YOLO BYPASS WESTSIDE TRIBUTARIES FLOW MONITORING PROJECT
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WESTSIDE TRIBUTARIES FLOW REPORT

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PREPARED BY

County of Yolo

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GLOSSARY OF ACRONYMS

Acronym	Meaning
3D	Three-dimensional
ADCP	Acoustic Doppler Current Profiler
ADV	Acoustic Doppler Velocimeter
BT	Bottom Track
CCSB	Cache Creek Settling Basin
CDEC	California Data Exchange Center
CDFW	California Department of Fish and Wildlife
CIMIS	California Irrigation Management Information System
CR	County Road
DWR	California Department of Water Resources

Acronym	Meaning
EIR	Environmental Impact Report
ET	Evapotranspiration
GGA	Global Positioning System Fix Data
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC	Hydrologic Engineering Center
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System
HMS	Hydrologic Modeling System
KLRC	Knights Landing Ridge Cut
LPCI505	Putah Creek at I-505 (SCWA gage)
LPCI80	Putah Creek at I-80 (SCWA gage)
NSE	Nash-Sutcliffe Efficiency
NAVD88	North American Vertical Datum 1988
OHI	Obermeyer Hydro, Inc.
OSW	Office of Surface Water (USGS)
PC	Putah Creek
PDD	Putah Diversion Dam
PDS	Putah Creek Downstream (near I-80)
PUS	Putah Creek Upstream (near Winters, CA)
RCS	Ridge Cut Slough at Knights Landing
RD 108	Reclamation District 108
RMSE	Root Mean Square Error
RTK	Real Time Kinematic
SCWA	Solano County Water Agency
USGS	U.S. Geological Survey
WDL	Water Data Library (DWR)
WSB	Willow Slough Bypass
WSE	Water Surface Elevation
WY	Water Year
Yolo Bypass Salmonid Project	Yolo Bypass Salmonid Habitat Restoration and Fish Passage
District	Yolo County Flood Control and Water Conservation District

1 INTRODUCTION

In support of Grant Agreement # P1596031 between Yolo County (County) and California Department of Fish and Wildlife (CDFW), cbec eco engineering, inc. (cbec) collected and analyzed flow and stage data on four westside tributaries to the Yolo Bypass: Knights Landing Ridge Cut (KLRC), Cache Creek Settling Basin (CCSB), Willow Slough Bypass (WSB), and Putah Creek (PC). Westside tributary inflows play an important role in Yolo Bypass inundation, so understanding the timing, volume, and magnitude of inflows is needed to determine their relative influence compared to larger inflows from the Fremont and Sacramento Weirs. Yolo County applied for the CDFW grant in 2016 to collect the additional data needed to improve westside tributary inflow estimates into the Yolo Bypass and verify westside tributary hydrologic assumptions used in the Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project (Yolo Bypass Salmonid Project) inundation analysis (USBR and DWR, 2019) . Following completion of this study, the new monitoring data can improve local agency reporting of inflows into the Yolo Bypass. The new data will also help decisionmakers better understand existing conditions and evaluate the benefits and impacts of future management proposals within the Yolo Bypass. The County contracted with cbec to complete this work on its behalf.

As such, cbec and the County identified the following monitoring and data analysis objectives:

1. Monitor westside tributary inflows into the Yolo Bypass consistent with recommendations identified in the Yolo Bypass Drainage and Water Infrastructure Study (Yolo County, 2014; https://www.yolocounty.org/home/showdocument?id=23985) and provide the data to local agencies responsible for stage and flow monitoring; and
2. Analyze the monitoring data to verify the hydrologic assumptions supporting the Yolo Bypass Salmonid Project (USBR and DWR, 2019) inundation analysis and provide recommendations to modify or update the hydrologic assumptions.

To satisfy the first study objective, and as further described in Sections 3, 4, and 5, cbec performed flow monitoring at KLRC, WSB, and PC during the winters of water years (WY; defined as October 1st through September 30th) 2017, 2018 and 2019. The flow monitoring generally involved co-locating the flow measurement locations and temporary stage gages with active stage and/or flow monitoring stations managed by other agencies to augment those efforts by developing flow rating curves and provide redundant stage data in the event of data issues with agency equipment. Regarding CCSB, cbec determined it was unnecessary to perform any flow monitoring at this location because the U.S. Geological Survey (USGS) was actively monitoring outflows from CCSB on behalf of the California Department of Water Resources (DWR).

To satisfy the second study objective, and as further described in Section 6, cbec analyzed the flow monitoring data and compared the data to the hydrologic assumptions used in the Yolo Bypass Salmonid Project inundation analysis to verify and/or recommend changes to those hydrologic assumptions. The hydrologic assumptions used in the Yolo Bypass Salmonid Project varied for each westside tributary, but generally had their origins with the Yolo Bypass Management Strategy (Management Strategy; Jones & Stokes, 2001). Within the Management Strategy, westside tributary inflows into the Yolo Bypass were estimated for WYs 1968 to 1998. As part of the Yolo Bypass Salmonid Project, westside tributary inflows were estimated for WYs 1997 to 2012 using a combination of Management Strategy equations and updated techniques. For KLRC, published flow data from the Colusa Basin and KLRC were used for estimating inflows into the Yolo Bypass. For CCSB, a combination of hydrologic modeling and published flow data were used for estimating inflows into the Yolo Bypass. For WSB and PC, Management Strategy equations were used for estimating inflows into the Yolo Bypass.

2 SUMMARY OF RESULTS AND RECOMMENDATIONS

The three-year study to monitor westside tributary inflows into the Yolo Bypass and analyze the monitoring data to verify the hydrologic assumptions supporting the Yolo Bypass Salmonid Project inundation analysis was successfully completed. Flow monitoring was implemented on three of the four westside tributaries during water years 2017 through 2019. The monitoring data was processed, flow rating curves were developed, the data were analyzed to understand the adequacy of the hydrologic assumptions, and recommendations were developed based on the findings.

2.1 FLOW MONITORING

cbec performed high flow and redundant stage monitoring in water years 2017 through 2019 at four monitoring sites located on three of the westside tributaries to the Yolo Bypass: Knights Landing Ridge Cut, Willow Slough Bypass, and Putah Creek (Figure 1). cbec did not monitor Cache Creek Settling Basin as part of this study because the USGS was actively monitoring outflows from Cache Creek Settling Basin on behalf of the California Department of Water Resources.

2.1.1 WATER YEAR 2017

During wet water year 2017, cbec concentrated flow monitoring activities at two sites on Putah Creek because Monticello Dam spilling via the “glory hole” presented a unique opportunity to collect high flow measurements. Concurrently, cbec collected measurements at a site on the Willow Slough Bypass. Monitoring was not performed at Knights Landing Ridge Cut because construction activities at Wallace Weir were not yet complete.

2.1.2 WATER YEAR 2018

cbec delayed high flow measurements on Knights Landing Ridge Cut because construction activities at Wallace Weir were not completed until February 2018. cbec timed Knights Landing Ridge Cut flow monitoring during this below normal water year to occur in March 2018 and later in September 2018 to coincide with California Department of Water Resource’s flow monitoring for the North Delta Flow Action. Because of the dry conditions, monitoring was not performed at the Putah Creek and Willow Slough Bypass sites.

2.1.3 WATER YEAR 2019

During wet water year 2019, cbec concentrated flow monitoring activities at Knights Landing Ridge Cut and Willow Slough Bypass. cbec also collected a limited number of measurements at the two Putah Creek sites as Lake Berryessa was again spilling via the glory hole. Measurements were collected at Knights Landing Ridge Cut up to 3,700 cfs as water levels approached the low chord of the Wallace Weir Bridge, a condition that is very near the 4,000 cfs design capacity of the structure during non-backwatered conditions from the Yolo Bypass. Measurements were also collected at Willow Slough Bypass to expand the data set collected in water year 2017.

2.2 RATING CURVE DEVELOPMENT

cbec developed rating curves for three of the four monitoring sites (Section 5), as well as combined measurements collected by various agencies and high flow measurements collected during this study. Rating curves were successfully developed for two sites on Putah Creek to augment the active monitoring stations managed by Solano County Water Agency. Solano County Water Agency can use these rating curves on Putah Creek to greatly expand their observed flow record that they already host on their public website. A rating curve was also developed for Willow Slough Bypass. The Yolo County Flood Control and Water Conservation District would need to make its telemetered stage gage available on a public web server and increase routine maintenance and monitoring of the gage to take advantage of the new rating curve.

cbec did not develop a rating curve for Knights Landing Ridge Cut at Wallace Weir. The data that was collected as part of this study was intended to verify the new flow rating for the newly reconstructed Wallace Weir. The new flow rating is based on standard weir equations and is affected by the elevation of the new operable gates. As part of the verification, it was determined that the stage gage mounted on the structure needed to be re-located further upstream and outside of the drawdown zone upstream of the operable weirs. The stage gage has subsequently been re-located by Reclamation District 108 and the California Department of Water Resources. Additional flow monitoring will be needed to further verify the flow rating for the structure using the re-located stage gage.

2.3 YOLO BYPASS SALMONID PROJECT INUNDATION ANALYSIS

cbec conducted an analysis of the flow monitoring data with the purpose of verifying hydrologic assumptions used in the Yolo Bypass Salmonid Project inundation analysis and to provide recommendations to modify or update those hydrologic assumptions. The outcome of the analysis demonstrated the hydrologic assumptions implemented in the Yolo Bypass Salmonid Project to generate westside tributary inflows to the Yolo Bypass for Knights Landing Ridge Cut, Cache Creek Settling Basin, and Putah Creek are reliable on a daily timescale and not expected to alter the relative results of the Yolo Bypass Salmonid Project inundation analysis between existing conditions and the alternatives. The new hydrologic assumptions for the Willow Slough Bypass developed as part of this study, however, may alter the results of the inundation analysis. Summaries for each westside tributary are provide below:

- **Knights Landing Ridge Cut:** The use of California Department of Water Resources daily flow data at Ridge Cut Slough as the Knights Landing Ridge Cut boundary condition at the location of Wallace Weir in the Yolo Bypass Salmonid Project is appropriate for inundation analyses conducted on a daily basis for the following reasons. There are no significant gains or losses between the Ridge Cut Slough gage near Knights Landing and Wallace Weir during the winter. Knights Landing Ridge Cut is a leveed channel and the cumulative volume of water entering the Yolo Bypass is not affected by the short travel time of 7 hours for inundation analyses conducted on a daily time scale (i.e., the time scale used in the Yolo Bypass Salmonid Project), and hence, the inundation patterns influenced by the KLRC boundary condition should not be affected. However, for inundation analyses conducted on a subdaily basis, a 7-hour lag should be applied to the Ridge Cut Slough gage data.

- **Cache Creek Settling Basin:** While no additional monitoring was performed at this location, the hydrologic assumptions used within the Yolo Bypass Salmonid Project were revisited and updated because the model generally over-estimated accumulated outflow volumes, especially during dry and critically dry water years or low flow periods. The updates to the model reduced the average annual volumetric percent error from 5.3% to 0.1%, as well as the range in interannual variability in percent error, but these reductions in error were largely associated with improvements in the drier periods for flows less than 100 cfs. Flows less than 100 cfs should not impact farmland inundation within the Yolo Bypass, because these flows are typically conveyed within the existing capacity of the Tule Canal.

- **Willow Slough Bypass:** The flow monitoring data analysis revealed the hydrologic assumptions used for the Yolo Bypass Salmonid Project inundation analysis, based purely on the Management Strategy approach using scaled inter-dam runoff from Putah Creek, resulted in significant over-estimation of inflows to the Yolo Bypass. The significance of Putah Creek inter-dam runoff as a poor predictor of flows in Willow Slough Bypass is not fully understood. Willow Slough Bypass enters the Yolo Bypass north of Interstate 80 in a portion of the Yolo Bypass that is generally one of the first locations to become inundated when the capacity of the Tule Canal / Toe Drain is exceeded. Considering Willow Slough Bypass inflows in average water years are generally over-estimated per the Yolo Bypass Salmonid Project, this result may lead to more frequent inundation in this portion of the Yolo Bypass under existing conditions, which may alter the relative impacts of the inundation analysis. See recommendation in Section 2.4.2 for addressing this uncertainty.

- **Putah Creek:** The study revealed the Yolo Bypass Salmonid Project over-estimated inflows into the Yolo Bypass during wetter water years when Monticello Dam was spilling via the glory hole and minimally so for drier water years when Monticello Dam was not spilling because the inundation analysis reasonably predicted the volumetric inflow to the Yolo Bypass. In years when Monticello Dam is spilling, even though the Yolo Bypass Salmonid Project over-estimates the volumetric inflow, the Yolo Bypass is experiencing deep system-wide flooding such that the impact on the relative inundation analysis is negligible. Further, since the Putah Creek reach between Winters and Interstate 80 was confirmed as a losing reach (i.e., flow rate decreases in the downstream direction as water moves from the channel into the adjacent ground), the inter-gage runoff between Winters and Interstate 80 could not be used to replace the inter-dam runoff (i.e., flow rate increases in the downstream direction) previously used for estimating the Willow Slough Bypass inflows.

2.4 RECOMMENDATIONS

The following recommendations resulting from the study include collection of additional monitoring data, application of the newly developed rating curves, and application of various hydrologic assumptions in future Yolo Bypass inundation analyses.

2.4.1 MONITORING DATA AND RATING CURVES

- **Knights Landing Ridge Cut:** Perform additional flow monitoring at Wallace Weir to verify the weir equation-based flow rating for the structure using the re-located stage gage. Once verified, the weir equation-based flow rating for the structure should provide reliable inflows into the Yolo Bypass up to 4,000 cfs. Coordinate with Reclamation District 108 and the California Department of Water Resources to collect this additional verification data to advance their ability to make the stage and flow data at Wallace Weir publicly available.

- **Cache Creek Settling Basin:** Monitor the operational agreement with the California Department of Water Resources that funds the U.S. Geological Survey to monitor Cache Creek Settling Basin flows though water year 2021. Consider additional funding opportunities should the agreement not be renewed to extend the public availability of monitoring data at Cache Creek Settling Basin.

- **Willow Slough Bypass:** Perform additional flow monitoring and document downstream conditions to identify potential sources of mid-range flow-stage rating error at this site (e.g., backwater from Yolo Bypass, localized runoff, agricultural diversions and or changes to channel geometry, etc.). Provide the rating curve to Yolo County Flood Control and Water Conservation District. Coordinate with the Yolo County Flood Control and Water Conservation District to apply the rating curve at their County Road 102 monitoring site, assist them in identifying opportunities to increase monitoring data reliability and accuracy by establishing routine data management protocols, and assist them in identifying mechanisms to make the data publicly available (i.e., viewing and retrieving).

- **Putah Creek:** Provide the rating curves to Solano County Water Agency to allow application of the rating curves to their monitoring sites at Putah Creek at Winters and Putah Creek at Interstate 80. Although Solano County Water Agency currently makes their data publicly available, it is only available for a period of five days and is view only. Coordinate with SCWA to provide options for extended viewing and data retrieval.

2.4.2 FUTURE YOLO BYPASS INUNDATION ANALYSES

The following recommendations pertain to using the improved westside tributary inundation information for future Yolo Bypass inundation analyses, such as analysis of the impacts of proposed projects:

- **Knights Landing Ridge Cut:** The California Department of Water Resources flow data for Ridge Cut Slough should continue to be used for all flows. For inundation analyses performed on a daily basis, the data can be used in its current form. For inundation analyses performed on a sub-daily basis, the data should be lagged by 7 hours. However, as soon as the weir equation-based flow rating at Wallace Weir is verified with subsequent flow measurements (per the Section 2.4.1 recommendation above), flows less than 4,000 cfs should rely upon the verified Wallace Weir flow rating (i.e., flows within the design capacity of the new structure when the Yolo Bypass is not in flood).

- **Cache Creek Settling Basin:** The U.S. Geological Survey published outflow data should continue to be used, but if the U.S. Geological Survey monitoring contract lapses or expires, the relatively minor updates implemented by cbec in the hydrologic model developed for the Yolo Bypass Salmonid Project for the Cache Creek Settling Basin to address dry year discrepancies should be used. If the hydrologic model continues to be used, especially on a sub-daily basis, then additional improvements to flow routing and disaggregation are recommended.

- **Willow Slough Bypass:** Even though the Management Strategy assumptions were determined to significantly over-estimate inflows into the Yolo Bypass, future inundation analyses should rely upon a direct measure of inflows based on the monitoring station Yolo County Flood Control and Water Conservation District maintains at County Road 102 (pending implementation of the Section 2.4.1 recommendations by Yolo County Flood Control and Water Conservation District). In the event the Section 2.4.1 recommendations for Willow Slough Bypass are slow to implement, it is recommended that additional sensitivity testing of the Willow Slough Bypass boundary conditions be performed to better understand how inundation in the area of the Yolo Bypass north of I80 is affected by Management Strategy hydrologic assumptions. This may involve reanalyzing previously developed inundation results and/or developing a hydrologic model specific to Willow Slough Bypass to replace scaling Putah Creek inter-dam runoff.

- **Putah Creek:** Even though the Management Strategy assumptions were verified to reasonably predict inflows to the Yolo Bypass, future inundation analyses should rely upon a direct measure of inflows based on the monitoring station Solano County Water Agency maintains for Putah Creek at Interstate 80 (pending implementation of the Section 2.4.1 recommendation by Solano County Water Agency).

The following sections describe flow monitoring site selection, flow monitoring methods and results, and review of the Yolo Bypass Salmonid Project hydrologic assumptions.

3 FLOW SAMPLING LOCATIONS

Specific flow sampling locations were finalized in December 2016 based on field reconnaissance performed by cbec following coordination with the County and other agencies. Since cbec anticipated collecting flow measurements during flood conditions, cbec considered the following site conditions:

1) Uniform flow conditions with minimal riparian vegetation or woody debris encroachment
2) Limited backwater conditions that could affect the flow-stage relationship
3) Distance to established agency stage gages to be used for flow rating
4) Accessibility for field staff to access both banks during flood flows
5) Landowner access permissions
6) Site safety for field staff

Figure 1 shows the location map of the sampling sites and agency gages referenced in this study.

3.1 KNIGHTS LANDING RIDGE CUT (KLRC) AT WALLACE WEIR

Since December 2006, the California Department of Water Resources (DWR) has monitored, and continues to monitor, KLRC for stage and flow at the Highway 113 Bridge (DWR Station A02939; Ridge Cut Slough at Knights Landing (RCS)), approximately seven miles upstream of the Yolo Bypass. DWR and the U.S. Bureau of Reclamation (USBR) used this data in the Yolo Bypass Salmonid Project inundation analysis to describe inflows into the Yolo Bypass (see Section 6.1). However, the construction of the Wallace Weir Fish Rescue Facility at the terminus of the KLRC with the Yolo Bypass has the potential for provide a more direct measure of inflows into the Yolo Bypass. Reclamation District 108 (RD 108) completed construction of the Wallace Weir in February 2018. The weir includes six (6) 16-foot wide inline Obermeyer Hydro, Inc. (OHI) bladder dams as well as an auxiliary fish rescue facility that conveys 50 cfs. RD 108 operates the bladder dams to manage water levels along the KLRC.

cbec installed two stage gages on the KLRC (Figure 2). One was installed approximately 40 feet upstream of the bladder dams and downstream of the fish trap facility intake screen. The other was installed immediately downstream of the bladder dams, downstream of the fish trap facility fish weir, and above the concrete sill to document backwater conditions from the Yolo Bypass. During the course of flow monitoring, it was determined that for flows less than 1,300 cfs (low flow), a flow measurement site approximately 1,300 feet downstream of the weir face on a channelized cross section was optimal to avoid any aeration caused by water coming over the weir. Above 1,300 cfs (high flow), all flow measurements were taken immediately downstream of the weir face to accurately measure all water passing through the weir.

3.2 CACHE CREEK SETTLING BASIN (CCSB)

cbec determined it was unnecessary to perform any physical sampling at CCSB. CCSB outflow is monitored by the USGS under an annual contract renewal with DWR as part of DWR's continuing efforts to understand mercury and sediment trap efficiency within the CCSB. This data (Figure 3) was used in the

Yolo Bypass Salmonid Project analysis to describe inflows into the Yolo Bypass (see Section 6.2). In March 2017, the USGS received additional funding to continue measurements, operations, and maintenance of the CCSB outflow gages (USGS Stations 11452900, 11452901, and 11452800). There is currently an operational agreement with DWR to fund the CCSB monitoring through WY 2021 and it is uncertain if funding will continue (D. Parker, USGS, pers. comm., 1/27/2020). Due to safety concerns, the USGS does not collect any direct flow measurements at the overflow weir over a stage of 35.7 ft (USGS gage datum). Flows above this stage are derived from theoretical equations provided by the U.S. Army Corps of Engineers and geometry of the weir (E. Lindbloom, USGS, pers .comm., 3/13/ 2017).

3.3 WILLOW SLOUGH BYPASS (WSB) AT CR 102

The USGS monitors WSB at County Road (CR) 102 as a "partial-record station" meaning that field measurements of stage and discharge are only recorded for flows less than 500 cfs within the low flow channel and a rating curve has not been developed. The Yolo County Flood Control and Water Conservation District (District) operates a telemetered, ultrasonic stage gage (i.e., IMP10 Lite Ultrasonic Level Sensor) on the upstream side of the bridge face. Although the stage gage is not flow rated, the stage data is calibrated to the same arbitrary datum as the USGS low flow measurements. Given the District operates a telemetered monitoring station, there was no longer a need to install a telemetered monitoring station as originally identified in the grant. However, the District monitoring station could be better managed for data reliability and accuracy by establishing routine data management protocols. The District data was not used in the Yolo Bypass Salmonid Project analysis to describe inflows into the Yolo Bypass because it was unavailable during that study.

During this monitoring study, cbec installed a temporary stage gage to provide data redundancy in the event the District stage gage reported erroneous data. cbec measured flow approximately 25 feet upstream of the CR 102 bridge (Figure 4). At the bridge, a staff plate was attached to the piling on the left bank of the low flow channel and a game camera was attached to the piling on the right bank to provide real-time pictures of the staff plate to inform flow sampling protocol since the District data was not available in real-time to the public.

3.4 PUTAH CREEK

SCWA has been monitoring stage and low flows (i.e., typically less than 100 cfs) at multiple locations along Putah Creek from the Putah Diversion Dam (PDD) downstream to the Los Rios Check Dam since July 2008. SCWA's monitoring stations typically include telemetered stage gages with plans to continue low flow monitoring at these stations to inform real-time water management focusing on minimum flow releases as part of the Putah Creek Accord. Two of these stations, which are critical to verifying current approaches for estimating historic flows into the Yolo Bypass as part of the Yolo Bypass Salmonid Project analysis, are Putah Creek at I505 (LPCI505) and Putah Creek at I80 (LPCI80), both of which are currently only rated for very low flows (i.e., less than 100 cfs). Only the LPCI80 low flow data was used in the Yolo Bypass Salmonid Project analysis to partially describe inflows into the Yolo Bypass (see Section 6.4).

3.4.1 PUTAH CREEK NEAR WINTERS (PUS)

Field reconnaissance identified transect placement for high flow sampling near the LPCI505 gage to be downstream of the Railroad Avenue Bridge near the City of Winters community garden (Figure 5). The transect was selected based on channel uniformity, favorable access from both banks, and scarcity of riparian vegetation within the high flow floodplain bench. The City of Winters provided access through a public trail easement.

3.4.2 PUTAH CREEK NEAR OLD DAVIS ROAD (PDS)

Field reconnaissance identified transect placement for high flow sampling near the LPCI80 gage approximately 0.5 miles downstream of Old Davis Road (Figure 6), which was accessible from the north side of the creek within a UC Davis research site. cbec received permission from the landowner on the south bank to install temporary equipment in the channel corridor. The north side of the channel included a high flow floodplain terrace which started to become inundated at approximately 4,500 cfs.

4 MONITORING METHODS

Flow monitoring requires advanced instrumentation and knowledge of the latest USGS guidance documentation. cbec staff is well versed in streamflow measurements and maintains field standard operating procedures that mirror the USGS Office of Surface Water (OSW) guidance releases. The following sections outline equipment and methods used for this project.

4.1 EQUIPMENT INSTALLATIONS

Prior to each storm season, cbec field staff installed temporary stage gages to measure water surface elevations (WSE) at each site. The temporary stage gages provide redundancy in case nearby agency gages report erroneous or no data. Each stage gage installation consisted of a perforated 2-inch PVC pipe with a locking well cap with a non-vented *Hobo U20L* pressure transducer (see Appendix A datasheet). The bottom of the PVC pipe was located as close to the channel bottom as possible and the transducers were placed at the bottom of the pipe. The pressure transducers were programmed to record pressure (i.e., water column plus atmospheric) every 15 minutes and the data was post-processed for atmospheric pressure (Section 4.4.1). Following installation of the temporary stage gages, vertical calibrations were performed at each installation to convert water depth to relate the stage gage readings to nearby agency stage gages.

4.2 ACOUSTIC DOPPLER CURRENT PROFILER

An Acoustic Doppler Current Profiler (ADCP) measures water velocity in three dimensions using high-frequency sound pulses (sonar) and their echoes through the profile of the channel water column. The timing of the returned Doppler shifted echoes provides a measure of distances from and relative velocities of backscattered particles traveling within water column such as suspended sediments and organic material. The ADCP is also equipped with and an internal flux gate compass that allows the instruments position and movement direction to be relative to the earth's magnetic field. This allows the separation of the three-dimensional (3D) velocity components into north/south, east/west, and vertical references. By simultaneously measuring the change in Doppler-shifted sound frequency when reflected back to the ADCP's transducer and the ADCP's relative position, an accurate profile of three-dimensional velocities can be calculated within the WinRiver II software (Teledyne Marine, 2019). Individual point velocities are averaged, called bins, from a predefined volume within the water column to provide a representation of water velocity conditions. ADCPs provide an accurate measurement of the cross-sectional area and the velocity magnitude for each bin within a given measurement/transect. With these data, the WinRiver II software can calculate the instantaneous discharge across a cross-sectional area (*Q = V x A*, *where Q = discharge in cubic feet per second, V = velocity in feet per second, and A = area in square feet*).

cbec collected velocity and flow measurements at each of the four measurement sites during high flow events using a tethered ADCP per USGS guidelines (Mueller & Wagner, 2013). cbec used a Teledyne RDI RiverRay ADCP secured in an Oceanscience Riverboat (see Figure 8 and Appendix A datasheet) to measure 3D velocities in automatically sized bins (10 cm minimum with higher resolution/smaller bins in areas with shallower depths) for flow depths greater than 0.98 feet. The ADCP unit includes a blanking layer (where measurements cannot be recorded) near the water surface approximately 0.66 feet below the transducer face (due to ringing effects near the transducer) and a blanking layer at the bottom equivalent to 6% of the side lobe layer plus one depth cell from the bottom for discharge calculations (due to bottom echo return contamination). cbec integrated the ADCP unit with a Trimble Global Navigation Satellite System (GNSS) Real-Time Kinematic (RTK) Global Positioning System (GPS) receiver to provide survey grade horizontal and vertical positioning to minimize errors with the ADCP's bottom tracking routine during moving bed conditions. cbec used the Teledyne RDI WinRiver II (version 2.18) software running on a Panasonic CF-31 Toughbook for ADCP setup, data collection, discharge calculations, data post processing, and data quality review in the field and in the office (see Figure 9 for typical outputs). Prior to the start of each day, cbec configured the instrument and performed pre-measurement field procedures (i.e., compass calibration, moving bed test, and water temperature and salinity checks). Using a combination of ADCP and ADV technologies (see Section 4.3), cbec collected and averaged together a minimum of four transects for computing flow.

4.3 ACOUSTIC DOPPLER VELOCIMETER

Like an ADCP, an Acoustic Doppler Velocimeter (ADV) uses sonar to measure acoustic backscatter in the water from suspended particulates, but unlike an ADCP does not measure velocity profiles through the channel water column, rather point velocities. ADV's are compact instruments designed to be used with a wading rod to measure a single point velocity. cbec used standard midsection methods (Terzi, 1981) to compute streamflow based on measurement interval, measurement spacing, and channel geometry. cbec used a *Sontek Flowtracker ADV* at PUS, PDS, and WSB to measure the overbank flows on the inset floodplain areas where water was higher than the low flow channel and too shallow to collect measurements with the ADCP.

4.4 QUALITY ASSURANCE/QUALITY CONTROL

cbec performed quality assurance/quality control on all the data cbec collected to maximize the accuracy of the analysis. Stage gage data was extracted from pressure transducers and directly surveyed RTK measurements of WSE. ADCP data was checked for quality during data collection in the field. It was further inspected in the office as part of the desktop post-processing. The following sections outline quality assurance and quality control methods used for this project.

4.4.1 STAGE GAGE DATA

Following installation of the pressure transducers, staff surveyed the water surface elevation multiple times during each monitoring season to calibrate and verify data accuracy, as well as to check each of the pressure transducers for drift during the duration of deployment. Barometric pressure gages were also downloaded and used to post-process the water level readings at each site (since the pressure transducers measure the pressure head of the water column plus barometric pressure). Additional water surface elevation measurements were made at the beginning and end of logging period to identify any possible equipment malfunction. The pressure transducers were downloaded with a Panasonic CF-31 Toughbook in order to plot and visually inspect the data during each data retrieval.

4.4.2 FLOW DATA

During data collection, field notes and observations were recorded. Data quality was reviewed in real-time, and critical data quality problems were noted. If the flow for any transect differed by more than 5% from the mean value of a minimum of four transects, then the number of additional transects needed was dependent upon the absence/presence of a critical data quality problem. Due to the unsteady flow conditions encountered during monitoring, it was sometimes difficult to meet the 5% threshold with four transects, so additional transects were collected. The four transects were typically captured within a one-hour window.

4.4.3 DESKTOP POST-PROCESSING

During post processing in the office, the field notes were compared to velocity and flow data for verification. This verification included review of configuration and setup files, comparisons between field notes and electronic files, and visual inspection of the velocity profiles for missing/invalid ensembles, velocity ambiguities, beam intensity inconsistencies, and boat speed irregularities. Also, because a Global Positioning System Fix Data (GGA) output string was being used real-time by WinRiver II, the quality of the GPS signal was reviewed and the positioning data was corrected, as necessary. The results were screened in WinRiver II to fix reverse flow and remove invalid transects based on the field notes. Following this screening, the measurements were processed in QRev per USGS guidelines (Mueller, 2016).

USGS developed QRev software to post process streamflow measurements. Qrev is used to flag transects with issues in heading, temperature, positioning, bottom tracking, and extrapolation of measured data to fill in gaps of the transect that the ADCP cannot measure. The most common parameters that were corrected in Qrev included positional accuracy and computed edge discharge. Intermittent loss in RTK data is corrected by filling in data gaps with Bottom Track data. Edge discharge parameters sometimes needed to be adjusted due to irregular velocity magnitude and/or direction in the last ten ensembles used by the Qrev software to calculate the edge discharge. This is usually caused by physical processes such as eddies, vegetation, or turbulence. The edge calculations assume a trapezoidal channel and uses the first and last ensembles of the transect to extrapolate edge velocities. In the case where an ADV was used to measure floodplain flow, the computed edge discharge in Qrev was replaced with the total flow produced by the ADV measurements. After all of the individual measurements were processed in Qrev, summary results tables were exported, as provided in Appendix B.

5 MONITORING RESULTS

The following sections detail the results of the post-processed flow data collected during the field monitoring efforts at the four study sites. cbec correlated the flow data to agency stage gages and used the data to develop rating curves for estimating inflows into the Yolo Bypass over a broad range of flow conditions.

5.1 KNIGHTS LANDING RIDGE CUT

Monitoring at KLRC did not begin until WY 2018 because of Wallace Weir construction. In total, cbec collected 18 valid measurements downstream of the weir (Table 1; Figure 9) in WY 2018 (6 measurements) and WY 2019 (12 measurements). Two measurements collected in September 2018 coincided with the North Delta Flow Action, an initiative by DWR to divert rice field drainage water from Colusa Basin Drain through KLRC into the Yolo Bypass and downstream to the Delta to benefit the Delta food web for fishes. Measured flows ranged from 291 cfs up to 3,699 cfs. At a peak flow of 3,699 cfs on 2/15/2019, which is nearing the design capacity of Wallace Weir, cbec noted the water level upstream of the weir started to encroach on the low chord of the weir bridge structure and neared the top of the access road over the weir. As flows reached the capacity of the weir, cbec did not collect any additional measurements for safety reasons.

5.1.1 STAGE DISCHARGE RATING CURVE

cbec did not develop a rating curve for Knights Landing Ridge Cut at Wallace Weir. The data that was collected as part of this study was intended to verify the new flow rating for the newly reconstructed Wallace Weir. The new flow rating is based on standard weir equations and is affected by the elevation of the new operable gates. During the verification process, cbec was unable to verify the new flow rating and determined the OHI stage gage mounted on the upstream nose of the wall between bladders 1 and 2 was inappropriately placed because the stage gage was within the drawdown zone of the weir versus upstream of the drawdown zone, which affected the reliability of the weir equation-based flow readings concurrent with this monitoring study. Based on this finding, and at the instruction of DWR and RD 108, the OHI stage gage was subsequently re-located in November 2019 to a more appropriate location.

Further, cbec recommends that DWR verify the weir equation-based flow rating by collecting additional flow measurements at Wallace Weir.

Table 1. Flow measurements at Knights Landing Ridge Cut

Date/Time	Upstream Stage (NAVD88, ft)	Downstream Stage (NAVD88, ft)	Measured Flow
3/27/18 16:02	22.84	19.37	291
9/4/18 15:09	22.88	20.76	370
1/8/19 12:15	23.05	19.92	375
9/5/18 13:37	22.90	21.17	448
4/11/18 13:45	22.30	20.77	479
4/7/18 14:53	23.06	21.00	583
4/8/18 10:44	22.05	21.75	796
1/9/19 15:39	22.75	22.33	905
1/10/19 13:22	23.25	22.30	1,135
1/10/19 15:29	23.31	22.72	1,243
1/11/19 12:39	23.73	23.47	1,310
2/4/19 13:30	24.18	23.84	1,530
1/18/19 12:31	24.80	24.46	1,785
1/20/19 11:32	25.10	24.87	2,157
1/21/19 13:12	25.28	25.04	2,365
1/22/19 14:47	25.39	25.16	2,448
2/14/19 13:04	25.76	25.42	3,268
2/15/19 14:45	26.71	26.27	3,699

5.2 WILLOW SLOUGH BYPASS

cbec collected a total of 17 measurements at the WSB over the course of the study (Table 2, Table 3) in WY 2017 (5 measurements) and WY 2019 (12 measurements), largely coinciding with the falling limb of storm events. A total of three measurements were augmented with ADV data on the river left floodplain bench when stage was greater than the capacity of the low flow channel. When water was greater than one foot deep on the bench, discharge was solely collected by a continuous ADCP transect. The flow range collected for WSB was 147 cfs to 2,383 cfs, which significantly expanded upon the flow data collected by the USGS by augmenting the data set with higher flows.

5.2.1 STAGE DISCHARGE RATING CURVE

cbec generated a rating curve for the WSB and CR 102 by combining the 17 measurements collected in this study with 10 field measurements collected by the USGS near CR 102 (see Figure 10). cbec fitted power curves through the high flow and low flow data based on the data provided in Table 2 and Table 3, respectively. cbec filtered USGS low flow measurements for quality (i.e., only retained GOOD or FAIR) and thinned to reduce overrepresentation of low flows in the RMSE during power curve fitting. cbec observed a moderate degree of scatter in the mid-range stage-discharge measurements, potentially due to a variety of factors (e.g., Yolo Bypass backwater, local water management, beaver activity). While this has the possibility to influence the rating curve fit, the equations used to generate the two-part power curves as provided in Table 4 have high R-squared values, meaning the spread of the data was acceptable.

Table 2. High Flow Measurements recorded at Willow Slough Bypass

Date/Time	Agency	Measured Stage (USGS datum, ft)	Measured Flow (cfs)
2/9/17 11:26	cbec	10.3	550
2/22/17 17:21	cbec	11.0	767
1/7/19 13:40	cbec	11.2	410
1/7/19 16:33	cbec	11.3	373
2/4/19 15:57	cbec	11.4	653
2/20/17 10:26	cbec	11.4	874
2/22/17 8:32	cbec	12.0	947
1/16/19 13:06	cbec	12.0	571
3/21/11 11:37	USGS	12.5	1,320
1/18/19 14:41	cbec	12.8	983
1/18/19 8:04	cbec	13.8	1,202
2/21/17 8:03	cbec	14.3	1,962
1/17/19 14:19	cbec	14.6	1,378
2/15/19 10:31	cbec	15.3	2,383
2/14/19 10:09	USGS	15.6	2,480

Table 3. Low Flow Measurements recorded at Willow Slough Bypass

Date/Time	Agency	Measured Stage (USGS datum, ft)	Measured Flow (cfs)
1/8/10 11:37	USGS	4.4	0.2
11/5/09 11:08	USGS	4.5	0.7
9/14/16 12:31	USGS	5.0	8.9
2/15/17 13:38	USGS	5.4	42.5
3/5/10 16:11	USGS	5.9	96.4
9/3/10 15:56	USGS	6.4	29.2
6/18/18 11:13	USGS	6.7	50.2
1/8/19 14:24	cbec	7.5	147
1/26/10 11:27	USGS	8.5	383
1/20/19 9:52	cbec	8.6	293
1/8/19 8:52	cbec	8.6	192
2/5/19 12:09	cbec	9.1	341
2/9/17 11:26	cbec	10.3	550
1/7/19 13:40	cbec	11.2	410
1/7/19 16:33	cbec	11.3	373
2/4/19 15:57	cbec	11.36	653
1/16/19 13:06	cbec	12.04	571

Table 4. Rating Curve Equations for WSB

Transition:	8.60	feet
Low Flow Curve:	$Q = 24.35*(H - 4.362)^{1.57}$	R2 = 0.887
High Flow Curve:	$Q - 60.00 = 0.01*(H)^{4.41}$	$R^2 = 0.873$

Where Q = Flow in cubic feet per second, H = Stage in feet, USGS datum

5.3 PUTAH CREEK NEAR WINTERS

Since WY 2017 was one of the wettest years on record, runoff from the Lake Berryessa watershed caused the lake to rise above the Monticello Dam 440 ft spillway, or “glory hole,” elevation from 2/17/2017 to 5/9/2017. This event provided a rare opportunity to measure high flows in Putah Creek since Lake Berryessa last spilled in May 2006. Lake Berryessa spilled again in WY 2019, starting on 2/26/2019, so cbec obtained one additional measurement. In total, cbec collected 18 measurements (Table 5) in WY 2017 (17 measurements) and WY 2019 (1 measurement). The flow measurements ranged from 560 cfs up to 8,435 cfs, which significantly expanded upon the flow data collected by SCWA by augmenting the data set with higher flows that included spills from Monticello Dam.

5.3.1 STAGE DISCHARGE RATING CURVE

cbec generated a high flow rating curve for SCWA’s Putah Creek near Winters monitoring station using the 18 measurements (Table 5) by fitting a power curve through the data and extrapolating to intersect the low flow curve published by SCWA (which is updated annually by SCWA). Equations used to generate the two-part curve are provided in Table 6 with high R-squared values indicating that the data closely fit the rating curves.

Table 5. High Flow Measurements recorded at Putah Creek near Winters

Date/Time	Stage (NAVD88)	Stage (SCWA datum, ft)	Discharge (cfs)
2/9/2017 14:35	101.06	6.69	562
2/13/2017 12:21	101.03	7.56	734
2/18/2017 16:27	105.72	11.25	3,142
2/20/2017 13:31	107.35	14.00	4,839
2/21/2017 11:37	109.54	17.00	7,433
2/21/2017 16:59	109.41	16.69	7,200
2/22/2017 10:48	109.28	16.48	7,164
2/23/2017 14:44	108.58	15.6	6,483
2/24/2017 13:52	107.94	14.71	5,821
2/25/2017 12:09	107.37	14.01	5,384
2/26/2017 12:38	-	13.41	4,851
2/27/2017 12:37	106.42	12.57	4,107
2/28/2017 12:04	106.06	12.23	4,022
3/3/2017 11:54	105.12	10.79	2,851
3/5/2017 9:14	103.91	9.87	2,269
3/7/2017 10:26	103.12	9.02	1,689
3/17/2017 12:28	101.47	8.11	1,023

**WSE was not recorded on 2/26/2017*

Table 6. Rating Curve Equations for Putah Creek near Winters

Transition:	6.07	feet
Low Flow Curve (produced by SCWA):	$Q = 41.99H^2 - 329.81H + 656.36$	R2 = 1
High Flow Curve:	$Q = 323.41*(H - 5.378)^{1.28}$	R2 = 0.997

Where Q = Flow in cubic feet per second, H = Stage in feet, SCWA datum

5.4 PUTAH CREEK NEAR OLD DAVIS ROAD

Similar to Putah Creek near Winters, cbec collected a total of 17 measurements (Table 7**Error! Reference source not found.Error! Reference source not found.**) in WY 2017 (16 measurements) and WY 2019 (1 measurement). The flow measurements ranged from 503 cfs to 7,835 cfs, which significantly expanded upon the flow data collected by SCWA by augmenting the data set with higher flows that included spills from Lake Berryessa.

5.4.1 STAGE DISCHARGE RATING CURVE

A high flow rating curve for LPCI80 (see Figure 12) was generated using the 17 measurements by fitting a power curve through the data and extrapolating to intersect the low flow curve published by SCWA (which is updated annually). Equations used to generate the two-part curve are provided in Table 8 with high R-squared values indicating that the data closely fit the rating curves **Error! Reference source not found.**.

Table 7. High Flow Measurements recorded at Putah Creek near Old Davis Road

Date/Time	Stage (NAVD88, ft)	Stage (SCWA datum, ft)	Discharge (cfs)
2/9/2017 17:11	31.58	9.24	504
2/13/2017 16:54	32.63	10.77	661
2/18/2017 11:16	40.23	17.94	3,471
2/20/2017 13:31	41.02	19.44	4,453
2/21/2017 15:04	45.52	22.93	7,123
2/23/2017 11:50	-	21.95	6,348
2/23/2017 16:03	44.40	21.84	6,252
2/24/2017 15:43	43.65	21.05	5,768
2/25/2017 14:04	42.79	20.40	5,571
2/26/2017 10:27	-	19.89	4,828
2/27/2017 15:07	41.09	18.95	4,407
2/28/2017 14:31	40.32	18.38	4,067
3/3/2017 14:24	38.36	16.69	2,919
3/5/2017 11:03	36.27	15.03	2,012
3/7/2017 11:53	35.27	13.93	1,723
3/17/2017 14:43	33.64	12.04	1,102
2/28/2019 10:33	-	23.43	7,835

** WSE was not recorded on 2/23/2017, 2/26/2017, 2/28/2019*

Table 8. Rating Curve Equations for Putah Creek near Old Davis Road

Transition:	7.09	feet
Low Flow Curve (produced by SCWA):	$Q = 1.24H^3 + 1.61H^2 - 83.07H + 229.34$	R2 = 1
High Flow Curve:	$Q = 5.19*(H - 2.906)^{2.42}$	R2 = 0.996

Where Q = Flow in cubic feet per second, H = Stage in feet, SCWA datum

6 COMPARISON TO THE YOLO BYPASS SALMONID PROJECT METHODOLOGY

Yolo County applied for a grant to improve the flow data available for the westside tributaries as a result of Yolo County concerns that the flow data on which DWR and USBR relied for development of the Yolo Bypass Salmonid Project did not adequately capture westside tributary flows. It was also considered that establishing flow gage locations for these tributaries is essential for future studies in the Yolo Bypass. As part of the Yolo Bypass Salmon Project Environmental Impact Statement/Environmental Impact Report (EIS/EIR) methodology (USBR and DWR, 2019), the DWR developed a TUFLOW (BMT WBM, 2016) 2-dimensional hydrodynamic model for the Yolo Bypass to evaluate a suite of Yolo Bypass Salmonid Project alternatives to increase the frequency and inundation of the Yolo Bypass for fish habitat and to improve fish passage, as well as to compare relative impacts and benefits of each alternative (HDR and cbec, 2017). DWR hired cbec and HDR to perform this work. cbec developed flow data timeseries for the westside tributaries for WYs 1997 to 2012. cbec applied these discharge timeseries data to create inflow boundary conditions for the Yolo Bypass, in addition to other boundaries applied for elements of the Sacramento and American River watersheds in the model. Based on the new flow and stage data collected as part of this study, cbec revisited the below assumptions used to generate boundary conditions in the EIS/EIR TUFLOW model in Section 6:

- **Knights Landing Ridge Cut:** DWR developed KLRC inflows upstream of Wallace Weir based on lagging Colusa Drainage Basin flows at Highway 20 prior to December 2006 and directly applying DWR published flows at the RCS gage post December 2006 (HDR and cbec, 2017).
- **Cache Creek Settling Basin:** DWR developed a HEC-HMS model (Hydrologic Modeling System (HMS); Hydrologic Engineering Center (HEC), 2010) to simulate outflows based on observed inflows (USGS gage 11452500) and modeled basin storage and outlet hydraulics.
- **Putah Creek and Willow Slough Bypass:** DWR applied flows per the Management Strategy (Jones & Stokes, 2001), which involved conditional scaling equations for estimates of inter-dam runoff between Lake Berryessa and Lake Solano (Jones & Stokes, 2001; HDR and cbec, 2017).

6.1 KNIGHTS LANDING RIDGE CUT

DWR applied KLRC flows in the EIS/EIR analyses using two methods. Prior to December 2006, KLRC flows were estimated using lagged flows from the Colusa Drainage Basin at Highway 20. After December 2006, DWR's RCS flow data collected upstream of the Wallace Weir near Knights Landing was applied directly as the boundary condition for KLRC. Based on the measured flows during WYs 2018 and 2019 (Section 5.1.1), cbec evaluated the use of RCS data as the KLRC boundary condition for the EIS/EIR on a daily timestep.

6.1.1 ANALYSIS OF RCS GAGED FLOWS AND KLRC FLOW OBSERVATIONS

To verify the direct application of RCS flows as KLRC boundary conditions to the Yolo Bypass using the flow measurements at Wallace Weir in the EIS/EIR, cbec applied a suite of transformations or adjustments to the RCS gage data and drew comparisons between these transformed data and the 18 new flow measurements collected at Wallace Weir (Section 5.1.1). cbec also generated a custom script using R (R Core Team, 2019), shifted the 15-minute RCS data in quarter-hour increments, scaled with a range of multiplicative factors, and compared to the new flow measurements using the Nash-Sutcliffe Efficiency[1] (NSE) statistic (Nash and Sutcliffe, 1970).

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[1] The Nash–Sutcliffe efficiency coefficient (NSE) is used to assess the predictive power of hydrological models and can range from −∞ to 1. An efficiency of 1 (NSE = 1) corresponds to a perfect match of modeled discharge to the observed data.

Through this process, cbec removed some of the measurements from the analysis to generate a more accurate and realistic comparison of wet season flows between the RCS gage location (i.e., seven miles upstream) and Wallace Weir (Figure 13 to Figure 16). cbec removed some of the observations from September 2018 because they were not within the October-May time frame with which the EIS/EIR analyses were concerned with and the flows during this time were affected by unaccounted agricultural management activities (e.g., drainage and diversions) that would not otherwise occur during the wet season (Figure 14). Additionally, cbec removed observations from the latter half of January 2019 because the published RCS flow data appeared to be affected by an unexplained rating curve shift within the published data (Figure 15). cbec retained new KLRC flow measurements from the first half of the month as they were paired with reliable RCS flows (Figure 15). Finally, cbec removed the February 15, 2019 observation, the highest measured flow at nearly 3,700 cfs, because the measurement was likely inaccurate since the flows were near the capacity of Wallace Weir and unmeasured (unaccounted) flows were likely escaping into neighboring fields (Figure 16). After removal of these measurements and refinement of the shift parameters in the R code, a 7-hour lag time between the RCS gage and Wallace Weir with a scaling factor of 1.0 (i.e., no scaling) were found to yield the best fit (NSE=0.992; Figure 17).

6.1.2 CONCLUSIONS

As applied in the EIS/EIR, the direct application of RCS flows near Knights Landing to the KLRC boundary condition at the location of Wallace Weir is appropriate for the following reasons. The optimal scaling factor of 1.0 from the analysis discussed in Section 6.1.1 suggests that no significant gains or losses occur between RCS and Wallace Weir during the winter. This is an expected result given that KLRC is a leveed channel between these two locations. Similarly, the 7-hour lag time identified from the analysis of 15-minute data suggests that, on a daily time scale (i.e., the time scale used in the EIS/EIR), direct application of RCS flows to the KLRC boundary condition is realistic and accurate because the cumulative volume of water entering the Yolo Bypass is not affected, and hence, the inundation patterns influenced by the KLRC boundary condition are not affected.

6.2 CACHE CREEK SETTLING BASIN

The HEC-HMS model that DWR used to generate TUFLOW boundary conditions in the EIS/EIR analyses for the CCSB low flow outlet and overflow weir generally over-estimated accumulated outflow volumes, especially during dry and critically dry water years. Therefore, cbec made edits to the basin and meteorological model components of the HEC-HMS model to simulate additional losses and allow for simplified hydrologic routing calculations. The previous iteration of the HEC-HMS model included a gaged inflow (USGS gage 11452500, Cache Creek at Yolo, CA) being applied directly into a reservoir element representing the CCSB, defined by a stage-volume curve and parameters for the low flow outlet culvert and overflow weir. The outflows were then combined to represent the total CCSB outflow. Following re-calibration of the updated HEC-HMS model, accumulated inflow volume statistics were calculated between the observed daily outflow record (USGS gage 11452901), the HEC-HMS model outputs from the EIR (HDR and cbec, 2017), and the re-calibrated model results.

6.2.1 HEC-HMS MODEL UPDATES

Several improvements were made to the model to add a hydrologic routing component for the reach between the inflow gage location and the CCSB (about six miles) and specify additional gains and losses to and from the system. A simple lag routing method was applied to the inflow reach to represent not only the travel time between the gage location and the upstream end of the CCSB, but also to account for some of the travel time within the CCSB boundary itself before inflow reaches the basin outlet. The model considers the CCSB to be a level-pool reservoir element, which is a reasonable assumption when the basin is full. However, the stage is often within the low flow channel of the basin, at which times a level-pool routing assumption is less valid, especially over the five-mile channel distance between the upstream and downstream ends of the CCSB. For this reason, it was appropriate to simulate a range of potential lag times, based on initial calculations of average velocity and determinations of distance traveled. Due to the leveed nature of the inflow reach and the fact that overbank storage within the CCSB is accounted for in the stage-volume curve, no attenuation of the inflow was accounted for in the routing methodology directly. Lag times of 250, 500, and 1,000 minutes were applied in a re-calibration analysis, in conjunction with some of the parameters discussed in the following paragraphs.

In addition to applying various lag times to CCSB inflows, direct precipitation onto the CCSB was incorporated by adding a subbasin element and specifying a rain gage with data from the California Irrigation Management Information System (CIMIS) Station 006 (Davis, CA). CIMIS Station 226 (Woodland, CA) was located closer to the site, but the length of the data record was insufficient. Therefore, following a regression analysis indicating that data from the CIMIS station in Davis could be used as a reasonable proxy for daily precipitation in Woodland, CIMIS Station 226 data were applied directly to the HMS model. The area of the subbasin was specified as the computed area of the CCSB (about 3.44 square miles, approximately following the bounding levees) and the simple canopy and simple surface methods were used to specify initial storage of 0% for both canopy and surface storage and maximum storage parameters for these elements of 0.04 and 0.15 inches, respectively, based on ranges of published values (Viessman and Lewis, 2002). Monthly values of reference evaporation from CIMIS (DWR, 2012; Zone 14) were added to the meteorological model as part of the canopy and surface calculations. As part of the re-calibration of the HMS model with the updated parameters, subbasin size was also varied to account for additional contributing area that may exist between the location of the inflow gage and the upstream end of the CCSB for an area of approximately 30 square miles. This was used to represent the maximum contributing area to the CCSB downstream of the inflow gage location, but the natural flow of water within this basin is impeded by urban development, levees, and other stormwater management infrastructure. Therefore, in addition to specifying the area of the CCSB as 3.44 square miles, values of 5, 10, 15, 20, 25, and 30 square miles were also simulated as part of the calibration.

Finally, riparian evapotranspiration (ET) losses were added to the HEC-HMS model as a specified outflow. As with the original model, open water evaporation was not simulated because during times with the highest evaporation potential, the stage in the CCSB is low and the water is confined to the low-flow channel. Conversely, when the stage in the CCSB is high enough to fill the overbank portions of the basin, the evaporative stress is relatively low. However, riparian vegetation along the low-flow channel represents a constant source of ET which does not depend upon the current stage within the CCSB, thereby allowing the outflow timeseries to be calculated external to the model. Monthly CIMIS reference ET values (DWR, 2012; Zone 14) were used in conjunction with riparian crop coefficients reported by USGS (2008) to determine daily ET rates in units of cubic feet per second per acre (cfs/acre). In this way, the riparian evapotranspiration flux could be scaled linearly with varying estimates of the size of the riparian area directly influencing water supply within the CCSB and particularly within the low flow channel. A preliminary measurement of the area of riparian vegetation surrounding the low-flow channel, including the area of the channel itself, was 250 acres. For the calibration, areas of 125, 250, and 500 acres were assessed to account for lesser or greater levels of interaction between vegetation adjacent to the creek and that located further from it.

Ultimately, a lag time of 250 minutes with a basin area of 3.44 square miles (i.e., no additional contributing area), and a riparian area of 250 acres (i.e., actual riparian footprint) yielded the highest NSE value (Table 9).

Table 9. Nash-Sutcliffe Efficiency values for the EIR and updated HEC-HMS models

HMS Model	Overall	Water Year										
		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
EIR	0.961	0.19	0.90	0.98	-0.20	0.82	-46.3	0.60	0.89	0.97	0.30	0.93
Updated	0.967	0.23	0.92	0.99	-0.20	0.81	-3.75	0.74	0.91	0.97	0.43	0.95

While the overall NSE only increased by 0.006 as a result of the re-calibration, the updated HEC-HMS model performed much better in critically dry WY 2014 (Table 9) as a result of applying evapotranspiration losses.

6.2.2 ACCUMULATED CCSB OUTFLOW VOLUMES

Nash-Sutcliffe Efficiency was not the only metric used to assess the goodness-of-fit of the HMS model results; accumulated inflow volumes to the Yolo Bypass were also assessed on a WY basis. The re-calibrated HEC-HMS model reduced the percent error in accumulated CCSB outflow volume from a > 5% over-estimation to a 0.1 % over-estimation (Table 10, Figure 18) over WYs 2009 to 2019, most notably by better handling low flow periods and dry years in which the EIS/EIR model greatly over-predicted CCSB outflows.

Table 10. Accumulated CCSB Outflow Volumes

WY	Observed	EIR HMS Model		Re-calibrated HMS Model	
	Volume (ac-ft)	Volume (ac-ft)	Error (%)	Volume (ac-ft)	Error (%)
2009	30,833	34,122	10.7	30,208	-2.0
2010	139,416	165,525	18.7	146,515	5.1
2011	372,639	392,061	5.2	375,360	0.7
2012	17,940	30,171	68.2	18,218	1.5
2013	83,167	96,647	16.2	90,061	8.3
2014	522	2,122	306.8	442	-15.2
2015	67,900	69,646	2.6	68,071	0.3
2016	92,089	114,323	24.1	105,933	15.0
2017	857,974	846,914	-1.3	833,080	-2.9
2018	6,781	12,883	90.0	5,522	-18.6
2019	365,296	377,804	3.4	363,037	-0.6
Overall	**2,034,557**	**2,142,216**	**5.3**	**2,036,448**	**0.1**

6.2.3 CONCLUSIONS

The EIS/EIR model displayed a higher average annual percent-error compared to the re-calibrated model (5.3% versus 0.1%) with greater interannual variability ranging from 306.8% (2014 critically dry year) to -1.3% (2017 wet year) relative to 15% (2016 below normal year) to -18.6% (2018 below normal year) for the re-calibrated model. The impacts to wet season CCSB inflow into the Yolo Bypass and subsequent inundation patterns are expected to be minor, because visual comparisons of computed versus observed CCSB outflows for each water year (Appendix C: Figures C1-C11) indicate the EIS/EIR model over-predicted mostly in low flow periods (i.e. flows less than 100 cfs). The model also tended to over-predict some peak outflows but yielded similar results to the updated HEC-HMS model for peaks, indicating the improvement in accumulated WY CCSB outflow error in the updated model was largely due to prediction improvements for the drier periods. The EIS/EIR was focused on estimating inflows into the Yolo Bypass between October through May of each water year, since that is the period in which the Yolo Bypass Salmonid Project proposes to open operable gates in the Fremont Weir and allow up to 6,000 cfs into the Yolo Bypass. Over-prediction in the EIS/EIR HEC-HMS model for CCSB low flows in drier periods is not critical to floodplain inundation, because these low flows should not impact inundation of farmlands within the Yolo Bypass because they are able to be conveyed within the existing capacity of the Tule Canal.

6.3 WILLOW SLOUGH BYPASS

Willow Slough Bypass flows were estimated for the EIR using equations specified by the Management Strategy (Jones & Stokes, 2001; HDR and cbec, 2017) because gaged flow records were not available for the historical period. Effectively, inter-dam runoff between Lake Berryessa and Lake Solano was scaled using relative drainage areas to estimate a flow timeseries for WSB according to Equation 1:

$$Q_{WS} = -0.000423\,(Q_{INT})^2 + 3.19\,Q_{INT} \quad \text{(Eq. 1)}$$

where Q_{WS} is the discharge for WSB and Q_{INT} is the inter-dam runoff (Jones & Stokes, 2001).

Using District gaged stage records from WYs 2017 through 2019 in conjunction with the rating curve discussed in Section 5.2.1, cbec constructed an observed WSB flow timeseries. The EIS/EIR method was used to generate predicted WSB flow for the same time period, and the resulting WSB estimated flow was compared to the WSB observed flow.

6.3.1 COMPARISON OF RATED WSB FLOWS AND EIS/EIR METHODOLOGY

cbec developed a custom R script to assess the goodness-of-fit of the Management Strategy equation that was applied for the EIS/EIR, as well to determine a more accurate relationship between inter-dam runoff and WSB flow. The analysis used data for October through May for a period from February 2017 through December 2019 corresponding with reliable District stage records. The analysis did not include data pairs for which missing or poor-quality data were found for either the stage records or the inter-dam runoff. Ultimately, the NSE for the EIS/EIR-computed WSB flow series was -3.5 (Figure 19), indicating that the application of Equation 1 to the inter-dam runoff did not provide a reasonable approximation of WSB flows. Rather, a linear fit of the data provided an improved NSE of 0.41 (Equation 2, Figure 19):

$$Q_{WS} = 0.6404\, Q_{INT} + 18.79 \qquad \text{(Eq. 2)}$$

cbec found the positive intercept of Equation 2 was necessary to better fit the data at times when cbec determined the inter-dam runoff was zero but the rated flow values were non-zero.

6.3.2 ACCUMULATED WSB INFLOW VOLUMES

Accumulated inflow volumes for WYs 1997 through 2019 were compared between the observed WSB flow (limited to WYs 2017 (partial) through 2019), the EIS/EIR estimated flow using Equation 1, and the revised EIS/EIR estimated flow using Equation 2. As show by Figure 20, the EIS/EIR estimated volume is approximately three times as large as the observed volume in WYs 2017 and 2019, which were two wet WYs when Lake Berryessa spilled via the glory hole. In WY 2018, which was classified as below normal for the Sacramento Valley, the EIS/EIR estimate is within 16% of observed. Based on this limited comparison across WY types, and in review of WYs 1997 through 2016, it is generally observed that the EIS/EIR estimate based on the Management Strategy assumptions using a second-degree polynomial fit significantly overestimated the WSB inflow to the Yolo Bypass in average and wetter WYs and is more reasonable in drier WYs when there is limited runoff.

6.3.3 CONCLUSIONS

Overall, it is difficult to accurately predict WSB inflows into the Yolo Bypass based on inter-dam runoff on Putah Creek per the EIS/EIR approach, which relied on equations instead of gage data. Stage within WSB may be dependent upon inflow from its watershed, agricultural management activities, and backwater conditions from the Yolo Bypass. The EIS/EIR methodology tended to dramatically overestimate WSB flows using the second-degree polynomial fit in Equation 1 (Figure 19), which was corrected using the linear fit (Equation 2) that was developed using observed data (Figure 19). However, the overall NSE with the linear fit was still relatively low (0.41), indicating inter-dam runoff for Putah Creek is a generally poor predictor of flows in WSB, especially in average and wetter WYs. Unfortunately, there is no easy remedy to the poor scaling of flows using the Management Strategy assumptions and given the relatively short period of reliable stage data on the WSB. In the future, project proponents should use the District's gage data to estimate flows.

6.4 PUTAH CREEK

As with WSB, flows for Putah Creek were calculated for the EIS/EIR using equations established by the Management Strategy (Jones & Stokes, 2001). Essentially, several conditions were evaluated depending on recent rainfall-runoff and whether Monticello Dam (i.e., Lake Berryessa) was spilling to determine Yolo Bypass inflows from inter-dam runoff or PDD releases with applied losses. While the Yolo Bypass Salmonid Project EIS/EIR report indicates that SCWA's low flow gaged data were not incorporated (HDR and cbec, 2017), SCWA data less than 100 cfs were included in the EIS/EIR analyses to correct for Putah Creek inflows within the range of applicability of SCWA's rating curve at LPCI80, in addition to other low flow modifications (Appendix D). The rating curve developed in this study for LPCI80 (Section 5.4.1) allowed for the calculation of a continuous flow timeseries. Further, because a rating curve was also developed for LPCI505 (Section 5.3.1), a comparison of rated flows for LPCI505 and LPCI80 could be conducted to determine the level of gains or losses experienced between the gaging locations to understand if inter-gage runoff on Putah Creek could replace the inter-dam runoff for Putah Creek.

6.4.1 COMPARISON OF I-80 RATED FLOWS AND EIS/EIR-COMPUTED FLOWS

The rating curves described in Section 5.4.1 were used to develop a 15-minute flow timeseries from July 2008 through December 2019. SCWA-observed low flows that corresponded to stages below 7.09 ft were used while stages above this threshold were transformed using the rating curve developed in Section 5.4.1. The daily average observed flows were then compared to the daily flow estimates that were developed using the EIS/EIR methodology.

A series of four comparisons were subsequently conducted with a custom R script using a paired dataset of observed Putah Creek at I-80 flows and Putah Creek inflows into the Yolo Bypass computed using the EIS/EIR methods. Dates with missing flow data from either of these paired sets were removed from the analysis. Observed flows less than or equal to 100 cfs were also excluded because this low flow data was already incorporated into the EIR methodology and skew the goodness of fit. Daily stage data from Lake Berryessa (California Data Exchange Center (CDEC) gage BER) and daily stage data for the Yolo Bypass at Lisbon Weir (WDL gage B91560) were obtained for calendar years 2008 to 2019 and processed to determine dates during which Lake Berryessa was spilling (BER stage >= 440) and dates during which the Yolo Bypass was inundated (Lisbon Weir stage >= 13). Figure 21 to Figure 24 show scatterplots for EIR flow estimates versus observed Putah Creek at I-80 flows (this study) using all data pairs, data pairs excluding Lake Berryessa spill days (i.e., Lake Berryessa stage >= 440 ft), data pairs excluding Yolo Bypass inundation days (i.e., Lisbon Weir stage >= 13 ft), and data pairs excluding both Lake Berryessa spill and

Yolo Bypass inundation days, respectively. The removal of dates experiencing Yolo Bypass inundation could limit backwater effects that would cause over-estimation of flows based solely on stage at I-80. Alternatively, Lake Berryessa spill dates are highly influential because of the large flow rates experienced over the spillway, so exclusion of these periods could allow for more direct comparisons of estimated and observed flows under standard conditions.

The analysis determined that inclusion of all data points yielded the highest NSE value (0.58), while removal of Lake Berryessa spill dates resulted in the lowest NSE value (-1.80). The scenarios for which Yolo Bypass inundation days were removed resulted in intermediate NSE values. When including all other data than the inundation days, the NSE was -0.04, but once Lake Berryessa spill dates were further removed, the NSE decreased to -0.74. The poor fits resulting from removal of either Lake Berryessa spill days or Yolo Bypass inundation days are because there is a high level of covariance between these two conditions and these data transformations remove the high flow pairs that are highly influential in NSE or regression statistics (Figures Figure 21 to Figure 24). For lower and intermediate discharges, there is a high degree of variability between estimated and observed Putah Creek flows, and the EIR methodology tended to over-predict Putah Creek flows (Figures Figure 21 to Figure 24).

6.4.2 ACCUMULATED PUTAH CREEK INFLOW VOLUMES

Accumulated inflow volumes for WYs 2009 (partial) through 2019 (limited between October 1 and May 31) were compared between the LPCI505 observed, LPCI80 observed, and EIS/EIR estimated. As shown by Figure 25, in years when Lake Berryessa did not spill via the glory hole, there is generally good agreement between EIS/EIR estimated with LPCI80 observed within 9% on average. For years when Lake Berryessa is spilling (i.e., WYs 2017 and 2019), the EIS/EIR over-estimated the volume by about 7%. Further, Figure 25 demonstrates that from LPCI505 to LPCI80, there is an 46% decrease in volume in non-spill years and an 4% decrease in spill years, indicating the presence of a losing reach between LPCI505 and LPCI80.

6.4.3 COMPARISON OF RATED FLOWS FOR I-505 AND I-80

Having compared the EIS/EIR flow estimates for Putah Creek to the observed record for LPCI80, a further analysis was conducted to identify a relationship between LPCI80 and LPCI505. Stage data was similarly processed for LPCI505 as it was for LPCI80 (Section 6.4.1) through the application of both low flow and high flow rating curves and conversion to daily averaged flow data. A custom R script was then used to simulate an array of scaling factors and additive shift values for the LPCI505 data to yield the highest NSE statistic with respect to LPCI80 flows in three bins[2] of LPCI505 data: 0 – 100 cfs, 100 – 1,000 cfs, and 1,000 to 10,000 cfs (greater than the highest daily value in the dataset). For each bin, the script would determine both the optimal scaling and additive factors with respect to NSE and subsequently determine which of the scaling or additive factors yielded the highest NSE. It would then transform the LPCI505 data by applying the optimal factor for each bin and then determine an overall NSE value for the entire dataset. Ultimately, multiplicative scaling factors of 0.48, 0.93, and 0.96 were applied to the bins (Table 11),

[2] Bins were inclusive of the upper limit of their range and non-inclusive of the lower bound.

indicating the presence of a losing reach between LPCI505 and LPCI80, consistent with Section 6.4.2 and the Management Strategy assumptions.

Table 11. Binned analysis of NSE for additive and multiplicative factors for transforming LPCI505 data

LPCI505 flow	Additive Method		Multiplicative Method		Best Fit Method
	Factor	NSE	Factor	NSE	
0 – 100	-30	0.259	0.48	0.341	Mult: 0.48
100 – 1,000	-25	0.723	0.93	0.726	Mult: 0.93
1,000 – 10,000	-100	0.971	0.96	0.972	Mult: 0.96

After applying the best-fit transformations (Table 11) to LPCI505 data (i.e., both additive and multiplicative), the overall NSE with respect to LPCI80 flow data was 0.985.

6.4.4 CONCLUSIONS

The results of the daily flow comparison between EIS/EIR-computed flows and the observed flows for Putah Creek at I-80 (Section 6.4.1) indicate that the EIS/EIR methodology over-predicted daily inflows to the Yolo Bypass, minimally so for flows less than 2,000 cfs and more so for higher flows indicative of Lake Berryessa spilling via the glory hole. There could be several reasons for this, one of which concerns the EIS/EIR method used to relate outflows from Lake Berryessa to flows at the downstream end of Putah Creek. A two-day shift was applied for the EIS/EIR calculations per the Management Strategy, such that the flow contribution of Lake Berryessa to the downstream end of the creek during any given day was calculated as the Lake Berryessa outflow two days prior. Regressions and NSE analyses can be sensitive to data shifts, which could misalign data and cause poor correlation between readings. It is possible the simplified 2-day lag between Monticello Dam and the downstream end of Putah Creek could be causing some discrepancies on a daily basis. However, the EIS/EIR methodology reasonably predicts the volumetric inflow to the Yolo Bypass (Section 6.4.2), especially when Monticello Dam (i.e., Lake Berryessa) is not spilling, which would suggest the potential impact to the relative (i.e., existing versus alternative) inundation results is minimal. When Monticello Dam is spilling, even though the EIS/EIR over-estimates the volumetric inflow, the Yolo Bypass is experiencing deep system-wide flooding such that the relative effect is negligible because the alternatives largely influence non-spill periods.

Further, the results of the analysis between LPCI505 and LPCI80 flows (Section 6.4.2 and Section 6.4.3) concluded that a losing reach exists between the two gage locations. The Management Strategy equations (Jones & Stokes, 2001) used a loss rate of 30 cfs between the Putah Diversion Dam and the downstream end of the creek, which was modified for the EIS/EIR according to Appendix D. The loss rate used by the Management Strategy is validated by flow rates of 30 and 25 cfs being the optimal additive factors for LPCI505 flows of less than 100 cfs and between 100 and 1,000 cfs, respectively (Table 11). However, the analysis in Section 6.4.3 also found that multiplicative scaling factors yielded a better fit to observed data than additive ones. This underestimation of losses could be another factor in why the EIR methodology tended to overpredict Yolo Bypass inflows from Putah Creek on a daily basis (Section 6.4.1). Further, because the Putah Creek reach between LPCI505 and LPCI80 was confirmed as a losing reach, it could not be used as a replacement for the inter-dam runoff used for scaling the WSB inflows.

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8 LIST OF PREPARERS

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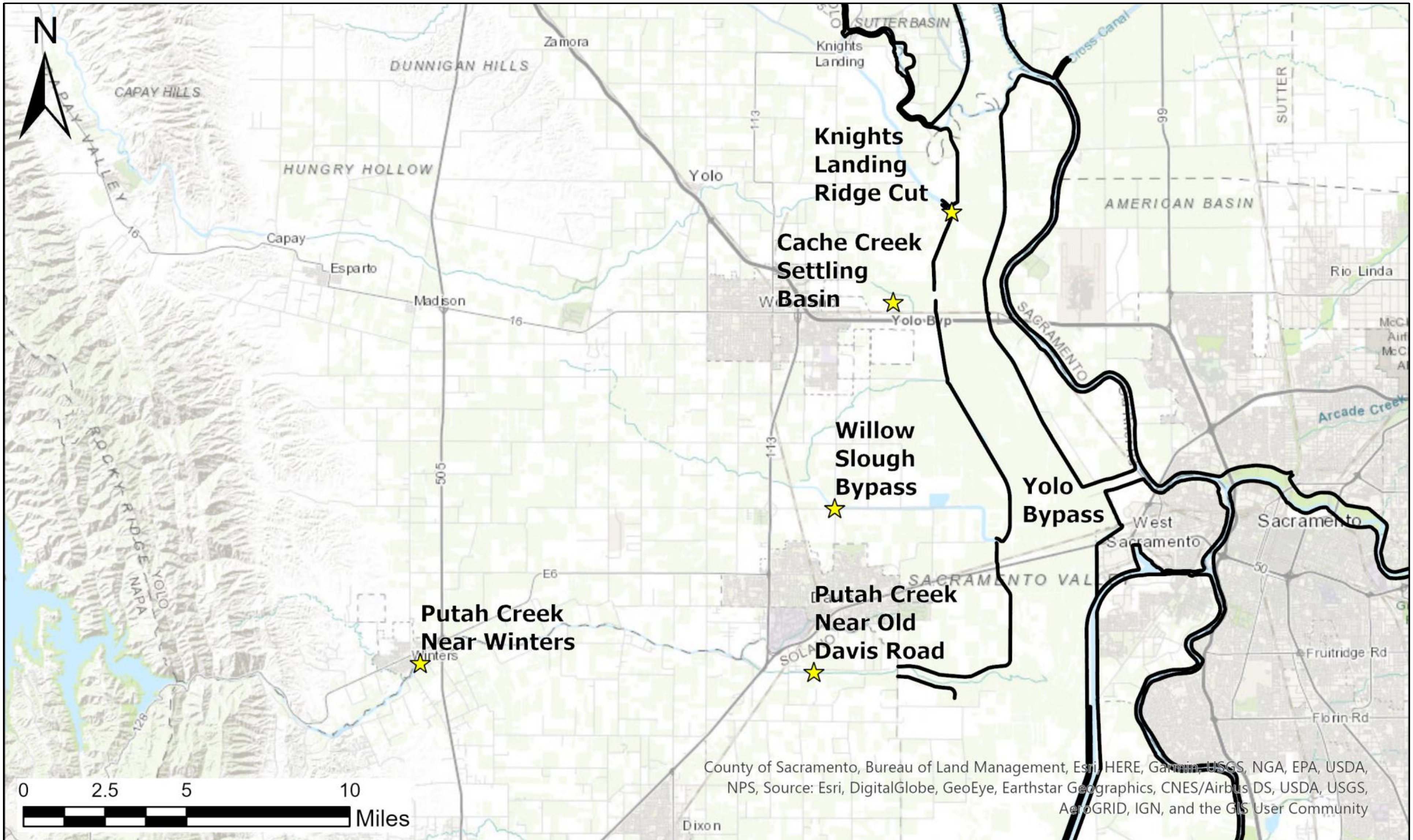

Notes: yellow stars show westside tributary monitoring and flow analysis locations relative to the Yolo Bypass

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Yolo Bypass Westside Tributaries Flow Monitoring Project

Site Location Map

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Figure 1

Notes: cbec referenced California Department of Water Resources monitoring station Ridge Cut Slough at Knights Landing when analyzing the inflow at Wallace Weir

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Yolo Bypass Westside Tributaries Flow Monitoring Project

Knights Landing Ridge Cut Monitoring Site Map

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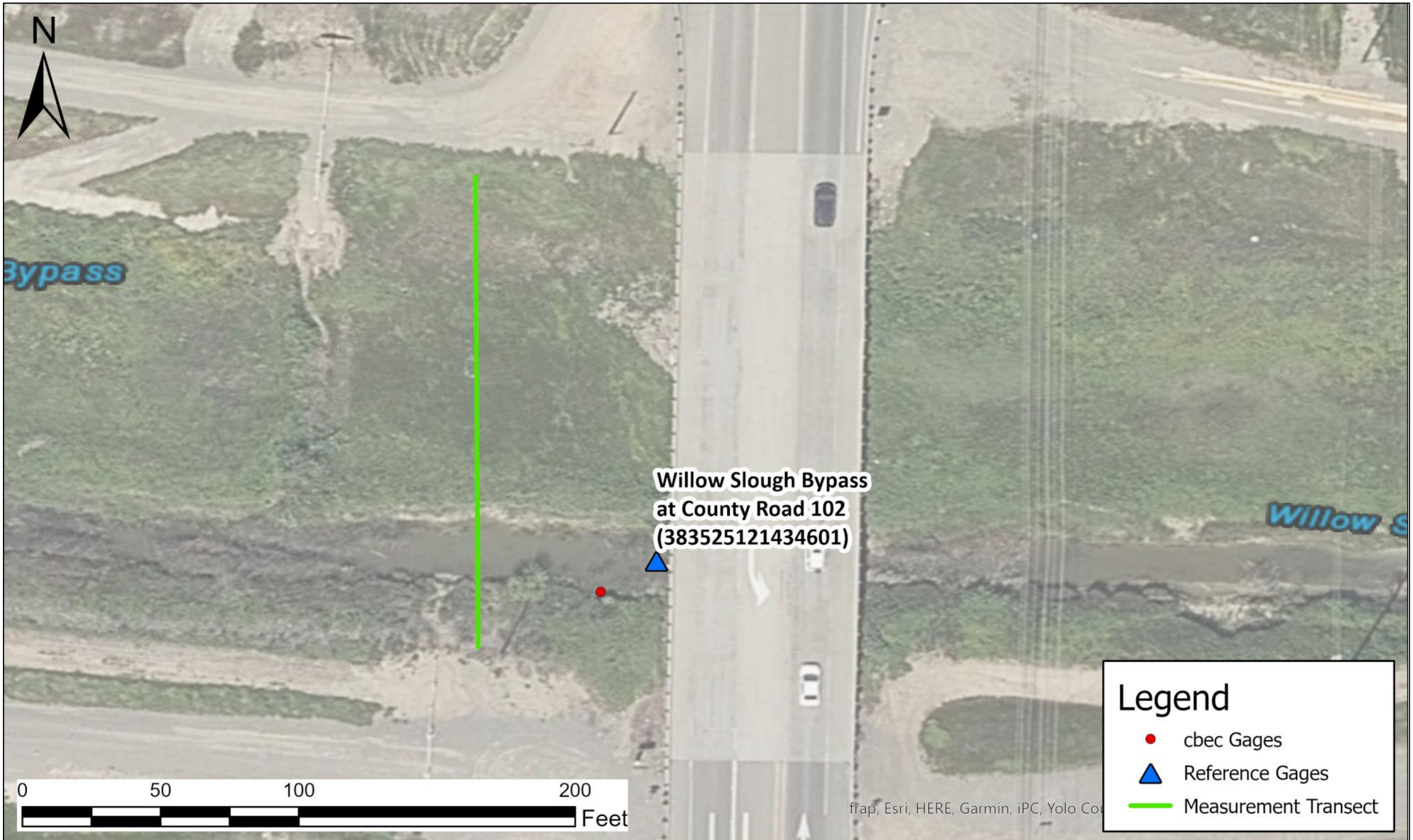
Figure 2

2/28/2020

Notes: cbec referenced USGS gages Cache Creek at Yolo CA, Cache Creek Total Flow from Settling Basin Near Woodland CA, and Yolo Bypass Near Woodland CA when analyzing the inflow to the Yolo Bypass.	cbec eco engineering	*Yolo Bypass Westside Tributaries Flow Monitoring Project* **Cache Creek Settling Basin Monitoring Site Map**	
		ERP Grant Agreement No. P1696008	**Figure 3**



Notes: cbec referenced Yolo County Flood Control and Water Conservation District monitoring station Willow Slough Bypass at County Road 102 in developing the flow rating curve at this location.

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Yolo Bypass Westside Tributaries Flow Monitoring Project

Willow Slough Bypass Monitoring Site Map

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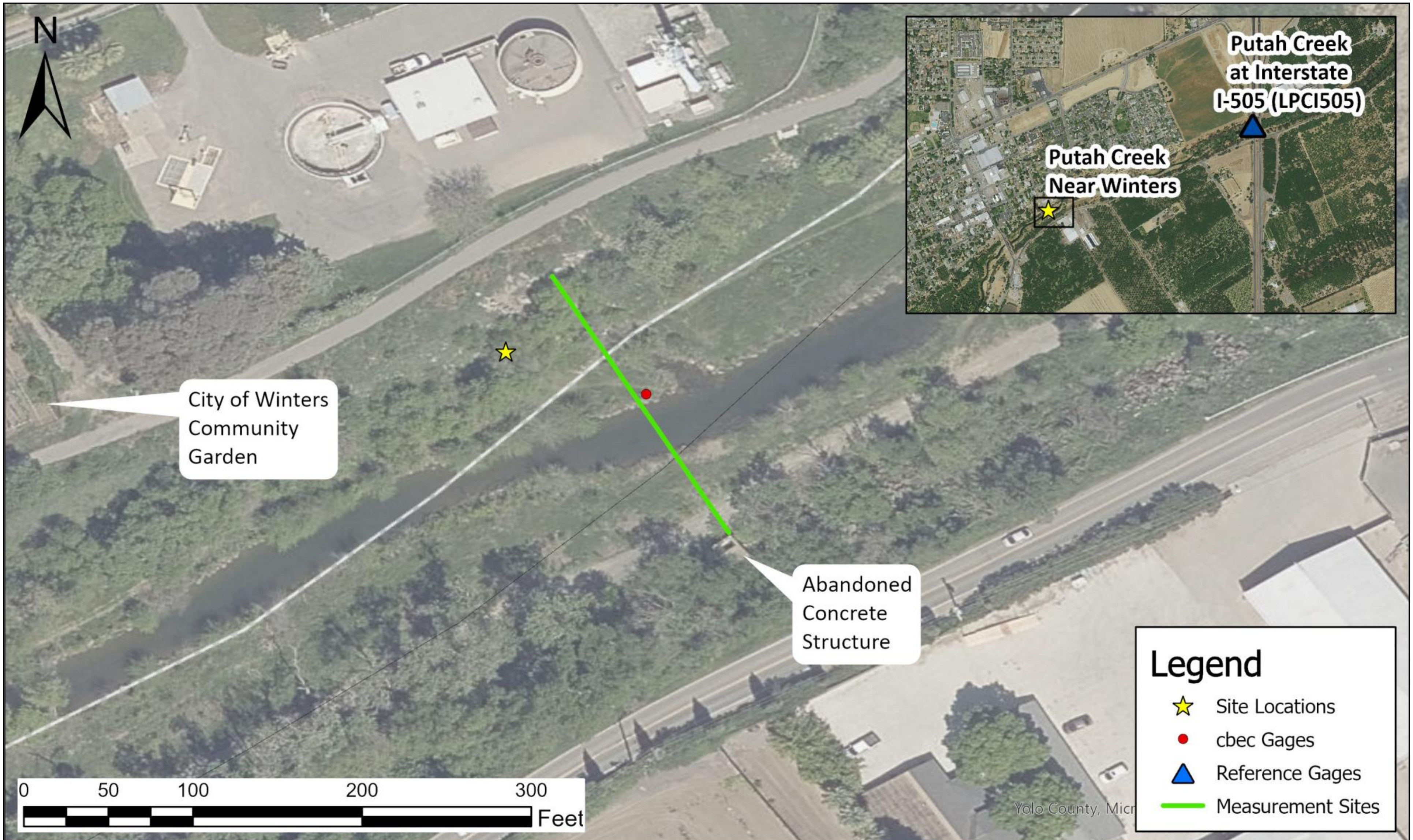
Figure 4



Notes: cbec referenced Solano County Water Agency stage gage Putah Creek at Interstate 505 when developing the flow rating at Interstate 505.

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Yolo Bypass Westside Tributaries Flow Monitoring Project

Putah Creek Near Winters Monitoring Site Map

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Figure 5

Notes: cbec referenced Solano County Water Agency stage gage Putah Creek at Interstate 80 when developing the flow rating at Interstate 80.

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Yolo Bypass Westside Tributaries Flow Monitoring Project

Putah Creek Near Old Davis Road Monitoring Site Map

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Figure 6

Notes: flow measurement at Wallace Weir showing typical Acoustic Doppler Current Profiler in a tethered trimaran.

Yolo Bypass Westside Tributaries Flow Monitoring Project

Tethered Boat Discharge Measurement

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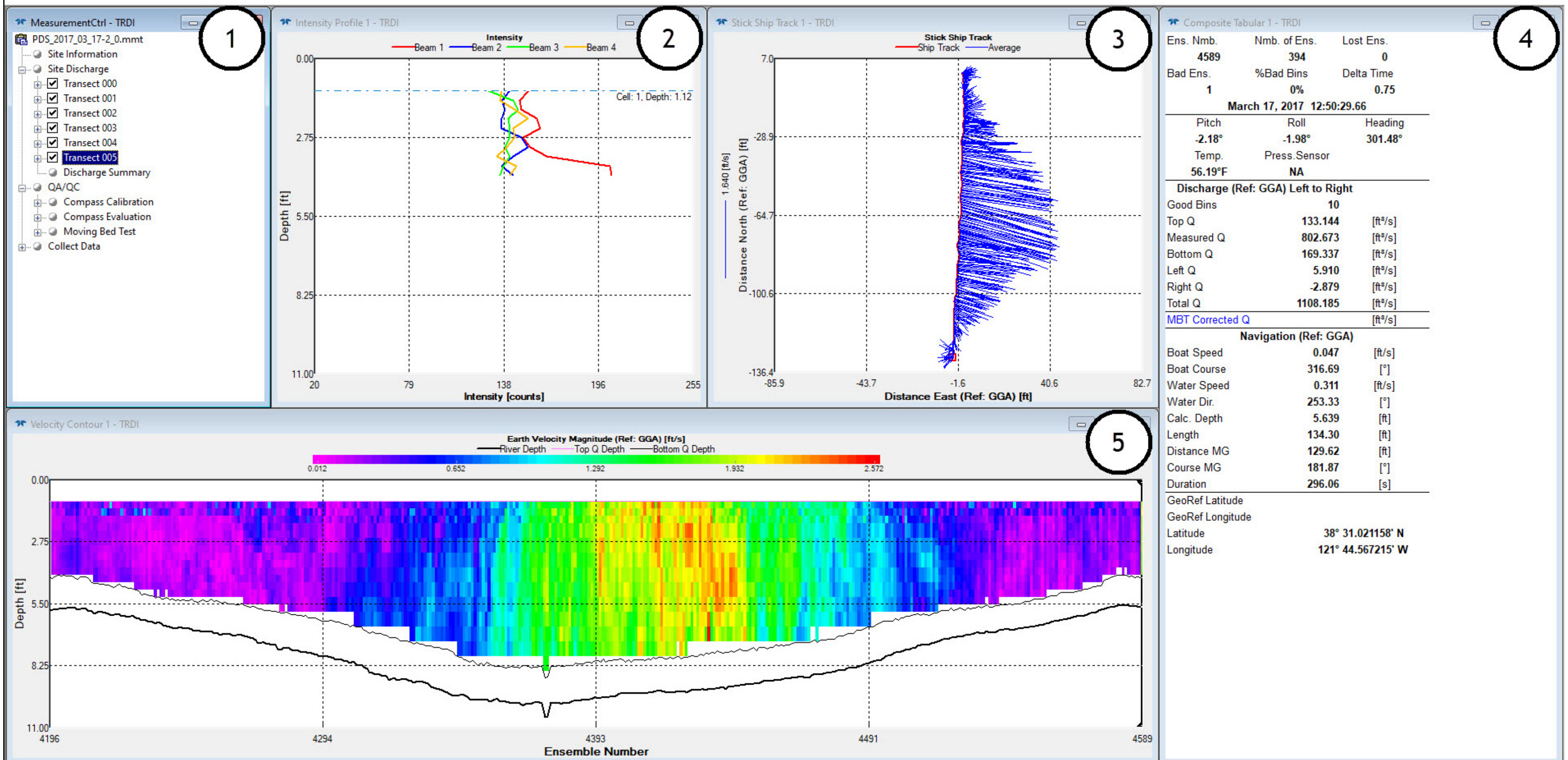
Figure 7



Notes: Winriver II output showing Acoustic Doppler Current Profiler (1) transect number, (2) beam intensity, (3) flow direction, (4) flow summary, and (5) velocity distribution.

Yolo Bypass Westside Tributaries Flow Monitoring Project

Typical Winriver II Graphical Output

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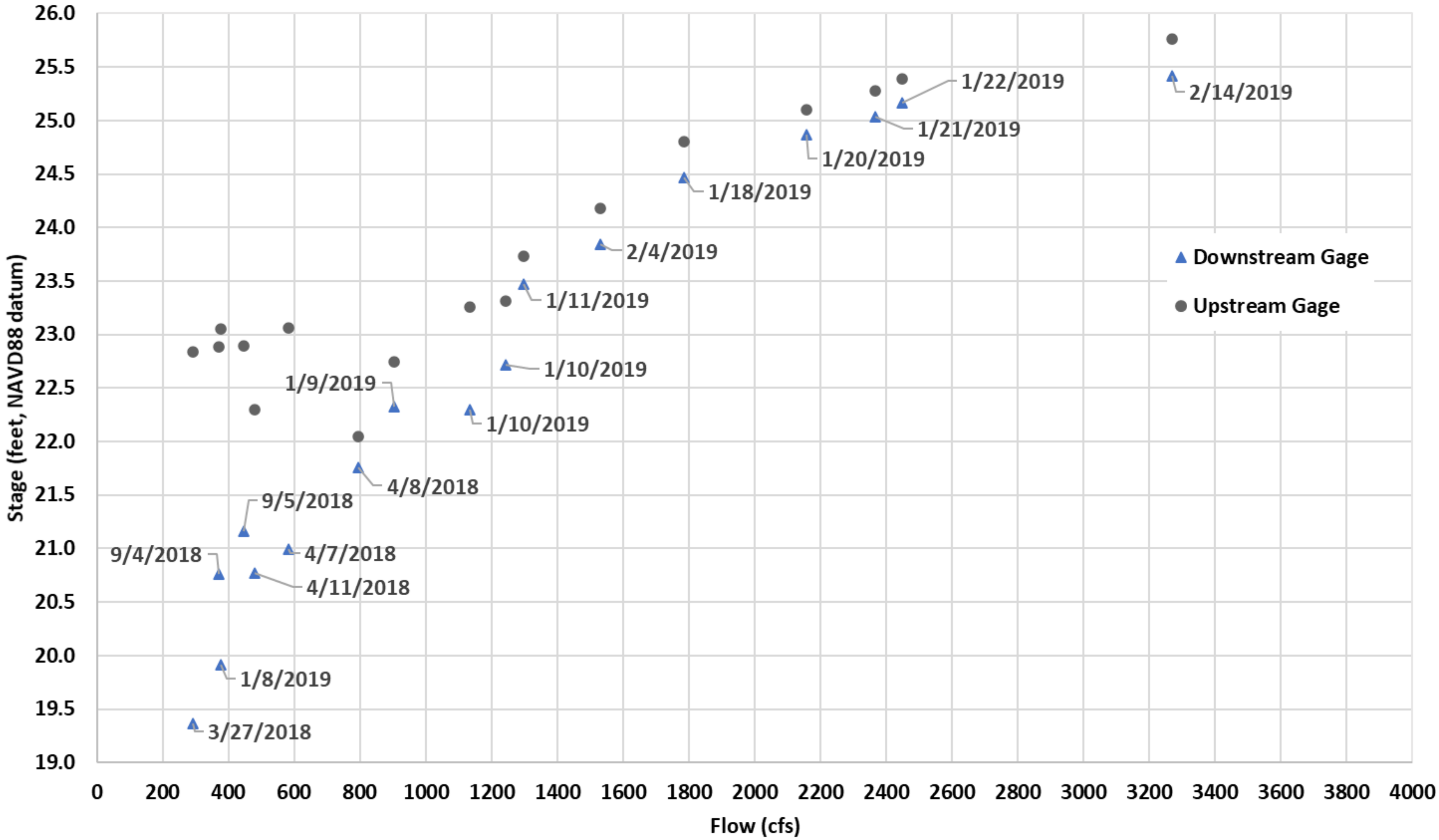
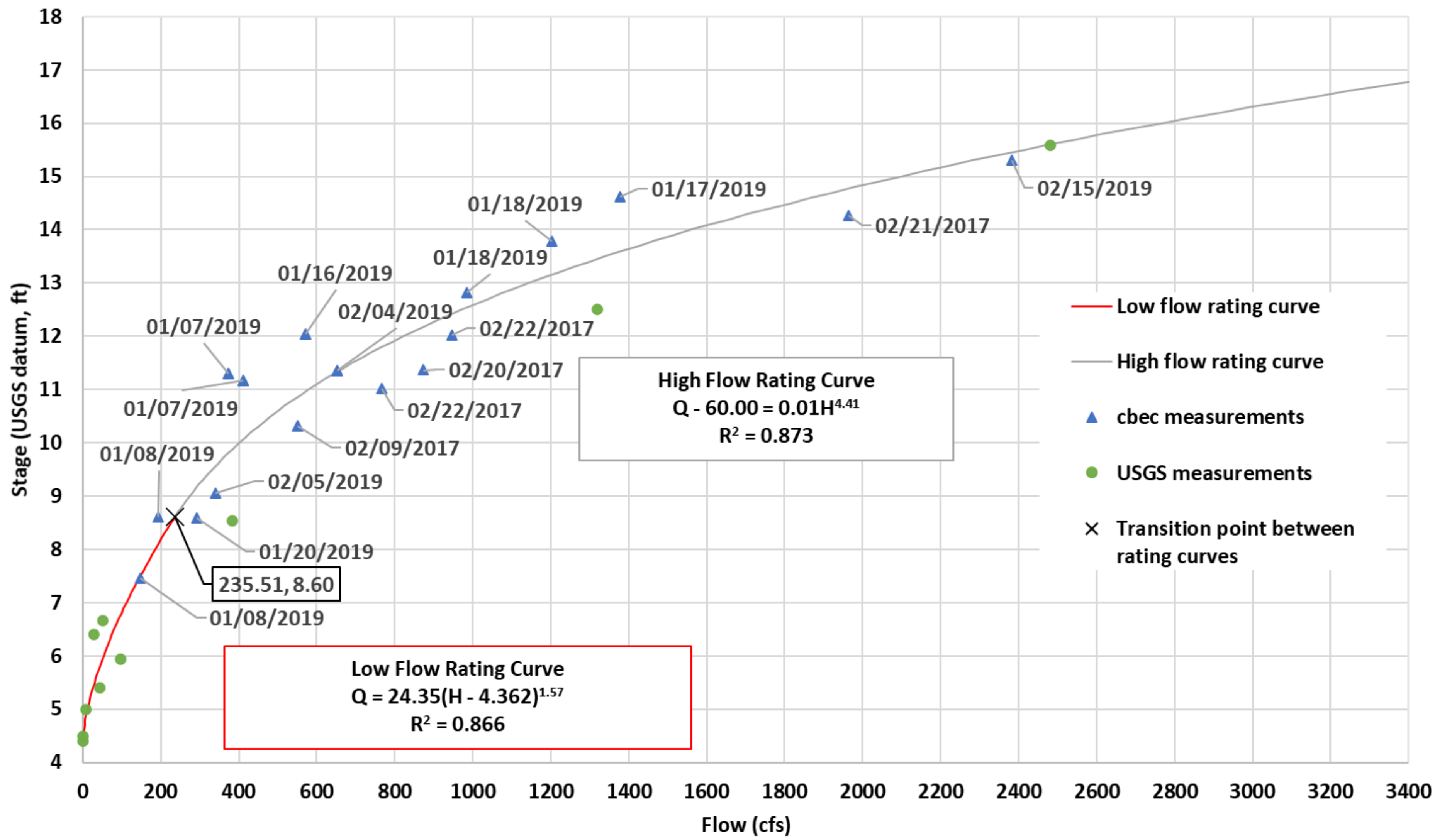
Figure 8



Notes: Stage and Flow correlation between measured flow and cbec redundant water level gages near Wallace Weir	cbec eco engineering	*Yolo Bypass Westside Tributaries Flow Monitoring Project* **Knights Landing Ridge Cut Measurements**
		ERP Grant Agreement No. P1696008 — **Figure 9**

2/28/2020



Notes: the low flow curve is based on USGS published data. The high flow rating curve is based on this study using measured flows and Yolo County Flood Control and Water Conservation District published stage.

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Yolo Bypass Westside Tributaries Flow Monitoring Project

Willow Slough Bypass Rating Curve

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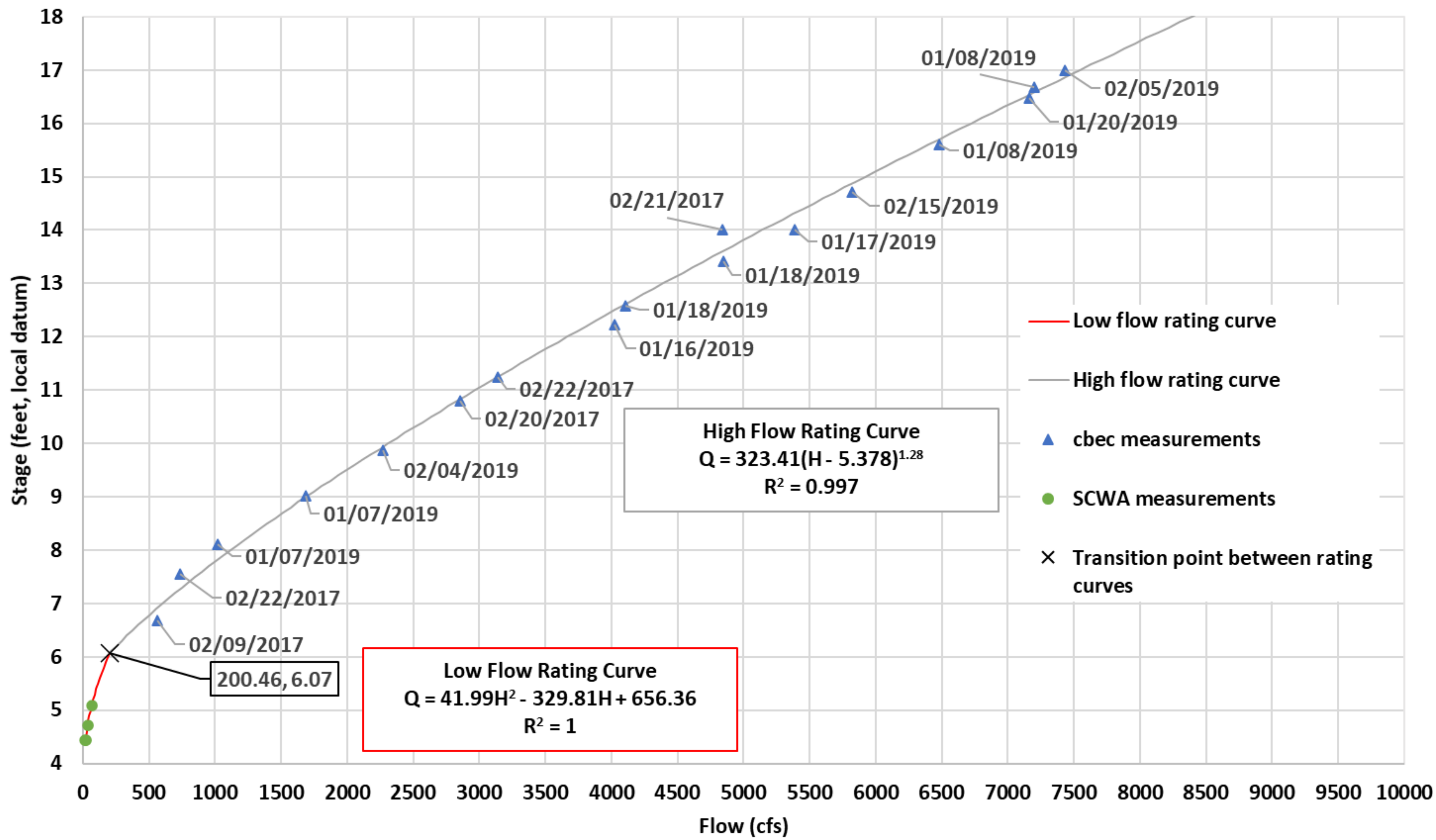
Figure 10

2/28/2020



Notes: the low flow curve is based on Solano County Water Agency (SCWA) published rating curve. The high flow rating curve is based on this study using measured flows and SCWA published stage.

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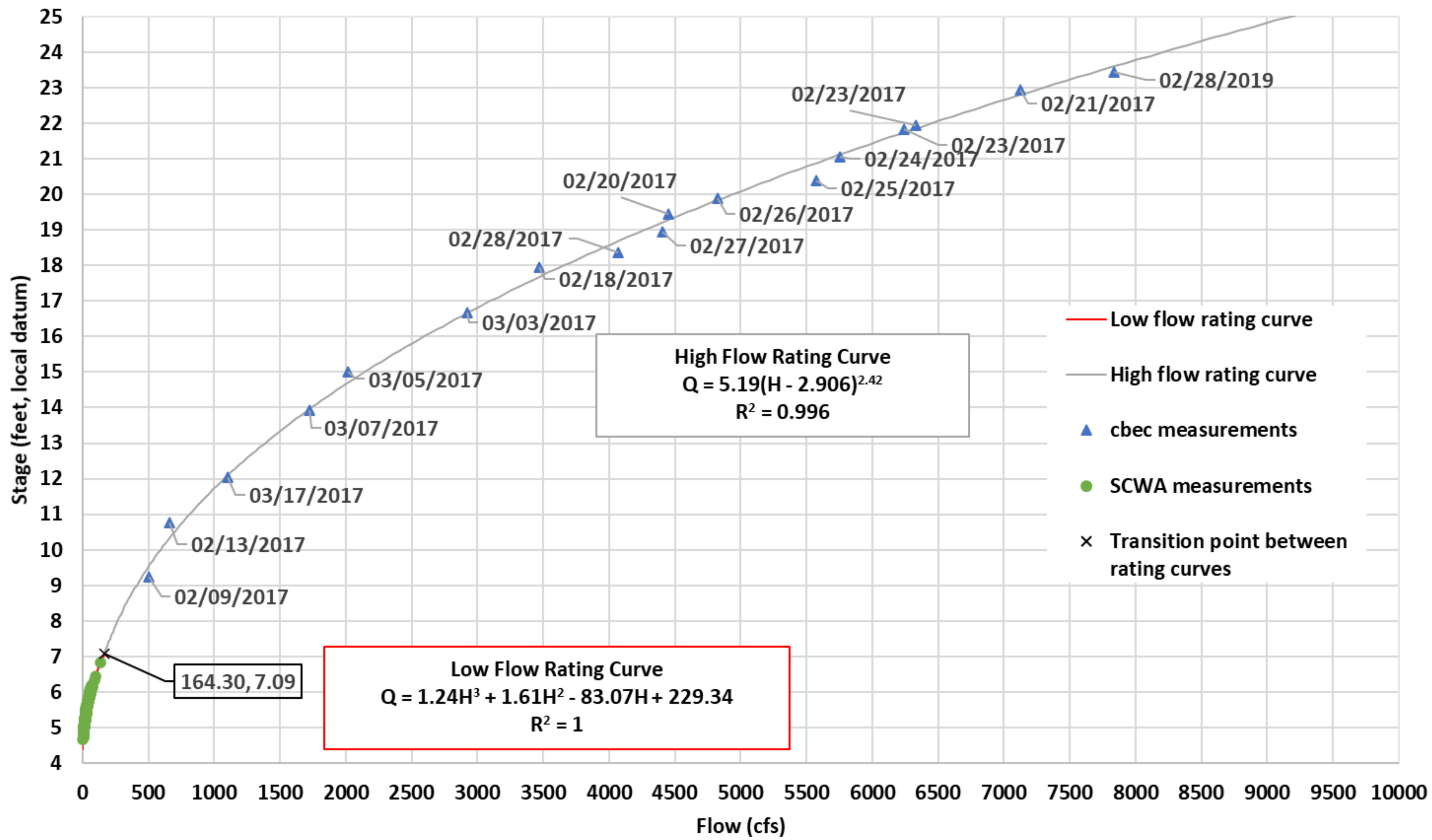
Yolo Bypass Westside Tributaries Flow Monitoring Project

Putah Creek Near Winters Rating Curve

ERP Grant Agreement No. P1696008

Figure 11

2/28/2020



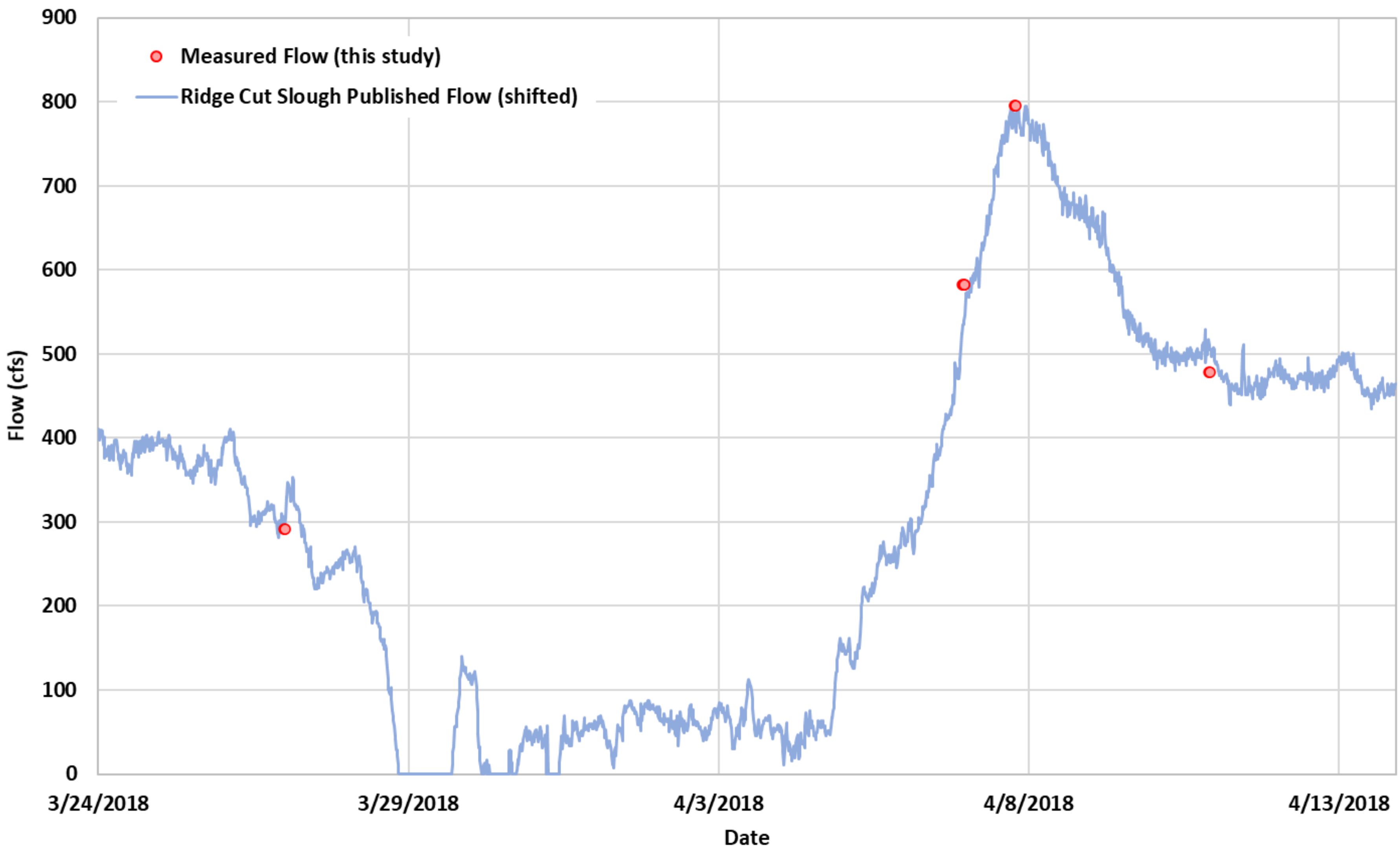
Notes: the low flow curve is based on Solano County Water Agency (SCWA) published rating curve. The high flow rating curve is based on this study using measured flows and SCWA published stage.

Yolo Bypass Westside Tributaries Flow Monitoring Project

Putah Creek Near Old Davis Road Rating Curve

ERP Grant Agreement No. P1696008

Figure 12



Notes: measured flows at Wallace Weir (this study) was compared to published flow at Ridge Cut Slough. A shift of 7 hours was applied to the Ridge Cut Slough data to produce the best fit.

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Yolo Bypass Westside Tributaries Flow Monitoring Project

Knights Landing Ridge Cut Flow: March / April 2018

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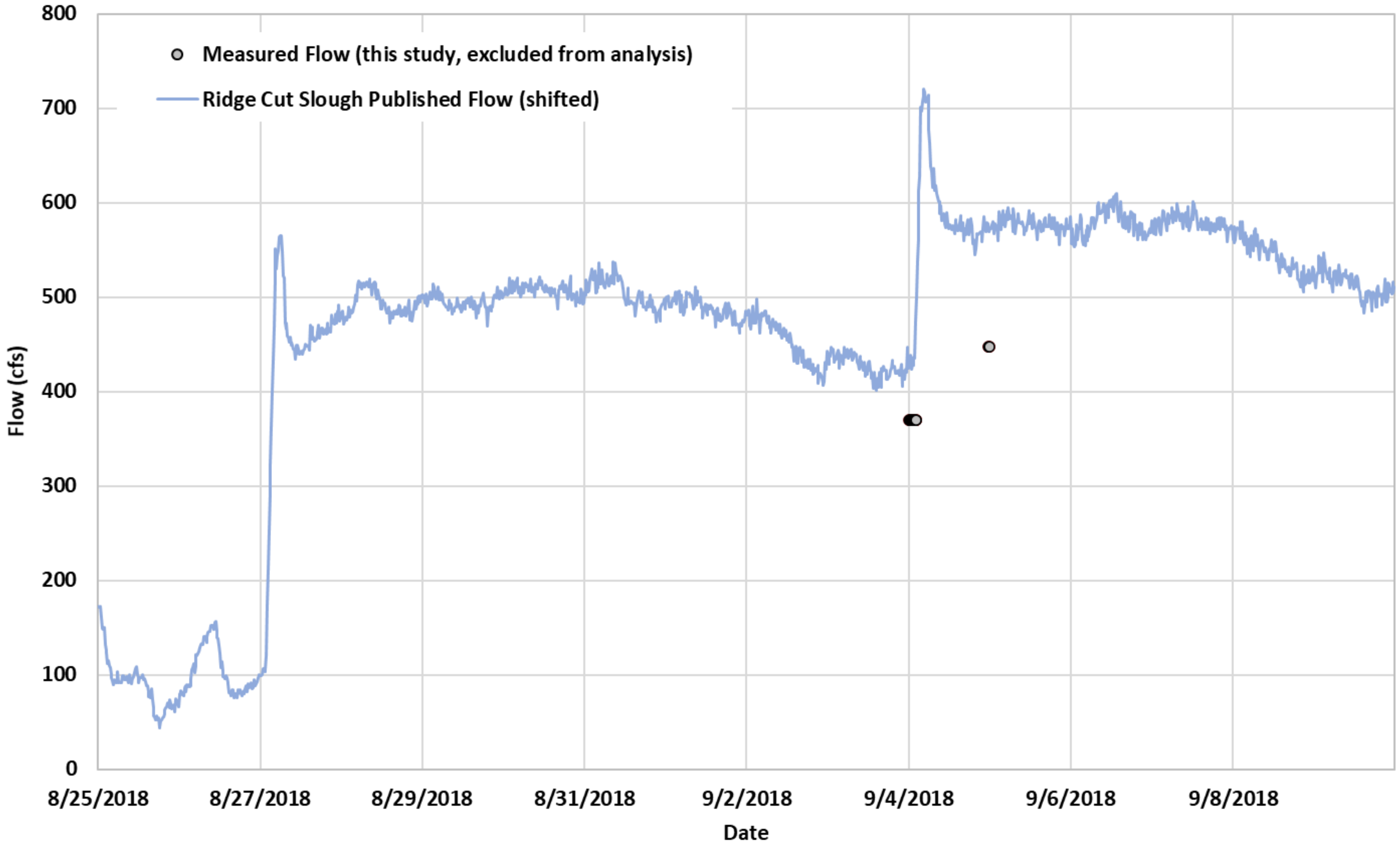
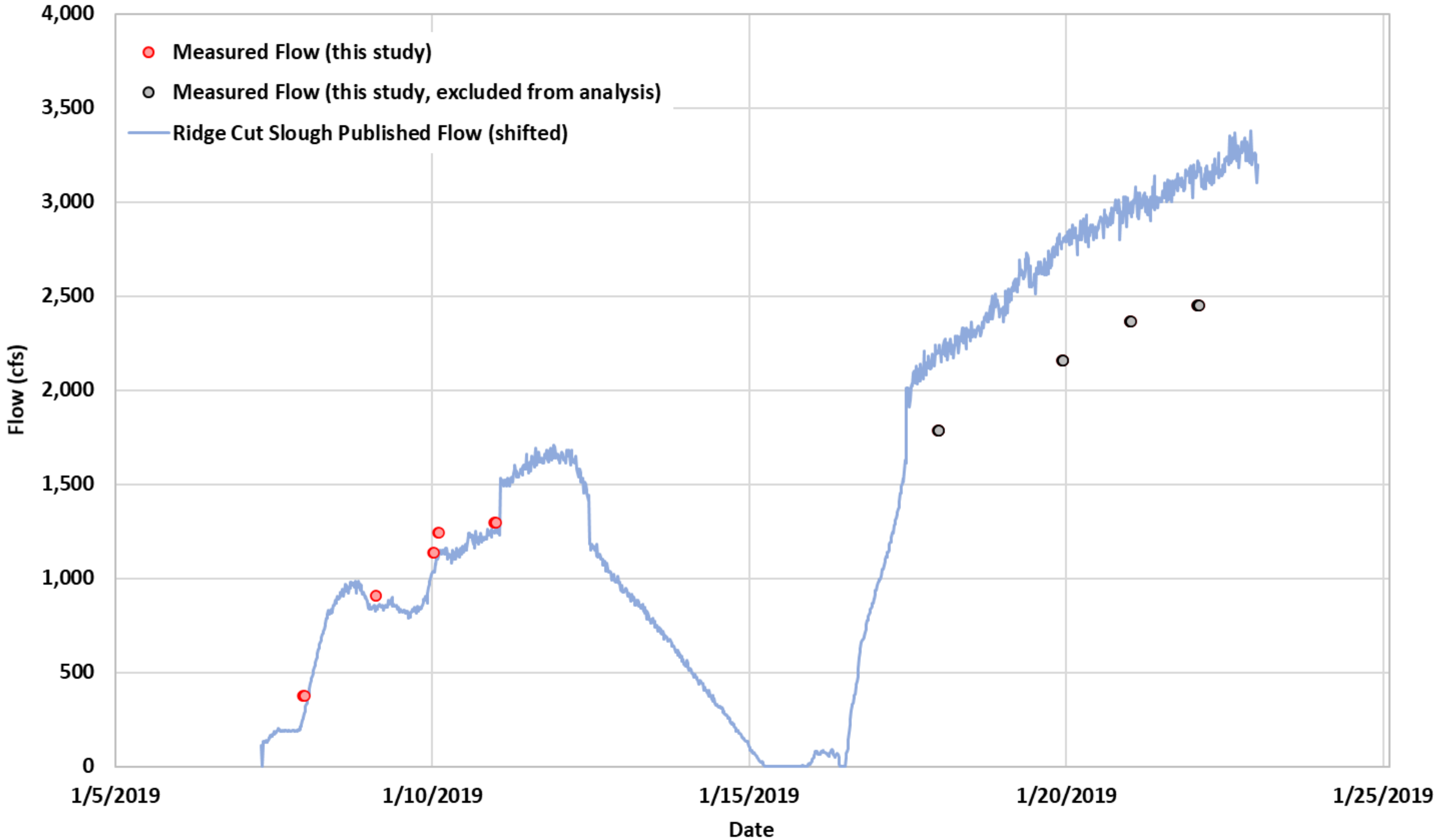
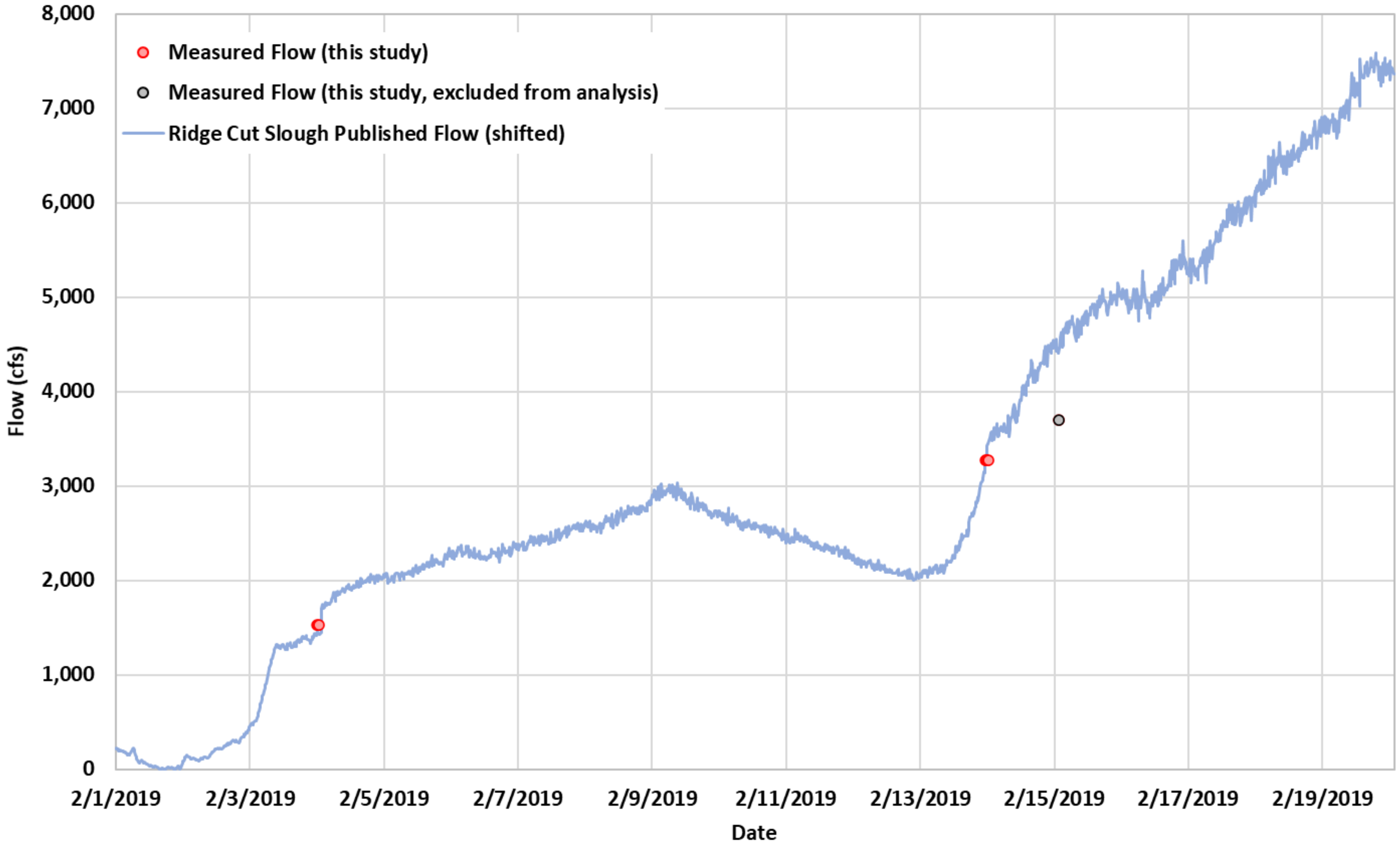
Figure 13



Notes: measured flows at Wallace Weir (this study) was compared to published flow at Ridge Cut Slough. A shift of 7 hours was applied to the Ridge Cut Slough data to produce the best fit.	cbec eco engineering	*Yolo Bypass Westside Tributaries Flow Monitoring Project* **Knights Landing Ridge Cut Flow: September 2018**
		ERP Grant Agreement No. P1696008 — **Figure 14**



Notes: measured flows at Wallace Weir (this study) was compared to published flow at Ridge Cut Slough. A shift of 7 hours was applied to the Ridge Cut Slough data to produce the best fit.	cbec eco engineering	*Yolo Bypass Westside Tributaries Flow Monitoring Project* **Knights Landing Ridge Cut Flow: January 2019**	
		ERP Grant Agreement No. P1696008	**Figure 15**



Notes: measured flows at Wallace Weir (this study) was compared to published flow at Ridge Cut Slough. A shift of 7 hours was applied to the Ridge Cut Slough data to produce the best fit.

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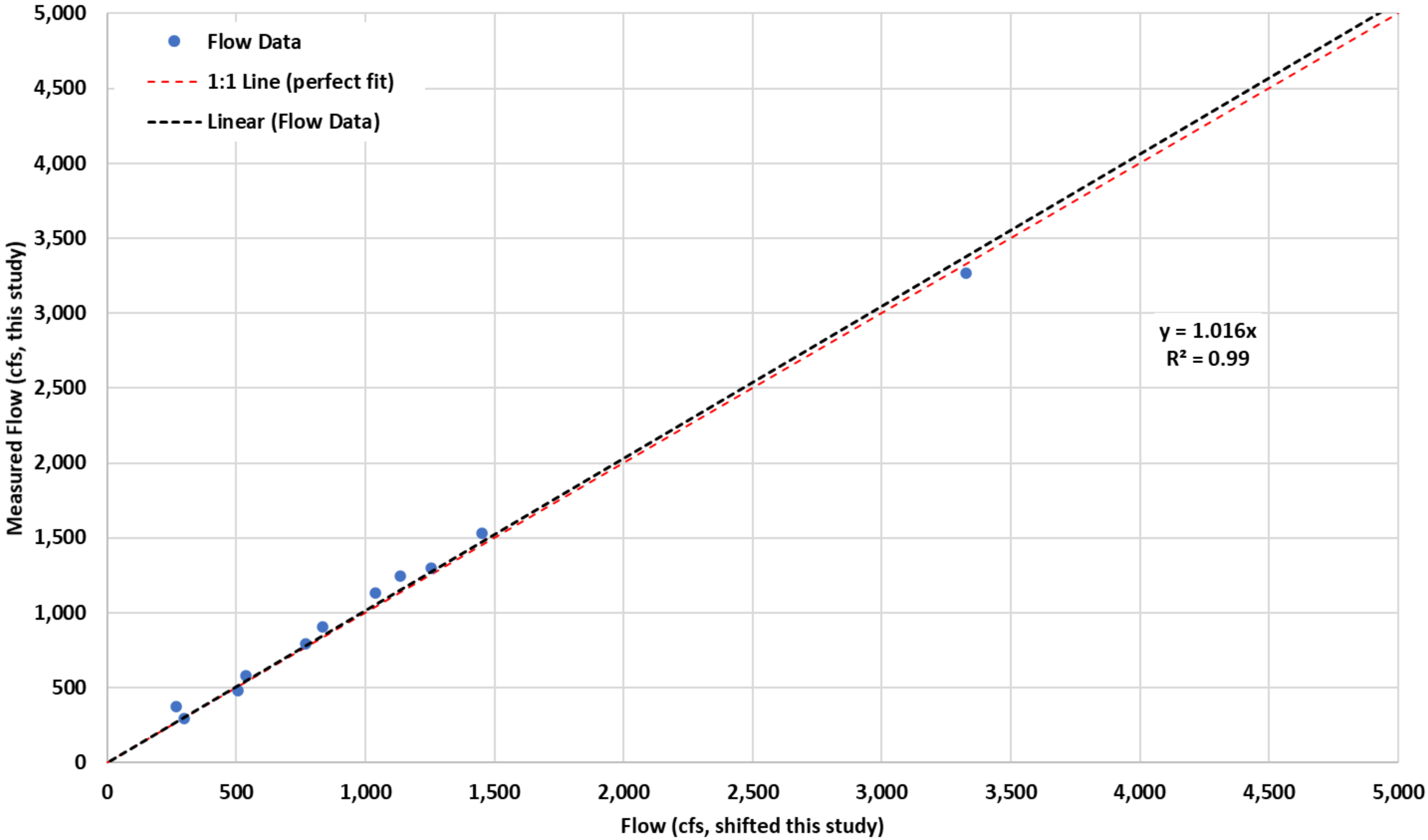
Yolo Bypass Westside Tributaries Flow Monitoring Project

Knights Landing Ridge Cut Flow: February 2019

ERP Grant Agreement No. P1696008 | **Figure 16**



Notes: measured flow at Wallace Weir was compared to published flow at Ridge Cut Slough. A shift of 7 hours was applied to the Ridge Cut Slough data to produce the best fit with an R^2 close to 1.

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Yolo Bypass Westside Tributaries Flow Monitoring Project

Knights Landing Ridge Cut Flow Regression

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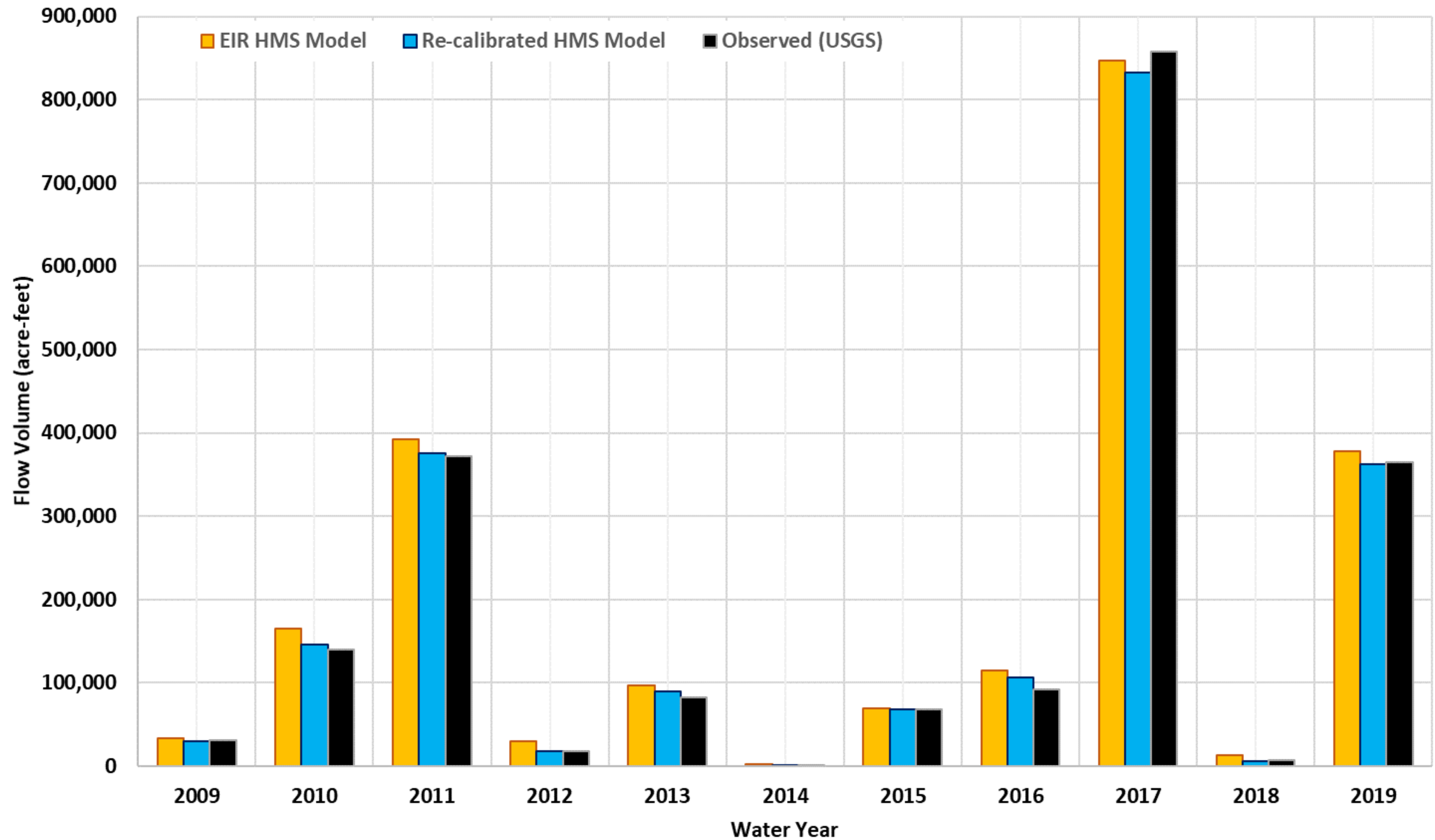
Figure 17



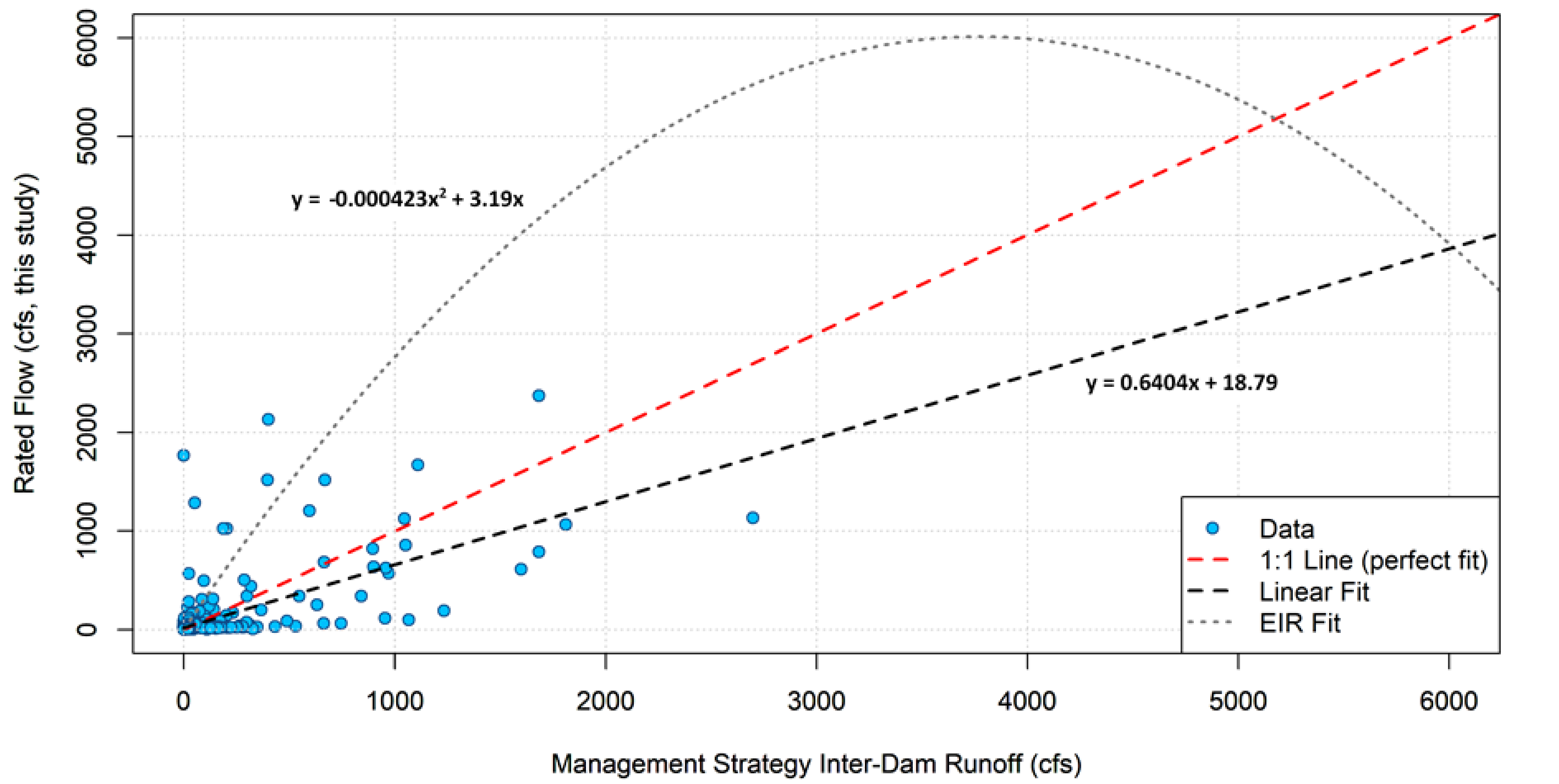
Notes: flow exiting the Cache Creek Settling Basin was compared between original EIR model predictions, re-calibrated EIR model predictions (this study), and USGS measured flows.

Yolo Bypass Westside Tributaries Flow Monitoring Project

Cache Creek Settling Basin Accumulated Outflow

ERP Grant Agreement No. P1696008

Figure 18



Notes: a comparison of Willow Slough Bypass flows at County Road 102 between rated flows (this study) and inter-dam runoff (i.e., between Lake Berryessa and Lake Solano) demonstrating that the Management Strategy approach overpredicts inflows to the Yolo Bypass.

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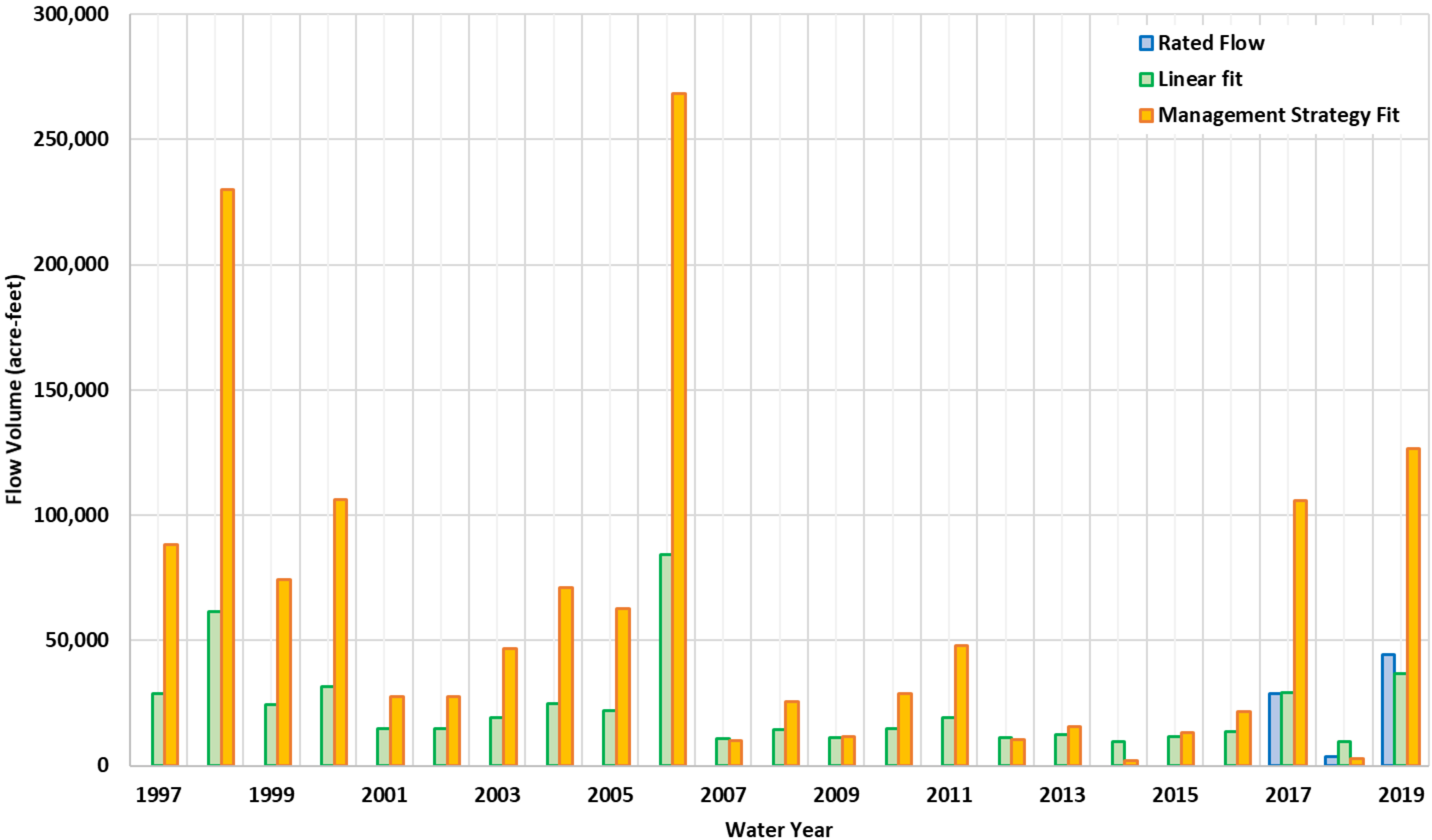
Yolo Bypass Westside Tributaries Flow Monitoring Project

Willow Slough Bypass Inflows to the Yolo Bypass

ERP Grant Agreement No. P1696008

Figure 19



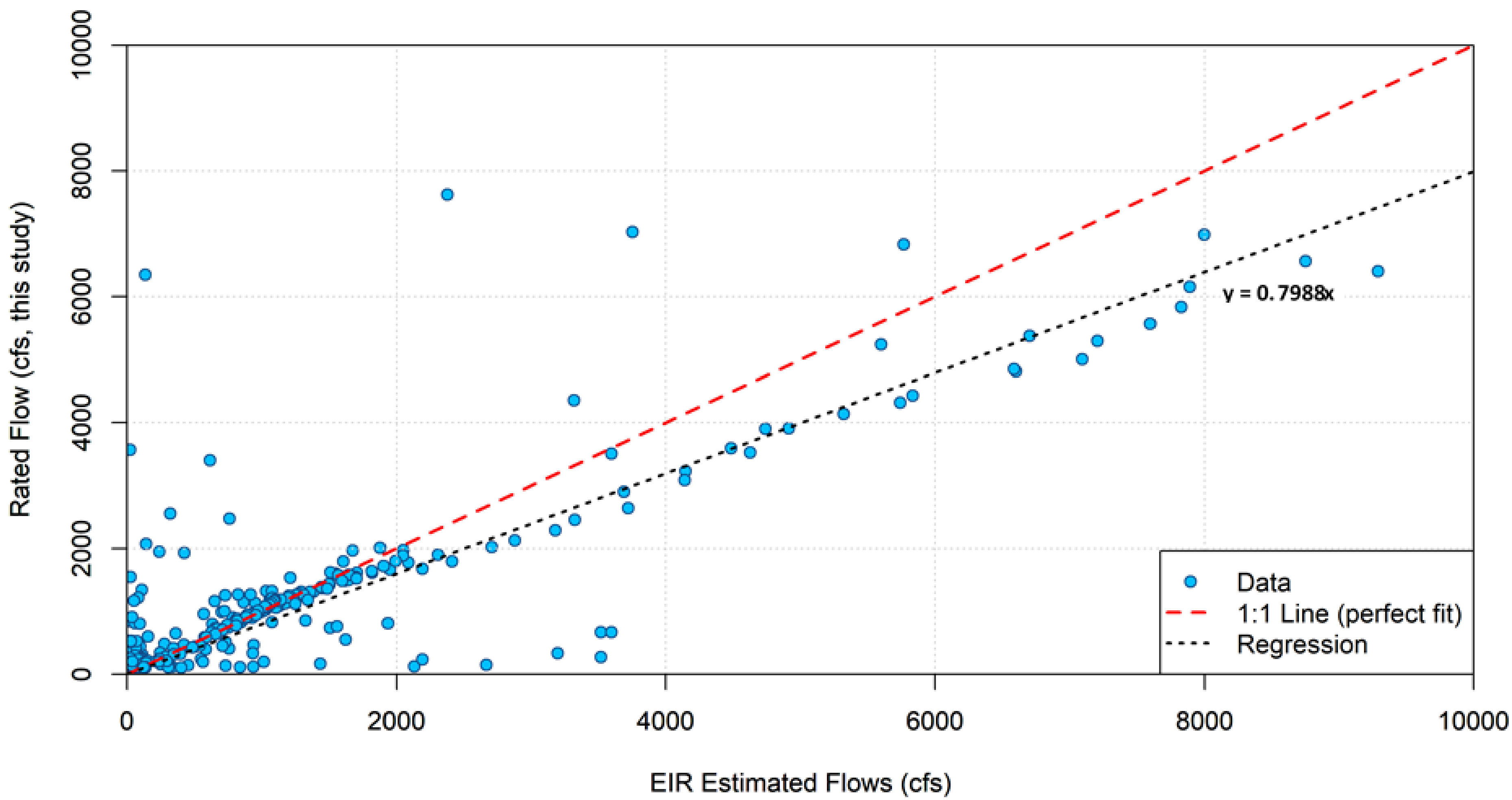
Notes: a comparison of Willow Slough Bypass inflows to the Yolo Bypass between rated flows (this study), linear fit (this study), and Management Strategy Fit demonstrating that the Management Strategy approach overpredicts inflows to the Yolo Bypass.

Yolo Bypass Westside Tributaries Flow Monitoring Project

Willow Slough Bypass Accumulated Outflow

ERP Grant Agreement No. P1696008

Figure 20



Notes: a comparison of Putah Creek flows at Interstate 80 between rated flows (this study) and EIR estimated flows using all data.

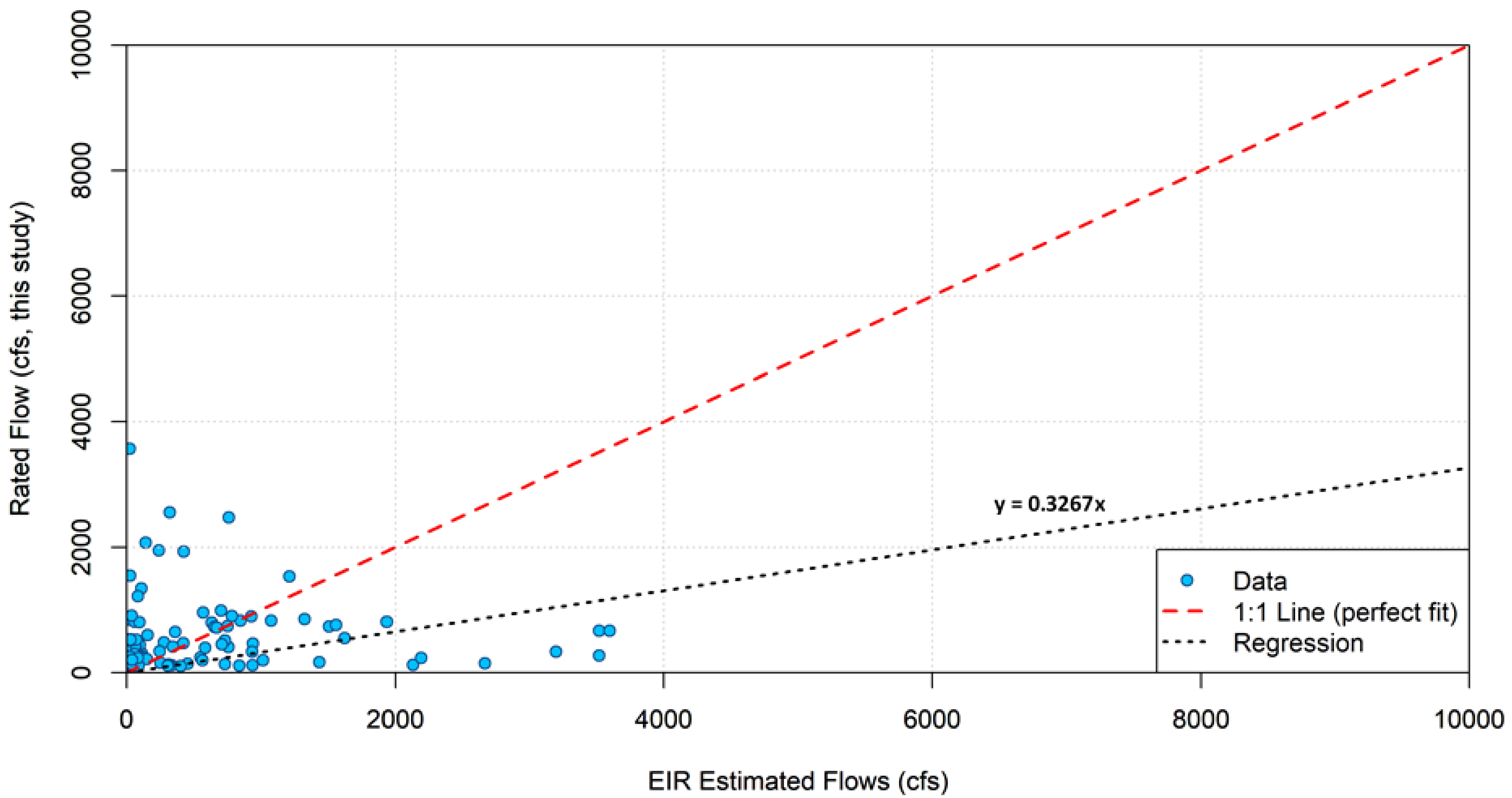
cbec eco engineering

Yolo Bypass Westside Tributaries Flow Monitoring Project

Putah Creek Inflows to the Yolo Bypass: All Data

ERP Grant Agreement No. P1696008

Figure 21



Notes: a comparison of Putah Creek flows at Interstate 80 between rated flows (this study) and EIR estimated flows using data except when Lake Berryessa was spilling via the glory hole.

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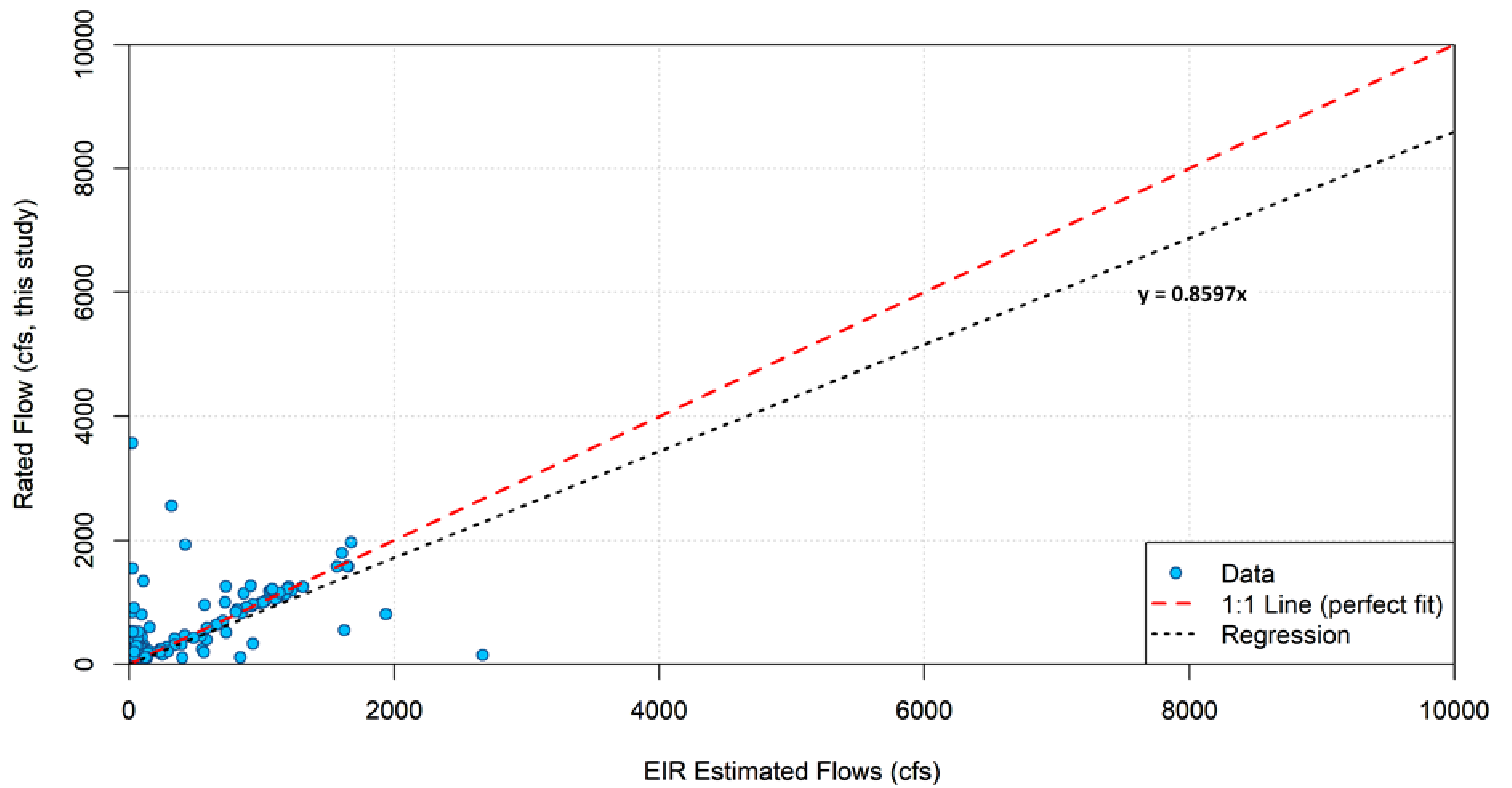
Yolo Bypass Westside Tributaries Flow Monitoring Project

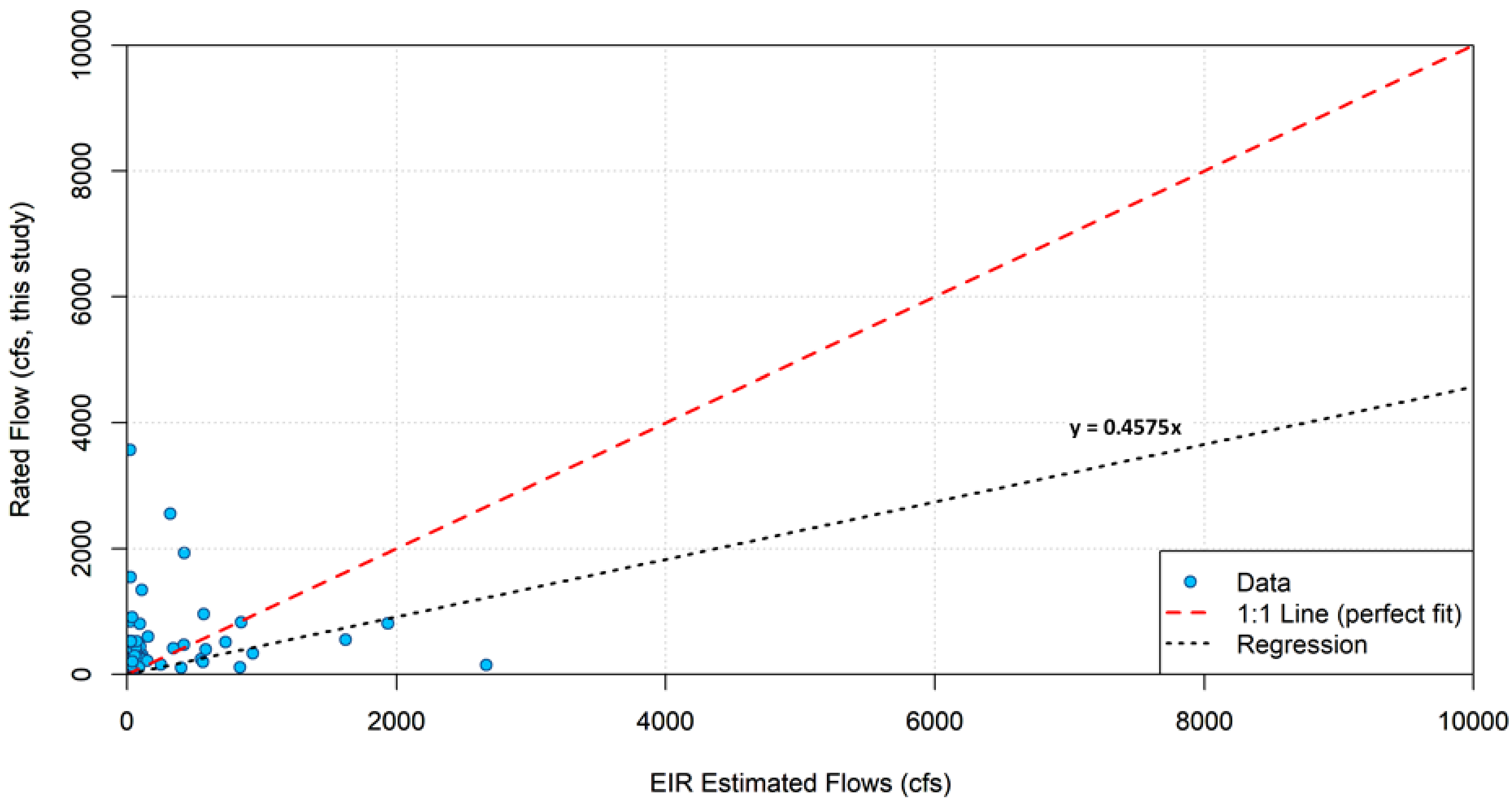
Putah Creek Inflows to the Yolo Bypass: No Lake Berryessa Spills

ERP Grant Agreement No. P1696008

Figure 22



Notes: a comparison of Putah Creek flows at Interstate 80 between rated flows (this study) and EIR estimated flows using data except when Lisbon Weir exceeded its monitoring stage indicating Yolo Bypass in flood.	cbec eco engineering	*Yolo Bypass Westside Tributaries Flow Monitoring Project* **Putah Creek Inflows to the Yolo Bypass: No Backwater** **ERP Grant Agreement No. P1696008** — **Figure 23**



Notes: a comparison of Putah Creek flows at Interstate 80 between rated flows (this study) and EIR estimated flows using data except when Lake Berryessa was spilling via the glory hole or when Lisbon Weir exceeded its monitoring stage indicating Yolo Bypass was in flood.

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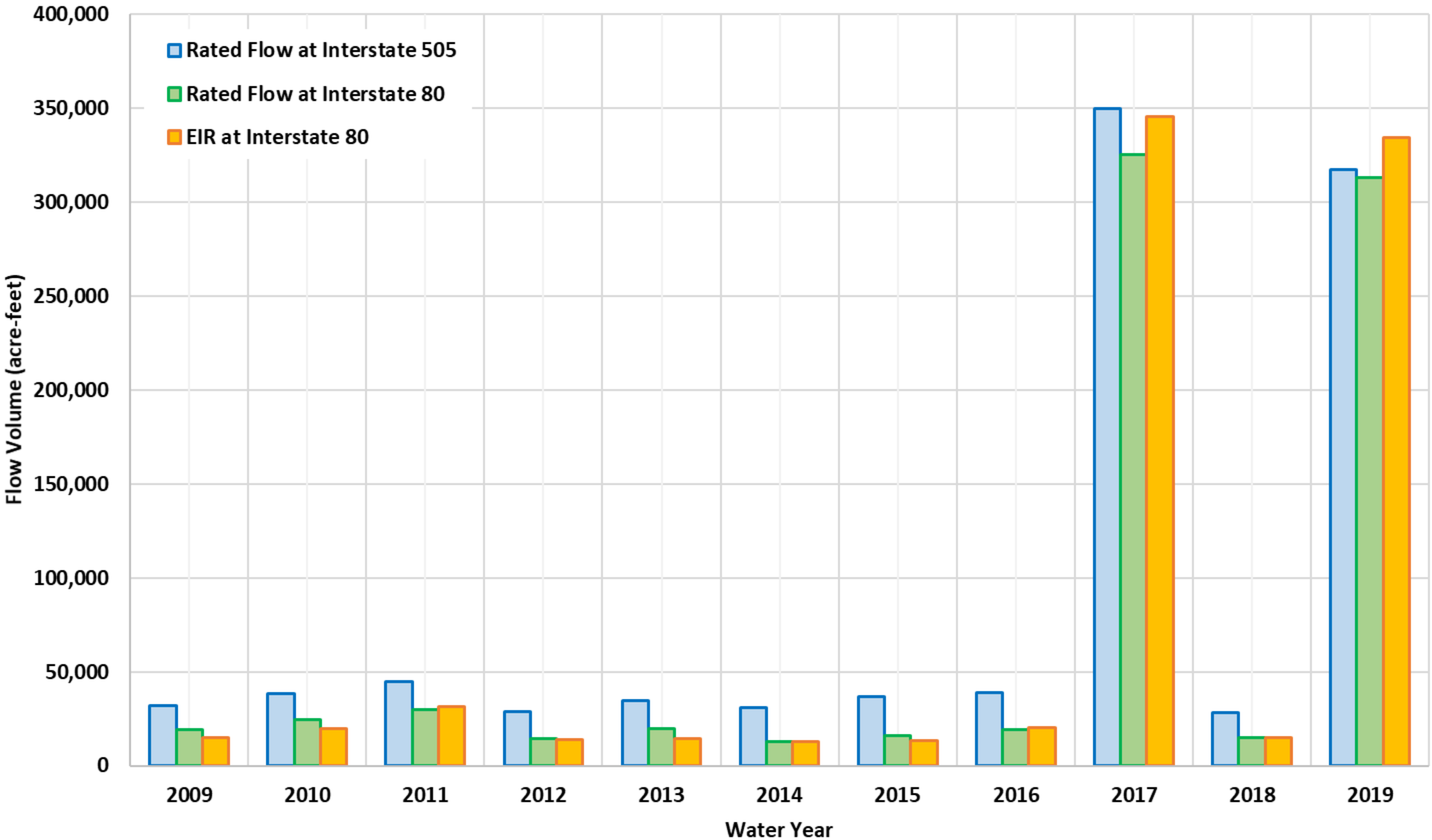
Yolo Bypass Westside Tributaries Flow Monitoring Project

Putah Creek Inflows to the Yolo Bypass: No Lake Berryessa Spills and No Backwater

ERP Grant Agreement No. P1696008

Figure 24



Notes: a comparison of flow volume between October to May of each water year showing flow losses between Interstate 505 downstream to Interstate 80 and overestimation of flows by EIR approach when Lake Berryessa is spilling via the glory hole.

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Yolo Bypass Westside Tributaries Flow Monitoring Project

Putah Creek Accumulated Outflow

ERP Grant Agreement No. P1696008 | **Figure 25**

APPENDIX A

EQUIPMENT DATASHEETS

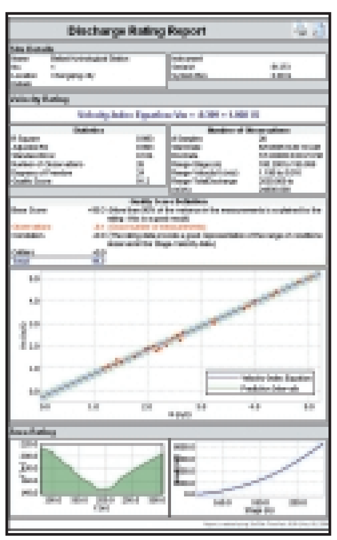
FlowTracker® Handheld ADV®

FlowTracker®

No other wading discharge device on the market comes with more useful options and accessories, making the FlowTracker a complete, turn-key solution.

The SonTek Deluxe wading rod, featuring a sturdy grip and bubble level

Rugged case provided with optional top-setting rod



FlowPack Velocity Indexing report software

Standard Features

- Low-profile 2-D ADV water velocity sensor on 2m flexible cable (measure in depths down to 2cm (1 inch))
- Automatic discharge computation protocols (ISO/USGS mid-section, mean-section, and Japanese)
- Handheld keypad interface with real-time display
- Velocity methods: ISO, USGS, under ice, Kreps, 5-point, and multipoint
- Languages supported: English, Spanish, German, Italian, and French
- Recorder space: up to 64 discharge measurements or over 150,000 individual velocity samples
- Data Set Documentation: up to 20 values of time-stamped user comments including gauge height and rated flow
- QA/QC: automated data review and discharge uncertainty calculations
- Communication protocol: RS232
- Software: Windows software with diagnostic beam-check, recorder access, data visualization and customizable reports
- Compatible with FlowPack Velocity Indexing software
- Temperature sensor
- Hard plastic case

SonTek®
A YSI Environmental Company

SonTek/YSI Inc.
9940 Summers Ridge Road
San Diego, CA 92121
Tel: +1 (858) 546-8327
Fax: + (858) 546-8150
Email: inquiry@sontek.com
www.sontek.com

Optional Features

- 2-D/3-D ADV side-looking probe
- 3m flexible cable
- Deluxe SonTek two piece, top-setting wading rod kit (1.2m Metric or 4 ft English) including case and mounting brackets
- Wading rod mounting bracket for controller/keypad
- Offset mounting bracket for ADV probe

Specifications

- Velocity range: ±0.001 to 4.0 m/s (±0.003 to 13 ft/s)
- Velocity resolution: 0.0001 m/s
- Velocity accuracy: ±1% of measured velocity, ±0.25 cm/s
- Sampling volume location: 10 cm from center transducer
- Power supply: 8 AA batteries
- Typical battery life: 25+ hours continuous operation (alkaline batteries)
- Weight: 1.8 kg/4.0 lbs
- Probe width: 130 mm (5.1 inches)
- Handheld controller/keypad: temporarily submersible to 1m
- Operating temperature: -20° to 50° C
- Storage temperature: -20° to 50° C

SmartQC

SmartQC is a built-in quality control feature that gives you the added assurance your FlowTracker data is correct. With each measurement, data is compared to a variety of adaptive QC criteria to ensure the best measurement possible.

SmartQC is our exclusive promise your SonTek/YSI system is performing at optimum standards and that your data is precise, reliable and exceeds your service expectations.

SonTek/YSI, founded in 1992 and advancing environmental science in over 100 countries, manufactures affordable, reliable acoustic Doppler instrumentation for water velocity measurement in oceans, rivers, lakes, harbors, estuaries, and laboratories. Headquarters are located in San Diego, California. Additional information can be found at www.sontek.com. SonTek/YSI is an employee-owned company.

SonTek, ADV and FlowTracker are trademarks of SonTek/YSI Inc., San Diego, CA USA
The FlowTracker is made in the USA. FT Brochure 10/06, Rev. 4 - Oxford Group

FlowTracker® Handheld ADV®

Sound Principles. Good Advice.

Wading Discharge Measurement Device

Portable. Precise. Practical.

Designed with the field user in mind, this handheld ADV® (Acoustic Doppler Velocimeter) measures 2D or 3D currents, attaches easily to wading rods, and features an automatic discharge computation using a variety of international methods, including ISO and USGS standards. At the end of the data run, just press a button and the FlowTracker calculates the discharge for you!

The FlowTracker is the ideal solution if you're looking for:

- Help in challenging outdoor conditions
- A way to avoid recurring calibration/maintenance
- Tough equipment that doesn't break down all the time
- Unmatched performance in shallow water and low flows
- An easy-to-use interface
- Fewer steps to follow
- Built-in quality checks (SmartQC) so you know your data is right.

The handy FlowTracker keypad is custom-designed for both discharge measurements and general purpose water velocity. Featuring provisions for starting edges, multiple channels, and even ice covered water, it is ready for any environmental situation. In addition, the FlowTracker's intelligent algorithm automatically prompts you for the proper measurement method based on your previous measurement stations.

FlowTracker Software Speaks Your Language

The FlowTracker comes with user-friendly, data analysis software that helps you produce attractive, customizable and professional reports in minutes. FlowTracker software also supports several languages, making it an ideal solution for international applications.

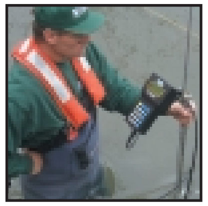
Example of FlowTracker discharge software and reports

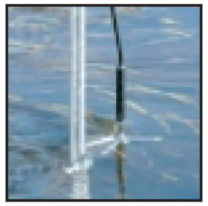
FlowTracker in the Field

With rugged construction for any climate and a backlit display easily read during both day and night, the FlowTracker goes wherever you need it to go.

- Natural Streams
- Irrigation Canals
- Mining Channels
- Water Treatment
- Weirs/Flumes
- Storm Water
- Open Channels
- Lakes



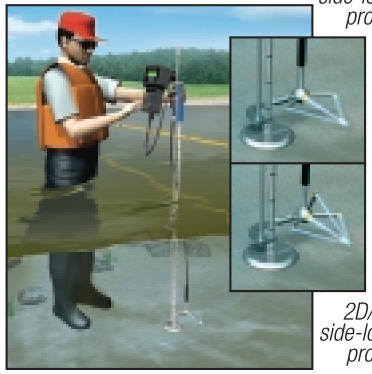


The FlowTracker Advantage

It doesn't matter if you are new to acoustic Doppler technology, or an old familiar friend, the FlowTracker provides unparalleled benefits you will only find with SonTek/YSI systems. Here is some of what sets the FlowTracker apart.

- Multi-language instrument and software (English, Spanish, French, Italian, and German)
- Proven velocity precision - accurate to as low as 0.001 m/s (0.003 ft/s) and up to 4.0 m/s (13 ft/s)
- Automatic discharge calculation - International techniques, including ISO and USGS standards
- Record changing gauge heights and rated flows, with comments in each measurement
- Automatic discharge uncertainty calculation to ISO standard. **A FlowTracker First!**
- Measure velocities in water as shallow as 2 cm (less than an 1 inch)
- Keypad interface with real-time velocity and flow display
- Automatic quality control for accurate data collection
- Two or three dimensional velocity measurement
- Recorded data is shielded from power loss
- Lightweight, rugged, and waterproof
- No calibration required - ever!
- Built-in temperature sensor

2D side-looking probe



2D/3D side-looking probe

Example of typical stance and technique when using the FlowTracker

River Discharge and Flow

Spot Current Sampling

Irrigation Canals

SonTek®

A YSI Environmental Company

Teledyne RD Instruments

New! RiverPro ADCP

Intelligent River Discharge Measurement System

5-Beam ADCP for Shallow River Environments

Teledyne RD Instruments is pleased to introduce **RiverPro**, the newest member of our growing family of Acoustic Doppler Current Profilers (ADCPs) for inland Water Resources applications.

The 1200 kHz RiverPro has been purpose-built to fill two specific needs:

- To provide an ADCP designed specifically for shallow river applications (20 cm to 25 m range)
- To provide an upgrade path for our current industry gold-standard **Rio Grande** ADCP users

Like our next-generation RiverRay ADCP, the RiverPro offers users a 5-beam solution, **auto-adaptive sampling**, user-friendly interface, and Teledyne RDI's unsurpassed quality, service, and support.

The RiverPro has also been designed to fit into our RiverRay float, allowing users to swap out their ADCPs based upon their environment, eliminating the need to purchase and transport a second float.

Rio Grande ADCP users can also use RiverPro as a conduit to upgrade their existing Workhorse ADCP to include the benefits derived from our next-generation electronics and technology advancements.

Q-VIEW

Combine your RiverPro with Teledyne RDI's **Q-View** software for unmatched measurement quality.

ADCP	IDEAL FIELD ENVIRONMENT
StreamPro ADCP	Shallow streams, 10 cm - 6 m *
RiverPro ADCP	Deep streams to shallow rivers, 20 cm - 25 m
RiverRay ADCP	Shallow to deep rivers, 40 cm - 60 m

• with extended range option

PRODUCT FEATURES

- A 20-degree beam, allowing users to collect data closer to the bottom
- A 600 kHz 5th beam collects true vertical velocity with a calibrated RSSI (return signal strength indicator) and range to bottom
- Fully integrated GPS for geo-referencing
- Auto-adaptive sampling, which quickly provides accurate discharge measurements without the need for user configuration
- A manual override, which allows advanced users the ability to fully customize their system setting as an alternative to auto-adaptive sampling

TELEDYNE RD INSTRUMENTS Everywhereyoulook™

A Teledyne Marine Company

RiverPro ADCP

Intelligent River Discharge Measurement System

TECHNICAL SPECIFICATIONS

Water Velocity Profiling	Operation mode	Broadband / pulse coherent; automatic / manual
	Velocity range	±5m/s default, ±20m/s max
	Profiling range	12cm[1] to 25m[2]
	Accuracy	±0.25% of water velocity relative to ADCP, ±2mm/s
	Resolution	1mm/s
	Number of cells	15-30 typical, 200 maximum
	Cell size	2cm to 5m
	Data output rate	1-2Hz (typical)
Bottom Tracking	Operation mode	Broadband
	Velocity range	±9m/s
	Depth range	15cm to 35m[2]
	Accuracy	±0.25% of bottom velocity relative to ADCP, ±2mm/s
	Resolution	1mm/s
Slant Beams (Depth Measurement)	Range	15cm to 35m[2]
	Accuracy	±1%[3,4]
	Resolution	1mm
Vertical Beam (Depth Measurement)	Range	120m[2]
	Accuracy	±1%[4]
	Resolution	1mm

Standard Sensors		Temperature	Tilt (pitch and roll)	Compass	GPS (Embedded)
	Range	-5°C to 45°C	±90°	0-360°	
	Accuracy	±0.5°C	±0.3°	±1°[5]	3m Horizontal/5m Vertical/ 0.02m/s Velocity

Transducer and Hardware	System frequency	1200kHz/600kHz
	Configuration	4 piston transducers, Janus arrangement with 20° beam angle/ 1 vertically oriented transducer
	Internal memory	16MB
Communications	Standard	RS-232, 1200 to 115,200 baud. Bluetooth, 115,200 baud, 200m range
	Optional	Radio modem, range >30km (line of sight)
Software (included)	WinRiver II (standard) for moving-boat measurement, Q-View (optional), SxS Pro (optional)	
Power	Input voltage	10.5-18 Volts
	Power consumption	1.5W typical
	Battery (inside float)	12V, 7A-hr lead acid gel cell (rechargeable)
	Battery capacity	> 40 hrs continuous operation
Float (included)	Configuration	Three hulls (trimaran)
	Material	Polyethylene
	Dimensions	Length 120cm, width 80cm, height 20cm
	Weight	10kg bare; 17kg with instrument and battery
GPS Integration (optional)	Integration with customer-supplied GPS, depth sounder, gyro compass via RS-232	
Environmental	Operating temperature	-5°C to 45°C
	Storage temperature	-20°C to 50°C

1 Distance measured from the center of the first cell to the transducer surface
2 Actual range depends on temperature and suspended solids concentration
3 For beam-averaged depth data
4 Assumes uniform water temperature and salinity profile
5 For combined tilt <+/-70° and dip angle <70°

TELEDYNE RD INSTRUMENTS
Everywhereyoulook™
www.rdinstruments.com

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Les Nertieres 5 Avenue Hector Pintus 06610 La Gaude France
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RiverRay ADCP

HIGHLY VERSATILE DISCHARGE MEASUREMENT SYSTEM

Take the Guesswork out of your Discharge Measurements

Go straight to work collecting highly accurate stream and river discharge data with the new **RiverRay Acoustic Doppler Current Profiler** (ADCP). This economical, turn-key system comes complete with: the ADCP, boat, software, and wireless communications—everything you need to collect superior, real-time data.

With over 25 years experience delivering acoustic Doppler products, Teledyne RDI's new RiverRay is the culmination of years of technology advances and invaluable customer feedback.

From a shallow stream to a raging river, the revolutionary RiverRay delivers the simplicity and reliability your operations require, at a price that won't break your budget.

The RiverRay ADCP utilizes a flat-surface, phased array transducer.

RiverRay Highlights:

- *Ease of use—easy to carry, easy to deploy, and easy to operate; just power and go.*
- *Qrz-control—automatic adaptive sampling continuously optimizes your discharge measurement from bank to bank, thus ensuring the highest quality data without your intervention.*
- *Reduced size, weight, and flow disturbance—the sleek new phased array transducer design provides increased data accuracy, as well as reduced size, weight, and flow disturbance.*
- *Versatile—a single instrument can now deliver high quality data in a 0.4m stream or a 40m river.*
- *Superior surface measurements—interwoven independent and short range measurements improve the discharge computation in your critical surface layer.*
- *Platform stability—RiverRay's new float, designed and built by OceanScience, boasts reduced drag, causes less flow disturbance, and provides superior handling—even in high water velocities and waves.*
- *No cables required—data is wirelessly transmitted to your shore station via Bluetooth™ technology.*
- *DGPS compatible—integrate an external DGPS for difficult conditions, such as moving beds.*

TELEDYNE
RD INSTRUMENTS
A Teledyne Technologies Company

RiverRay ADCP

HIGHLY VERSATILE DISCHARGE MEASUREMENT SYSTEM

Technical Specifications

Water Velocity Profiling	
Operation mode	*Broadband or pulse-coherent, automatic*
Velocity range	*±5m/s (default), ±20m/s max.*
Profiling range[1]	*0.4m to 40m*
Accuracy	*±0.25% of water velocity relative to ADCP, ±2mm/s*
Resolution	*1mm/s*
Number of cells	*automatic, 25 typical, 200 max.*
Cell size:	*automatic, 10cm min.*
Surface cell range[2]	*25cm*
Data output rate	*1-2 Hz (typical)*

Bottom Tracking:	
Operation mode	*Broadband*
Velocity range	*±9.5m/s*
Maximum depth	*70m (@15°C, fresh water)*
Accuracy	*±0.25% of bottom velocity relative to ADCP, ±2.5mm/s*
Resolution	*1mm/s*

Depth Measurement:	
Range	*0.3m to 70m (@15°C, fresh water)*
Accuracy	*1% (with uniform water temperature and salinity profile)*
Resolution	*1mm*

Standard Sensors:

Sensor	**Temperature**	**Tilt** (solid state)	**Compass** (solid state)
Range	*-5° to 45°C*	*± 15°*	*0-359.99°*
Accuracy	*± 0.4°C*	*± 0.5°*	*± 2°*
Resolution	*0.01°C*	*0.01°*	*0.01°*

[1]Minimum range assumes one good cell (10cm), range measured from the transducer surface.
[2]Distance measured from the center of the first cell to the transducer surface.

Transducer and Hardware

System frequency: 600kHz
Configuration: Phased array (flat surface), Janus four beams at 30° beam angle
Internal memory: 16mb internal recorder

Communications

Standard: RS-232, 1200 to 115,200 baud. Bluetooth,115,200 baud, 200m range.
Optional: Radio modem, range >30km (line of sight)

Software *(included)*

WinRiver II
Windows XP/Vista compatible

Power

Input voltage: 10.5 to 18 VDC
Power consumption: 1.5W typical
Battery *(inside float)*: 12V, 7A-hr lead acid gel cell (rechargeable)
Battery capacity: >40 hrs continuous operation

Float *(included)*

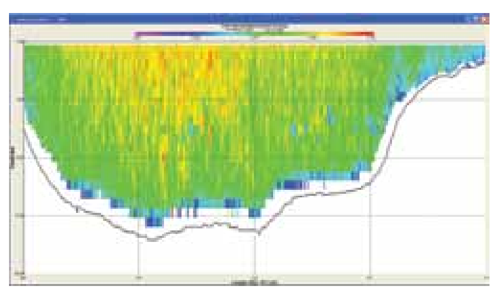
Configuration: Three hulls (trimaran)
Material: Polyethylene
Dimensions: L 1200mm, W 800mm, H 180mm
Weight: 10kg bare, 17kg with instrument and battery

GPS Integration *(optional)*

Integration with GPS (customer supplied) through RS-232 to RR data stream

Environmental

Operating temperature: -5° to 45°C
Storage temperature: -20°C to 50°C



Sample data.

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Tel. +33-49-211-0930 • Fax +33-49-211-0931 • E-mail: rdie@teledyne.com

Free online product training
Free 24/7 emergency support

DATASHEET

TRIMBLE R8 GNSS RECEIVER

KEY FEATURES

Advanced Trimble R-Track technology

Unmatched GNSS tracking performance

Includes Trimble Maxwell 6 chip with 220 channels

Remote configuration and access

Base and rover communications options to suit any application

The Trimble® R8 GNSS Receiver sets the new standard for full-featured GNSS (Global Navigation Satellite System) receiver technology. This integrated system delivers unmatched power, accuracy and performance in a rugged, compact unit.

ADVANCED TRIMBLE R-TRACK TECHNOLOGY

The Trimble R8 GNSS delivers the latest advancements in R-Track™ technology, designed to deliver reliable, precise positioning performance. In challenging areas for GNSS surveying, such as tree cover or limited sky view, Trimble R-Track provides unmatched tracking performance of GNSS satellite signals.

Trimble R-Track with Signal Prediction™ compensates for intermittent or marginal RTK correction signals, enabling extended precision operation after an RTK signal is interrupted.

The new CMRx communications protocol provides unprecedented correction compression for optimized bandwidth and full utilization all of the satellites in view, giving you the most reliable positioning performance.

Featuring the Trimble Maxwell™ 6 chip, the Trimble R8 GNSS advances the industry with more memory and more GNSS channels. Trimble delivers business confidence with a sound GNSS investment for today and into the future.

Broad GNSS Support

The Trimble R8 GNSS supports a wide range of satellite signals, including GPS L2C and L5 and GLONASS L1/L2 signals. In addition, Trimble is committed to the next generation of modernized GNSS configurations by providing Galileo-compatible products available for customers well in advance of Galileo system availability[1,2]. In support of this plan, the new Trimble R8 GNSS is capable of tracking the experimental GIOVE-A and GIOVE-B test satellites for signal evaluation and test purposes.

FLEXIBLE SYSTEM DESIGN

The Trimble R8 GNSS receiver combines the most comprehensive feature set into an integrated and flexible system for demanding surveying applications. The Trimble R8 GNSS includes a built-in transmit/receive UHF radio, enabling ultimate flexibility for rover or base operation. As a base station, the internal NTRIP caster provides you with customized access[3] to base station corrections via the internet.

Trimble's exclusive, Web UI™ eliminates travel requirements for routine monitoring of base station receivers. Now you can assess the health and status of base receivers and perform remote configurations from the office. Likewise, you can download post-processing data through Web UI and save additional trips out to the field.

ENABLING THE CONNECTED SITE

Pair the speed and accuracy of the Trimble R8 GNSS receiver with flexibility and collaboration tools of Trimble Access™ software. Trimble Access brings field and office teams closer by enabling data sharing and collaboration in a secure, web-based environment. With optional streamlined workflows, Trimble Access further empowers surveyors and survey teams for success. Now it is easier than ever to realize the potential of the Trimble Connected Site. Connecting the right tools, techniques, services and relationships enables surveying businesses to achieve more every day.

1 ***Galileo Commercial Authorization***
Receiver technology having Galileo capability to operate in the Galileo frequency bands and using information from the Galileo system for future operational satellites is restricted in the publicly available Galileo Open Service Signal-In-Space Interface Control Document (GAL OS SIS ICD) and is not currently authorized for commercial use.
Receiver technology that tracks the GIOVE-A and GIOVE-B test satellites uses information that is unrestricted in the public domain in the GIOVE A + B Navigation Signals-In-Space Interface Control Document. Receiver technology having developmental GIOVE-A and B capability is intended for signal evaluation and test purposes.

2 *For more information about Trimble and GNSS modernization, please visit* ***http://www.trimble.com/srv_new_era.shtml***.

3 *Cellular modem required.*

Trimble.

PERFORMANCE SPECIFICATIONS

Measurements

- Trimble R-Track technology
- Advanced Trimble Maxwell 6 Custom Survey GNSS chip with 220 channels
- High precision multiple correlator for GNSS pseudorange measurements
- Unfiltered, unsmoothed pseudorange measurements data for low noise, low multipath error, low time domain correlation and high dynamic response
- Very low noise GNSS carrier phase measurements with <1 mm precision in a 1 Hz bandwidth
- Signal-to-Noise ratios reported in dB-Hz
- Proven Trimble low elevation tracking technology
- Satellite signals tracked simultaneously:
  - GPS: L1C/A, L2C, L2E (Trimble method for tracking L2P), L5
  - GLONASS: L1C/A, L1P, L2C/A (GLONASS M only), L2P
  - SBAS: L1C/A, L5
  - Galileo GIOVE-A and GIOVE-B

Code differential GNSS positioning[1]

Horizontal . . . . . . 0.25 m + 1 ppm RMS
Vertical . . . . . . 0.50 m + 1 ppm RMS
WAAS differential positioning accuracy[2] . . . . . . typically <5 m 3DRMS

Static and FastStatic GNSS surveying[1]

Horizontal . . . . . . 3 mm + 0.1 ppm RMS
Vertical . . . . . . 3.5 mm + 0.4 ppm RMS

Kinematic surveying[1]

Horizontal . . . . . . 10 mm + 1 ppm RMS
Vertical . . . . . . 20 mm + 1 ppm RMS
Initialization time[3] . . . . . . typically <10 seconds
Initialization reliability[4] . . . . . . typically >99.9%

HARDWARE

Physical

Dimensions (W×H) . . . . . . 19 cm × 11.2 cm (7.5 in x 4.4 in), including connectors
Weight . . . . . . 1.34 kg (2.95 lb) with internal battery, internal radio, standard UHF antenna.
3.70 kg (8.16 lb) entire RTK rover including batteries, range pole, controller and bracket
Temperature[5]
Operating . . . . . . –40 °C to +65 °C (–40 °F to +149 °F)
Storage . . . . . . –40 °C to +75 °C (–40 °F to +167 °F)
Humidity . . . . . . 100%, condensing
Water/dustproof . . . . . . IP67 dustproof, protected from temporary immersion to depth of 1 m (3.28 ft)

Shock and vibration . . . . . . Tested and meets the following environmental standards:
Shock . . . . . . Non-operating: Designed to survive a 2 m (6.6 ft) pole drop onto concrete. Operating: to 40 G, 10 msec, sawtooth
Vibration MIL-STD-810F, FIG.514.5C-1

Electrical

- Power 11 to 28 V DC external power input with over-voltage protection on Port 1 (7-pin Lemo)
- Rechargeable, removable 7.4 V, 2.4 Ah Lithium-Ion battery in internal battery compartment. Power consumption is 3.2 W, in RTK rover mode with internal radio. Operating times on internal battery:
  - 450 MHz receive only option . . . . . . 5.8 hours[7]
  - 450 MHz receive/transmit option . . . . . . 3.7 hours[8]
  - GSM/GPRS . . . . . . 4.1 hours[7]
- Certification Class B Part 15, 22, 24 FCC certification, 850/1900 MHz. Class 10 GSM/GPRS module. CE Mark approval, and C-tick approval

Communications and Data Storage

- 3-wire serial (7-pin Lemo) on Port 1. Full RS-232 serial on Port 2 (Dsub 9 pin)
- Fully Integrated, fully sealed internal 450 MHz receiver/transmitter option:
  - Transmit power: 0.5 W
  - Range[6]: 3–5 km typical / 10 km optimal
- Fully integrated, fully sealed internal GSM/GPRS option[7]
- Fully integrated, fully sealed 2.4 GHz communications port (Bluetooth®)[9]
- External cellphone support for GSM/GPRS/CDPD modems for RTK and VRS operations
- Data storage on 57 MB internal memory: 40.7 days of raw observables (approx. 1.4 MB /Day), based on recording every 15 seconds from an average of 14 satellites
- 1 Hz, 2 Hz, 5 Hz, 10 Hz, and 20 Hz positioning
- CMR+, CMRx, RTCM 2.1, RTCM 2.3, RTCM 3.0, RTCM 3.1 Input and Output
- 16 NMEA outputs, GSOF, RT17 and RT27 outputs. Supports BINEX and smoothed carrier

1 Accuracy and reliability may be subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions. Always follow recommended survey practices.
2 Depends on WAAS/EGNOS system performance.
3 May be affected by atmospheric conditions, signal multipath, obstructions and satellite geometry.
4 May be affected by atmospheric conditions, signal multipath, and satellite geometry. Initialization reliability is continuously monitored to ensure highest quality.
5 Receiver will operate normally to –40 °C, internal batteries are rated to –20 °C.
6 Varies with terrain and operating conditions.
7 Varies with temperature.
8 Varies with temperature and wireless data rate.
9 Bluetooth type approvals are country specific. Contact your local Trimble Authorized Distribution Partner for more information.

Specifications subject to change without notice.

PN 022543-079J (11/09)

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Trimble R10

GNSS SYSTEM

A NEW LEVEL OF PRODUCTIVITY

Collect more accurate data faster and easier – no matter what the job or the environment, with the Trimble® R10 GNSS System. Built with powerful technologies integrated into a sleek design, this unique system provides Surveyors with a powerful way to increase productivity in every job, every day.

Trimble HD-GNSS Processing Engine

The advanced Trimble HD-GNSS processing engine provides markedly reduced convergence times as well as high position and precision reliability while reducing measurement occupation time. Transcending traditional fixed/float techniques, it provides a more accurate assessment of error estimates than traditional GNSS technology.

Trimble SurePoint

With Trimble SurePoint™ technology, advanced sensors onboard the Trimble R10 continuously stream pole tilt and heading information that is used to display an electronic level bubble on the Trimble controller screen, allowing surveyors to maintain focus where it matters most. Full tilt compensation allows the survey pole to be tilted up to 15° when measuring, allowing the Trimble R10 to capture points that would be inaccessible to other GNSS surveying systems.

Trimble 360 Receiver

Powerful Trimble 360 receiver technology in the Trimble R10 supports signals from all existing and planned GNSS constellations and augmentation systems. With two integrated Trimble Maxwell™ 6 chips, the Trimble R10 offers 440 GNSS channels.

Trimble CenterPoint RTX

Trimble CenterPoint® RTX delivers RTK level precision anywhere in the world without the use of a local base station or VRS network. Survey using satellite delivered, CenterPoint RTX corrections in areas where terrestrial based corrections are not available. When surveying over a great distance in a remote area, such as a pipeline or utility right of way, CenterPoint RTX eliminates the need to continuously move base stations or maintain connection to a cellular network.

Trimble xFill

Leveraging a worldwide network of Trimble GNSS reference stations and satellite datalinks, Trimble xFill® seamlessly fills in for gaps in your RTK or VRS connection stream. Maintain centimeter level accuracy beyond five minutes with a CenterPoint RTX subscription.

Smart, Versatile

A smart lithium-ion battery inside the Trimble R10 system delivers extended battery life and more reliable power. A built-in LED battery status indicator allows the user to quickly check remaining battery life.

The Trimble R10 system provides a number of communications options to support any workflow. Receive VRS corrections and connect to the Internet from the field with the integrated cellular modem. Using Wi-Fi, easily connect to the Trimble R10 system using a laptop or smartphone to configure the receiver without a Trimble controller.

The Complete Solution

Bring the power and speed of the Trimble R10 system together with trusted Trimble software solutions, including Trimble Access™ and Trimble Business Center.

Trimble Access field software provides specialized and customized workflows to make surveying tasks quicker and easier while enabling teams to communicate vital information between field and office in real time. Back in the office, users can seamlessly process data with Trimble Business Center software.

Key Features

- Cutting-edge Trimble HD-GNSS processing engine
- Precise position capture and full tilt compensation with Trimble SurePoint technology
- Trimble CenterPoint RTX provides RTK level precision anywhere without the need for a base station or VRS network
- Trimble xFill technology provides centimeter-level positioning during connection outages
- Advanced satellite tracking with Trimble 360 receiver technology
- Sleek ergonomic design for easier handling

PERFORMANCE SPECIFICATIONS		
MEASUREMENTS		
	Measuring points sooner and faster with Trimble HD-GNSS technology	
	Increased measurement productivity and traceability with Trimble SurePoint electronic tilt compensation	
	Worldwide centimeter level positioning using Trimble CenterPoint RTX satellite delivered corrections	
	Reduced downtime due to loss of radio signal with Trimble xFill technology	
	Advanced Trimble Maxwell 6 Custom Survey GNSS chips with 440 channels	
	Future-proof your investment with Trimble 360 GNSS tracking	
	Satellite signals tracked simultaneously:	GPS: L1C/A, L1C, L2C, L2E, L5 GLONASS: L1C/A, L1P, L2C/A, L2P, L3 SBAS: L1C/A, L5 (For SBAS satellites that support L5) Galileo: E1, E5A, E5B, E5 AltBOC BeiDou: B1, B2, B3
	CenterPoint RTX, OmniSTAR® HP, XP, G2, VBS positioning	
	QZSS, WAAS, EGNOS, GAGAN, MSAS	
	Positioning Rates	1 Hz, 2 Hz, 5 Hz, 10 Hz, and 20 Hz
POSITIONING PERFORMANCE[1]		
CODE DIFFERENTIAL GNSS POSITIONING		
	Horizontal	0.25 m + 1 ppm RMS
	Vertical	0.50 m + 1 ppm RMS
	SBAS differential positioning accuracy[2]	typically <5 m 3DRMS
STATIC GNSS SURVEYING		
High-Precision Static		
	Horizontal	3 mm + 0.1 ppm RMS
	Vertical	3.5 mm + 0.4 ppm RMS
STATIC AND FAST STATIC		
	Horizontal	3 mm + 0.5 ppm RMS
	Vertical	5 mm + 0.5 ppm RMS
REAL TIME KINEMATIC SURVEYING		
Single Baseline <30 km		
	Horizontal	8 mm + 1 ppm RMS
	Vertical	15 mm + 1 ppm RMS
Network RTK[3]		
	Horizontal	8 mm + 0.5 ppm RMS
	Vertical	15 mm + 0.5 ppm RMS
RTK start-up time for specified precisions[4]		2 to 8 seconds
TRIMBLE RTX™ TECHNOLOGY (SATELLITE AND CELLULAR/INTERNET (IP))		
CenterPoint RTX[5]		
	Horizontal	2 cm RMS
	Vertical	5 cm RMS
	RTX convergence time for specified precisions - Worldwide	< 15 min
	RTX QuickStart convergence time for specified precisions	< 1 min
	RTX convergence time for specified precisions in select regions (Trimble RTX Fast Regions)	< 1 min
TRIMBLE XFILL[6]		
	Horizontal	RTK[7] + 10 mm/minute RMS
	Vertical	RTK[7] + 20 mm/minute RMS

HARDWARE		
PHYSICAL		
Dimensions (W×H)	11.9 cm x 13.6 cm (4.6 in x 5.4 in)	
Weight	1.12 kg (2.49 lb) with internal battery, internal radio with UHF antenna, 3.57 kg (7.86 lb) items above plus range pole, controller & bracket	
Temperature[8]		
	Operating	−40° C to +65° C (−40° F to +149° F)
	Storage	−40° C to +75° C (−40° F to +167° F)
Humidity		100%, condensing
Ingress Protection		IP67 dustproof, protected from temporary immersion to depth of 1 m (3.28 ft)
Shock and vibration (Tested and meets the following environmental standards)		
	Shock	Non-operating: Designed to survive a 2 m (6.6 ft) pole drop onto concrete. Operating: to 40 G, 10 msec, sawtooth
	Vibration	MIL-STD-810F, FIG.514.5C-1
ELECTRICAL		
	Power 11 to 24 V DC external power input with over-voltage protection on Port 1 and Port 2 (7-pin Lemo)	
	Rechargeable, removable 7.4 V, 3.7 Ah Lithium-ion smart battery with LED status indicators	
	Power consumption is 5.1 W in RTK rover mode with internal radio[9]	
Operating times on internal battery[10]		
	450 MHz receive only option	5.5 hours
	450 MHz receive/transmit option (0.5 W)	4.5 hours
	450 MHz receive/transmit option (2.0 W)	3.7 hours
	Cellular receive option	5.0 hours
COMMUNICATIONS AND DATA STORAGE		
Serial	3-wire serial (7-pin Lemo)	
USB v2.0	Supports data download and high speed communications	
Radio Modem	Fully Integrated, sealed 450 MHz wide band receiver/transmitter with frequency range of 403 MHz to 473 MHz, support of Trimble, Pacific Crest, and SATEL radio protocols:	
	Transmit power: 2 W	
	Range: 3–5 km typical / 10 km optimal[11]	
Cellular	Integrated, 3.5 G modem, HSDPA 7.2 Mbps (download), GPRS multi-slot class 12, EDGE multi-slot class 12, UMTS/HSDPA (WCDMA/FDD) 850/1900/2100MHz, Quad-band EGSM 850/900/1800/1900 MHz, GSM CSD, 3GPP LTE	
Bluetooth	Fully integrated, fully sealed 2.4 GHz communications port (Bluetooth®)[12]	
Wi-Fi	802.11 b,g, access point and client mode, WPA/WPA2/WEP64/WEP128 encryption	
USB v2.0	Supports data download and high speed communications	
External communication devices for corrections supported on	Serial, USB, TCP/IP and Bluetooth ports	
Data storage	4 GB internal memory; over seven years of raw observables (approx. 1.4 MB /day), based on recording every 15 seconds from an average of 14 satellites	
	CMR+, CMRx, RTCM 2.1, RTCM 2.3, RTCM 3.0, RTCM 3.1, RTCM 3.2 input and output	
	24 NMEA outputs, GSOF, RT17 and RT27 outputs	
WEBUI		
	Offers simple configuration, operation, status, and data transfer	
	Accessible via Wi-Fi, Serial, USB, and Bluetooth	
SUPPORTED TRIMBLE CONTROLLERS		
	Trimble TSC7, Trimble T10, Trimble TSC3, Trimble Slate, Trimble CU, Trimble Tablet Rugged PC	
CERTIFICATIONS		
	IEC 60950-1 (Electrical Safety); FCC OET Bulletin 65 (RF Exposure Safety); FCC Part 15.105 (Class B), Part 15.247, Part 90; PTCRB (AT&T); Bluetooth SIG; WFA IC ES-003 (Class B); Radio Equipment Directive 2014/53/EU, RoHS, WEEE; Australia & New Zealand RCM; Japan Radio and Telecom MIC	

Trimble R10 GNSS SYSTEM

1 Precision and reliability may be subject to anomalies due to multipath, obstructions, satellite geometry, and atmospheric conditions. The specifications stated recommend the use of stable mounts in an open sky view, EMI and multipath clean environment, optimal GNSS constellation configurations, along with the use of survey practices that are generally accepted for performing the highest-order surveys for the applicable application including occupation times appropriate for baseline length. Baselines longer than 30 km require precise ephemeris and occupations up to 24 hours may be required to achieve the high precision static specification.
2 Depends on WAAS/EGNOS system performance.
3 Network RTK PPM values are referenced to the closest physical base station.
4 May be affected by atmospheric conditions, signal multipath, obstructions and satellite geometry. Initialization reliability is continuously monitored to ensure highest quality.
5 RMS performance based on repeatable in field measurements. Achievable accuracy and initialization time may vary based on type and capability of receiver and antenna, user's geographic location and atmospheric activity, scintillation levels, GNSS constellation health and availability and level of multipath including obstructions such as large trees and buildings.
6 Accuracies are dependent on GNSS satellite availability. xFill positioning without a Trimble CenterPoint RTX subscription ends after 5 minutes of radio downtime. xFill positioning with a CenterPoint RTX subscription will continue beyond 5 minutes providing the Trimble RTX solution has converged, with typical precisions not exceeding 6 cm horizontal, 14 cm vertical or 3 cm horizontal, 7 cm vertical in Trimble RTX Fast regions. xFill is not available in all regions, check with your local sales representative for more information.
7 RTK refers to the last reported precision before the correction source was lost and xFill started.
8 Receiver will operate normally to –40° C, internal batteries are rated to –20° C.
9 Tracking GPS, GLONASS and SBAS satellites.
10 Varies with temperature and wireless data rate. When using a receiver and internal radio in the transmit mode, it is recommended that an external 6 Ah or higher battery is used.
11 Varies with terrain and operating conditions.
12 Bluetooth type approvals are country specific.

Specifications subject to change without notice.

Contact your local Trimble Authorized Distribution Partner for more information

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Singapore 099254
SINGAPORE

PN 022543-544J (07/18)

ONSET®

HOBO® U20L Series Water Level Loggers

A new standard for price/performance

HOBO U20L Series Water Level loggers set a new standard for price/performance for accurate water level and temperature monitoring. The loggers combine 0.1% measurement accuracy, a polypropylene housing for use in both fresh and salt water, and a non-vented design for convenient and hassle-free deployment.

Supported Measurements: Water Level, Barometric Pressure, Pressure (Absolute), Temperature

Key Advantages:

- Self-contained, non-vented design enables easy deployment
- Ideal for use in both fresh and saltwater environments
- Durable ceramic pressure sensor
- Ideal for use in wells, streams, lakes, wetlands and tidal areas

Minimum System Requirements:

Software | Base Station[1] | Coupler[2]

[1]HOBO Base Station or HOBO Waterproof Shuttle required. See page 39 for more details.
[2]Coupler included with HOBO Base Station or HOBO Waterproof Shuttle.

For complete information and accessories, please visit: **www.onsetcomp.com**

Part number	U20L-04	U20L-01	U20L-02
	HOBO Water Level Specifications		
Range	0-4 m (0-13 ft) 0 to 145 kPa (0 to 21 psia)	0-9 m (0-30 ft) 0 to 207 kPa (0 to 30 psia)	0-30.6 m (0-100 ft) 0 to 400 kPa (0 to 58 psia)
Factory Calibrated Range (0° to 40°C; 32° to 104°F)	69 to 145 kPa (10 to 21 psia)	69 to 207 kPa (10-30 psia)	69 to 400 kPa (10 to 58 psia)
Water Level Accuracy (Typical Error)	± 0.4 cm (0.013 ft) (± 0.1% FS)	± 1.0 cm (0.03 ft) (± 0.1% FS)	± 3.0 cm (0.1 ft) (± 0.1% FS)
Resolution	0.14 cm (0.005 ft) water	0.21 cm (0.007 ft) water	0.41 cm (0.013 ft) water
Burst Pressure	310 kPa (45 psia) 18 m (60 ft) depth	310 kPa (45 psia) 18 m (60 ft) depth	500 kPa (72.5 psia) 40.8 m (134 ft) depth
	Temperature Specifications (all models)		
Range	-20° to 50°C (-4° to 122°F)		
Accuracy	± 0.37° @ 20°C (± 0.67° @ 68°F) ± 0.44° from 0° to 50°C (± 0.79° from 32° to 122°F)		
Resolution (10 bit)	0.1° @ 20°C (0.18° @ 68°F)		
Response time	10 minutes (to 90% in water)		
Dimensions	3.18 cm diameter x 15.24 cm (1.25 x 6.0 in) hole in mounting bail 6.3 mm (0.25 in)		
CE compliant	Yes		

Contact Us

Sales (8am to 5pm ET, Monday through Friday)

- Email sales@onsetcomp.com
- Call 1-508-759-9500
- In U.S. toll free 1-800-564-4377
- Fax 1-508-759-9100

Technical Support (8am to 8pm ET, Monday through Friday)

- Contact Product Support onsetcomp.com/support/contact
- Call 1-508-759-9500
- In U.S. toll free 1-877-564-4377

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APPENDIX B

QREV MEASUREMENT TABLES

KLRC Qrev Results

DISCHARGE	Start Time (03/27/2018)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	15:54:49	**290.996**	90.818	122.702	46.251	17.305	13.92	1015.8
2018_03_27_KLRC_4000	15:54:49 R	288.701	97.497	125.886	50.417	10.907	3.994	138.3
2018_03_27_KLRC_4001	15:58:02 L	287.336	88.36	121.456	44.186	18.616	14.719	148.6
2018_03_27_KLRC_4002	16:01:27 R	307.747	92.016	128.349	46.88	21.523	18.978	143.2
2018_03_27_KLRC_4003	16:03:59 L	293.350	89.023	121.340	45.312	22.422	15.252	153.4
2018_03_27_KLRC_4004	16:06:46 R	287.378	89.013	119.976	46.606	15.255	16.527	178.1
2018_03_27_KLRC_4005	16:09:54 L	288.626	89.924	121.961	44.84	18.486	13.415	116.1

DISCHARGE	Start Time (04/07/2018)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:26:01	**582.991**	142.168	383.15	55.492	2.071	0.11	1617
KnightsLanding001	14:26:01 L	602.704	150.087	391.81	60.074	1.109	-0.376	420.9
KnightsLanding002	14:34:35 R	588.287	143.339	385.019	54.686	4.78	0.463	230
KnightsLanding003	14:42:24 L	579.975	141.271	384.051	54.46	-0.467	0.661	345.3
KnightsLanding004	14:48:30 R	583.813	143.076	382.269	54.374	3.912	0.181	238.1
KnightsLanding005	15:06:07 L	570.882	138.481	380.77	53.285	-1.137	-0.518	206.6

DISCHARGE	Start Time (04/08/2018)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	10:36:13	**795.816**	153.368	566.657	73.38	2.36	0.05	1013.9
KnightsLanding017	10:36:13 L	767.623	148.527	543.9	72.155	2.894	0.147	331.7
KnightsLanding018	10:41:56 R	777.468	150.015	554.063	70.398	2.959	0.034	209
KnightsLanding019	10:45:38 L	835.186	160.547	595.479	77.321	2.023	-0.184	253.4
KnightsLanding020	10:50:01 R	802.986	154.384	573.188	73.645	1.564	0.204	219.8

DISCHARGE	Start Time (04/11/2018)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	13:38:21	**478.68**	113.195	318.133	43.651	3.144	0.557	910.7
KLRC_2018_04_11000	13:38:21 L	475.5	110.115	317.475	44.243	2.766	0.902	245.6
KLRC_2018_04_11001	13:42:34 R	482.293	114.801	320.816	42.945	2.722	1.009	201.2
KLRC_2018_04_11002	13:46:00 L	476.555	111.396	317.163	43.55	3.693	0.753	257
KLRC_2018_04_11003	13:50:22 R	480.371	116.467	317.077	43.869	3.393	-0.435	206.9

DISCHARGE	Start Time (09/04/2018)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:05:56	**369.582**	88.925	218.932	48.291	5.078	8.355	1993.2
WST_RCS_2018_0904002	14:05:56 L	354.849	90.182	215.632	46.641	4.019	-1.625	175.3
WST_RCS_2018_0904003	14:18:10 L	349.609	90.853	206.576	50.506	2.152	-0.478	244.2
WST_RCS_2018_0904004	14:23:39 R	384.438	92.006	212.765	51.915	3.224	24.527	182.7
WST_RCS_2018_0904006	14:30:38 R	377.429	88.036	213.736	47.778	5.905	21.974	125.7
WST_RCS_2018_0904007	14:59:32 R	355.216	88.006	213.469	45.222	15.213	-6.693	113.7
WST_RCS_2018_0904008	15:49:34 L	371.977	82.279	220.509	47.593	6.013	15.584	166.3
WST_RCS_2018_0904009	15:54:38 R	384.481	88.428	223.671	48.747	6.273	17.362	128.5
WST_RCS_2018_0904010	15:56:57 L	363.308	95.91	233.034	54.005	-7.439	-12.203	174.6
WST_RCS_2018_0904011	16:00:02 R	371.657	92.602	230.899	45.663	8.879	-6.386	131.3
WST_RCS_2018_0904013	16:07:03 R	395.965	92.809	233.781	52.126	6.442	10.807	188.8
WST_RCS_2018_0904014	16:10:44 L	357.568	85.745	208.153	43.301	5.912	14.456	210.4

DISCHARGE	Start Time (09/04/2018)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	16:55:30	**55.803**	14.431	33.898	5.863	1.784	-0.173	720.7
WST_RCS_2018_0904018	16:55:30 L	52.288	11.469	35.466	4.369	1.356	-0.371	192.8
WST_RCS_2018_0904019	16:58:57 R	55.694	17.078	29.691	7.236	1.815	-0.125	183.5
WST_RCS_2018_0904020	17:02:31 L	55.789	12.676	35.98	4.962	2.39	-0.219	197.3
WST_RCS_2018_0904021	17:06:04 R	59.441	16.503	34.454	6.884	1.576	0.023	147.2

DISCHARGE	Start Time (09/05/2018)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	13:34:17	**447.535**	64.452	315.651	45.2	20.782	1.449	516.2
WST_RCS_2018_0904018	13:34:17 L	445.995	61.469	317.27	40.868	24.659	1.729	109.4
WST_RCS_2018_0904019	13:36:48 R	430.617	61.212	304.83	39.419	24.534	0.624	156.1
WST_RCS_2018_0904020	13:39:53 L	465.609	68.889	326.201	54.937	13.894	1.687	117.2
WST_RCS_2018_0904021	13:41:57 R	447.92	66.241	314.302	45.578	20.041	1.757	133.6

DISCHARGE	Start Time (01/08/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	12:01:38	**375.198**	88.388	251.213	28.539	4.678	2.38	1568.3
KLRC_2019_01_08_4000	12:01:38 L	375.84	90.871	253.208	29.56	0.175	2.025	223.9
KLRC_2019_01_08_4001	12:05:29 R	368.88	87.037	246.4	27.741	5.503	2.198	158.8
KLRC_2019_01_08_4002	12:08:16 L	372.686	87.171	249.389	27.052	7.453	1.621	229.1
KLRC_2019_01_08_4003	12:12:11 R	377.971	88.891	251.99	28.891	5.769	2.43	167.5
KLRC_2019_01_08_4004	12:15:05 L	361.661	84.788	241.434	27.476	5.096	2.867	225.3
KLRC_2019_01_08_4005	12:18:54 R	370.757	88.162	248.628	29.048	2.977	1.942	157.9
KLRC_2019_01_08_4006	12:25:53 L	396.475	92.345	266.028	30.171	5.049	2.882	246.2
KLRC_2019_01_08_4007	12:30:05 R	377.318	87.838	252.629	28.373	5.399	3.078	159.5

DISCHARGE	Start Time (01/09/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	15:31:40	**904.722**	145.859	667.21	79.857	6.505	5.291	792.9
WST_KLRC000	15:31:40 R	872.911	143.175	641.996	79.587	5.638	2.515	154.5
WST_KLRC001	15:35:05 L	925.087	144.762	685.806	81.386	7.183	5.95	176.2
WST_KLRC002	15:38:10 R	883.437	141.383	649.655	84.43	3.589	4.381	132.5
WST_KLRC003	15:41:00 L	931.003	153.257	683.912	79.042	7.194	7.598	111
WST_KLRC004	15:44:35 R	910.535	145.067	670.835	81.992	8.503	4.138	116.2
WST_KLRC005	15:47:12 L	905.36	147.509	671.058	72.705	6.926	7.162	102.4

DISCHARGE	Start Time (01/10/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	13:12:10	**1135.312**	323.515	705.993	77.602	15.942	12.259	947.2
KLRC_2019_01_10_3000	13:12:10 R	1140.88	321.373	698.27	76.243	20.574	24.42	226.3
KLRC_2019_01_10_3001	13:18:13 L	1160.168	332.297	725.538	81.726	14.354	6.252	245.8
KLRC_2019_01_10_3002	13:25:09 R	1143.799	332.667	712.195	78.349	11.077	9.51	219
KLRC_2019_01_10_3003	13:32:44 L	1096.401	307.722	687.971	74.089	17.763	8.856	256

DISCHARGE	Start Time (01/10/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	15:22:18	**1242.944**	336.697	786.795	97.446	9.2	12.806	732
KLRC_2019_01_10_3006	15:22:18 R	1291.957	356.858	816.235	92.807	7.09	18.967	156.7
KLRC_2019_01_10_3007	15:26:29 L	1238.001	326.558	787.409	99.129	12.78	12.125	209.8
KLRC_2019_01_10_3008	15:31:31 R	1232.781	330.53	774.51	105.488	7.85	14.403	155.2
KLRC_2019_01_10_3009	15:36:16 L	1209.036	332.843	769.025	92.359	9.08	5.73	210.2

DISCHARGE	Start Time (01/11/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	12:13:03	**1284.634**	190.106	952.697	126.057	15.774	0	2065.4
KLRC_2019_01_11_1000	12:13:03 R	1244.819	177.845	915.901	119.96	31.113	0	135.8
KLRC_2019_01_11_1001	12:17:34 L	1203.527	188.748	870.712	130.963	13.105	0	163
KLRC_2019_01_11_1003	12:21:55 R	1288.675	187.107	955.919	126.904	18.746	0	144
KLRC_2019_01_11_1004	12:24:38 L	1320.883	207.724	965.868	122.993	24.299	0	163.6
KLRC_2019_01_11_1005	12:28:23 R	1213.559	180.337	887.857	132.327	13.038	0	137.3
KLRC_2019_01_11_1006	12:32:52 L	1381.456	220.921	1019.829	133.929	6.776	0	147
KLRC_2019_01_11_1007	12:38:35 R	1363.017	195.045	1019.697	126.406	21.87	0	149
KLRC_2019_01_11_1010	12:42:54 L	1263.472	182.822	946.896	123.706	10.048	0	137.3
KLRC_2019_01_11_1011	12:46:24 R	1245.425	180.959	939.548	118.373	6.545	0	143.8
KLRC_2019_01_11_1012	12:49:33 L	1338.016	200.414	993.521	127.799	16.282	0	134.8
KLRC_2019_01_11_1013	12:53:39 R	1238.342	182.93	932.981	119.131	3.301	0	140.7
KLRC_2019_01_11_1014	12:56:44 L	1286.668	195.698	947.247	124.7	19.023	0	130.4
KLRC_2019_01_11_1015	13:01:40 R	1291.004	186.261	971.409	127.377	5.957	0	198.7
KLRC_2019_01_11_1016	13:06:07 L	1306.017	174.68	970.37	130.231	30.736	0	140.1

DISCHARGE	Start Time (01/18/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	12:12:47	**1784.842**	215.456	1115.255	433.171	9.585	11.375	1399.1
KLRC_2019_01_18_1002	12:12:47 L	1850.618	225.603	1147.756	459.432	8.076	9.751	340.3
KLRC_2019_01_18_1003	12:18:41 R	1820.886	220.301	1148.589	436.297	7.882	7.817	294.5
KLRC_2019_01_18_1005	12:33:25 R	1755.198	209.723	1104.245	418.652	9.349	13.229	370.5
KLRC_2019_01_18_1007	12:49:58 R	1712.667	206.196	1060.43	418.304	13.031	14.705	393.8

DISCHARGE	Start Time (01/20/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	11:18:43	**2156.852**	248.497	1305.431	578.526	0	24.397	1573.2
KLRC_2019_01_20_1000	11:18:43 L	2172.046	248.412	1312.784	591.66	0	19.189	244.5
KLRC_2019_01_20_1001	11:22:59 R	2037.074	229.916	1243.437	534.758	0	28.963	399.1
KLRC_2019_01_20_1002	11:29:49 L	2250.207	266.724	1348.269	607.689	0	27.526	468.2
KLRC_2019_01_20_1004	11:46:40 L	2168.08	248.937	1317.236	579.997	0	21.91	461.5

DISCHARGE	Start Time (01/21/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	13:02:41	**2365.302**	282.405	1499.101	551.36	0	32.437	1644.3
KLRC_2019_01_21000	13:02:41 L	2331.718	282.135	1457.854	568.299	0	23.43	381.5
KLRC_2019_01_21001	13:09:43 R	2322.973	273.905	1482.713	532.645	0	33.71	443.3
KLRC_2019_01_21002	13:17:10 L	2406.78	293.659	1511.875	570.003	0	31.242	377.7
KLRC_2019_01_21003	13:23:31 R	2399.738	279.92	1543.962	534.492	0	41.365	441.8

DISCHARGE	Start Time (01/22/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:27:11	**2448.353**	302.98	1652.765	464.526	0	28.082	1856.3
KLRC_2019_01_22_2002	14:27:11 L	2557.081	324.487	1746.455	447.758	0	38.381	479.6
KLRC_2019_01_22_2004	14:45:48 L	2319.598	274.226	1558.353	461.472	0	25.547	518.8
KLRC_2019_01_22_2005	14:54:32 R	2365.701	305.333	1599.174	443.423	0	17.771	459.2
KLRC_2019_01_22_2006	15:08:05 L	2551.032	307.876	1707.078	505.45	0	30.629	398.6

DISCHARGE	Start Time (02/04/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	13:16:45	**1530.278**	117.977	881.986	500.859	0	29.456	1836.5
KLRC_2019_02_04_1000	13:16:45 L	1559.79	125.892	876.146	530.335	0	27.416	241.5
KLRC_2019_02_04_1001	13:21:05 R	1550.203	113.547	905.614	502.802	0	28.239	394.6
KLRC_2019_02_04_1002	13:27:44 L	1498.659	122.341	850.945	495.263	0	30.11	304.7
KLRC_2019_02_04_1003	13:33:12 R	1479.414	116.744	856.353	478.209	0	28.107	324.2
KLRC_2019_02_04_1004	13:38:45 L	1539.952	114.467	898.556	495.285	0	31.644	330.8
KLRC_2019_02_04_1005	13:44:20 R	1553.651	114.869	904.299	503.262	0	31.221	240.8

DISCHARGE	Start Time (02/14/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	12:37:49	3263.104	**304.189**	2211.228	538.334	-13.62	75.339	785.3
klrc_take2001	12:37:49 R	3473.183	326.052	2395.742	561.318	-21.017	52.756	150.3
klrc_take2002	12:40:31 L	3050.632	299.31	2093.776	479.734	-11.305	60.158	118.2
klrc_take2003	12:43:48 R	3362.975	292.774	2311.858	561.183	-12.22	56.206	129.1
klrc_take2005	12:51:02 L	3244.211	292.893	2145.453	544.217	25.482	85.839	142
klrc_take2006	12:53:40 R	3268.334	315.671	2197.514	538.947	-30.695	85.394	127.1
klrc_take2009	13:32:30 R	3179.287	298.432	2123.027	544.606	-31.968	111.68	118.8

DISCHARGE	Start Time (02/15/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:42:05	**3699.222**	377.103	2651.666	652.815	-17.344	34.982	581.9
wst_klrc_20190215000	14:42:05 L	3834.89	401.4	2754.618	665.802	-14.464	27.534	171.1
wst_klrc_20190215001	14:45:03 R	3629.945	391.154	2609.73	625.103	-21.292	25.25	122
wst_klrc_20190215002	14:47:19 L	3733.958	362.205	2658.311	683.693	-16.892	46.641	138
wst_klrc_20190215003	14:49:53 R	3598.094	353.654	2584.003	636.663	-16.728	40.503	150.8

WSB Qrev Results

DISCHARGE	Start Time (02/09/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	11:21:50	**550.413**	80.218	292.744	147.584	5.227	24.641	386.1
WSB_020917002	11:21:50 L	548.466	83.555	292.809	149.134	4.383	18.585	79.7
WSB_020917003	11:26:55 R	551.141	80.708	293.069	143.465	4.284	29.615	93.2
WSB_020917004	11:28:54 L	550.473	78.608	290.002	153.554	6.534	21.774	100
WSB_020917006	11:32:09 R	551.574	77.999	295.097	144.182	5.706	28.589	113.2

DISCHARGE	Start Time (02/20/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	10:20:30	**873.956**	101.995	451.035	252.586	12.746	55.594	622.3
WSB_022017000	10:20:30 R	857.258	100.917	456.475	247.942	8.034	43.891	118.6
WSB_022017001	10:22:49 L	820.547	104.946	446.462	239.161	8.802	21.176	101.8
WSB_022017003	10:25:18 R	888.466	100.741	446.971	270.789	21.1	48.865	153.2
WSB_022017004	10:29:02 L	921.38	105.551	455.052	254.302	14.479	91.996	120.8
WSB_022017005	10:32:11 R	882.13	97.82	450.215	250.735	11.314	72.046	127.9

DISCHARGE	Start Time (02/21/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	7:57:24	**1962.425**	355.52	1089.208	465.348	47.077	5.271	816.6
WSB_2017_02_21000	07:57:24 L	1997.867	362.544	1103.97	484.957	45.209	1.187	259.7
WSB_2017_02_21001	08:03:31 R	1991.565	354.9	1100.217	469.349	56.101	10.999	263.1
WSB_2017_02_21002	08:09:33 L	1897.841	349.116	1063.438	441.737	39.922	3.628	293.7

DISCHARGE	Start Time (02/22/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	8:27:13	**928.305**	112.2	497.957	294.866	18.714	4.569	675.6
WSB_2017_02_22001	08:27:13 R	909.957	106.938	489.597	289.555	18.714	5.154	139.1
WSB_2017_02_22002	08:31:28 L	929.031	112.547	501.569	292.635	18.714	3.567	121.1
WSB_2017_02_22003	08:33:43 R	936.96	115.817	506.391	290.95	18.714	5.087	139.3
WSB_2017_02_22004	08:36:09 L	953.507	117.088	506.305	307.668	18.714	3.732	132.3
WSB_2017_02_22005	08:38:27 R	912.071	108.611	485.921	293.522	18.714	5.303	143.8

DISCHARGE	Start Time (02/22/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	17:17:25	**766.9**	97.124	398.509	238.909	11.716	20.643	475.6
WSB_2017_02_22007	17:17:25 L	791.554	96.937	403.577	249.27	20.011	21.759	111.4
WSB_2017_02_22008	17:20:17 R	757.711	93.82	398.595	234.675	10.459	20.162	164.1
WSB_2017_02_22009	17:23:21 L	763.371	101.762	398.161	231.527	9.218	22.705	101.4
WSB_2017_02_22010	17:25:13 R	754.965	95.976	393.704	240.165	7.176	17.945	98.7

DISCHARGE	Start Time (09/19/2018)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	4:59:01	**410.143**	39.015	302.479	65.019	4.644	-1.015	751.3
WSB_2019_01_07_2000	04:59:01 R	423.081	36.903	309.79	72.279	5.305	-1.195	151.2
WSB_2019_01_07_2001	05:01:50 L	375.754	33.839	275.12	61.584	5.894	-0.683	159.1
WSB_2019_01_07_2002	13:38:59 R	425.905	38.509	311.923	72.97	4.005	-1.502	157.2
WSB_2019_01_07_2003	13:42:10 L	415.659	46.649	304.203	60.738	4.824	-0.755	150.3
WSB_2019_01_07_2005	13:49:23 L	410.317	39.176	311.361	57.526	3.193	-0.939	133.5

DISCHARGE	Start Time (01/07/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	16:29:01	**372.93**	33.4	273.66	61.96	5.087	-1.177	453.1
WSB_2019_01_07_7001	16:29:01 L	336.053	28.319	248.804	54.349	5.526	-0.945	108.9
WSB_2019_01_07_7003	16:33:06 L	379.138	32.216	279.943	61.953	6.214	-1.188	100.4
WSB_2019_01_07_7004	16:34:56 R	384.168	34.285	282.083	64.629	4.027	-0.857	151.8
WSB_2019_01_07_7005	16:37:32 L	392.362	38.781	283.809	66.91	4.58	-1.718	92

DISCHARGE	Start Time (01/08/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	8:47:04	**192.255**	25.846	134.173	25.609	7.657	-1.03	764.5
WSB_2019_01_08_2000	08:47:04 L	191.035	26.251	129.748	24.46	11.086	-0.51	95.8
WSB_2019_01_08_2001	08:48:48 R	204.045	25.519	142.934	29.755	7.815	-1.978	132
WSB_2019_01_08_2002	08:51:09 L	192.287	25.711	134.062	26.809	7.308	-1.602	120.1
WSB_2019_01_08_2003	08:53:13 R	181.154	24.526	127.733	23.966	7.355	-2.425	139.4
WSB_2019_01_08_2004	08:55:39 L	191.978	27.438	134.906	24.069	6.79	-1.225	124.7
WSB_2019_01_08_2005	08:57:50 R	193.028	25.628	135.654	24.598	5.586	1.563	152.6

DISCHARGE	Start Time (01/08/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:19:50	**146.548**	26.824	91.545	15.733	4.767	7.679	641
WSB_2019_01_08_3000	14:19:50 L	145.853	26.954	90.739	14.81	4.601	8.749	105.3
WSB_2019_01_08_3001	14:21:47 R	144.602	26.214	92.393	15.986	3.663	6.347	109.1
WSB_2019_01_08_3002	14:23:40 L	148.207	26.626	92.093	17.839	4.873	6.776	107.8
WSB_2019_01_08_3003	14:25:33 R	149.189	26.766	93.004	16.29	6.197	6.931	107
WSB_2019_01_08_3004	14:27:25 L	151.913	28.296	94.034	14.975	6.737	7.871	111.9
WSB_2019_01_08_3005	14:29:57 R	139.526	26.088	87.005	14.5	2.531	9.403	99.8

DISCHARGE	Start Time (01/16/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	12:42:49	**561.743**	40.482	415.146	100.889	5.97	-0.745	1056.5
WSB_2019_01_16_5000	12:42:49 R	540.864	39.982	397.466	102.048	4.411	-3.042	169.7
WSB_2019_01_16_5002	12:48:21 R	563.448	41.988	415.227	99.457	7.512	-0.737	135.1
WSB_2019_01_16_5003	12:50:42 L	524.1	38.023	383.134	96.563	7.327	-0.947	137.8
WSB_2019_01_16_5004	12:58:19 R	589.686	40.438	439.842	105.095	5.847	-1.536	108.2
WSB_2019_01_16_5008	13:25:14 R	566.982	42.053	417.555	99.412	6.692	1.27	122.9
WSB_2019_01_16_5009	13:27:25 L	550.45	38.814	409.324	97.219	6.279	-1.186	126.1
WSB_2019_01_16_5010	13:29:39 R	573.824	42.268	424.214	103.699	4.419	-0.776	113.6
WSB_2019_01_16_5011	13:31:39 L	584.588	40.292	434.404	103.619	5.277	0.996	143

DISCHARGE	Start Time (01/17/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	12:32:21	**1377.58**	229.808	820.704	283.65	33.433	9.985	1430.7
WSB_2019_01_17_2001	12:32:21 L	1330.99	225.268	806.953	258.595	31.675	8.498	315.6
WSB_2019_01_17_2004	12:46:16 L	1380.712	225.181	837.672	274.039	37.36	6.46	349.8
WSB_2019_01_17_2006	14:50:07 R	1390.567	244.659	828.303	302.317	10.158	5.13	224.4
WSB_2019_01_17_2008	15:01:05 R	1373.374	231.33	810.112	289.868	28.869	13.195	257.8
WSB_2019_01_17_2009	15:06:15 L	1412.259	222.603	820.479	293.433	59.103	16.641	283.1

DISCHARGE	Start Time (01/18/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	7:49:40	**1202.163**	191.513	703.399	265.773	31.037	10.44	1159.2
WSB_2019_01_18_1000	07:49:40 R	1174.22	184.295	709.289	254.379	22.547	3.711	156.3
WSB_2019_01_18_1001	07:53:21 L	1220.842	188.411	714.703	266.067	48.205	3.456	222.6
WSB_2019_01_18_1002	07:58:09 R	1196.512	189.561	693.973	265.085	29.457	18.436	192.9
WSB_2019_01_18_1004	08:06:39 R	1189.515	190.141	685.861	262.8	33.502	17.21	202.9
WSB_2019_01_18_1006	08:15:22 R	1234.924	196.512	714.94	284.739	24.942	13.791	188.1
WSB_2019_01_18_1007	08:19:06 L	1196.963	200.156	701.63	261.568	27.571	6.037	196.4

DISCHARGE	Start Time (01/18/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:34:26	**904.178**	96.149	520.853	255.825	25.101	6.25	647.7
WSB_2019_01_18_2000	14:34:26 R	933.236	114.233	549.196	254.584	12.877	2.347	182.1
WSB_2019_01_18_2002	14:42:37 R	874.42	86.834	503.383	254.784	22.82	6.598	170.5
WSB_2019_01_18_2003	14:46:09 L	916.193	91.993	518.702	257.169	43.469	4.859	157.1
WSB_2019_01_18_2004	14:49:45 R	892.865	91.536	512.129	256.763	21.24	11.197	138

DISCHARGE	Start Time (01/20/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	9:49:56	**292.952**	53.703	160.618	67.141	8.695	2.796	490.9
WSB_2019_01_20_1002	09:49:56 R	289.698	52.148	160.152	66.242	9.287	1.869	146.1
WSB_2019_01_20_1003	09:52:27 L	304.297	55.221	166.809	65.762	10.025	6.479	107.9
WSB_2019_01_20_1004	09:54:22 R	282.82	53.048	153.679	66.057	8.887	1.15	127.2
WSB_2019_01_20_1005	09:56:38 L	294.992	54.393	161.83	70.502	6.58	1.685	109.8

DISCHARGE	Start Time (02/04/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	15:50:31	**653.296**	73.235	352.38	208.411	20.52	-1.25	929
WSB_2019_02_04_1000	15:50:31 R	646.734	72.132	346.689	203.008	22.662	2.244	170.8
WSB_2019_02_04_1001	15:53:42 L	659.745	72.461	352.999	220.532	24.323	-10.57	159.6
WSB_2019_02_04_1002	15:56:28 R	614.329	66.812	330.321	202.812	21.604	-7.22	144.8
WSB_2019_02_04_1003	15:58:59 L	672.048	72.904	363.685	208.982	22.04	4.437	154.3
WSB_2019_02_04_1004	16:02:04 R	669.908	78.747	359.123	205.407	15.726	10.905	123.5
WSB_2019_02_04_1005	16:04:15 L	657.015	76.353	361.462	209.726	16.766	-7.292	175.9

DISCHARGE	Start Time (02/15/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	10:17:44	**2383.142**	388.001	1408.929	531.83	7.488	46.894	1038.1
wst_wsb_20190215000	10:17:44 L	2483.936	402.45	1465.71	553.813	8.886	53.077	215.1
wst_wsb_20190215001	10:22:01 R	2279.712	381.75	1340.533	500.74	8.582	48.108	243.8
wst_wsb_20190215002	10:26:19 L	2433.513	390.541	1428.396	548.418	8.557	57.601	191
wst_wsb_20190215003	10:29:42 R	2395.226	393.214	1420.786	527.427	4.571	49.229	172
wst_wsb_20190215005	10:45:01 R	2323.32	372.052	1389.221	528.752	6.841	26.454	216.1

PUS Qrev Results

DISCHARGE	Start Time (02/09/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:12:37	**561.834**	48.077	255.15	147.935	106.91	3.761	702
pus_020917001	14:12:37 L	498.051	42.986	229.02	120.306	106.91	-1.172	124.4
pus_020917003	14:26:24 L	555.64	51.306	262.99	132.126	106.91	2.308	97.4
pus_020917004	14:30:28 R	554.008	44.207	241.9	151.492	106.91	9.498	103
pus_020917005	14:35:41 L	564.104	48.373	253.275	149.018	106.91	6.528	99.4
pus_020917008	14:40:46 R	566.902	46.555	254.822	156.12	106.91	2.494	84.5
pus_020917009	14:43:56 L	592.63	53.076	281.851	148.996	106.91	1.797	90.9
pus_020917010	14:45:54 R	601.5	50.034	262.189	177.489	106.91	4.878	102.3

DISCHARGE	Start Time (02/13/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	12:09:43	**733.556**	138.293	358.832	163.63	37.698	35.103	1411.4
PUS-021317001	12:09:43 R	703.818	131.861	339.062	155.897	37.698	39.3	275.7
PUS-021317002	12:20:03 L	762.272	147.241	368.916	169.486	37.698	38.931	184.1
PUS-021317003	12:23:26 R	765.093	142.484	370.789	181.149	37.698	32.973	313.4
PUS-021317004	12:30:16 L	732.08	134.982	361.656	160.786	37.698	36.958	249.1
PUS-021317005	12:34:57 R	704.516	134.895	353.735	150.834	37.698	27.355	389.1

DISCHARGE	Start Time (02/18/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	16:21:15	**3141.776**	391.581	1961.63	769.956	4.13	14.48	807.9
PUS021817001	16:21:15 L	3149.306	392.092	1967.684	771.472	9.251	8.808	230.6
PUS021817002	16:25:35 R	3172.804	387.532	1972.787	757.882	5.767	48.836	171.4
PUS021817003	16:29:57 L	3072.012	382.261	1926.249	772.492	2.931	-11.921	177.5
PUS021817004	16:33:54 R	3172.983	404.441	1979.799	777.978	-1.431	12.196	228.3

DISCHARGE	Start Time (02/20/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	13:18:00	**4839.273**	483.976	2987.528	1342.192	17.454	8.124	965.1
PUS_022017000	13:18:00 L	4907.098	502.553	3084.432	1310.872	19.999	-10.758	184.7
PUS_022017001	13:23:00 R	4826.701	487.122	2968.144	1345.056	13.725	12.654	145.4
PUS_022017003	13:29:26 L	4621.737	461.588	2848.813	1319.968	17.425	-26.056	168.8
PUS_022017004	13:34:15 R	4804.35	468.999	2971.641	1354.499	15.603	-6.393	161.6
PUS_022017005	13:40:19 L	5055.127	501.68	3116.253	1386.267	24.268	26.659	172.5
PUS_022017006	13:44:39 R	4820.628	481.911	2935.883	1336.489	13.707	52.638	132.1

DISCHARGE	Start Time (02/21/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	11:26:50	**7433.413**	678.785	4752.751	1935.141	2.813	63.923	1039.1
PUS_2017_02_21000	11:26:50 L	7563.595	688.089	4765.445	1992.67	3.668	113.723	346.4
PUS_2017_02_21001	11:34:05 R	7162.481	653.227	4623.355	1819.508	2.866	63.525	211.4
PUS_2017_02_21002	11:38:05 L	7530.986	693.13	4791.154	2009.698	2.243	34.762	242.3
PUS_2017_02_21003	11:49:30 R	7476.589	680.695	4831.052	1918.687	2.476	43.68	238.9

DISCHARGE	Start Time (02/21/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	16:52:29	**7200.41**	610.015	4633.456	1898.729	3.113	55.097	829.1
PUS_022017007	16:52:29 L	7060.467	602.538	4535.897	1876.51	3.142	42.38	232.8
PUS_022017008	16:57:52 R	7283.294	614.607	4672.761	1924.252	2.954	68.721	188.5
PUS_022017009	17:01:41 L	7231.568	621.926	4660.404	1915.614	1.792	31.832	210.4
PUS_022017010	17:06:27 R	7226.311	600.991	4664.761	1878.539	4.563	77.457	197.4

DISCHARGE	Start Time (02/22/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	10:39:50	**7163.457**	670.286	4563.113	1869.515	2.638	57.906	1064
PUS_2017_02_22000	10:39:50 L	7246.87	679.928	4637.044	1888.083	2.725	39.089	306.7
PUS_2017_02_22001	10:46:30 R	7083.818	657.504	4498.616	1827.689	2.12	97.89	244.6
PUS_2017_02_22002	10:51:36 L	7335.363	689.024	4666.607	1951.569	1.727	26.436	290.6
PUS_2017_02_22003	10:57:16 R	6987.776	654.687	4450.184	1810.717	3.978	68.211	222

DISCHARGE	Start Time (02/23/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:39:50	**6483.279**	644.741	4077.27	1746.705	4.099	10.463	721.3
PUS_2017_02_23000	14:39:50 L	6526.567	651.248	4112.849	1771.919	5.181	-14.63	194.2
PUS_2017_02_23001	14:43:18 R	6402.263	632.45	3991.916	1729.042	3.84	45.015	167.7
PUS_2017_02_23002	14:46:19 L	6654.568	661.25	4192.918	1774.144	4.035	22.221	179.3
PUS_2017_02_23003	14:50:22 R	6349.716	634.017	4011.395	1711.716	3.341	-10.753	180.1

DISCHARGE	Start Time (02/24/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	13:47:24	**5821.145**	557.352	3593.871	1641.368	3.675	24.879	676.4
PUS_2017_02_24000	13:47:24 L	5839.756	563.978	3611.686	1645.911	3.598	14.582	198
PUS_2017_02_24001	13:52:03 R	5672.661	537.505	3498.508	1591.772	3.835	41.041	168.3
PUS_2017_02_24002	13:55:04 L	5870.76	570.427	3642.64	1644.599	3.427	9.668	156.6
PUS_2017_02_24003	13:58:39 R	5901.405	557.499	3622.65	1683.19	3.84	34.226	153.4

DISCHARGE	Start Time (02/25/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	12:03:54	**5383.855**	590.656	3385.562	1398.016	2.532	7.089	670
PUS_2017_02_25-2000	12:03:54 L	5423.202	593.954	3404.824	1427.701	2.425	-5.703	184.8
PUS_2017_02_25-2001	12:08:12 R	5307.64	584.438	3331.217	1372.632	2.386	16.968	187.4
PUS_2017_02_25-2002	12:11:41 L	5332.61	584.768	3356.65	1406.071	2.916	-17.795	161.7
PUS_2017_02_25-2003	12:15:34 R	5471.969	599.465	3449.557	1385.662	2.4	34.885	136.1

DISCHARGE	Start Time (02/26/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	12:33:14	**4851.069**	526.842	2902.269	1420.864	8.25	-7.156	655.5
PUS_2017_02_26000	12:33:14 L	4987.811	534.825	2945.417	1474.326	25.199	8.043	149.8
PUS_2017_02_26001	12:37:02 R	4845.963	529.464	2939.945	1392.265	2.799	-18.51	172.7
PUS_2017_02_26002	12:40:20 L	4777.243	523.654	2868.325	1394.207	2.413	-11.356	171.1
PUS_2017_02_26003	12:44:19 R	4793.261	519.425	2855.39	1422.658	2.591	-6.803	161.8

DISCHARGE	Start Time (02/27/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	12:32:19	**4107.448**	470.019	2509.546	1102.953	10.536	14.393	628.5
PUS_022717001	12:32:19 L	4077.078	459.48	2470.601	1117.691	18.323	10.983	162.2
PUS_022717002	12:35:45 R	3963.681	455.692	2397.151	1093.527	3.562	13.748	162.7
PUS_022717003	12:39:12 L	4183.595	479.162	2572.18	1111.923	15.11	5.22	151.9
PUS_022717004	12:42:37 R	4205.436	485.74	2598.252	1088.673	5.15	27.621	151.7

DISCHARGE	Start Time (02/28/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	11:58:16	**4021.919**	467.635	2423.931	1101.208	9.837	19.308	710.2
PUS_022817_02000	11:58:16 L	4106.388	481.003	2478.174	1141.534	13.787	-8.11	202.9
PUS_022817_02001	12:02:25 R	3997.792	458.076	2395.339	1082.295	5.321	56.762	158.1
PUS_022817_02002	12:05:58 L	4033.681	470.421	2436.387	1123.462	15.026	-11.615	187.9
PUS_022817_02003	12:10:49 R	3949.817	461.041	2385.824	1057.542	5.215	40.194	161.2

DISCHARGE	Start Time (03/03/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	11:47:48	**2850.941**	364.61	1761.303	648.698	3.984	72.345	749.2
PUS_030317000	11:47:48 L	2902.78	360.898	1803.059	665.001	3.352	70.47	171.6
PUS_030317001	11:51:22 R	2897.252	368.466	1750.54	708.814	3.473	65.959	165
PUS_030317003	11:57:54 L	2802.731	371.597	1768.075	591.082	5.129	66.849	203
PUS_030317004	12:01:41 R	2800.999	357.48	1723.539	629.896	3.981	86.103	209.6

DISCHARGE	Start Time (03/05/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	9:07:11	**2269.003**	318.048	1337.73	513.53	0.524	99.171	1067.5
PUS_2017_03_05000	09:07:11 L	2289.959	328.189	1354.223	509.847	0.876	96.823	245
PUS_2017_03_05001	09:11:42 R	2277.061	312.7	1347.767	527.634	1.205	87.754	248.6
PUS_2017_03_05002	09:16:08 L	2258.746	315.668	1329.131	503.248	1.589	109.11	290.3
PUS_2017_03_05003	09:21:07 R	2250.248	315.635	1319.801	513.389	-1.574	102.998	283.6

DISCHARGE	Start Time (03/07/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	10:18:07	**1688.723**	282.131	985.232	382.312	5.335	33.712	1361
PUS_2017_03_07001	10:18:07 L	1702.159	286.839	987.57	385.013	6.35	36.387	313.7
PUS_2017_03_07002	10:23:28 R	1665.505	282.528	963.561	383.72	5.055	30.642	399.9
PUS_2017_03_07003	10:30:14 L	1676.624	281.617	982.885	369.991	6.416	35.716	298.5
PUS_2017_03_07004	10:35:17 R	1710.603	277.54	1006.913	390.525	3.521	32.103	348.9

DISCHARGE	Start Time (03/17/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:35:08	**1022.567**	205.183	555.94	242.395	0.977	18.072	1245.8
PUS_2017_03_17000	14:35:08 L	1059.748	209.762	575.251	252.469	1.563	20.702	378.2
PUS_2017_03_17001	14:41:48 R	1008.843	202.47	546.043	238.606	1.986	19.738	311.6
PUS_2017_03_17002	14:47:04 L	1055.473	200.304	569.944	268.792	1.263	15.171	287.9
PUS_2017_03_17003	14:52:00 R	966.202	208.196	532.521	209.712	-0.904	16.676	268

DISCHARGE	Start Time (02/28/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	9:18:21	**8521.273**	734.586	5399.921	2177.838	105.759	103.169	768
2019_02_27_PUS000	09:18:21 L	8610.636	740.242	5442.231	2240.956	101.817	85.389	111.4
2019_02_27_PUS001	09:21:05 R	8813.74	742.65	5488.022	2332.394	120.107	130.567	129.6
2019_02_27_PUS002	09:23:27 L	8310.072	713.604	5335.512	2080.874	97.618	82.464	134.5
2019_02_27_PUS003	09:25:46 R	8581.329	751.808	5434.811	2155.481	106.126	133.103	148.6
2019_02_27_PUS004	09:28:49 L	8306.664	710.643	5326.873	2075.47	92.998	100.681	123.7
2019_02_27_PUS005	09:30:57 R	8505.199	748.57	5372.075	2181.856	115.887	86.811	120.2

PDS Qrev Results

DISCHARGE	Start Time (02/28/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	10:07:13	**7835.172**	451.092	6543.194	832.013	7.192	1.681	789.7
PDS_2019_02_28001	10:07:13 L	8369.289	651.132	6856.062	854.377	4.15	3.568	190.8
PDS_2019_02_28002	10:10:36 R	7996.665	391.478	6716.193	870.687	17.81	0.497	188.6
PDS_2019_02_28006	10:26:44 R	7538.082	392.26	6282.326	859.374	3.114	1.009	212.7
PDS_2019_02_28008	10:35:46 R	7436.652	369.497	6318.196	743.614	3.695	1.649	197.6

DISCHARGE	Start Time (02/13/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	16:39:08	**660.937**	83.472	467.492	112.349	-0.725	-1.652	1411.4
PDS_021317010	16:39:08 L	661.811	83.177	442.73	137.464	-2.85	1.289	178.1
PDS_021317014	16:59:11 L	611.214	81.657	438.138	95.913	-2.314	-2.179	228
PDS_021317015	17:03:20 R	687.275	88.998	490.924	108.097	0.953	-1.696	336.6
PDS_021317016	17:09:46 L	659.346	85.966	468.229	110.317	-1.805	-3.361	276.4
PDS_021317017	17:14:37 R	685.037	77.563	497.441	109.955	2.393	-2.315	392.4

DISCHARGE	Start Time (02/18/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	11:01:39	**3471.066**	234.589	2427.9	763.701	0.282	44.593	1729.3
PDS021817002	11:01:39 L	3207.753	209.18	2264.276	671.783	3.604	58.911	638
PDS021817004	11:15:10 R	3407.259	233.941	2384.812	767.137	-5.611	26.981	408.2
PDS021817006	11:26:13 L	3718.633	253.997	2587.221	842.392	1.862	33.162	326.7
PDS021817007	11:31:57 R	3550.617	241.239	2475.292	773.491	1.275	59.32	356.4

DISCHARGE	Start Time (02/20/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	16:51:37	**4452.861**	228.408	3052.633	1051.672	1.428	118.721	1253.4
PDS_022017001	16:51:37 L	4446.266	233.027	3043.107	1020.107	-4.431	154.456	279.4
PDS_022017003	16:59:42 L	4545.904	236.229	3133.896	1065.338	5.861	104.58	253.2
PDS_022017004	17:04:07 R	4425.44	211.98	3023.358	1111.592	7.081	71.43	185.8
PDS_022017005	17:07:30 L	4611.575	235.587	3155.546	1089.418	-5.321	136.344	330.6
PDS_022017006	17:13:20 R	4235.123	225.217	2907.26	971.902	3.949	126.795	204.5

DISCHARGE	Start Time (02/21/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:40:03	**7123.164**	524.051	5410.079	1038.012	4.415	146.607	717.9
PDS_2017_02_21002	14:40:03 L	6655.825	469.406	4978.335	883.509	-9.272	333.846	194.2
PDS_2017_02_21003	14:49:23 R	6617.987	474.329	5046.34	1021.064	20.005	56.249	278.9
PDS_2017_02_21004	15:10:56 L	8095.681	628.417	6205.563	1209.463	2.512	49.727	244.8
PDS_2017_02_21005	15:19:32 R	6664.114	490.907	5049.998	1037.242	6.733	79.234	210.4
PDS_2017_02_21006	15:28:27 R	6351.09	484.313	4735.32	1075.867	6.532	49.058	209.2

DISCHARGE	Start Time (02/23/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	11:34:27	**6328.015**	376.586	4432.182	1339.494	20.431	159.323	16:48:00
PDS_2017_02_23003	11:34:27 R	6808.674	387.344	4676.168	1419.045	20.431	305.686	178.7
PDS_2017_02_23006	11:43:15 R	6094.16	378.09	4207.956	1309.817	20.431	177.866	178.8
PDS_2017_02_23007	11:49:41 L	6001.525	351.729	4251.623	1268.969	20.431	108.772	106.9
PDS_2017_02_23008	11:56:04 R	6419.541	375.826	4520.827	1353.044	20.431	149.413	155.8
PDS_2017_02_23011	12:04:53 L	6769.922	411.475	4765.042	1452.456	20.431	120.518	104
PDS_2017_02_23012	12:07:40 R	5874.27	355.053	4171.473	1233.632	20.431	93.68	144.6

DISCHARGE	Start Time (02/23/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	15:53:02	**6238.905**	392.775	4438.048	1239.086	12.69	156.305	730.4
PDS_2017_02_23-2000	15:53:02 L	6226.136	386.412	4432.188	1244.208	12.69	150.638	125.9
PDS_2017_02_23-2001	15:56:12 R	6693.688	420.972	4803.565	1302.258	12.69	154.204	190.2
PDS_2017_02_23-2003	16:03:10 R	6429.677	399.629	4589.192	1245.789	12.69	182.376	144.2
PDS_2017_02_23-2004	16:09:24 L	5931.781	373.13	4243.207	1218.576	12.69	84.178	141.2
PDS_2017_02_23-2005	16:12:47 R	5913.242	383.734	4122.091	1184.599	12.69	210.129	128.9

DISCHARGE	Start Time (02/24/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	15:29:42	**5751.283**	322.921	4028.74	1304.462	16.871	78.289	972.6
PDS_2017_02_24000	15:29:42 L	5688.392	320.767	3928.251	1325.225	16.871	97.278	132.3
PDS_2017_02_24001	15:32:48 R	5283.773	272.101	3734.284	1176.844	16.871	83.674	153.4
PDS_2017_02_24002	15:36:36 L	5930.471	373.274	4215.766	1287.349	16.871	37.211	172.6
PDS_2017_02_24005	15:49:35 R	5657.977	316.187	3926.803	1301.703	16.871	96.413	182
PDS_2017_02_24006	15:54:20 L	5792.89	318	4040.568	1328.154	16.871	89.298	128.2
PDS_2017_02_24007	15:57:42 R	6154.194	337.2	4326.767	1407.497	16.871	65.858	204.1

DISCHARGE	Start Time (02/25/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	13:56:38	**5570.973**	356.652	3932.99	1146.014	13.454	121.863	651.6
PDS_2017_02_25000	13:56:38 L	5627.379	360.106	4021.43	1147.955	-12.809	110.698	150.3
PDS_2017_02_25002	14:03:23 L	5664.272	377.479	3972.381	1204.572	20.283	89.557	103.4
PDS_2017_02_25003	14:06:04 R	5478.854	347.185	3904.35	1118.291	12.842	96.186	185.7
PDS_2017_02_25005	14:13:38 R	5513.386	341.837	3833.8	1113.24	33.499	191.011	212.2

DISCHARGE	Start Time (02/26/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	10:19:42	**4827.443**	279.679	3372.195	1116.284	0.399	58.886	670.4
PDS_2017_02_26001	10:19:42 L	5125.924	322.819	3626.03	1152.998	0.399	23.678	120.8
PDS_2017_02_26002	10:22:57 R	4805.261	274.548	3305.93	1118.084	0.399	106.3	135.2
PDS_2017_02_26003	10:26:26 L	4549.437	262.806	3198.479	1025.697	0.399	62.057	115
PDS_2017_02_26004	10:29:15 R	4779.657	276.301	3335.058	1101.656	0.399	66.242	174.7
PDS_2017_02_26005	10:35:07 L	4876.939	261.922	3395.477	1182.985	0.399	36.156	124.7

DISCHARGE	Start Time (02/27/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:54:59	4406.72	296.879	3105.744	957.353	3.804	42.94	753.1
PDS_022717001	14:54:59 L	3990.088	269.943	2809.952	873.178	6.899	30.116	155
PDS_022717004	15:01:16 R	4407.363	287.987	3087.341	924.619	-5.565	112.981	190.6
PDS_022717006	15:06:41 L	4473.977	306.242	3147.261	984.074	8.402	27.999	117.7
PDS_022717007	15:10:08 R	4551.809	305.433	3187.075	1022.898	10.358	26.045	174.5
PDS_022717008	15:14:05 L	4610.364	314.789	3297.092	981.998	-1.075	17.561	115.4

DISCHARGE	Start Time (02/28/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:18:50	4067.328	270.073	2889.673	905.949	-1.734	3.366	1083
PDS_022817001	14:18:50 L	4065.64	265.49	2867.098	934.073	4.454	-5.474	238.2
PDS_022817002	14:26:03 R	3982.043	264.188	2857.417	861.919	-4.07	2.589	242.7
PDS_022817003	14:30:42 L	4302.544	297.117	3050.464	955.817	-2.644	1.79	203.4
PDS_022817005	14:39:59 L	4130.782	276.744	2936.638	908.973	-3.995	12.422	192.8
PDS_022817006	14:44:03 R	3855.629	246.827	2736.75	868.963	-2.416	5.504	205.9

DISCHARGE	Start Time (03/03/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	14:08:56	**2918.574**	196.426	2026.527	634.993	8.231	52.397	1336.4
pds030317003	14:08:56 L	3002.718	198.792	2057.602	678.8	-12.246	79.771	231.4
pds030317005	14:27:12 L	2906.91	192.16	2024.069	643.25	15.794	31.637	217.5
pds030317006	14:31:05 R	2919.483	194.864	2044.897	636.942	7.397	35.383	333.3
pds030317007	14:37:10 L	2818.36	192.516	1954.689	594.658	14.233	62.264	270.8
pds030317008	14:41:57 R	2945.397	203.797	2051.38	621.314	15.979	52.928	283.3

DISCHARGE	Start Time (03/05/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	10:36:53	**2011.867**	179.838	1430.783	338.059	7.779	55.407	2096.7
PDS_2017_03_05000	10:36:53 L	1959.713	173.399	1391.15	322.769	24.647	47.748	233.2
PDS_2017_03_05002	10:45:59 L	2024.203	179.862	1435.586	347.434	11.874	49.447	325.1
PDS_2017_03_05003	10:51:49 R	1990.038	177.104	1412.376	361.334	8.055	31.169	375.9
PDS_2017_03_05005	11:04:59 R	2182.56	197.8	1555.192	356.327	12.123	61.118	410.1
PDS_2017_03_05007	11:31:51 R	1902.82	171.027	1359.608	302.432	-17.802	87.554	752.4

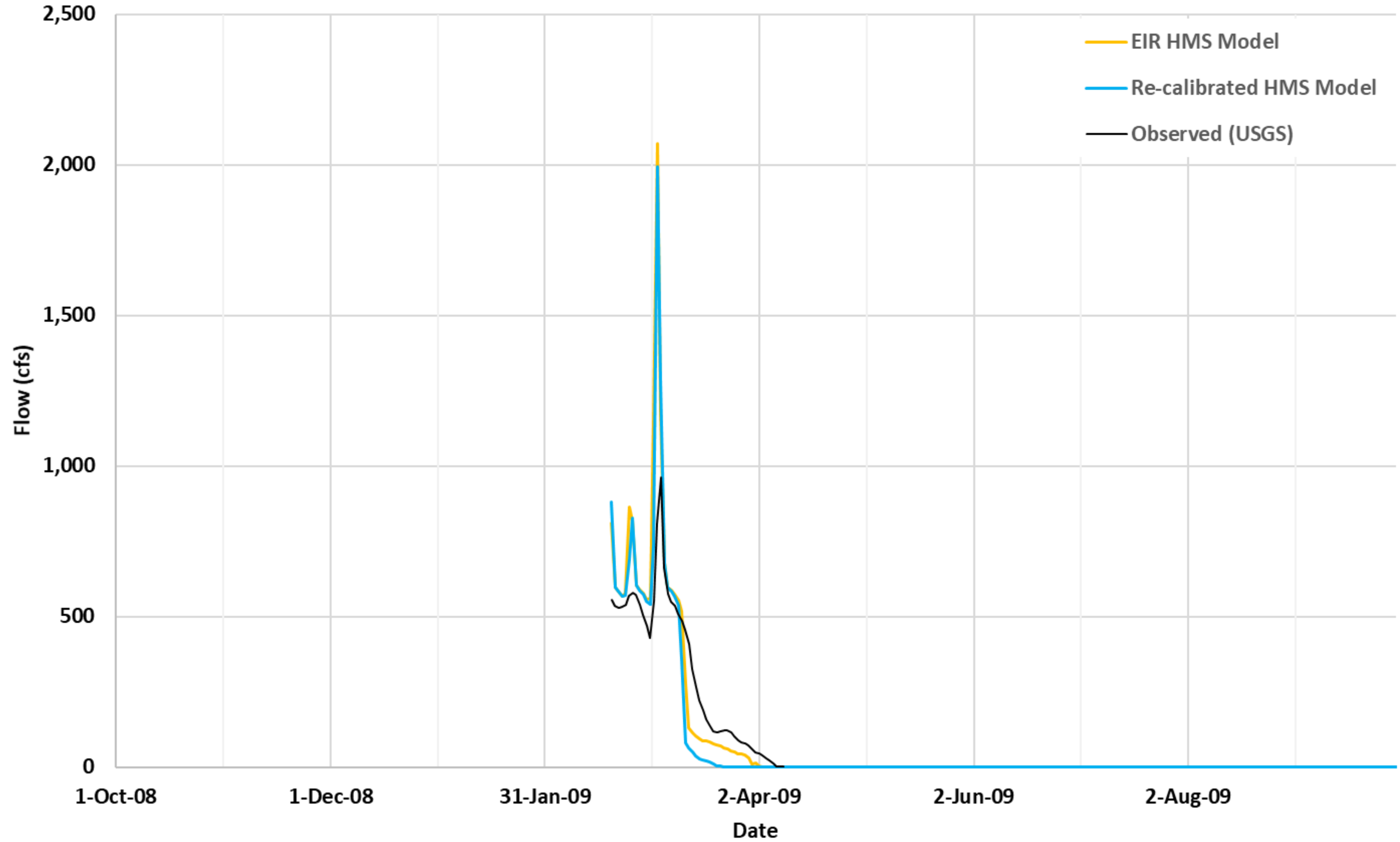
DISCHARGE	Start Time (03/07/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	11:44:29	**1723.43**	148.38	1261.685	299.012	-9.258	23.61	1544.7
PDS_2017_03_07000	11:44:29 L	1699.014	152.42	1239.319	284.058	-7.011	30.228	353.2
PDS_2017_03_07001	11:50:38 R	1724.534	146.988	1264.131	291.297	-4.792	26.909	367.1
PDS_2017_03_07002	11:56:51 L	1706.215	141.049	1244.363	310.916	-3.311	13.198	407.5
PDS_2017_03_07003	12:03:46 R	1763.956	153.063	1298.927	309.779	-21.918	24.106	416.9

DISCHARGE	Start Time (03/17/2017)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	12:12:27	**1102.284**	114.445	803.913	187.124	-1.871	-1.327	1731.3
PDS_2017_03_17-2002	12:12:27 R	1117.414	120.943	804.532	194.94	-1.835	-1.166	510.2
PDS_2017_03_17-2003	12:21:08 L	1140.766	118.506	838.02	189.868	-5.074	-0.554	518.7
PDS_2017_03_17-2004	12:29:53 R	1046.091	102.378	770.508	179.894	-5.982	-0.708	406.4
PDS_2017_03_17-2005	12:45:33 L	1104.866	115.951	802.593	183.792	5.408	-2.879	296.1

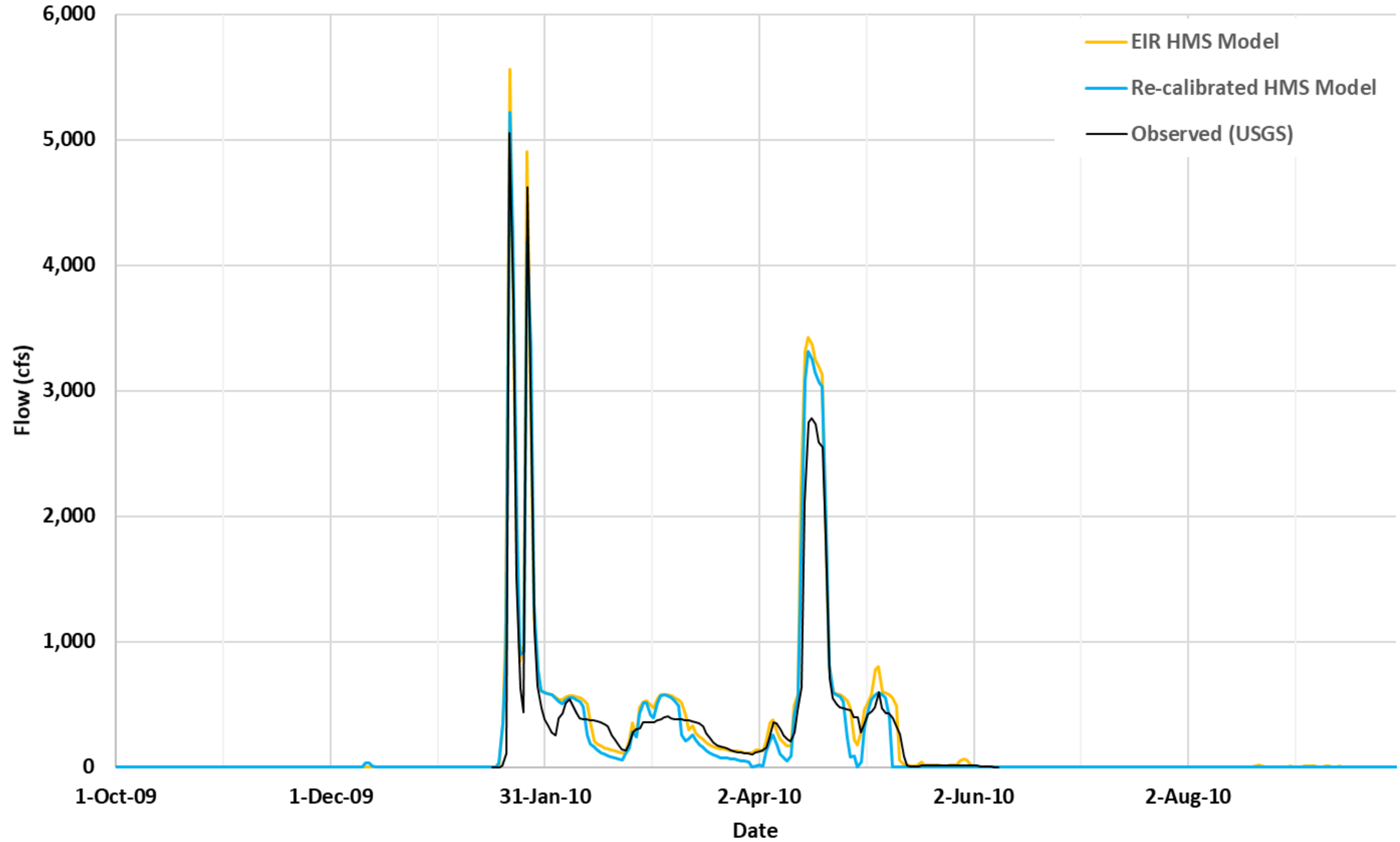
DISCHARGE	Start Time (02/28/2019)	Total Q (ft3/s)	Top Q (ft3/s)	Middle Q (ft3/s)	Bottom Q (ft3/s)	Left Q (ft3/s)	Right Q (ft3/s)	Duration (s)
Cumulative	10:07:13	**7835.172**	451.092	6543.194	832.013	7.192	1.681	789.7
PDS_2019_02_28001	10:07:13 L	8369.289	651.132	6856.062	854.377	4.15	3.568	190.8
PDS_2019_02_28002	10:10:36 R	7996.665	391.478	6716.193	870.687	17.81	0.497	188.6
PDS_2019_02_28006	10:26:44 R	7538.082	392.26	6282.326	859.374	3.114	1.009	212.7
PDS_2019_02_28008	10:35:46 R	7436.652	369.497	6318.196	743.614	3.695	1.649	197.6

APPENDIX C

VISUAL COMPARISONS OF COMPUTED VERSUS OBSERVED CCSB OUTFLOWS FOR EACH WATER YEAR



Notes:		*Yolo Bypass Westside Tributaries Flow Monitoring Project* **CCSB HMS Model: WY 2009**		
		Project No. 17-1004	Created By: LST	**Figure C1**

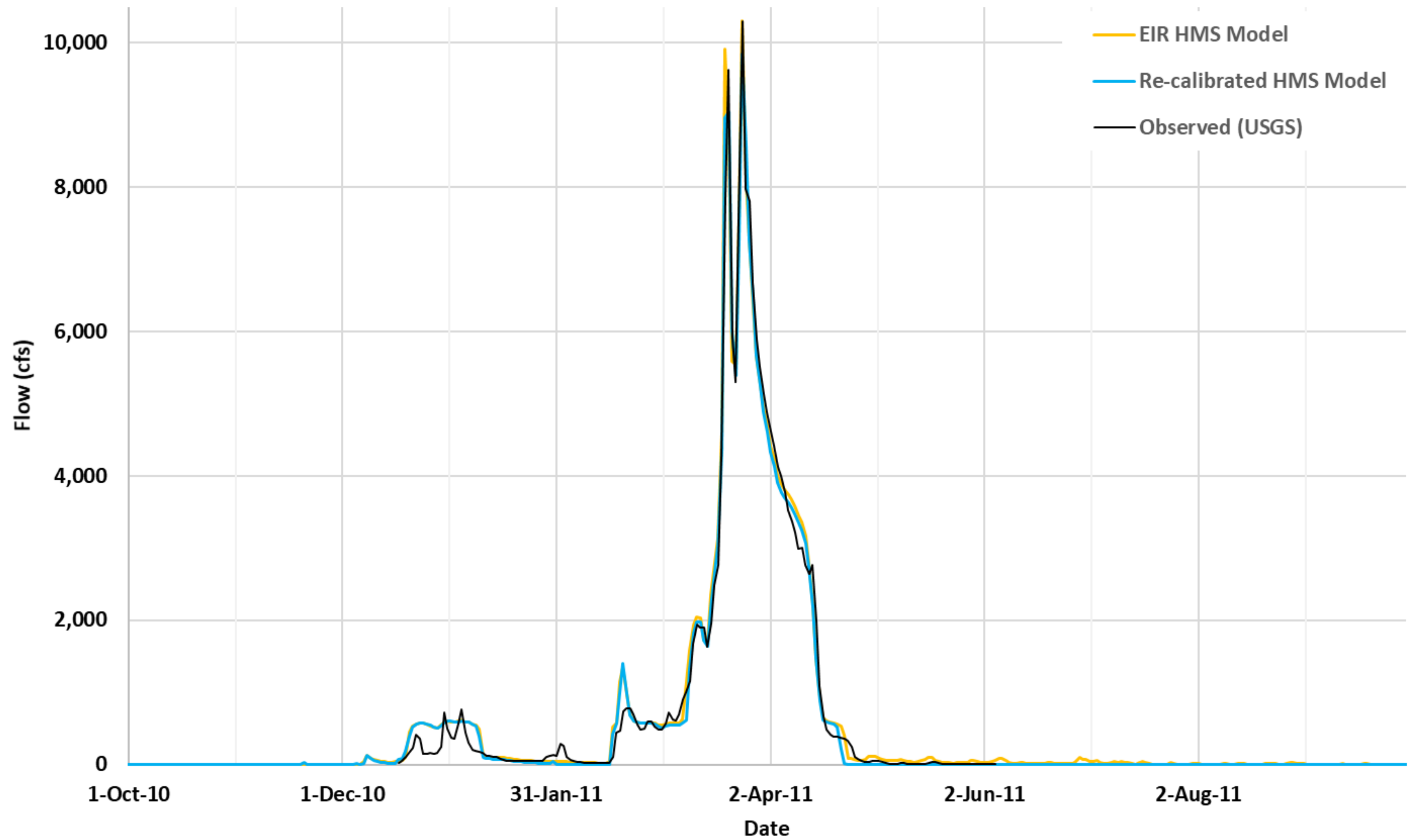


Notes:

Yolo Bypass Westside Tributaries Flow Monitoring Project

CCSB HMS Model: WY 2010

Project No. 17-1004	Created By: LST	**Figure C2**

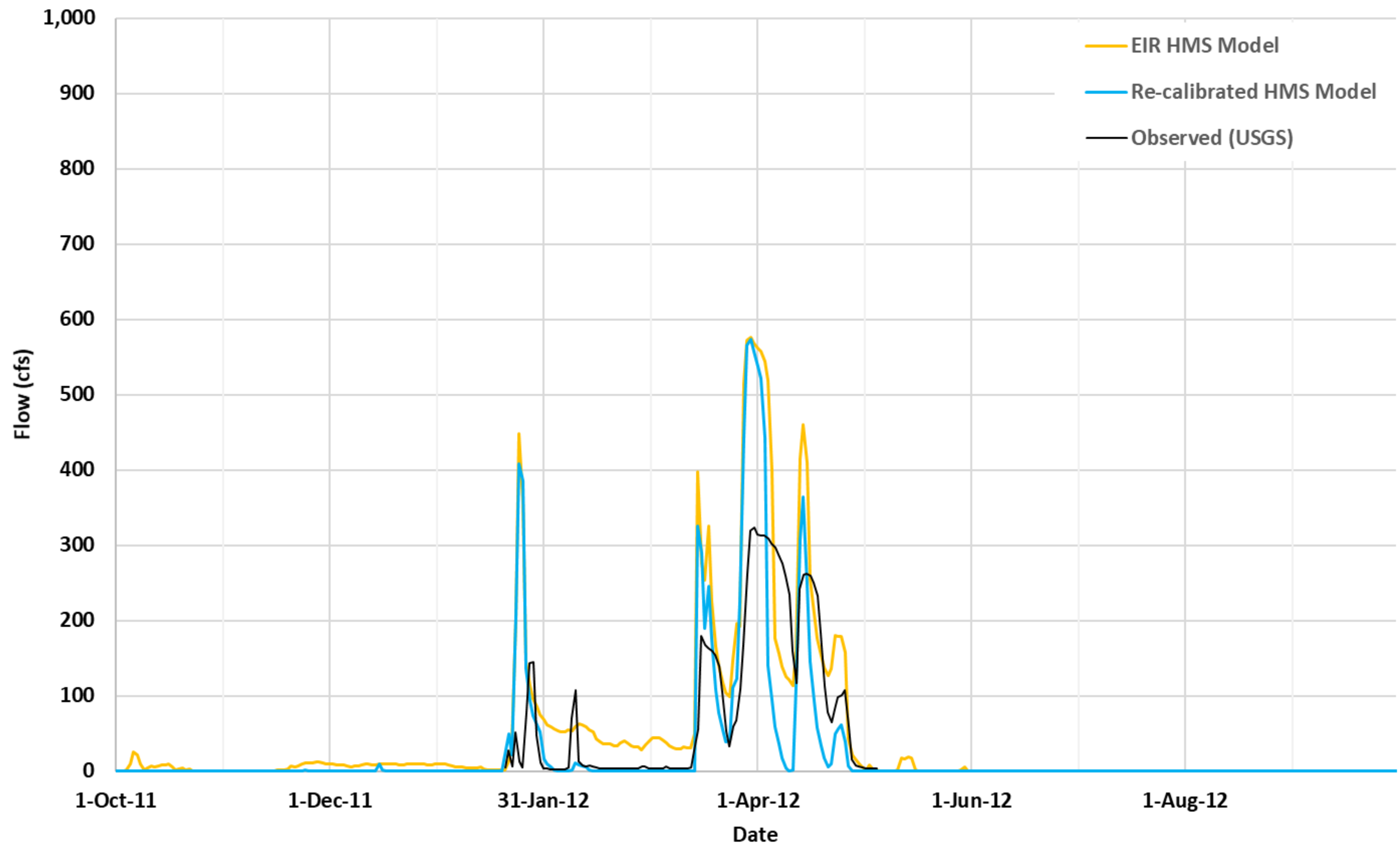


Notes:

Yolo Bypass Westside Tributaries Flow Monitoring Project

CCSB HMS Model: WY 2011

Project No. 17-1004	Created By: LST	**Figure C3**



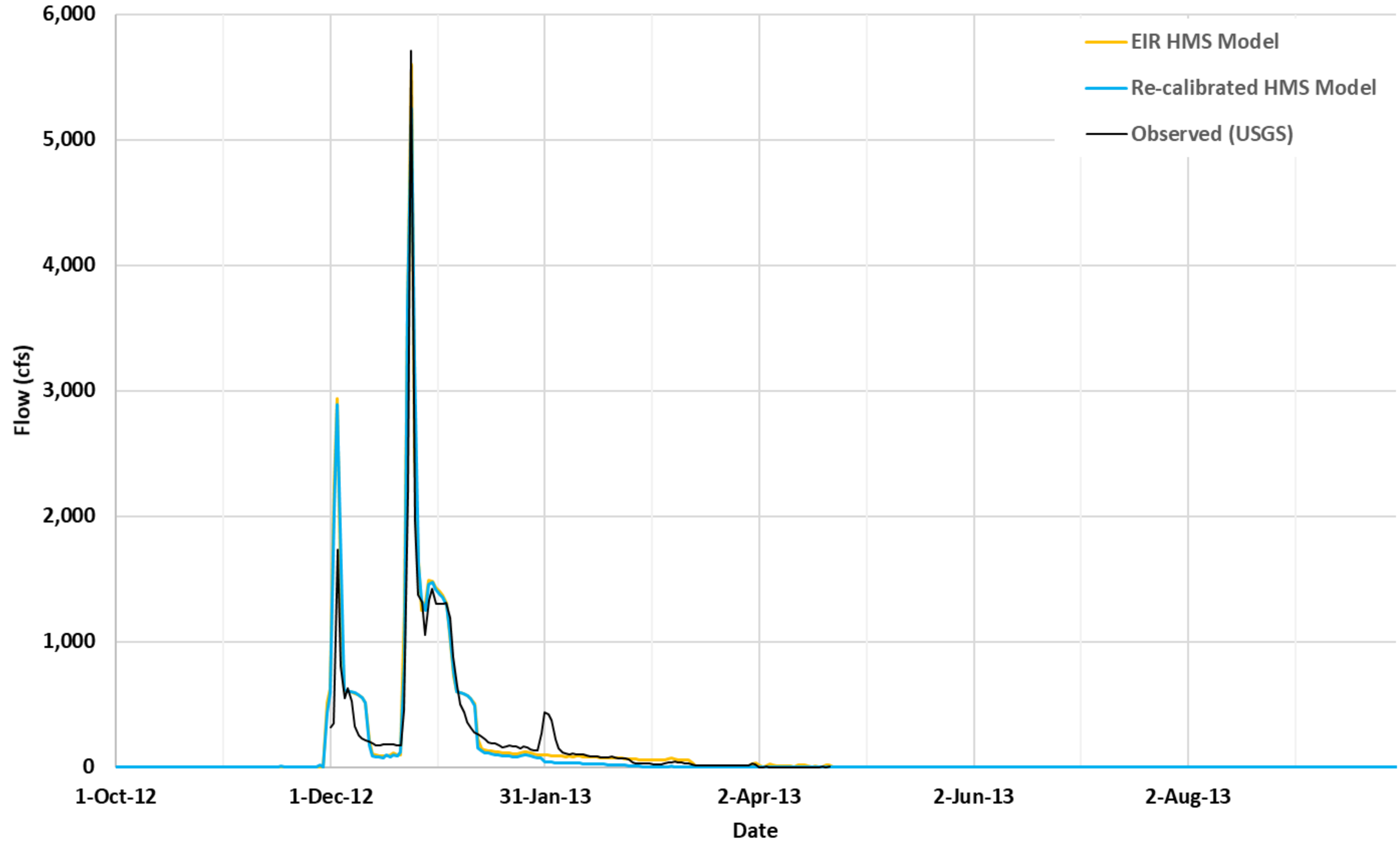
Notes:

cbec eco engineering

Yolo Bypass Westside Tributaries Flow Monitoring Project

CCSB HMS Model: WY 2012

Project No. 17-1004	Created By: LST	**Figure C4**



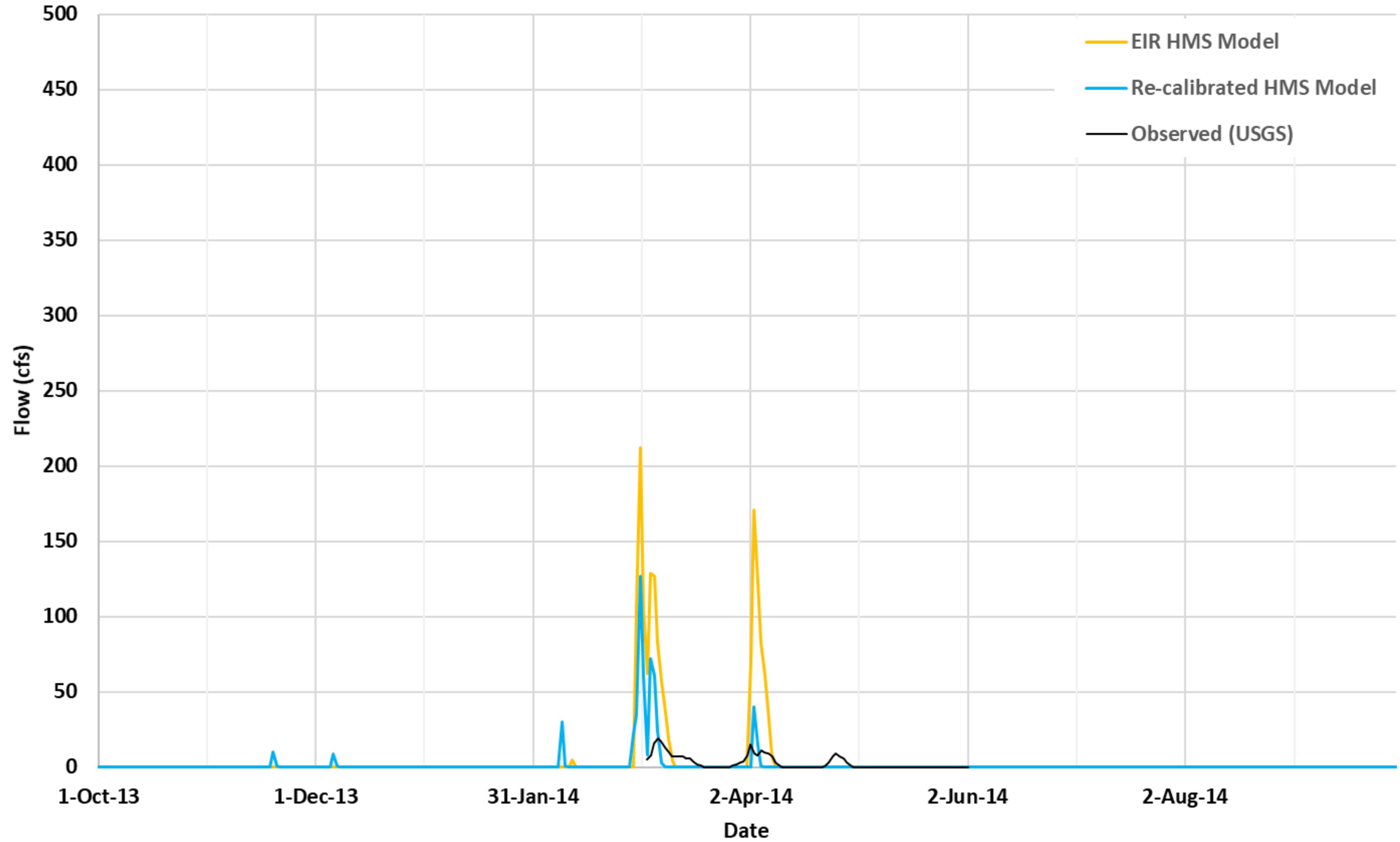
Notes:

cbec eco engineering

Yolo Bypass Westside Tributaries Flow Monitoring Project

CCSB HMS Model: WY 2013

Project No. 17-1004	Created By: LST	**Figure C5**

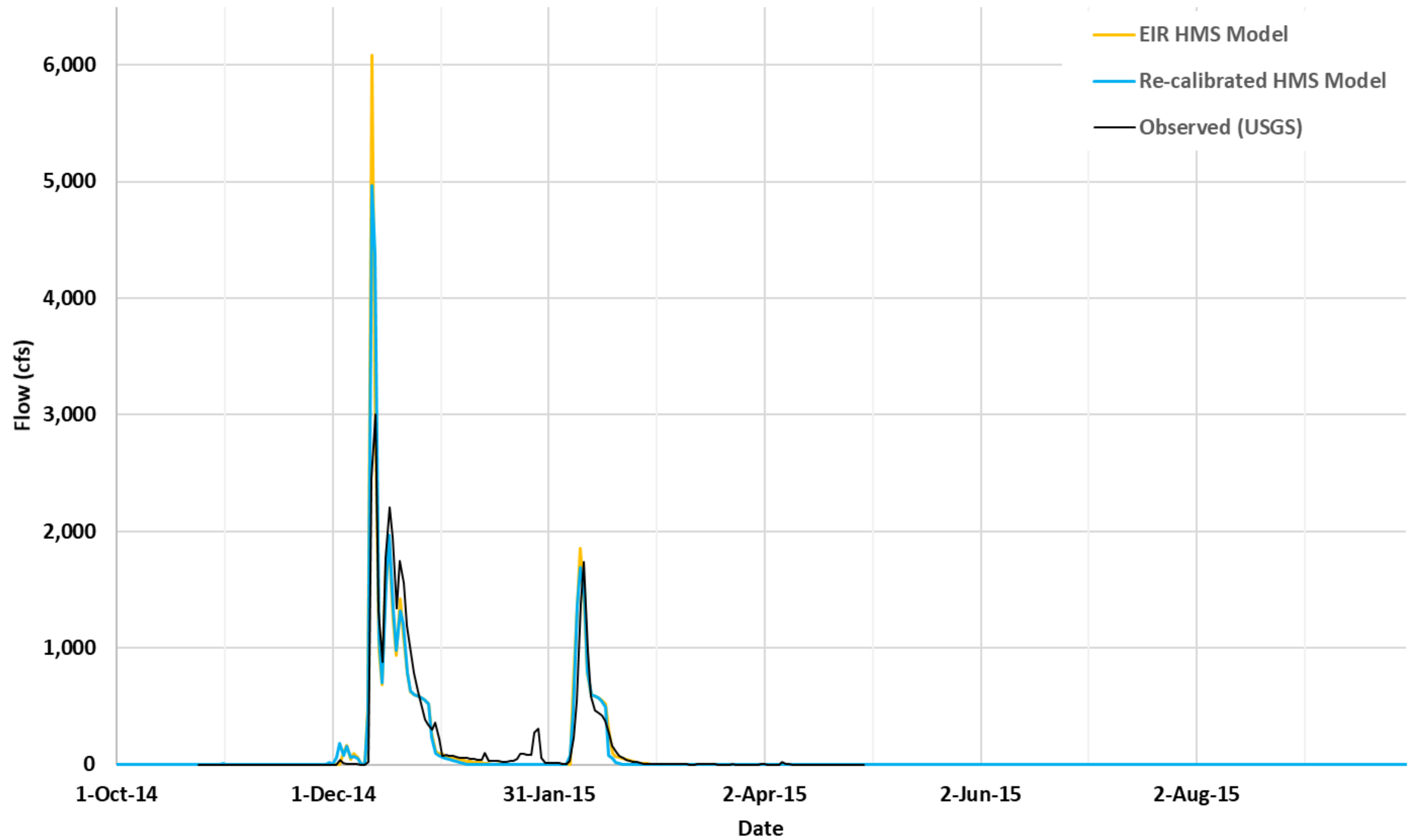


Notes:

Yolo Bypass Westside Tributaries Flow Monitoring Project

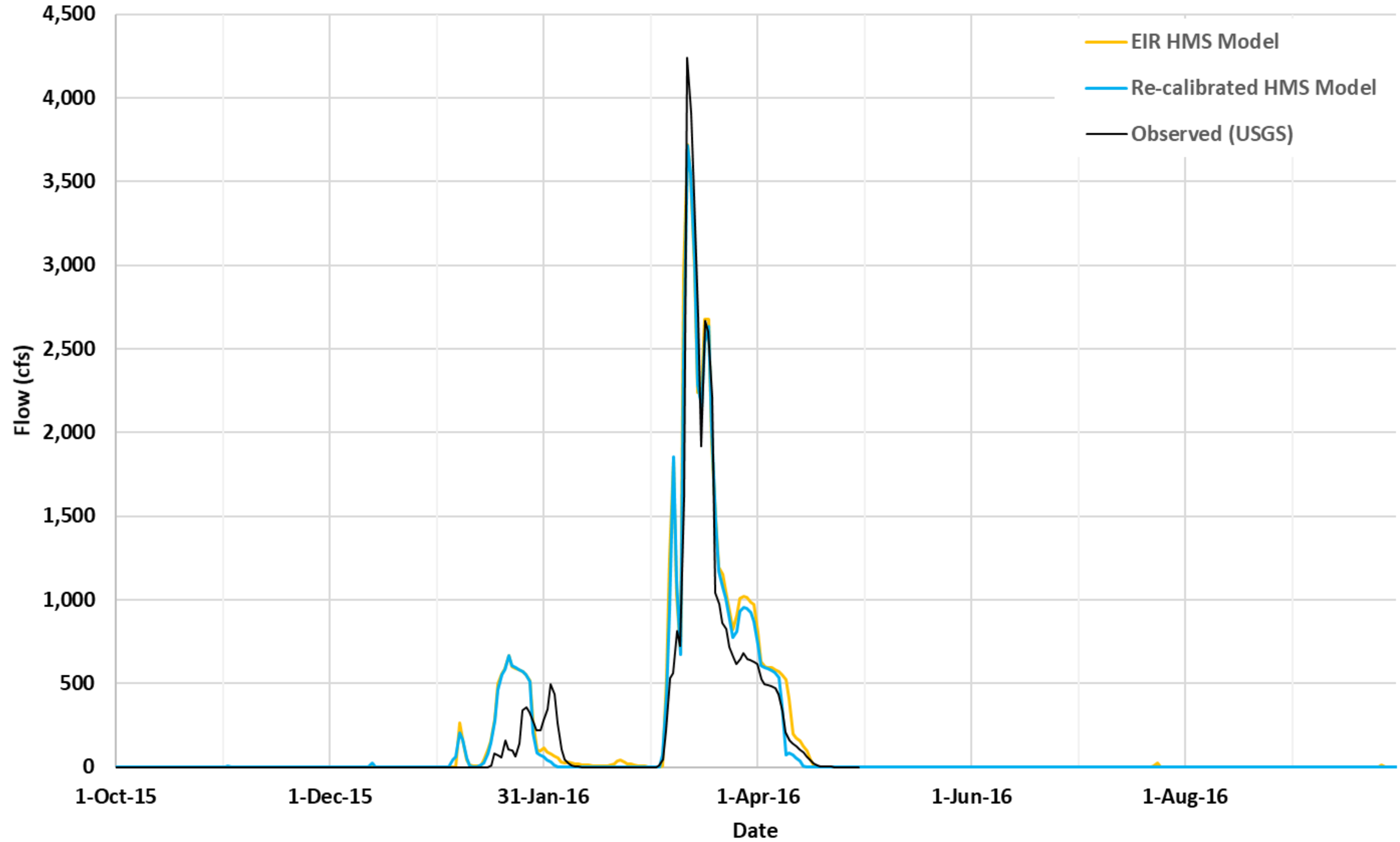
CCSB HMS Model: WY 2014

Project No. 17-1004 | Created By: LST | **Figure C6**

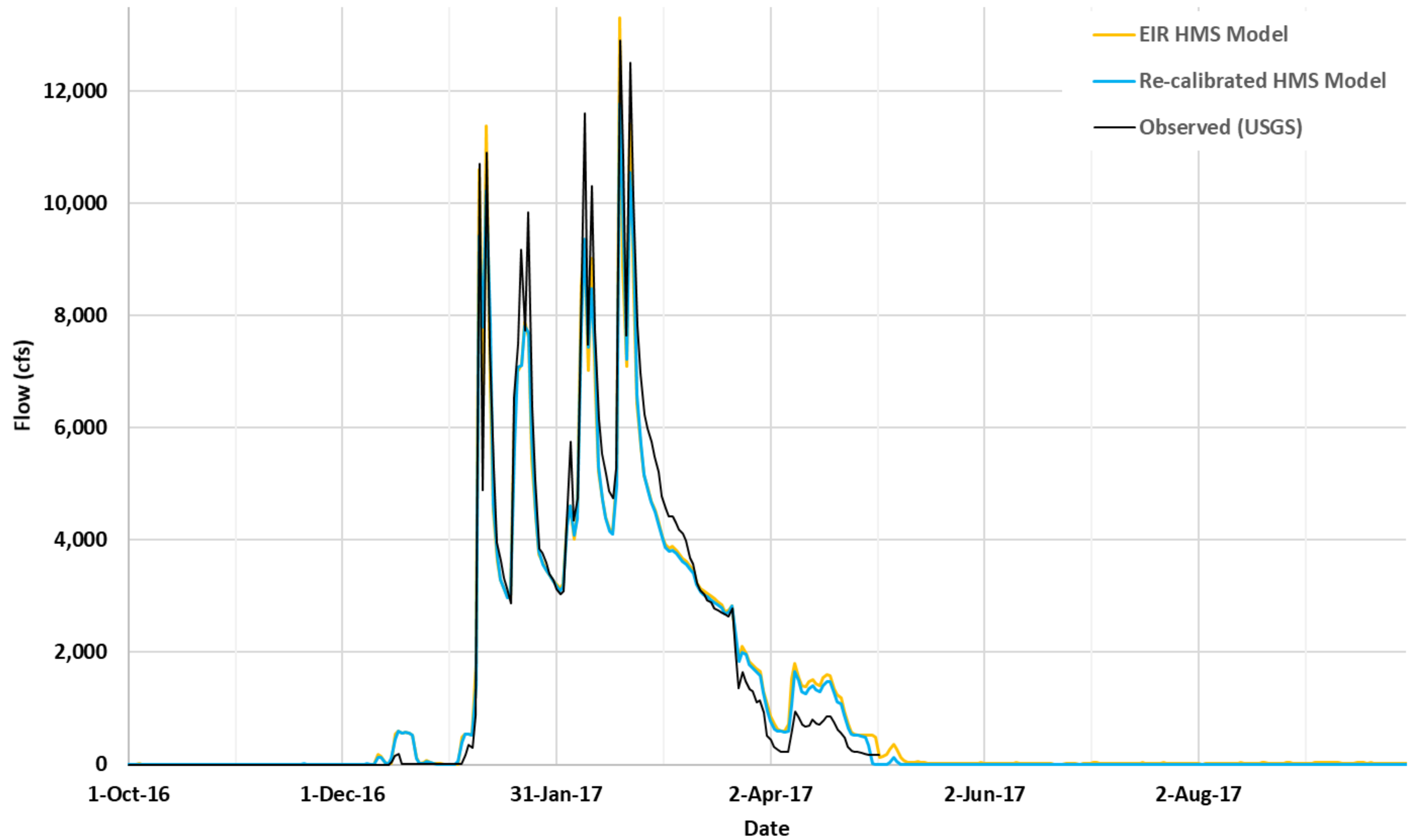


Notes:	cbec eco engineering	*Yolo Bypass Westside Tributaries Flow Monitoring Project* **CCSB HMS Model: WY 2015**		
		Project No. 17-1004	Created By: LST	**Figure C7**

1/29/2020



Notes:	cbec eco engineering	*Yolo Bypass Westside Tributaries Flow Monitoring Project* **CCSB HMS Model: WY 2016**		
		Project No. 17-1004	Created By: LST	**Figure C8**

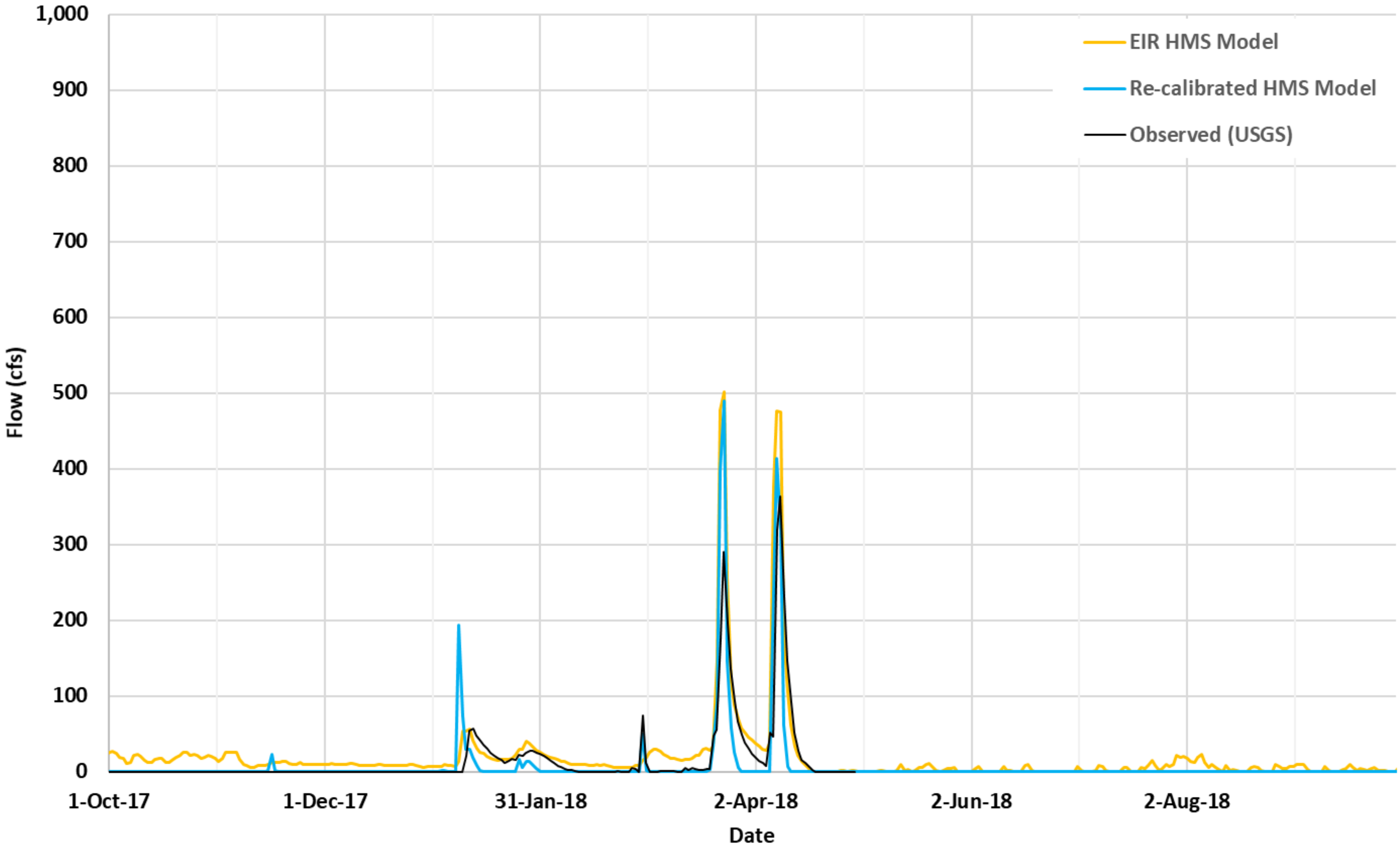


Notes:

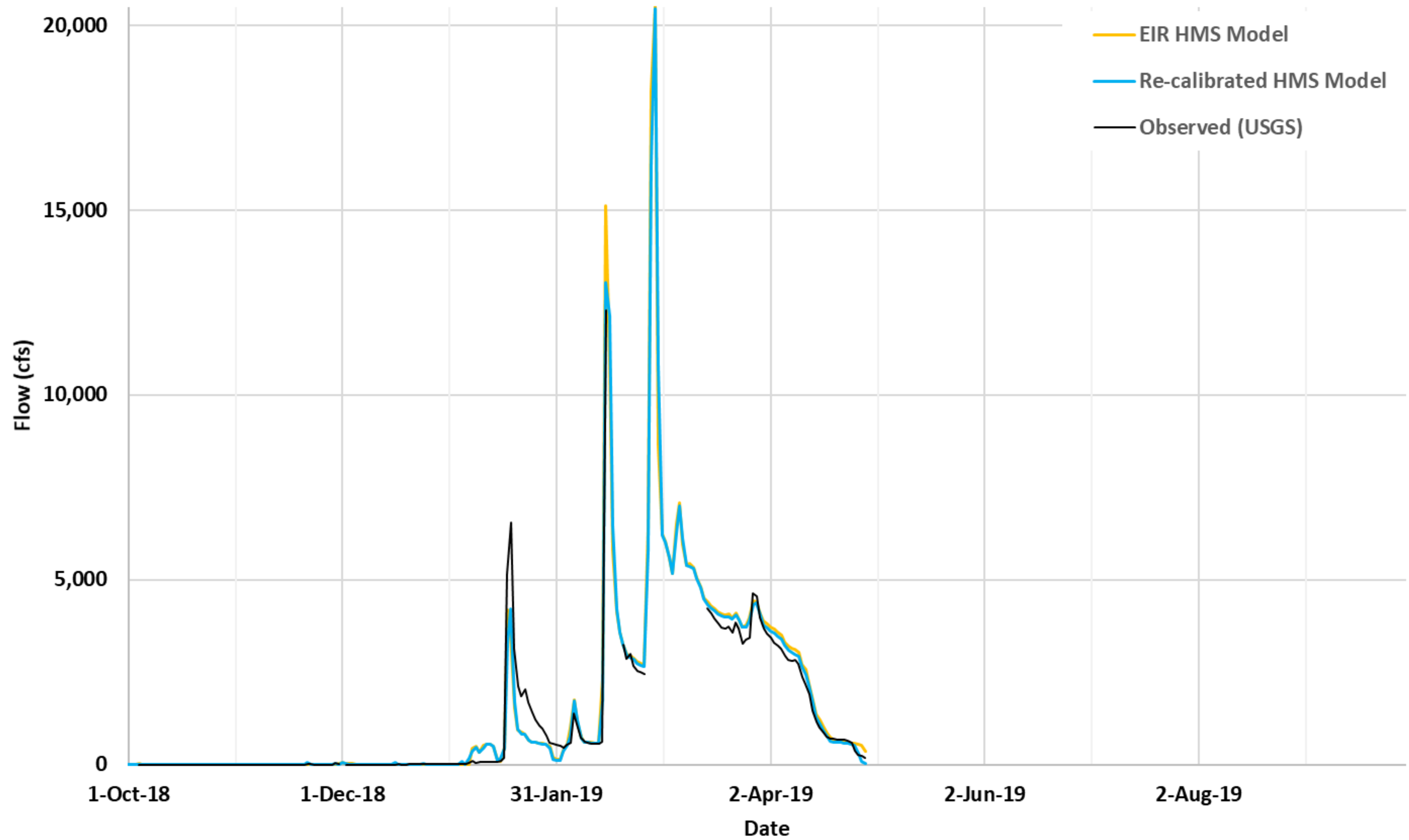
Yolo Bypass Westside Tributaries Flow Monitoring Project

CCSB HMS Model: WY 2017

Project No. 17-1004 | Created By: LST | **Figure C9**



Notes:	cbec eco engineering	*Yolo Bypass Westside Tributaries Flow Monitoring Project* **CCSB HMS Model: WY 2018**		
		Project No. 17-1004	Created By: LST	**Figure C10**



Notes:	cbec eco engineering	*Yolo Bypass Westside Tributaries Flow Monitoring Project* **CCSB HMS Model: WY 2019**		
		Project No. 17-1004	Created By: LST	**Figure C11**

APPENDIX D

LONG-TERM LOW FLOW CORRECTIONS FOR PUTAH CREEK

Hydrology | Hydraulics | Geomorphology | Design | Field Services

TECHNICAL MEMORANDUM

Date:	April 20, 2016 (Revised November 16, 2018 per Final Report)
To:	Project File
From:	Sridhar Ponangi, Chris Campbell
Project:	12-1024 – Lower Putah Creek Restoration Project
Subject:	Long-term Low Flow Corrections

1 INTRODUCTION

As part of the Yolo Bypass Management Strategy (Management Strategy) prepared by Jones & Stokes (2001), measured and estimated hydrology for the flood control weirs and Westside tributaries was compiled for WY 1968 through WY 1998. cbec extended this data set through WY 2012 in support of the Yolo Bypass Salmonid Habitat Restoration and Fish Passage (YBSHRFP) Project using measured data and refinements to the Management Strategy flow estimation techniques. The final long-term record used in the YBSHRFP and herein is from WY 1997 through WY 2012 for the months of October through May.

As described herein, the Lower Putah Creek long-term boundary conditions were further refined by modifying the Management Strategy estimation techniques and better representing minimum flows and pulses as provided by the Putah Creek Accord of 2000 (Accord).

2 MANAGEMENT STRATEGY EQUATIONS

The Management Strategy estimated inflows to the Yolo Bypass from Lower Putah Creek are based on release and spill at Monticello Dam and PDD. During times of no active rainfall-runoff (Condition 1) or if Monticello Dam is spilling (Condition 3), inflow to the Yolo Bypass equals PDD releases minus 30 cfs for seepage and evapotranspiration losses. When there is active rainfall-runoff (Condition 2), defined as Interdam Runoff in excess of 100 cfs, then inflow to the Yolo Bypass equals two times the PDD releases minus 30 cfs to account for losses. The Management Strategy provides a more detailed discussion of these assumptions.

Interdam Runoff is defined as the difference between (a) Berryessa release plus spill and (b) Putah Diversion Dam release after diversion to the Putah South Canal.

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3 MODIFICATIONS TO MANAGEMENT STRATEGY EQUATIONS

Management Strategy equations developed for Lower Putah Creek in 2001 are based on data for WY 1968 through WY 1998. As such, the method does not account for minimum flows required by the Accord. Therefore, revisions to the estimated flows, especially the minimum flows, are needed.

Changes to the Management Strategy equations to improve the Lower Putah Creek flow estimates into the Yolo Bypass included:

- Modified losses
- Accord minimum flows and pulse flows
- Travel time to account for routing from PDD to the Yolo Bypass

SCWA started measuring flows starting 2008. However, the SCWA gauge is rated for flows only up to 100 cfs. Therefore, in addition to the changes to Management Strategy equations, measured flows were retained for below 100 cfs.

3.1 MODIFIED LOSSES

The Management Strategy equations assume a constant flow loss of 30 cfs between PDD and the Yolo Bypass to reflect seepage losses, tributary inflows, irrigation diversions, evapotranspiration, and channel storage. cbec modified the losses to account for variability on a monthly and WY type basis. These loss estimates were derived by comparing the flows estimated using Management Strategy equations to the SCWA measured flows for Lower Putah Creek at I-80 (PC-80) recorded between July 2008 and March 2013. The SCWA gauge is only rated for flows up to 100 cfs, so flows above 100 cfs were not used to estimate the losses.

As mentioned above, the losses were classified based on WY type. However, the monthly losses were grouped from December to November of the following WY rather than the typical October to September. This modification was based on observed flow data that exhibited losses during October and November months consistent with the prior WY. For example, observed flow data exhibited greater losses extending past the end of dry WY into the months of October and November. Similarly, smaller losses were observed during the months of October and November following a normal/wet WY.

The losses were estimated to be even lower during wet years with flood events occurring late in winter or early spring (e.g., WY 2011). This was also evidenced by higher than typical stage recorded during April through June at Lisbon Weir (LIS) gauge (see Table 1). This WY type was termed "Late Wet" and had lower losses during April - June period than typical normal/wet years and was hence assigned lower losses. **Error! Reference source not found.** summarizes the monthly losses for the WY types.

Table 1. Mean Daily Stage for Yolo Bypass gauge at Lisbon Weir

Timing Assumption	Water Year type	Water Year	Date	Mean Stage (ft, NAVD88)[1]	Date	Mean Stage (ft, NAVD88)[1]	Date	Mean Stage (ft, NAVD88)[1]
Late	Wet	2011	4/1/2011	17.2	5/1/2011	5.2	6/1/2011	5.6
Late	Wet	2006	4/1/2006	14.8	5/1/2006	14.0	6/1/2006	5.2
Late	Wet	1999	4/1/1999	11.1	5/1/1999	5.1	6/1/1999	5.0
Late	Wet	1998	4/1/1998	15.7	5/1/1998	7.1	6/1/1998	9.4
Normal	Wet	1997	4/1/1997	4.6	5/1/1997	4.0	6/1/1997	4.5

Notes:
[1] Daily mean stage

Table 2. Estimated Lower Putah Creek losses

Month[1]	Dry / Critical	Below Normal / Above Normal / Wet	Late Wet
December	15	15	15
January	10	10	10
February	5	5	5
March	0	5	5
April	0	10	0
May	5	10	0
June	15	20	5
July	20	20	15
August	25	20	20
October	30	20	20
November	22	20	15

Notes:
[1] The monthly losses were grouped from December to November of the following year

3.2 ACCORD MINIMUM FLOWS AND PULSE FLOWS

Following the Accord, water releases from PDD to the creek were modified to maintain minimum flows for fish, water rights at Interstate 80, and to maintain continuous flow downstream to RM 0. This included coordinated efforts between SCWA operating PDD pulse flows and Los Rios Check Dam operators managing the flashboards during the Fall and Spring pulses. As such, the Management Strategy equations were modified to capture the required minimum flows in Lower Putah Creek as provided by the Accord. For the purposes of this study, even though the Accord was not effective until 2000, the minimum flows were incorporated into Management Strategy equations for all WYs to reflect present day operations in the analysis.

3.3 TRAVEL TIME

A 2-day lag was incorporated into the Management Strategy equation to account for travel time from PDD to I-80.