MIDDLE SHASTA RIVER WATER BALANCE: SEPTEMBER-OCTOBER 2017

SUBMITTED BY:
Shasta Valley Resource Conservation District
215 Executive Court, Suite A
Yreka, CA – 96097

SUBMITTED TO:
Amy Campbell and Ada Fowler
The Nature Conservancy
701 Mt. Shasta Blvd, Suite A
Mt. Shasta, CA – 96067

February 2018

CONTENTS

Figures ... 2
Tables ... 3
A. INTRODUCTION ... 4
i. Project Summary and Objectives ... 4
B. BACKGROUND ... 5
i. Shasta River Watershed ... 5
ii. Water Quality Impairments ... 5
iii. Geology of the Shasta Valley ... 5
iv. Shasta River Water Transactions Program Background ... 7
C. STUDY DESIGN ... 9
i. Fall Flow Program ... 9
ii. Study Period ... 10
iii. Meteorological Data ... 10
iv. Study Area ... 11
v. Study Area: Irrigation Development ... 13
i. Study Area: Reach Descriptions ... 13
Reach 1: Q0.8 to Q0.9 - Shasta River (above Parks Creek) to Louie Rd. Bridge ... 13
Reach 2: Q0.9 to Q2 - Louie Bridge to District 1 Pump Station ... 14
Reach 3: Q2 to Q3 – Above District 1 Pump Station to Below A12 Road Overpass ... 17
Reach 4: Q3 to Q4 – Below A12 Road Overpass to Below District 2 Pump Station ... 17
Reach 5: Q4 to Q5 – District 2 to Montague-Grenada Weir ... 17
D. METHODs ... 18
I. Terminology ... 18
II. Methods Overview ... 18
III. Measuring and Calculating Flow ... 19
IV. Transit Times ... 21
iv. Unaccounted Accretion/Depletion Calculations ... 22
E. RESULTS AND DISCUSSION ... 23
I. Overview – All Sites and Reaches ... 23
II. Reach 1: Shasta River above Parks Creek to Louie Bridge (Q0.8 to Q0.9) ... 25
Reach 1: Accretions and Depletions ... 28
III. Reach 2: Q0.9 to Q2-SPU – Louie Bridge to above District 1 ... 29

Reach 2: Accretions and Depletions 31
IV. Reach 3: Q2 to Q3 - Above DISTRICT 1 to Below A12 Road Overpass 36
Reach 3: Accretions and Depletions 37
V. Reach 4: Q3 to Q4 – Below A12 Road Overpass to BElow DISTRICT 2 Pump Station 38
Reach 4: Accretions and Depletions 39
VI. Reach 5: Q4 to Q5 – Below DISTRICT 2 Pump Station to Montague-Grenada Rd. Weir (SRM) . 41
F. CONCLUSION 42
References 44
Appendix A: Shasta River Watershed Geologic Map and Explanation of Geologic abbreviations and symbols 46
Appendix b: Rating Curves (Stage-Discharge Relationships) 48

FIGURES

Figure 1. Hydrological zones in the Shasta Basin based on the dominant hydrograph components that determine runoff patterns in the mainstem Shasta River. Boundaries are approximate. Graphic modified from McBain & Trush, Inc et al. (2010). 7
Figure 2. Chinook salmon observed migrating through Shasta River fish counting facility in 2016, and flow from nearby USGS gauge (Graphic retrieved from Chesney & Knechtle, 2017). 8
Figure 3. Base flow and flow contributions (added flow) secured by TNC's fall flow program (graphic courtesy of Ada Fowler, TNC). 9
Figure 4. Meteorological data including maximum air temperature, solar radiation, and precipitation during late summer and fall 2017 with study period highlighted. Data source CDEC station WED (Weed Airport): July 15, 2017 - Oct. 24, 2017. 10
Figure 5. Map of Flow Study area including major tributaries with all measurement sites (numbers preceded by Q), existing gages, and reaches (numbers not preceded by Q). 12
Figure 6. Geologic map of the Big Springs Complex area. 15
Figure 7. Map of the Big Springs Complex including measurement sites and "water wheel" existing stage/discharge site on Big Springs Creek. Also identified is Little Springs Creek downstream of the Water wheel site. 16
Figure 8. Shasta River calculated flows by river mile on date/times associated with each assessment day during the study period, 2017. 24
Figure 9. Dwinnell Reservoir/Dam flow releases measured at Cross Canal (SRX) and Dwinnell Fish Bypass (DFB) (Retrieved from CDEC, 2017). 25
Figure 10. Stage, Measured Flow (Q), and calculated flow (Q) for Q0.8 during the study period. Missing values in hydrograph exceeded measured values used to create rating curve. 26
Figure 11. Stage, measured flow (Q), and calculated flow (Q) for Q0.9 (Louie Br.) August 24th through October 20th, 2017. Rating curve was split into separate "high" and "low" curves due to changes in channel morphology that occurred during the study. These changes led to a poor fitting (low r^2 value) rating curve. Low values fall on the curve prior to September 23. High values fall on the curve after

October 3rd. Values in between exceeded measured values used to create rating curve and were therefore removed.......... 27
Figure 12. Stage, measured flow (Q), and calculated flow (Q) for QP1-Parks Creek above Shasta River confluence, September 24th through October 24th, 2017. Rating prior to September 24th not used due to poor fitting rating curve.......... 28
Figure 13. Stage and single point measured flow (Q) for Q1 throughout the study period.......... 30
Figure 14. stage, measured Q, and calculated flow (Q) for Q2 throughout the study period. Stage data retrieved from CDEC (DWR station SPU).......... 31
Figure 15. Unaccounted flow (cfs) vs. change in flow (cfs) in Reach 1 between Q0.9 and Q2.......... 35
Figure 16. Stage, measured flow (Q), and calculated flow (Q) for Q3 throughout the study period.......... 37
Figure 17. Diverted flow vs. change in flow in Reach 3 (Q2 – Q3).......... 38
Figure 18. Stage, measured flow (Q), and calculated flow (Q) for Q4 throughout the study period.......... 39
Figure 19. Diverted flow vs. change in flow in Reach 4 (Q3 to Q4).......... 40
Figure 20. Stage, measured flow (Q), and calculated flow (Q) for Q5 throughout the study period. This site is maintained by USGS. Data was retrieved from CDEC, 2017.......... 41

TABLES

Table 1. Flow measurement sites (reference name and site id), reach, river mile, and type of flow [Shasta River (Shasta R.) flow (Q), or other].......... 13
Table 2. Sub-reach lengths, average transit times through each sub-reach, and total average transit time through the study area. Transit times presented with standard deviation (SD).......... 22
Table 3. discharge calculated from rating curves at each measurement location for each assessment day in 2017.......... 24
Table 4. Start flow, end flow, change in flow, diversions, measured inflows, and unaccounted accretions and depletions between Q0.8 and Q0.9 on assessment days.......... 29
Table 5. Start flow, end flow, diversions, change in Q, measured inflows (from Big Springs Creek at water wheel), and unaccounted accretions and depletions between Q0.9 and Q1 on measurement days.......... 32
Table 6. 2016 and 2017 flow comparison. Start flow, end flow, change in Q, diversions, measured inflows, and unaccounted accretions and depletions between Q1 and Q2 on assessment days using single point method.......... 33
Table 7. Start flow, end flow, change in flow, diversions, measured inflows (from Big Springs Creek at water wheel), and unaccounted accretions and depletions between Q0.9 and Q2-SPU using single point method.......... 34
Table 9. Start flow, end flow, change in flow, diversions, measured inflows (from Big Springs Creek at water wheel), and unaccounted accretions and depletions between Q0.9 and Q2-SPU using 12 hour average method. Note: October 12th assessment is based on a 3-hour average discharge at both sites. This was done to capture and compare the most stable flows that were closest (in time) to our field-measured flow that was captured in unstable flow conditions.......... 35
Table 10. Start flow, end flow, diversions, and unaccounted accretions and depletions between Q2 and Q3 on assessment days. Inflows to this reach were not measured.......... 37
Table 11. Start flow, end flow, diversions, unaccounted accretions and depletions, and 2016/2017 comparison between Q3 and Q4 on assessment days. Inflows to this reach were not measured.......... 40
Table 12. Q4 to Q5 start flow, end flow, diversions, unaccounted accretions and depletions and 2016/2017 comparison on assessment days. Inflows to this reach were not measured.......... 42

A. INTRODUCTION

I. PROJECT SUMMARY AND OBJECTIVES

Chinook salmon return to the Shasta River in September and October to spawn, and are often met with low flow conditions and associated poor water quality conditions such as high temperatures and low dissolved oxygen levels. The Shasta Water Transaction Program has worked with willing landowners over the last few years to forgo irrigation during mid- to late September to ensure there is sufficient instream flow for this critical salmonid life stage. In prior years, the Watermaster assisted the Shasta Water Transaction Program (WTP) by tracking the status of diversions and helping to monitor whether water secured through short-term forbearance agreements or donated water was left instream. Although water forgone should result in additional flows in the river, this relationship was unclear until more detailed flow balance monitoring occurred in 2016 and 2017.

Findings during the Lower Shasta River Water Balance: September 2016 study (Phase I), suggested that accretion and depletion within upper or middle reaches of the Shasta River below Dwinnell Dam was complex, and a more detailed accounting of water inputs and outputs was required to create an accurate water balance through these reaches. Therefore, new project goals and objectives were set for a 2017 Middle Shasta River Water Balance study (Phase II), including:

Goal:

I. To develop a more thorough understanding of accretions and depletions within the Middle Shasta River (defined below) which will inform and improve upon the ability of the Shasta WTP to deliver much needed flows for Chinook salmon in September. The Phase II study area was adjusted to focus on the Shasta River and select tributaries from the Shasta River just above Parks Creek through the Shasta River at Montague-Grenada Road weir, hereafter referred to as the "Middle Shasta River".
    a. Reaches 3, 4, and 5 from the Phase I study were not included in the Phase II assessment. These reaches were determined to have minimal unaccounted flows during the Phase I study and therefore, efforts were focused on upstream reaches.
    b. Phase II also included secondary assessments of Reaches 1 and 2 from the Phase I study (Below Big Springs Creek through Highway A-12, and Highway A-12 through Montague Grenada Road Weir, respectively).
    c. The phase II study area was expanded in the upstream direction to better understand the effect of Parks Creek and Big Springs Creek tributaries.

Objectives:

I. Monitor river discharge and develop seasonal rating curves at sites throughout the middle Shasta.
II. Track diversions by installing flow equipment and/or monitoring when diversions are on/off by communicating with diversion operators or Watermaster.

III. Determine transit times from site to site.
IV. Determine accretions and depletions by reach (and from site to site) through the middle Shasta.

B. BACKGROUND

I. SHASTA RIVER WATERSHED

The Shasta River watershed covers 793 square miles and is located entirely within Siskiyou County, California. The Shasta River is a major tributary to the Klamath River. Hydrology in the Shasta River watershed is largely driven by snowmelt in the Klamath Mountains located on the western side of the basin, and discharge from springs along its eastern flanks. From its origin in the Klamath Mountains, the Shasta River flows north, then northwestward for a total of approximately 60 miles before entering the Klamath River at river mile (RM) 177. The mainstem Shasta River is impounded by Dwinnell Dam at RM 41.1. Primary tributaries are Parks Creek (RM 34.0), Big Springs Creek (RM. 32.7), Willow Creek (RM 24.3), Little Shasta River (RM 16.7), and Yreka Creek (RM 7.3). Accretion from tributaries and springs, combined with agricultural diversion and return flows, contribute to a complex annual flow regime both seasonally and longitudinally (Deas et al. 2004). Wherever water is available for irrigation it is used, either from surface water from the Shasta River or its tributaries, or from groundwater. Over 52,000 acres are irrigated and provide the essential economic underpinning of agricultural activities in the watershed.

II. WATER QUALITY IMPAIRMENTS

Beneficial uses of the Shasta River include cold water fish (fall Chinook, state and federally ESA-listed coho salmon, and steelhead), drinking water, recreation, and irrigation. The Shasta River provides habitat necessary for egg incubation, fry emergence, rearing habitat for coho and Chinook prior to their migration to the ocean as well as habitat for spawning upon their return as adults. The Shasta River is 303(d) listed for high temperature and low dissolved oxygen. No single factor has been responsible for declining anadromous salmonid populations in the Shasta Basin. However, reduced flows, tailwater return flows to the river, along with reduced stream shade are listed as factors that can impact water quality and consequently affect the beneficial uses (NCRWQCB 2007). Indeed, the Shasta River TMDL, adopted in 2007, identifies flow alterations due to irrigation withdrawals and subsequent return flows (tailwater) as primary factors contributing to declining water quality and salmonid populations. The Shasta River TMDL recognizes that fine sediment and warm, nutrient-rich tailwater from long-standing flood irrigation practices can decrease DO and increase stream temperatures. While substantial progress has been documented in the Shasta River Watershed through efforts such as pulsed flows in the spring, increased fall flows, riparian restoration and tailwater reduction, much work remains to be done.

III. GEOLOGY OF THE SHASTA VALLEY

The Shasta Valley is the meeting point of multiple tremendous geological forces that collectively create and complicate the hydrology of the Shasta River basin. To the west, the Klamath Mountain Terrane forms the western edge of the Shasta Valley, with elevations reaching up to 10,000 ft. These mountains are the visible result of the subduction of the Pacific Plate beneath the North American Plate. This subduction process scraped off a variety of ocean sediments and island arcs which now form the Klamath Mountains.

In addition, this process has contributed to multiple uplift events, created faults, and ultimately set the stage for the geologic processes on the east side of the valley, where volcanic eruptions in the Western Cascades prevail, and have created Mt. Shasta, Whaleback, Deer Mt., and Goosenest, collectively forming the eastern edge of the Shasta Valley.

The bulk of the visible surface of the Shasta Valley is comprised of volcanic materials overlying the deeper ocean sediments forming the underlying Hornbrook formation. Volcanic deposits include an extensive debris avalanche (~350,000 years before present). This debris avalanche transported large block-sized andesite and stratigraphic successions of previously erupted Mount Shasta volcanic rocks and alluvium forming a series of hills and ridges along the southwestern side of the Shasta Valley (Crandell 1984). The matrix of this large debris avalanche contained mudflow-like deposits of sand, silt, clay and rock fragments which formed the bulk of the relatively flat central portion of the Shasta Valley. The debris avalanche is overlain in several areas by Plutos Cave basalt deposited during an eruption of Mt. Shasta ~100,000-300,000 years before present. The Plutos Cave Basalt is comprised of fractured surface and subsurface lava formation that transmits the majority of the water which make up the base flows of the Shasta River. This water is discharged as springs throughout the southeast part of the Shasta Valley. In addition to volcanic basalt and debris avalanche deposits, more recent alluvial deposits are found along the perimeter of the Shasta Valley and within hydrologic flow paths that lead to the Shasta River and its tributaries. These geologic features are displayed in Appendix A and related hydrologic zones are displayed in Figure 1.

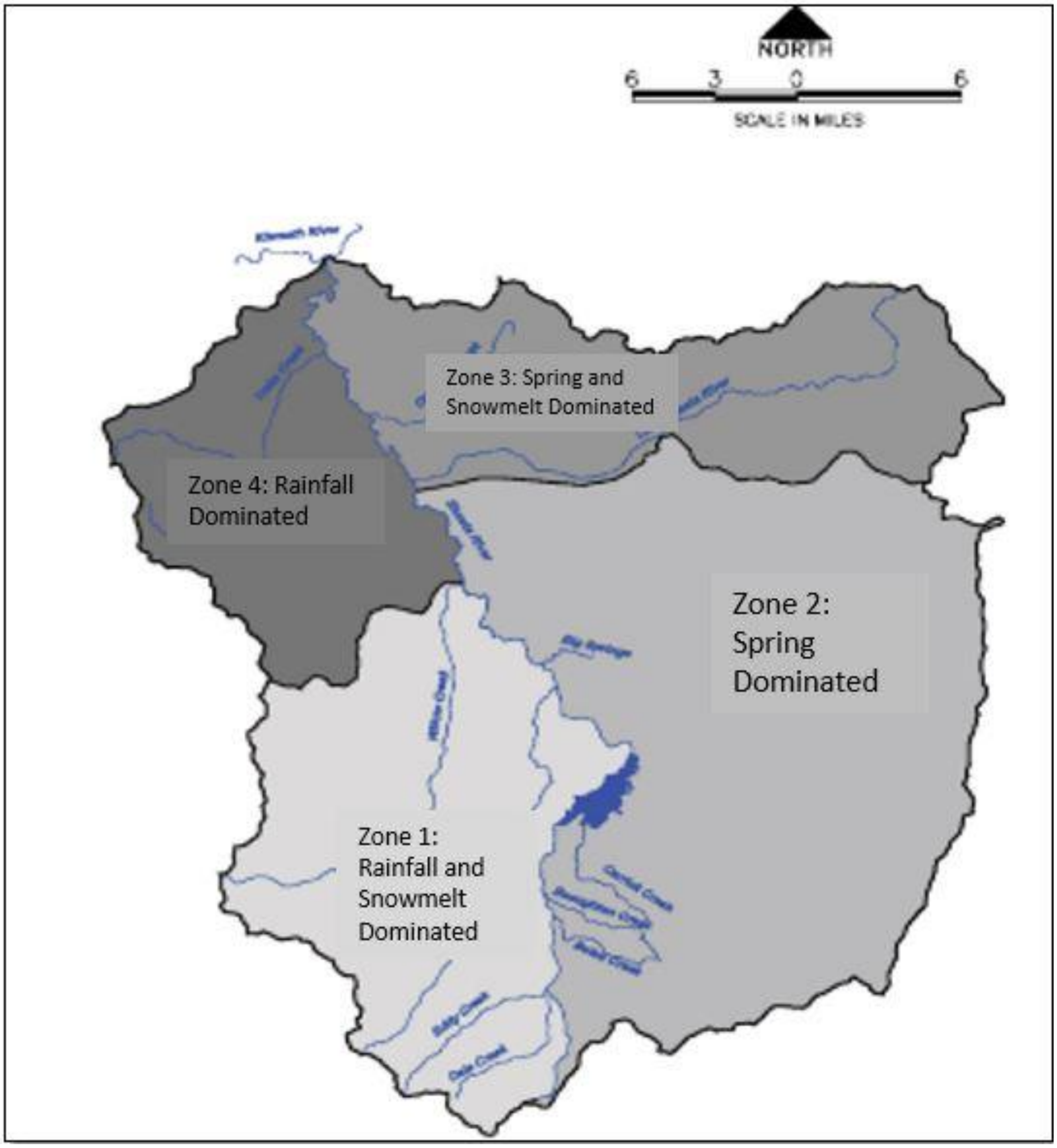


FIGURE 1. HYDROLOGICAL ZONES IN THE SHASTA BASIN BASED ON THE DOMINANT HYDROGRAPH COMPONENTS THAT DETERMINE RUNOFF PATTERNS IN THE MAINSTEM SHASTA RIVER. BOUNDARIES ARE APPROXIMATE. GRAPHIC MODIFIED FROM MCBAIN & TRUSH, INC ET AL. (2010).

IV. SHASTA RIVER WATER TRANSACTIONS PROGRAM BACKGROUND

Since 2012, the Shasta River Water Transaction Program has secured over 6,700 acre-feet of water to benefit salmon in the Shasta River. The goal of the program is to improve water quality and flows in the Shasta Watershed by working with landowners on a voluntary basis to lease or acquire their water rights during strategic times of the year to benefit coho, fall Chinook, and steelhead salmonids. To date, the program has used a variety of dynamic conservation tools to leave water instream when and where salmon need it most. Water is either donated instream by water right holders or secured via short-term forbearance agreements.

The Fall Flow Program was designed to provide water instream to benefit the migration of spawning fall Chinook into the Lower Shasta during the month of September. The California Department of Fish and Wildlife has demonstrated that a period of time including the last three weeks in September through mid-October is a critical time for fall Chinook salmon migration (Figure 2). For a majority of water right holders, the irrigation season ends on October 1st and therefore, flow augmentation needs end on September 30th. In 2015 -the fifth year of a historic drought in California- the program secured over 40 cubic feet per second (cfs) of water instream, which tripled the amount of water that would otherwise have been available for these fish in September (Figure 3). In 2016, the program secured 36 cfs of water instream. Over the years, The Nature Conservancy has worked closely with the Shasta Valley agricultural community, the Shasta Valley Resource Conservation District, the Shasta/Scott Watermaster District, and federal and state resource agencies to implement the Shasta River Water Transaction Program.

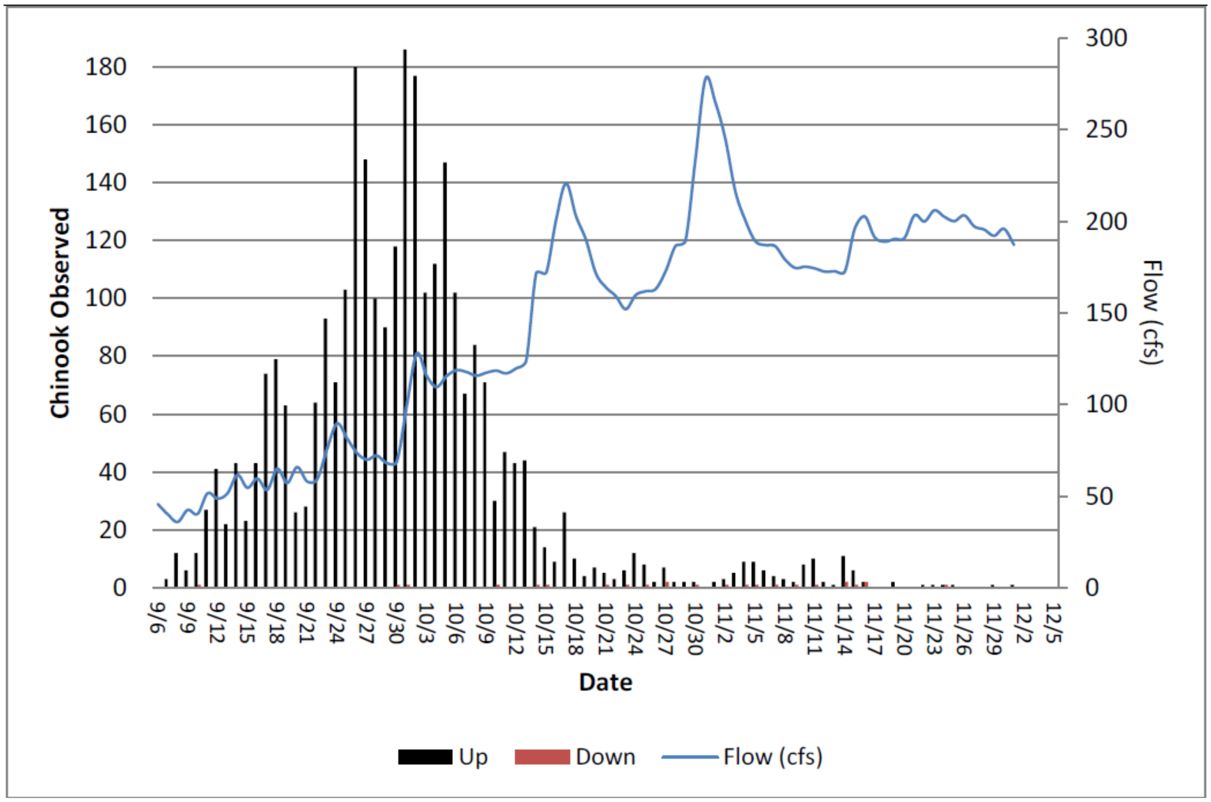


FIGURE 2. CHINOOK SALMON OBSERVED MIGRATING THROUGH SHASTA RIVER FISH COUNTING FACILITY IN 2016, AND FLOW FROM NEARBY USGS GAUGE (GRAPHIC RETRIEVED FROM CHESNEY & KNECHTLE, 2017).

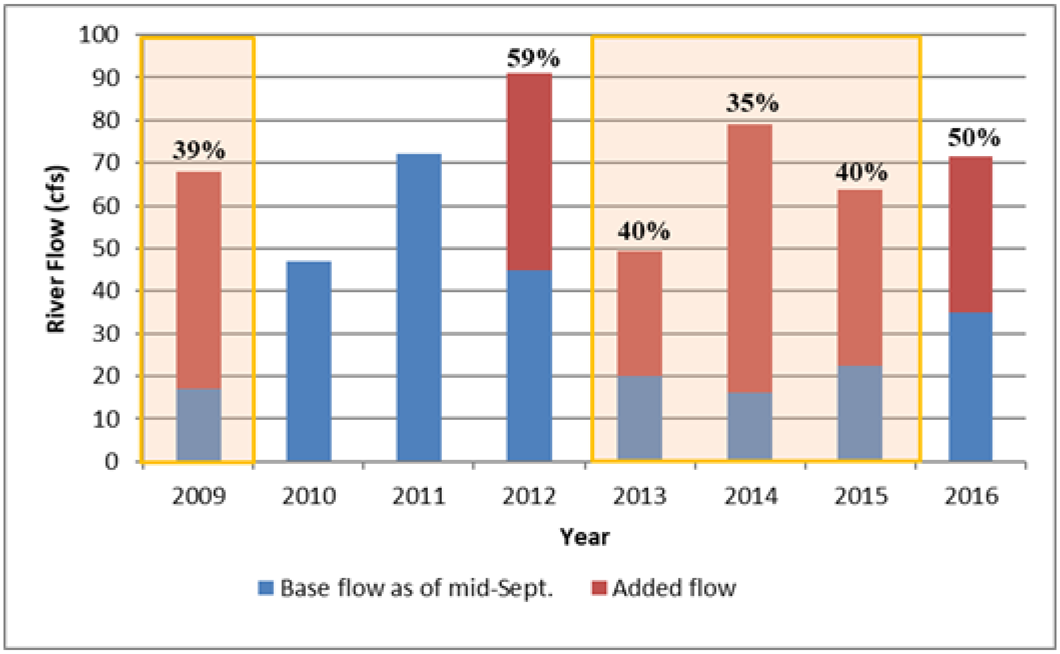


FIGURE 3. BASE FLOW AND FLOW CONTRIBUTIONS (ADDED FLOW) SECURED BY TNC'S FALL FLOW PROGRAM (GRAPHIC COURTESY OF ADA FOWLER, TNC).

The outpouring of support by the agricultural community to provide water instream to benefit these fish has been impressive. Recognizing that the water being contributed was equally as valuable to the agricultural community for their ranching operations, a 2012 study by The Nature Conservancy, Watercourse Engineering and UC Davis Center for Watershed Sciences, confirmed that water being left instream during the Fall Flow Program was providing a downstream benefit to instream habitat by increasing dissolved oxygen levels and river pool capacity (Willis et al. 2016).

C. STUDY DESIGN

I. FALL FLOW PROGRAM

The Shasta River Water Transaction Program assisted the Shasta Valley agricultural community with completing eight years of a community-wide Fall Flow Program. In 2016, the Fall Flow Program secured 752 acre-feet of water instream through short-term forbearance agreements. In support of the 2016 Fall Flow Program, the Nature Conservancy and the Shasta Valley Resource Conservation District completed Phase I of a Water Balance Study. The Phase I Study report developed a water balance for the month of September and the first week of October, 2016. Phase I also provided insight as to which reaches of the Shasta River may be gaining or losing water through percolation into the water table or gained through unknown springs, seeps or unmeasured return tailwater flows.

Due to the above average water year experienced throughout California and in the Shasta River watershed in 2017, it was determined that flows in the Shasta River were sufficient to facilitate fall Chinook migration without the need for forbearance agreements from the agricultural community. However, Phase II of the Water Balance Study was able to proceed to help inform Phase I results, answer questions raised during Phase I, and investigate earlier qualitative observations that anywhere from 10-30 cfs of water was being lost as it traveled downstream to the Lower Shasta during the month of September.

II. STUDY PERIOD

The study period lasted from early-August through mid-October 2017. Equipment was installed by August 20th, 2017 and removed on October 21st, 2017. Diversions monitored for 48 hours via communication with diversion/pump operators on the following dates: August 23rd, September 6th and 20th, October 4th and October 11th. Discharge was measured (in cfs) at each study site during these 48-hour time frames when possible.

III. METEOROLOGICAL DATA

Meteorological data was obtained through the Weed Airport (WED) which is available through California Data Exchange Center (CDEC) and operated by CAL Fire. These data are displayed below in Figure 4.

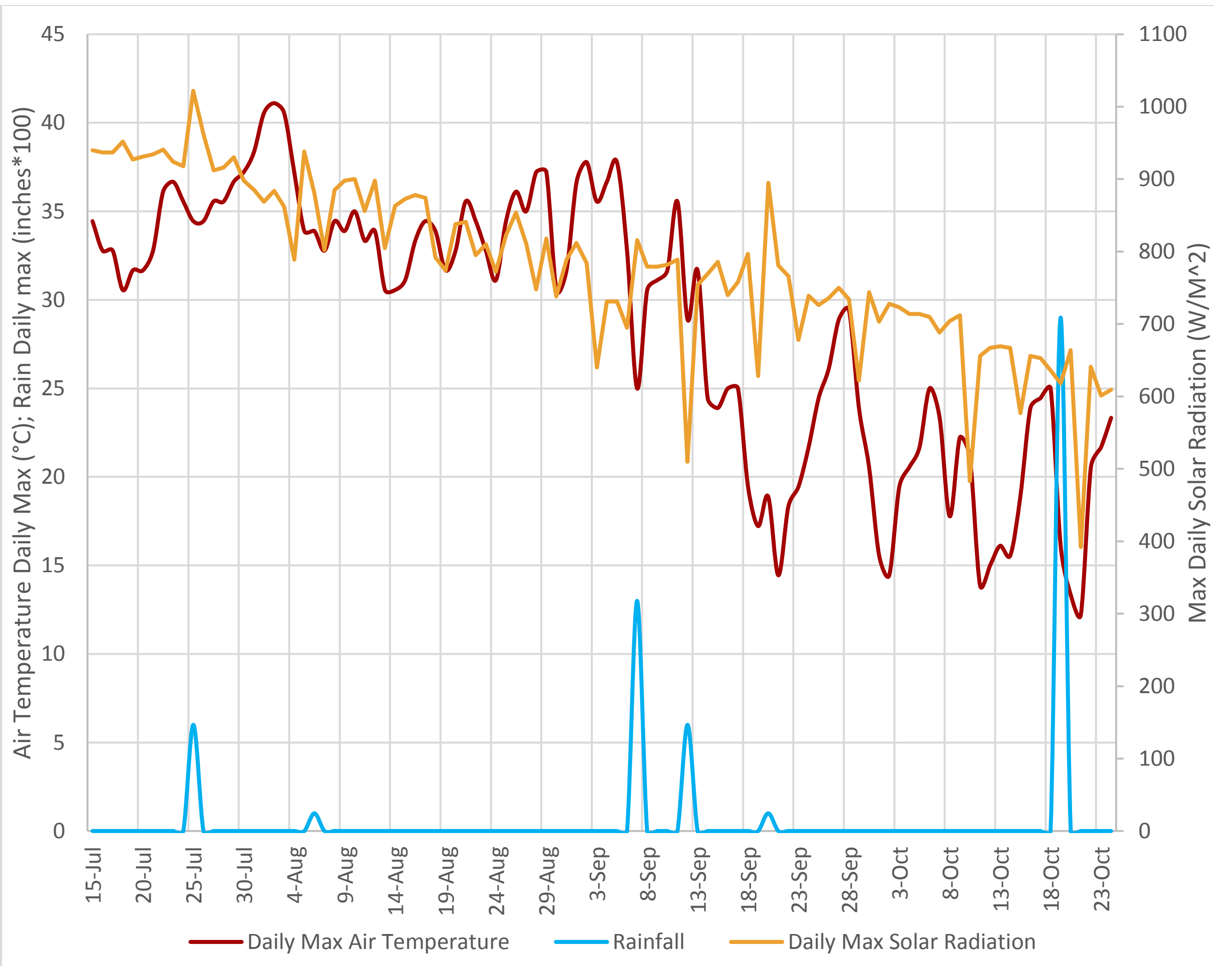


FIGURE 4. METEOROLOGICAL DATA INCLUDING MAXIMUM AIR TEMPERATURE, SOLAR RADIATION, AND PRECIPITATION DURING LATE SUMMER AND FALL 2017 WITH STUDY PERIOD HIGHLIGHTED. DATA SOURCE CDEC STATION WED (WEED AIRPORT): JULY 15, 2017 - OCT. 24, 2017.

Solar radiation and maximum air temperatures fluctuated through the study period, but generally followed a cooling trend. A regional storm front produced sporadic showers (approximately 0.13 inches on September 7th and 0.06 inches on September 14th recorded at WED) during the second week in September. This storm front produced some locally heavy rain throughout the valley (as observed by field technicians on September 7th) that may not be reflected in the WED data (i.e., some parts of the Shasta Valley may have received more than the amount collected at WED rain gage). Another rain event produced approximately 0.3 inches of rain on October 19th.

IV. STUDY AREA

The study area spans roughly 22 river miles and includes approximately 13 diversions/diversion points with a diversion potential of up to approximately 121 cfs. The study area was divided into five reaches (Figure 5). Flow assessments were calculated for the whole reach as well as between adjacent measurement sites within a reach (where a reach had more than two sites). Flow measurement sites were chosen with the following objectives: 1) to include locations upstream of Big Springs Creek to obtain greater resolution with respect to river flows and unaccounted flows in the Middle Shasta River, and 2) to inform results from the 2016 Flow Study by returning to 2016 sites.

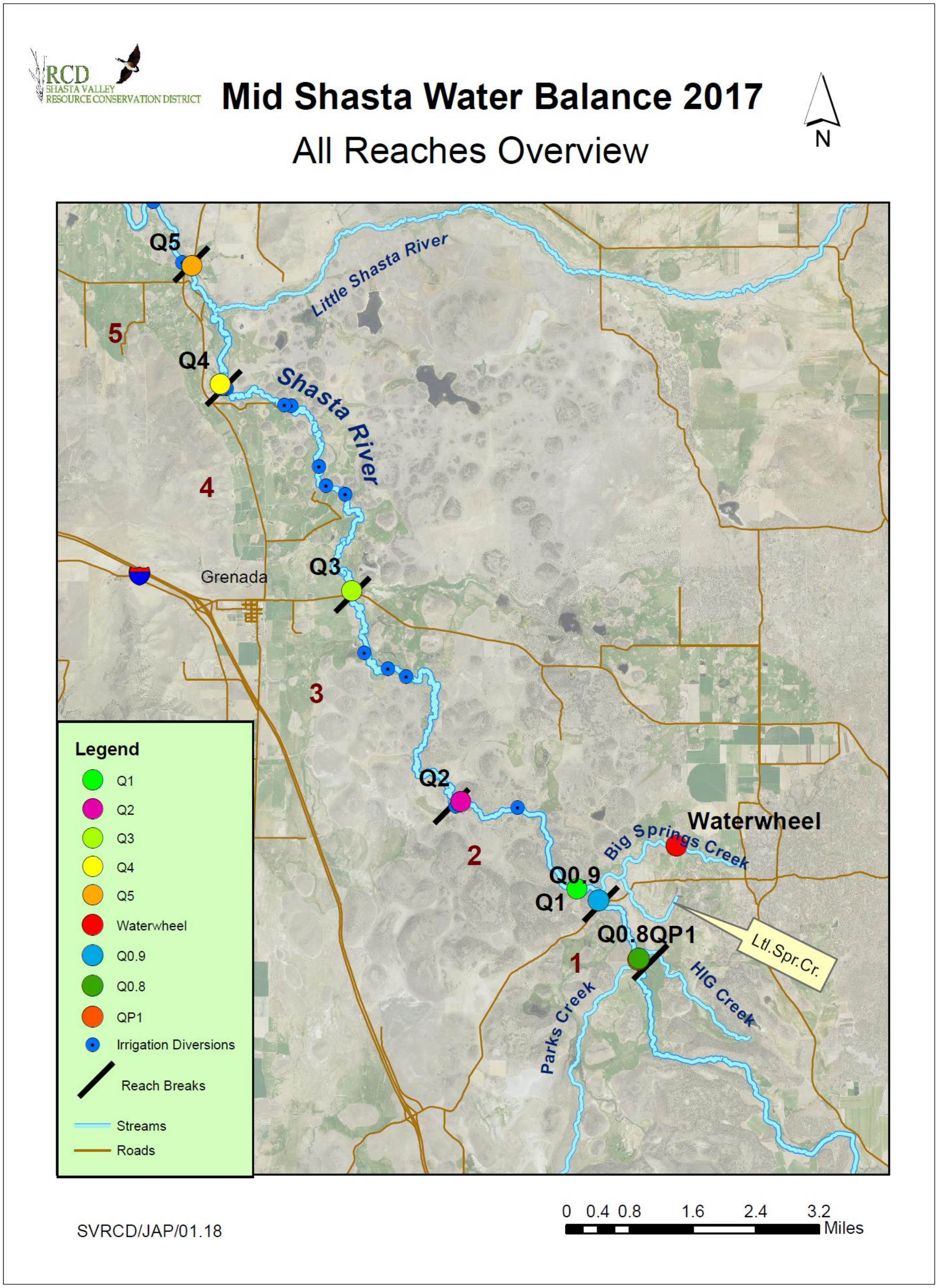


FIGURE 5. MAP OF FLOW STUDY AREA INCLUDING MAJOR TRIBUTARIES WITH ALL MEASUREMENT SITES (NUMBERS PRECEDED BY Q), EXISTING GAGES, AND REACHES (NUMBERS NOT PRECEDED BY Q).

Flow measurement stations within each reach, river mile, and type of flow are provided in Table 1.

TABLE 1. FLOW MEASUREMENT SITES (REFERENCE NAME AND SITE ID), REACH, RIVER MILE, AND TYPE OF FLOW [SHASTA RIVER (SHASTA R.) FLOW (Q), OR OTHER].

Station Reference Name	Station ID	River Mile	Type
REACH 1: Shasta River above Parks Creek to Louie Bridge			
Shasta River above Parks Creek	Q0.8	36.5	Shasta R. Q
Parks Creek above Shasta River	QP1	0.4	Parks Ck. Q
Louie Bridge	Q0.9	35.4	Shasta R. Q
REACH 2: Louie Bridge to District 1			
Louie Bridge	Q0.9	35.4	Shasta R. Q
Below Big Springs Creek	Q1	34.8	Shasta R. Q
Above District 1 - SPU[1]	Q2	29.8	Shasta R. Q (DWR gage)
REACH 3: District 1 to A12 Road Overpass			
Above District 1 - SPU[1]	Q2	29.8	Shasta R. Q (USGS gage)
Below A12 Rd. overpass (A12)	Q3	22.8	Shasta R. Q
REACH 4: A12 to District 2			
Below A12 Rd. overpass (A12)	Q3	22.8	Shasta R. Q
Below District 2	Q4	16.6	Shasta R. Q
REACH 5: District 2 to Montague-Grenada Weir (M-G Weir)			
Below District 2	Q4	16.6	Shasta R. Q
SRM[2]	Q5	14.5	Shasta R. Q

[1]SVRCD rated this site, but DWR Gage (SPU) was used for stage measurements.
[2]Existing USGS gage. Did not independently verify rating.

V. STUDY AREA: IRRIGATION DEVELOPMENT

The diversion of Shasta River water for agriculture is the primary use of Shasta River water in the watershed. While Shasta River adjudication allows for diversion of water in varying quantities year-round depending on each water right holder's specific beneficial uses, water use during the irrigation season (April 1- October 1) creates the largest short-term impacts on water quality and salmonid survival. Beginning early in the irrigation season, surface water is fully appropriated and, thus, flows in the lower portions of the river are drastically reduced until the end of the irrigation season.

Although many farmers own and operate their own individual irrigation systems within the Shasta Valley, there are four major water districts or associations: Grenada Irrigation District, Montague Water Conservation District, Huseman Water Users, and Shasta River Water Users Association that operate and manage large irrigation systems using surface water. As with individual diverters, these districts or associations pay the maintenance costs related to the operation of these systems and allocate water distribution within their district boundaries.

I. STUDY AREA: REACH DESCRIPTIONS

REACH 1: Q0.8 TO Q0.9 - SHASTA RIVER (ABOVE PARKS CREEK) TO LOUIE RD. BRIDGE

Reach Length: 1.2 miles

Discharge Measurement locations:

I. **Q0.8** – Shasta River above Parks Creek
II. **QP1** – Parks Creek (approx. 25 meters upstream of confluence with Shasta River)
III. **Q0.9** – Louie Rd. Bridge (on Shasta River)

Reach 1 is the uppermost reach in our study. No known diversions occur in this reach. Inflows to the Shasta River here include Parks Creek (measured), Hole in the Ground Creek (HIGC - not measured), and return flow from a Parks Creek diversion upstream of our Parks Creek measurement point referred to as "Parks Creek Overflow" (not measured). Parks Creek water rights may continue to be used through November 1st. Hole in the Ground Creek consistently discharges approximately 3 cfs to the Shasta River (pers. comm. Ada Fowler – TNC). Reach one can be seen in Figure 5.

Reach 1 starts on the Shasta River above Parks Creek and ends just below the Louie Road Bridge. This reach provided a baseline of flow and a snapshot of conditions on the Upper Shasta River prior to reaching the complicated hydrogeology of the "Big Springs Complex". This complex, which includes Big Springs Creek, Little Springs Creek and numerous other small, unidentified springs and seeps, more than doubles the flow of the Shasta River upstream of Big Springs Creek.

REACH 2: Q0.9 TO Q2 - LOUIE BRIDGE TO DISTRICT 1 PUMP STATION

Reach Length: 5.6 miles
Discharge Measurement Locations:

I. **Q0.9** – Below Louie Bridge (Shasta River)
II. **Q1** – Below Big Springs Confluence (Shasta River)
III. **Q2** – SPU - Above District 1 Pump Station (Shasta River)

Reach 2 spans a hydrologically and geologically complex part of the study area, and only one diversion of up to 2.1 cfs lies on the Shasta River in this reach at Nelson Ranch, owned by TNC. Numerous large and small springs and seeps, including Big Springs Creek and Little Springs Creek, provide surface and sub-surface inflows to this part of the reach. Traversing the Big Springs Complex, the Shasta River between Louie Bridge and Q1 (just below the mouth of Big Springs Creek) receives spring water emanating from the geologic intersection of Quaternary Volcanic Debris Avalanche facies and slightly younger Pluto Cave Basalt that lies just east of the Shasta River on Big Springs Creek. Spring water sources in this area consistently provide greater than 50 cfs to Big Springs Creek, and an unknown quantity to numerous groundwater wells (Figure 6).

Measurement sites in this reach were selected to attempt to quantify inflows to the Shasta River from the Big Springs Complex. Station Q0.9 (new site in 2017) was located just above the mouth of Big Springs Creek, and Q1 is approximately 0.5 miles downstream. Inflows from the Big Springs Complex were retrieved from an existing stage/discharge station maintained by TNC known as the "Water Wheel", 1.6 miles upstream on Big Springs Creek, which did not quantify inflows from Little Springs Creek or any unknown seeps or springs between the Water Wheel and Q1 (Figure 7).

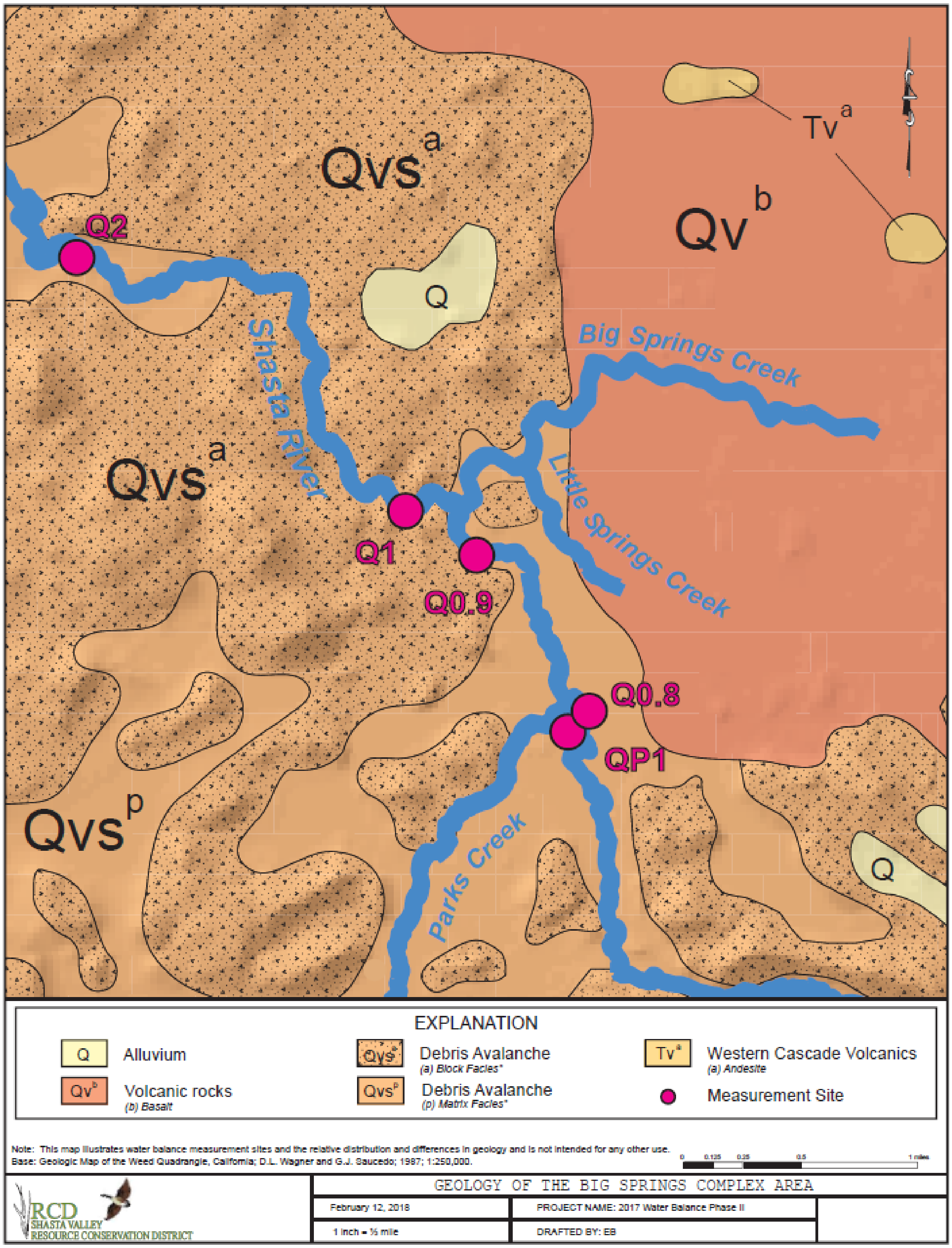


FIGURE 6. GEOLOGIC MAP OF THE BIG SPRINGS COMPLEX AREA.

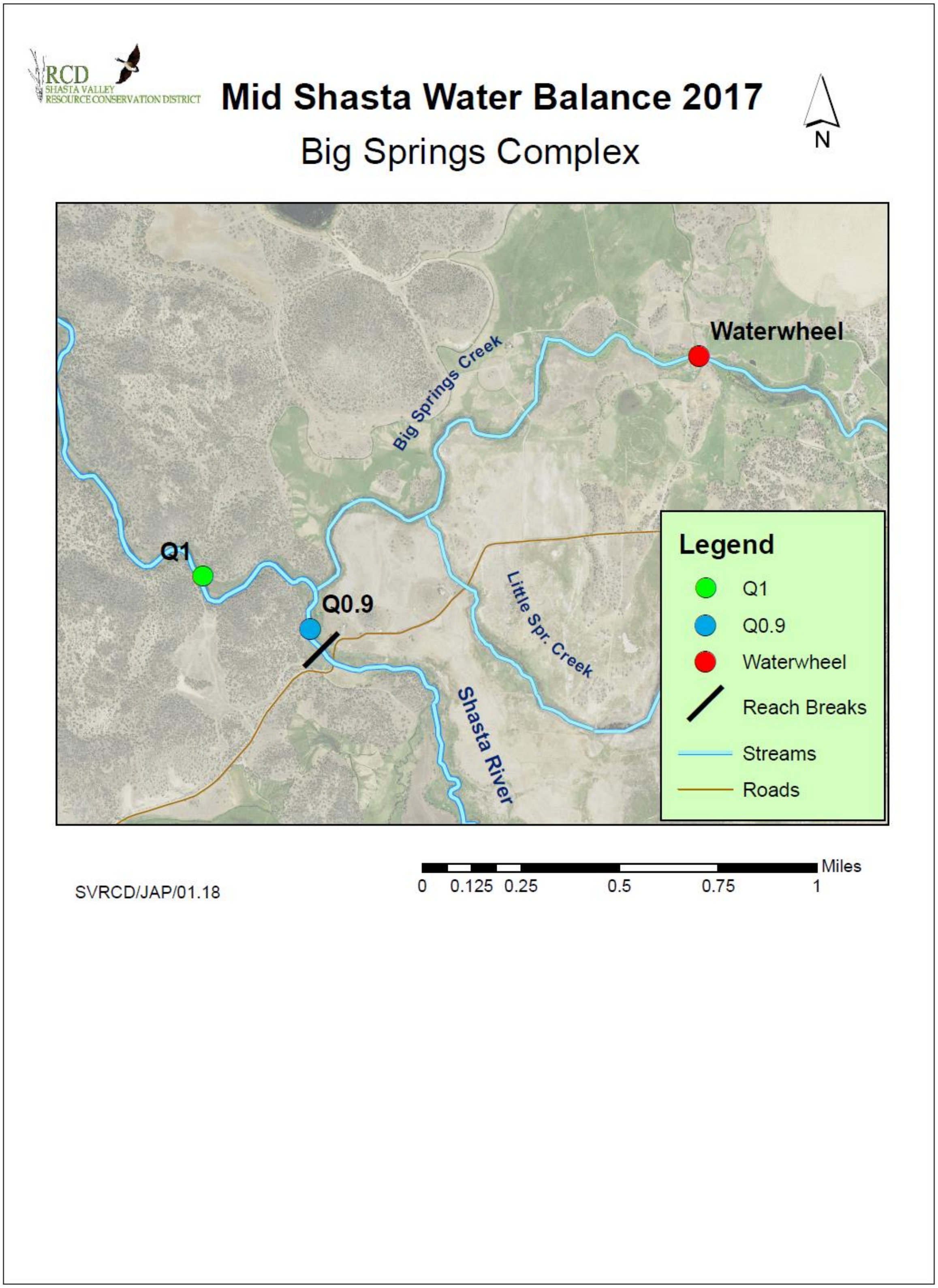


FIGURE 7. MAP OF THE BIG SPRINGS COMPLEX INCLUDING MEASUREMENT SITES AND "WATER WHEEL" EXISTING STAGE/DISCHARGE SITE ON BIG SPRINGS CREEK. ALSO IDENTIFIED IS LITTLE SPRINGS CREEK DOWNSTREAM OF THE WATER WHEEL SITE.

REACH 3: Q2 TO Q3 – ABOVE DISTRICT 1 PUMP STATION TO BELOW A12 ROAD OVERPASS

Reach Length: 7.5 miles

Discharge Measurement Locations:

I. Q2 – Above District 1 Pump Station (Shasta River)
II. Q3 – Below A12 Road Overpass (Shasta River)

Reach 3 has seven diversion points, with a diversion potential of up to 53 cfs. However, one large diversion (42 cfs) was turned off during the study period. Reach 3 can be found in Figure 5 .

The McCloud Slough and one other unnamed slough drain to the river in this reach on river left, though surface flows are not typically observed here. In addition, leakage from the District 1 diversion canal (up to 10 cfs, along with any deep percolation from irrigation, less any transpiration enroute) may return to the river sub-surface in this reach and/or Reach 4 when District 1 is diverting water.

Near the lower end of this reach, Willow Creek enters the Shasta River. Although surface flows in Willow Creek are generally small to non-existent in summer, there may be sub-surface flows present.

REACH 4: Q3 TO Q4 – BELOW A12 ROAD OVERPASS TO BELOW DISTRICT 2 PUMP STATION

Reach Length: 5.8 miles

Discharge Measurement locations:

I. **Q3** – Below A12 Rd. Overpass
II. **Q4** – Below District 2 Pump Station

Reach 4 has eight diversion points, with a diversion potential of up to 54.2 cfs.

Within this reach geologic complexities continue. A narrow branch of the Plutos Cave Basalt overlays and bisects the debris flow, providing a potential pathway for subsurface flows to enter the river just downstream of A-12 from river right. On river left, Julien Creek joins the Shasta River, and has left behind one of the very few substantial alluvial fans bordering the Shasta River, though much of it is hidden below irrigated improved pasture. That alluvial fan likely provides a conduit for Julien Creek underflow, spring flow from springs visible and not visible adjoining the Julien Creek channel, and sub-surface tailwater returning from District 1 and District 2.

Further downstream, leakage from storage reservoirs and/or irrigation tailwater, as well as water from the California Department of Fish and Wildlife wildlife area, can reach the Shasta River around river mile 18.8.

REACH 5: Q4 TO Q5 – DISTRICT 2 TO MONTAGUE-GRENADA WEIR

Reach Length: 2.1 miles

Discharge Measurement Locations:

I. **Q4** – Below District 2 Pump Station
II. **Q5** – At Montague-Grenada (MG) Weir

The City of Montague pump resides in this reach, but was off during the duration of the flow study.

Substantial (but unquantified) amounts of District 2 tailwater crosses Breceda Lane (just downstream of Q4 on river left) when irrigation is occurring upgradient. This tailwater is either caught in a tailwater re-use system, or returns to the river.

The Little Shasta River, with its origins in the Cascade Mountains to the East, enters the Shasta River at river mile 26.3. Surface water is rarely seen in the Little Shasta during irrigation season as most of its flow is adjudicated during this time. However, periodic locally heavy rains may produce flows that reach the Shasta River on occasion during irrigation season.

At the reach breakpoint at Q5-SRM on river right is a large wetland area where an upwelling of water appears to contribute water to the stream via sub-surface gravel or old river channels, even though no surface flows are apparent. This water may come from a spring (or several springs) on a private ranch just east of the river, which is then impounded by a tailwater pond on the ranch. Due to the existence of "hardpan" below the soil horizon throughout this area, one hypothesis is that this water travels sub-surface under the hardpan until it reaches a break where it re-emerges and creates a wetland habitat (pers. comm. Dave Webb, retired, SVRCD).

Additionally, there are multiple small springs visibly discharging near the river bank between Q4 and Q5, the largest nearing 1 cfs in flow.

Interestingly, investigations by DWR in the 1950's of a potential dam site within this reach found evidence of a 130 feet deep lava canyon completely buried by the debris avalanche covering the bottom of the Shasta valley (CDWR, 1964). Such re-sculpting of the landscape provides ample opportunity for unpredictable hydrology throughout this area.

D. METHODS

I. TERMINOLOGY

Calculated flows (Calculated Q) refers to discharge (Q) values calculated using stage-discharge relationships.

Measured flows (Measured Q) refers to discharge (Q) values physically measured in stream.

Flows is occasionally used in reference to measured or calculated discharge when either or both terms could apply.

II. METHODS OVERVIEW

Discharge, diversion, and accretions and depletions (unaccounted flows) in the Shasta River and two tributaries (Parks Creek and Big Springs Creek) were measured, calculated and/or inferred by:

1) Installation of level loggers at measurement stations (QP1, Q0.8, Q0.9, Q1, Q3, and Q4); existing TNC level logger data was used at QBS (Big Springs Creek – Water Wheel); a level logger was installed at the DWR station Q2-SPU but due to level logger malfunction, DWR stage data was used; and the existing USGS stage-discharge relationship and data were used at Q5-SRM);
2) Five to six flow measurements with an Acoustic Doppler flow meter at measurement stations (QP1, Q0.8, Q0.9, Q1, Q2-SPU, Q3, and Q4);

3) Creation of a stage-discharge relationship for measurement stations (QP1, Q0.8, Q0.9, Q1, Q2-SPU, Q3, and Q4);
4) Acquisition of flow data from two existing flow gages [USGS station Shasta River near Montague (Q5-SRM) and TNC station Big Springs Creek at Water Wheel (QBS)];
5) Creation of 15-minute hydrographs for the study period using stage-discharge relationships;
6) Diversion tracking for 48-hour windows by communicating with pump/diversion operators (note: flow measurements were performed in stream during this 48-hour window when possible);
7) Calculation of transit times between measurement stations;
8) Comparison of flows between measurement stations (accounting for transit times);
9) Calculation of unaccounted accretions or depletions;

III. MEASURING AND CALCULATING FLOW

STAGE-DISCHARGE RELATIONSHIPS AND RATING CURVE DEVELOPMENT

To estimate stream discharge at each site, stage-discharge relationships (rating curves) were developed as described in Rantz et al. (1982). Following this protocol, rating curves were developed for each site by: 1) plotting measured discharge (Q) values with measured stage/level values (from level loggers) on an X-Y axis in an Excel spreadsheet, 2) inserting a trendline, and 3) producing a power function in the form:

$$Y = aX^b$$

Where **a** and **b** are constants that are then applied to the following equation to create calculated discharge (Q) values for each logged stage or level value recorded every 15 minutes,

$$\text{Calculated Q} = (\text{Level (ft)}/\mathbf{a})^{1/\mathbf{b}}$$

Using calculated discharge values, 15-minute hydrographs were then created for each measurement station.

LEVEL LOGGERS (STAGE LOGGERS)

Onset U20-001-04 level loggers were deployed at each flow measurement site. These level loggers measured stage height that was then converted to feet using local barometric data, and are accurate within $\pm$ 0.02 feet in water depths of 0 to 4 meters. All level loggers were deployed at depths less than 4 meters. Level loggers were deployed inside a 4-inch diameter PVC pipe with holes drilled near the bottom (under water) and top (exposed to air) to prevent potential deviations in water level from capillary action. PVC pipes were attached to a t-post in the river, placed at relatively calm and accessible location within 200 feet from each flow measurement site. Level loggers were attached to a small wire cable and fixed to a PVC cap at the top of the pipe. Stoppers were placed on the PVC pipe to secure the cap to a fixed height on the pipe and insure that level loggers were always re-deployed at the same height after data downloads. Level loggers recorded water height at 15-minute intervals and were downloaded on each sampling day. Water level was also physically measured on each sampling day at logger locations using an engineer's ruler.

ADV AND ADCP FLOW MEASUREMENTS

Flow measurements were measured with either: 1) SonTek FlowTracker Handheld-ADV® and top-setting wading rod kit (hereafter referred to as FlowTracker®), which uses acoustic Doppler technology to measure velocity and calculates discharge using the current-meter midsection method (Buchanan and Somers 1969), or 2) Teledyne RD Instruments' Streampro Acoustic Doppler Current Profiler (ADCP), which also uses acoustic doppler technology attached to a pontoon-style boat that is pulled across the stream via a "tagline" by operators on either stream bank. Method 2 allows for the safe measurement of flow during conditions that are unwadeable or unsafe (i.e., very high flow).

Measuring methods are slightly different between the Flowtracker Handheld-ADV® and the Streampro ADCP:

When using the FlowTracker®, a transect perpendicular to the flow was established by the hydrographer and divided into a proportional amount of stations so that each station constituted 5% or less than the total discharge. Velocity measurements were taken at the center of each station and were generally measured at a depth of 60% below the surface. This 0.6 method is recommended for an effective depth of less than 2.5 ft; if water depth rose to 2.5 ft or greater and conditions allowed, the 2-point method was used and measurements are made at a depth of 20% and 80% below the surface (Buchanan and Somers 1969, Rantz et al. 1982).

For each measurement, the FlowTracker® recorded velocity every second and averaged it over a period of 40 seconds. Station location and stream depth were input by the hydrographer and used to calculate area for each station. The current-meter method summed the products of the partial areas of the stream cross-section and their average velocities (Buchanan and Somers 1969 and Rantz et al. 1982). Several quality control parameters were measured with each velocity measurement (i.e. signal-to-noise ratio, standard error of velocity, boundary adjustment, the number of spikes filtered from data, and velocity angle) and were available to the hydrographer instantaneously, allowing the measurement to be repeated in the case of poor data quality. This substantially reduced error within the various components of the discharge measurement and overall discharge uncertainty was kept to less than 5%.

The Streampro ADCP was used when flow conditions were unwadeable or unsafe. The Streampro utilized a four-beam acoustic probe attached to a small pontoon style boat tethered and pulled from bank to bank by operators on either side; while one operator, or an additional operator, initiated contact between the probe and a laptop via Bluetooth® wireless technology. The four-beam probe transmitted velocity profiles by sampling velocity in multiple cells (a.k.a. bins) along verticals ensembles that were displayed on the laptop screen in real time so the operator could monitor the progress (using WinRiverII software) of the Streampro ADCP as it tracked across the transect. It also acoustically measured water column depth and computed Doppler velocity from averaged profile data (Marsden, 2005). A minimum of four transects were performed per site per measurement day using the Streampro. One "transect" refers to one left to right (or right to left) transverse of the stream cross-section perpendicular to flow.

In addition to real-time quality control during which the operator could abort a transect if an obvious error (e.g., probe came out of water, slack in tagline caused the boat to fall out of the transect line) occurred while pulling the ADCP across, operators scrutinized collected data post-hoc and had the option of removing transects that appear consistent with other transects. The use of WinRiverII software allowed the operator to view inconsistencies in tracking of the ADCP probe across transects, and calculated percent differences between discharges (>5% differences were highlighted in red to emphasize the need to scrutinize further).

After quality control was performed on ADCP data, discharges were averaged to create a single discharge/flow value for each measurement site on each measurement day.

The Streampro ADCP also has an optional moving bed test that, when utilized, can detect movement of particles in the stream bed in high velocity conditions that may impact the accuracy of recorded velocities and column depths. This test was performed prior to running transects at each site on each sampling day.

RATING CURVE DEVELOPMENT AND CALCULATED DISCHARGE

Rating curves were developed for each flow measurement site as described in Rantz et al. (1982). Using the rating curves and 15-minute stage data from level loggers, 15-minute discharge hydrographs were created for each site. Rating curves were only created for the range of flows that were encountered during the study period. Rating curves are provided in Appendix B.

Diversion information was obtained directly from irrigators throughout the study period. Irrigators were asked to provide diversion information for a 48-hour period (minimum). Diversion tracking occurred on the following dates: August 23rd, September 6th and 20th, and October 4th, 11th and October 20th.

IV. TRANSIT TIMES

Due to large (up to 20 cfs) fluctuations in flow throughout the study area it was important to assess flow between measurement sites using a theoretical “parcel of water” approach. In this way, we attempted to follow (temporally and spatially) and calculate the time it took for a parcel of water to travel from site to site (i.e., the transit time of that parcel of water).

To estimate transit times, hydrographs were plotted together and trends between hydrograph shapes were assessed. Trends that carried through the study area (i.e., crests or troughs whose amplitude could be followed spatially and temporally through stacked hydrographs) were noted and then calculated discharge values at tops of crests or bottoms of troughs were selected to represent the start and end of transit through a sub-reach. The transit time for each sub-reach was estimated as the difference between start and end times between measurement sites. Estimated transit times for each sub-reach on each assessment day were then averaged to create one estimated transit time for each sub-reach.

In 2016, discharge at each site during assessment days was compared using 15-minute calculated discharge values staggered by estimated transit times for each sub-reach. This method resulted in two discrete discharge values to calculate sub-reach accretion or depletion, and this method appeared to work fine during stable flow periods when an error in transit time estimation would not result in a substantial gain or loss in flow rate. To reduce potential errors associated with uncertainty in transit times (between each sub-reach and larger uncertainty associated with cumulative transit time through the study area) as well as short-term fluctuations in discharge, 12-hour blocks of 15-minute calculated discharge values were averaged to buffer the potential for small errors to magnify over space and time. The increment of 12 hours was chosen after looking at stacked hydrographs of all measurement sites, and determining an increment that would “smooth” fluctuations without diluting results to the point where balancing flows from site to site and throughout the study area would be ineffective. The trade-off was the potential for reduction in precision or resolution. The intention was to provide a conservative representation of flows between sites and through the whole study area, from which observations and assumptions could be made about the balance of water in the system.

In addition, a separate set of 12-hour averages was calculated to compare to the first. The second set was staggered six hours ahead of the initial set.

Note: A robust stage-discharge relationship could not be created at Q1, as could be created at all other sites. Instead, measured discharge values from this site were used in conjunction with calculated discharge values upstream and downstream of Q1 in order to determine a water balance for Q0.9 to Q1 and Q1 to Q2. Associated transit times were used to match flows per the parcel-of-water method mentioned previously.

Estimation of transit times was difficult due several factors: large inflows from the Big Springs Complex, large and small diversions throughout the study area, unknown seeps, springs and tailwater returns, as well as fluctuations caused by variances in flow released by Dwinnell Dam that manipulated the shapes of hydrographs through the study area.

The average transit time through the study area (from Q0.8 to Q5) was approximately 12.8 hours. Although estimated transit times varied between assessment days and these times were used in accretion and depletion calculations, average transit times for each sub-reach and the study area are provided in Table 2.

TABLE 2. SUB-REACH LENGTHS, AVERAGE TRANSIT TIMES THROUGH EACH SUB-REACH, AND TOTAL AVERAGE TRANSIT TIME THROUGH THE STUDY AREA. TRANSIT TIMES PRESENTED WITH STANDARD DEVIATION (SD).

Sub-reach	Sub-reach Length (mi)	Average Estimated Transit time w/SD (σ)
Q0.8 to Q0.9	1.2	1.1 (0.14)
Q0.9 to Q2[1]	5.6	2.0 (0.16)
Q2 to Q3	7.5	3.5 (1.7)
Q3 to Q4	5.8	3.2 (1.6)
Q4 to Q5	2.3	3.0 (1.1)
Q0.8 to Q5[1]	22.4	12.8

[1]Q0.8 to Q5 includes the total length and average estimated transit time through the study area.

IV. UNACCOUNTED ACCRETION/DEPLETION CALCULATIONS

Unaccounted accretions/depletions are the amount of accretion or depletion that occurred which was not attributed to reported diversions or measured inflows. Accretions are positive numbers while depletions are listed as negative numbers.

The unaccounted accretions/depletions were calculated for each reach and sub-reach by the calculating the difference between reported discharge and theoretical discharge (Equation 1).

EQUATION 1:

UNACCOUNTED ACCRETION/DEPLETION = BOTTOM OF REACH Q – (TOP OF REACH Q – KNOWN OUTFLOWS + KNOWN INFLOWS)

Unaccounted accretions/depletions values may be affected by variations in actual versus reported diversion amounts, error in discharge measurements, stage-discharge relationships, 12-hour average discharge values, and estimated transit times. Error was not estimated for this report but could be estimated in future analyses of 2016 and 2017 data.

E. RESULTS AND DISCUSSION

I. OVERVIEW – ALL SITES AND REACHES

In general, flows increased at each site over the length of the study period (Table 3, Figure 8). Relatively large (15 to 20 cfs) releases from Dwinnell Reservoir (upstream of the furthest upstream measurement site in this study) during the 3rd week in September, and again at the end of irrigation season on October 1st, contributed to overall increases in flow (Figure 9). Moreover, possible cessation of groundwater pumping within the Big Springs Complex after October 1st may have increased flow contributions to the Shasta River from Big Springs Creek and other unknown seeps and springs in the area. Reduced irrigation demands and potentially other factors (e.g., reduced air temperatures and evapotranspiration) also contributed to increases in flow throughout the study period.

Spatial and temporal changes in flows can be attributed to both known accretion and depletion (e.g., diversions and tributaries) as well as unknown accretion and depletion (e.g., tailwater and unknown seeps or springs). Flows generally decreased from Q1 to Q4 (upstream to downstream) in September most likely due to diversions. The increase in flow between Q4 and Q5 during irrigation season can be attributed to known (but unmeasured) tailwater returns in this reach and possibly Little Shasta subsurface inflows. The effect of diversions on flow is evidenced by post-irrigation season flows that remain fairly consistent (very little accretion or depletion relative to irrigation season flows) between Q1 and Q5.

TABLE 3. DISCHARGE CALCULATED FROM RATING CURVES AT EACH MEASUREMENT LOCATION FOR EACH ASSESSMENT DAY IN 2017.

Site ID	Site Nickname	River Mile	24-Aug	6-Sep	20-Sep	4-Oct	11-Oct	20-Oct
Q0.8	Shasta above Parks	36.5	19.9	15.3	14.6	26.4	19.0	19.6
QP1	Parks Ck at Shasta R.	0.1	20.4	17.2	14.7	14.8	21.1	21.3
Q0.9	Louie Br.	35.4	46.0	39.3	36.8	44.1	48.1	46.1
QBS	Big Springs Ck	1.6	61.8	68.0	64.0	63.6	69.0	73.2
Q1[1]	Below Big Springs	34.8	113.9	111.5	117.5	123.5	149.7	150.0
Q2	Above District 1 - SPU	29.8	100.1	105.6	117.6	122.9	144.8	155.0
Q3	A-12	22.8	86.2	98.0	106.3	123.1	135.7	147.4
Q4	District 2	16.6	56.1	60.0	68.3	123.1	136.0	141.7
Q5	SRM	14.5	64.5	69.1	78.3	126.1	136.9	151.2

[1]The rating curve developed for Q1 yielded a low R-squared value and therefore was not used to calculate discharge values. Q1 measured values are presented instead, which do not fall within transit times used with all other sites and values.

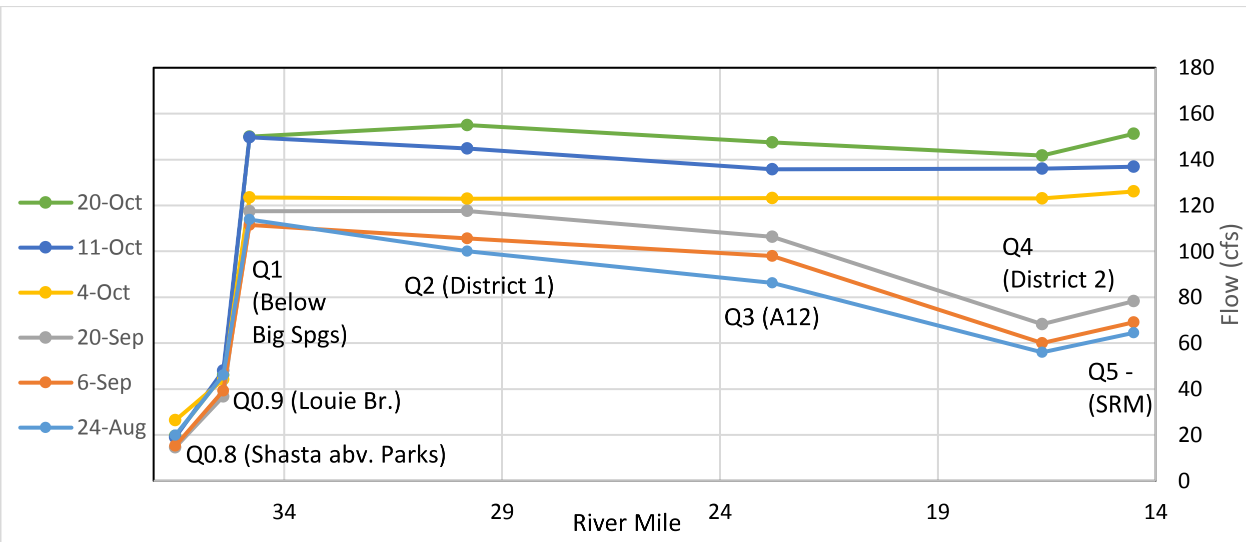


FIGURE 8. SHASTA RIVER CALCULATED FLOWS BY RIVER MILE ON DATE/TIMES ASSOCIATED WITH EACH ASSESSMENT DAY DURING THE STUDY PERIOD, 2017.

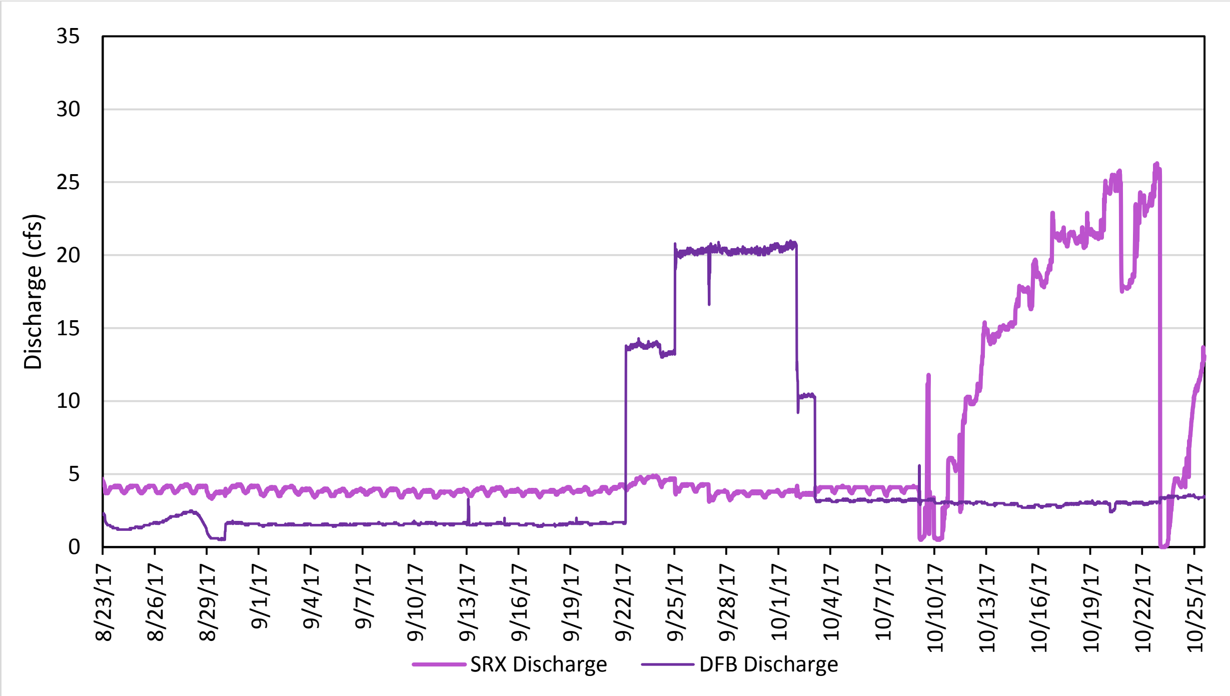


FIGURE 9. DWINNELL RESERVOIR/DAM FLOW RELEASES MEASURED AT CROSS CANAL (SRX) AND DWINNELL FISH BYPASS (DFB) (RETRIEVED FROM CDEC, 2017).

II. REACH 1: SHASTA RIVER ABOVE PARKS CREEK TO LOUIE BRIDGE (Q0.8 TO Q0.9)

Rating curves for each site are provided in Appendix A and 15-minute discharge hydrographs with associated stage values are displayed below.

Q0.8: DISCHARGE AND STAGE AT Q0.8 – SHASTA RIVER ABOVE PARKS CREEK

Streamflow in the upper Shasta River (below Dwinnell Dam through Parks Creek) is largely a product of water releases from Dwinnell Reservoir with additional inputs from seeps, springs and tailwater flows. During low-flow (5 -20 cfs) periods on the upper Shasta River, when dam releases are as low as 5-10 cfs, the majority of upper Shasta River flow is an accumulation of non-Dwinnell sources (seeps, springs, tailwater returns) downstream of the dam. High-flow (>20 cfs) flows on the upper Shasta River are typically a result of large releases from Dwinnell Reservoir. However, these releases primarily occur during cooler, non-irrigation season months.

From June 28th to September 24th (89 days), approximately 5 cfs (approximately 30% of total flow at Q0.8) was from water released from Dwinnell Reservoir (CDEC, 2017).

The 15-minute discharge hydrograph for the upper Shasta River site (Q0.8) just above Parks Creek is displayed in Figure 10. Discharge measurements were not collected for flows at the upper end of the rating. Therefore, calculated flows greater than 33 cfs, the highest measured discharge, would have needed to have been extrapolated and so not presented here. Discharge ranged from approximately 10 cfs to >33 cfs through the study period.

As previously noted, a large increase in discharge (15 cfs to >33 cfs) occurred on September 24th and lasted through October 3rd before tapering off and receding to approximately 20 cfs with +/- 5 cfs fluctuations through the remainder of the study. This sudden increase in flow that lasted from late September through October was due to approximately 20 cfs released from Dwinnell Reservoir.

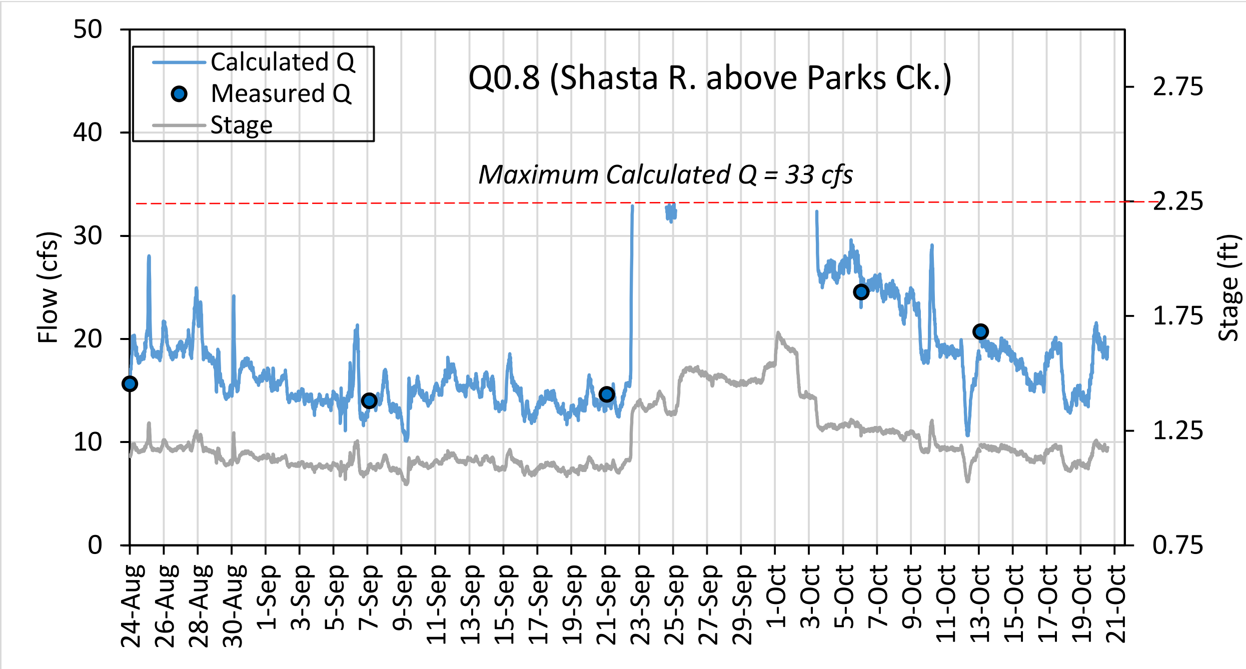


FIGURE 10. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q0.8 DURING THE STUDY PERIOD. MISSING VALUES IN HYDROGRAPH EXCEEDED MEASURED VALUES USED TO CREATE RATING CURVE.

Q0.9: DISCHARGE AND STAGE AT LOUIE BRIDGE - RM 35.4

Q2-SPU 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 11 . Discharge ranged from approximately 25 cfs to >65 cfs during the study period, with a slight decreasing trend through September 23rd followed by a sharp increase similar to Q0.8 due to releases from Dwinnell Reservoir, and highly fluctuating (but generally increasing) flows following the end of irrigation season.

During the study period, high flows contributed to channel scouring and modification of the stream bed at Q0.9 resulting in the need to create two distinct rating curves to maintain accuracy in calculated discharge values. The break in the hydrograph in Figure 11 signifies the increase in flow that modified the channel and corresponds to the use of separate low-flow and high-flow rating curves for discharge calculation.

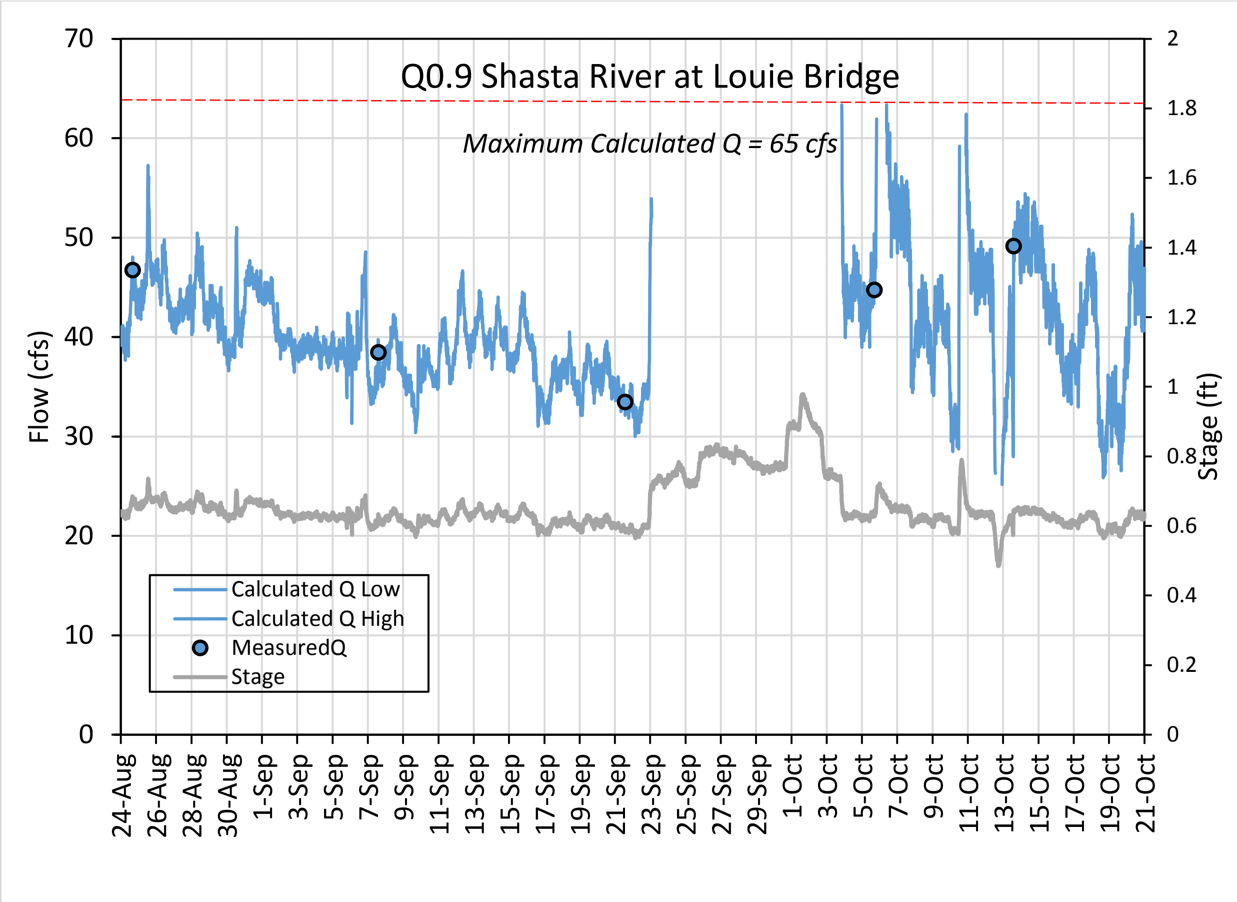


FIGURE 11. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q0.9 (LOUIE BR.) AUGUST 24TH THROUGH OCTOBER 20TH, 2017. RATING CURVE WAS SPLIT INTO SEPARATE "HIGH" AND "LOW" CURVES DUE TO CHANGES IN CHANNEL MORPHOLOGY THAT OCCURRED DURING THE STUDY. THESE CHANGES LED TO A POOR FITTING (LOW R^2 VALUE) RATING CURVE. LOW VALUES FALL ON THE CURVE PRIOR TO SEPTEMBER 23. HIGH VALUES FALL ON THE CURVE AFTER OCTOBER 3RD. VALUES IN BETWEEN THESE DATES EXCEEDED MEASURED VALUES USED TO CREATE RATING CURVE AND THEREFORE REMOVED.

QP1: DISCHARGE AND STAGE ABOVE PARKS CREEK MOUTH

QP1 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 12. Flows greater than 26 cfs exceeded measured discharge used to create rating curve. Flow ranged from approximately 11 cfs to >26 cfs during the study period. Parks Creek measurements helped to quantify accretions between Q0.8 and Q0.9.

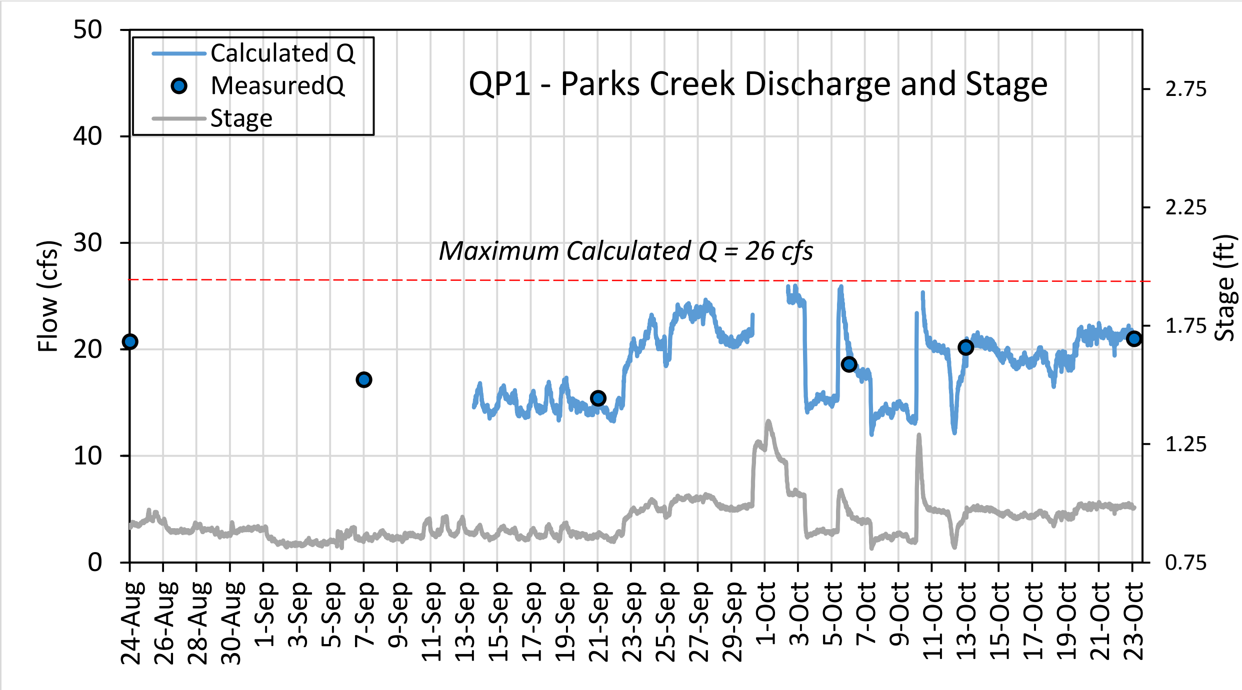


FIGURE 12. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR QP1-PARKS CREEK ABOVE SHASTA RIVER CONFLUENCE, SEPTEMBER 24TH THROUGH OCTOBER 24TH, 2017. RATING PRIOR TO SEPTEMBER 24TH NOT USED DUE TO POOR FITTING RATING CURVE.

REACH 1: ACCRETIONS AND DEPLETIONS

Change in flow, total amount diverted, and the unaccounted accretions and depletions were assessed in each sub-reach. Measured inflows in Reach 1 included Parks Creek. Unmeasured inflows in Reach 1 included Parks Creek overflow and Hole in the Ground Creek.

Q0.8 TO Q0.9

Start flow (Start Q), end flow (End Q), change in flow (Change Q), diversions, measured inflows, and unaccounted accretions and depletions between Q0.8 and Q0.9 on assessment days are provided in Table 4.

TABLE 4. START FLOW, END FLOW, CHANGE IN FLOW, DIVERSIONS, MEASURED INFLOWS, AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q0.8 AND Q0.9 ON ASSESSMENT DAYS.

Q0.8 to Q0.9							
Total Potential Diversions: 0 cfs							
Season	Date	Start Q (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	Measured Inflows (cfs)	**Unaccounted (cfs)**
Irrigation	24-Aug	19.9	46.1	26.2	0.0	20.7	**5.4**
	6-Sep	15.3	39.3	24.0	0.0	17.2	**6.9**
	19-Sep	14.6	36.8	22.2	0.0	14.7	**7.5**
Post-Irrigation	3-Oct	26.4	44.1	17.8	0.0	14.8	**3.0**
	10-Oct	19.0	48.1	29.1	0.0	21.1	**8.0**
	20-Oct	19.6	46.1	26.5	0.0	21.1	**5.3**
Irrigation	Average:	16.6	40.7	0.0	17.5	6.6	6.6
Post-Irr	Average:	21.7	46.1	0.0	19.0	5.4	5.4

The average unaccounted accretion in this sub-reach was 6.6 cfs during irrigation season and 5.4 cfs post-irrigation season. Combined inflows from Parks Creek overflow and Hole in the Ground Creek are known to be 0-8 cfs. Therefore, unaccounted accretions in this reach were assumed to be all (or mostly) derived from Parks Creek overflow and Hole in the Ground Creek.

REACH 1 CONCLUSIONS

Sites in Reach 1 (2017) were not measured in 2016. Therefore, no annual comparison can be made. However, it is clear that releases from Dwinnell Dam can significantly alter flow in the upper reaches of the Shasta River, impacting temperatures, DO, and critical habitat for endangered species.

III. REACH 2: Q0.9 TO Q2-SPU – LOUIE BRIDGE TO ABOVE DISTRICT 1

Reach 2 includes measurement locations Q0.9 (Louie Bridge), Q1 (below Big Springs), Q2-SPU (above District 1), and includes calculated discharge from a monitoring station on Big Springs Creek 1.6-miles above its mouth at a location referred to as Water Wheel. Q0.9 hydrograph and description are displayed in the previous section. A rating curve for Q2-SPU (above District 1) is provided in Appendix A and a 15-minute discharge hydrograph with associated stage values is displayed in Figure 14.

Due to the same flow conditions on September 23rd that caused changes in channel morphology at Q0.9, along with stream bed alteration caused by the creation of "redds" (for spawning) by migrating Chinook salmon, we could not create a usable flow rating curve for Q1 (below Big Springs) and therefore this site does not have an associated hydrograph or calculated flow/discharge data. However, measured discharges at Q1 were used in conjunction with associated transit times from Q0.9 and Q2 to assess flows from Q0.9 to Q1 to Q2. Because flow assessments that included Q1 are based around the exact time points when flow measurements were performed in-stream, results reflected conditions in the river at the time of the Q1 field measurement. Interestingly, these conditions were not ideal for assessing flow in a stable state, which typically call for relatively unchanging flow conditions. Instead, the Q1 measurement occurred during a turbulent flux in flows upstream of, downstream of, and including Big Springs Creek. This undoubtedly affected flow transit times and increased the *potential* for error when selecting flow values for comparison between sites. On the other hand, it may have *provided* a snapshot of how the Big Springs Complex reacted to high levels of flux in the system.

Due to the increased potential for error in these calculations (when Q1 is included in analysis), this section includes two sets of flow assessments for this reach:

1) Flows assessed between Q0.9and Q2 *including Q1* (using Q1 flow rates measured in the field, and associated calculated flow rates at Q0.9 and Q2 selected by adding transit times from Q1 to Q0.9 or Q1 to Q2), and
2) Flows assessed between Q0.9 and Q2 *excluding Q1* (using 12-hour average flow calculations assessed during relatively stable flow conditions).

Flows assessed using method 1 are denoted by the term "single point" and flows assessed by method 2 are denoted by "12-hour average".

Q1: BELOW BIG SPRINGS CREEK CONFLUENCE WITH SHASTA RIVER

Q1 measured discharge values (single point) are displayed in Figure 13. Measured flows ranged from 111 – 150 cfs.

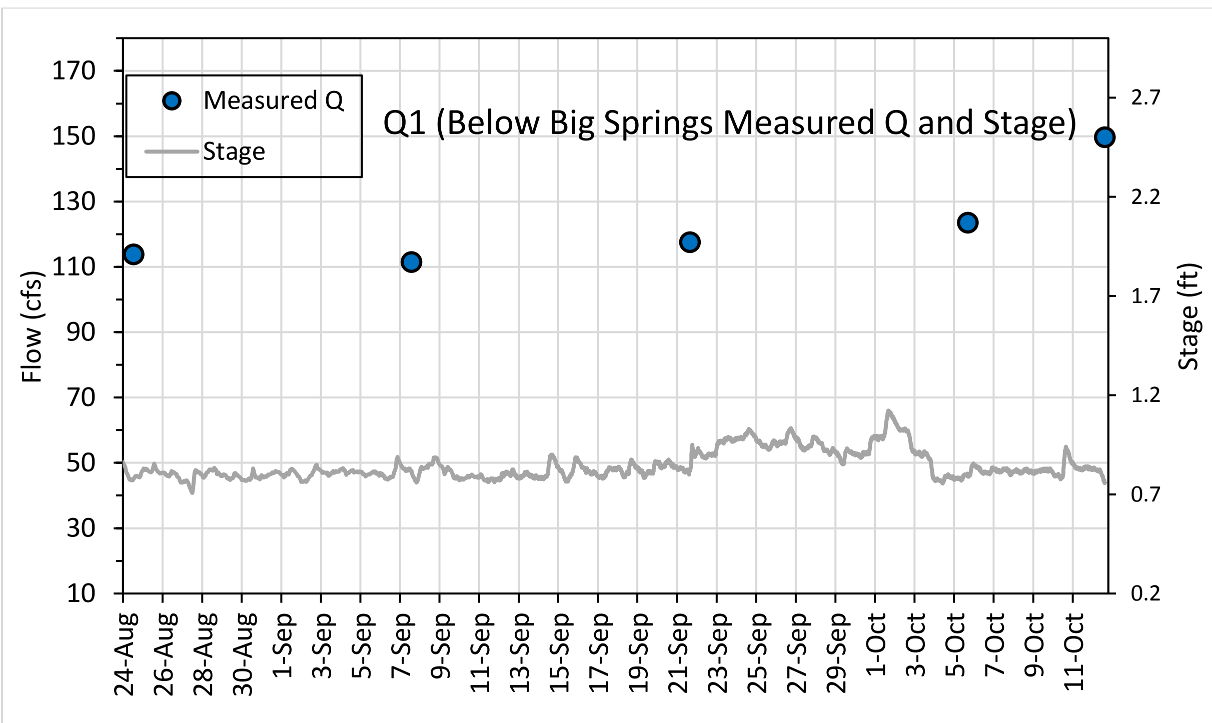


FIGURE 13. STAGE AND SINGLE POINT MEASURED FLOW (Q) FOR Q1 THROUGHOUT THE STUDY PERIOD.

Q2-SPU: ABOVE DISTRICT 1 PUMP STATION

Q2 15-minute discharge hydrograph with associated stage values is displayed in Figure 14. Flow ranged from approximately 95 cfs to >154 cfs with a general trend of increasing flows through the study period. In 2016, large fluctuations (approximately 5 to 20 cfs over 1 to 4 day cycles) were observed in the hydrograph for Q2. In 2017, fluctuations of 5 to 20 cfs can be seen in the hydrograph. However, a uniform pattern of cycles was not detected. It was anticipated that the addition of upstream measurement sites (Q0.8, Q0.9 and QP1) in 2017 would inform 2016 observations at this and other (Q1 and Q5) sites. Though upstream hydrograph shapes often reflect those of downstream sites, no uniformity that might suggest a link to irrigation practices, dam releases or other mechanisms were found. Sporadic fluctuations in 2017 tend to resemble those observed in other river systems.

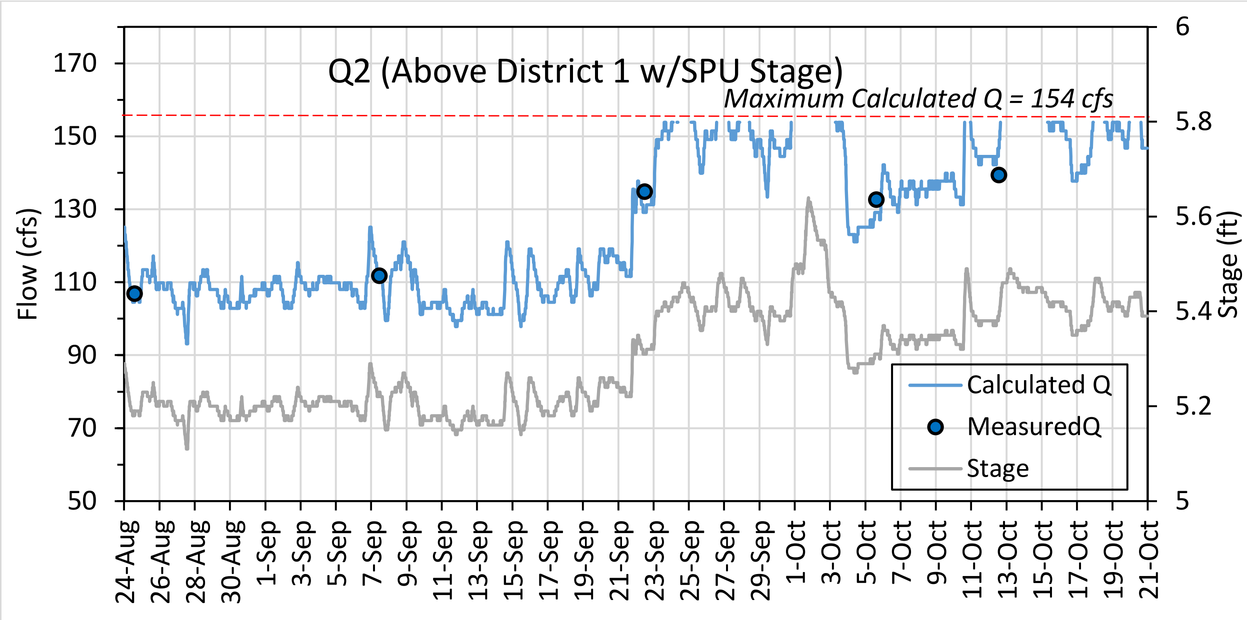


FIGURE 14. STAGE, MEASURED Q, AND CALCULATED FLOW (Q) FOR Q2 THROUGHOUT THE STUDY PERIOD. STAGE DATA RETRIEVED FROM CDEC (DWR STATION SPU).

REACH 2: ACCRETIONS AND DEPLETIONS

Change in flow, total amount diverted, and unaccounted accretions and depletions were assessed in each sub-reach (i.e. Q0.9 to Q1 and Q1 to Q2) and through the entire reach (i.e. Q0.9 to Q2). Flows were assessed using two methods: 1) Single point method including Q1, and 2) 12-hour averages excluding Q1 (due to unstable conditions in Reach 1 at the time of Q1 measurement).

Q0.9 TO Q1

Table 5 includes start flow, end flow, change in flow, measured diversions, measured inflows and unaccounted accretions/depletions.

TABLE 5. START FLOW, END FLOW, DIVERSIONS, CHANGE IN Q, MEASURED INFLOWS (FROM BIG SPRINGS CREEK AT WATER WHEEL), AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q0.9 AND Q1 ON MEASUREMENT DAYS.

Q0.9 to Q1 (Single Point)							
Total Potential Diversions: 0 cfs							
Season	Date	Start Q (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	Measured Inflows (cfs)	**Unaccounted (cfs)**
	24-Aug	41.2	113.9	72.7	0.0	62.6	**10.2**
	7-Sep	36.9	111.5	74.6	0.0	61.3	**13.3**
Irrigation	21-Sep	32.6	117.5	84.9	0.0	71.0	**13.9**
	5-Oct	44.8	123.5	78.7	0.0	65.6	**13.1**
	12-Oct	30.0	149.7	119.7	0.0	73.8	**45.9**
Post-Irrigation	20-Oct	46.0	150.0	104.0	0.0	73.2	**30.8**[Error! Bookmark not defined.]
Irrigation	Average:	36.9	114.3	**77.4**	0.0	65.0	**12.5**
Post-Irr	Average:	40.3	141.1	**100.8**	0.0	70.9	**29.9**

[1] Theoretical value based on estimates from upstream and downstream measurement sites.

This sub-reach has unaccounted accretions on all assessment days, which remain fairly consistent until October 12th when they increase by more than 30 cfs over the previous assessment day (October 5th).

To verify that this increase was not just an anomaly or isolated event, theoretical values were conservatively estimated for October 20th (no measurements were taken at Q1 after October 12th). The October 20th estimate is more than double the highest unaccounted flow prior to October 12th.

In addition, two distinct flow events were observed in data surrounding the large increase in unaccounted flows between Q0.9 and Q1 during the October 12th assessment period. These flow events included: 1) a sharp decrease in flow recorded at Q0.9, and 2) a sharp increase in flow simultaneously recorded at Q1. These flow events can be partially explained by a reduction in flow released from Dwinnell Reservoir, which decreased flow at Q0.9; and an increase in flow from Big Springs Creek, which increased flow recorded at Q1 on October 12th.

To test the effect of the flow variability caused by these independent forces within the system, flow values in our flow accounting tables were aggressively manipulate to reflect the potential for confounded transit times (and subsequent selection of the calculated flow value to be used for accounting). These manipulations yielded results of +/- 10 cfs from the original calculation of 45.9 cfs in unaccounted flows on October 12th. Therefore, manipulating flow accounting tables to reflect variable flow scenarios demonstrated that unaccounted flows were still at least three times greater on October 12th than on any of the previous assessment days.

Some of the unaccounted accretions between Q0.9 and Q1 can be attributed to Little Springs flows, which have historically amounted to a consistent 7-8 cfs during irrigation season (pers. comm. with Ada Fowler), which accounts for more than half the accretion through October 5th. Additional accretion during this time can be attributed to temporally and spatially diffuse tailwater returns, as well as small, unquantified springs entering Big Springs Creek and the Shasta River along the Busk Ranch property (Jeffres et al. 2009).

Q1 TO Q2

Start flow, end flow, change in flow, diversions, measured inflows, and unaccounted flows between Q1 and Q2 on assessment days are provided in Table 6. In general, start and end flows were higher in 2017. However, unaccounted flows were higher in 2016 and not consistent with 2017 values.

TABLE 6. 2016 AND 2017 FLOW COMPARISON. START FLOW, END FLOW, CHANGE IN Q, DIVERSIONS, MEASURED INFLOWS, AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q1 AND Q2 ON ASSESSMENT DAYS USING SINGLE POINT METHOD.

Q1 to Q2-SPU (Single point)												
Total Potential Diversions: -2.1 cfs												
	2016						2017					
Season	Date	Start Q (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	**Unaccounted (cfs)**	Date	Start Q (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	**Unaccounted (cfs)**
Irrigation	24-Aug	84.4	92.9	8.5	-2.1	**10.8**	24-Aug	113.9	106.3	-7.6	-2.1	**-5.5**
	8-Sep	103.1	109.6	6.5	-2.1	**8.8**	7-Sep	111.5	109.8	-1.7	-2.1	**0.4**
	13-Sep	105.6	112.2	6.6	-2.1	**8.9**				0.0		
	14-Sep	92.5	102.2	9.7	-2.1	**12.0**				0.0		
	19-Sep	100.7	110.9	10.2	-2.1	**12.5**	21-Sep	117.5	119.1	1.6	-2.1	**3.7**
	26-Sep	89.1	104.6	15.5	0.0	**15.5**				0.0		
Post-Irrigation	1-Oct	108.8	121.7	12.9	0.0	**12.9**				0.0		
	2-Oct	96.6	112.2	15.6	0.0	**15.6**				0.0		
	3-Oct	98.8	112.2	13.4	0.0	**13.4**	5-Oct	123.5	129.2	5.7	0.0	**5.7**
							12-Oct	149.7	161.3	11.6	0.0	**11.6**
							20-Oct	150.0	155.0	5.0	0.0	**5.0**
Irrigation	Average:	95.9	105.4	9.5	-1.8	**11.4**		114.3	111.7	-1.3	-2.1	**-0.5**
Post-Irr	Average:	101.4	115.4	14.0	0.0	**14.0**		136.6	145.3	4.3	0.0	**7.4**

In sharp contrast to the high unaccounted flows assessed in upper section of Reach 1, Q1 to Q2-SPU shows relatively low unaccounted flows that generally increase as overall flow increases. As in 2016, unaccounted flows generally reflect change in flow between the two sites. 2016 flows are generally more consistent, while 2017 flows show more variability between sites, possibly an effect of higher overall flows in 2017.

Q0.9 TO Q2-SPU

Start flow, end flow, change in flow, diversions, measured inflows, and unaccounted flows between Q0.9 and Q2 on assessment days are provided in Table 7.

TABLE 7. START FLOW, END FLOW, CHANGE IN FLOW, DIVERSIONS, MEASURED INFLOWS (FROM BIG SPRINGS CREEK AT WATER WHEEL), AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q0.9 AND Q2-SPU USING SINGLE POINT METHOD.

Q0.9 to Q2 (Single Point)							
Total Potential Diversions: -2.1 cfs							
Season	Date	Start Q (cfs)	Inflows (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	**Unaccounted (cfs)**
Irrigation	24-Aug	41.2	62.6	106.3	65.1	-2.1	**4.7**
	7-Sep	36.9	61.3	109.8	72.9	-2.1	**13.7**
	21-Sep	32.6	71.0	119.1	86.5	-2.1	**17.6**
Post-Irrigation	5-Oct	44.8	65.6	129.2	84.4	0.0	**18.8**
	12-Oct	30.0	73.8	161.3	131.3	0.0	**57.5**
	20-Oct	46.0	73.2	155.0	109.0	0.0	**35.8**
Irrigation	Average:	36.9	65.0	111.7	74.8	-2.1	**12.0**
Post-Irr	Average:	40.3	70.9	148.5	108.2	0.0	**37.4**

Single point flow assessments for Q0.9 to Q2 display a positive relationship between change in Q and unaccounted accretion (as change in flow increases, unaccounted accretion increases). Moreover, average unaccounted flows during irrigation season are considerably lower than post-irrigation season unaccounted flows (12 cfs to 37.4 cfs, respectively). However, the relatively small amount of diverted water in this reach (2.1 cfs) suggests that the increase in unaccounted flows has more to do with the positive relationship between change in flow between sites ("Change Q" in Table 7) and unaccounted flows, than with irrigation season surface water diversions. This positive relationship may be driven by changes in flow coming from unknown groundwater, springs, and seeps between Waterwheel on Big Springs Creek and Q1.

To inform these results and to provide an alternative analysis to the single point analysis (Table 7) that included less than ideal measurement conditions on October 12th, a 12-hour average assessment was calculated for the same range of dates (Table 8).

TABLE 8. START FLOW, END FLOW, CHANGE IN FLOW, DIVERSIONS, MEASURED INFLOWS (FROM BIG SPRINGS CREEK AT WATER WHEEL), AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q0.9 AND Q2-SPU USING 12 HOUR AVERAGE METHOD. NOTE: OCTOBER 12TH ASSESSMENT IS BASED ON A 3-HOUR AVERAGE DISCHARGE AT BOTH SITES. THIS WAS DONE TO CAPTURE AND COMPARE THE MOST STABLE FLOWS THAT WERE CLOSEST (IN TIME) TO OUR FIELD-MEASURED FLOW THAT WAS CAPTURED IN UNSTABLE FLOW CONDITIONS.

Q0.9 to Q2 (12 hr Avgs.)							
Total Potential Diversions: -2.1 cfs							
Season	Date	Start Q (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	Inflows (cfs)	**Unaccounted (cfs)**
Irrigation	23-Aug	46.1	100.1	54.0	-2.1	61.8	**-5.7**
	6-Sep	39.3	105.6	66.3	-2.1	68.0	**0.4**
	21-Sep	36.8	117.6	80.8	-2.1	64.0	**18.9**
Post-Irrigation	3-Oct	44.1	122.9	78.8	0.0	63.6	**15.2**
	8-Oct	41.0	135.3	94.3	0.0	69.4	**24.9**
	10-Oct	48.1	144.8	96.7	0.0	69.0	**27.7**
	12-Oct	45.7	144.1	98.4	0.0	70.0	**28.4**
	20-Oct	46.0	155.0	109.0	0.0	73.2	**35.8**
Irrigation	Average:	40.7	107.8	67.0	-2.1	64.6	**4.5**
Post-Irr	Average:	45.0	140.4	95.5	0.0	69.0	**26.4**

The positive relationship between change in flow and unaccounted flows (accretions) demonstrated in single point calculations is informed and verified by our 12-hour average analysis (Figure 15).

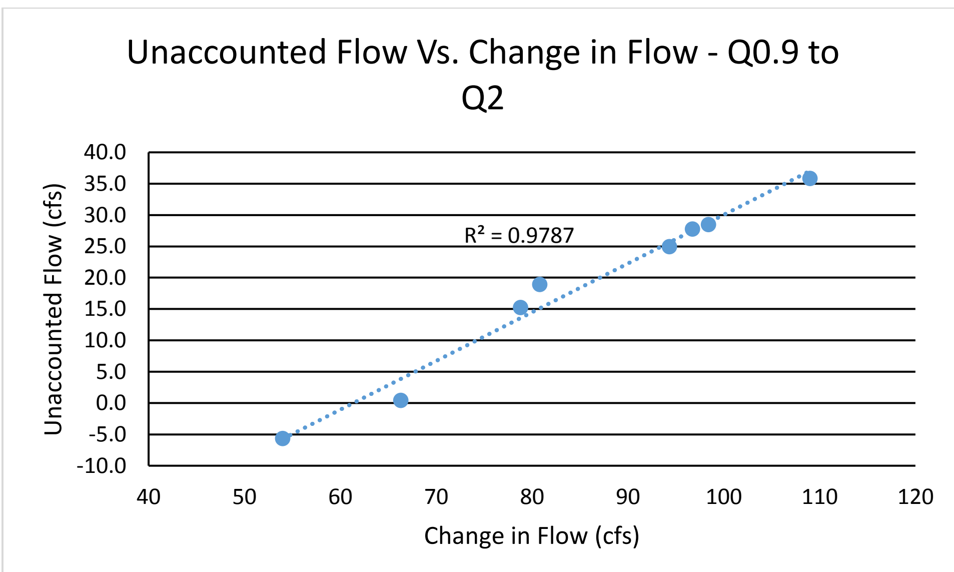


FIGURE 15. UNACCOUNTED FLOW (CFS) VS. CHANGE IN FLOW (CFS) IN REACH 1 BETWEEN Q0.9 AND Q2.

Two additional assessment days (October 8th and 12th) were added to the calculations for Q0.9 to Q2 to further compare and scrutinize the unexpectedly high unaccounted flow values calculated by the single point method for October 12th. The October 12th assessment yielded unaccounted accretions of 28.4 cfs (compared to 57.5 cfs on the same date using the single point method). This difference may be indicative of one or a combination of the following explanations: 1) The volatility and variability in flows surrounding the timing of the single-point assessment may have confounded transit times, which created a greater potential for error, and 2) Volatility and variability in flows within the Big Springs Complex can potentially produce more unaccounted flows emanating from unknown seeps and springs between Water Wheel on Big Springs Creek and Q1 on the Shasta River.

REACH 2 CONCLUSIONS

The complex hydrogeology that provides the mechanism(s) for flows through Reach 1 make flow assessments difficult to calculate on a micro level. Indeed, changes in channel morphology during this study at Q0.9 and Q1 due to erratic and rapidly changing flows made the development of a rating curve difficult at Q0.9 and impossible at Q1. Therefore, two flow calculation methods (single point and 12-hour average) were employed to increase confidence and provide a more robust set of calculations to reference.

12-hour average assessments (with one 3-hour average on October 12th) demonstrated that as change in Q (difference in flow between sites) increased between Q0.9 and Q2, unaccounted flows also increased. Moreover, flows at Q2 increased more during the study period (approximately 55 cfs; or a range of 100.1 – 155.0 cfs) than at Q0.9 (approximately 9 cfs; or a range of 36.8 – 46 cfs). This suggests that more unaccounted accretions come from Big Springs inflows (and additional seeps, springs and tailwater returns on the Shasta River downstream of Big Springs), than from the Shasta River above Big Springs Creek.

Single point assessments from Q0.9 to Q1, and Q1 to Q2, demonstrated that the bulk of these unaccounted flows (accretions) between Q0.9 and Q2 were occurring between Q0.9 and Q1. This is consistent with statements made in Jeffres et al. (2009) referencing unknown seeps and springs emanating from lower Big Springs Creek. This assessment quantifies unidentified flow sources originating between Q0.9 and Q1 including lower Big Springs Creek (below Water Wheel) during the study period. Inflows to Big Springs Creek from Little Springs Creek (below the Water Wheel) were not measured during this study but are known to consistently flow at 7-8 cfs (pers. comm. Christopher Babcock, TNC). Therefore, Little Springs Creek accounts for approximately 28% of post-irrigation season unaccounted accretions

The missing component in all of these calculations is groundwater extraction within the Big Springs Complex. Further investigation into the impacts of groundwater pumping on flows in Big Springs Creek and the Shasta River is needed to inform current findings.

IV. REACH 3: Q2 TO Q3 - ABOVE DISTRICT 1 TO BELOW A12 ROAD OVERPASS

Reach 3 includes measurement locations Q2 and Q3. Rating curves for each site are provided in Appendix A.

Q3 – BELOW A12 ROAD OVERPASS

Q3 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 16 (Q2 provided in previous section). Discharge measurements are lacking to define the upper end of the rating and therefore, flows greater than 155 cfs could not be calculated. Flow ranged from approximately 90 cfs to > 155 cfs during the study period, with large fluctuations in flow (approximately 10 to 20 cfs) over 1 to 4 day cycles, and a general trend of increasing flows over the study period.

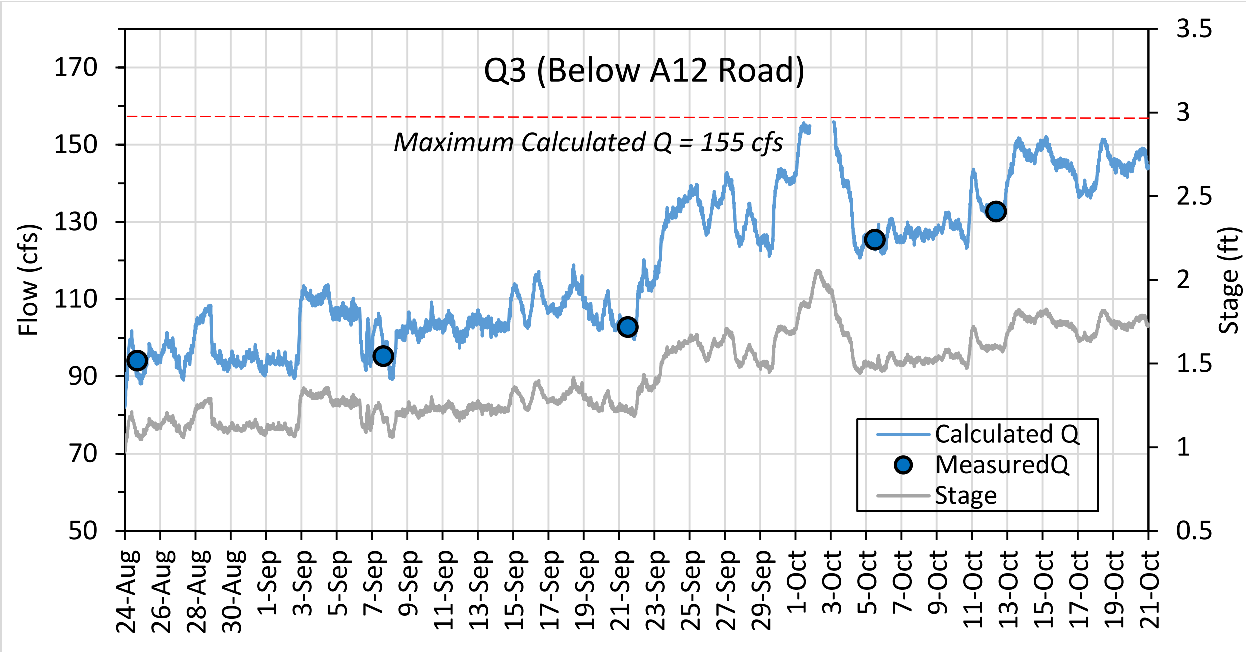


FIGURE 16. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q3 THROUGHOUT THE STUDY PERIOD.

REACH 3: ACCRETIONS AND DEPLETIONS

Change in flow, total amount diverted, and unaccounted accretions and depletions were assessed from Q2 to Q3, along with 2016/2017 comparison (Table 9).

TABLE 9. START FLOW, END FLOW, DIVERSIONS, AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q2 AND Q3 ON ASSESSMENT DAYS. INFLOWS TO THIS REACH WERE NOT MEASURED.

Q2-SPU to Q3												
Total Potential Diversions: -64.7 cfs												
2016							**2017**					
Season	Date	Start Q (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	**Unaccounted (cfs)**	Date	Start Q (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	**Unaccounted (cfs)**
Irrigation	24-Aug	92.9	75.2	-17.7	-8.1	**9.7**	23-Aug	100.1	86.2	-13.9	-21.5	**7.6**
	8-Sep	109.6	80.5	-29.1	-25.6	**-3.5**	6-Sep	105.6	98.0	-7.6	-23.4	**15.8**
	13-Sep	112.2	82.7	-29.5	-25.9	**-3.6**						
	14-Sep	102.2	79.2	-23.0	-26.0	**3.0**						
	19-Sep	110.9	88.8	-22.1	-23.5	**1.3**	19-Sep	117.6	106.3	-11.3	-20.0	**8.7**
	26-Sep	104.6	91.4	-13.2	0.0	**-13.2**						
Post-Irrigation	2-Oct	112.2	94.2	-18.0	-8.8	**-9.2**						
	3-Oct	112.2	93.2	-19.0	-10.5	**-8.5**	3-Oct	122.9	123.1	0.3	-11.5	**11.8**
							10-Oct	144.8	135.7	-9.1	-11.5	**2.4**
							20-Oct	155.0	147.4	-7.6	-5.5	**2.1**
Irrigation	Average:	105.4	83.0	-22.4	-18.2	**-1.1**		107.8	96.8	-10.9	-21.6	**10.7**
Post-Irr	Average:	112.2	93.7	-18.5	-9.7	**-8.8**		140.9	135.4	-5.5	-9.5	**5.4**

In general, flows were higher in 2017 than 2016, corresponding to a higher water year in 2017, but amount diverted was slightly higher on average during irrigation season in 2017. Also, unaccounted flows decreased in post-irrigation season during both years suggesting decreased tailwater returns after more than half of the diversions were turned off, as expected. Minimal unaccounted flows post-irrigation season also suggests that this reach is impacted less by sub-surface flows and may not be as vulnerable to mild fluctuations in groundwater levels as other reaches. High unaccounted flows (15.8 cfs) on September 6, 2017 are possibly a result of a rain event on this date, which may have provided locally heavy rainfall that impacted only certain reaches.

REACH 3 CONCLUSIONS

Diversion potential in Reach 3 is 64.7 cfs, and variable diversions during this study made it possible to calculate the impact of diversions on flow retention from upstream to downstream sites. In Reach 3, increased diversion rates amounted to a decrease in change in flow from upstream to downstream sites (Figure 17). Simply put, as water diversion within the reach increases, flow measured at the end of the reach decreases. This may seem obvious but in a complicated system of diversions and various other unknown accretions and depletions (e.g., springs, seeps, tailwater returns and groundwater recharge or discharge) it can be difficult to quantify the impact of diversions or the efficacy of water transactions as a tool for preserving dedicated water in stream. This is one way to accomplish that, and underscores the effectiveness of water transactions as a means to increase flow in the river.

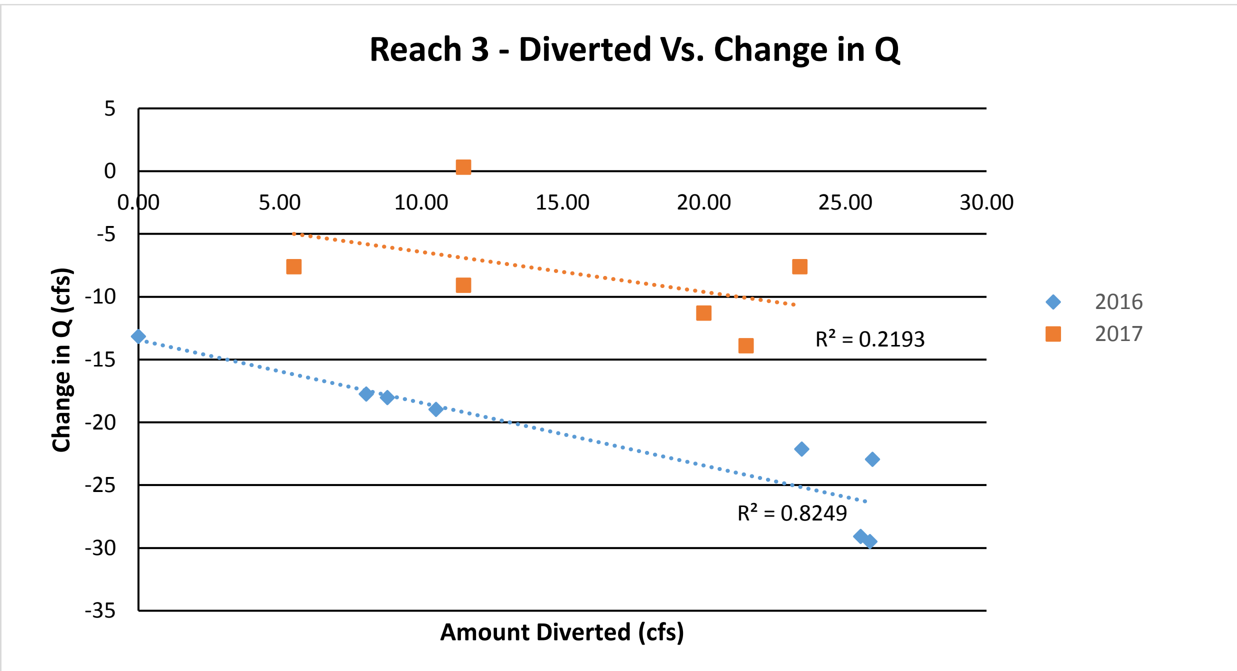


FIGURE 17. DIVERTED FLOW VS. CHANGE IN FLOW IN REACH 3 (Q2 – Q3).

V. REACH 4: Q3 TO Q4 – BELOW A12 ROAD OVERPASS TO BELOW DISTRICT 2 PUMP STATION

Reach 4 includes measurement locations Q3 and Q4. Rating curves for each site are provided in Appendix A and a 15-minute discharge hydrograph with associated stage values is displayed in Figure 18.

Q4: BELOW DISTRICT 2 PUMP STATION

Q4 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 18. Flow ranged from approximately 20 cfs to 159 cfs during the study period, with a general trend of increasing flows over the study period.

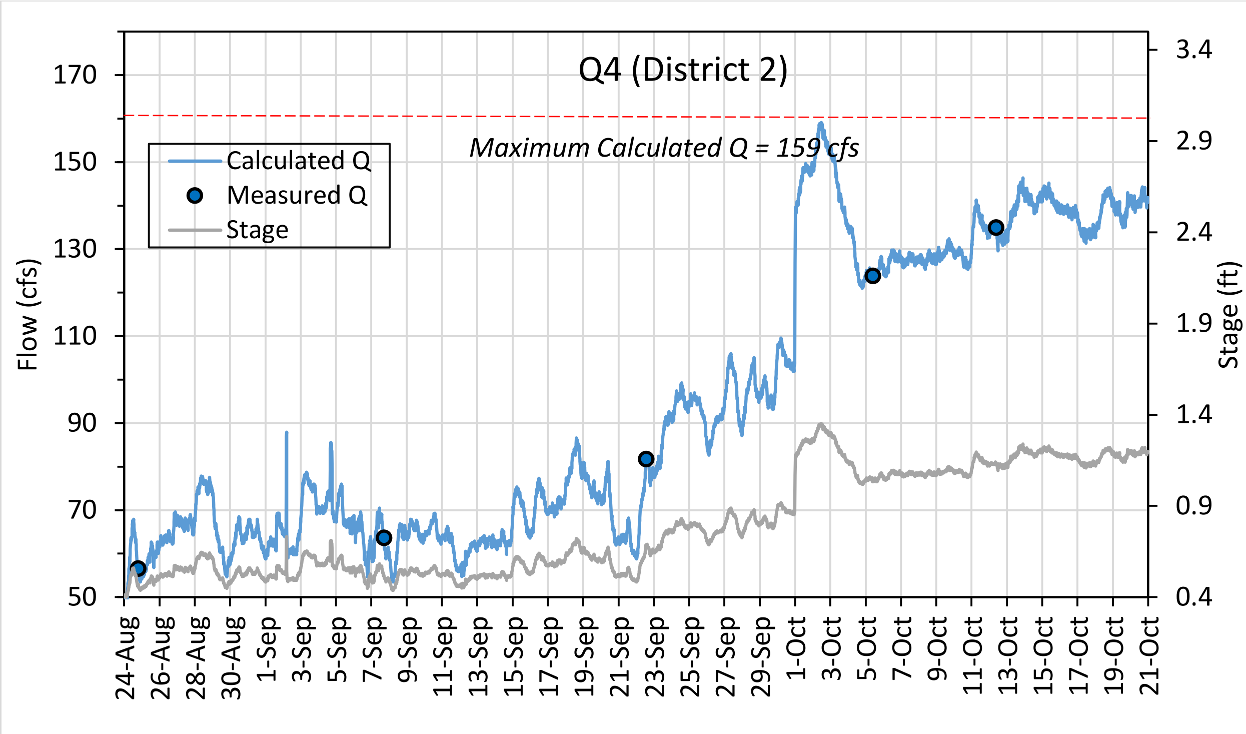


FIGURE 18. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q4 THROUGHOUT THE STUDY PERIOD.

REACH 4: ACCRETIONS AND DEPLETIONS

Q3 TO Q4

Start flow, end flow, diversions, unaccounted accretions and depletions, and 2016/2017 comparison are provided in Table 10. Irrigation season diversion amounts were very similar in 2016 and 2017 (average of -48 cfs and -50 cfs, respectively). Irrigation season unaccounted flows were also very similar (15.2 cfs and 14.6 cfs, respectively). Unaccounted flows in this reach can be attributed to tailwater returns originating outside the reach.

Unaccounted flows decreased sharply after the end of irrigation season. On October 3rd and 10th there were effectively no unaccounted flows (0 cfs and 0.3 cfs, respectively). On October 20th this reach saw depletions of -5.7 cfs from Q3 to Q4. This may be due to groundwater recharge or differences in transit times and/or fluctuations in flow that may have skewed calculated discharge values.

TABLE 10. START FLOW, END FLOW, DIVERSIONS, UNACCOUNTED ACCRETIONS AND DEPLETIONS, AND 2016/2017 COMPARISON BETWEEN Q3 AND Q4 ON ASSESSMENT DAYS. INFLOWS TO THIS REACH WERE NOT MEASURED.

Q3 to Q4 (12 hr Avg. Qs)												
Total Potential Diversions: -54.2 cfs												
	2016						2017					
Season	Date	Start Q (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	**Unaccounted (cfs)**	Date	Start Q (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	**Unaccounted (cfs)**
Irrigation	24-Aug	75.2	39.1	-36.1	-52.7	**16.6**	23-Aug	86.2	56.1	-30.2	-49.2	**19.0**
	8-Sep	80.5	43.1	-37.4	-48.9	**11.5**	6-Sep	98.0	60.0	-38.0	-50.3	**12.3**
	13-Sep	82.7	54.2	-28.5	-50.7	**22.2**						
	14-Sep	79.2	40.5	-38.7	-50.7	**12.0**						
	19-Sep	88.8	59.9	-28.8	-43.9	**15.1**	19-Sep	106.3	68.3	-38.0	-50.3	**12.3**
	26-Sep	91.4	63.0	-28.4	-42.3	**13.8**						
Post-Irrigation							3-Oct	123.1	123.1	0.0	0.0	**0.0**
							10-Oct	135.7	136.0	0.3	0.0	**0.3**
							20-Oct	147.4	141.7	-5.7	0.0	**-5.7**
Irrigation	Average:	83.0	50.0	-33.0	-48.2	**15.2**		96.8	61.5		-49.9	**14.6**
Post-Irr	Average:	0.0	0.0		0.0	**0.0**		135.4	133.6		0.0	**-1.8**

REACH 4 CONCLUSIONS

As in Reach 3, increased diversion rates in Reach 4 amounted to a decrease in flow from upstream to downstream sites (Figure 19). Again, this underscores the efficacy of water transactions as a tool to conserve water in stream.

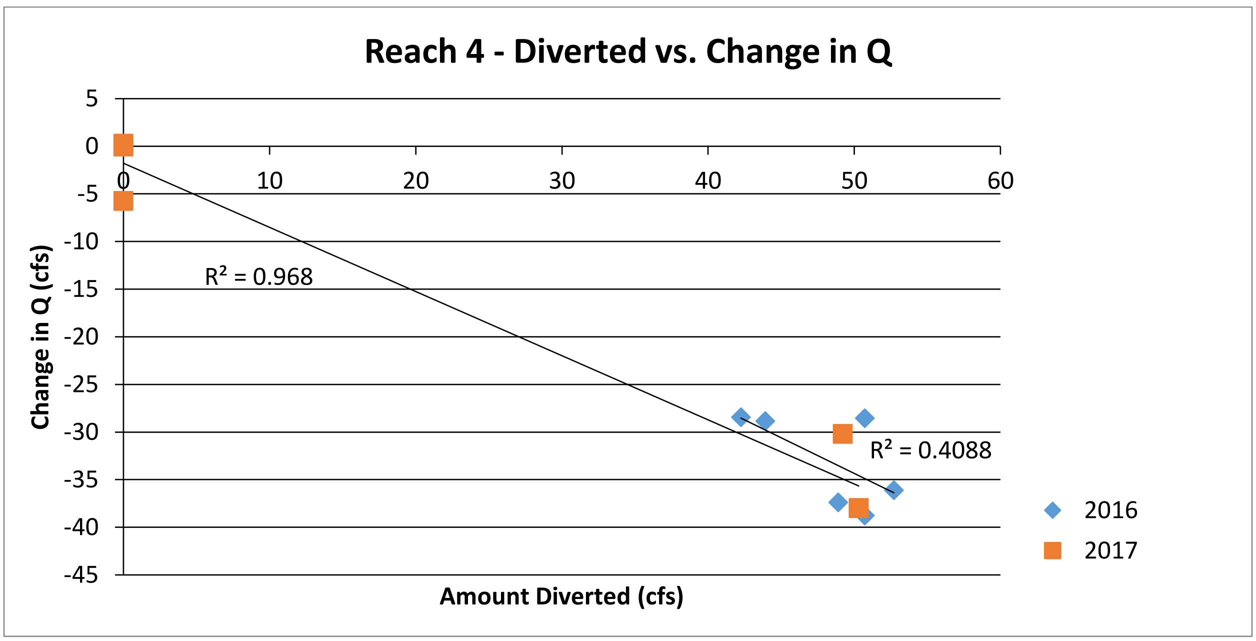


FIGURE 19. DIVERTED FLOW VS. CHANGE IN FLOW IN REACH 4 (Q3 TO Q4).

VI. REACH 5: Q4 TO Q5 – BELOW DISTRICT 2 PUMP STATION TO MONTAGUE-GRENADA RD. WEIR (SRM)

Q4 TO Q5

Q5 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 20. Flow ranged from approximately 62 cfs to 152 cfs during the study period, with a general trend of increasing flows over the study period. Stage and discharge values were downloaded from CDEC, which reports USGS monitoring station (SRM) data at the weir just upstream of the Montague-Grenada Road overpass on the Shasta River.

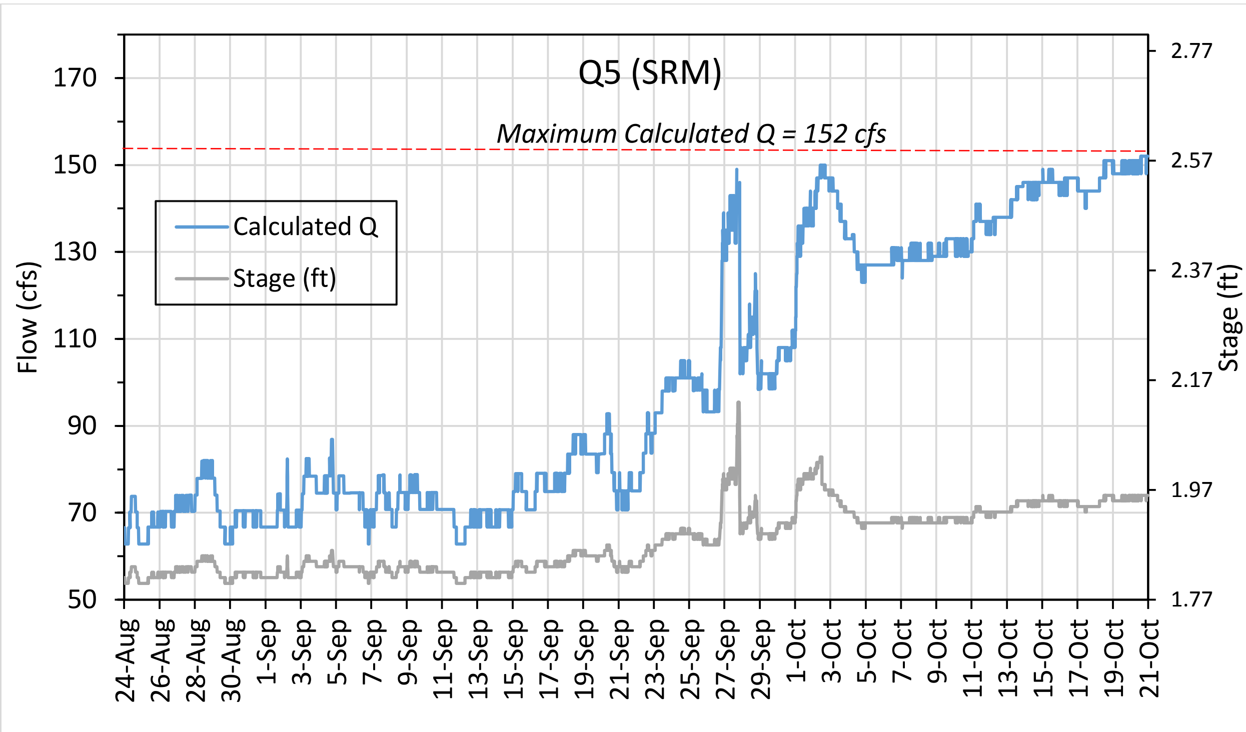


FIGURE 20. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q5 THROUGHOUT THE STUDY PERIOD. THIS SITE IS MAINTAINED BY USGS. DATA WAS RETRIEVED FROM CDEC, 2017.

Start flow, end flow, diversions, unaccounted accretions and depletions, and 2016/2017 comparison are provided in Table 11.

TABLE 11. Q4 TO Q5 START FLOW, END FLOW, DIVERSIONS, UNACCOUNTED ACCRETIONS AND DEPLETIONS AND 2016/2017 COMPARISON ON ASSESSMENT DAYS. INFLOWS TO THIS REACH WERE NOT MEASURED.

Q4 to Q5 (SRM)(12 hr Avg. Qs)												
Total Potential Diversions: 0 cfs												
	2016						**2017**					
Season	Date	Start Q (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	**Unaccounted (cfs)**	Date	Start Q (cfs)	End Q (cfs)	Change Q (cfs)	Diversions (cfs)	**Unaccounted (cfs)**
Irrigation	24-Aug	39.1	49.0	9.9	0.0	**9.9**	23-Aug	56.1	64.5	8.5	0.0	**8.5**
	8-Sep	43.1	55.0	11.9	0.0	**11.9**	6-Sep	60.0	69.1	9.0	0.0	**9.0**
	13-Sep	54.2	67.0	12.8	0.0	**12.8**				0.0		
	14-Sep	40.5	55.0	14.5	0.0	**14.5**				0.0		
	19-Sep	59.9	74.0	14.1	0.0	**14.1**	19-Sep	68.3	78.3	10.0	0.0	**10.0**
	26-Sep	63.0	78.0	15.0	0.0	**15.0**				0.0		
Post-Irrigation				0.0			3-Oct	123.1	126.1	3.0	0.0	**3.0**
				0.0			10-Oct	136.0	136.9	1.0	0.0	**1.0**
				0.0			20-Oct	141.7	151.2	9.5	0.0	**9.5**
Irrigation	**Average:**	50.0	63.0	13.0	0.0	**13.0**		61.5	70.6	4.6	0.0	**9.2**
Post-Irr	**Average:**	NA	NA	NA	NA	**NA**		133.6	138.1	4.5	0.0	**4.5**

REACH 5 CONCLUSIONS

Overall flow increased approximately 10 cfs during irrigation season (no post-irrigation season flow calculations were made in 2016) at both sites from 2016 to 2017.

Unaccounted flows were similar though slightly lower in 2017 during irrigation season. These flows can be attributed to outside-of-reach tailwater returns and sub-surface flows from Little Shasta River. The Little Shasta River flows through alluvium near its confluence and is known to disappear and reappear at locations just upstream of the confluence. Therefore, subsurface flows may contribute to most of the accretion within this reach. Unaccounted flows reduce to 1 cfs on October 3rd and 3 cfs on October 10th before climbing back up to 9.5 cfs on October 20th. A rain event in the Shasta Valley that occurred late in the evening on October 19th (Figure 4) may have contributed to surface or sub-surface inflows to this reach, resulting in increased unaccounted flows during this assessment time.

F. CONCLUSION

The goal of the 2017 Phase II Water Balance Study was to develop a more thorough understanding of accretions and depletions within the Middle Shasta River to inform and improve upon the ability of the Shasta Water Transaction Program to deliver much needed flows for migrating Chinook salmon in September. With this goal in mind the Phase II study area was adjusted to focus on the Middle Shasta River and select tributaries from the Shasta River just above Parks Creek through the Montague-Grenada Road weir. Phase II of the Water Balance Study was able to accomplish this goal by demonstrating that the reduction of water diversions in Reaches 3 and 4 resulted in a reduction in flow loss, upstream to downstream, in both 2016 and 2017. This analysis could not be repeated in Reaches 1, 2 and 5 because these reaches have little to no diversion potential. However, flow assessments within these reaches helped to quantify water gains (accretions), which may occur through other mechanisms such as tailwater returns or unknown springs. Moreover, the assessment of flows during, and post-, irrigation season helped to clarify the impact of diversions on net flow (net gain or loss) from the top of the Phase II study area at Q0.8, to the bottom at Q5.

In addition to assessing the impact of water diversions on flows within Phase II reaches, the addition of three new measurement locations (Q0.8, QP1 and Q0.9) upstream of the furthest upstream 2016 locations created a snapshot of flows on the Shasta River above Big Springs Creek, which are largely controlled by water releases from Dwinnell Reservoir. Indeed, the addition of Q0.8 (Shasta River above Parks Creek) helped us track these releases during a critical salmonid migration period where flows can drop to less than 15 cfs on the Upper Shasta River (above Big Springs Creek). Sustained flow releases of approximately 8-26 cfs from Dwinnell Dam beginning on September 23rd more than doubled the flow in the Shasta River above Parks Creek on 26 of 32 days through October 23rd. Chinook salmon were observed at Q0.8 during late September and early October measurement days.

In Reach 2 (Q0.9 to Q2), this study demonstrated that unaccounted and unidentified accretions (Little Springs Creek accounts for 7-8 cfs of unaccounted/unmeasured flows consistently) likely emanated from unknown seeps and springs discharging into the Shasta River between the Water Wheel on Big Springs Creek and Q1 (Below Big Springs Creek). Moreover, unaccounted accretions in Reach 2 during irrigation season amounted to approximately 4.5 cfs while unaccounted accretions increased to approximately 26.4 cfs during post-irrigation season. One hypothesis for this sudden increase in unaccounted flows is that groundwater pumping from nearby irrigation districts may have decreased or stopped during this time, which increased groundwater inflows to the Big Springs Complex (and ultimately to the Shasta River), but the inaccessibility of groundwater pumping records has left this hypothesis untested for the time being.

The inclusion of post-season irrigation measurement days in Phase II produced several interesting results. In general, flows decreased between Q2 and Q5 during irrigation season (a small uptick in flow occurred between Q4 and Q5 most likely due to tailwater returns and subsurface flows). This amounted to a net loss in flow of approximately 40 cfs between Q2 and Q5 during irrigation season. However, after irrigation season ended flows remained stable (very little net increase or decrease) between Q2 and Q5.

In Reaches 3, 4 and 5, unaccounted flows decreased after irrigation season ended. This may have been caused by a return to a more stable state (less diversion, movement, and returns of water for irrigation) within the Shasta River.

Another change between Phase I and Phase II of the Water Balance Study was the tracking of diversions over 48 hours during flow measurement/assessment periods. This increased confidence in quantifying the accuracy of diversion amounts during the study. Communication with willing landowners (diversion and pump operators) was key to the success of this task.

Throughout the study area, unaccounted accretions/depletions can be attributed to unmeasured distributed or point flow sources (e.g. irrigation return flows, sub-surface base flow, springs) and unmeasured distributed or point flow channel losses. There are limitations and challenges in measuring accretions and depletions in a dynamic and complex system such as the Shasta River, including: changes in management; discrepancies in diversion notes; tailwater flow returns locations changing depending on irrigation sets and locations; impacts from groundwater pumping on sub-surface base flows; complex alluvial and volcanic geology; stream flow fluctuations, and the margin of error within each discharge measurement.

This coarse assessment provides valuable insight into where accretion and depletion generally occur within this study area, and the effects of water diversions on flows in the Shasta River.

REFERENCES

Buchanan, T. J., and Somers, W. P., 1969, Discharge measurements at gaging stations: U.S. Geological Survey, Techniques of Water-Resources Investigations, Book 3, Chapter A8, 65 p.

California Department of Water Resources. 2008. Shasta Valley, Siskiyou County, Groundwater Data Needs Assessment, State of California, The Resources Agency, Department of Water Resources, Red Bluff, Ca 2008 Draft.

California Department of Water Resources. 1964. Bulletin 87: Shasta Valley Investigation, State of California, The Resources Agency, Department of Water Resources, July 1964, page 107, plate 6.

Chesney, D. and M. Knechtle. 2017. Shasta River Chinook and Coho Salmon Observations in 2016 Siskiyou County, CA. California Department of Fish and Wildlife online library.

Crandell, D. R., Miller, C. D., Glicken, H. X., Christiansen, R. L. & Newhall, C. G. (1984). Catastrophic debris avalanche from ancestral Mount Shasta volcano, California. Geology, 12, pp. 143-146.

Deas. M., P.B. Moyle, J. Mount, J.R. Lund, C. L. Lowney, and S. Tanaka. 2004. Priority Actions for Restoration of the Shasta River – Technical Report. Report prepared for The Nature Conservancy, CA.

Jeffres, C. A., R.A. Dahlgren, M.L. Deas, J.D. Kiernan, A.M. King, R.A. Lusardi, J.M. Mount, P.B. Moyle, A.L. Nichols, S.E. Null, S.K. Tanaka, A.D. Willis. 2009. Baseline Assessment of Physical and Biological Conditions Within Waterways on Big Springs Ranch, Siskiyou County, California. Report prepared for: California State Water Resources Control Board.

Marsden, R., 2005. StreamPro ADCP Performance Characteristics. Proceedings of the IEEE/OES Eighth Working Conference on Current Measurement Technology.

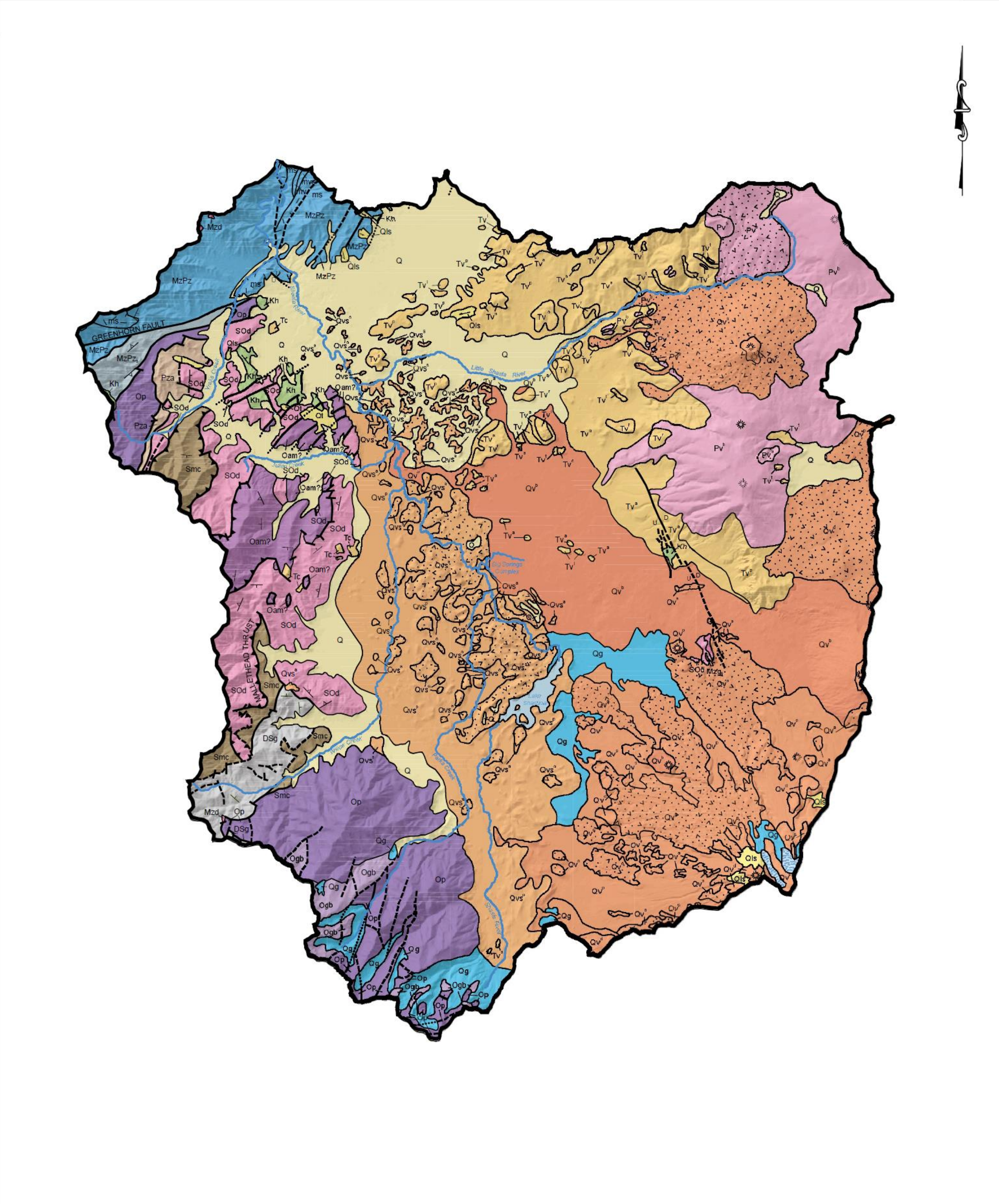
McBain & Trush, Inc., Shasta Valley Resource Conservation District, and Graham Matthews and Associates. 2010. Spawning Gravel Evaluation and Enhancement Plan for the Shasta River, CA. Prepared for Pacific States Marine Fisheries Commission and California Department of Fish and Game.

North Coast Regional Water Quality Control Board. 2007. Action Plan for the Shasta River Watershed Temperature and Dissolved Oxygen Total Maximum Daily Loads. Water Quality Control Plan for the North Coast Region.

Rantz, S.E., and others. 1982. Measurements and Computation of Streamflow, volumes 1 and 2: U.S. Geological Survey Water Supply Paper 2175. Reston, VA.

Willis, A.D., Campbell A.M., Fowler A.C., Babcock C.A., Howard J.K., Deas M.L., and A.L. Nichols. 2016. Instream flows: new tools to quantify water quality conditions for returning adult Chinook salmon. Journal of Water Resources Planning and Management: 142(2): 1943-5452.

APPENDIX A: SHASTA RIVER WATERSHED GEOLOGIC MAP AND EXPLANATION OF GEOLOGIC ABBREVIATIONS AND SYMBOLS

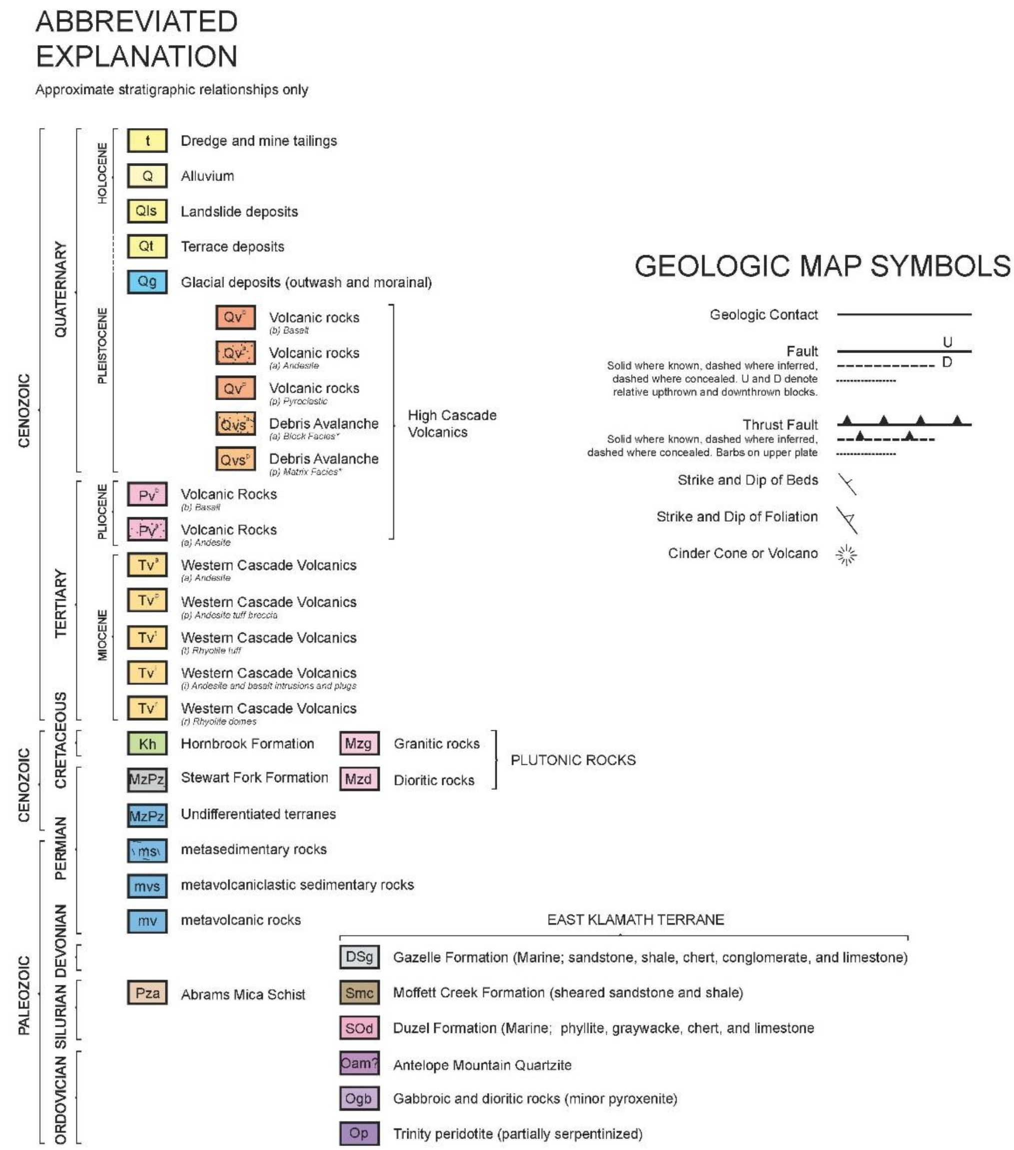


Note: This explanation is taken from the Geologic Map of the Weed Quadrangle, California; D.L. Wagner and G.J. Saucedo; 1987; 1:250,000.
This explanation is adapted to reflect the geologic units within the Shasta River watershed boundary.
*Explanations of volcanic rocks have been changed to reflect modern interpretations.

0 1.75 2.5 5 10 miles

RCD SHASTA VALLEY RESOURCE CONSERVATION DISTRICT

GEOLOGIC MAP OF THE SHASTA RIVER WATERSHED		
February 12, 2018	PROJECT NAME: 2017 Water Balance Phase II	
1 inch = 5 miles	DRAFTED BY: EB	Figure 01

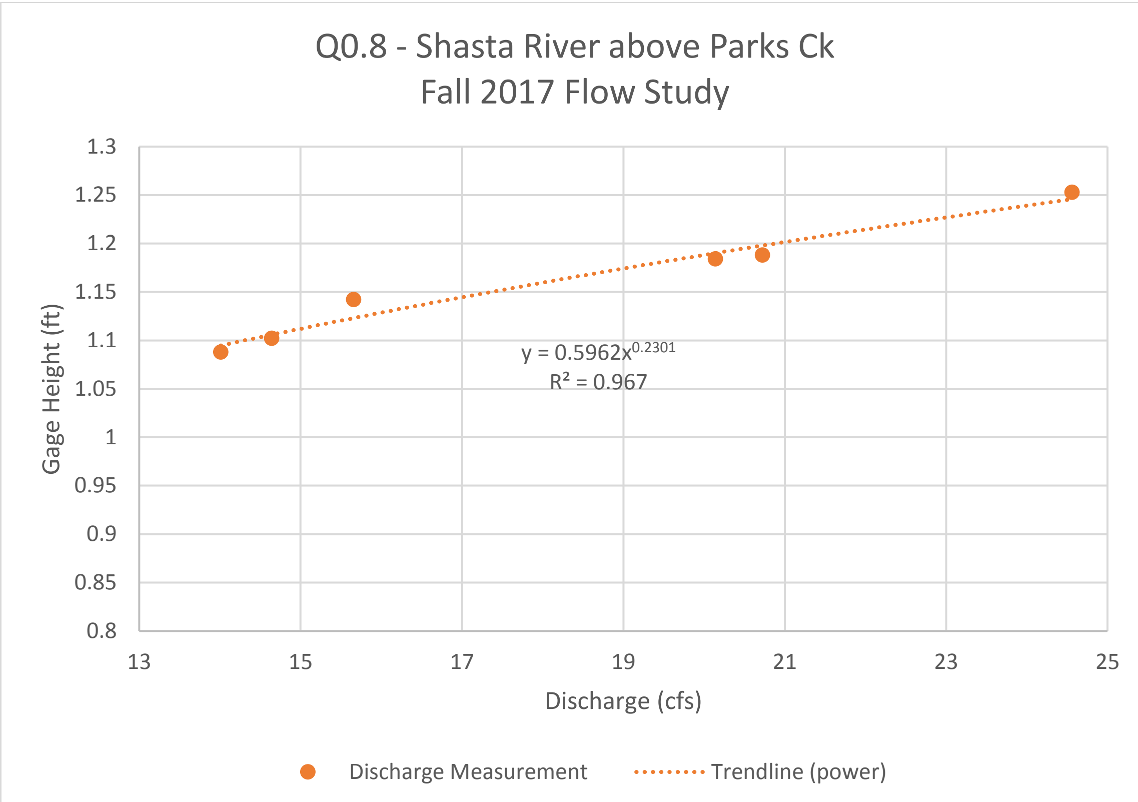


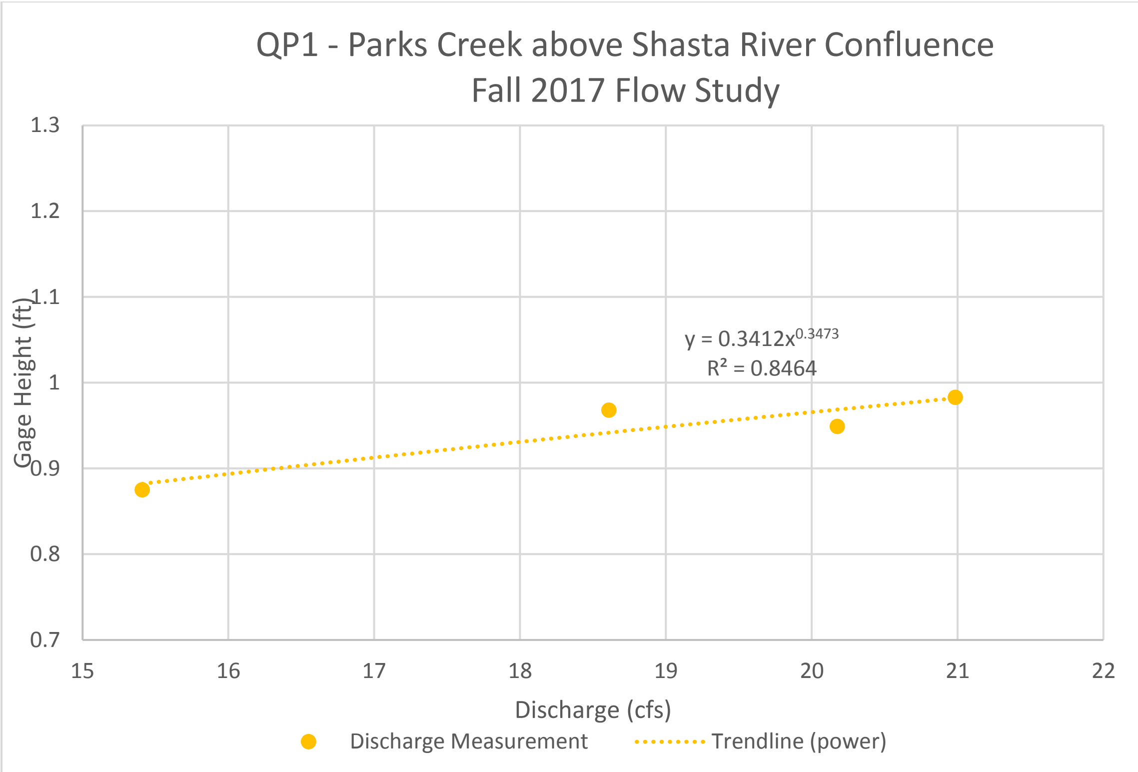
Note: This explanation is taken from the Geologic Map of the Weed Quadrangle, California; D.L. Wagner and G.J. Saucedo; 1987; 1:250,000.
This explanation is adapted to reflect the geologic units that occurr within the Shasta River watershed boundary.
*Explanations of volcanic rocks have been changed to reflect modern interpretations.

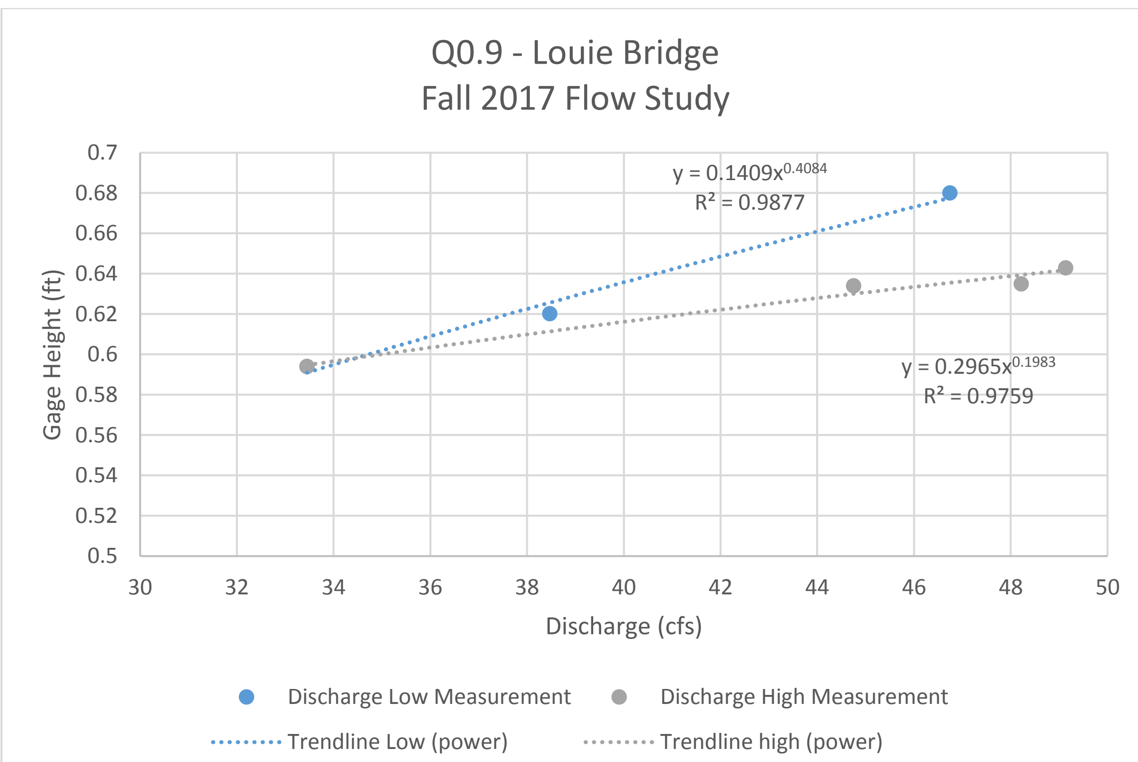
RCD SHASTA VALLEY RESOURCE CONSERVATION DISTRICT

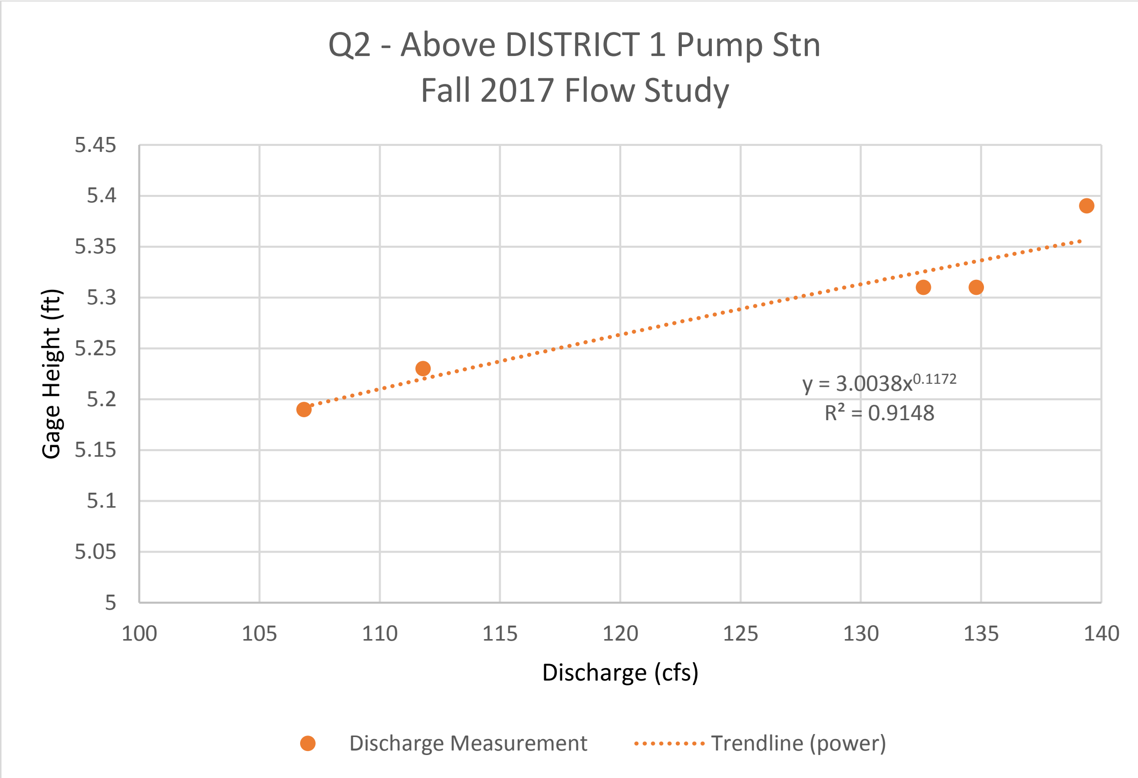
EXPLANATION OF THE GEOLOGY OF THE SHASTA RIVER WATERSHED		
February 1, 2018	PROJECT NAME: 2017 Flow Study Phase II	
SCALE: n/a	DRAFTED BY: EB	APPENDIX A2

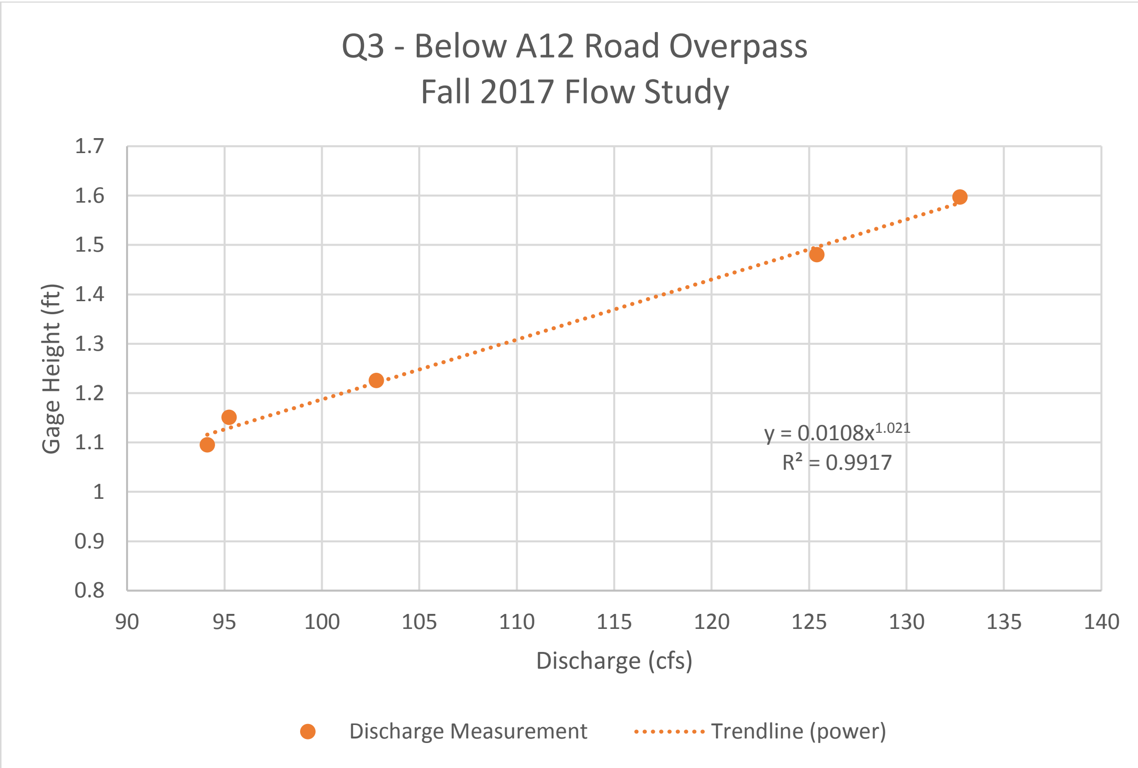
APPENDIX B: RATING CURVES (STAGE-DISCHARGE RELATIONSHIPS)

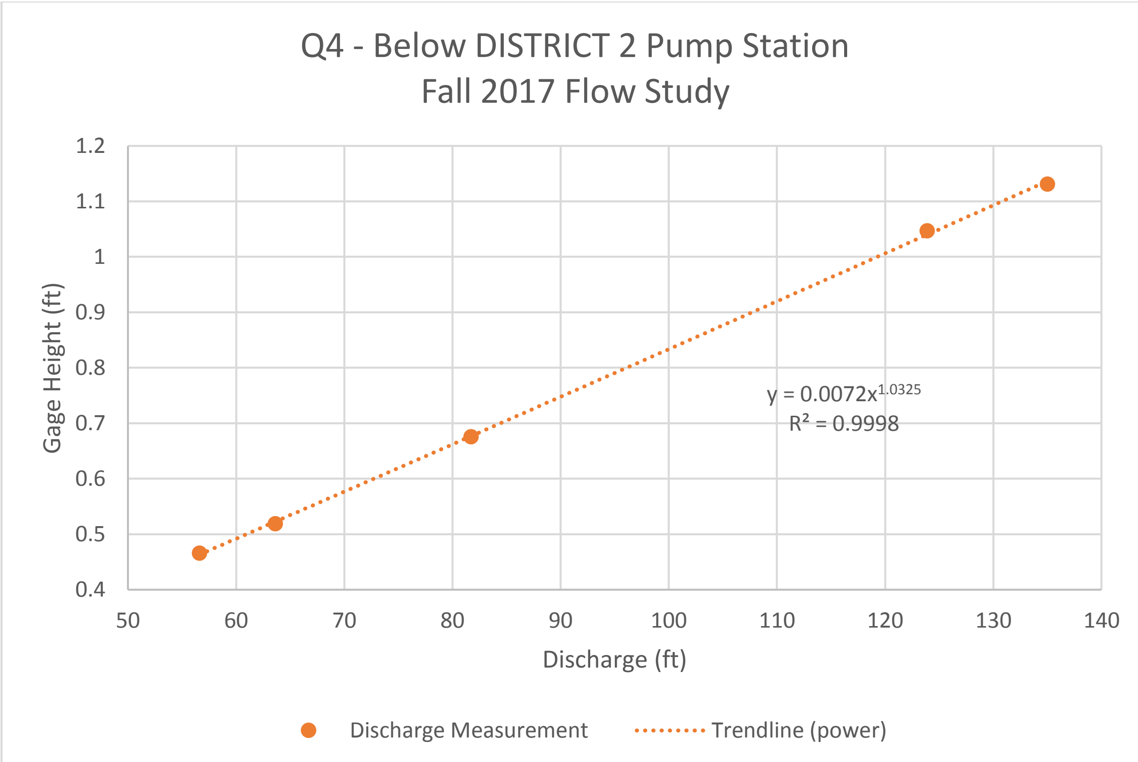



QP1 - Parks Creek above Shasta River Confluence
Fall 2017 Flow Study
Gage Height (ft)
1.3
1.2
1.1
1
0.9
0.8
0.7
15
16
17
18
19
20
21
22
y = 0.3412x^0.3473
R² = 0.8464
Discharge (cfs)
Discharge Measurement
Trendline (power)


Q0.9 - Louie Bridge
Fall 2017 Flow Study
Gage Height (ft)
0.7
0.68
0.66
0.64
0.62
0.6
0.58
0.56
0.54
0.52
0.5
30
32
34
36
38
40
42
44
46
48
50
y = 0.1409x^0.4084
R² = 0.9877
y = 0.2965x^0.1983
R² = 0.9759
Discharge (cfs)
Discharge Low Measurement
Discharge High Measurement
Trendline Low (power)
Trendline high (power)


Q2 - Above DISTRICT 1 Pump Stn
Fall 2017 Flow Study
Gage Height (ft)
5.45
5.4
5.35
5.3
5.25
5.2
5.15
5.1
5.05
5
100
105
110
115
120
125
130
135
140
Discharge (cfs)
y = 3.0038x^0.1172
R² = 0.9148
Discharge Measurement
Trendline (power)


Q3 - Below A12 Road Overpass
Fall 2017 Flow Study
Gage Height (ft)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
90
95
100
105
110
115
120
125
130
135
140
Discharge (cfs)
y = 0.0108x^1.021
R² = 0.9917
Discharge Measurement
Trendline (power)


Q4 - Below DISTRICT 2 Pump Station
Fall 2017 Flow Study
Gage Height (ft)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
50
60
70
80
90
100
110
120
130
140
Discharge (ft)
y = 0.0072x^1.0325
R² = 0.9998
Discharge Measurement
Trendline (power)