrated to produce estimates of streamflow that match the observed data. The study basins have few diversions and the observed flows are relatively unimpaired

[1] At sites WC2 and WC4, only habitat data were collected.

although at some locations (WC4 and MC5) there are existing diversions on downstream tributaries which affect observed flow at the POIs. The calibrated HSPF simulated flows are referred to in this study as "unimpaired flows" because the model simulates rainfall-runoff with no diversions.

The streamflow data time series used for calibration are included in Appendix B-2.  The appendix includes Stetson's field data as well as data from the USGS and Deitch and Kondolf (2012).

**Table 4 - Summary of Existing Diversions in Study Basins**

| Basin | Stream | Gage(s) Affected | Application ID | Max Direct Diversion (cfs) | Max Storage (ac-ft) | Max Annual Use (ac-ft) |
|---|---|---|---|---|---|---|
| Maacam | McDonnell Cr | MC3 & MC5 | A020901* | 0.0006 | 0 | 0.3 |
| Maacam | Briggs Cr | MC4 & MC5 | A013578 | 0.670 | 0 | 485.1 |
| Maacam | Briggs Cr | MC4 & MC5 | A023098 | 0.225 | 0 | 156 |
| Maacam | Briggs Cr | MC4 & MC5 | D030712R | 0.0007 | 0.5 | 0.9 |
| Maacam | Briggs Cr | MC4 & MC5 | D030759R | 0 | 8 | 8 |
| Maacam | Briggs Cr | MC4 & MC5 | D031005R | 0.008 | 2.5 | 4.1 |
| Maacam | Briggs Cr | MC4 & MC5 | S006316 | 0 | 0 | 0 |
| Maacam | Briggs Cr | MC4 & MC5 | S015758 | 0 | 0 | 0 |
| Maacam | Briggs Cr | MC4 & MC5 | S015759 | 0 | 0 | 0 |
| Maacam | Briggs Cr | MC4 & MC5 | S015904 | 0.600 | 0 | 0 |
| Maacam | Briggs Cr | MC4 & MC5 | S015905 | 0.225 | 0 | 0 |
| Maacam | Coon Cr | MC4 & MC5 | S014979 | 0.008 | 0 | 0 |
| Maacam | Coon Cr | MC4 & MC5 | S014980 | 0.008 | 0 | 0 |
| Maacam | Little Briggs Cr | MC4 & MC5 | S014973 | 0.019 | 0 | 0 |
| Maacam | Little Briggs Cr | MC4 & MC5 | S014974 | 0.019 | 0 | 0 |
| Maacam | Little Briggs Cr | MC4 & MC5 | S014975 | 0.019 | 0 | 0 |
| Maacam | Little Briggs Cr | MC4 & MC5 | S014976 | 0.019 | 0 | 0 |
| Maacam | Little Briggs Cr | MC4 & MC5 | S014977 | 0.019 | 0 | 0 |
| Maacam | Little Briggs Cr | MC4 & MC5 | S014978 | 0.013 | 0 | 0 |
| Sonoma | Rattlesnake Cr | SC4, SC6 & USGS | S000118* | 0.082 | 0 | 0 |
| Sonoma | Rattlesnake Cr | SC4, SC6 & USGS | S015983* | 0.00001 | 0 | 10 |
| Sonoma | Bear Cr | SC5, SC6 & USGS | A028978* | 0 | 4.3 | 4.3 |
| Sonoma | Sonoma Cr nr Hwy 12 | SC6 & USGS | A008390 | 0.0019 | 0 | 0.8 |
| Sonoma | Upper Sonoma Cr | SC6 & USGS | S014957 | 0.005 | 0 | 0 |
| Sonoma | Upper Sonoma Cr | SC6 & USGS | S015600 | 0.013 | 0 | 0 |
| Sonoma | Sonoma Trib abv USGS | USGS | A005050 | 0.030 | 7 | 28.7 |
| Sonoma | Sonoma Trib abv USGS | USGS | A016192 | 0.150 | 0 | 32.7 |
| Sonoma | Sonoma Trib d/s Bear | USGS | A017938 | 0 | 4.8 | 4.8 |
| Walker | Walker Ranch | WC3 | S013201 | 0.0028 | 0 | 0 |
| Walker | Verde Canyon | WC4 & USGS | A023829 | 0 | 45 | 45 |
| Walker | Walker Trib | WC4 & USGS | A024744 | 0 | 48 | 48 |
| Walker | Walker Trib | WC4 & USGS | A027728 | 0 | 18 | 18 |

*Existing POD location is on a Class II or Class III stream.

## 5.2 HSPF Parameters

### 5.2.1 HSPF Meteorological Factors

For HSPF, each land segment is assigned a precipitation and evapotranspiration multiplication factor. These factors are used to estimate hourly precipitation and evapotranspiration on the land segment from the input time series measured at the meteorological station.

These meteorological factors have a strong influence on the volume of simulated streamflow and were adjusted during calibration to balance water volumes and adjust the distribution of streamflow throughout the watershed.

Precipitation factors for each land segment were initially estimated as the GIS-calculated segment average annual precipitation from PRISM (2012) divided by the PRISM value for the meteorological station. Maacama was divided into 4 sub-basins, Sonoma into 5 sub-basins and Walker into 3 sub-basins based on flow differences at the gages. During calibration, the precipitation factors were raised or lowered by a constant multiplier for each sub-basin.

The calibrated evapotranspiration factors are 1.0 for Walker and Sonoma and 0.75 for Maacama.

### 5.2.2 HSPF Land Segment Parameters

Table 5 lists the HSPF land segment parameters used to simulate the components of the water budget on pervious land. A description and value are also provided.

The HSPF land segment parameters which have a strong influence on simulated streamflow are AGWRC, CEPSC, INFILT, INTFW, IRC, KVARY, LZETP, LZSN and UZSN. These parameters were determined during calibration as indicated in Table 5 by 'calibrated' in the value column.

The HSPF land segment parameters which do not have a strong influence on streamflow were set to the standard values given in Table 5. The average slope of the overland flow plane (SLSUR) for each segment was calculated in the GIS.

**Table 5 - HSPF Land Segment Parameters**

| Parameter | Description | Value[1] |
|---|---|---|
| AGWETP | Fraction of remaining PET which can be satisfied from active groundwater | 0 |
| AGWRC | Active groundwater recession constant (ratio of active groundwater outflow today to active groundwater outflow yesterday) | calibrated |
| BASETP | Fraction of remaining PET which can be satisfied from base flow | 0 |
| CEPSC | Interception storage capacity | calibrated |
| DEEPFR | Fraction of groundwater inflow which will enter deep (inactive) groundwater | 0 |
| FOREST | | |
| INFEXP | Infiltration equation exponent | 1.5 |
| INFILD | Ratio between the maximum and mean infiltration capacity | 2 |
| INFILT | Index to the infiltration rate capacity | calibrated |
| INTFW | Interflow inflow parameter | calibrated |
| IRC | Interflow recession parameter (ratio of interflow outflow today to interflow outflow yesterday) | calibrated |
| KVARY | Variability of groundwater recession flow | calibrated |
| LSUR | Length of the assumed overland flow plane | 250 ft |
| LZETP | Lower zone evapotranspiration | calibrated |
| LZSN | Lower zone nominal storage | calibrated |
| NSUR | Manning's n for the overland flow plane | 0.3500 |
| PETMAX | Temperature below which potential evapotranspiration (PET) is reduced | 40 deg F |
| PETMIN | Minimum temperature when PET occurs, PET is reduced from the input value at PETMAX to 0 at PETMIN | 30 deg F |
| SLSUR | Slope of the overland flow plane | GIS |
| UZSN | Upper zone nominal storage | calibrated |

Note:
[1] For parameter values noted as 'calibrated' or 'GIS', specific values used for each land segment may be found in the HSPF UCI files included in Appendix B-3.

### 5.2.3 HSPF Reach Parameters

Table 6 lists the HSPF reach parameters used to simulate the hydraulic processes occurring in a reach. For each reach, the reach length, slope and contributing area were measured in the GIS. The weighting factor for hydraulic routing (KS) is set to the standard value of 0.5.

Each reach also requires input of an FTABLE which gives the reach area, volume and outflow over a range of water depths. FTABLEs were calculated for each reach assuming a trapezoidal cross section and using the reach channel properties measured in the GIS to estimate slope, channel width as a function of drainage area, and Manning's n as a function of slope (results range from 0.030 to 0.035).

The reach parameters and FTABLEs do not have a strong influence on simulated streamflow in the study basins. They were not adjusted during calibration.

**Table 6 - HSPF Reach Parameters**

| Parameter | Description | Value[1] |
|---|---|---:|
| DELTH | Change in water elevation over the length of the reach | GIS |
| KS | Weighting factor for hydraulic routing | 0.5 |
| LEN | Length of reach | GIS |
| STCOR | Stage correction to calculate stage from depth | 0 ft |

Note:
[1] For parameter values noted as 'GIS', specific values used for each reach may be found in the HSPF UCI files included in Appendix B-3.

## 5.3 Calibration Procedures

Calibration of HSPF models is an iterative procedure of parameter estimation and evaluation. PEST was used for auto-calibration of land segment parameters in combination with manual calibration of meteorological factors and land segment parameters to minimize observed and simulated stream flow differences and to match hydrograph shape.

PEST minimizes the weighted sum of squared differences between model simulated streamflow and the observed values using the Gauss-Marquardt-Levenberg algorithm. Multiple PEST runs were made for the calibration of each basin. Runs differ by the calibration parameters considered, the starting value and bound of each parameter, the gage at which flows are compared, and the period and range of flow data compared. PEST run results provide the recommended value and sensitivity of each calibration parameter.

For each study basin, initial values for all calibration parameters were taken from a previous model created for a watershed in Napa County (Appendix F of R2 and Stetson, 2008).

Steps taken for calibration were:

1. manually adjust the meteorological factors to match observed water budget within 10%
2. run PEST auto-calibration for land segment parameters that influence groundwater
3. run PEST auto-calibration for land segment parameters that influence storm hydrograph shape
4. manually adjust the land segment parameters based on PEST recommendations

These steps were completed iteratively until both stream flow volume and timing matched the observed data. Calibration ended when further parameter changes resulted in no significant improvement in the flow differences or hydrograph shape.

The final calibrated parameters are given in the HSPF UCI files included in Appendix B-3.

### 5.3.1 Maacama Creek Calibration

The primary calibration locations in the Maacama Creek HSPF model were the field study sites at MC2, MC3 and MC5. These are the three habitat sites (POIs) where protectiveness of the alternative guidelines will be evaluated. At MC2 and MC3, calibration was done using the field data from 2012-2013. At MC5, calibration was done using the field data from 2012-2013, as well Deitch and Kondolf's data taken at that location from 2003-2005. MC5 is regulated by existing diversions on the Briggs Creek tributary which enters downstream of the study area but impacts flow at this POI; simulated flows at MC5 represent unimpaired flow from the study area but may include the impacts of existing Briggs Creek diversions.

### 5.3.2 Sonoma Creek Calibration

The primary calibration locations in the Sonoma Creek HSPF model were the field study sites at SC4 and SC5, and the USGS gage at Kenwood (#11458433). Calibration at SC4 and SC5 was done for the field season of 2012-2013. At the USGS gage, calibration data were available for October 2008 through April 2013.

Calibration was not completed at the field site at SC6 because of sub-surface flow in that area. Despite obtaining a good calibration upstream at SC4 and SC5 and downstream at the USGS gage on Sonoma Creek, the observed flows at SC6 did not match the simulated flows. This is likely due to the transition from surface to sub-surface flow that occurs in that reach of the stream where a portion of the stream discharge flows underground and therefore was not gaged by the field equipment[2].

The sub-surface flow was accounted for outside the HSPF model by applying adjustment factors to the simulated results at SC6. The adjustment factors were calculated from comparison of the field study flow data at the two upstream sites SC4 and SC5 with the USGS flow records downstream. The adjusted flow at SC6 is computed as:

$$SC6_{adj} = \text{Larger of } (SC6_{sim} * 0.5, SC6_{sim} - 1.0)$$

where $SC6_{adj}$ = Adjusted flow at Sonoma Creek near Highway 12 in cubic feet per second (cfs) and $SC6_{sim}$ = Simulated HSPF flow at SC6 in cfs.

### 5.3.3 Walker Creek Calibration

The primary calibration locations for the Walker Creek model were the field sites at WC1, WC3 and WC6.

The Walker study basin has three main sub-basins: Salmon Creek, Arroyo Sausal, which is regulated by Soulajule Reservoir, and Walker Creek from the confluence of Salmon Creek and Arroyo Sausal down to the WC4 gage. There are few existing diversions on the Walker and Salmon sub-basins (Table 4). The WC4 gage is located approximately one half mile upstream of the USGS gage on Walker Creek. The WC4 gage has a total drainage area of 30.7 square miles including the Arroyo Sausal sub-basin (19 $mi^2$). The USGS gage has a total drainage area of 31.1 square miles. The local tributary area between WC4 and the USGS gages is 0.36 square miles of which 0.22 square miles are gaged at site WC3, the Unnamed Tributary at Walker Ranch.

[2] This sub-surface flow was confirmed anecdotally by residents living adjacent to the stream near Highway 12 who reported that the portion of the stream near Highway 12 may be dry when there is both flow upstream near Sugarloaf Park and downstream near the USGS gage. Flow measurements observed in the field in May 2013 also confirmed this: on May 16, 2013, the gage at SC6 was dry, while the gage at SC4 had measurable surface flow.

For the protectiveness analysis, the required flow at Walker Creek at site WC4 is the unimpaired flow from the Salmon and Walker sub-basins plus the regulated Arroyo Sausal contribution. Rather than modeling the WC4 flows using the HSPF model and the Soulajule outflow records[3], the WC4 flow was calculated by subtracting the simulated flow at WC3 from the observed flow at the USGS gage which provides a more accurate representation of the required WC4 flow. At all other points in the study basin, the HSPF model results were used to estimate unimpaired flow.

## 5.4 Results

Three HSPF models were set up and calibrated to produce representative streamflow on the study basins for a 10-year period.

The impaired flow and protectiveness analysis to be completed for the Volume Depletion Approach Study will use daily unimpaired flows from the HSPF models. Appendix B-4 contains HSPF output of daily flow time series at all locations where flow will be analyzed for the protectiveness analysis. Model locations used only for calibration are not included. Table 7 lists the locations and descriptions of all locations included in Appendix B-4. The HSPF IDs correspond to the particular reach or flow value used in the HSPF model files included in Appendix B-3. The location type is also noted in the table. Each location is either at:

(1) a potential POD at headwaters
(2) an existing POD location
(3) the location of the upper limit of anadromy
(4) a POI where impacts on habitat will be evaluated

Each location has an associated HSPF ID. IDs that begin with RCH (reach) are simulated flow in an HSPF reach. IDs that begin with COPY are a summation of simulated runoff from HSPF land segments and/or reaches. A flow time series may have more than one type of location associated with it; this occurs, for example, when an existing POD occurs at the same location as a potential headwater diversion (as occurs at COPY 432 in the Sonoma Creek model).

Figs. 9 through 12 show the calibration results at the Maacama model locations. Figs. 13 through 15 show calibration results for Sonoma Creek, and Figs. 16 through 18 show results for Walker Creek.

[3] Soulajule release records were obtained from MMWD for the period 1/2008 to 4/2013. Comparisons between the Soulajule outflows (releases plus spill) and the downstream USGS flow records show discrepancies which are likely due to inaccuracies in the Soulajule records.

**Table 7 - Summary of Locations of Model Output Included in Appendix B-4**

| HSPF Model | HSPF ID[1] | Location Type | Description |
|---|---|---|---|
| MAACAMA | COPY 331 | Headwater | Headwater 1 above Ingalls Cr |
| | COPY 332 | Headwater | Headwater 2 above Ingalls Cr |
| | COPY 333 | Headwater | Headwater 3 above Ingalls Cr |
| | COPY 334 | Headwater | Headwater 4 above Ingalls Cr |
| | COPY 335 | Headwater | Headwater above Little Ingalls Cr |
| | COPY 336 | Headwater | Headwater 1 above McDonnell Cr/Existing POD |
| | COPY 337 | Headwater | Headwater 2 above McDonnell Cr |
| | COPY 338 | Headwater | Headwater 3 above McDonnell Cr |
| | COPY 339 | Headwater | Headwater 4 above McDonnell Cr |
| | RCH 301 | ULA | Little Ingalls Cr ULA (at MC1) |
| | RCH 302 | ULA/POI/POD | Ingalls Cr ULA (at MC2) |
| | RCH 310 | ULA | McDonnell Cr ULA |
| | COPY 312 | POI | McDonnell Cr at MC3 |
| | RCH 318 | POI | Maacama Cr at MC5 |
| SONOMA | COPY 431 | Headwater | Headwaters 1 above Bear Cr |
| | COPY 432 | Headwater/POD | Headwaters 2 above Bear Cr/Existing POD |
| | COPY 433 | Headwater | Headwaters 3 above Bear Cr |
| | COPY 434 | Headwater | Headwaters 1 above Malm Fork |
| | COPY 435 | Headwater | Headwaters 2 above Malm Fork |
| | COPY 436 | Headwater | Headwaters 1 above Rattlesnake Cyn |
| | COPY 437 | Headwater | Headwaters 1 above Sonoma Cr |
| | COPY 438 | Headwater | Headwaters 2 above Sonoma Cr |
| | COPY 439 | Headwater | Headwaters 1 above Tributary abv Trib abv Rattlesnake Cyn |
| | COPY 440 | Headwater | Headwaters above Unnamed Trib at SC2 |
| | RCH 403 | POD | Rattlesnake Canyon |
| | RCH 404 | ULA/POI | Bear Cr ULA/POI at SC5 |
| | RCH 414 | ULA | Sonoma Cr above SC4 |
| | RCH 416 | POI | Sonoma Cr at SC4 |
| | RCH 418 | POI | Sonoma Cr at SC6 |
| WALKER | COPY 531 | Headwater | Headwater 1 above Frink Cyn |
| | COPY 532 | Headwater | Headwater 2 above Frink Cyn |
| | COPY 533 | Headwater | Headwater 3 above Frink Cyn |
| | COPY 534 | Headwater | Headwater above Salmon Cr |
| | COPY 535 | Headwater | Headwater above Trib to Salmon Cr |
| | RCH 501 | POD | Trib to Salmon Cr/Existing POD |
| | RCH 506 | ULA | Frink ULA |
| | RCH 507 | POI | Frink WC6 |
| | RCH 512 | ULA | Salmon ULA |
| | RCH 514 | POI | Salmon WC2 |
| | RCH 520 | POI | Walker WC4 |

Note:
[1] HSPF IDs that begin with RCH (reach) are simulated flow in an HSPF reach. HSPF IDs that begin with COPY are a summation of simulated runoff from HSPF land segments and/or reaches.

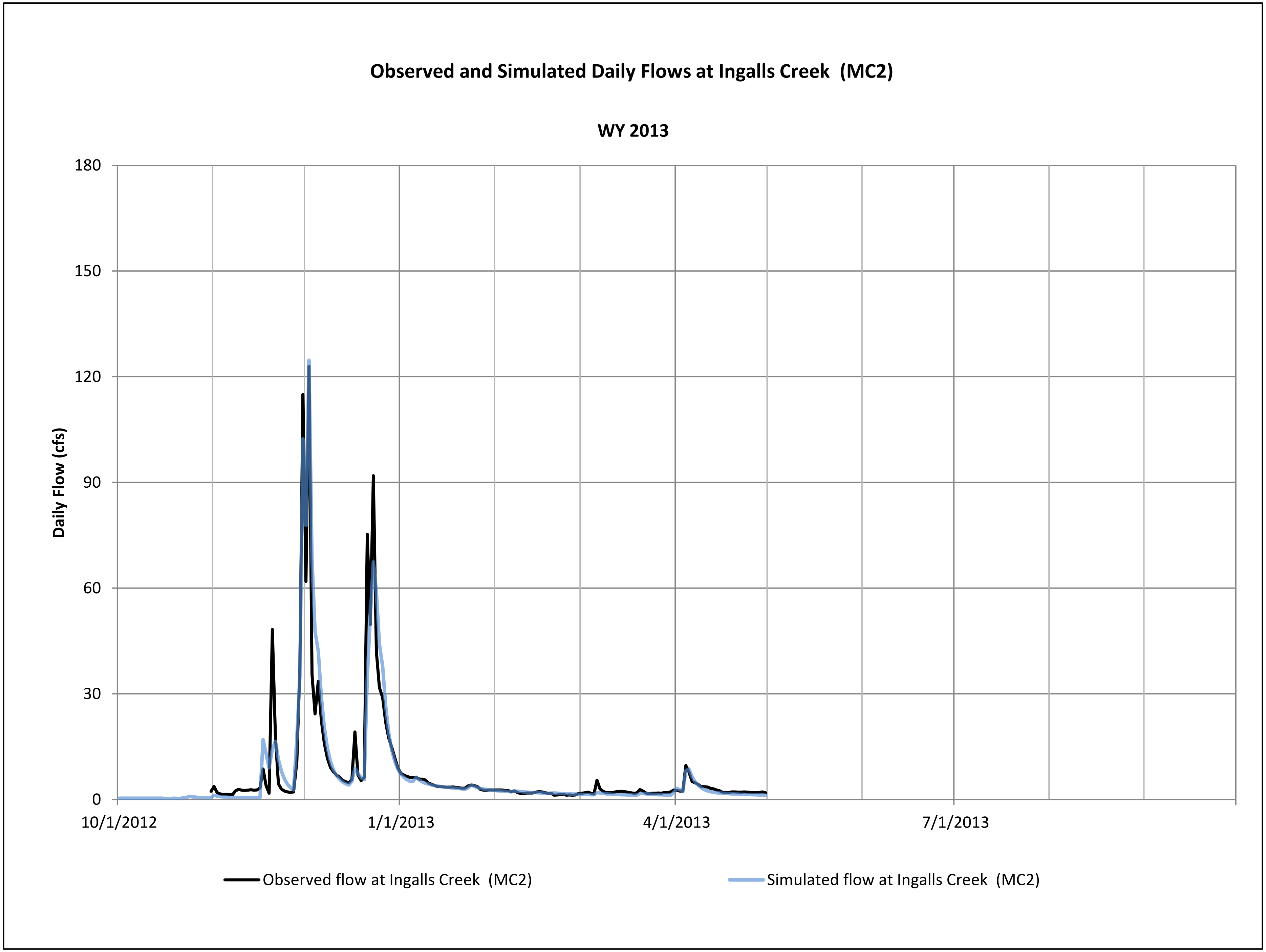
Observed and Simulated Daily Flows at Ingalls Creek (MC2)
WY 2013
Daily Flow (cfs)
180
150
120
90
60
30
0
10/1/2012
1/1/2013
4/1/2013
7/1/2013
Observed flow at Ingalls Creek (MC2)
Simulated flow at Ingalls Creek (MC2)

FIGURE 9

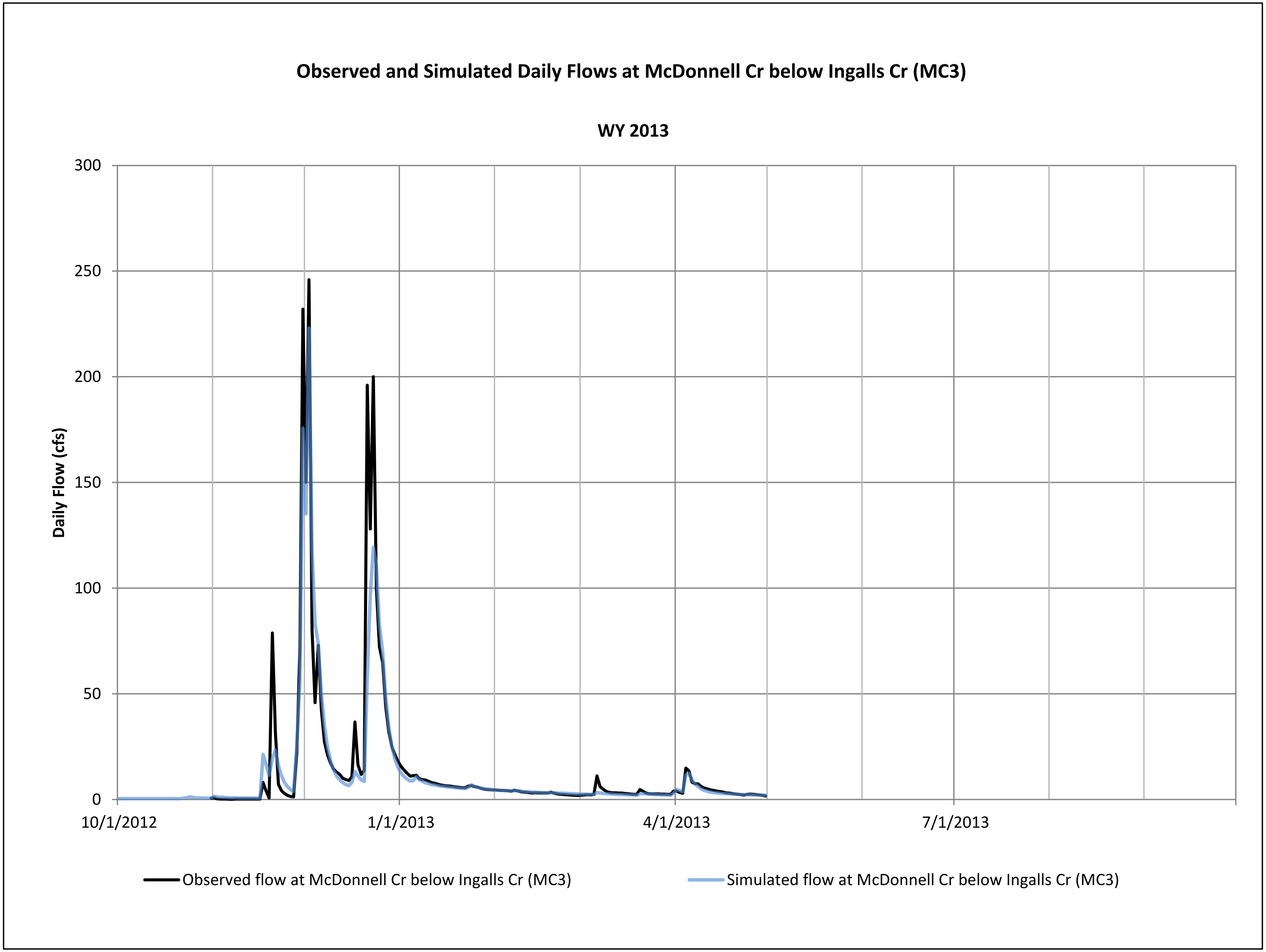
Observed and Simulated Daily Flows at McDonnell Cr below Ingalls Cr (MC3)
WY 2013
Daily Flow (cfs)
300
250
200
150
100
50
0
10/1/2012
1/1/2013
4/1/2013
7/1/2013
Observed flow at McDonnell Cr below Ingalls Cr (MC3)
Simulated flow at McDonnell Cr below Ingalls Cr (MC3)

FIGURE 10

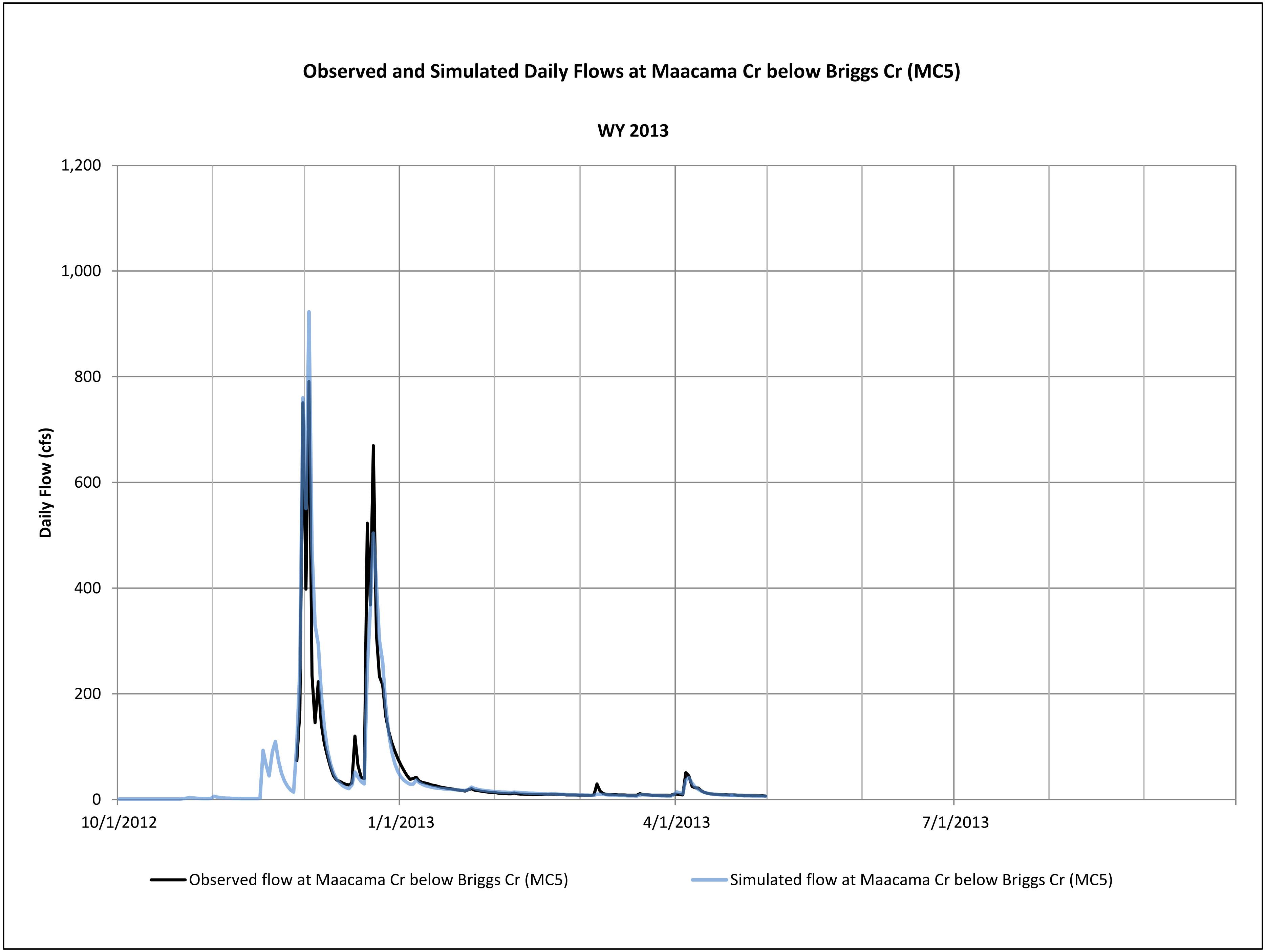
Observed and Simulated Daily Flows at Maacama Cr below Briggs Cr (MC5)
WY 2013
Daily Flow (cfs)
1,200
1,000
800
600
400
200
0
10/1/2012
1/1/2013
4/1/2013
7/1/2013
Observed flow at Maacama Cr below Briggs Cr (MC5)
Simulated flow at Maacama Cr below Briggs Cr (MC5)

FIGURE 11

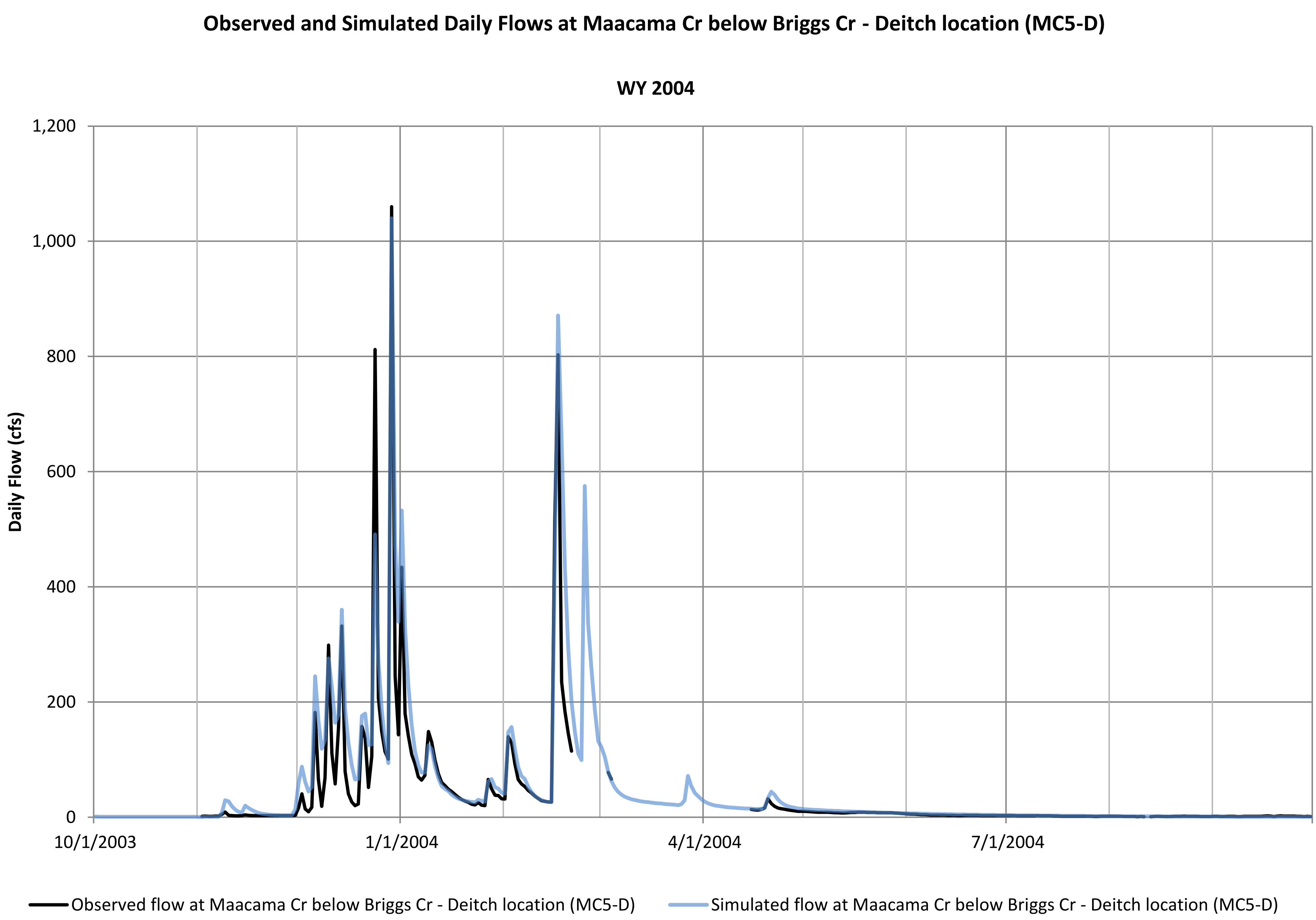
Observed and Simulated Daily Flows at Maacama Cr below Briggs Cr - Deitch location (MC5-D)
WY 2004
Daily Flow (cfs)
1,200
1,000
800
600
400
200
0
10/1/2003
1/1/2004
4/1/2004
7/1/2004
Observed flow at Maacama Cr below Briggs Cr - Deitch location (MC5-D)
Simulated flow at Maacama Cr below Briggs Cr - Deitch location (MC5-D)

FIGURE 12A

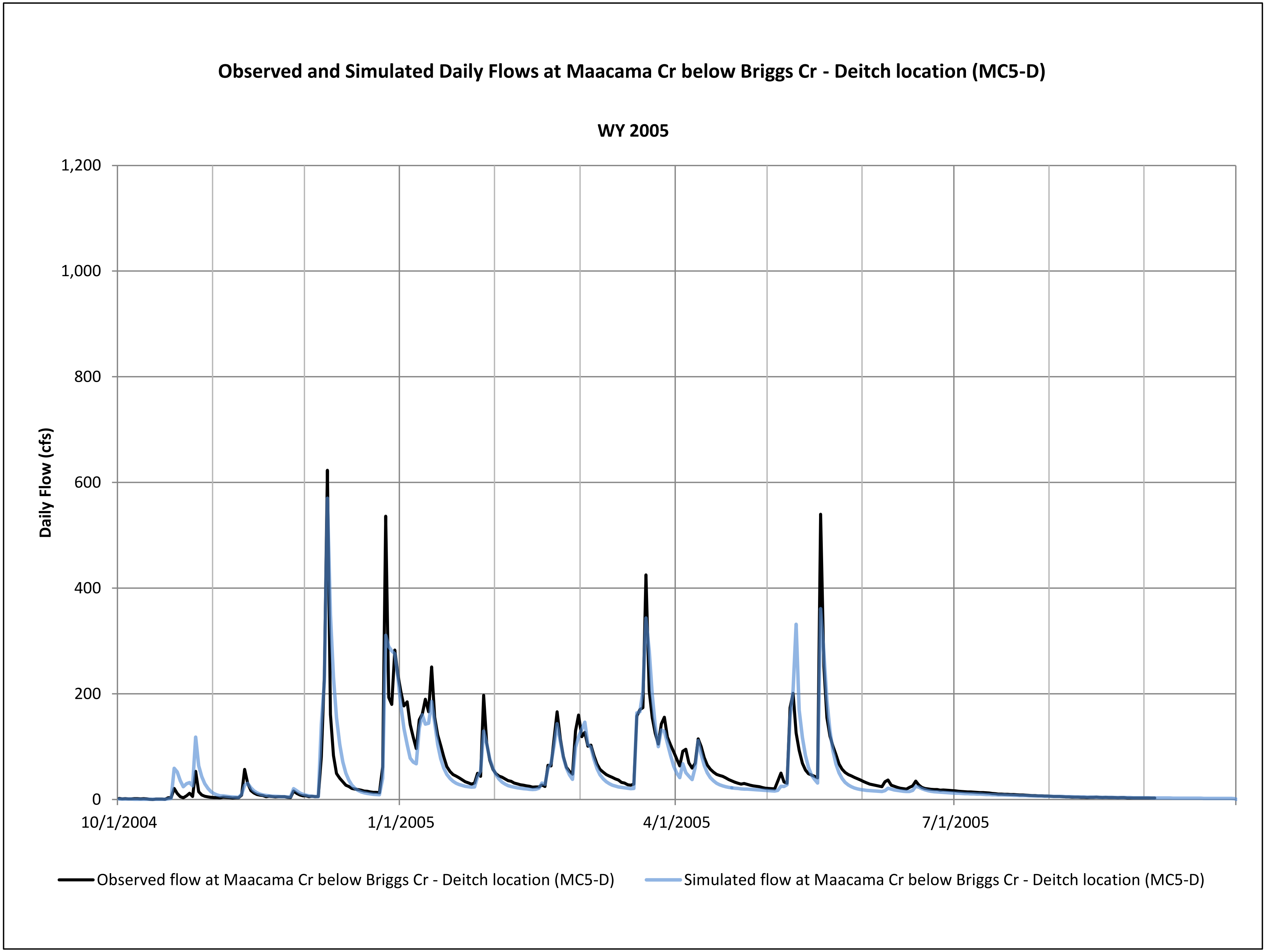
Observed and Simulated Daily Flows at Maacama Cr below Briggs Cr - Deitch location (MC5-D)
WY 2005
Daily Flow (cfs)
1,200
1,000
800
600
400
200
0
10/1/2004
1/1/2005
4/1/2005
7/1/2005
Observed flow at Maacama Cr below Briggs Cr - Deitch location (MC5-D)
Simulated flow at Maacama Cr below Briggs Cr - Deitch location (MC5-D)

FIGURE 12B

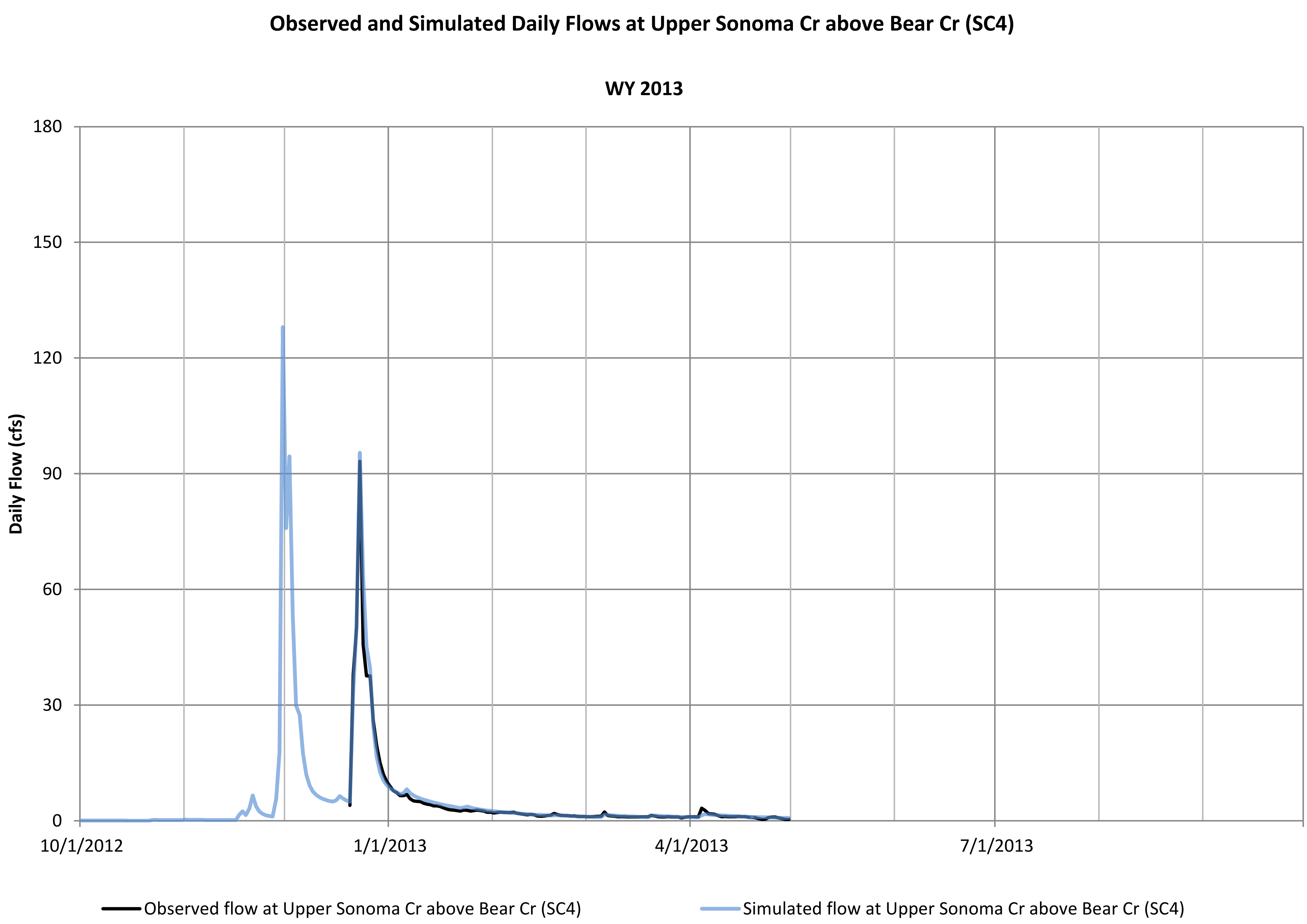
Observed and Simulated Daily Flows at Upper Sonoma Cr above Bear Cr (SC4)
WY 2013
Daily Flow (cfs)
180
150
120
90
60
30
0
10/1/2012
1/1/2013
4/1/2013
7/1/2013
Observed flow at Upper Sonoma Cr above Bear Cr (SC4)
Simulated flow at Upper Sonoma Cr above Bear Cr (SC4)

FIGURE 13

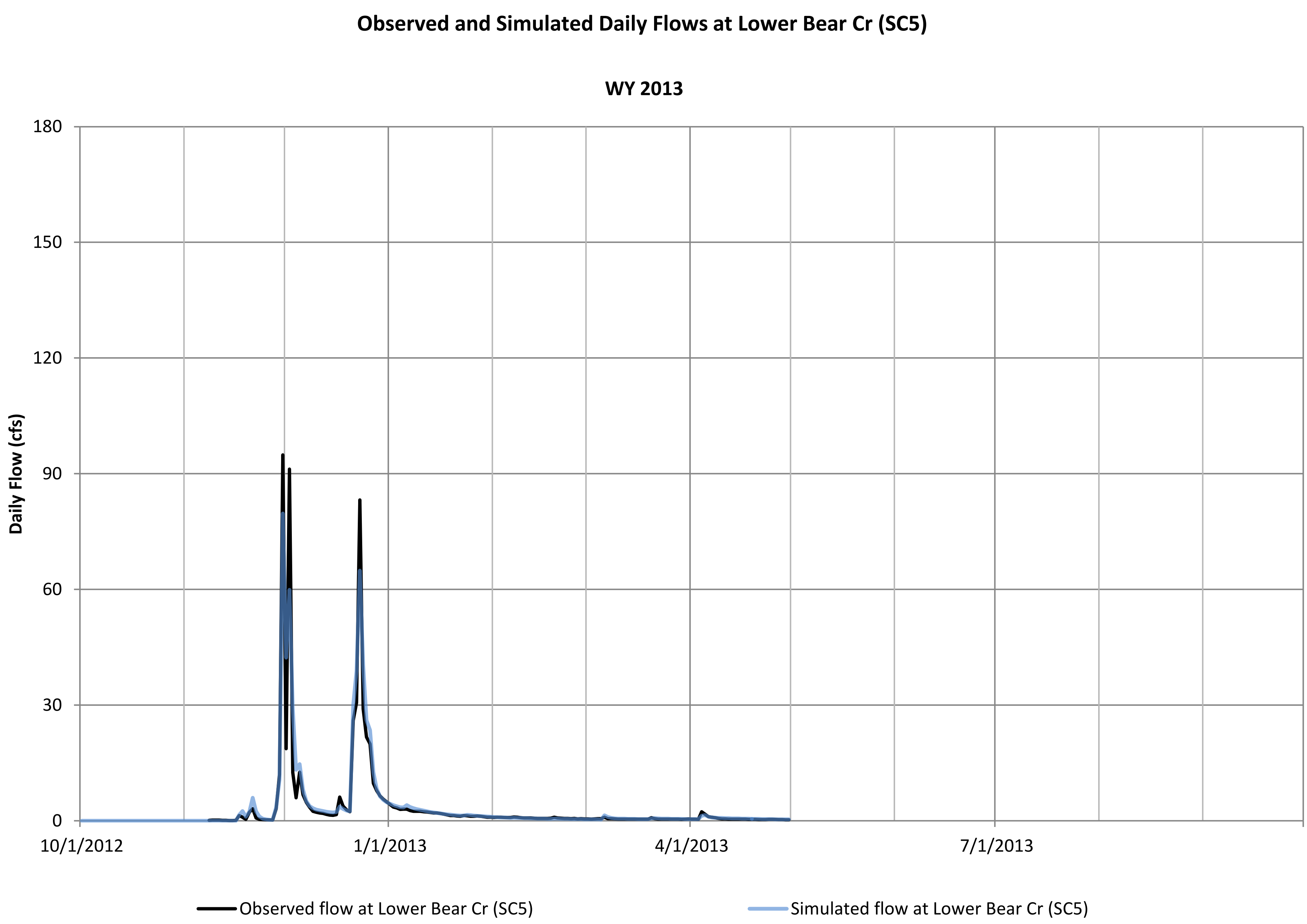
Observed and Simulated Daily Flows at Lower Bear Cr (SC5)
WY 2013
Daily Flow (cfs)
180
150
120
90
60
30
0
10/1/2012
1/1/2013
4/1/2013
7/1/2013
Observed flow at Lower Bear Cr (SC5)
Simulated flow at Lower Bear Cr (SC5)

FIGURE 14

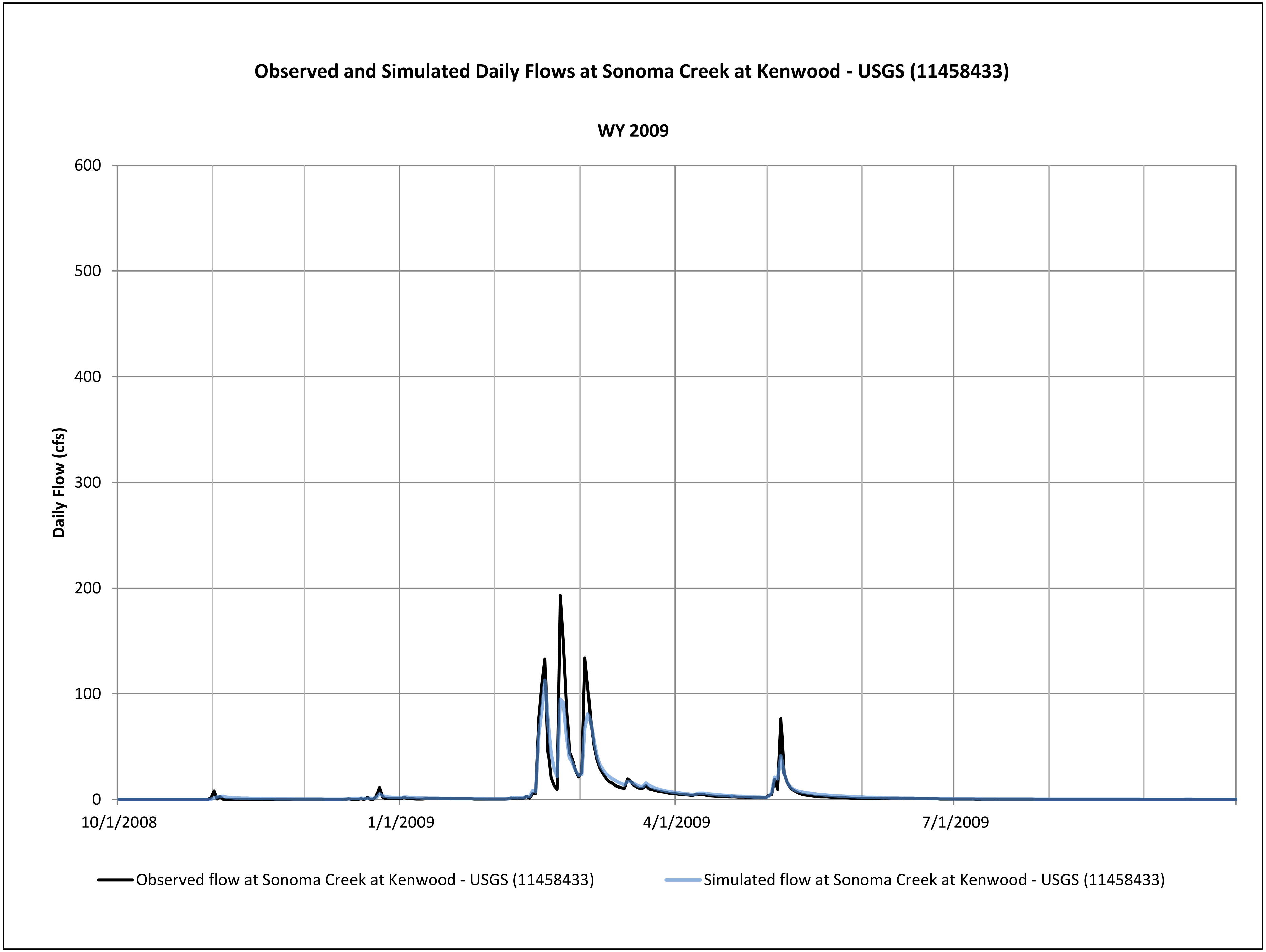
Observed and Simulated Daily Flows at Sonoma Creek at Kenwood - USGS (11458433)
WY 2009
Daily Flow (cfs)
600
500
400
300
200
100
0
10/1/2008
1/1/2009
4/1/2009
7/1/2009
Observed flow at Sonoma Creek at Kenwood - USGS (11458433)
Simulated flow at Sonoma Creek at Kenwood - USGS (11458433)

FIGURE 15A

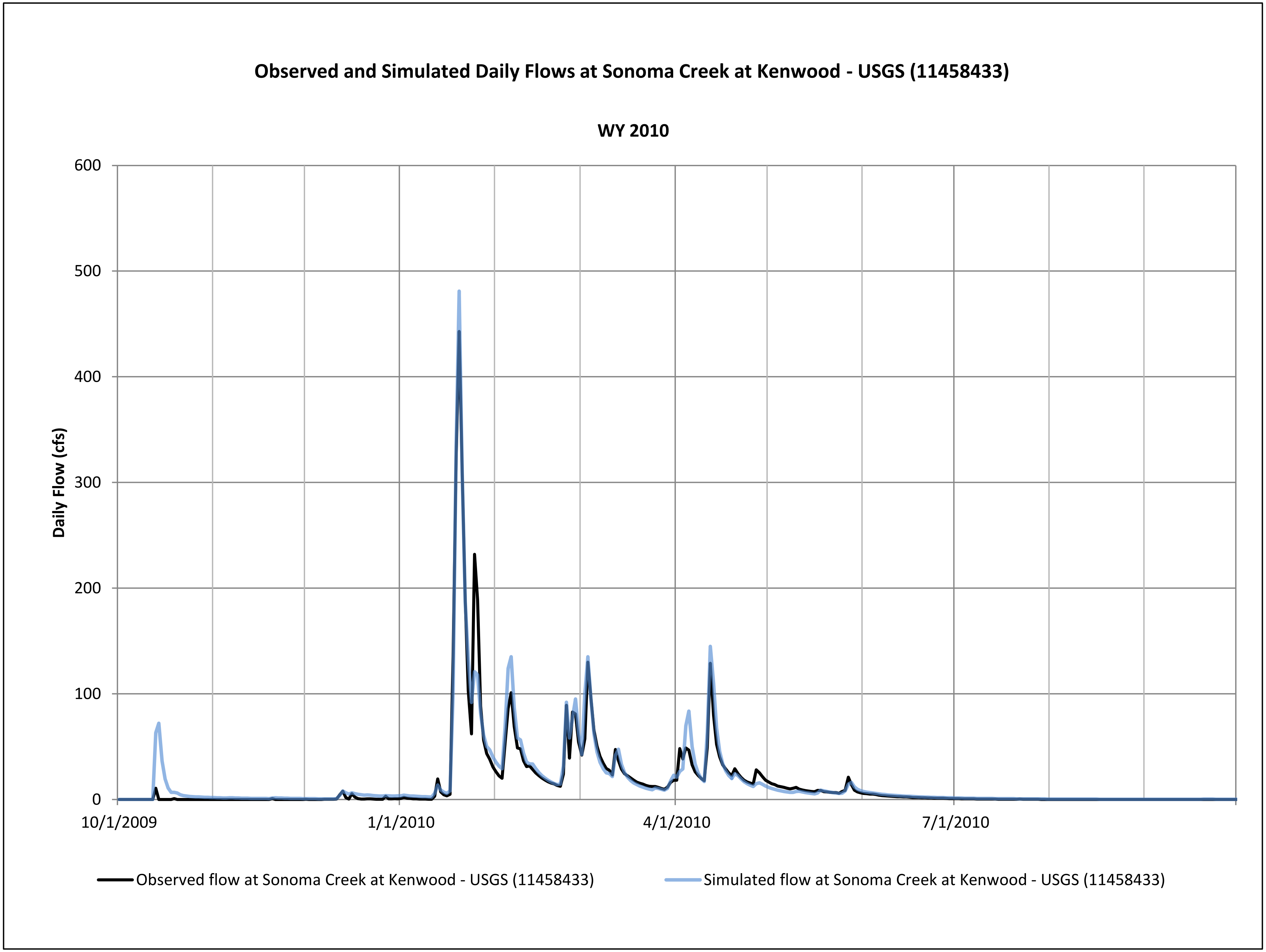
Observed and Simulated Daily Flows at Sonoma Creek at Kenwood - USGS (11458433)
WY 2010
Daily Flow (cfs)
600
500
400
300
200
100
0
10/1/2009
1/1/2010
4/1/2010
7/1/2010
Observed flow at Sonoma Creek at Kenwood - USGS (11458433)
Simulated flow at Sonoma Creek at Kenwood - USGS (11458433)

FIGURE 15B

2416\Task 4 - Hydrologic Models\Report\[Calibration figures v02.xlsm]

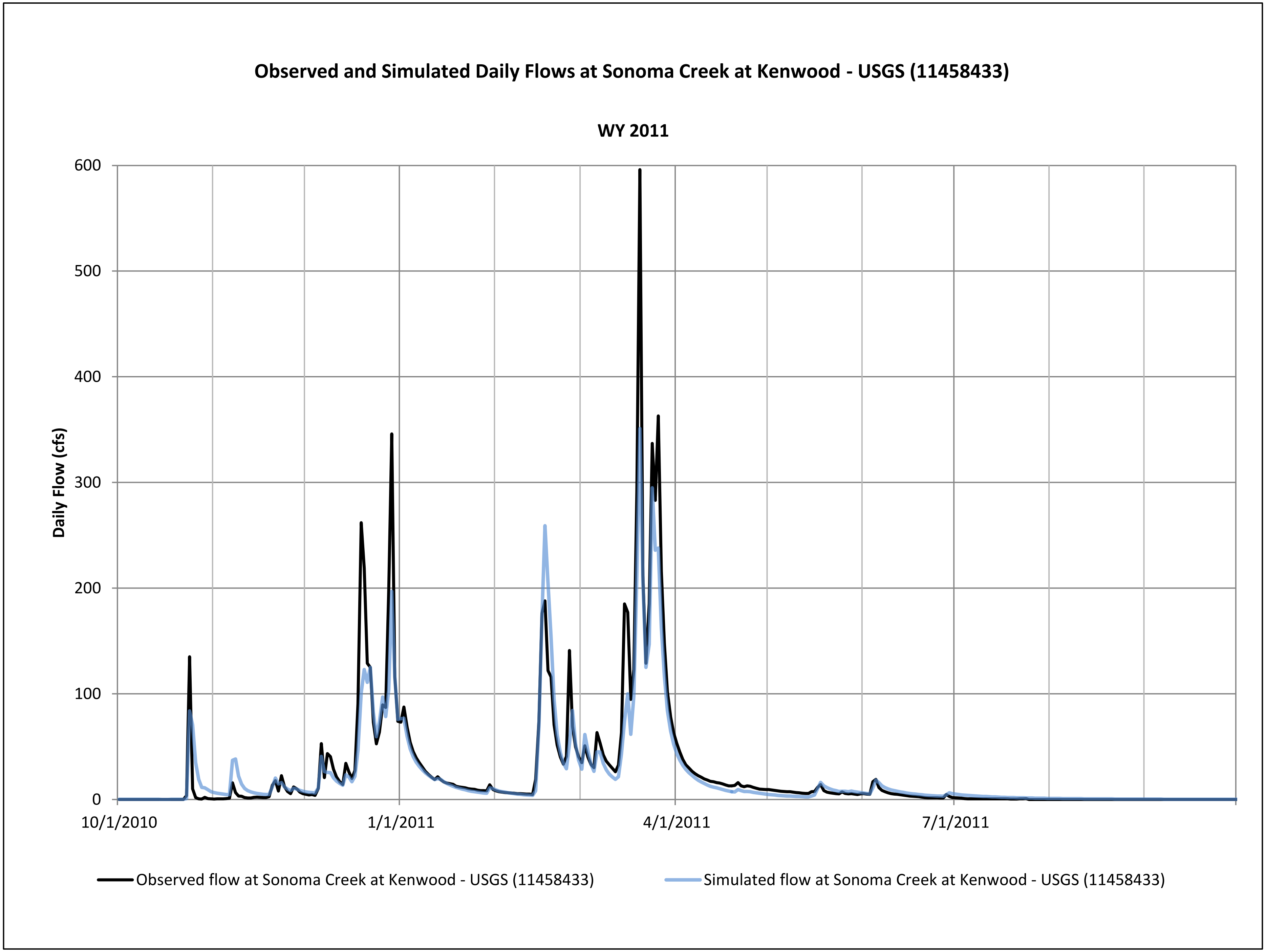


FIGURE 15C

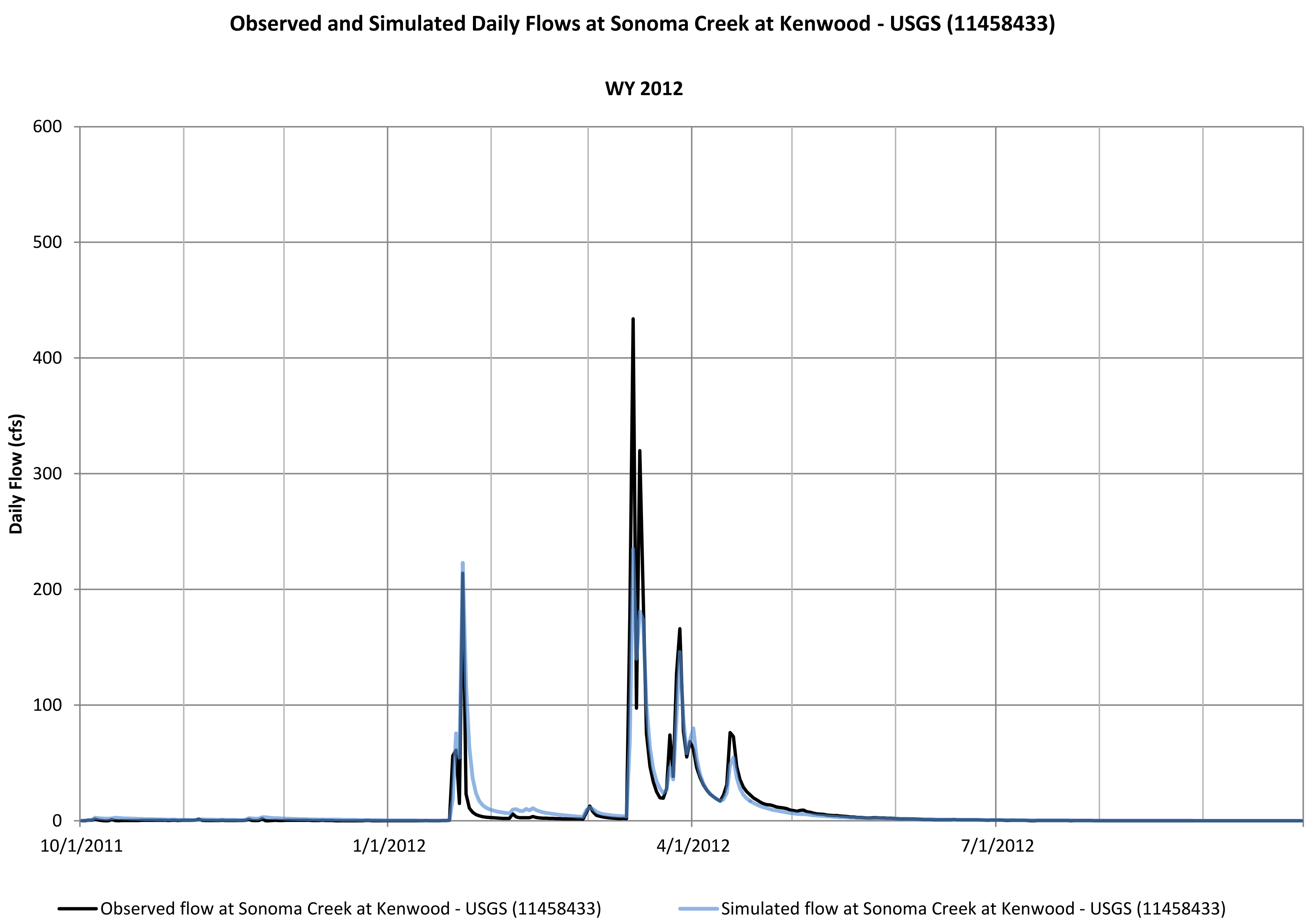
Observed and Simulated Daily Flows at Sonoma Creek at Kenwood - USGS (11458433)
WY 2012
Daily Flow (cfs)
600
500
400
300
200
100
0
10/1/2011
1/1/2012
4/1/2012
7/1/2012
Observed flow at Sonoma Creek at Kenwood - USGS (11458433)
Simulated flow at Sonoma Creek at Kenwood - USGS (11458433)

FIGURE 15D

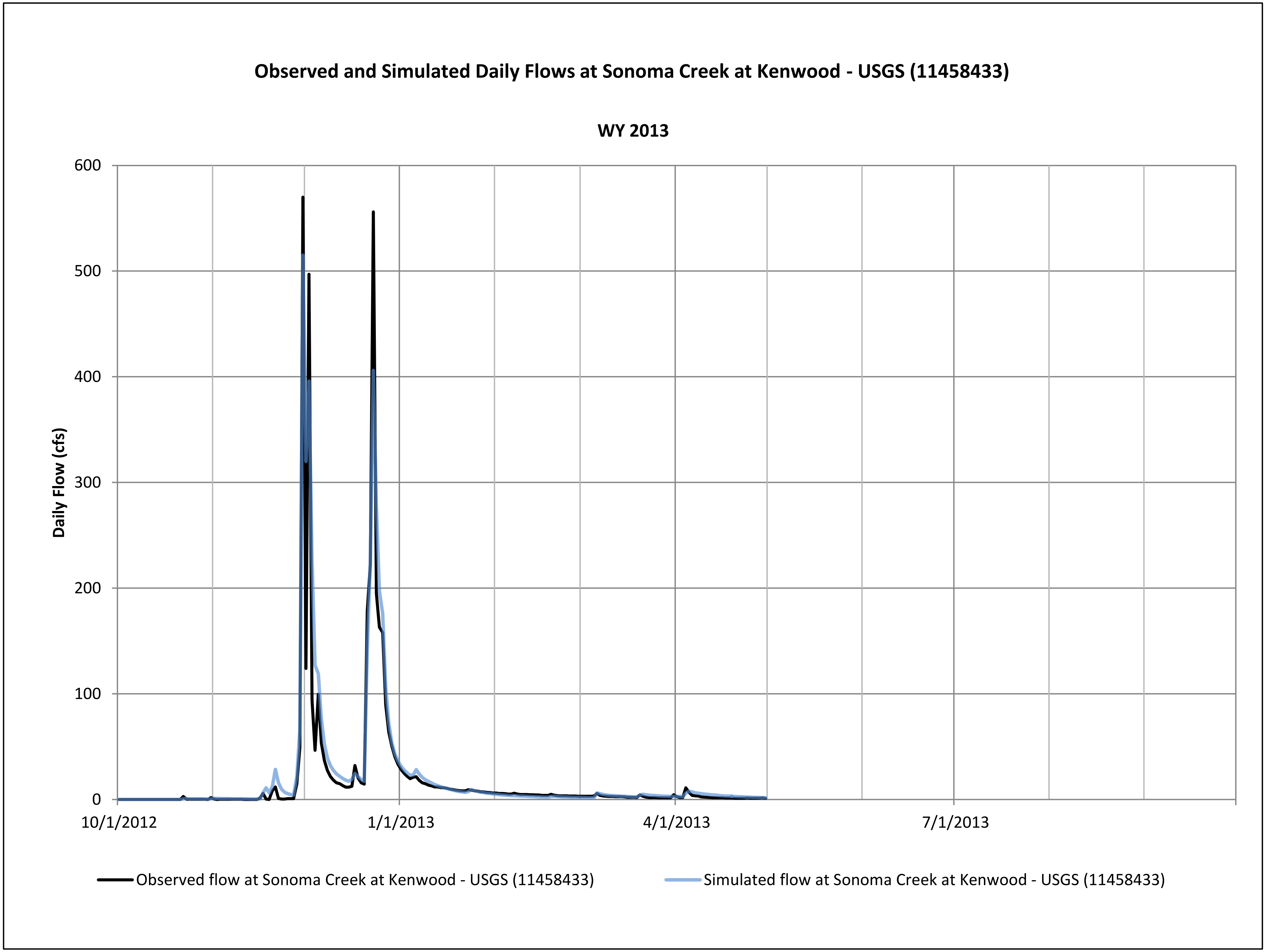
Observed and Simulated Daily Flows at Sonoma Creek at Kenwood - USGS (11458433)
WY 2013
Daily Flow (cfs)
600
500
400
300
200
100
0
10/1/2012
1/1/2013
4/1/2013
7/1/2013
Observed flow at Sonoma Creek at Kenwood - USGS (11458433)
Simulated flow at Sonoma Creek at Kenwood - USGS (11458433)

FIGURE 15E

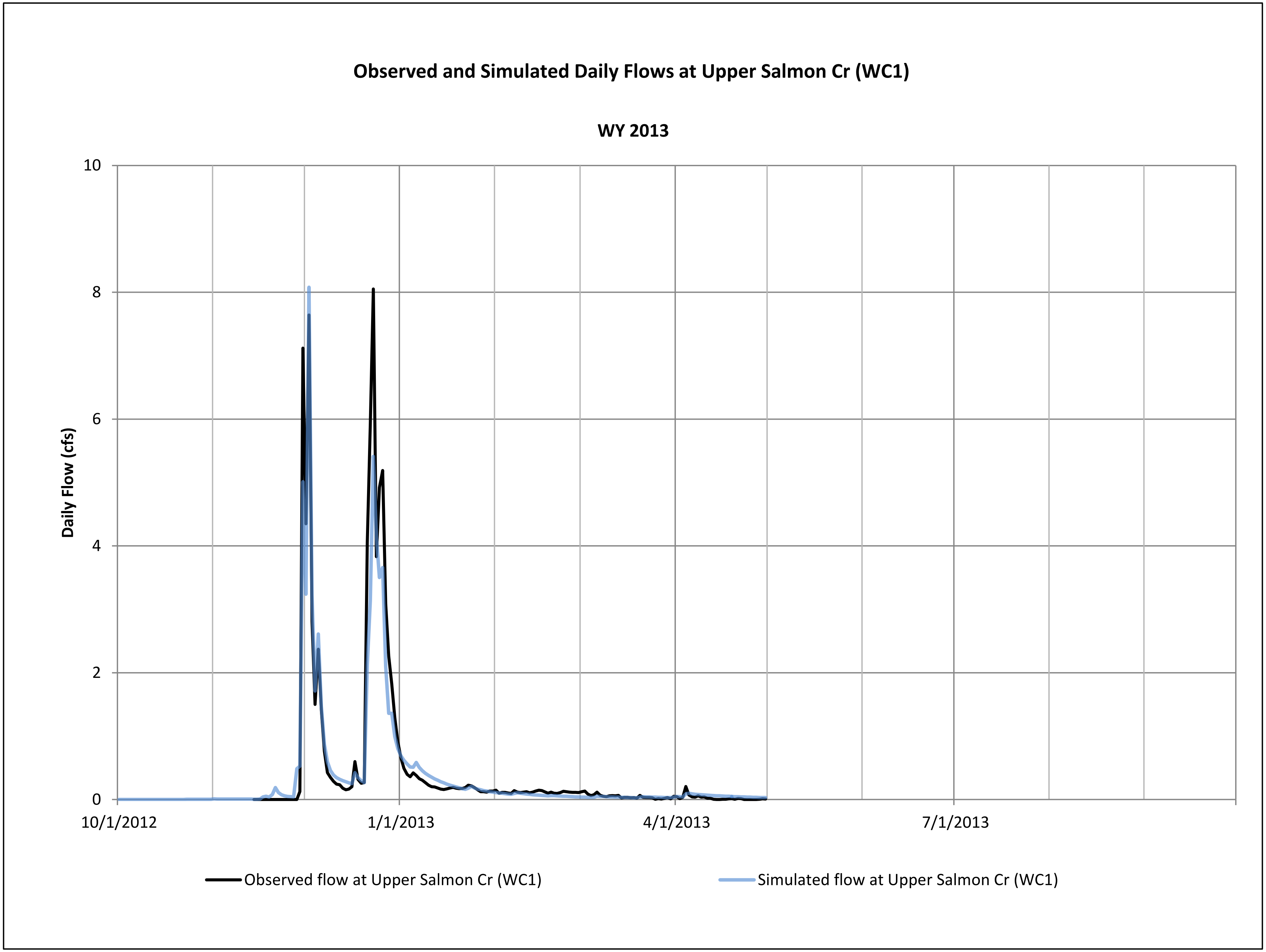
Observed and Simulated Daily Flows at Upper Salmon Cr (WC1)
WY 2013
Daily Flow (cfs)
10
8
6
4
2
0
10/1/2012
1/1/2013
4/1/2013
7/1/2013
Observed flow at Upper Salmon Cr (WC1)
Simulated flow at Upper Salmon Cr (WC1)

FIGURE 16

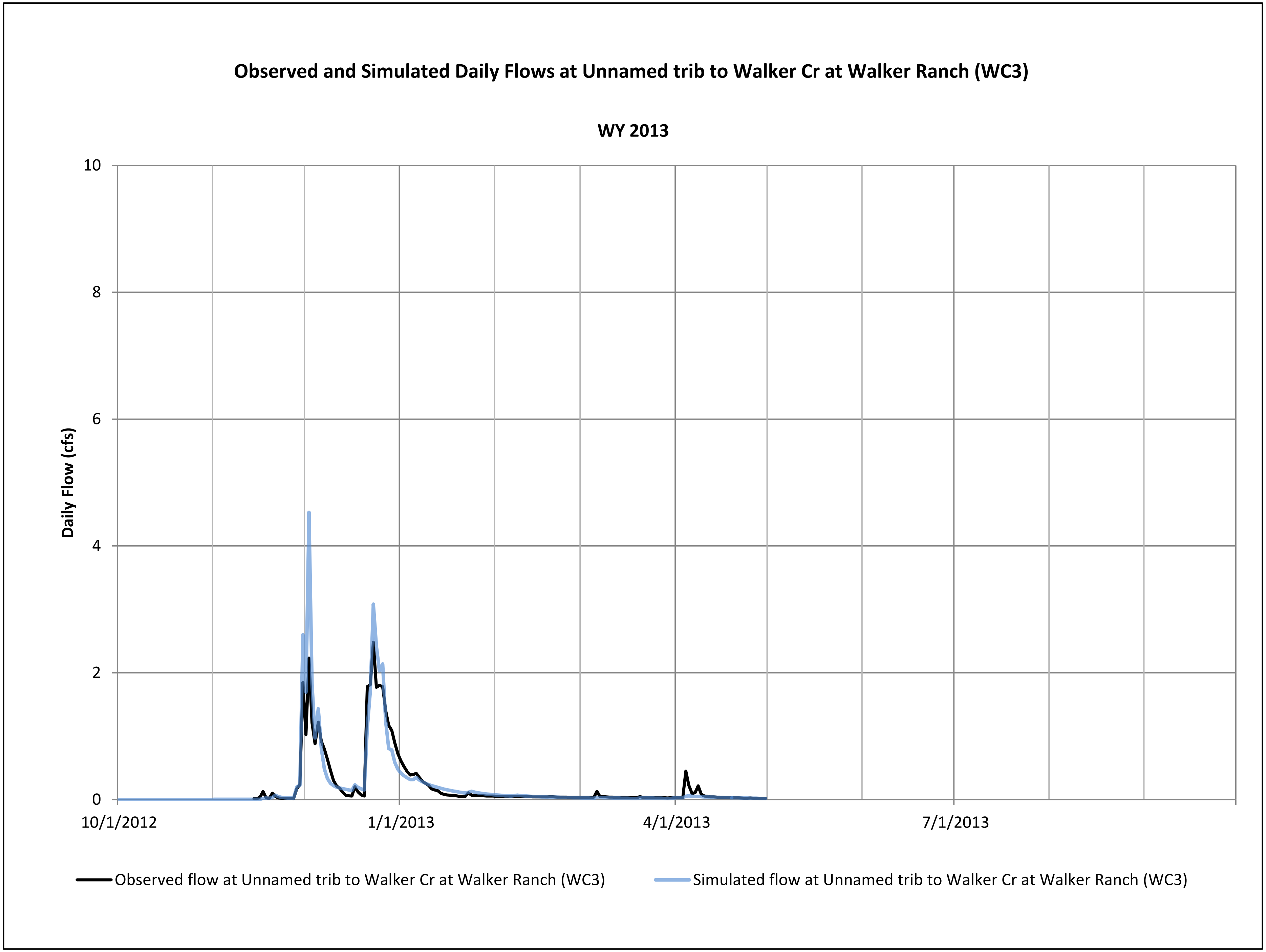
Observed and Simulated Daily Flows at Unnamed trib to Walker Cr at Walker Ranch (WC3)
WY 2013
Daily Flow (cfs)
10
8
6
4
2
0
10/1/2012
1/1/2013
4/1/2013
7/1/2013
Observed flow at Unnamed trib to Walker Cr at Walker Ranch (WC3)
Simulated flow at Unnamed trib to Walker Cr at Walker Ranch (WC3)

FIGURE 17

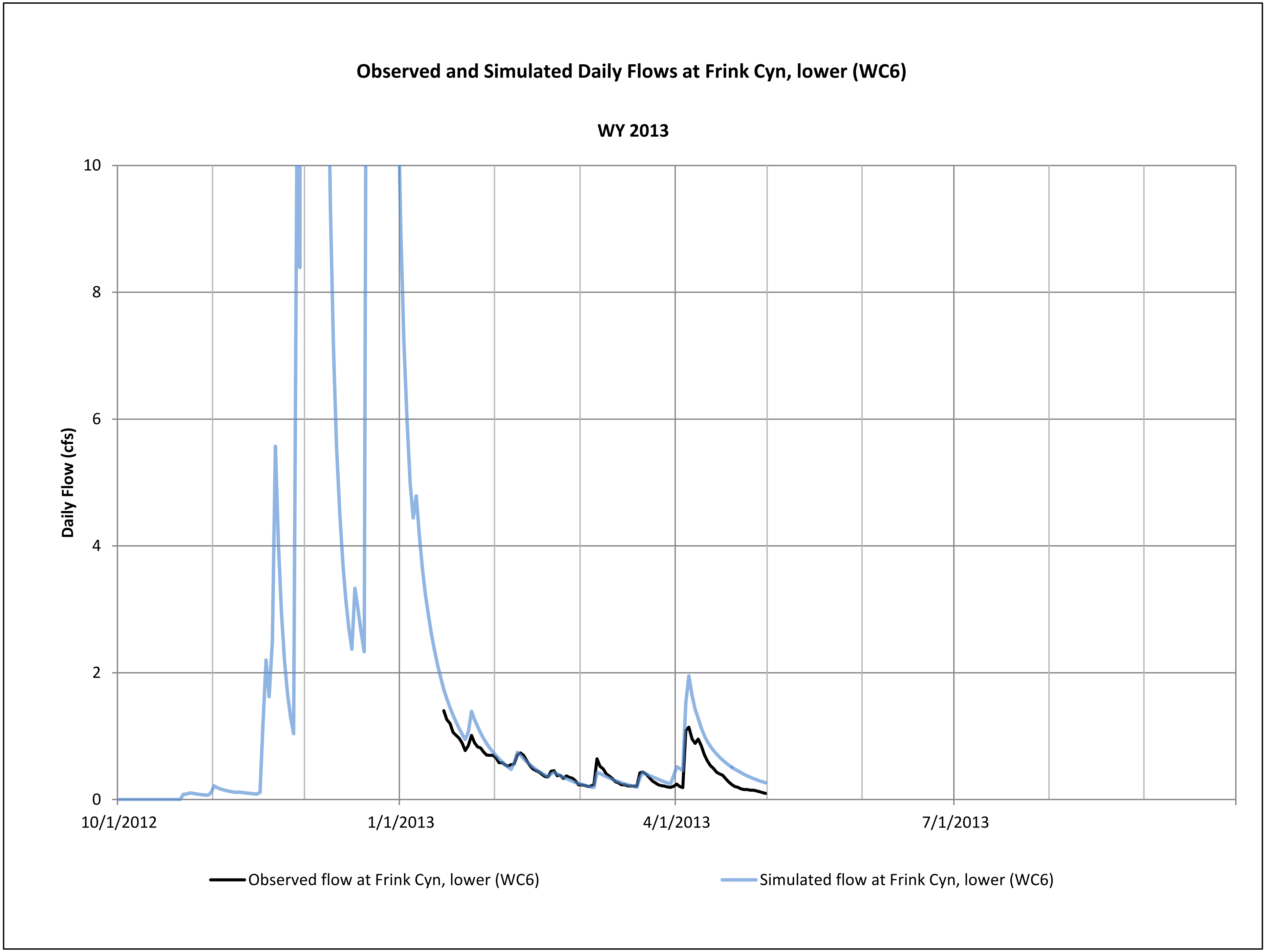
Observed and Simulated Daily Flows at Frink Cyn, lower (WC6)
WY 2013
Daily Flow (cfs)
10
8
6
4
2
0
10/1/2012
1/1/2013
4/1/2013
7/1/2013
Observed flow at Frink Cyn, lower (WC6)
Simulated flow at Frink Cyn, lower (WC6)

FIGURE 18

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