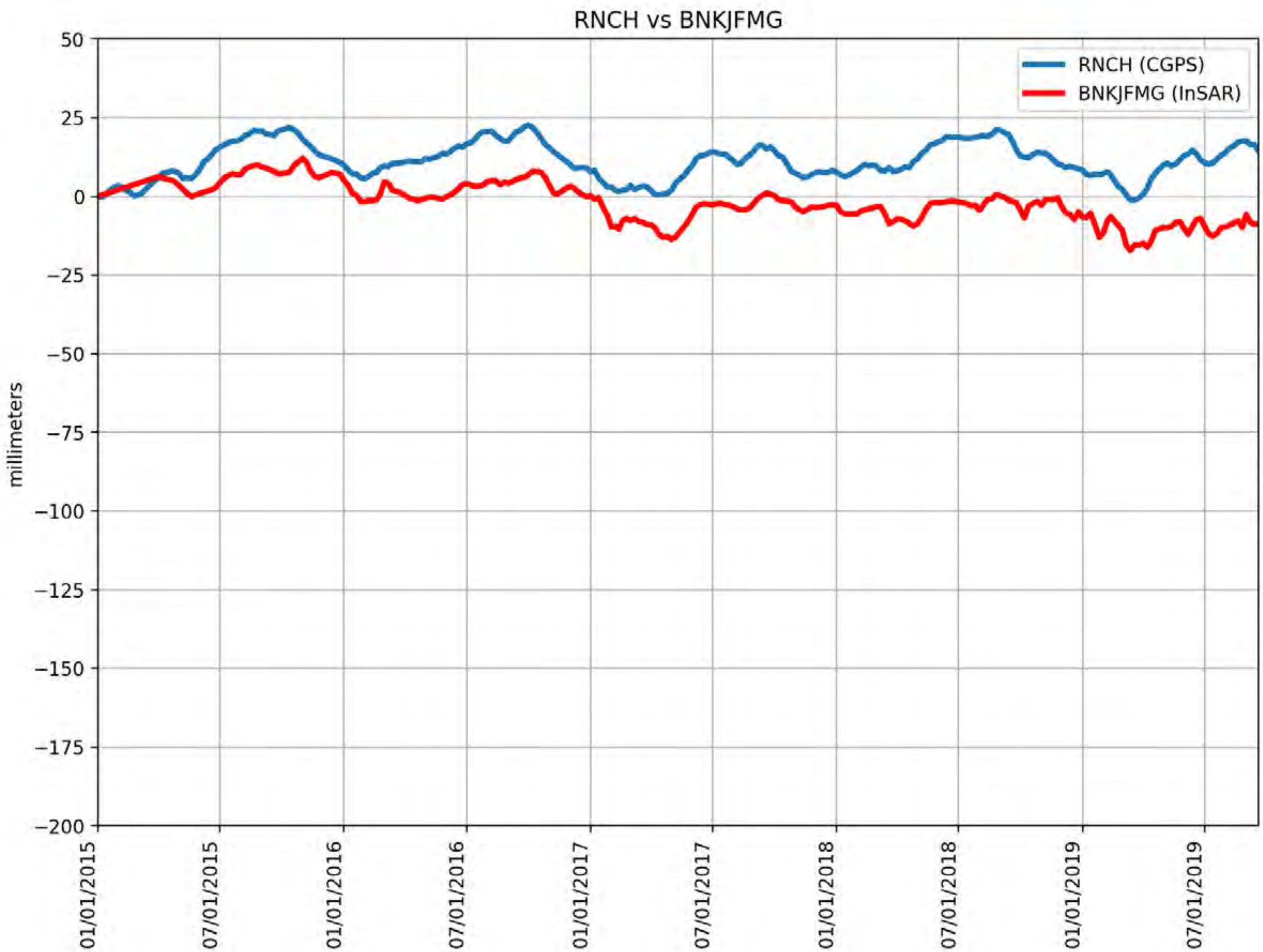
Appendix B



RMSE: 14.32 mm
Correlation: 0.50

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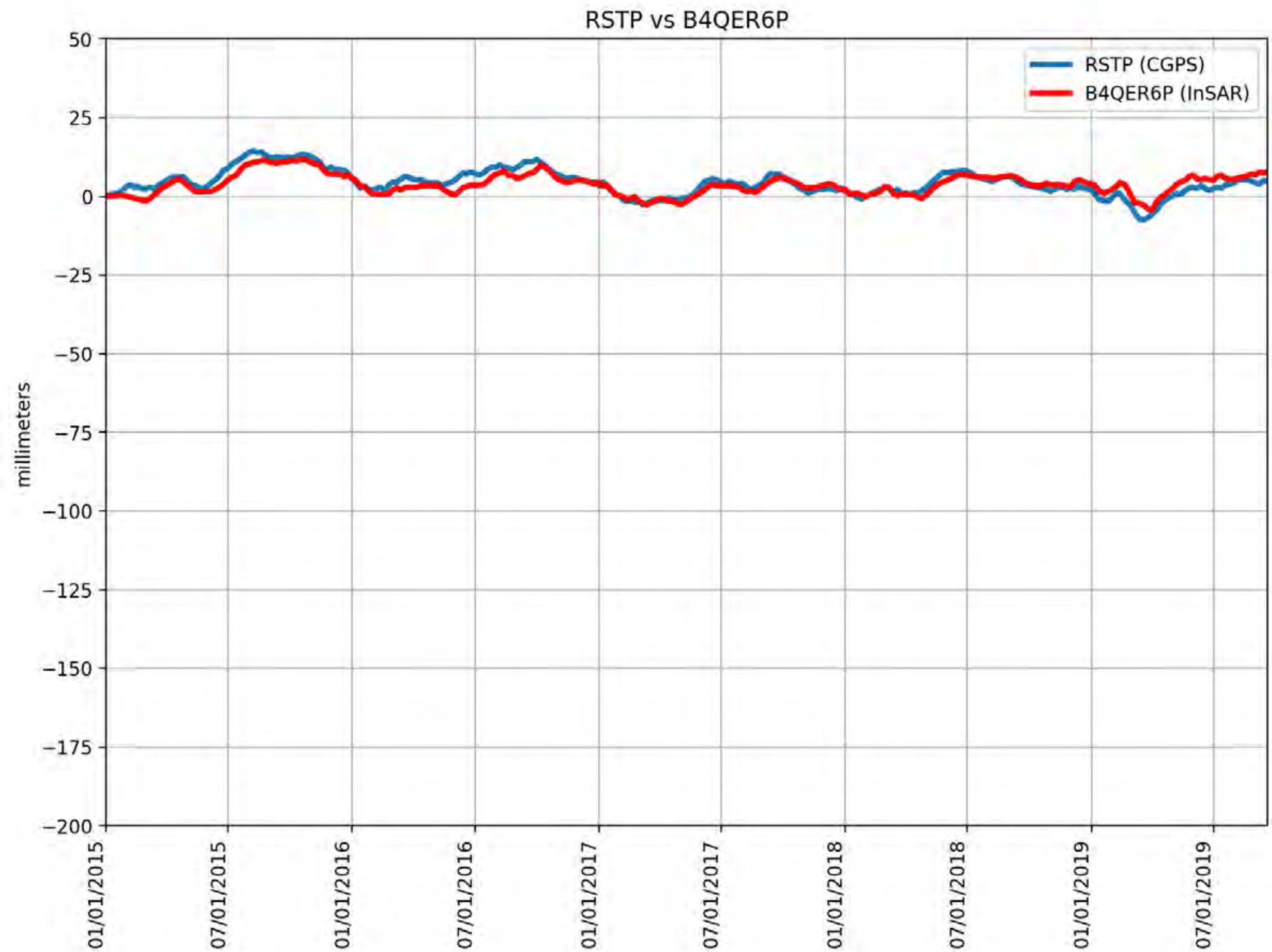

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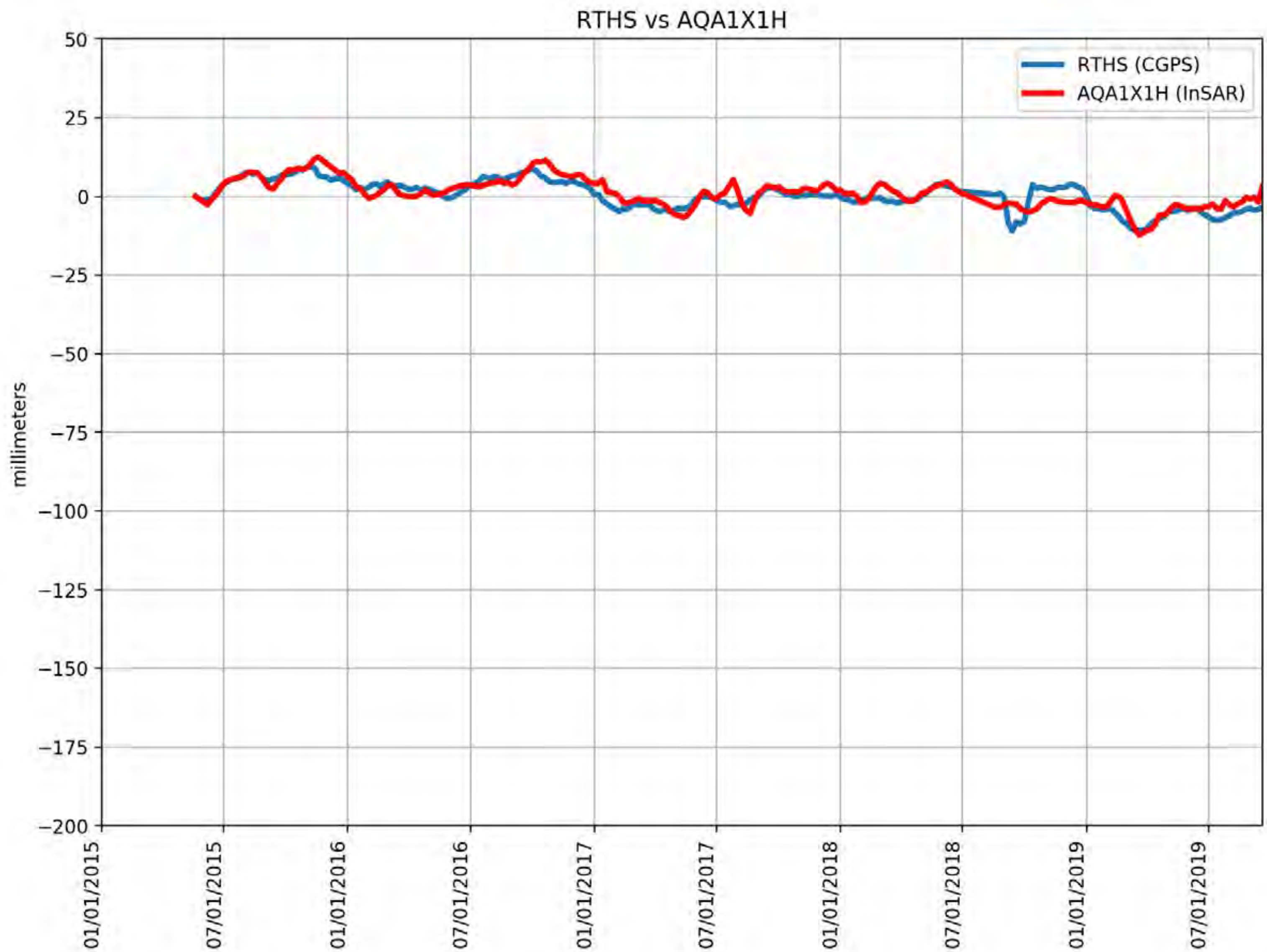

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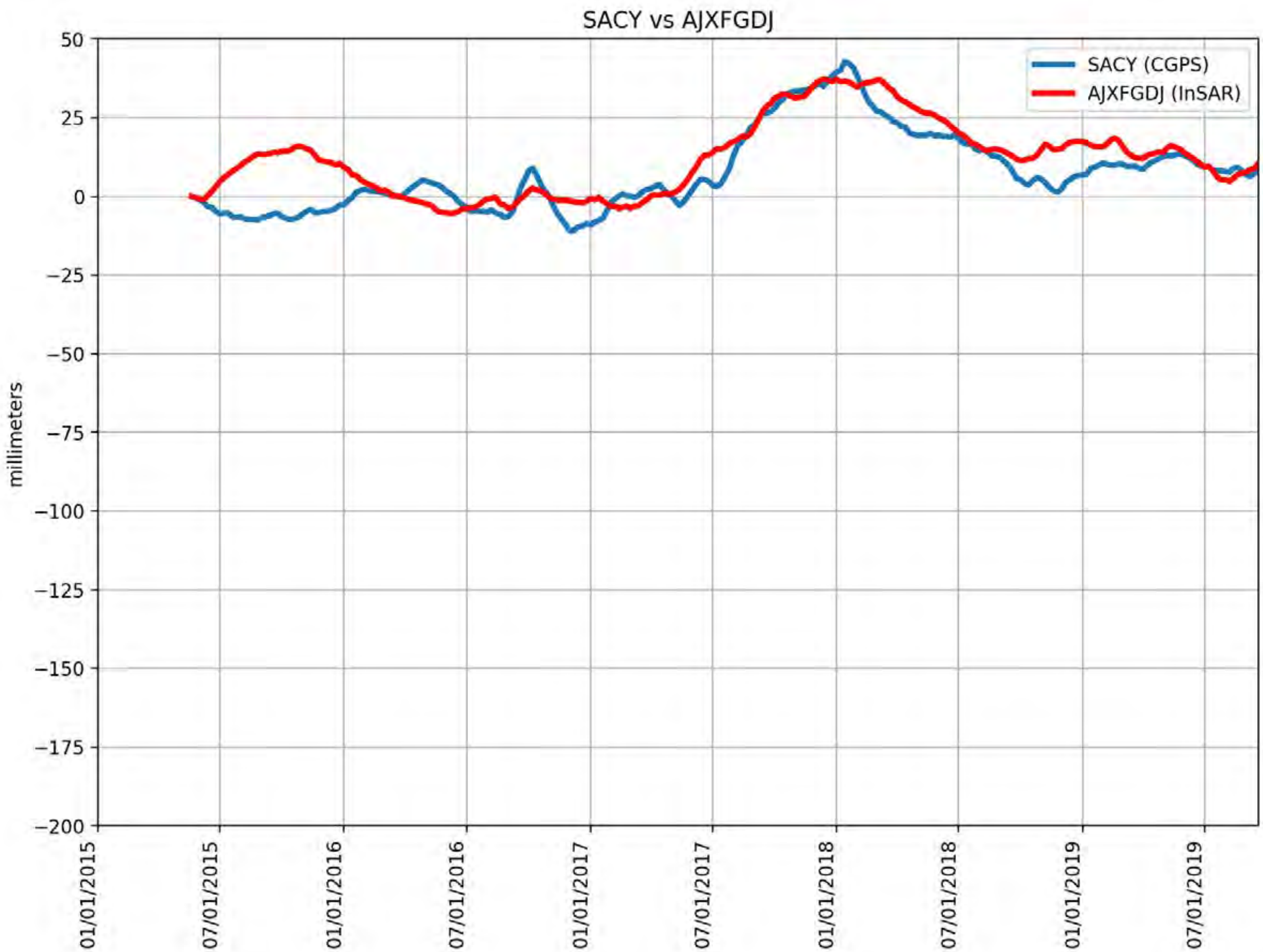

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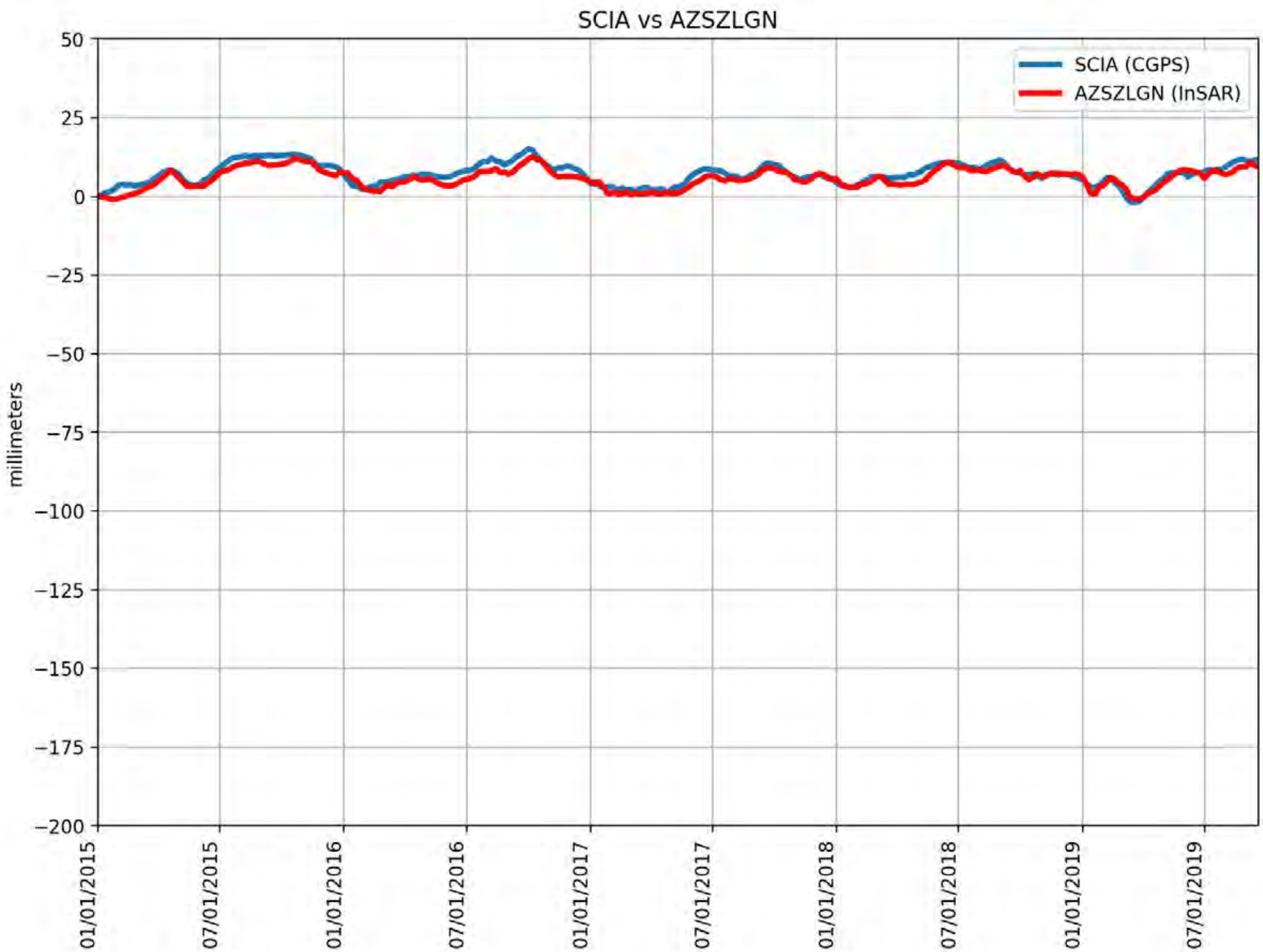

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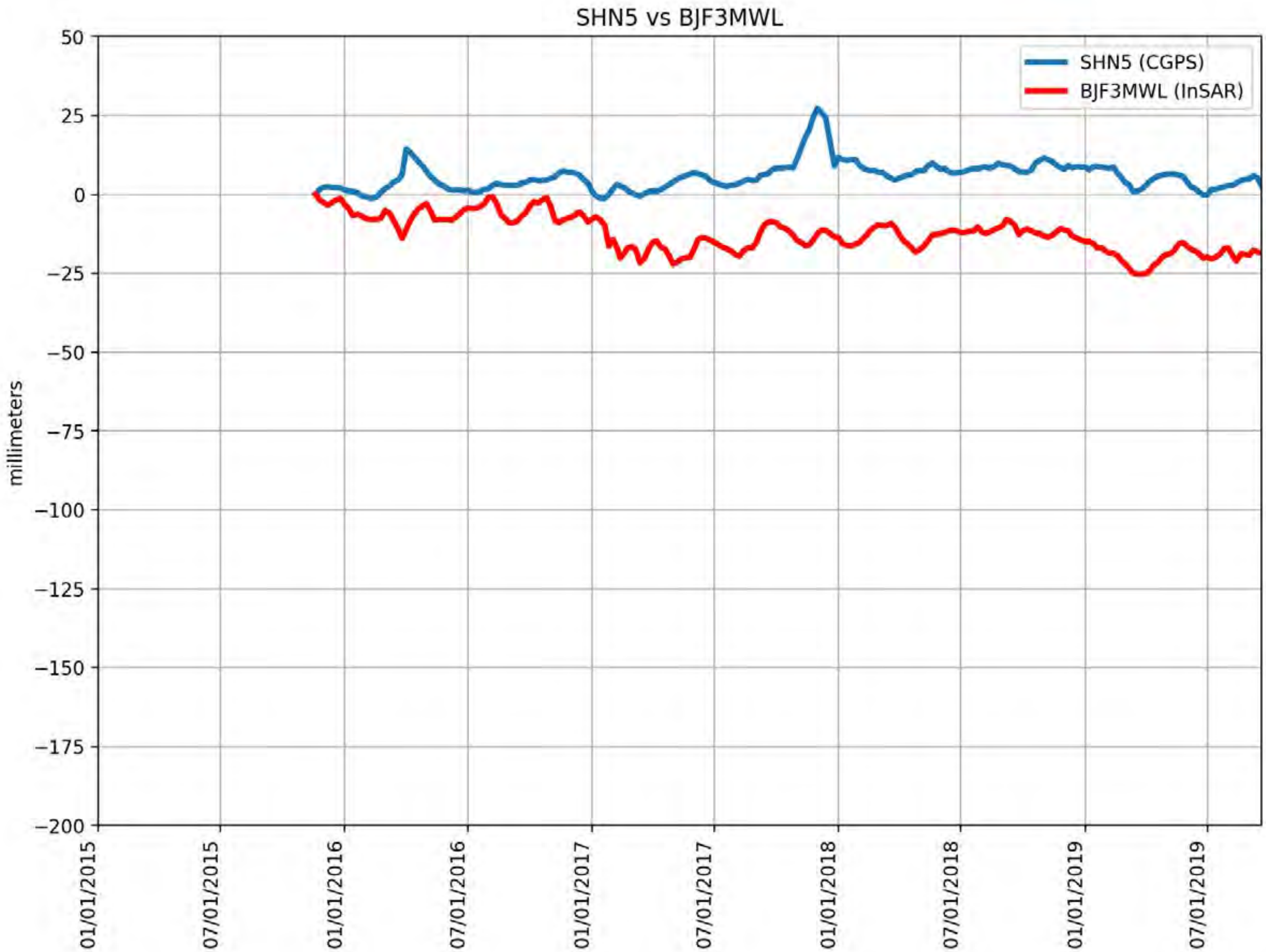

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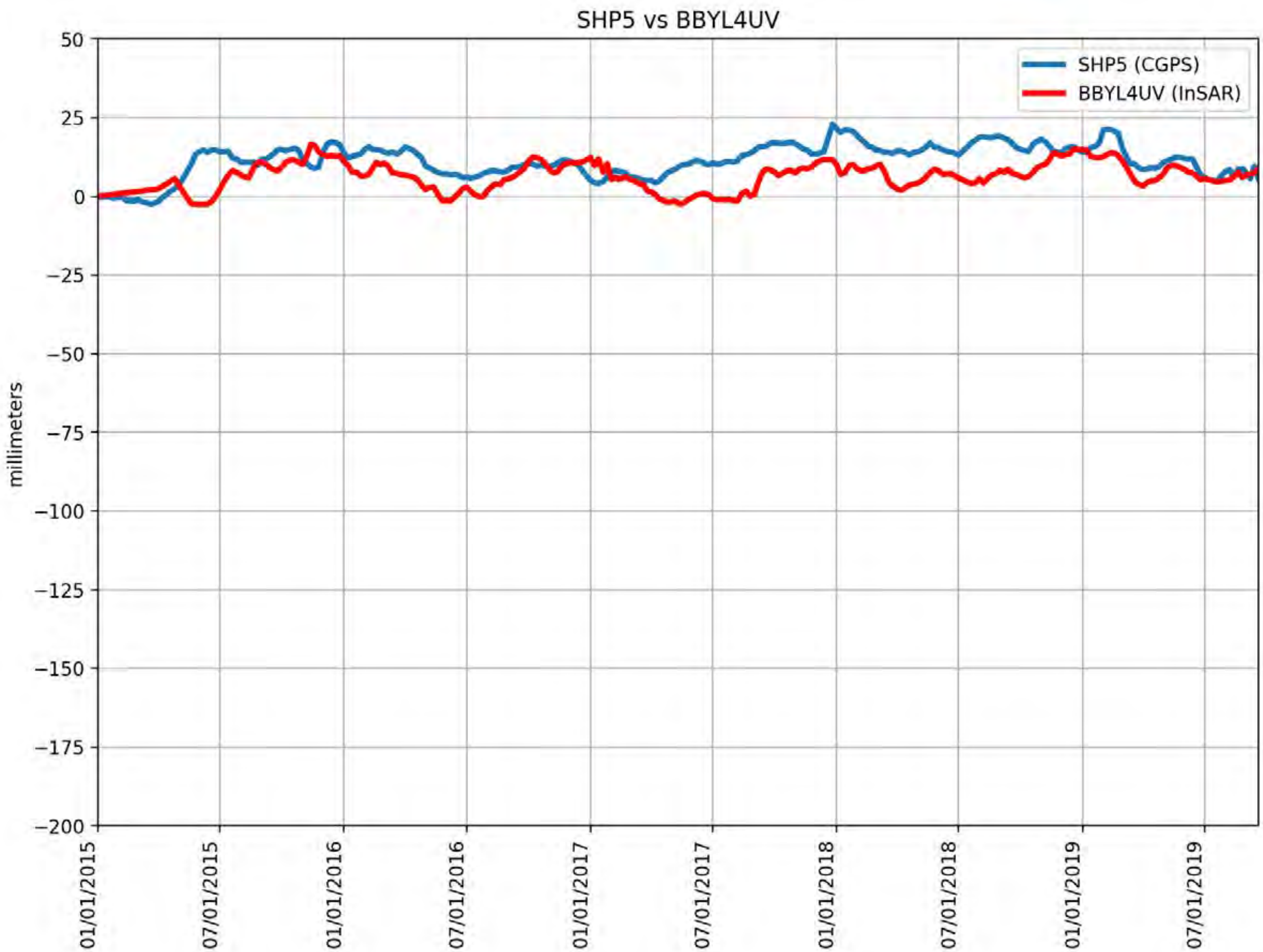

RMSE: 7.19 mm
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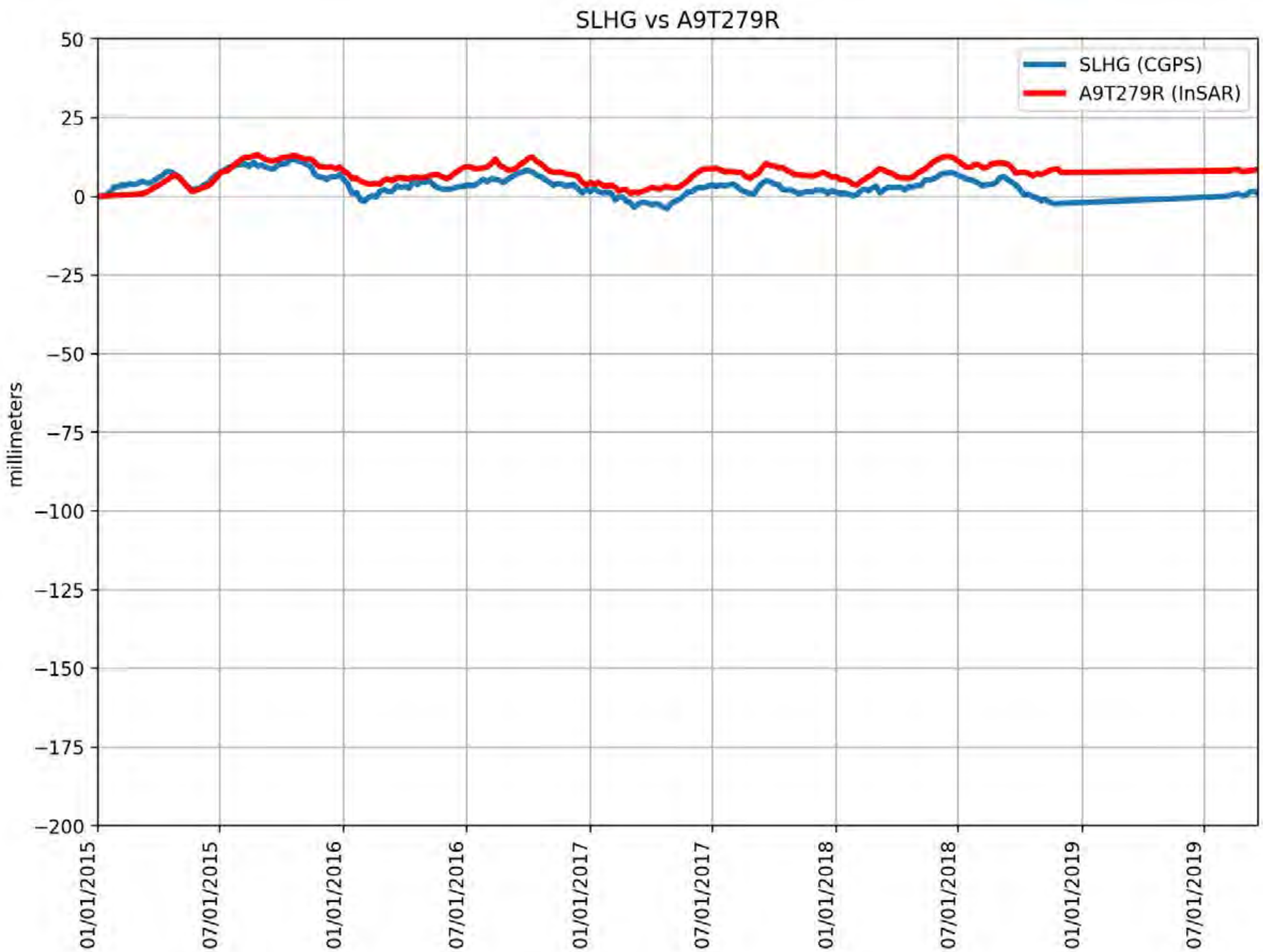

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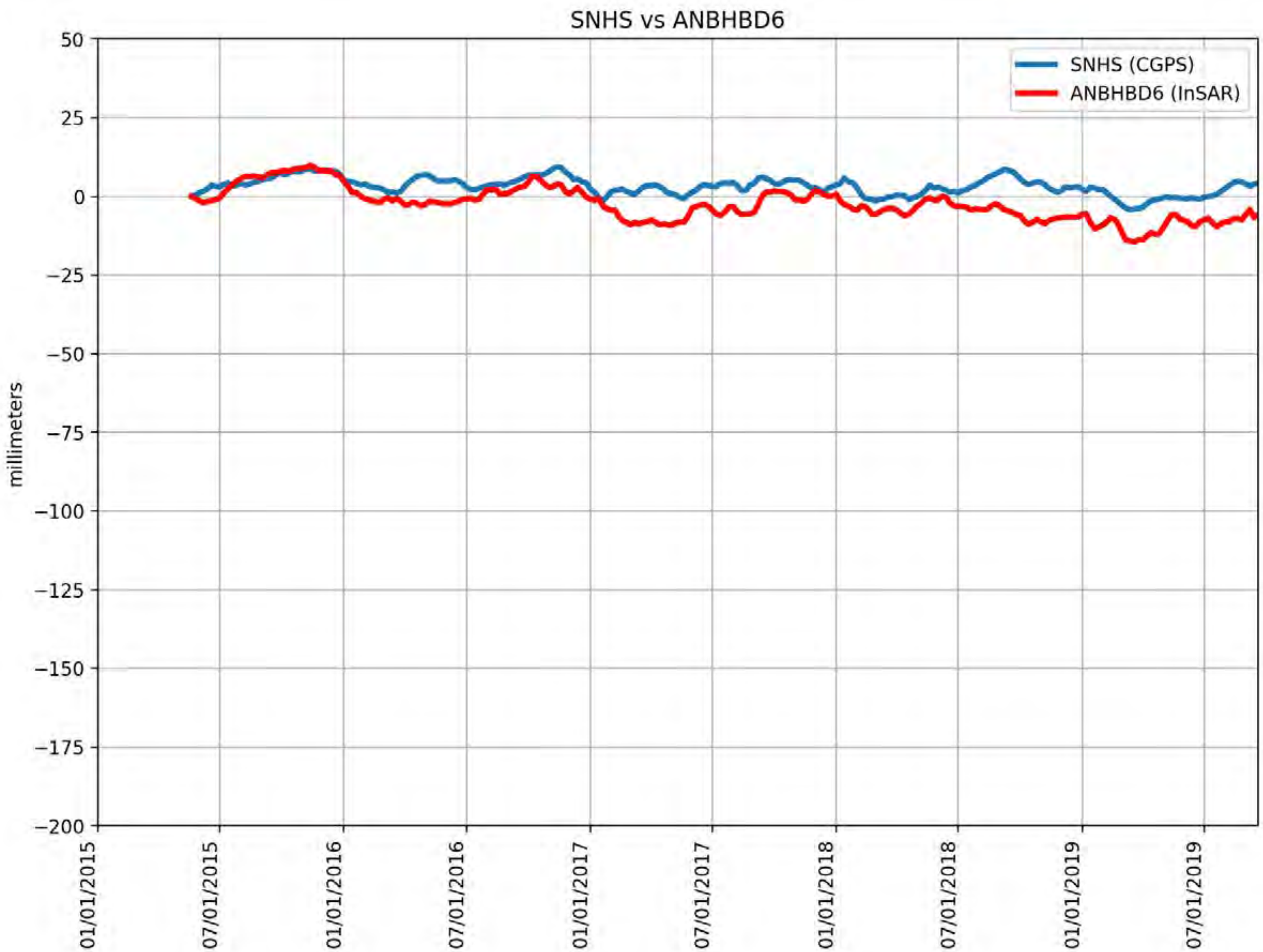

RMSE: 6.90 mm
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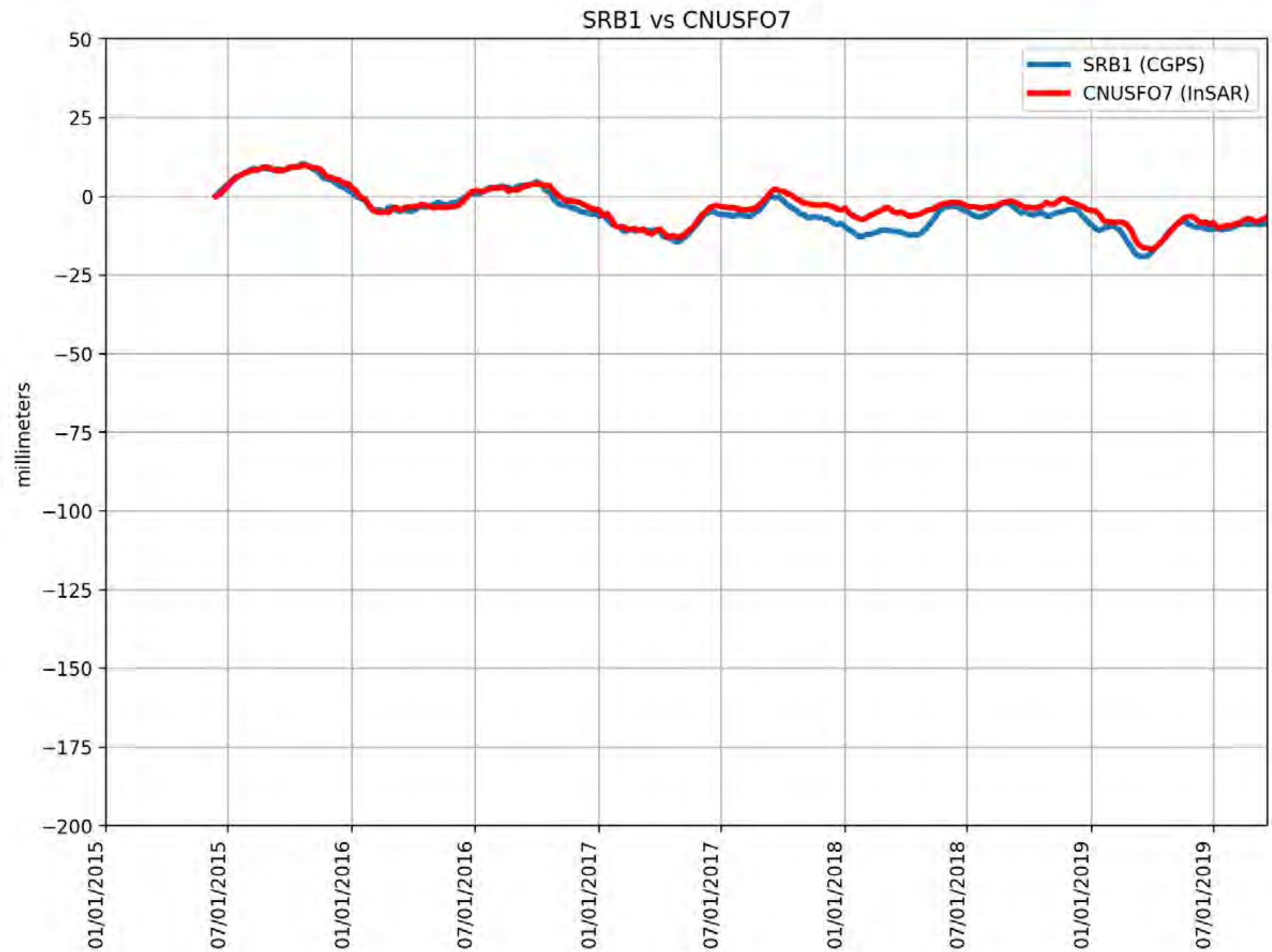

RMSE: 2.61 mm
Correlation: 0.95

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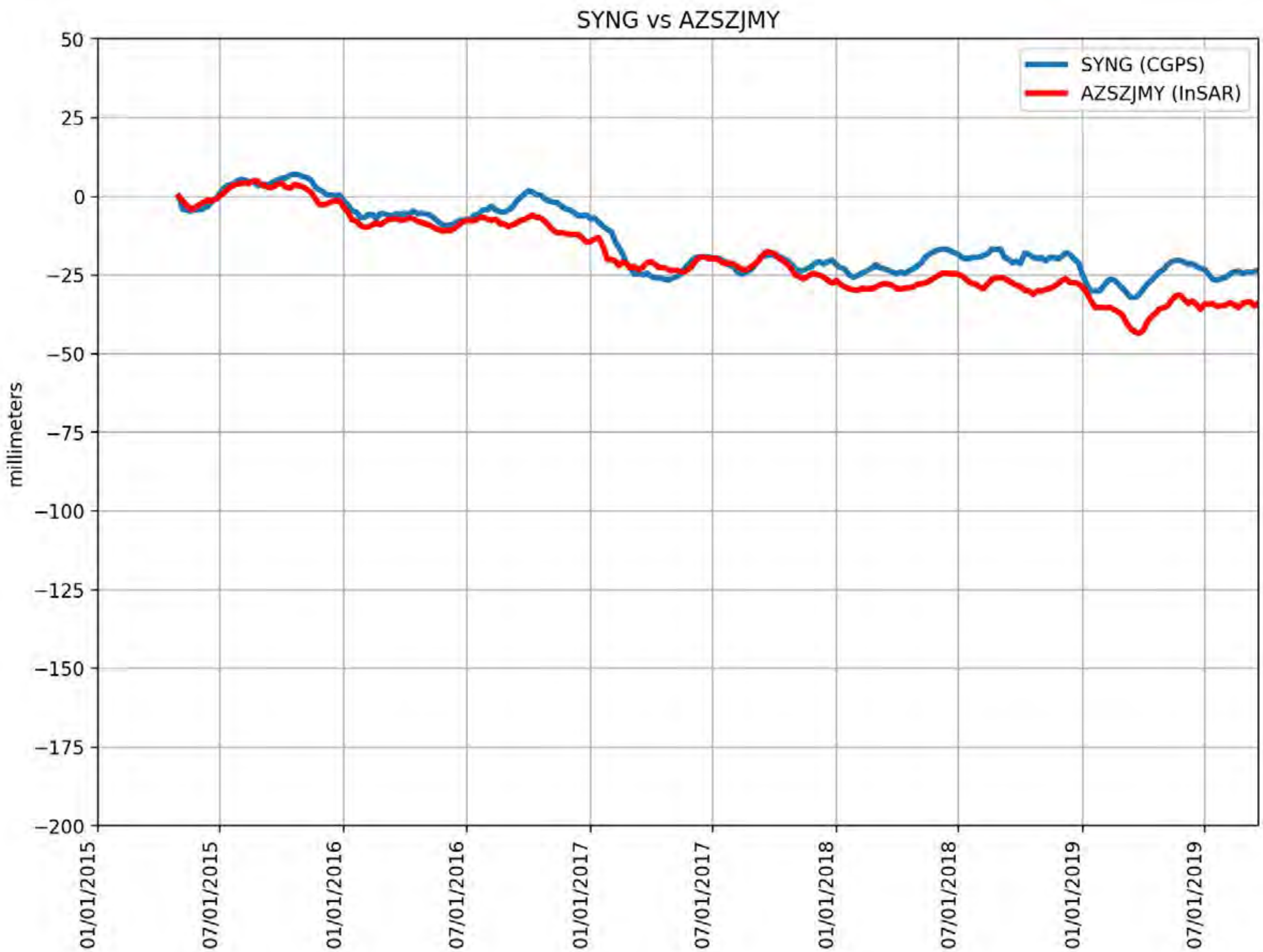

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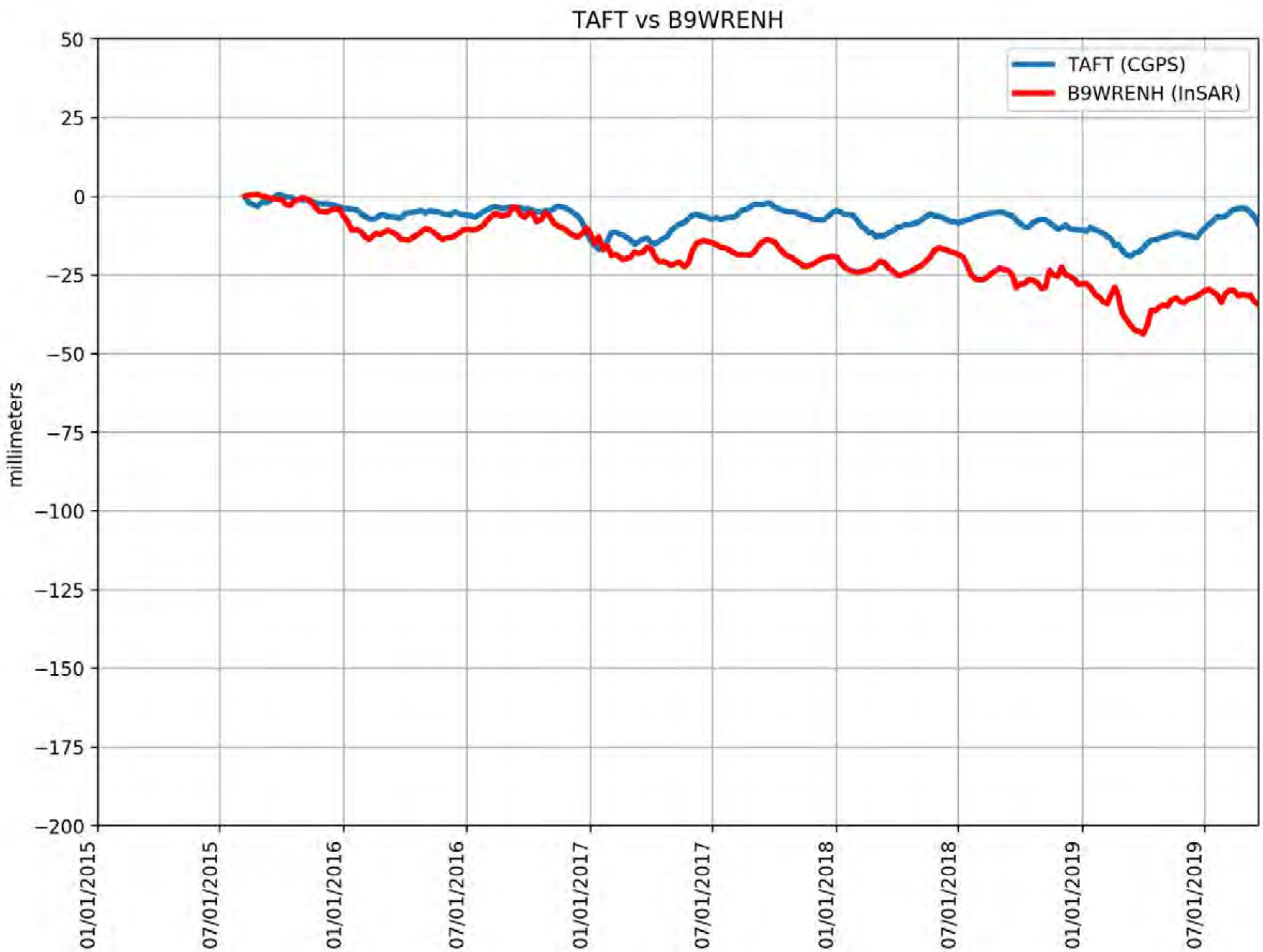

RMSE: 13.54 mm
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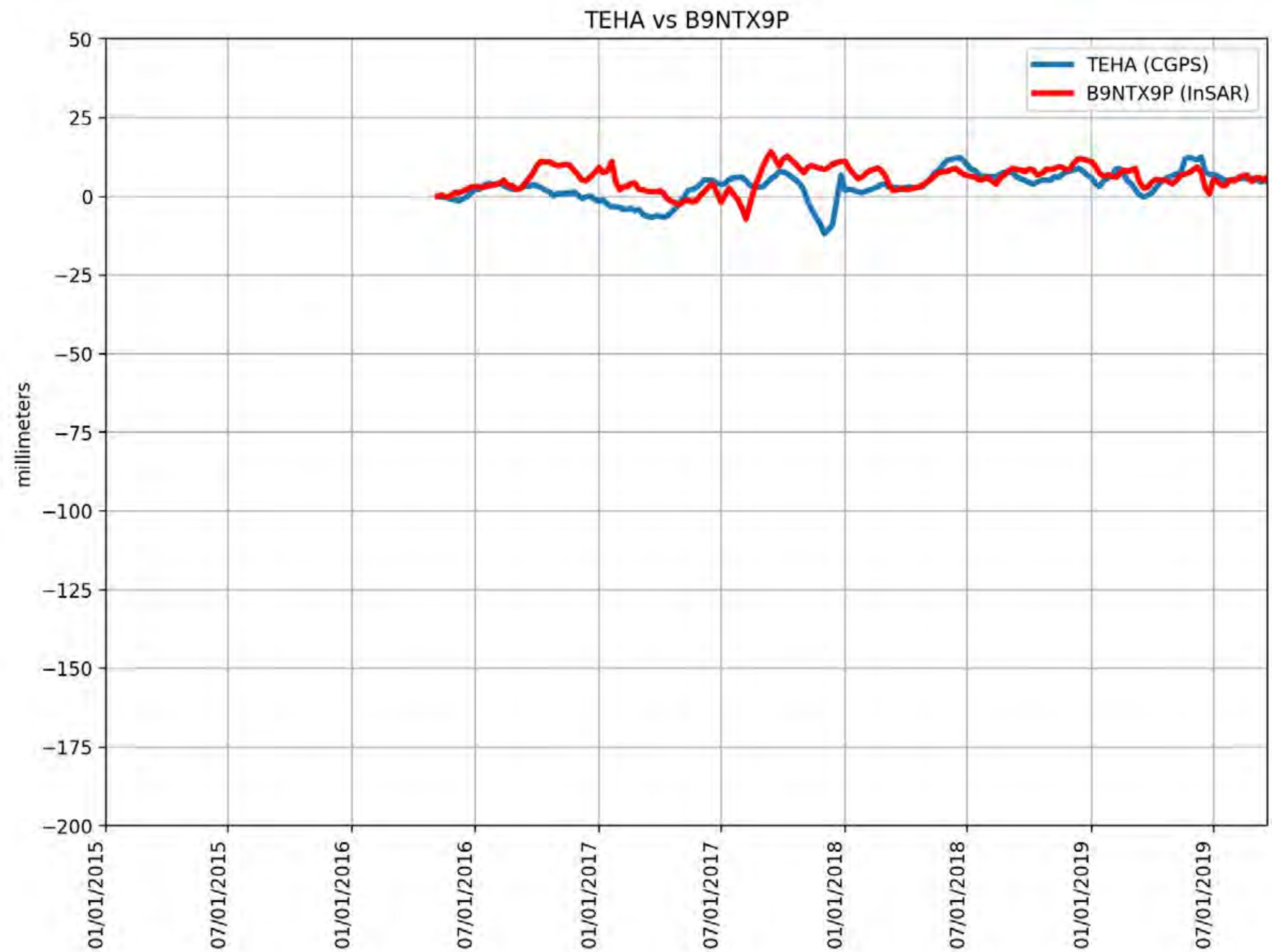

RMSE: 5.60 mm
Correlation: 0.26

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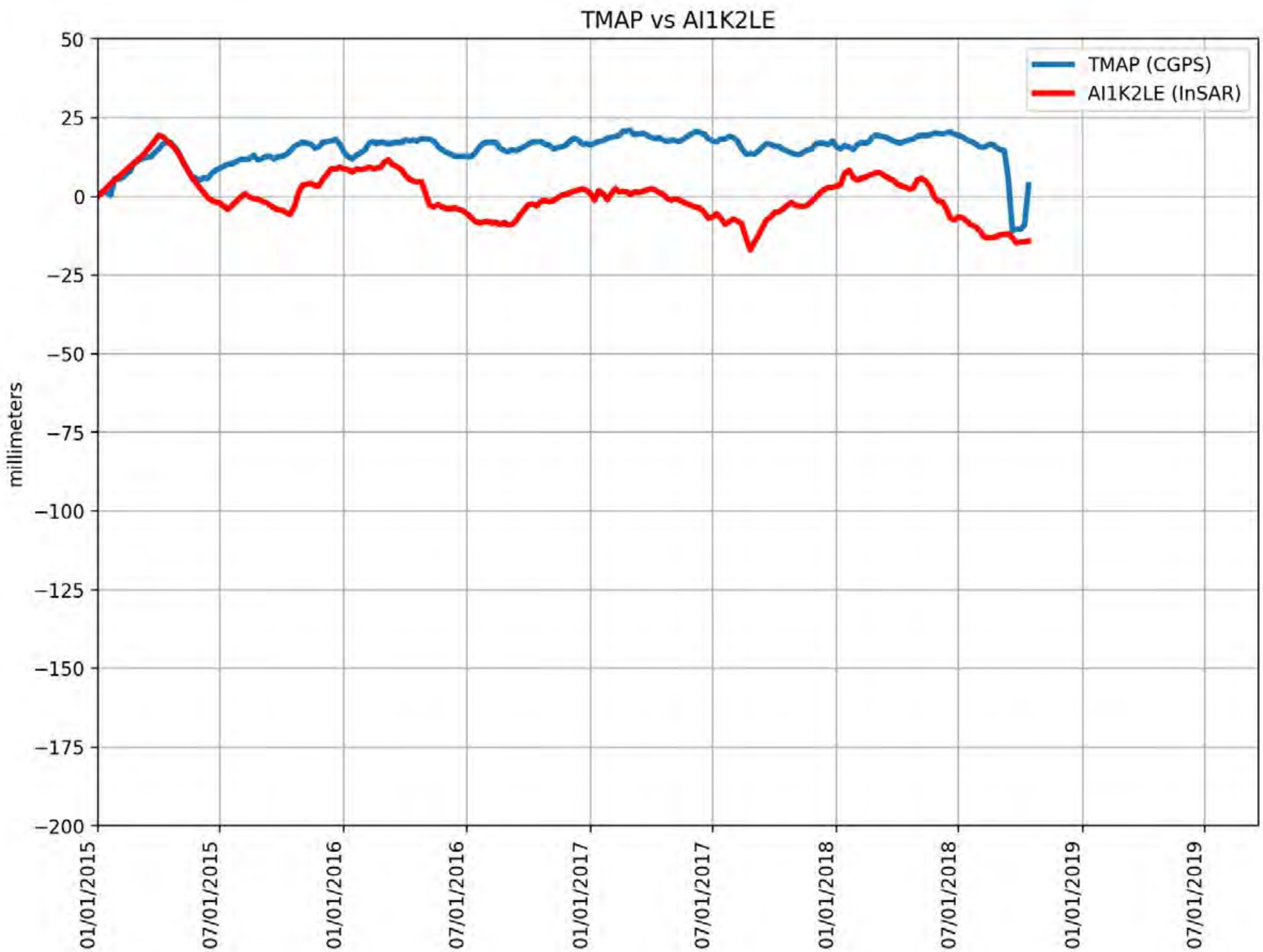

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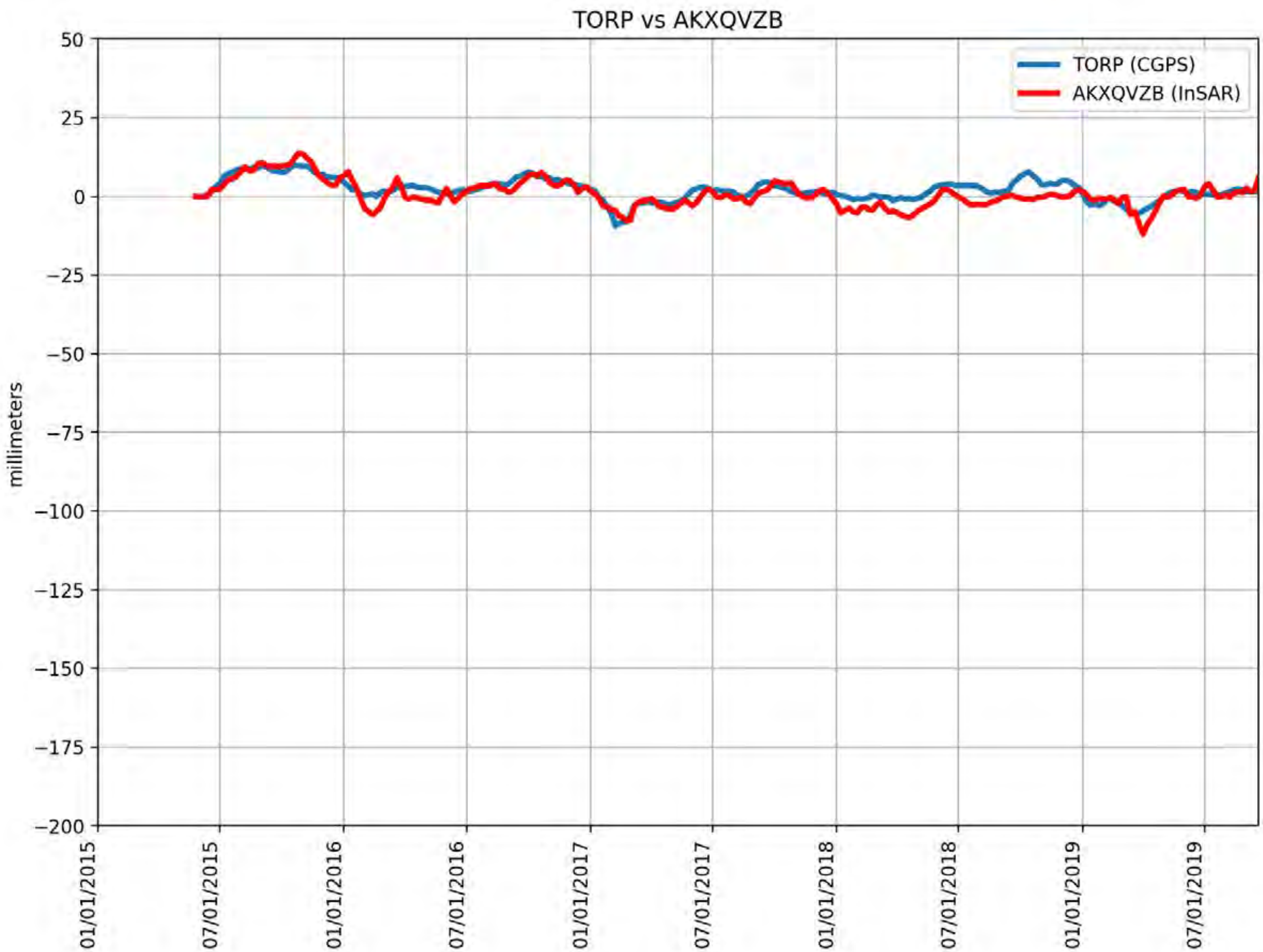

RMSE: 2.84 mm
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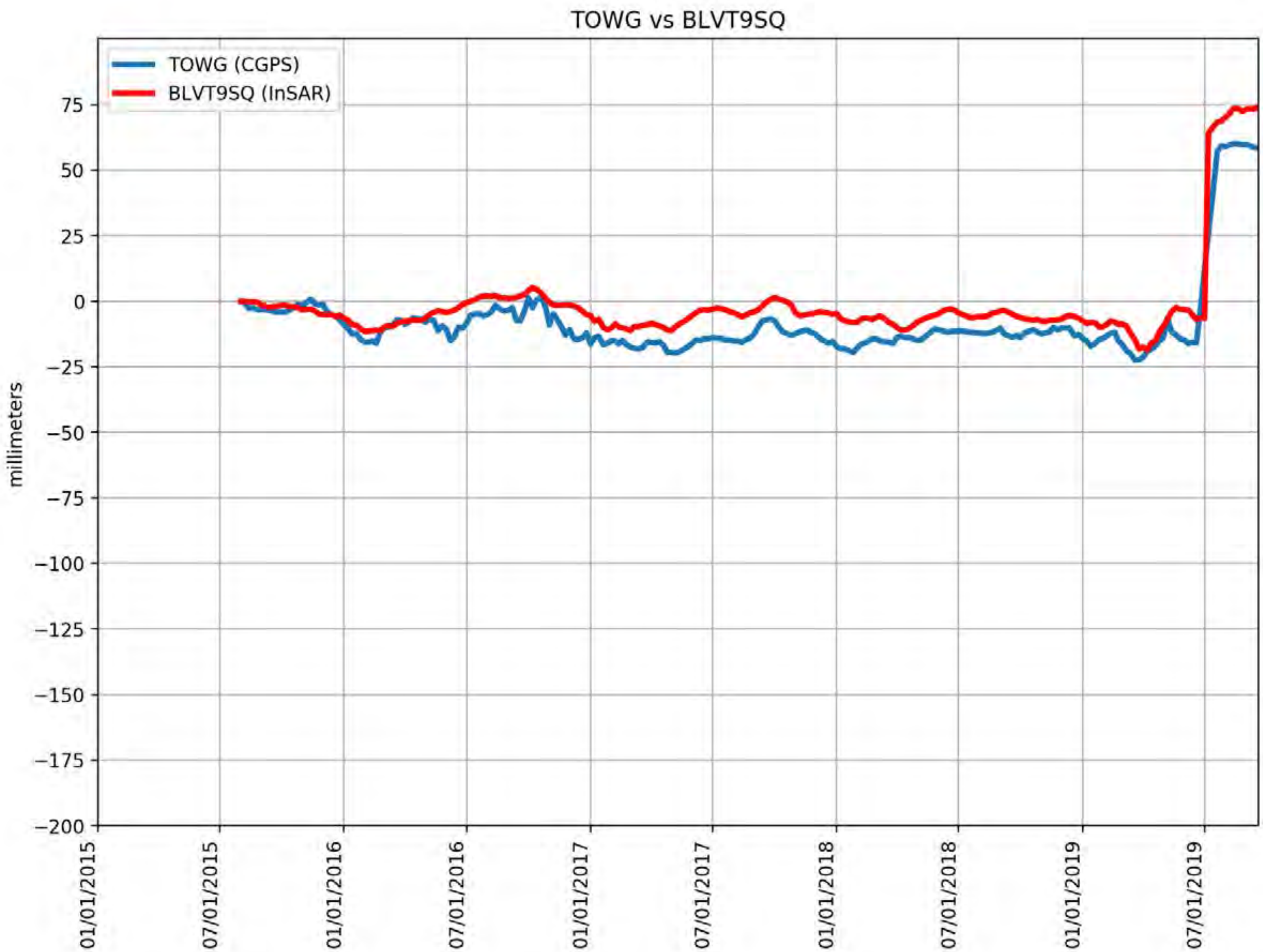

RMSE: 8.04 mm
Correlation: 0.96

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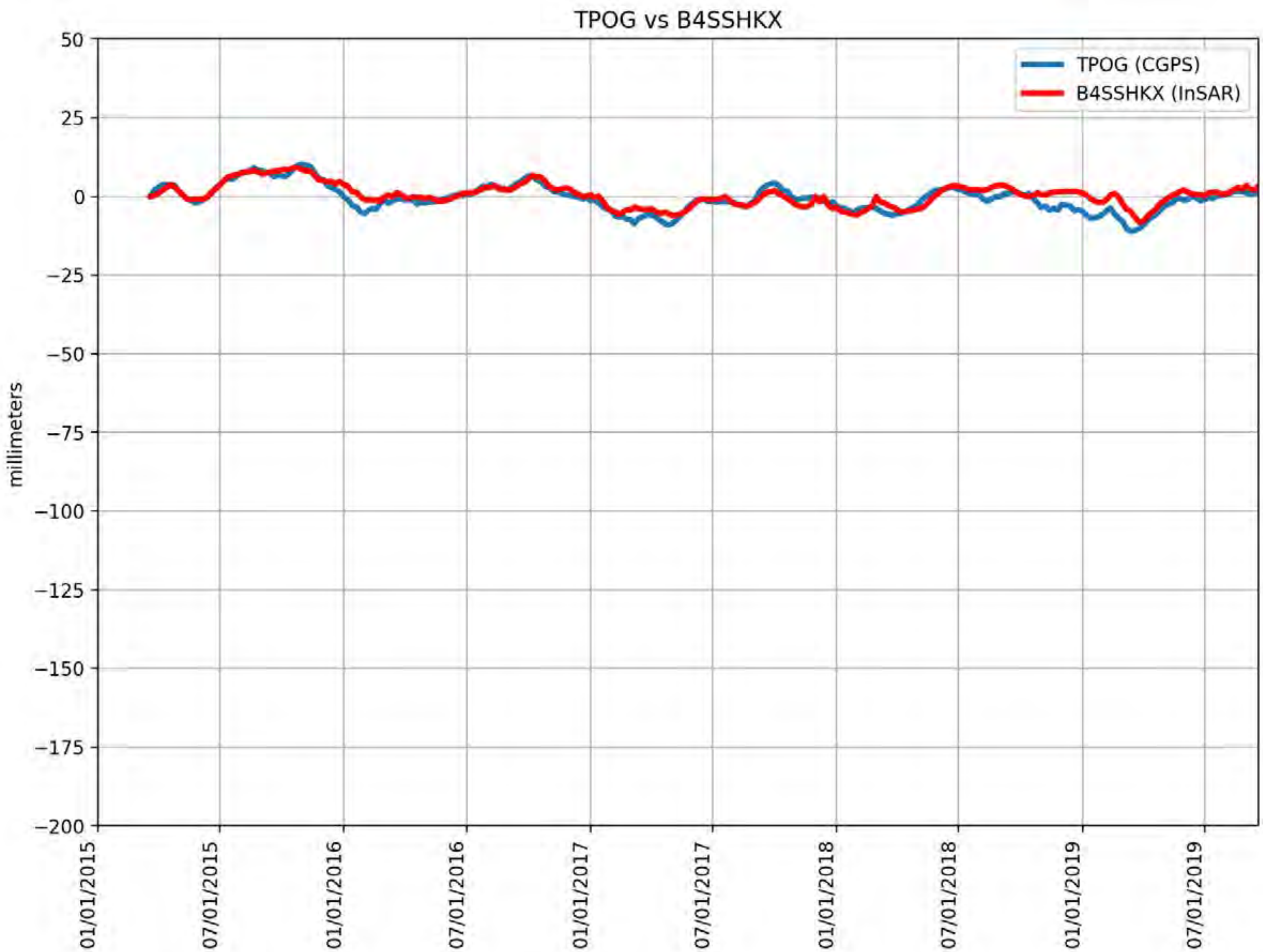

RMSE: 2.28 mm
Correlation: 0.88

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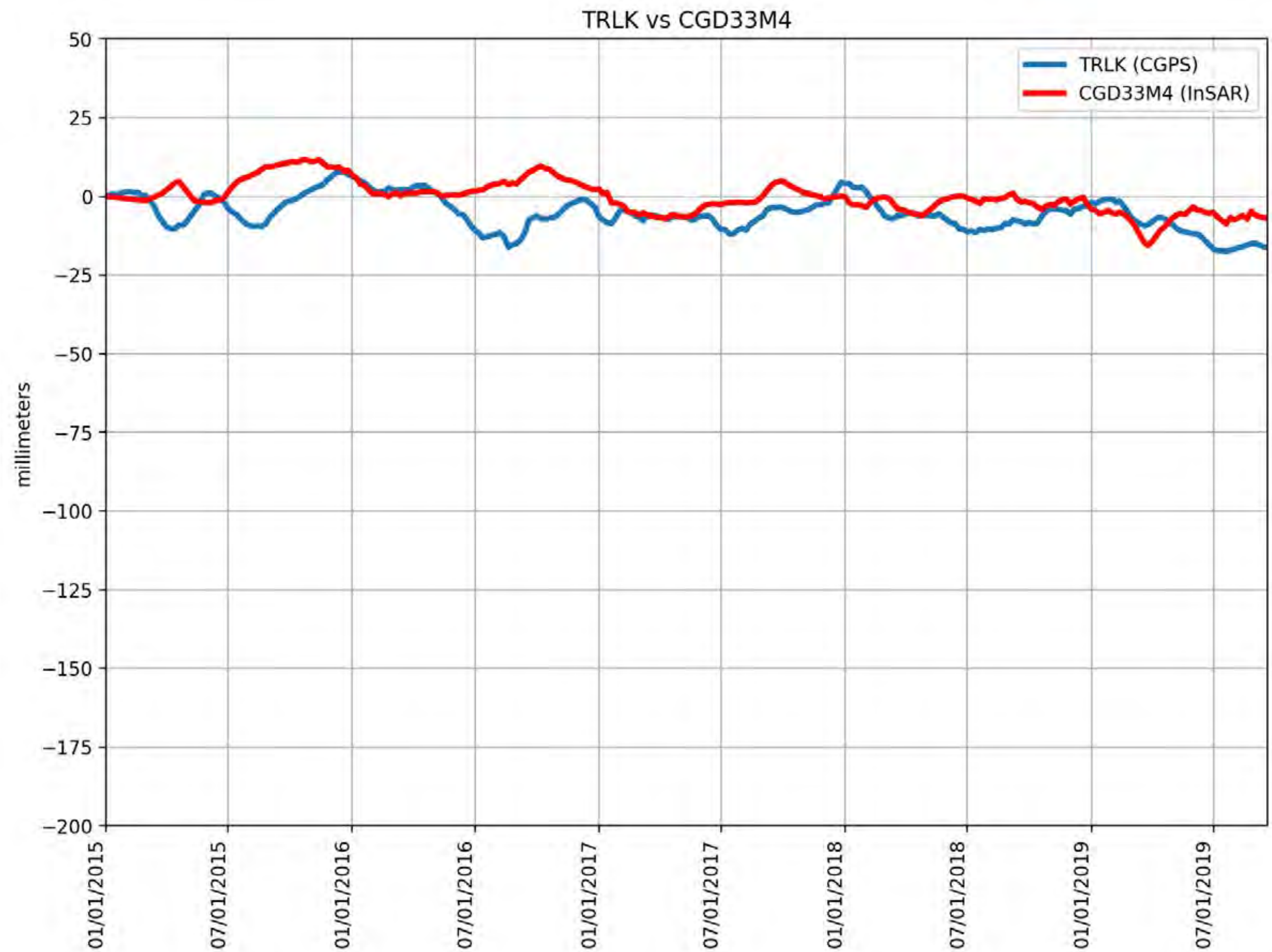

RMSE: 7.88 mm
Correlation: 0.34

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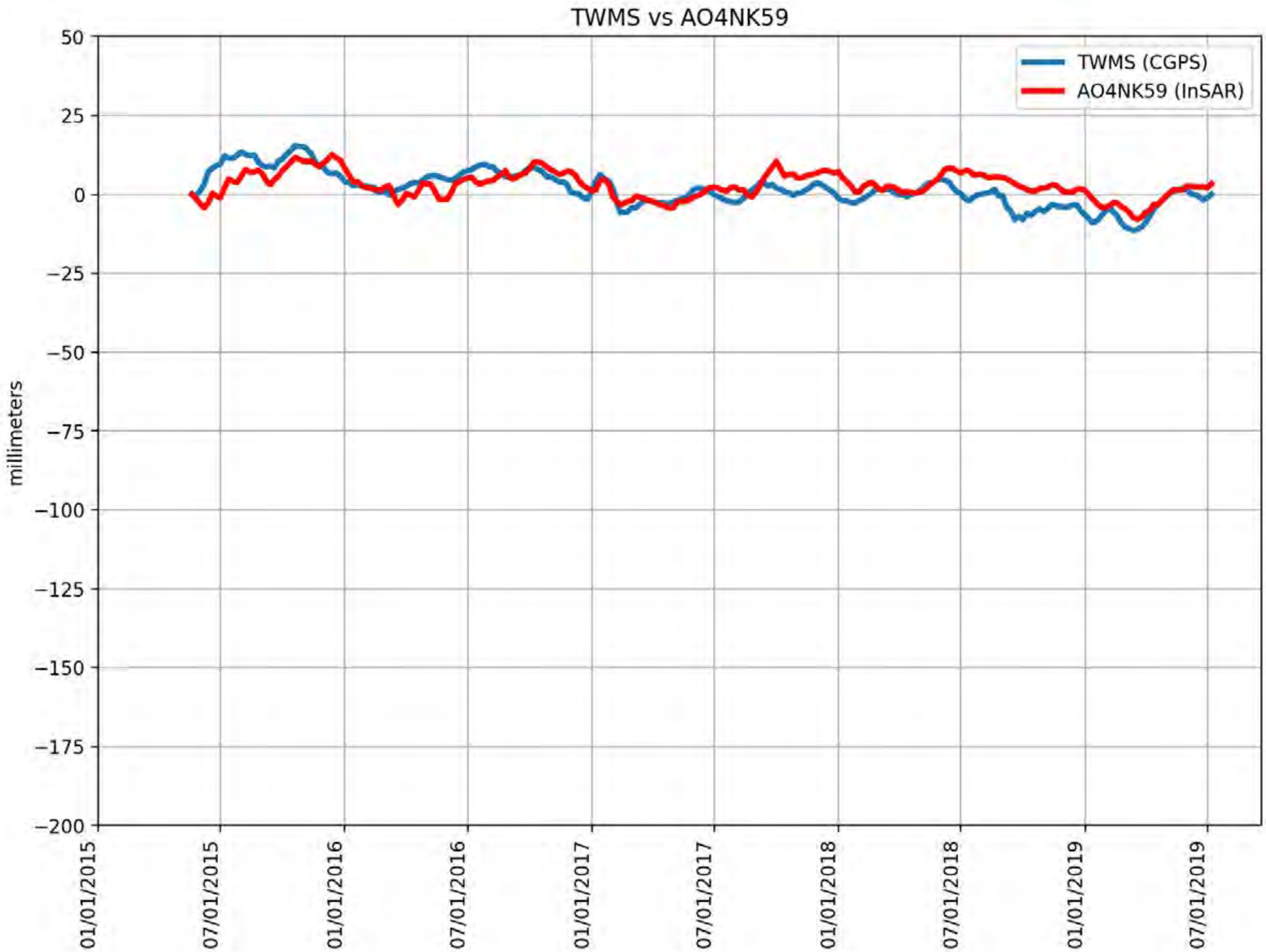

RMSE: 4.42 mm
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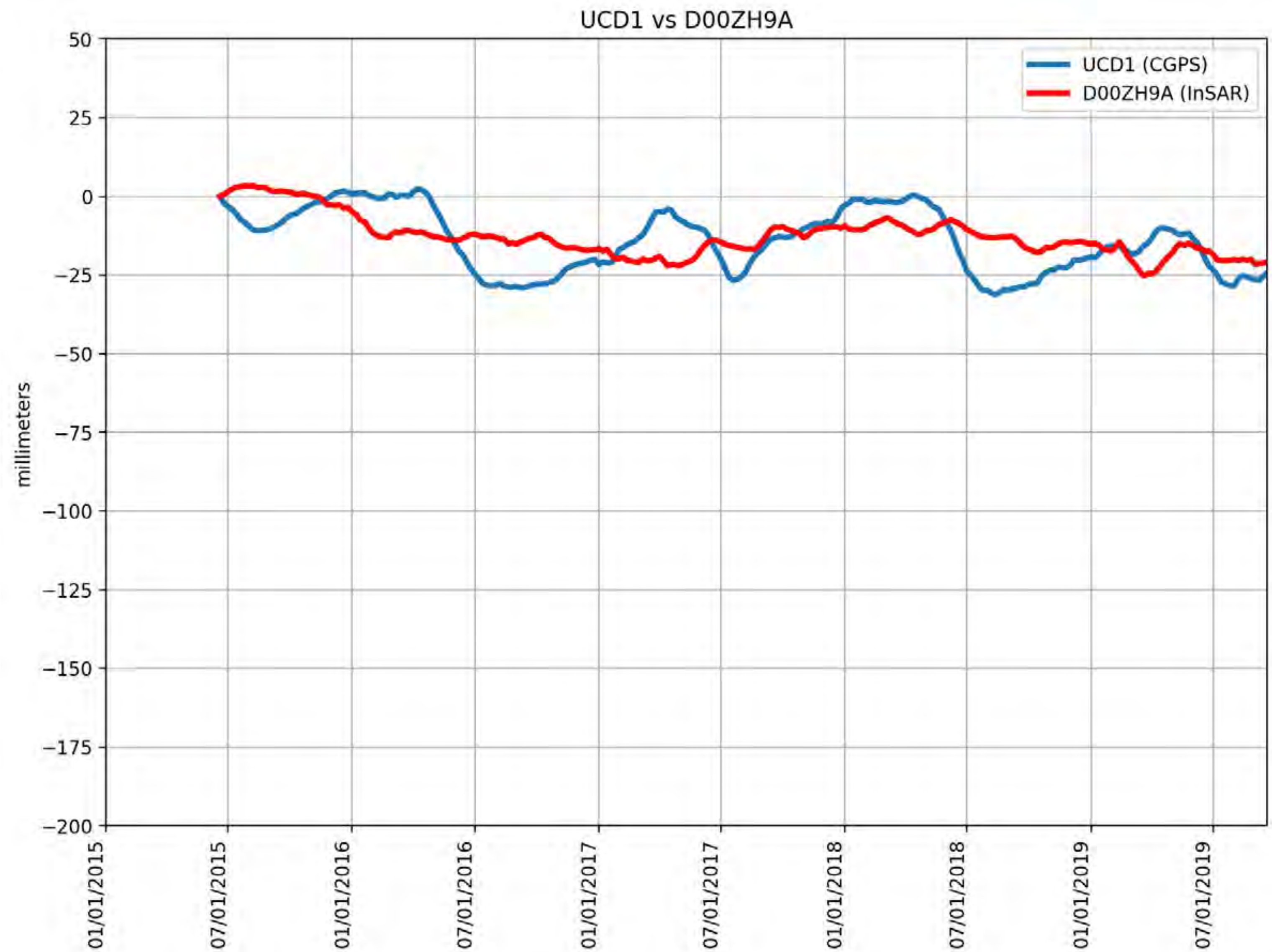

RMSE: 9.19 mm
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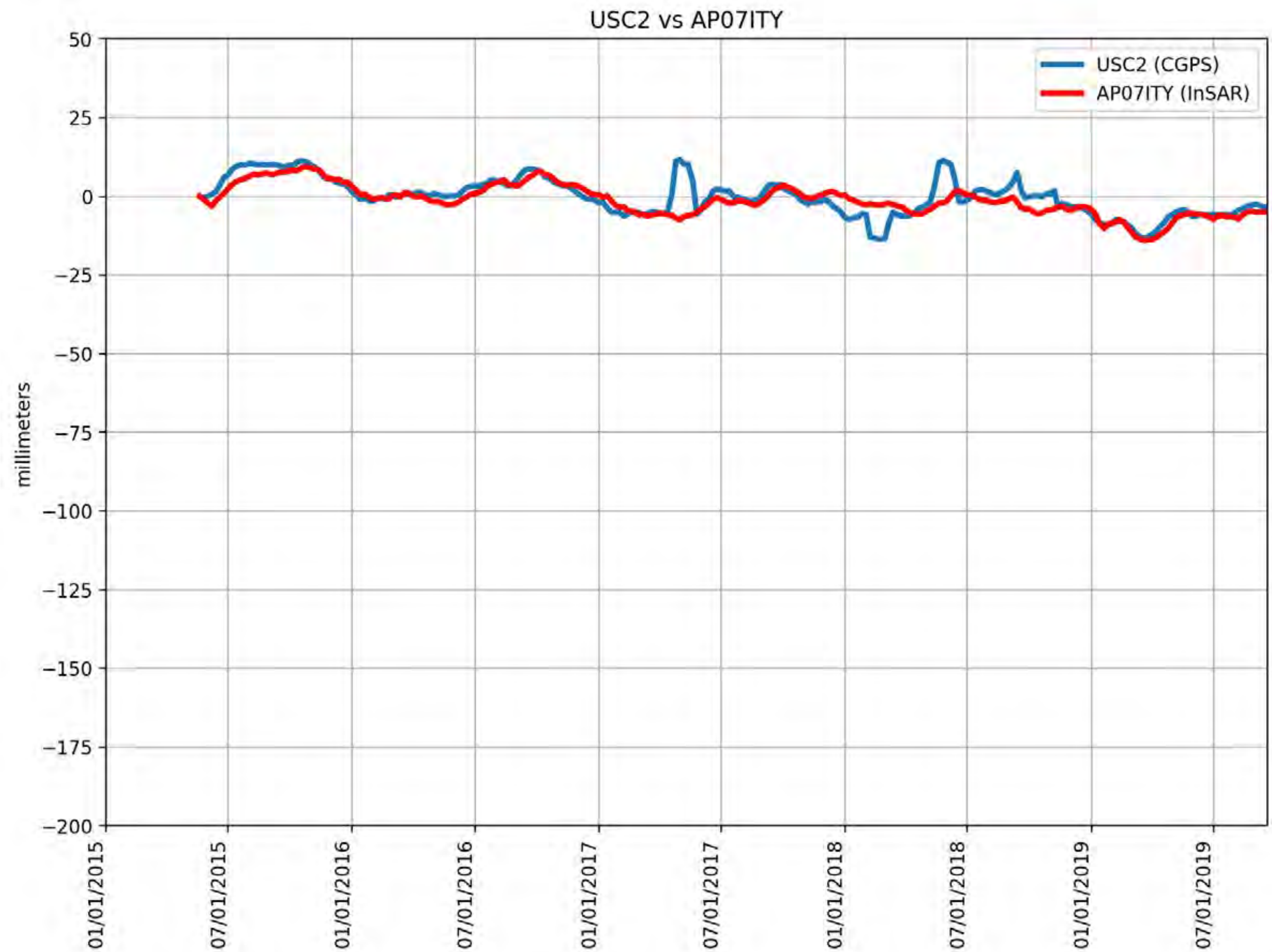

RMSE: 3.98 mm
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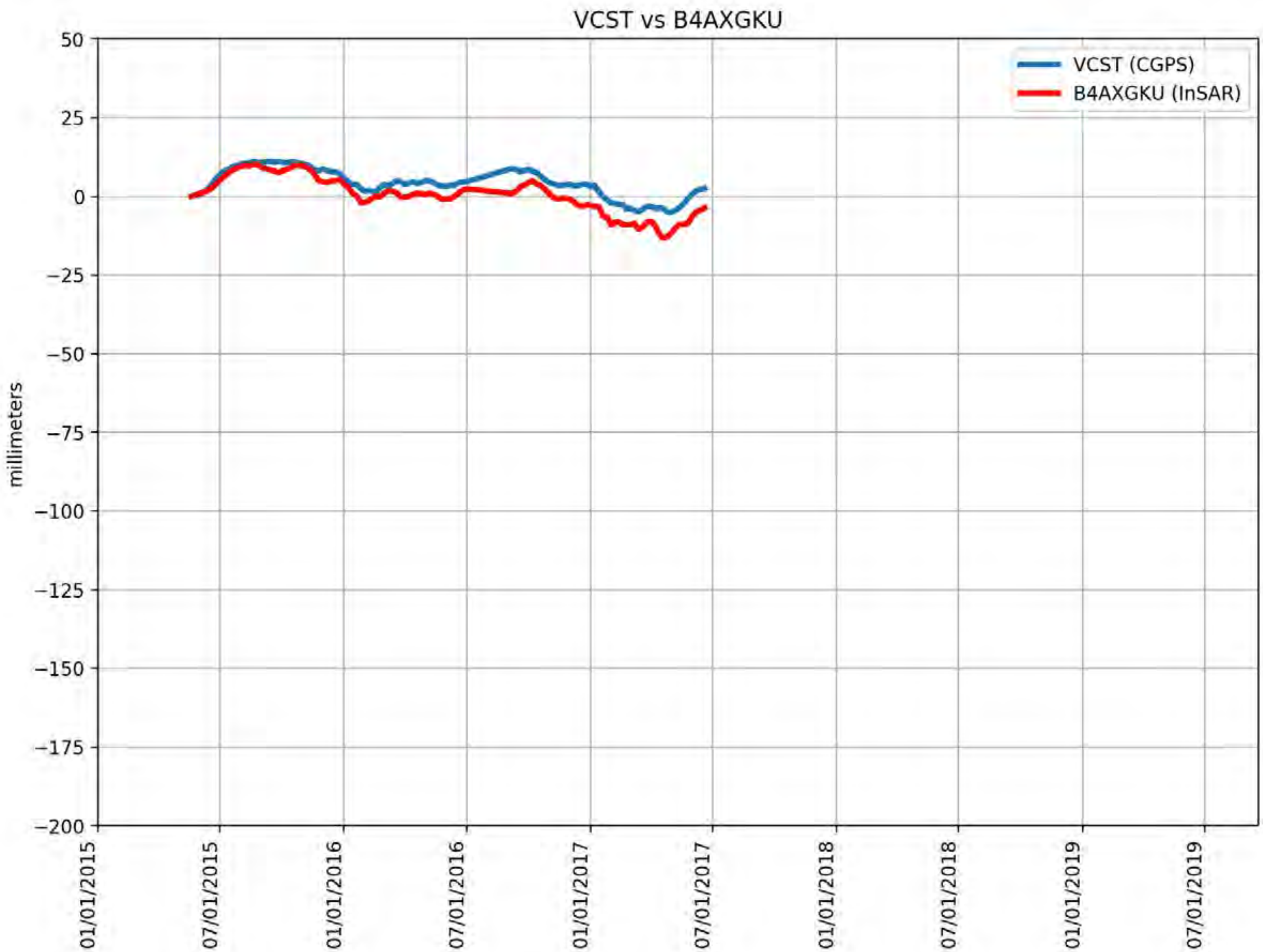

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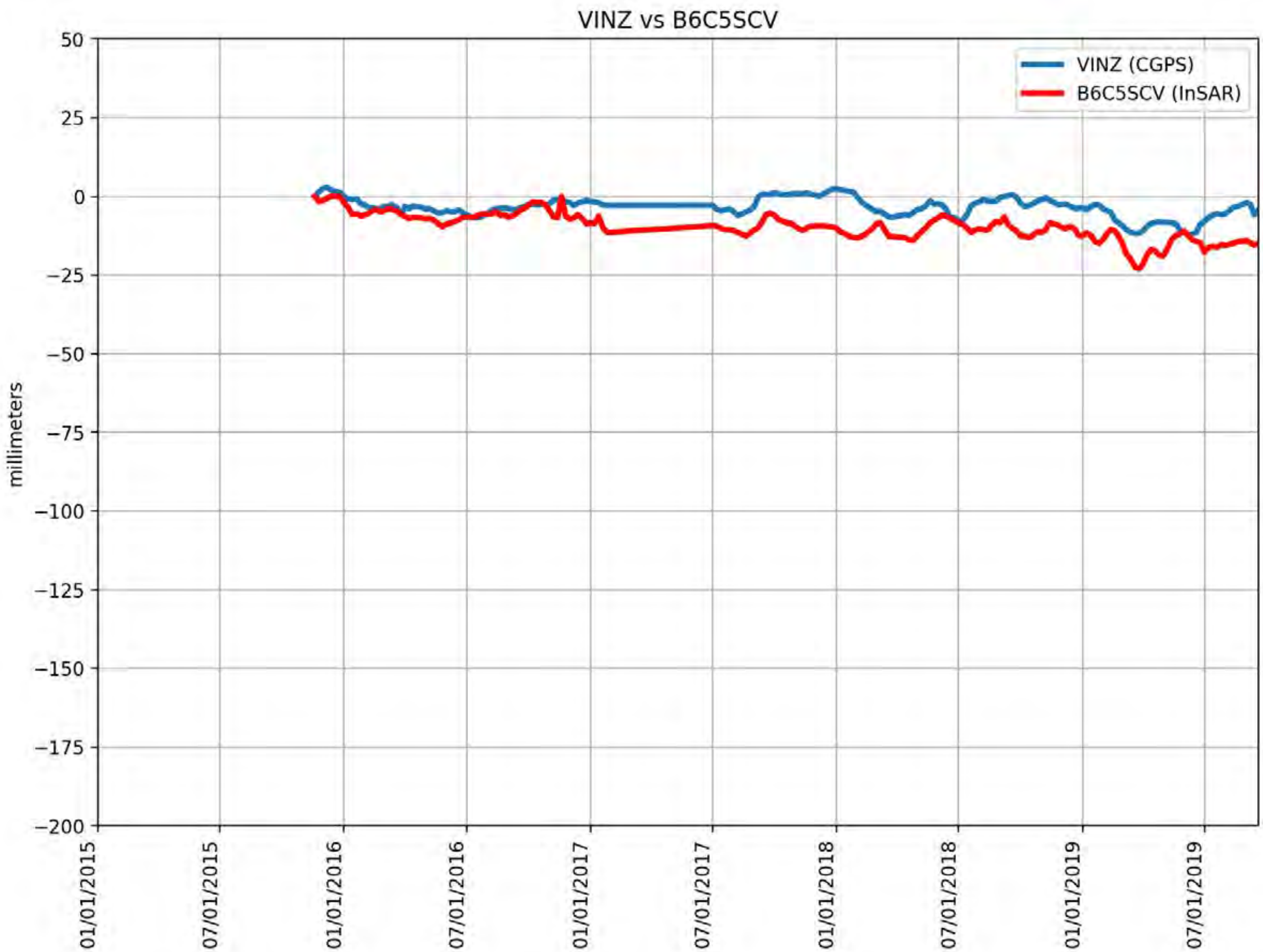

RMSE: 7.14 mm
Correlation: 0.53

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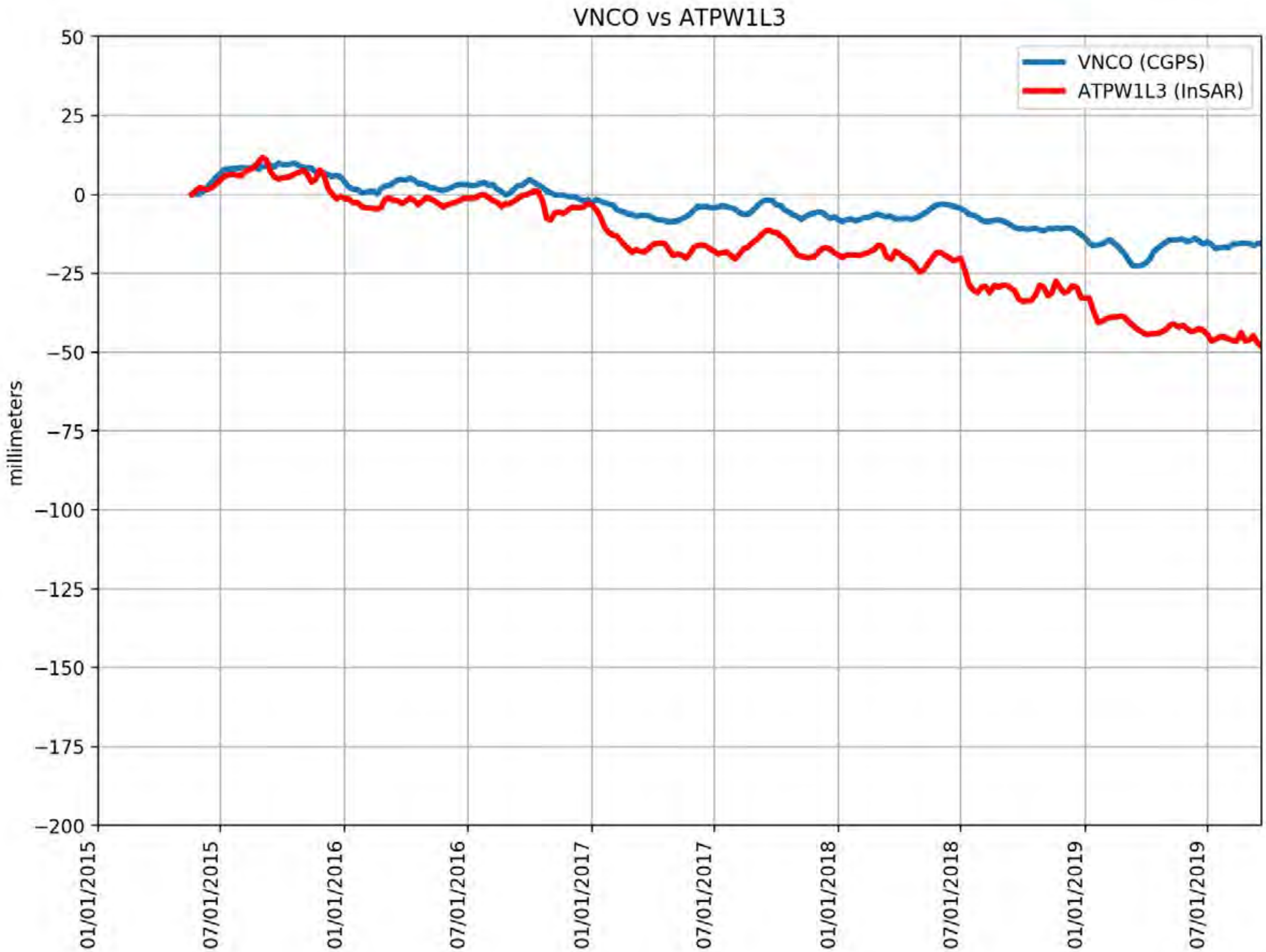

RMSE: 14.85 mm
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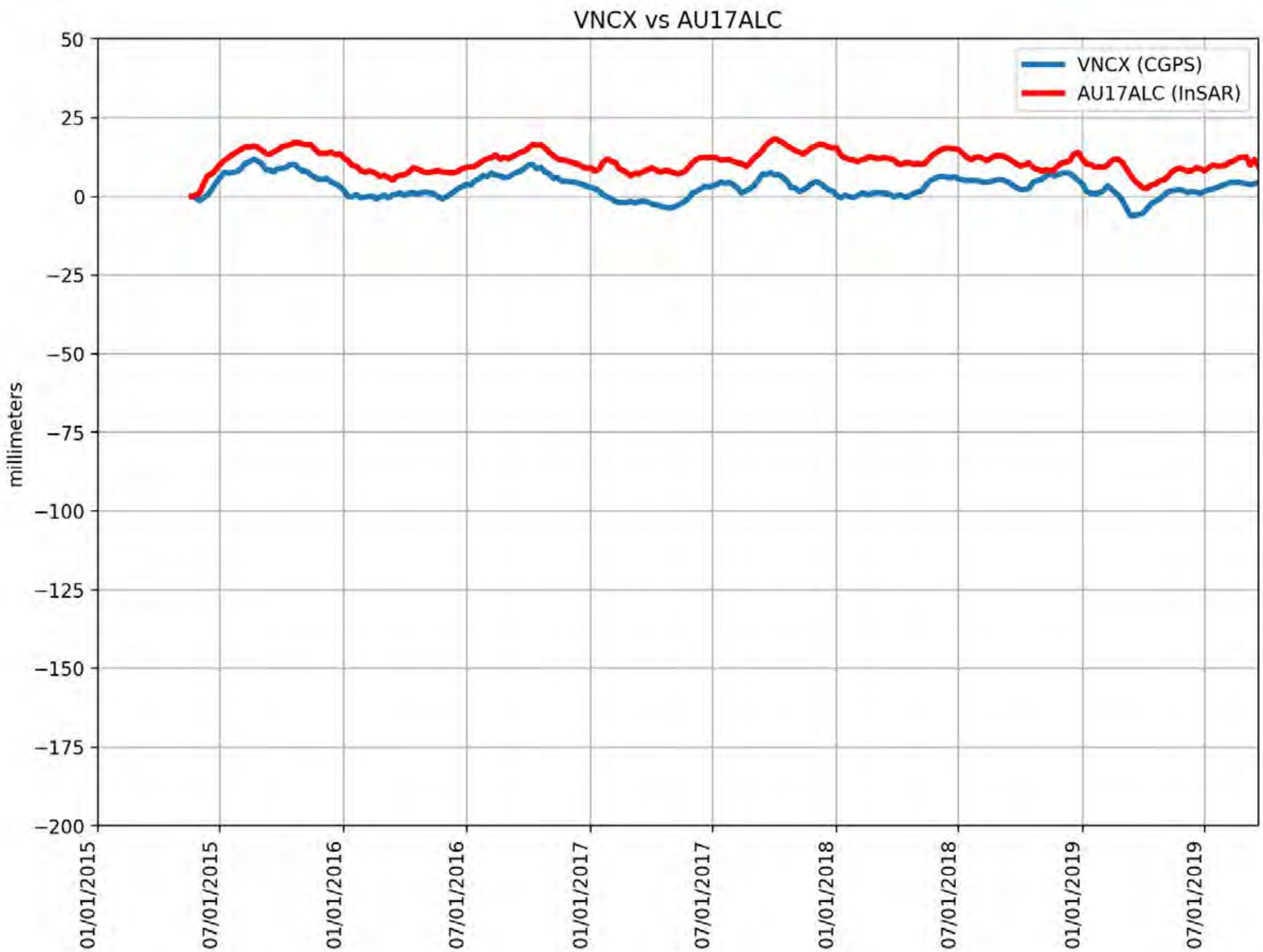

RMSE: 8.30 mm
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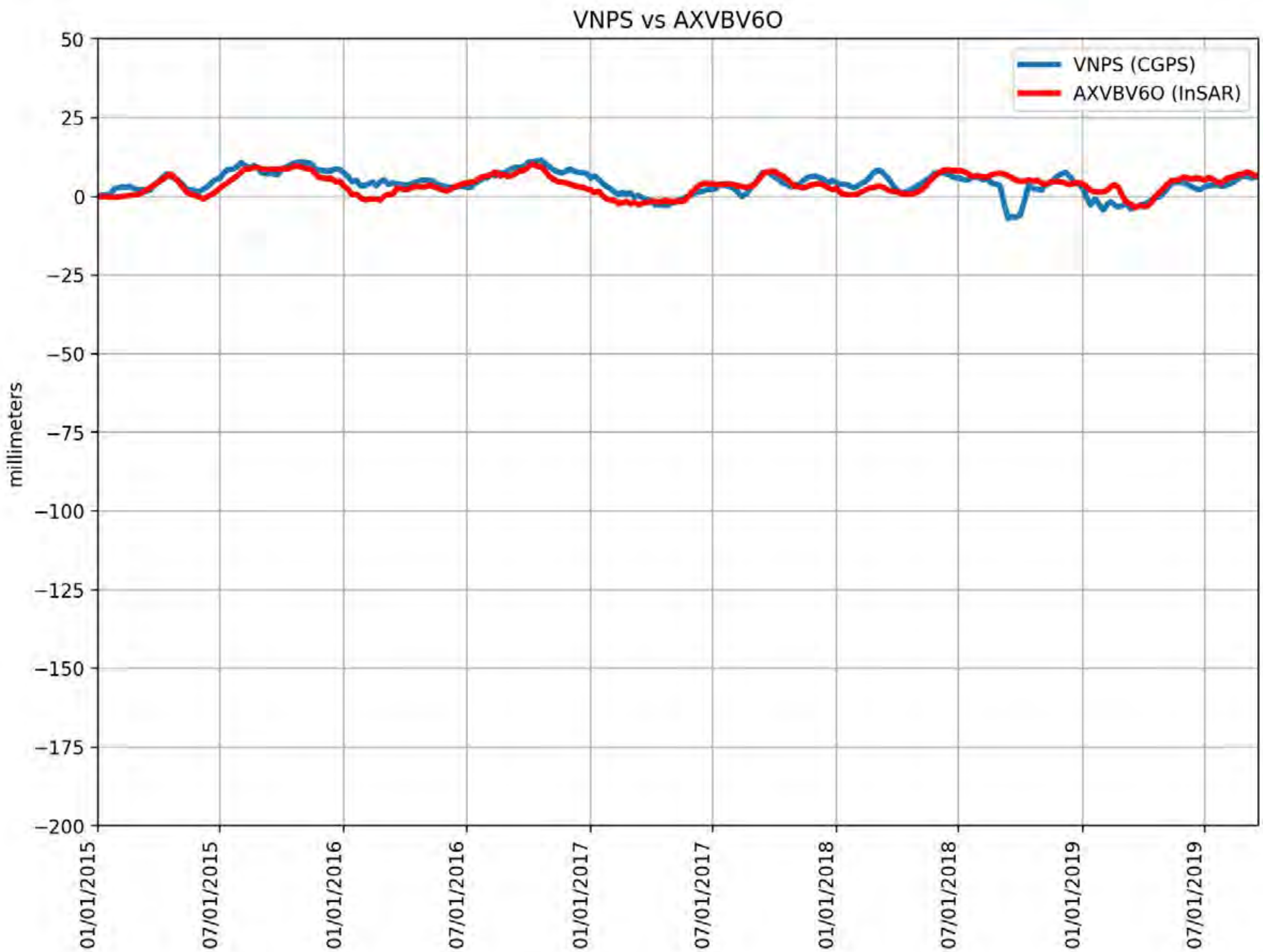

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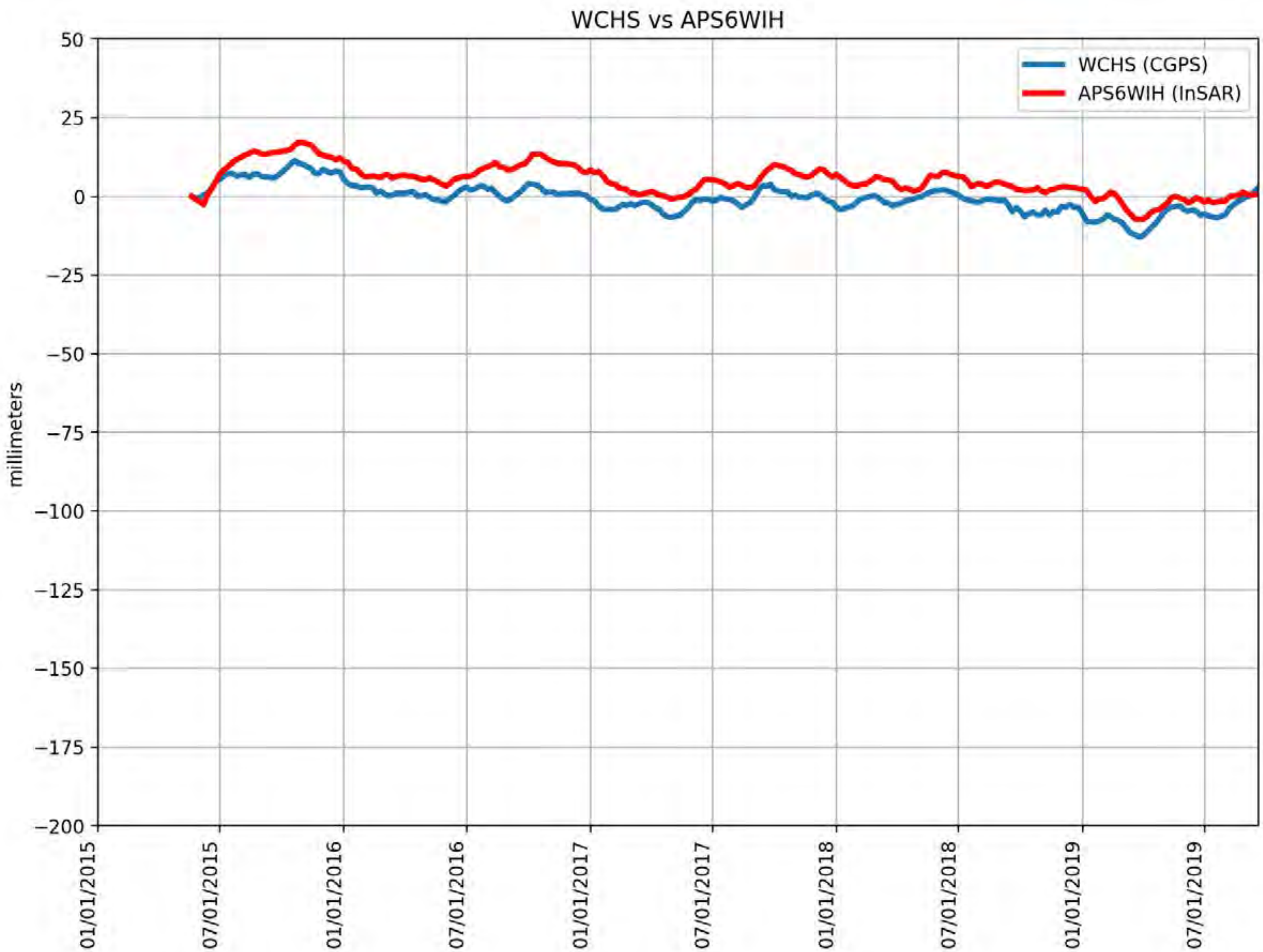

RMSE: 6.16 mm
Correlation: 0.88

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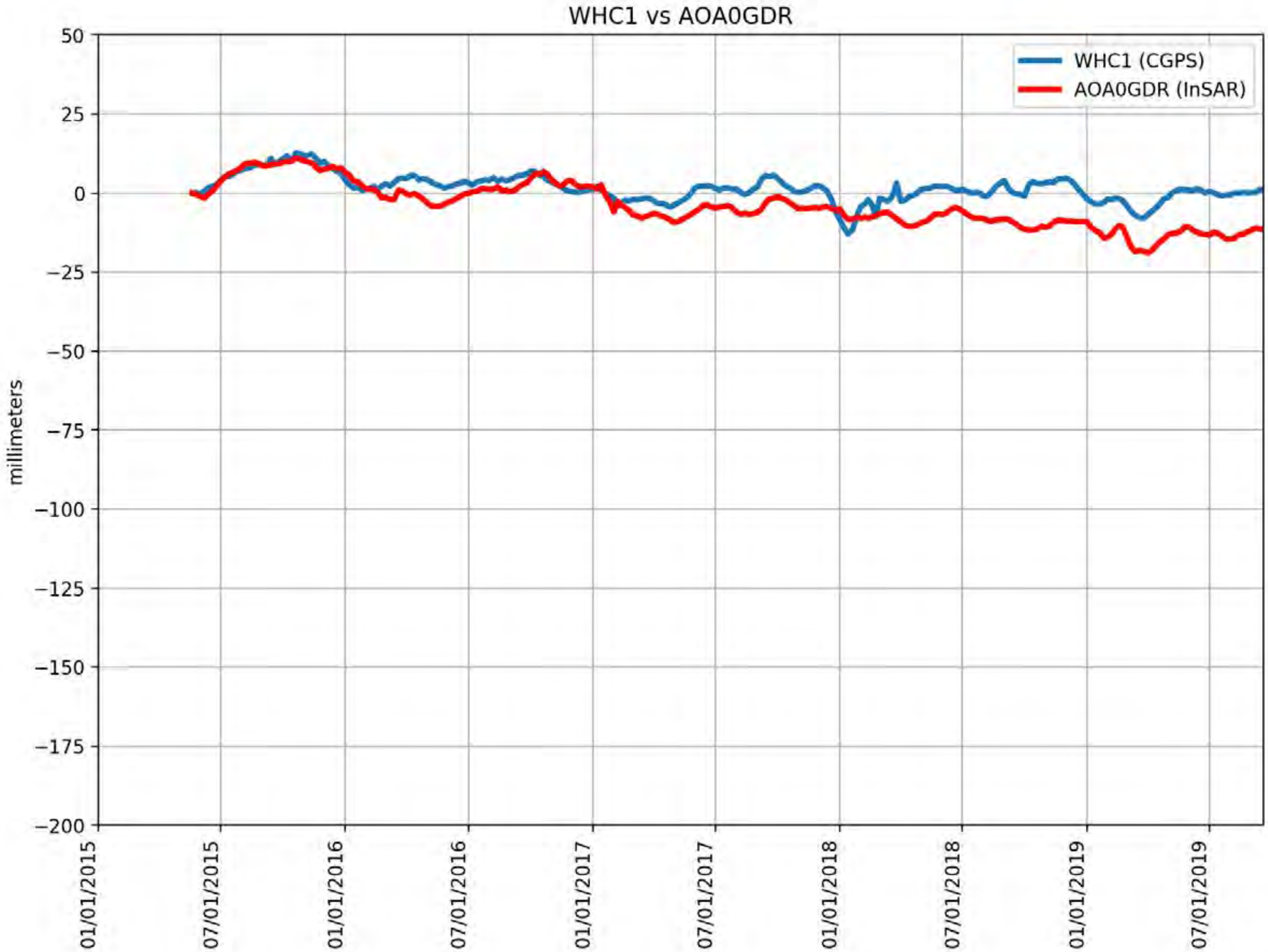

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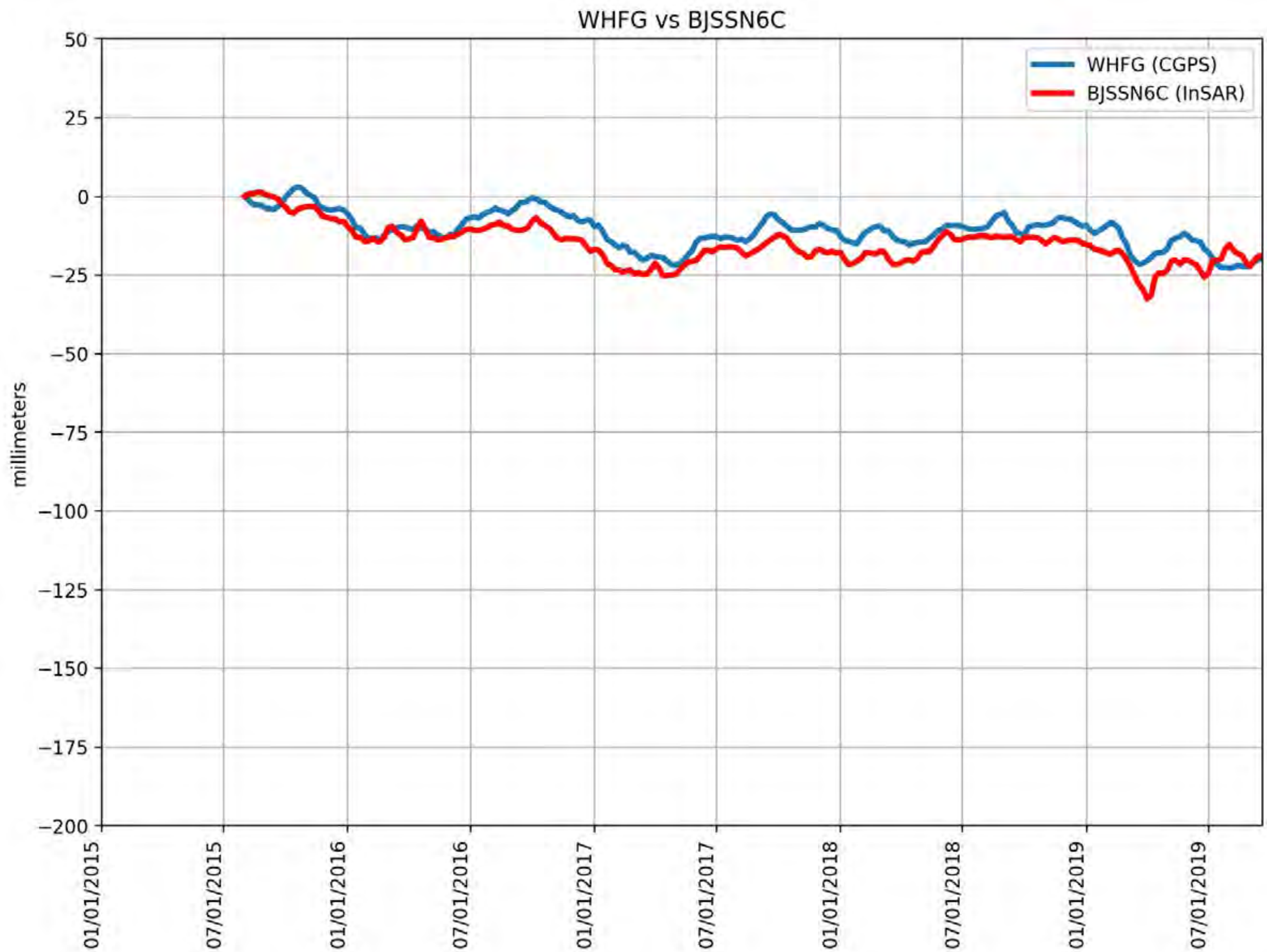

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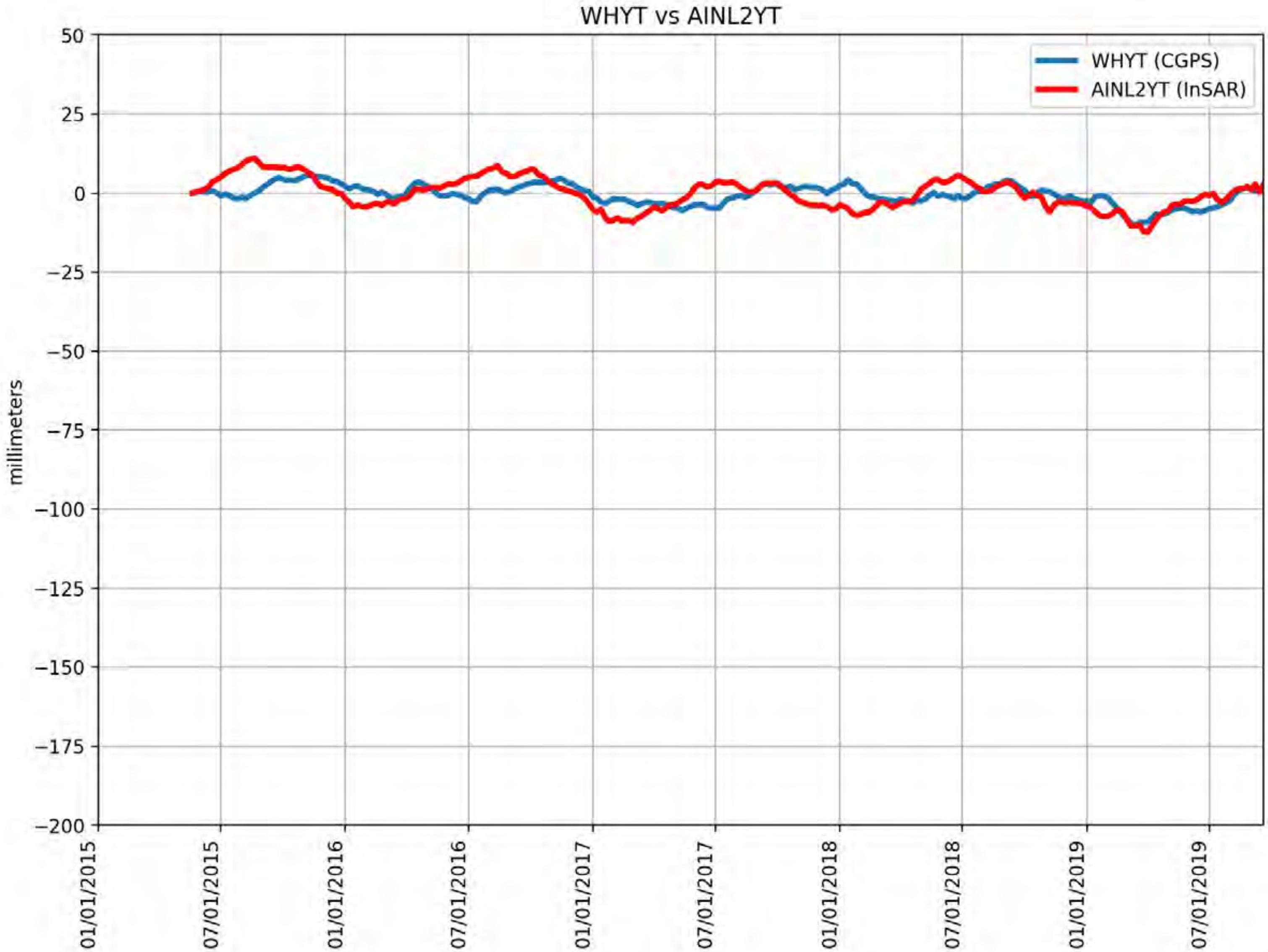

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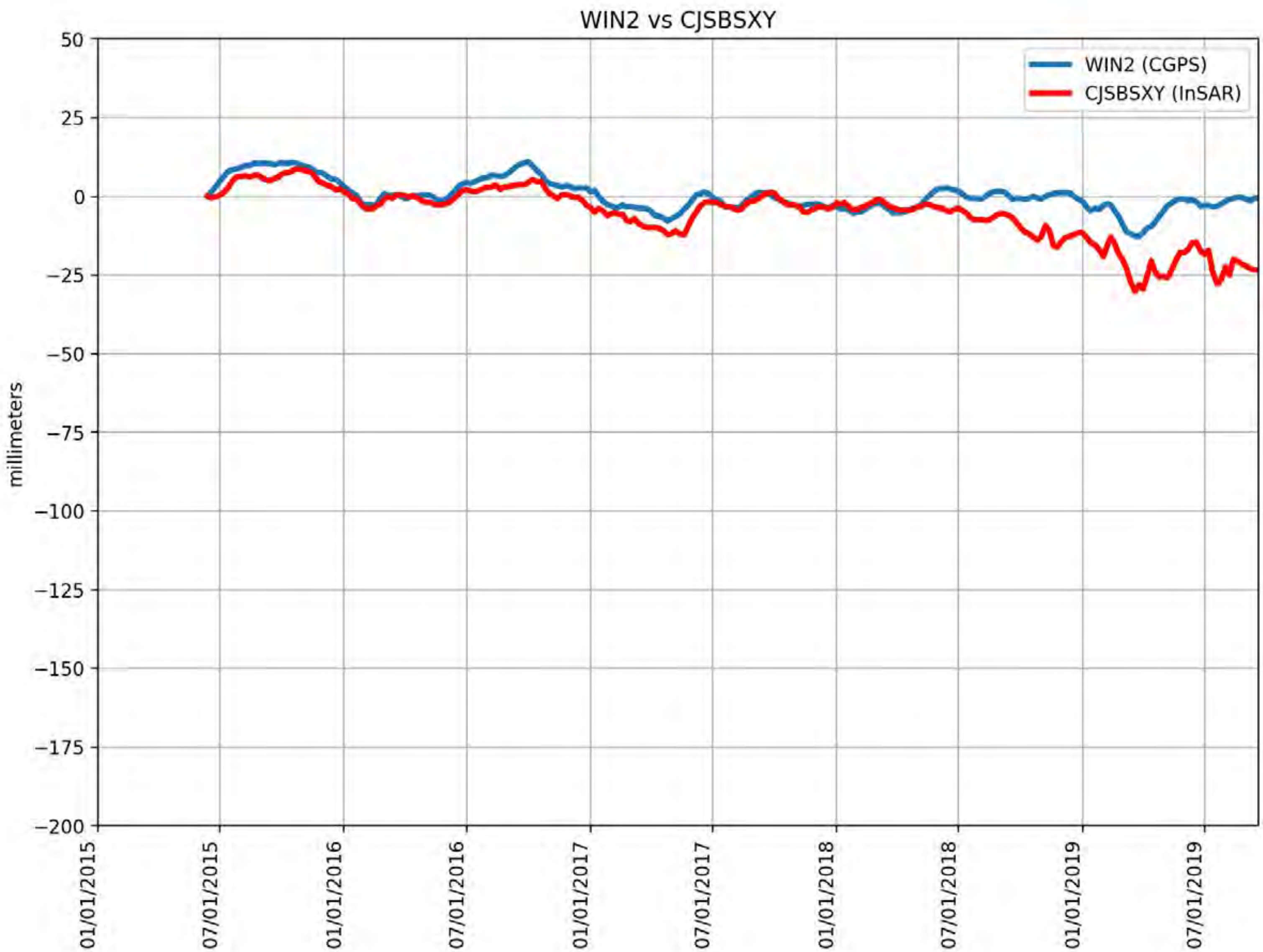

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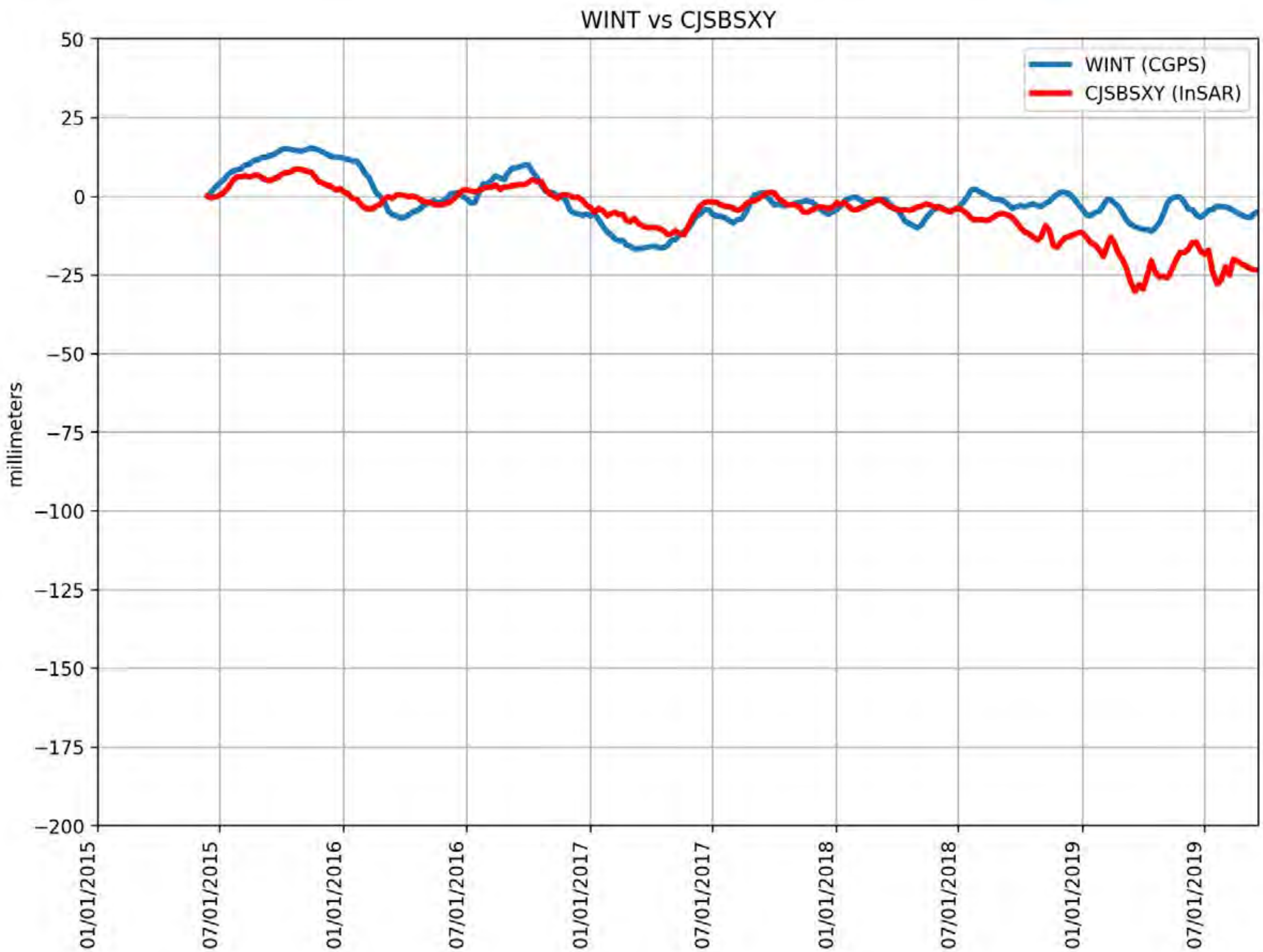

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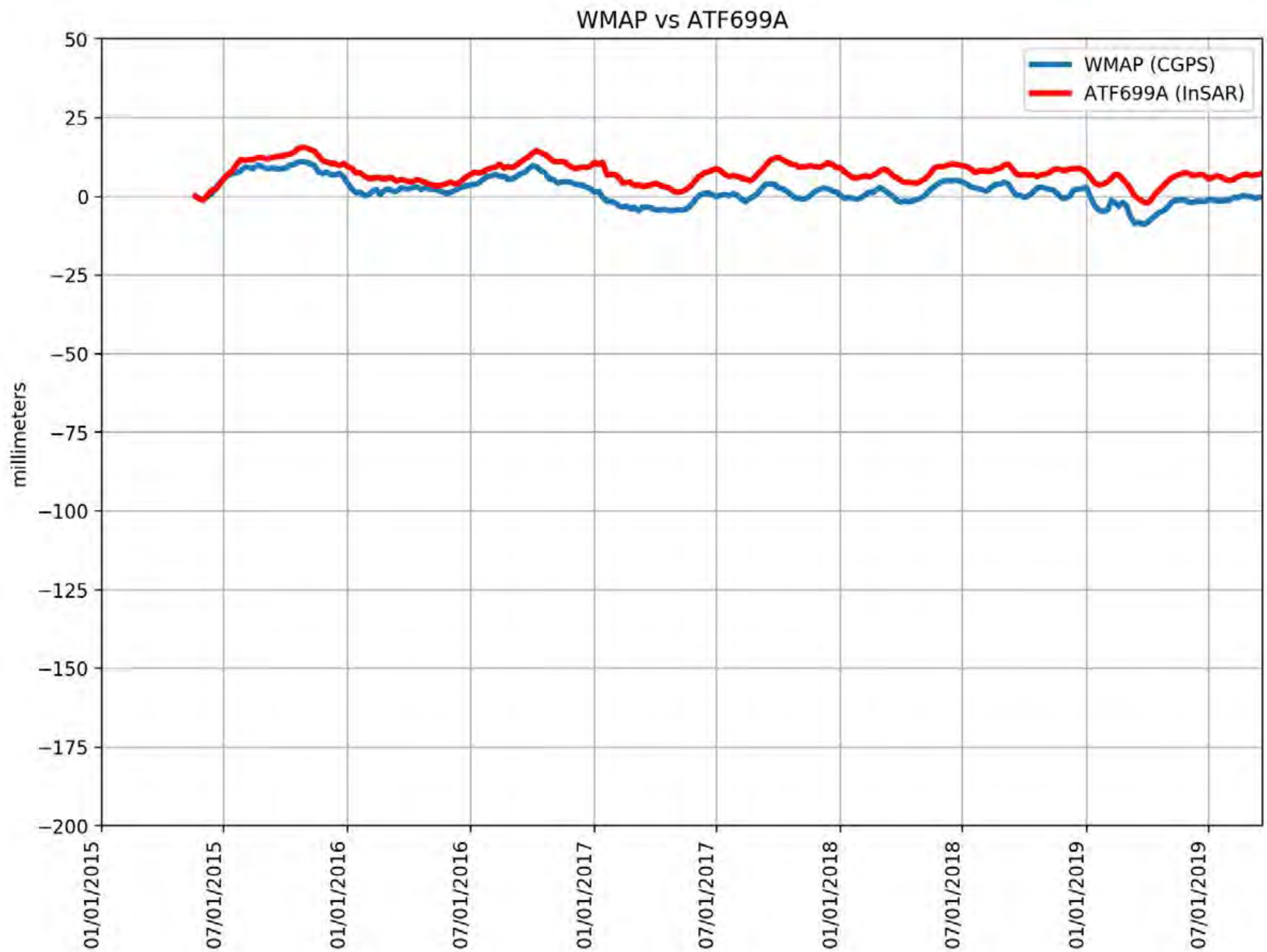
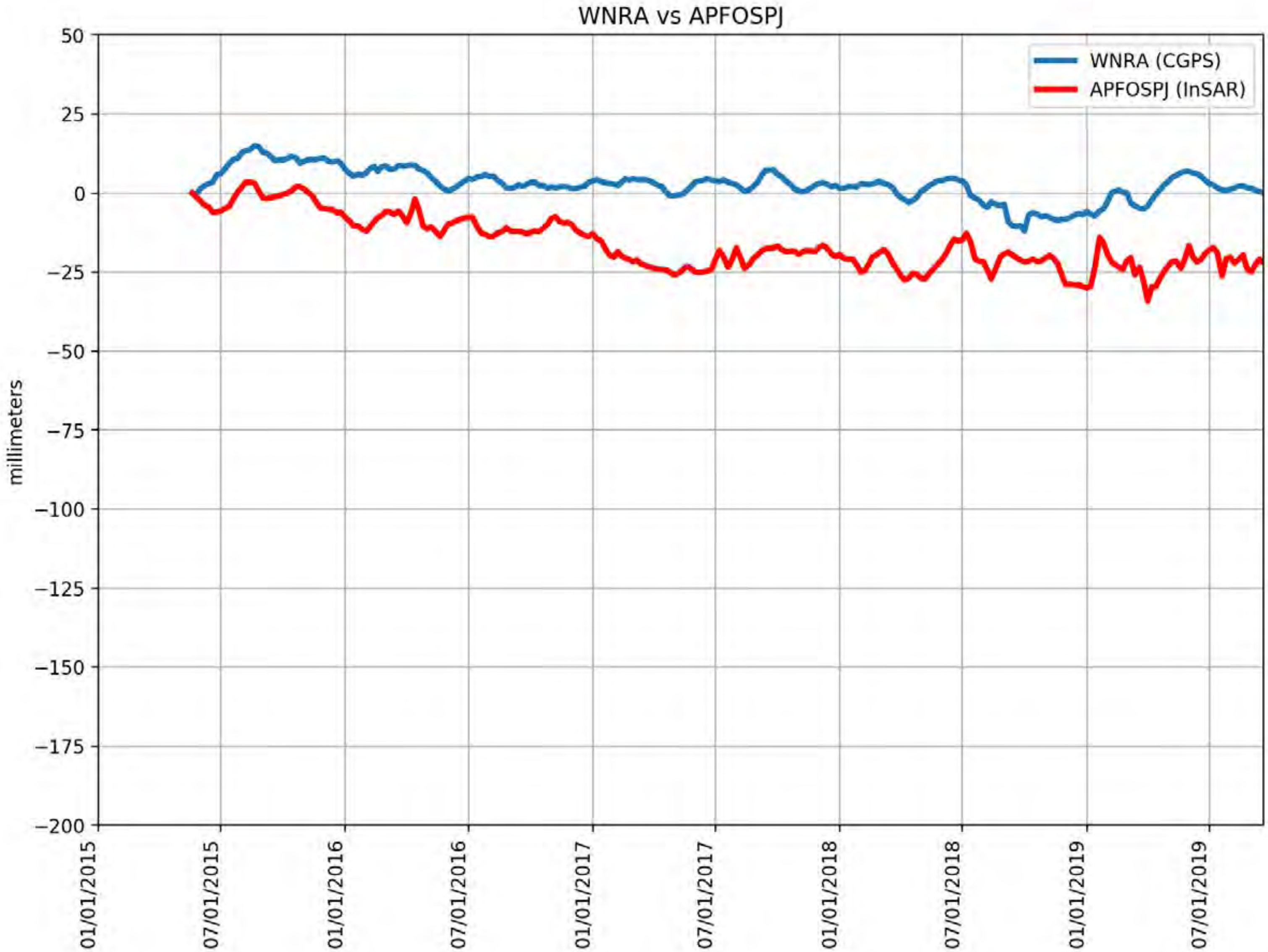


RMSE: 6.16 mm
Correlation: 0.81

Appendix B



RMSE: 19.81 mm
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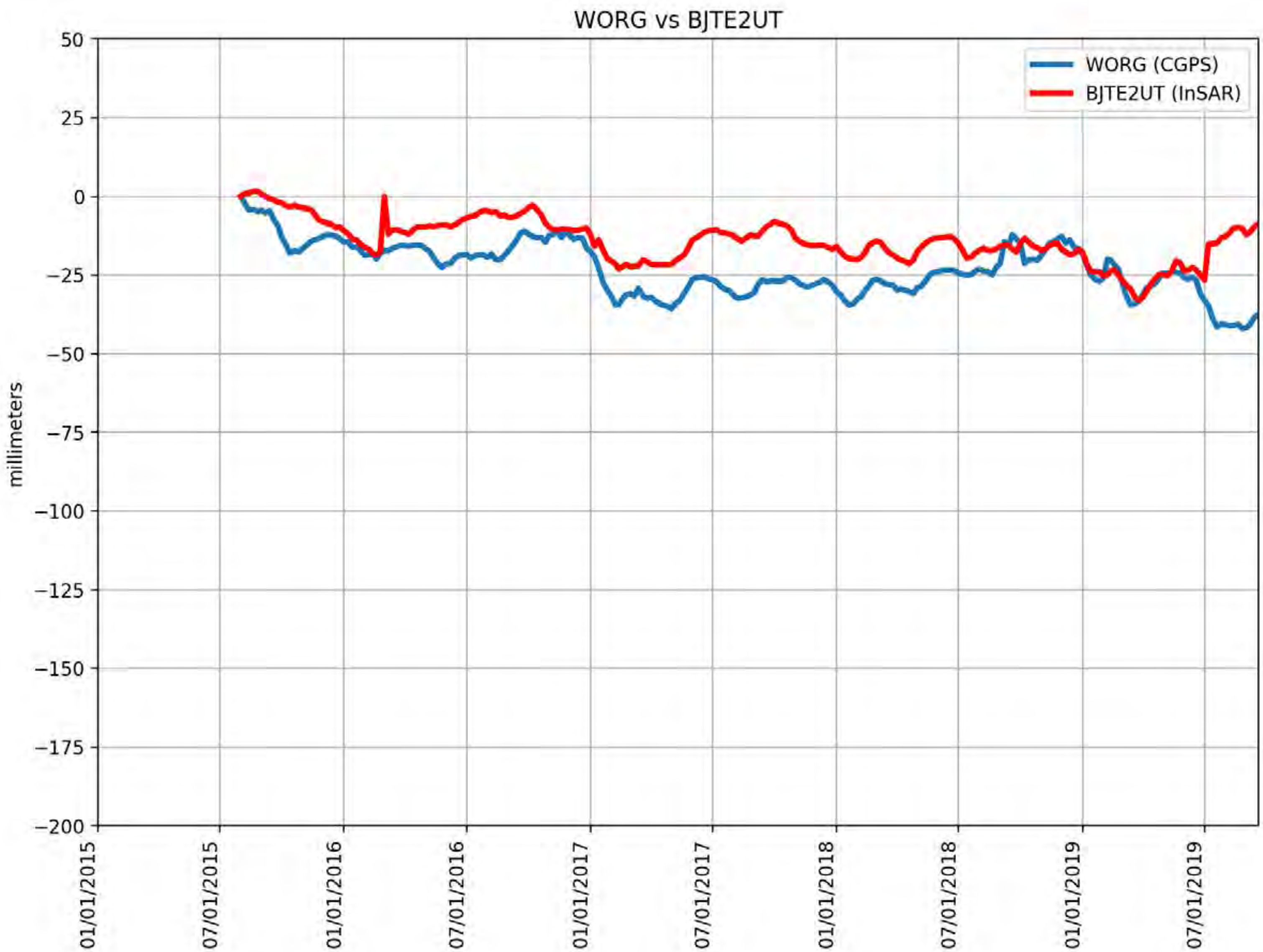
Appendix B



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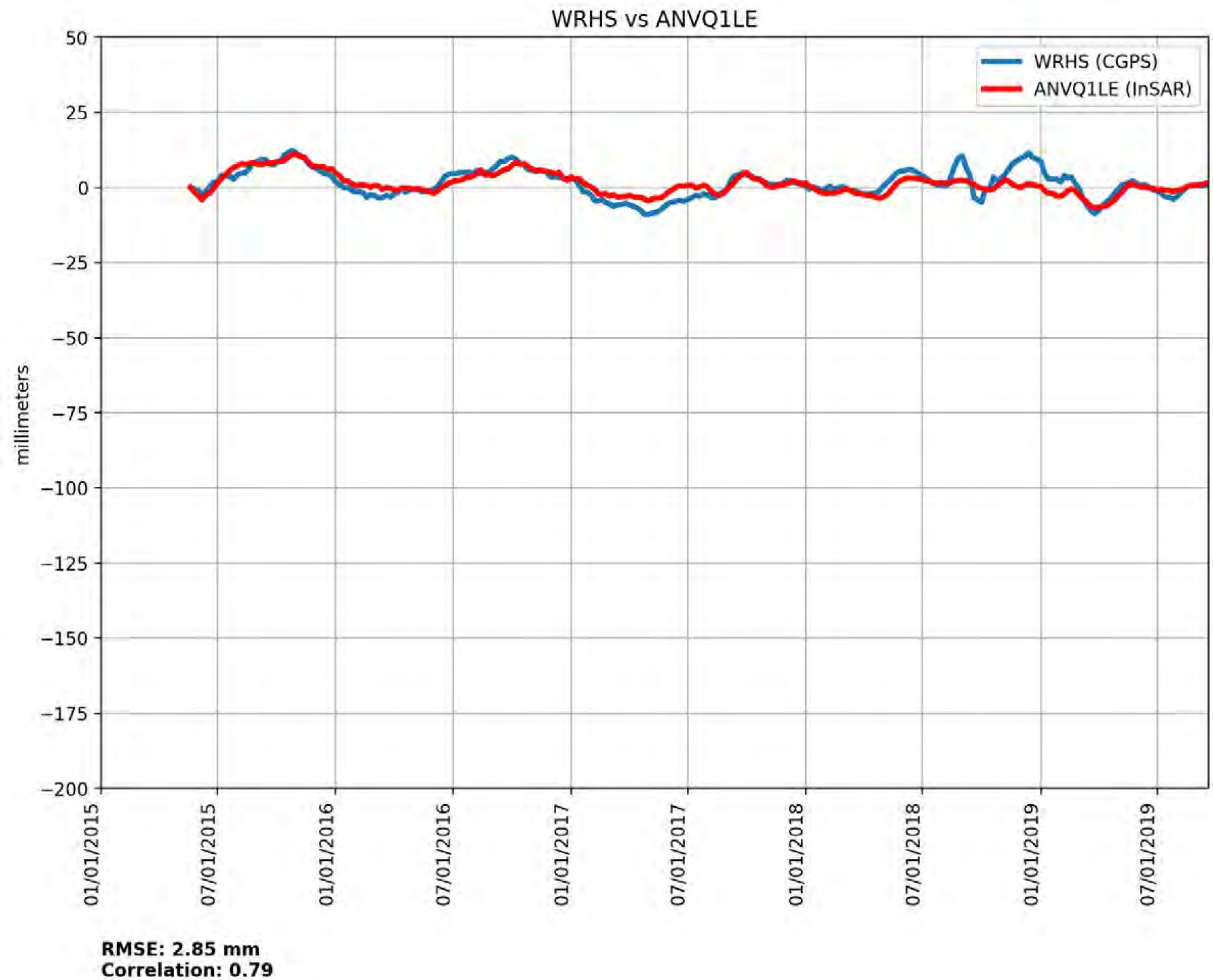
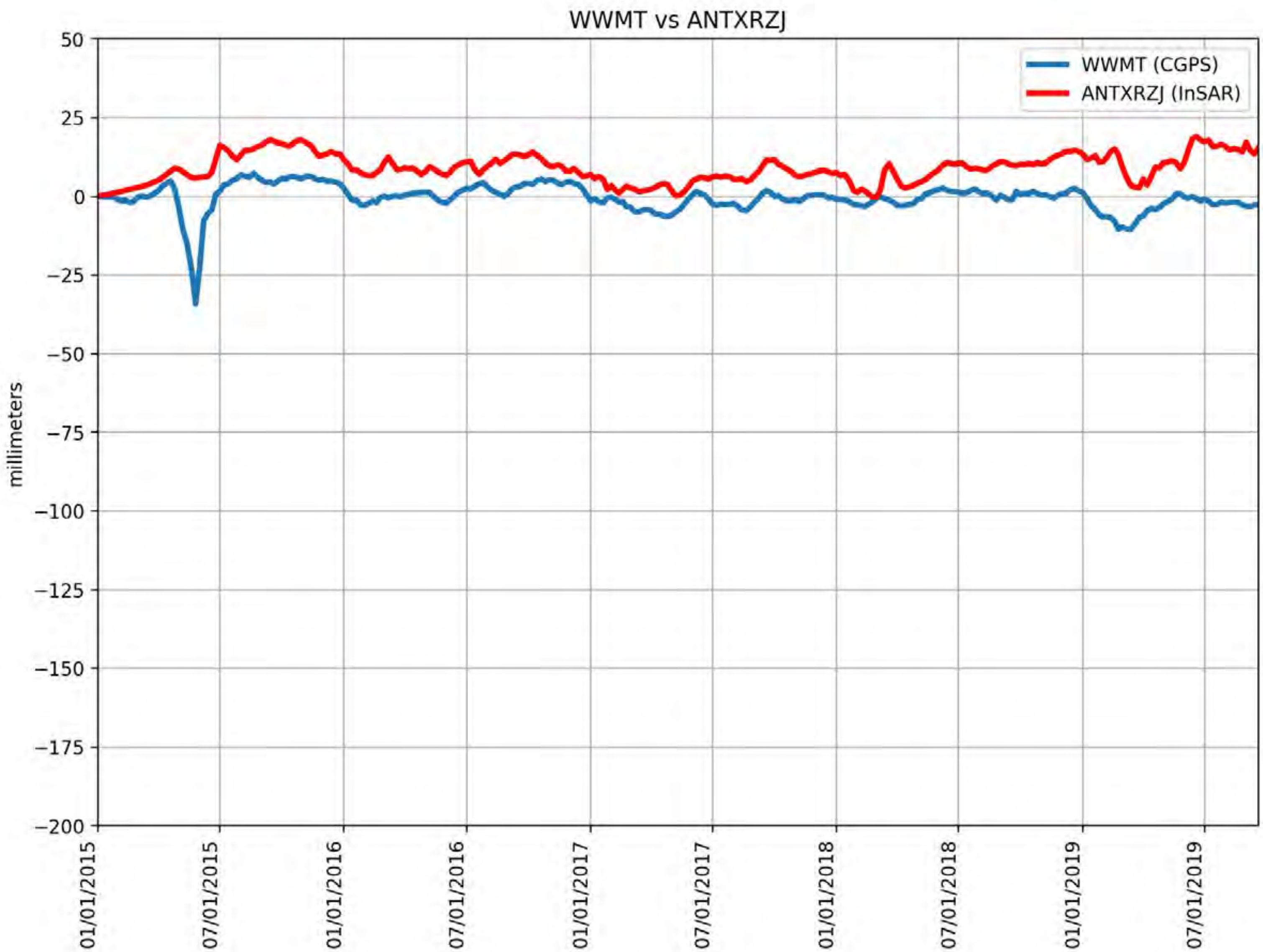

WRHS vs ANVQ1LE
WRHS (CGPS)
ANVQ1LE (InSAR)
millimeters
50
25
0
−25
−50
−75
−100
−125
−150
−175
−200
01/01/2015
07/01/2015
01/01/2016
07/01/2016
01/01/2017
07/01/2017
01/01/2018
07/01/2018
01/01/2019
07/01/2019
RMSE: 2.85 mm
Correlation: 0.79

Appendix B



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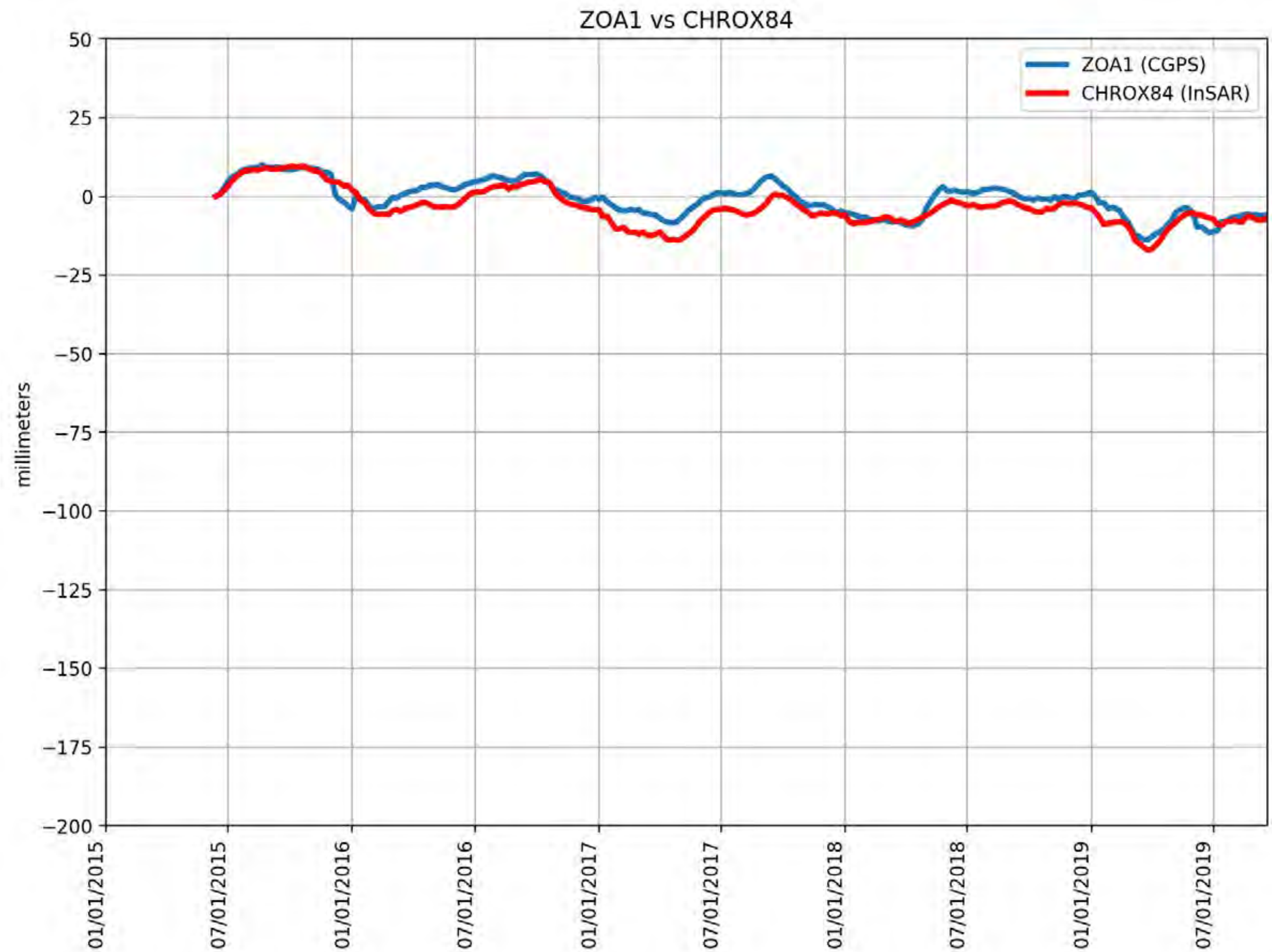

RMSE: 3.85 mm
Correlation: 0.89

APPENDIX C

Contract No. 4600011239
Task Order No. 26
Towill, Inc.

Final Report
CGPS Data Acquisition and Analysis

February 2019

Prepared for

California Department of Water Resources

Prepared by

TOWILL | Surveying, Mapping and GIS Services

Towill Project Number:
14750-0126

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ACKNOWLEDGEMENTS

- We acknowledge Yehuda Bock, Sharon Kedar and Angelyn Moore. MEaSUREs Enhanced Solid Earth Science ESDR System. La Jolla, California and Pasadena, California USA.
- We acknowledge David A. Phillips, Project Manager at UNAVCO[1] for his prompt and insightful responses to our numerous questions.
- We acknowledge Simon Banville and Brian Donahue of NRCan[2] Earth Sciences, Geomatics Group for assistance and programming support for the use of the new multi-GNSS 'SPARK' precise point positioning (PPP) software.
- We also acknowledge the scientific community who make available the CGPS/CGNSS time-series data and processing resources used in this study:

UNAVCO, a non-profit university-governed consortium, facilitating geoscience research and education using geodesy. UNAVCO CGPS data were downloaded on July 17, 2018 from:
ftp://data-out.unavco.org/pub/products/position/.
Towill downloaded the time series files 'SSSS.pbo.igs08.csv' where 'SSSS' is the four-character alphanumeric station code.
The data used span the date interval 2014.12.14 to 2018.07.15.

SOPAC[3], an organzition devoted to researching, analyzing and archiving high-precision geodetic and seismic data. CGPS data were downloaded from the SOPAC archive on September 9, 2018 from:
ftp://garner.ucsd.edu/pub/timeseries/measures/ats/WesternNorthAmerica/.
The time series file downloaded and used by Towill is:
WNAM_Clean_TrendNeuTimeSeries_sopac_20180911.tar.gz. This contains all of the station time series processed by SOPAC for stations in the Western North American (WNAM) polygon. The data used span the date interval 2014.12.14 to 2018.07.15.

NRCan Earth Sciences, Geomatics Group. This group provides useful on line tools for tools for ITRF reference frame transformations and the new online 'SPARK' PPP processor.

[1] Formerly, the University NAVSTAR Consortium.

[2] Natural Resources Canada.

[3] The Scripps Orbit and Permanent Array Center.

EXECUTIVE SUMMARY

This report and accompanying certification describe activities and results of the CGPS Data Acquisition and Analysis activities which were performed as part of Task Order No. 26, issued to Towill, Inc. under DWR contract 4600011239. These activities are described below.

Continuous Global Positioning System (CGPS) time-series data were downloaded from UNAVCO and SOPAC archives and evaluated for use in a SGMA study which uses satellite based InSAR data to measure land subsidence. Geographic location (latitude and longitude) and ellipsoidal height were recorded each day for more than 800 CGPS stations dispersed across California. The geographic position of all CGPS stations used in this study was transformed to the ITRF2014 reference frame. Time-series data were clipped to the study period beginning January 1, 2015 and ending June 30, 2018 and smoothed using a 31-day moving average filter. The time-series data present differential movement in latitude, longitude, and height of the CGPS station relative to the start of the study period (January 1, 2015). The time-series data files are included in the electronic deliverables.

A subset of the CGPS time-series data were supplied to TRE Altamira enabling calibration of the InSAR dataset. Towill provided TRE with the geographic location of more than 800 CGPS points along with documentation of the temporal extent of the time-series data for each CGPS station. TRE selected 203 CGPS stations for use in the InSAR data calibration process. Actual ellipsoidal height values were provided to TRE following their selection of calibration points. CGPS points not selected for calibration are candidate for use as validation points. Validation points and their heights were not disclosed to TRE.

As an independent accuracy test of the online CGPS time-series data, Towill randomly selected 10% of the CGPS points residing within SGMA basins and downloaded raw 24-hour RINEX files on two dates for each CGPS station; the first date was January 1, 2015 and the second date was randomly selected within the study period. The RINEX files were processed independently using a Precision Point Positioning (PPP) processor and the change in height values between the two dates were calculated. Height differences between these two dates were also calculated from the CGPS time-series data (pre-31 day smoothing) and a comparison was made. We determined there is excellent agreement between the two data sets, yielding an RMSE of 4.3 mm for the ellipsoidal height discrepancies and 3.7 mm and 2.5 mm in the case of the Northing and Easting differences.

SURVEYOR'S CERTIFICATION STATEMENT

I hereby certify that this report was prepared by me or under my direction, and its contents represent an accurate assessment of the results shown.

Frank Borges, PLS, CA, No. 7922
Associate Principal

Signature: ______________________

Date: 02/01/2019

LICENSED LAND SURVEYOR
FRANK A. BORGES
No. 7922
Exp: 12-31-19
STATE OF CALIFORNIA

1. Introduction

1.1 Summary of Scope of Work and Purpose

CGPS Data Acquisition and Analysis activities required researching technical details of publicly available CGPS datasets, downloading CGPS time-series datasets from online archives, performing a quality assurance test on 10% of the CGPS points, transforming the datasets onto a common reference frame, calculating a 31-day moving average on the CGPS time-series data, and reformmating the datasets to a structure supplied by TRE Altamira. These CGPS time-series datasets provided TRE Altimara with data for use in calibrating the InSAR dataset and provide Towill with validation points for use in assessing the accuracy of the InSAR derived surface height measurements.

1.2 Points of Contact

Questions regarding this report should be addressed to:

Contractor’s Project Manager	Contractor's Contract Manager
Frank Borges, PLS 2300 Clayton Road, Suite 1200 Concord, California 94520-2176 Phone: (925) 682-6976 ext. 1036 Frank.Borges@towill.com	Brian Young 2300 Clayton Road, Suite 1200 Concord, California 94520-2176 Phone: (925) 682-6976 ext. 1041 Brian.Young@ towill.com

2. Geodetic Reference Frames and Datums

2.1 The International Earth Rotation and Reference Systems Service (IERS)

The IERS was established in 1987 as the Earth Rotation Service by the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG). In 2003 it was renamed as the International Earth Rotation and Reference Systems Service. The Service’s website is at www.iers.org.

As identified by the Service’s mandate, its primary objectives, quoted verbatim below, are to serve the astronomical, geodetic and geophysical communities by providing the following:

- The International Celestial Reference System (ICRS) and its realization, the International Celestial Reference Frame (ICRF).
- The International Terrestrial Reference System (ITRS) and its realization, the International Terrestrial Reference Frame (ITRF).
- Earth orientation parameters required to study earth orientation variations and to transform between the ICRF and the ITRF.
- Geophysical data to interpret time/space variations in the ICRF, ITRF or earth orientation parameters, and model such variations.

- Standards, constants and models (i.e., conventions) encouraging international adherence.

From a geodetic surveying point-of-view, the key focus is the realization (ITRF) of the ITRS.

2.2 The International Terrestrial Reference Frame (ITRF)

The ITRS is ultimately realized as the ITRF by a combination of data from four so-called 'Techniques', namely:

- VLBI (Very Long Baseline Interferometry) – IVS
- GNSS (Global Navigation Satellite System) – IGS
- DORIS (The French acronym for a high precision Doppler orbit determination and positioning system) – IDS
- SLR (Satellite Laser Ranging) – ILRS

Figure 1 below shows the network of IERS technique stations used for the realization of ITRF2014.

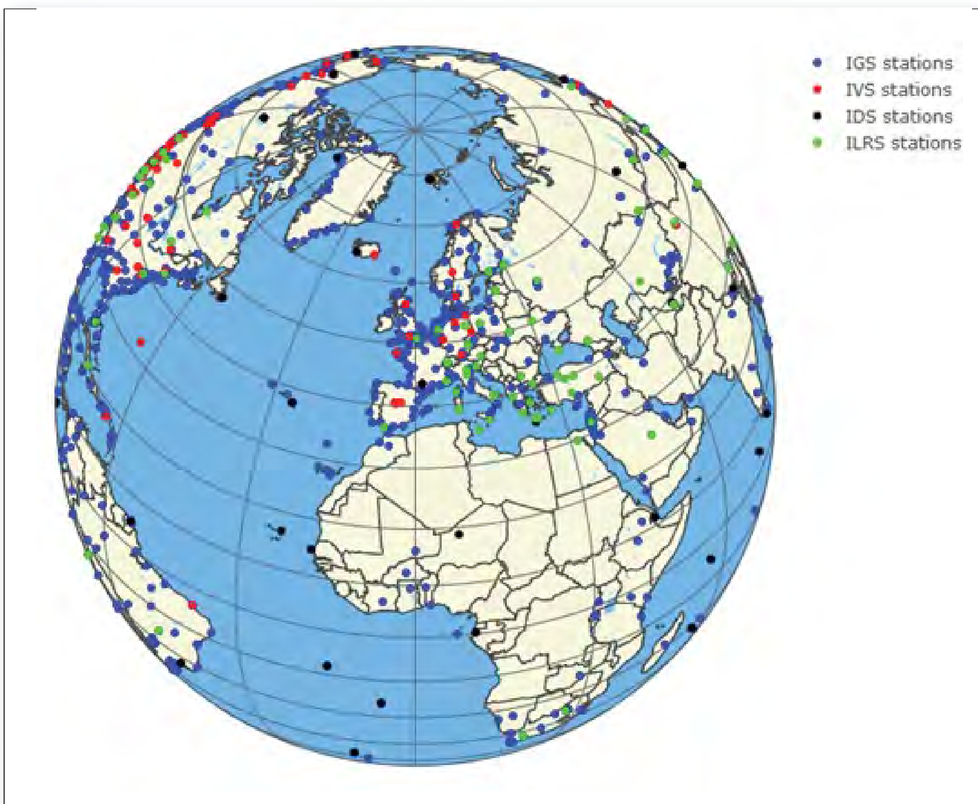


Figure 1. ITRF2014 Network Map

Figure 2 shows the co-location of the four technique instruments at the Hartebeesthoek Radio Atronomy Observatory in South Africa. Each of the techniques contributes in different ways to the realization of the ITRS in terms of its spatial orientation, location of the origin, scale and the time evolution of these parameters.

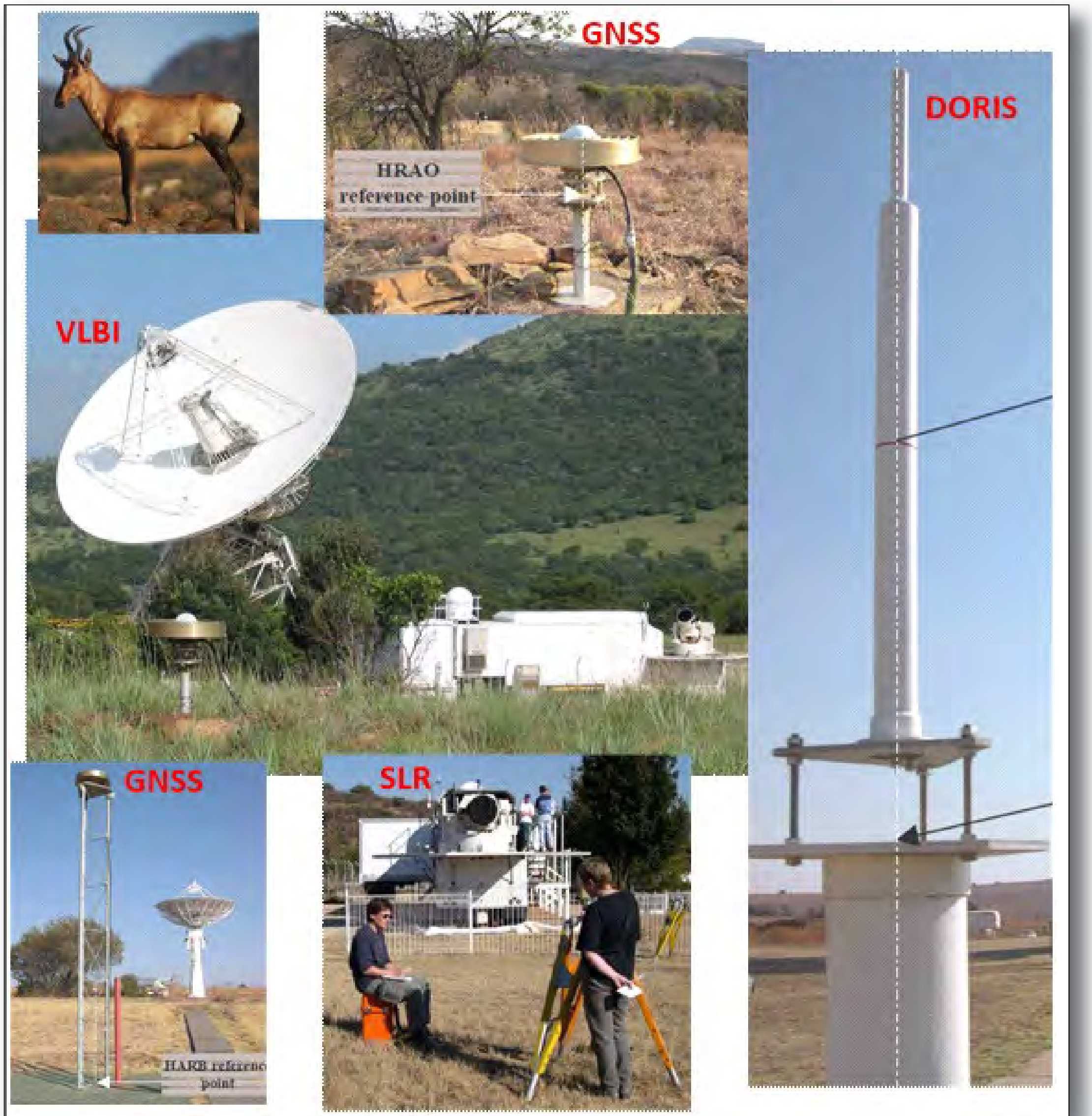


Figure 2. ITRF – Four Techniques Co-located[4]

[4] Note the surveyors (bottom center) performing a high-precision co-location survey tying together the reference points of the various sensors.

2.2.1 ITRF Realizations

The latest realization is ITRF2014. Previous realizations of the ITRF include ITRF89, ITRF90, ITRF91, ITRF92, ITRF93, ITRF94, ITRF95, ITRF96, ITRF97, ITRF2000, ITRF2005, ITRF2008, ITRF2014; with the magnitudes of the incremental differences generally becoming smaller with each realization.

Details of the development and realization of ITRF2008 may be found in Altamimi, et al. (2012), while the description of the realization of ITRF2014 is provided in Altamimi, et al. (2016, 2017). Table 1 contains the data for the fourteen (14) parameter transformations from ITRF2014 to the superseded realizations. Note that there are 7 constant parameters valid at epoch 2010.0 and 7 annualized time varying components which must be evaluated at the desired epoch by computing the time interval (in years) from 2010.0. Note that for most purposes, ITRF2008 and ITRF2014 are practically congruent.

2.3 The International GNSS Service (IGS)

Once the IERS produces a new ITRF realization, the IGS usually produces a matching GNSS-only solution based on a subset of the ITRF points. The current IGS reference frame is IGS14 which is aligned to ITRF2014. The IGS is one of the four Technique Centers (Services) which provides GNSS data for the ITRF realizations if the ITRS.

Figure 3 shows the IGS network, reproduced after Johnston, et al. (2017). This publication also provides an excellent description of the IGS mission, structure operations, services and products, while Kouba (2015) delivers a useful end-user guide to IGS products (e.g., precise orbits, clocks, EOPs[5], etc).

2.3.1 IGS14 Realization

IGS Technical Report 2017 (see Villiger, A., Dach, R. Eds. 2018) includes numerous 'sub-reports' from the IGS and a multitude of contributors, including Rebischung, et al. (2017) who review the status of the new IGS14 realization.

On January 29th, 2017 (GPS week 1934), the new reference frame, IGS14, was adopted by the IGS together with an associated set of ground and satellite antenna calibrations, igs14_wwww.atx, where 'wwww' represents the GPS week number of the latest .atx release. The new IGS14/igs14.atx framework replaces the previous IGS08/igs08.atx realization that had been used since GPS week 1632 (April 17, 2011). As stated by Rebischung, et al. (2017), "… the switch to IGS14 on week 1934 is marked by a clear increase in the number of available reference frame stations and a clear decrease of the transformation residuals, indicating an improvement in the precision of the alignment of the IGS daily solutions to the reference frame. Since then, both the number of available reference frame stations and the transformation residuals have remained at fairly stable levels. An update of the IGS14 reference frame does thus not seem necessary for now".

[5] Earth Orientation Parameters, such as Polar Motion (PM), Length of Day (LOD), UT1 – UTC, etc.

Table 1. Transformation Parameters from ITRF2014 to past ITRFs[6]

SOLUTION	Tx	Ty	Tz	D	Rx	Ry	Rz	EPOCH
UNITS---------->	mm	mm	mm	ppb	.001"	.001"	.001"	
RATES	$\dot{T}x$	$\dot{T}y$	$\dot{T}z$	$\dot{D}$	$\dot{R}x$	$\dot{R}y$	$\dot{R}z$	
UNITS---------->	mm/y	mm/y	mm/y	ppb/y	.001"/y	.001"/y	.001"/y	
ITRF2008	1.6	1.9	2.4	-0.02	0.00	0.00	0.00	2010.0
rates	0.0	0.0	-0.1	0.03	0.00	0.00	0.00	
ITRF2005	2.6	1.0	-2.3	0.92	0.00	0.00	0.00	2010.0
rates	0.3	0.0	-0.1	0.03	0.00	0.00	0.00	
ITRF2000	0.7	1.2	-26.1	2.12	0.00	0.00	0.00	2010.0
rates	0.1	0.1	-1.9	0.11	0.00	0.00	0.00	
ITRF97	7.4	-0.5	-62.8	3.80	0.00	0.00	0.26	2010.0
rates	0.1	-0.5	-3.3	0.12	0.00	0.00	0.02	
ITRF96	7.4	-0.5	-62.8	3.80	0.00	0.00	0.26	2010.0
rates	0.1	-0.5	-3.3	0.12	0.00	0.00	0.02	
ITRF94	7.4	-0.5	-62.8	3.80	0.00	0.00	0.26	2010.0
rates	0.1	-0.5	-3.3	0.12	0.00	0.00	0.02	
ITRF93	-50.4	3.3	-60.2	4.29	-2.81	-3.38	0.40	2010.0
rates	-2.8	-0.1	-2.5	0.12	-0.11	-0.19	0.07	
ITRF92	15.4	1.5	-70.8	3.09	0.00	0.00	0.26	2010.0
rates	0.1	-0.5	-3.3	0.12	0.00	0.00	0.02	
ITRF91	27.4	15.5	-76.8	4.49	0.00	0.00	0.26	2010.0
rates	0.1	-0.5	-3.3	0.12	0.00	0.00	0.02	
ITRF90	25.4	11.5	-92.8	4.79	0.00	0.00	0.26	2010.0
rates	0.1	-0.5	-3.3	0.12	0.00	0.00	0.02	
ITRF89	30.4	35.5	-130.8	8.19	0.00	0.00	0.26	2010.0
rates	0.1	-0.5	-3.3	0.12	0.00	0.00	0.02	
ITRF88	25.4	-0.5	-154.8	11.29	0.10	0.00	0.26	2010.0
rates	0.1	-0.5	-3.3	0.12	0.00	0.00	0.02	

Note : These parameters are derived from those already published in the IERS Technical Notes and Annual Reports. The transformation parameters should be used with the standard model (1) given below and are valid at the indicated epoch.

$$\begin{pmatrix} XS \\ YS \\ ZS \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} + \begin{pmatrix} Tx \\ Ty \\ Tz \end{pmatrix} + \begin{pmatrix} D & -Rz & Ry \\ Rz & D & -Rx \\ -Ry & Rx & D \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \qquad (1)$$

Where X,Y,Z are the coordinates in ITRF2014 and XS,YS,ZS are the coordinates in the other frames.

On the other hand, for a given parameter P, its value at any epoch t is obtained by using equation (2).

$$P(t) = P(EPOCH) + \dot{P} * (t - EPOCH) \qquad (2)$$

where EPOCH is the epoch indicated in the above table (currently 2010.0)

and $\dot{P}$ is the rate of that parameter.

[6] Reproduced from http://itrf.ign.fr/doc_ITRF/Transfo-ITRF2014_ITRFs.txt.

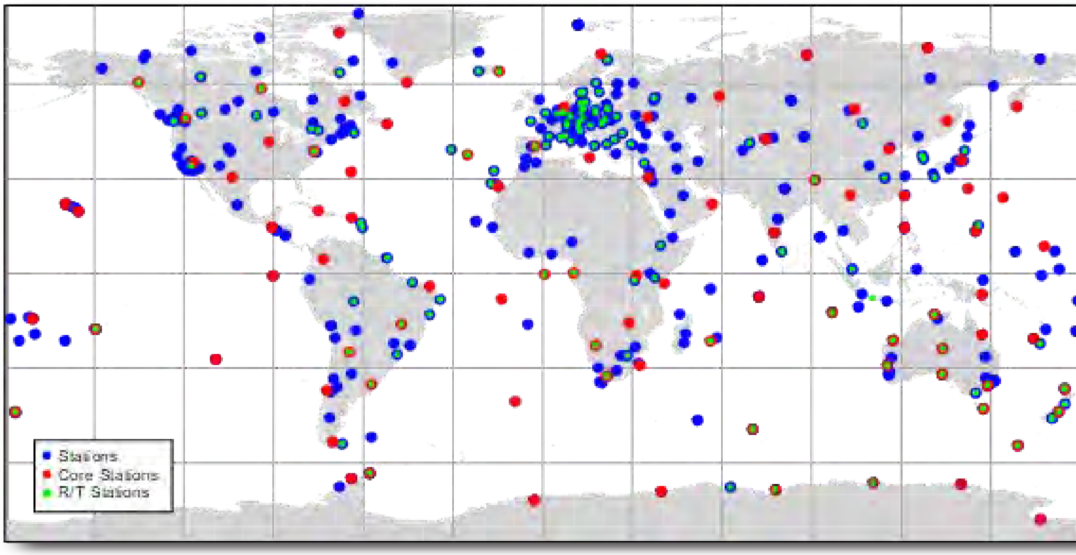


Figure 3. The IGS Tracking Network Oct. 2015

2.3.2 Mid-Study Epoch ITRF2014 Reference Positions

Since the geodetic position is not static for many of the CGPS stations, we elected to set and hold the horizontal position of each station to its location at the mid-study period epoch (09-30-2016). The process used in this study for transforming IGS08 (ITRF2008) to ITRF2014 and adding seismic delta to position CGPS to 09-30-2016 (mid-study period epoch) is outlined below:

1. Started with ListVf.csv and extracted Lat, Lon, and h into a separate file
2. Used NRCAN and converted ITRF2008 to ITRF2014
3. Used NRCAN to convert ITRF2014 to UTM Zone 10 and 11
4. Added dN and dE (based on change bewteen January 1, 2015 and September 30, 2016) to UTM northing and easting to calculate final UTM coordinates for each CGPS
5. Used ArcGIS to convert UTM to WGS84 (“WGS84_ITRF2014_09-30-2018.xls”)

3. UNAVCO and SOPAC GNSS Processing

Both UNAVCO and SOPAC employ similar software and processing strategies for the GNSS processing. In both cases, the strategy involves a pair of Analysis Centers (ACs)

3.1 GAMIT and GLOBK

Useful descriptions of the GAMIT/GLOBK suite of software may be found in Herring, et al. (2018) and in Bock and Melgar (2016). This package has been developed over a number of years and by numerous individuals at a range of universities and research institutions.

Additional and more extensive details may be found in the GAMIT and GLOBK Reference Manuals via MIT's 'GeoWeb' site: http://www-gpsg.mit.edu . The current release of the software suite is version 10.7 (June 2018).

GAMIT[7] is a suite of programs used for the analysis of GPS data. It uses the GPS carrier phase and pseudorange observables to estimate three-dimensional relative positions of ground stations, precise satellite orbits, atmospheric zenith delays, and earth orientation parameters (EOPS).

GLOBK[8] is a Kalman filter whose primary purpose is to combine various geodetic solutions such as GPS, VLBI, and SLR. It accepts as data, or "quasi-observations" the estimates and covariance matricies for station coordinates, EOPs, orbits, and positions generated from the analysis of the primary observations. The input solutions are generally performed with loose a priori constraint uncertainties assigned to all global parameters, so that constraints can be consistently applied during the processing of the combined solution.

3.2 GIPSY-OASIS

GIPSY-OASIS, or **GIPSY**, is the **GNSS-Inferred Positioning System and Orbit Analysis Simulation Software** package. GIPSY is developed by the Jet Propulsion Laboratory (JPL), and maintained by the Near Earth Tracking Applications and Systems groups. GIPSY uses JPL's precise orbit and clock products and provides GNSS (GPS and GLONASS) solutions incorporating DORS and SLR data. Note that GIPSY was replaced in 2018 by GIPSYx which adds numerous new features including models of geometric effects, support for Galileo and BeiDou and a variety of new force models such as such as solar and terrestrial radiation pressure[9].

3.3 UNAVCO GAGE Workflow and Time Series Products

Figure 4, below, is reproduced after Herring, et al. (2016). UNAVCO downloads the raw GNSS/GPS data translates it to Level 1 (e.g., RINEX files), performs QC checks, stores and archives the datasets and posts it to servers for access by the public, the scientific community and the Geodesy Advancing Geosciences and EarthScope (GAGE) Facility Analysis Centers (ACs). This part of the workflow is highlighted in pink on the left-hand side of the diagram. The right-hand side of the diagram (colored blue) shows the two ACs which process the data to generate the Level 2a products. Finally, the Analysis Center Coordinator (ACC) merges the two Level 2a datasets and produces the combined Level 2b solution.

[7] **G**NSS **at MIT** (Massachusetts Institute of Technology).

[8] **Glob**al **K**alman filter.

[9] Details of the extensive GIPSYx upgrades can be found at https://gipsy-oasis.jpl.nasa.gov/index.php?page=software.

The rationale behind this tactic is to use dissimilar algorithms and software so as to identify potential processing errors and to evaluate any differences which might be attributed to modeling variations and other disparate algorithmic approaches.
The two GAGE Facility ACs are:

- Central Washington University (CWU) which uses the GPS Inferred Positioning System, Orbit Analysis and Simulation Software (GIPSY/OASIS).
- New Mexico Tech (NMT) using the GPS At MIT (GAMIT) and GLOBK (Kalman filtering) software packages.

The past few years have witnessed a transition from ITRF2008, and IGb08 to ITRF2014 and IGS14. The year 2018 has been particularly active in terms of this transition. For this reason, and since the study-period extends half-way through the year, Towill compiled a list of questions for UNAVCO staff. These were answered promptly and fully in an email response (David A. Phillips[10], personal communication, Nov 21, 2018). For the sake of brevity, Towill's questions are not repeated in toto here; however the full context can be inferred by the italized responses below:

- **Towill**: We are using SSSS.pbo.igs08.csv files for the UNAVCO time series.
  UNAVCO: *These are good files to use for solutions up through 2018-09-15. As discussed further below in response to another question though, please use the "cwu" named files (SSSS.cwu.igs08.csv or *.pos) instead of the "pbo" named files for solutions after 2018-09-15.*

- **Towill**: Is the reference frame IGS08 as stated in the header metadata or is it IGb08?
  UNAVCO: *IGb08.*

- **Towill**: During 'repro' were the data processed using IGS14 products including IGS14 antenna models, orbits and clocks?
  UNAVCO: *No, the repro solutions in the currently available files were not produced using IGS14 models. However, the good news is that we just completed another repro run using IGS14 products and these should be released soon, hopefully before the end of December* <2018>*. IGS14 based products will then be available from 1996 up through summer 2018. Please note that, like other analysis centers, we have been in a transition to IGS14 over the past year and our recent final and rapid solutions have been generated using IGS14 models, orbits and clocks even though the solutions are still provided in the IGS08 (IGb08) frame until we release our IGS14 frame files. Details about the IGS14 transition are described in this document:*

[10] Project Manager at UNAVCO.

http://www.unavco.org/data/gps-gnss/derived-products/docs/GAGE_IGS14_transition_update_20180626.pdf

- **Towill:** The following response relates to a question regarding metadata.
  UNAVCO: *This is a good suggestion. We have tried to find the right balance between essential information and not overloading the headers by providing the details in separate documentation, especially for the combination solutions since multiple sets of parameters would need to be included and the headers would be very long. Details regarding the analysis methods including tropospheric models and other parameters used are provided in two main sources*:

  The Reviews of Geophysics publication that you mention below:
  http://www.unavco.org/data/gps-gnss/derived-products/docs/Herring_et_al_2016_RevGeophys.pdf

  And a summary including file descriptions as an "analysis plan" white paper:
  http://www.unavco.org/data/gps-gnss/derived-products/docs/GAGE_GPS_Analysis_Plan_20170912.pdf

- **Towill:** Are the details highlighted in blue still valid? (The reader is referred to Figure 4.)
  UNAVCO: *… yes there are recent changes. Specifically, the NMT Analysis Center ceased operations last month <October 2018>, leaving the CWU Analysis Center as the ONLY UNAVCO/GAGE analysis center at the present time. And because we lost one of the two AC's this means that we can no longer generate the PBO "combination" solutions that we did previously.*

  So the … flow chart is valid for UNAVCO products up through September 2018. More specifically, the "final" final NMT and PBO combination solutions were for 2018-09-15.

  Since you are using the CSV files, please note that you may see "finac" solutions for PBO files from 2018-09-15 through about 2018-10-27. These are actually CWU solutions appended to the last true combined "final" solutions. These "finac" solutions will be purged from these files when we next update them.

  *For solutions after 2018-09-15 please use the CWU files: SSSS.cwu.igs08.csv or *.pos.*

  We do plan (hope) to provide new types of combination solutions in the future, possibly including UNR solution, but details are unknown at present. If/when we do develop new combination products, they won't be available until some time next year <2019>.

- **Towill:** What is your preferred citation for use of your products?
  UNAVCO: *Thank you very much for asking! We really appreciate this! Our preference would be to include a reference to the Herring et al. 2016 Reviews of Geophysics paper via the citation you used above.*

  Also, it would be nice to include the DOIs related to the specific data products you are using. For example, the most recent DOI describing the PBO combination products would be:

  https://doi.org/10.7283/P2HT0Z

  We update product DOIs annually, so the most recent one describes products through 2017-12-02. A new product DOI will be released early next year for data up through 2018-12. The the DOI above is the most current.

3.3.1 UNAVCO Data Source

The UNAVCO time series data can be downloaded anonymously from the following ftp site:
ftp://data-out.unavco.org/pub/products/position/.

In this case, the data are stored in subdirectories, one for each station; e.g., SSSS.pbo.igs08.csv, where 'SSSS' is the alphanumeric station code. The release date for these data is 2018.07.17.

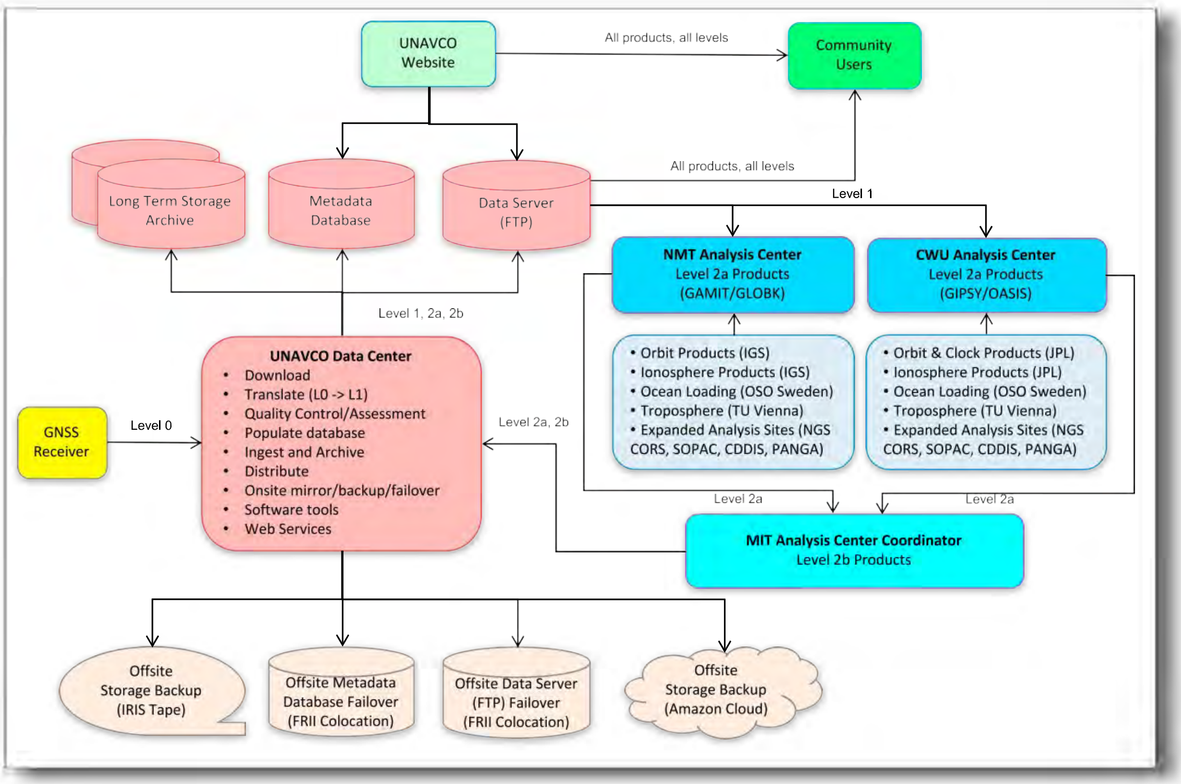


Figure 4. UNAVCO GNSS Data Processing and GAGE Workflow.

3.4 SOPAC GNSS Processing

Like UNAVCO, GAMIT/GLOBK paired with the JPL's GIPSY(x) software is used to complete two processing streams, one network based (GIPSY), the other PPP (JPL), the solutions of which which are then combined using spatio-temporal filtering (st_filter) to produce the combined calibrated and validated geodetic time series (station positions).

Appendix A includes a flowchart (see Bock et al., 2016) outlining the the generation of the SESES[11] ESDR[12] data products as part of NASA's MEaSUREs [13] project. SESES is an ongoing collaborative effort by JPL and SOPAC. The archived products are time series of geodetic station positions, velocity fields, strain and strain rate, and time series offsets. Weekly updates are issued by the project. In addition, the project has developed the GPS Explorer data portal (available at http://geoapp03.ucsd.edu/gridsphere/gridsphere), which provides tools to access and explore these data products. Note that the plots shown in Figure 9 were generated using GPS Explorer.

[11] Solid Earth Science ESDR System.

[12] Earth Science Data Records.

[13] Making Earth Science Data Records for Use in Research Environments. (https://earthdata.nasa.gov/our-community/community-data-system-programs/measures-projects).

The left-hand side of the flowcart in Appendix A presents the workflow for the GPS timeseries products co-produced by SOPAC and the JPL. A simplified view is included in Figure 7. At the time of Towill's processing effort, it is believed that JPL's PPP software was being upgraded to support multi-GNSS solutions[14] and the JPL solutions may not have been available. For this reason, only the SOPAC network solution was used by Towill. The global network of processed points is shown in

Figure 5. We downloaded (see Section 4.1) and used the the WNAM[15] time series for the SOPAC points involved in this study (refer to Figure 6).

For the updating of the California Spatial Reference System's (CSRS) most recent realization of NAD83 at epoch 2017.50, SOPAC also did not use the JPL product. A clear and thorough step-by-step description of the process is included in the project report (Bock, et al., 2018).

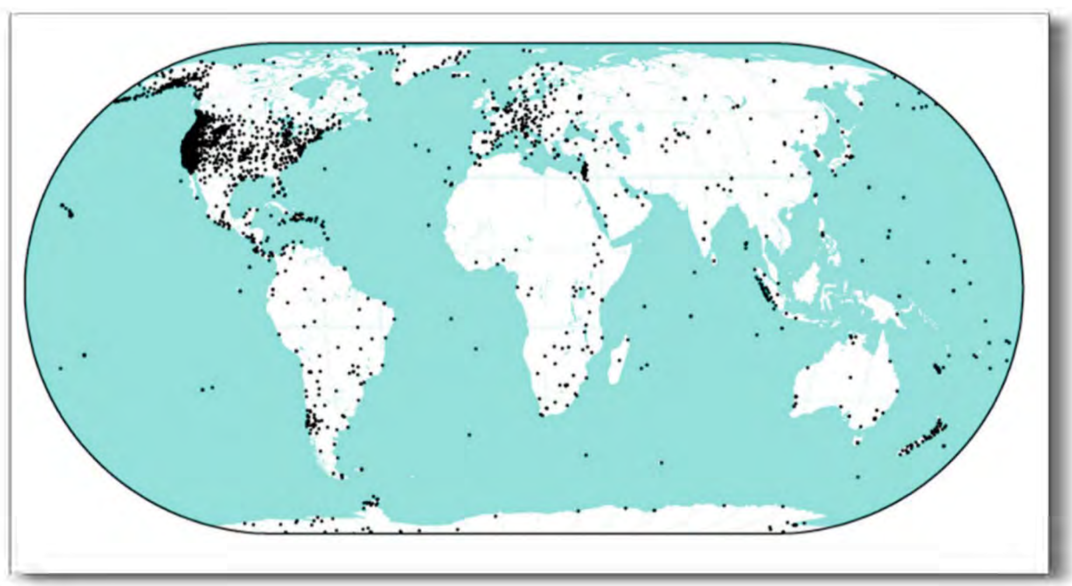


Figure 5. Global Distribution of Stations Processed Independently by SOPAC and the JPL (reproduced after Bock et al., 2016)

[14] Multiple GNSS satellite constellations: GPS, GLONASS, Galileo and BeiDou.
[15] Western North America.

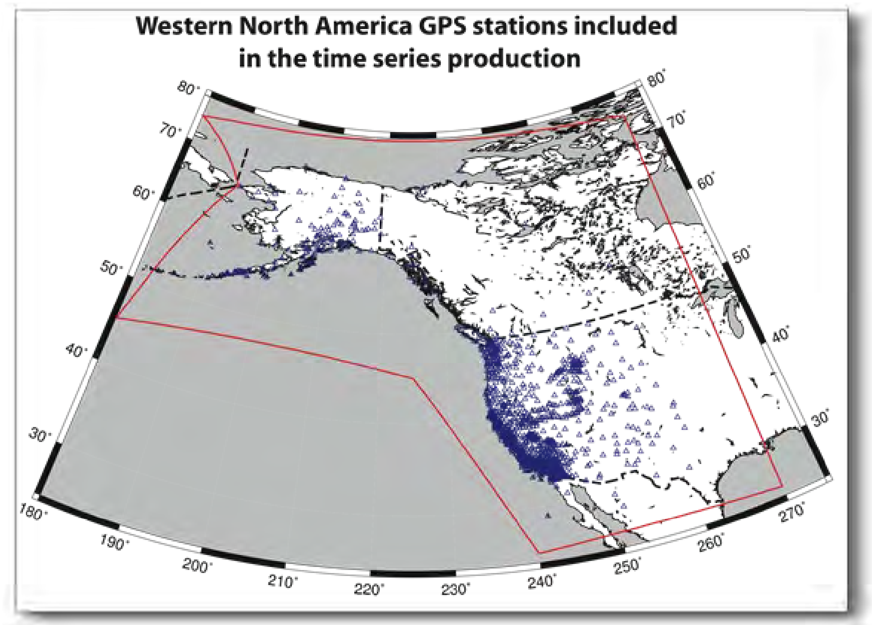


Figure 6. WNAM GNSS Product Coverage

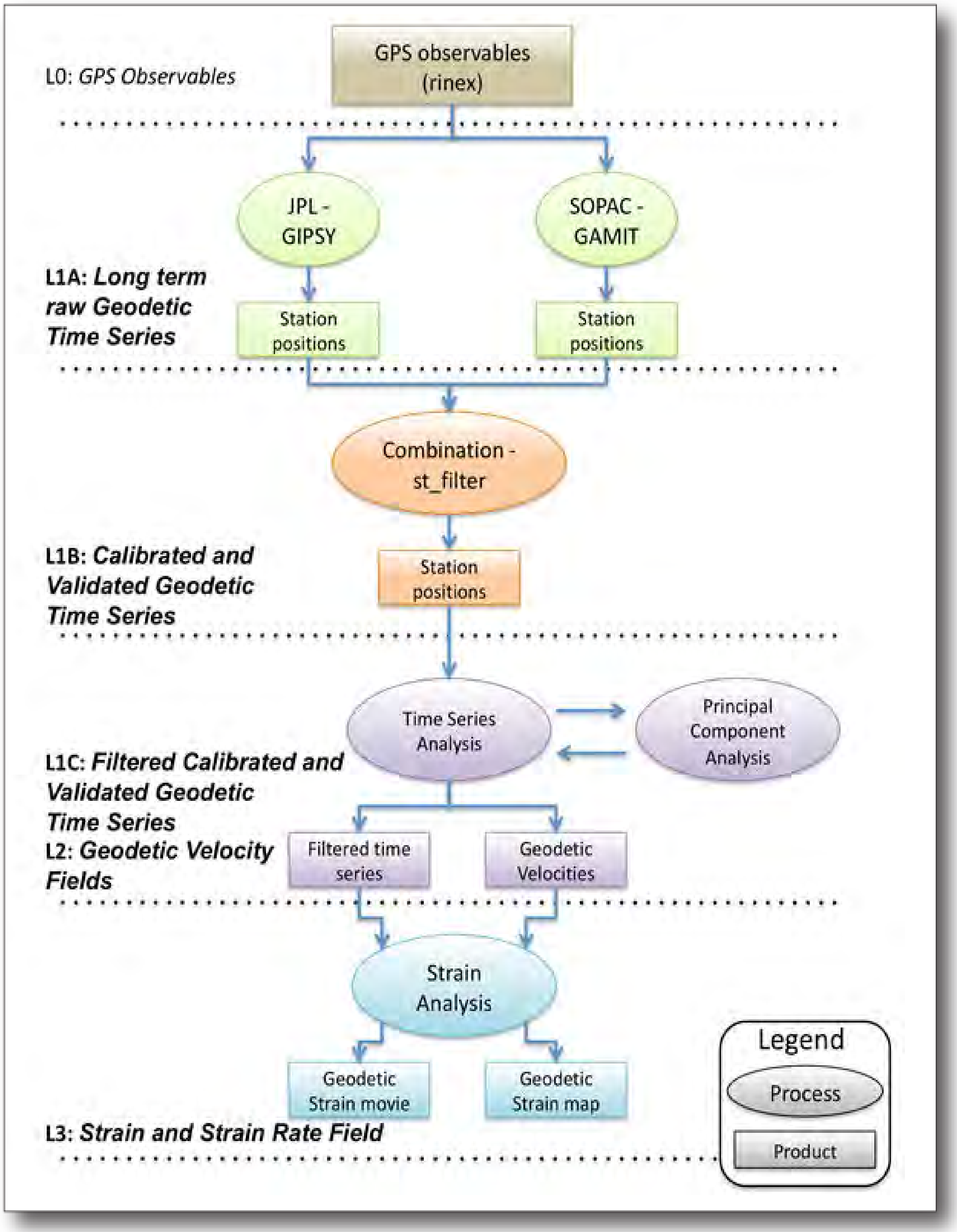


Figure 7. Basic SOPAC/JPL Process and Product Workflow

4. Time Series Data Sources and Smoothing

4.1 UNAVCO and SOPAC Data Sources

CGPS time series data were acquired within the overall study area spatial extents and spanning the study period. These data were drawn from a variety of suitable CGPS networks including the PBO (UNAVCO), CORS (NGS), and the Caltrans and SOPAC Real-time network stations. RTNs. Ultimately these time series were obtained from two ftp data archives, namely SOPAC and UNAVCO:

SOPAC: ftp://garner.ucsd.edu/pub/timeseries/measures/ats/WesternNorthAmerica/.
The time series file downloaded and used by Towill is:
WNAM_Clean_TrendNeuTimeSeries_sopac_20180911.tar.gz. This contains all of the station time series processed by SOPAC for stations in the WNAM polygon shown in Figure 6.

The data span the timeframe 2014.12.17 to 2018.07.15 (see Bock and Webb, 2012). Note: in this case, only the SOPAC geodetic time series data were employed. The combined solution incorporating the JPL GIPSY solution was not used.

UNAVCO: ftp://data-out.unavco.org/pub/products/position/.
In this case, the data are stored in subdirectories, one for each station; e.g., SSSS.pbo.igs08.csv, where 'SSSS' is the alphanumeric station code. The release date for these data is 2018.07.17.

4.2 Data Transformation and Reformatting

CGPS time-series data were downloaded from the online archives identifed above. Computer scripts and VBA macros were developed and applied to reorganize the data into a format requested by TRE Altimara.

Horizontal positions used for the CGPS stations were calculated based on the date of September 30, 2016 (mid-study epoch).

Horizontal position and ellipsoid height for CGPS stations were transformed to the ITRF2014 reference frame.

4.3 Time Series Smoothing

A 31 -day moving average was used for smoothing the time series data. A similar method and window span was employed on a similar project (see Sneed et al., 2013), and was also requested by Ben Brezing (personal communication, 2018).

After selecting the 31-day moving average, the time series data were extracted from the source files identified in Section 4.1 above. To facilitate the smoothing process, the data were extended by fifteen (15) days beyond each end of the study-period. After completing the smoothing, the time series data, both smoothed and original were 'normalized' to the study start date and time, namely 2015.01.01 at 1200 UTC by resetting each time series component to zero at that time and date. The 15-day excess data at each end of the time series (study period) were discarded.

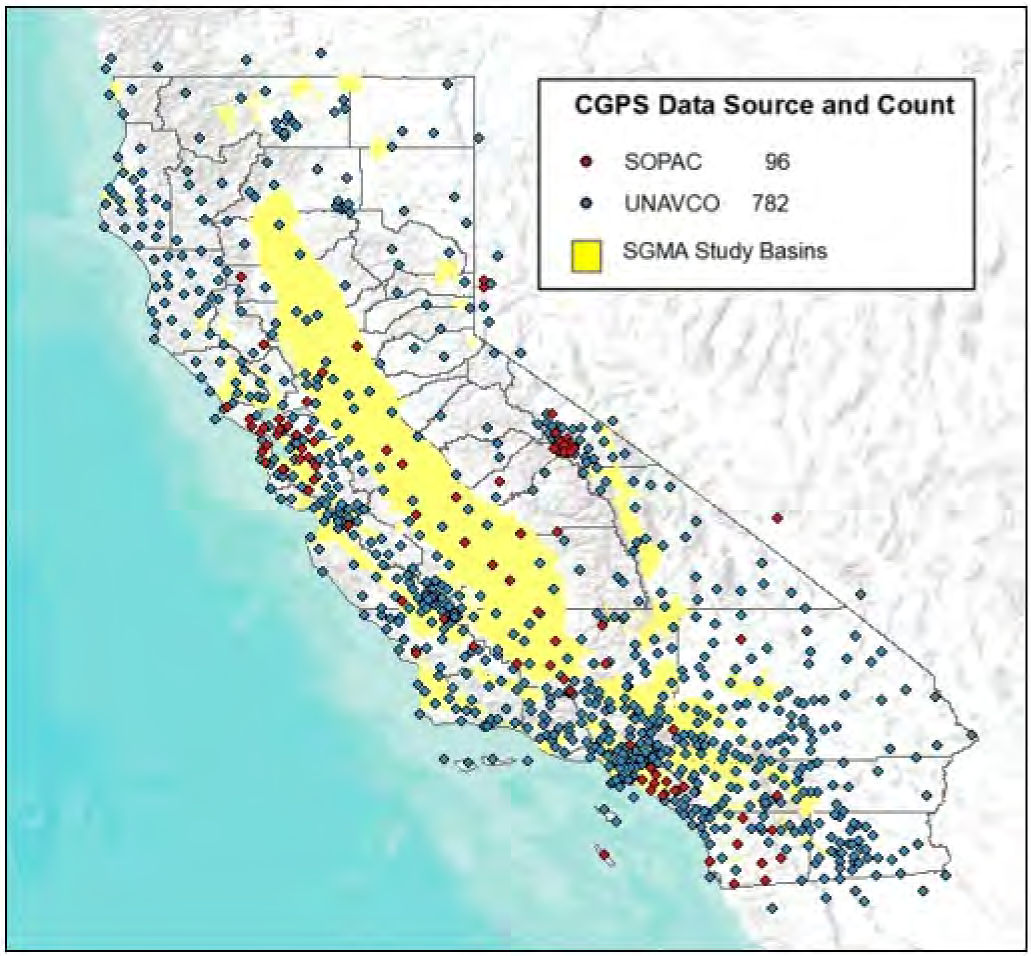


Figure 8. CGPS Stations Processed for the Study

4.4 InSAR Calibration Points

A subset of the CGPS time-series data were supplied to TRE Altamira enabling calibration of the InSAR dataset. Towill provided TRE with the geographic location of more than 800 CGPS points along with documentation of the temporal extent of the time-series data for each CGPS station. TRE selected 203 CGPS stations for use in the InSAR data calibration process. Actual ellipsoidal height values were provided to TRE following the selection of calibration points. CGPS points not selected for calibration are candidate for use as validation points. Validation points and their heights were not disclosed to TRE.

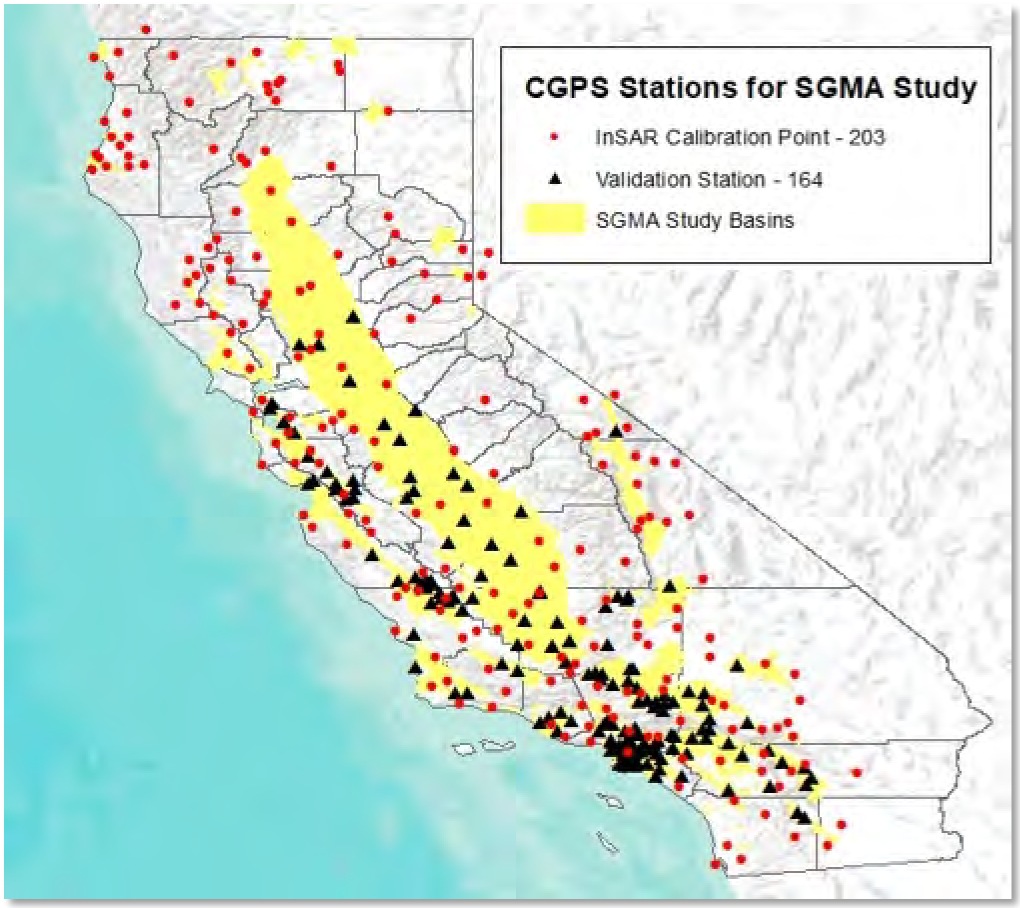
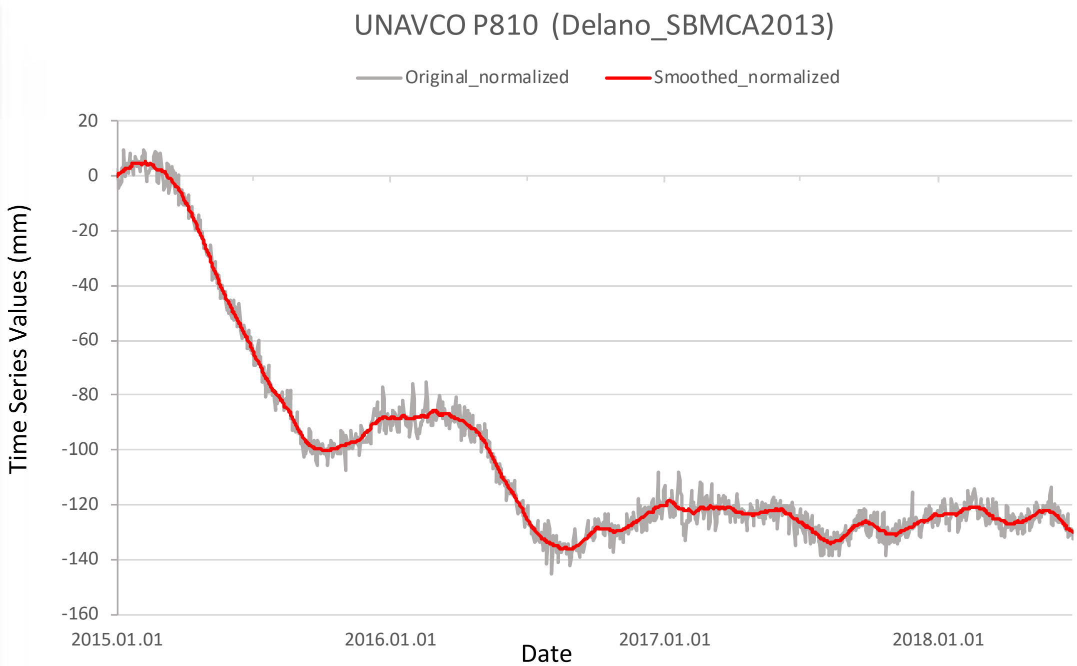


Figure 9. CGPS Stations Selected for Calibration and Validation of InSAR Data

4.5 Graphical Review and Statistical Analysis of Typical Results

At two randomly selected stations, the smoothed time series results were reviewed graphically and the residuals analyzed using Microsoft™ Excel's Descriptive Statistics and Histogram addon utilities. For PBO station P810 the results are presented in Figure 10 while for PBO station P546 they are shown in Figure 11. A review of these two samples suggests that the smoothed time series should meet project requirements.



Residual Statistics	
values in mm where applicable	
Mean	-0.01
Standard Error	0.09
RMSE	3.31
Median	0.12
Mode	-0.31
Standard Deviation	3.31
Sample Variance	10.98
Kurtosis	0.78
Skewness	-0.29
Range	24.27
Minimum	-13.15
Maximum	11.12
Sum	-14.29
Count	1276
Confidence Level (95.0%)	0.18

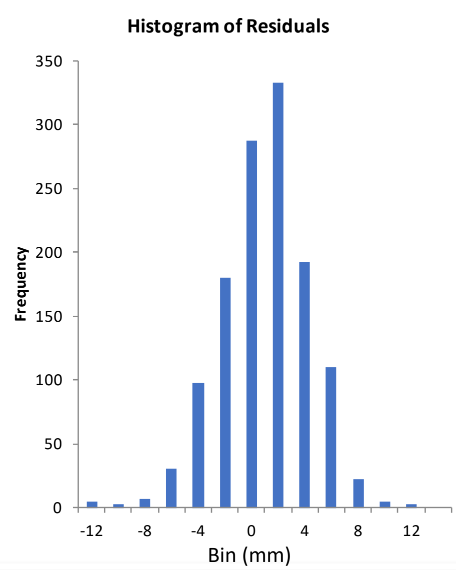
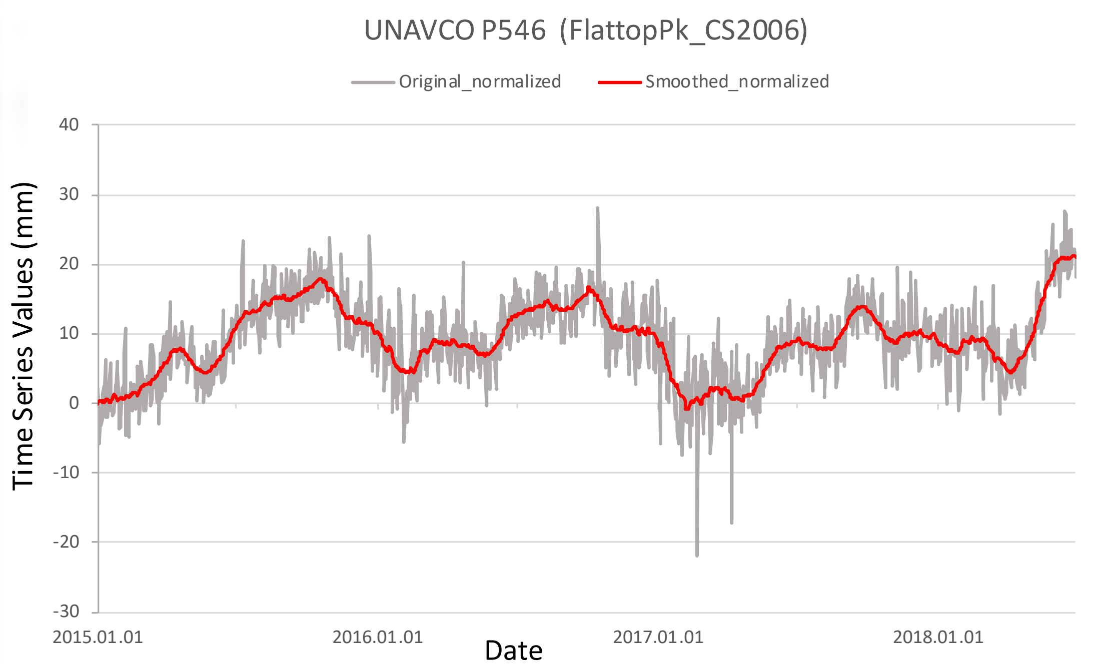


Figure 10. Graph and Statistics for PBO Station P810



Residual Statistics	
values in mm where applicable	
Mean	0.00
Standard Error	0.10
RMSE	3.49
Median	-0.01
Mode	-0.61
Standard Deviation	3.49
Sample Variance	12.20
Kurtosis	2.25
Skewness	0.10
Range	36.22
Minimum	-13.41
Maximum	22.81
Sum	-0.35
Count	1276
Confidence Level (95.0%)	0.19

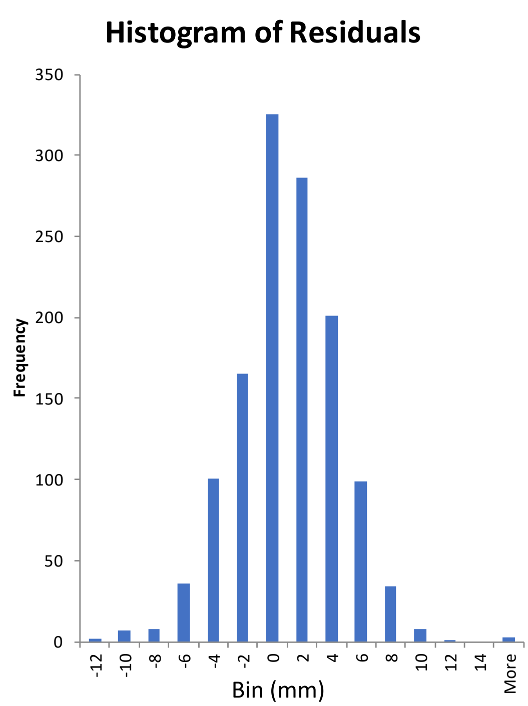


Figure 11. Graph and Statistics for PBO Station P546

5. Ten Percent Positional Data Validation

The Scope of Work (SOW) for the Task Order recommended that ~10 percent of the time series used should be independently validated to provide a measure of quality control. To this end, a random geographically dispersed sample of UNAVCO and SOPAC points were selected. A handful of these points were visually selected so as to provide project area coverage.

For each station, a time span starting at 2015.01.01 and ending at a randomly selected date within the study period was identified. Since the reference positions in the original time series are approximate and cannot be used to compute positions, Towill elected to check time series differences by comparing the 'normalized' time series data with independently processed position differences between the start and end dates. Raw RINEX data were down loaded for the SOPAC and UNAVCO stations. Data (24-hour files) were downloaded from the following locations:

- SOPAC: ftp://garner.ucsd.edu/pub/rinex/.
- UNAVCO: ftp://data-out.unavco.org/pub/rinex/obs/.

5.1 NRCan PPP SPARK Processing

The Natural Resources Canada (NRCan) Precise Point Postioning (PPP) 'SPARK' processor was used for processing the sampled RINEX files. 'SPARK' is a new modernized Multi-constellation GNSS processing engine made available for public use in August 2018. It is particularly useful in that a selection of RINEX files can simply be dragged and dropped onto a small applications which will upload the data for processing and then return the results in an email or to a specified directory on the user's computer. The primary author[16] of the SPARK software referred Towill to an excellent paper written by a colleague (see Kouba, 2015). This provides a thorough explanation as to how IGS products are used for high accuracy positioning.

Prior to processing the random set of station data files, the NRCan SPARK algorithm performance was compared with a number of other online geodetic positioning services. A comparison of the results may be found in Table 2. All of the results are in extremely good agreement as indicated from the residuals from the mean of all determinations. The three PPP processing engines are all believed to have been upgraded in 2018 to accommodate the IGS move to multi-constellation GNSS processing. However, it should be noted that most algorithms use the same recommended IERS conventions and the raw data and physical conditions were identical. Hence, the solutions are not fully independent. Current conventions may be located here:

https://www.iers.org/IERS/EN/Publications/TechnicalNotes/tn36.html,

[16] Simon Banville, PhD. Senior Geodetic Engineer, Surveyor General Branch, Natural Resources Canada/Government of Canada

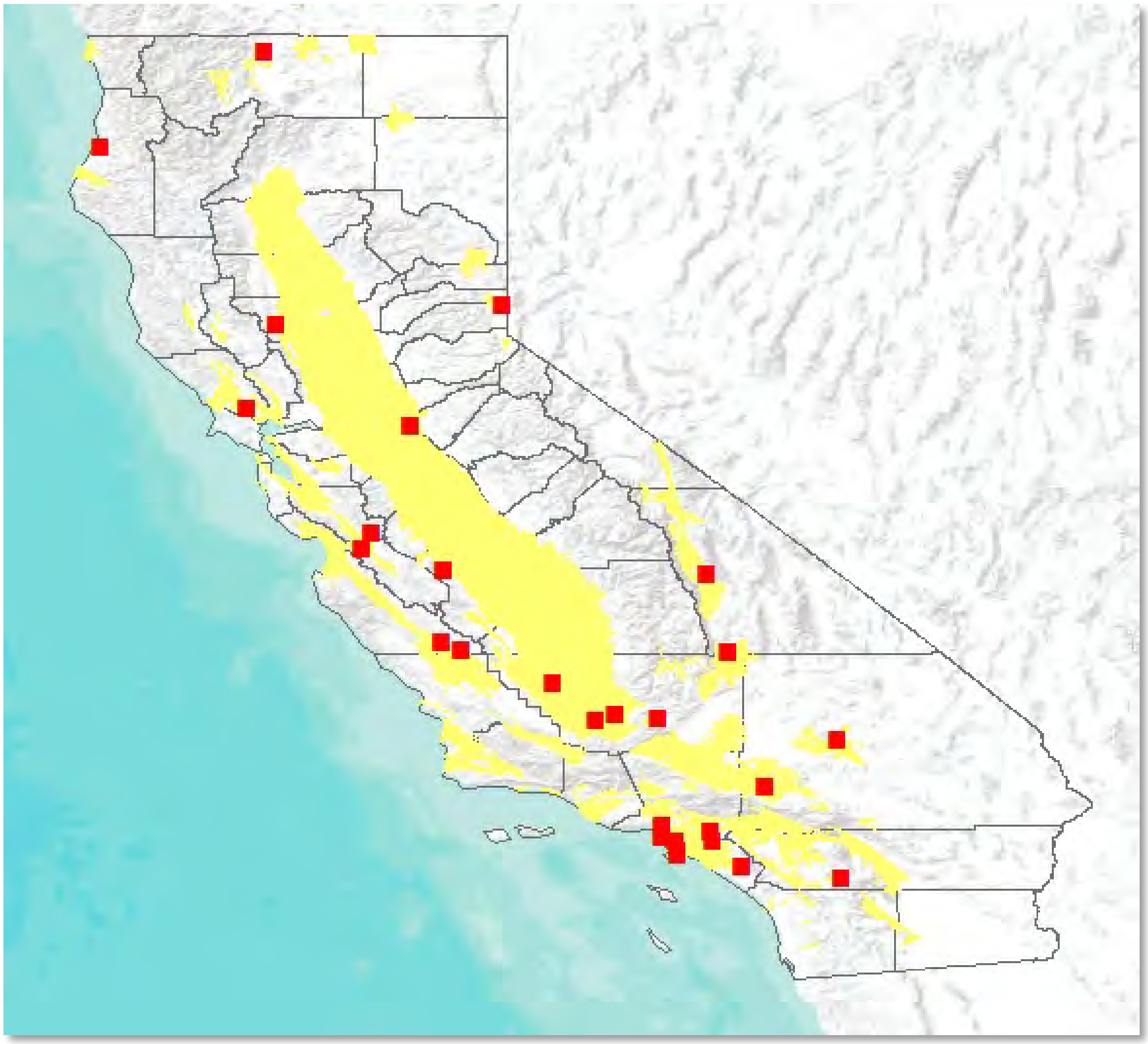


Figure 12. Validation CGPS Stations Selected for Testing Positional Accuracy

5.2 Positional Comparisons and Analysis of Results

Appendix B contains the results of the time series validation. The analysis for each CGPS station comprises two lines in the table. The columns are identified by the numbers 1 through 9. To aid in the interpretation, they are summarized as follows:

1. Four-character alphanumeric CGPS station code.
2. Time series data source (SOPAC/UNAVCO).
3. For each station, the top line is either the start date of the study period, or the station operation commencement date, if after the study period start date. The second date was randomly selected from within the study period.
4. The processing code assigned by UNAVCO. This identifies the processed solution type.
5. Extracted time series data at each of the two dates identified in item 3., above.
6. NRCan PPP solutions at each date (ITRF2014/IGS14, UTM Zone 10 or 11 North).
7. NRCan coordinate differences.
8. Time series differences.
9. Discrepancies between columns 8 and 7.

Note the apparent outlier for station 'TEHA', which is identified by pink shading. The time series discontinuity is clearly evident in Figure 9. Descriptive statistics for each of the remaining 27 stations are presented in Table 3. Figure 10 shows the distribution of all 81 discrepancies. A χ^2 – Goodness of fit test for normality (Gaussian distribution) was not performed. Considering the disparate data sources and the differencing of results at two dates, the discrepancies may be considered to be 'as expected'.

Table 2. Comparison of a NRCan PPP Solution with Those of Other On-line Services

ID	Epoch	Results			Residuals			Processed By	Solution Type	Frame Realizations
		Northing (N)	Easting (E)	Ellips. Hgt (h) WGS84	v_N	v_E	v_h			
		(All values in meters)								
P208	12:00:00 PM	4329136.622	560186.411	74.291	0.005	-0.001	0.004	JPL GIPSY v. 6.4	PPP	ITRF2014*
	4/13/2018	4329136.627	560186.412	74.290	0.000	-0.002	0.005	NRCAN SPARK (2.18.0)	PPP	IGS14/ITRF2014
	2014.647945	4329136.631	560186.407	74.302	-0.004	0.003	-0.007	UNB GAPS (6.0.1)**	PPP	IGS14/ITRF2014
		4329136.623	560186.407	74.297	0.004	0.003	-0.002	AUSPOS v. 2.3***	Network: Relative Carrier Phase	IGS14/ITRF2014
		4329136.633	560186.413	74.296	-0.006	-0.003	-0.001	NGS OPUS (page5 v. 1603.24)	Network: Relative Carrier Phase	IGS08/ITRF2008

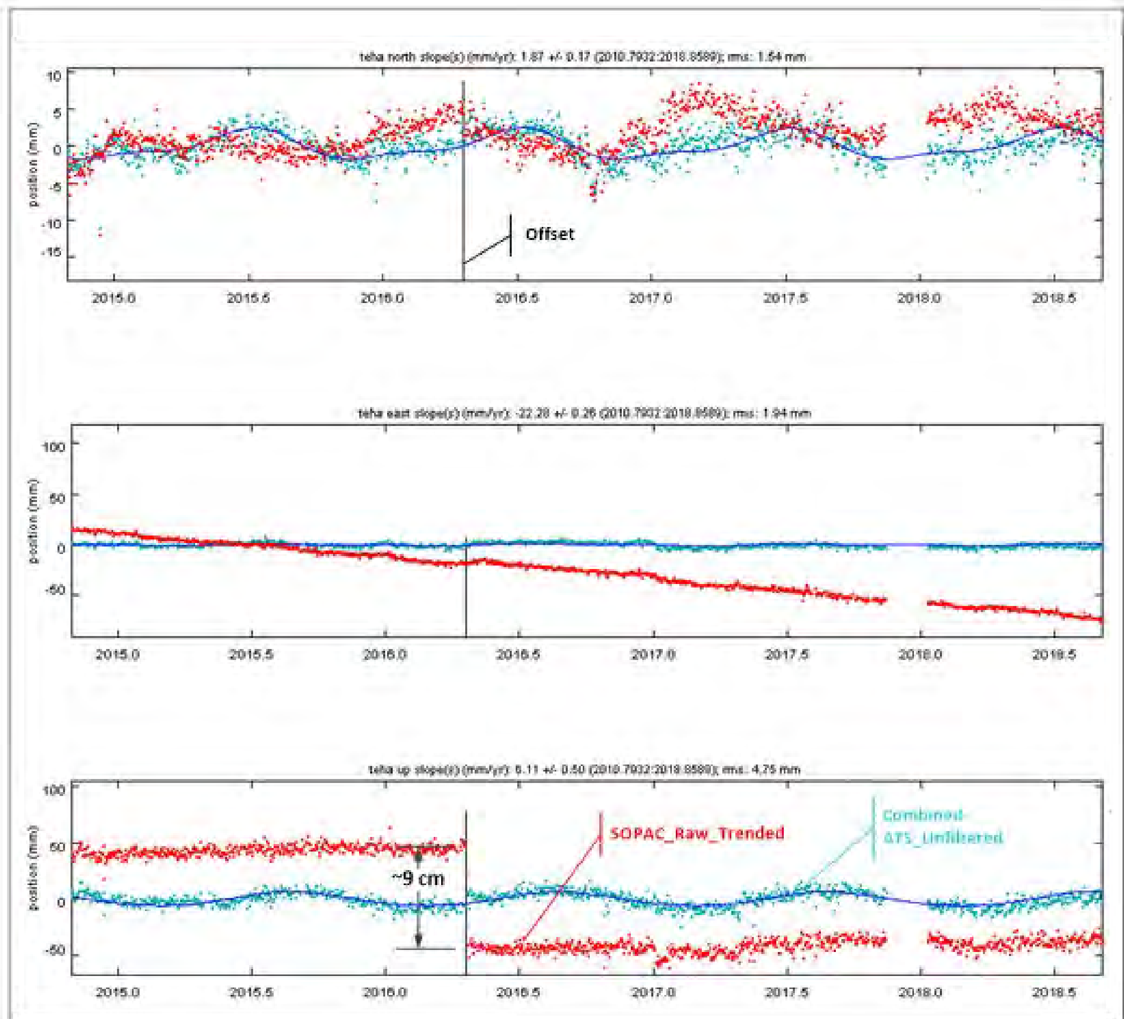


Figure 13. Explanation of the Outlier for Station 'TEHA'

Table 3. Descriptive Statistics for the Discrepancies

Descriptive Statistics - Discrepancies			
(values in mm where applicable)			
	Northing	Easting	Ellps. Height
Mean	0.9	0.4	-0.2
Standard Error	0.7	0.5	0.8
Median	0.0	-0.2	0.1
Standard Deviation	3.6	2.5	4.4
RMSE	3.7	2.5	4.3
Sample Variance	13.1	6.2	19.5
Excess Kurtosis	-0.4	0.8	-0.8
Skewness	0.6	0.8	-0.3
Range	13.4	10.4	15.8
Minimum	-4.9	-4.1	-9.1
Maximum	8.5	6.4	6.7
Sum	25.4	10.7	-6.3
Count	27	27	27
Confidence Level of Mean (95.0%)	1.4	1.0	1.7

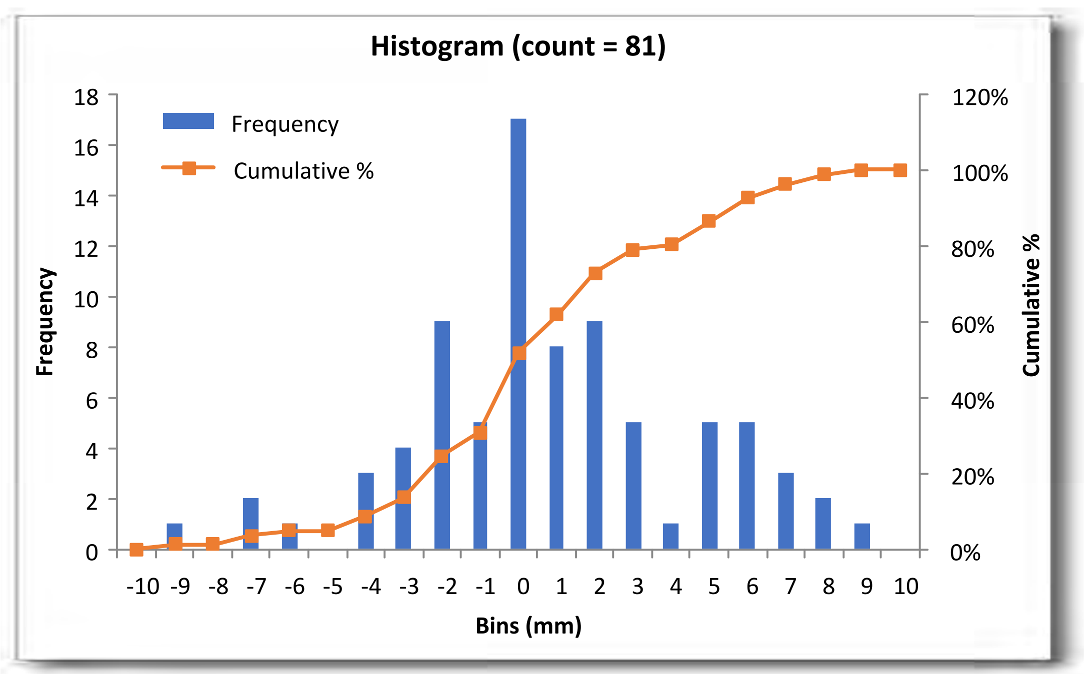


Figure 14. Distribution of 81 Samples

6. Deliverables

This task includes the following deliverables:

- CGPS time-series files supplied in CSV format.
- Shapefile showing CGPS stations through California; identified are which points are selected for calibration and validation of the InSAR dataset.
- This report in digital (PDF) format.

7. References

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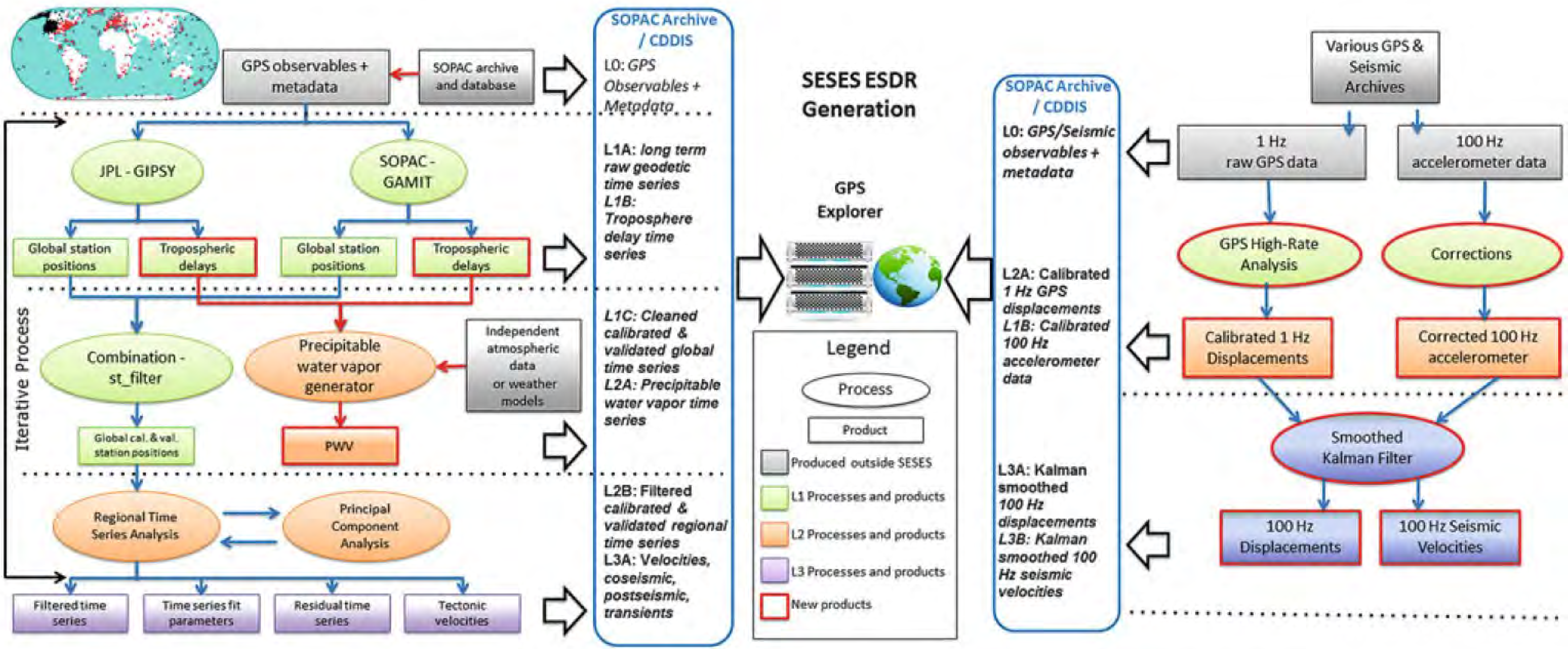
SESES ESDR PROCESSES AND PRODUCTS (reproduced after Bock et al., 2016)



❶	❷	❸	❹	❺				❻			❼			❽			❾		
Station	Source	Date	Processing	Time Series Values at Date			UTM	NRCan PPP Solution at Date			NRCan PPP Solution Differences			Time Series Differences			Discrepancies		
ID		mm/dd/yyyy	Code	ΔN	ΔE	Δh	Zone	Northing	Easting	h	ΔN	ΔE	Δh	Δ(ΔN)	Δ(ΔE)	Δ(Δh)	❽	minus	❼
				(mm)				(meters)			(meters)			(meters)			(meters)		
BKR1	SOPAC	1/1/2015	N/A	16.12	-273.01	-280.01	11	3889761.116	307802.183	56.613									
BKR1	SOPAC	5/11/2015	N/A	17.42	-287.41	-301.31	11	3889761.121	307802.169	56.594	0.005	-0.014	-0.019	0.001	-0.014	-0.021	-0.004	0.000	-0.002
SNHS	SOPAC	1/1/2015	N/A	254.49	-584.13	8.52	11	3754487.667	414168.614	66.421									
SNHS	SOPAC	2/17/2015	N/A	255.79	-590.13	8.02	11	3754487.671	414168.602	66.423	0.004	-0.012	0.002	0.001	-0.006	-0.001	-0.003	0.006	-0.002
TEHA	SOPAC	1/1/2015	N/A	10.47	-93.67	33.40	11	3889896.658	366107.617	1174.689									
TEHA	SOPAC	6/20/2017	N/A	14.98	-146.56	54.52	11	3889896.655	366107.565	1174.619	-0.003	-0.052	-0.070	0.005	-0.053	0.021	0.008	-0.001	0.091
WHYT	SOPAC	1/1/2015	N/A	252.37	-502.76	-0.97	11	3726250.935	440351.668	265.406									
WHYT	SOPAC	3/30/2018	N/A	302.57	-621.16	-6.27	11	3726250.986	440351.551	265.394	0.051	-0.117	-0.012	0.050	-0.118	-0.005	-0.001	-0.001	0.007
ARM1	UNAVCO	1/1/2015	suppf	-8.90	-389.77	-261.33	11	3897033.216	326087.531	76.585									
ARM1	UNAVCO	1/25/2016	suppf	-8.36	-417.37	-310.04	11	3897033.219	326087.507	76.534	0.003	-0.024	-0.051	0.001	-0.028	-0.049	-0.002	-0.004	0.002
AZRY	UNAVCO	1/1/2015	suppf	231.47	-486.44	-15.59	11	3711223.498	534379.718	1265.695									
AZRY	UNAVCO	6/11/2017	suppf	260.02	-563.98	1.05	11	3711223.518	534379.638	1265.707	0.020	-0.080	0.012	0.029	-0.078	0.017	0.009	0.002	0.005
CRHS	UNAVCO	1/1/2015	suppf	287.02	-615.72	11.96	11	3743315.141	382216.301	-23.554									
CRHS	UNAVCO	12/19/2015	suppf	303.45	-652.23	21.92	11	3743315.158	382216.265	-23.546	0.017	-0.036	0.008	0.016	-0.037	0.010	-0.001	-0.001	0.002
HBCO	UNAVCO	1/1/2015	suppf	277.37	-551.47	-16.44	11	3738910.449	380955.354	-26.896									
HBCO	UNAVCO	10/22/2016	suppf	309.93	-621.86	-9.88	11	3738910.482	380955.283	-26.887	0.033	-0.071	0.009	0.033	-0.070	0.007	0.000	0.001	-0.002
LPHS	UNAVCO	1/1/2015	suppf	251.03	-637.65	-13.05	11	3765536.895	411674.879	68.476									
LPHS	UNAVCO	4/26/2015	suppf	251.51	-649.38	-11.18	11	3765536.896	411674.865	68.485	0.001	-0.014	0.009	0.000	-0.012	0.002	-0.001	0.002	-0.007
MASW	UNAVCO	1/1/2015	suppf	316.57	-531.19	15.43	10	3968399.585	730961.071	713.732									
MASW	UNAVCO	4/25/2017	suppf	358.66	-611.60	10.35	10	3968399.621	730960.990	713.736	0.036	-0.081	0.004	0.042	-0.080	-0.005	0.006	0.001	-0.009
P058	UNAVCO	1/1/2015	suppf	41.17	-87.28	0.58	10	4525582.510	409390.049	21.409									
P058	UNAVCO	1/29/2016	suppf	44.32	-98.04	6.20	10	4525582.518	409390.037	21.413	0.008	-0.012	0.004	0.003	-0.011	0.006	-0.005	0.001	0.002
P093	UNAVCO	1/1/2015	suppf	-31.41	-147.97	3.33	11	4051628.868	411089.219	1339.057									
P093	UNAVCO	8/26/2015	suppf	-35.00	-162.16	11.57	11	4051628.864	411089.203	1339.062	-0.004	-0.016	0.005	-0.004	-0.014	0.008	0.000	0.002	0.003
P150	UNAVCO	1/1/2015	suppf	-27.44	-136.88	-4.11	10	4353418.391	755806.119	2619.079									
P150	UNAVCO	9/8/2017	suppf	-39.93	-194.89	-4.94	10	4353418.371	755806.060	2619.077	-0.020	-0.059	-0.002	-0.012	-0.058	-0.001	0.008	0.001	0.001
P198	UNAVCO	1/1/2015	suppf	123.19	-305.56	-4.59	10	4234722.167	534342.696	-4.623									
P198	UNAVCO	1/1/2018	suppf	159.43	-391.65	-21.07	10	4234722.199	534342.610	-4.633	0.032	-0.086	-0.010	0.036	-0.086	-0.016	0.004	0.000	-0.006
P208	UNAVCO	1/1/2015	suppf	-38.42	-200.06	13.68	10	4329136.643	560186.483	74.295									
P208	UNAVCO	4/13/2018	suppf	-52.70	-272.05	6.11	10	4329136.627	560186.412	74.290	-0.016	-0.071	-0.005	-0.014	-0.072	-0.008	0.002	-0.001	-0.003
P238	UNAVCO	1/1/2015	suppf	114.74	-265.07	19.86	10	4079247.677	637942.744	44.899									
P238	UNAVCO	6/6/2017	suppf	146.00	-330.29	12.06	10	4079247.704	637942.680	44.896	0.027	-0.064	-0.003	0.031	-0.065	-0.008	0.004	-0.001	-0.005

❶	❷	❸	❹	❺				❻			❼			❽			❾		
Station	Source	Date	Processing	Time Series Values at Date			UTM	NRCan PPP Solution at Date			NRCan PPP Solution Differences			Time Series Differences			Discrepancies		
ID		mm/dd/yyyy	Code	ΔN	ΔE	Δh	Zone	Northing	Easting	h	ΔN	ΔE	Δh	Δ(ΔN)	Δ(ΔE)	Δ(Δh)	❽	minus	❼
				(mm)				(meters)			(meters)			(meters)			(meters)		
P244	UNAVCO	1/1/2015	suppf	-11.37	-227.97	16.09	10	4097338.659	646393.246	58.712									
P244	UNAVCO	11/26/2016	suppf	-12.00	-281.49	16.74	10	4097338.656	646393.193	58.720	-0.003	-0.053	0.008	-0.001	-0.054	0.001	0.002	-0.001	-0.007
P291	UNAVCO	1/1/2015	suppf	159.80	-281.43	-10.33	10	3977946.685	712496.546	661.360									
P291	UNAVCO	5/31/2018	final	233.26	-407.89	-2.21	10	3977946.751	712496.415	661.363	0.066	-0.131	0.003	0.073	-0.126	0.008	0.007	0.005	0.005
P302	UNAVCO	1/1/2015	suppf	-10.24	-202.57	1.64	10	4056993.933	712916.705	122.647									
P302	UNAVCO	11/1/2016	suppf	-10.29	-232.37	3.35	10	4056993.932	712916.677	122.648	-0.001	-0.028	0.001	0.000	-0.030	0.002	0.001	-0.002	0.001
P309	UNAVCO	1/1/2015	suppf	-27.30	-204.96	10.56	10	4217781.757	679664.920	41.410									
P309	UNAVCO	3/16/2018	suppf	-29.06	-280.53	-3.89	10	4217781.751	679664.846	41.399	-0.006	-0.074	-0.011	-0.002	-0.076	-0.014	0.004	-0.002	-0.003
P470	UNAVCO	1/1/2015	suppf	48.72	-253.19	20.60	11	3813498.806	463823.213	991.377									
P470	UNAVCO	9/6/2015	suppf	50.98	-270.80	22.76	11	3813498.807	463823.189	991.374	0.001	-0.024	-0.003	0.002	-0.018	0.002	0.001	0.006	0.005
P545	UNAVCO	1/1/2015	suppf	16.98	-172.20	-50.04	11	3931432.734	269994.520	50.706									
P545	UNAVCO	1/15/2016	suppf	17.28	-195.61	-59.81	11	3931432.737	269994.497	50.691	0.003	-0.023	-0.015	0.000	-0.023	-0.010	-0.003	0.000	0.005
P604	UNAVCO	1/1/2015	suppf	-33.12	-131.25	22.17	11	3866086.792	530003.348	588.427									
P604	UNAVCO	1/11/2015	suppf	-33.10	-132.07	25.14	11	3866086.793	530003.347	588.424	0.001	-0.001	-0.003	0.000	-0.001	0.003	-0.001	0.000	0.006
P784	UNAVCO	1/1/2015	suppf	-36.90	-103.93	-3.15	10	4631154.452	548123.356	802.242									
P784	UNAVCO	6/1/2018	final	-57.21	-154.23	-1.30	10	4631154.430	548123.306	802.244	-0.022	-0.050	0.002	-0.020	-0.050	0.002	0.002	0.000	0.000
P799	UNAVCO	2/1/2015	suppf	68.70	-154.05	6.40	11	3754902.185	379255.118	24.832									
P799	UNAVCO	1/12/2016	suppf	89.05	-185.26	9.25	11	3754902.208	379255.087	24.833	0.023	-0.031	0.001	0.020	-0.031	0.003	-0.003	0.000	0.002
TOWG	UNAVCO	9/1/2015	suppf	-3.47	-0.52	-1.07	11	3962985.600	430894.981	657.080									
TOWG	UNAVCO	2/20/2016	suppf	-3.10	-9.58	-10.10	11	3962985.603	430894.976	657.074	0.003	-0.005	-0.006	0.000	-0.009	-0.009	-0.003	-0.004	-0.003
UCLP	UNAVCO	1/1/2015	suppf	316.54	-725.61	11.96	11	3770758.156	366945.161	111.536									
UCLP	UNAVCO	3/12/2017	suppf	349.18	-809.44	2.17	11	3770758.189	366945.079	111.527	0.033	-0.082	-0.009	0.033	-0.084	-0.010	0.000	-0.002	-0.001
WRHS	UNAVCO	1/1/2015	suppf	276.24	-597.64	17.16	11	3758434.138	368093.546	7.870									
WRHS	UNAVCO	11/14/2016	suppf	309.23	-667.06	15.28	11	3758434.171	368093.474	7.868	0.033	-0.072	-0.002	0.033	-0.069	-0.002	0.000	0.003	0.000

1. Four-character alphanumeric CGPS station code.
2. Time series data source (SOPAC/UNAVCO).
3. For each station, the top line is either the start date of the study period, or the station operation commencement date, if after the study period start date. The second date was randomly selected from within the study period.
4. The processing code assigned by UNAVCO. This identifies the processed solution type.
5. Extracted time series data at each of the two dates identified in item 3., above.
6. NRCan PPP solutions at each date (ITRF2014/IGS14, UTM Zone 10 or 11 North).
7. NRCan coordinate differences.
8. Time series differences.
9. Discrepancies between columns 8 and 7.

APPENDIX D

InSAR land surveying and mapping services in support of the DWR SGMA program

Technical Report - March 2020

TRE ALTAMiRA
A CLS Group Company

Report prepared by

TRE ALTAMIRA Inc.

Address:	#410 – 475 West Georgia Street Vancouver, BC, V6B 4M9
Date:	16 March 2020

Executive Summary

TRE Altamira Inc. (TRE) has been contracted by Towill, Inc (Towill) to provide InSAR ground deformation measurements over groundwater basins in California (Task Order No. 37 – Contract No. 4600011239, *supporting the Sustainable Groundwater Management Act (SGMA) of the California Department of Water* Resources.

The objective of the work is to update the 2018 ground deformation measurements (Task Order No. 26 – Contract No. 4600011239) up to September 2019. The output consists of continuous uninterrupted vertical deformation time series from 01 January 2015 to Sept 2019, obtained by stitching the 2019 results to the 2018 historical data.

TRE's SqueeSAR algorithm is used to generate the ground deformation measurements and the results are calibrated and validated using ground-based, continuously operating Global Positioning System (GPS) stations located throughout the state of California.

This **Milestone 4 Report** represents the final deliverable and provides a description of all tasks and milestones.

- **Task 1 - Study Area:** The study area defined by DWR covers 101,210 km^2 (39,000 mi^2) in California. It has increased by 6,737 km^2 (2,600 mi^2) compared to the 2018 study as it now includes additional basins located in the north and in the south of California.
- **Task 2.1 - Imagery procurement**: All available (2,235) Sentinel images were downloaded. The new imagery covers the period 01 June 2018 - 30 September 2019 for the areas in common with the 2018 analysis and the full 01 January 2015 – 30 September 2019 period for the new areas.
- **Task 2.2 - Processing polygons definition:** The downloaded imagery was analyzed and 35 polygons defined for the data processing. To maintain maximum consistency with the 2018 results, the 27 processing polygons over the 2018 areas have remained unchanged while 8 new processing polygons were defined for the new basins.
- **Task 2.3 – SqueeSAR Processing:** The SqueeSAR data processing for the 27 previous processing polygons produced LOS measurements that cover 01 January 2018 - 30 September 2019, which includes an overlap of 15-20 images with the previous analysis. These results were then integrated with the 01 January 2015 – 01 June 2018 measurements to generate uninterrupted deformation time series from January 2015 to September 2019. Over the new areas, the SqueeSAR processing was carried out from scratch, using the entire image archive available from January 2015 to September 2019.

- **Task 2.4 – Data calibration**: 231 GPS station were selected from the UNAVCO network to calibrate the LOS measurements. The calibration was performed using the methodology defined in the 2018 analysis.
- **Task 2.5 – Vertical measurements**: The vertical measurements were derived from the LOS calibrated time series using the same methodology of the 2018 analysis. To maintain the maximum consistency with the previous results, the same spatial grid and temporal sampling were used.
- **Task 2.6 – Draft deliverables**: The draft deliverables were generated for both the common period and the variable start date results, using the same format defined in the 2018 analysis and made available on the TREmaps web platform and a dedicated SFTP.
- **Task 2.7 – Final deliverables**: TRE received and addressed the modification requests from DWR and Towill to produce the final deliverables, including the high-resolution LOS data. All deliverables were provided to Towill and DWR through TREmaps and SFTP.

Contents

Acronyms and Abbreviations

AOI	Area of Interest (study area)
ASC/A	Ascending orbit
DESC/D	Descending orbit
GNSS	Global Navigation Satellite System
InSAR	Interferometric Synthetic Aperture Radar
LOS	Line of Sight
MP	Measurement Point
SNT	Sentinel Satellite
TS	Time series
SqueeSAR®	Advanced InSAR algorithm patented by TRE Altamira

Confidentiality disclaimer

1. Introduction

TRE has been contracted by Towill under Task Order No. 37 - Contract No. 4600011239 to provide InSAR ground deformation monitoring data over groundwater basins in California, in support of land surveying and mapping services for the Department of Water Resources (DWR) and its mission to enact the Sustainable Groundwater Management Act (SGMA).

The project consists of four Tasks (Table 1), with TRE responsible for Task 2 - *InSAR data Acquisition and Analysis*, whose objective is to update the ground deformation measurements provided in 2018 (Task Order No. 26 – Contract No. 4600011239) to September 2019. Task 2 comprised seven sub-tasks and four milestones (Table 2) and this Milestone 4 report constitutes the final document.

Project Task	Description	Appointed
1	Study Area definition	DWR
2	InSAR data Acquisition and Analysis	TRE
3	CGPS Data Acquisition and Analysis	Towill
4	InSAR-CGPS Comparative Analysis	Towill

Table 1: Project Tasks

Task 2	Description	Milestone (report)	Expected Delivery	Delivery date
2.1	Imagery procurement	M1	25 Oct 2019	28 Oct 2019
2.2	Processing polygons definition	M2	16 Dec 2019	23 Dec 2019
2.3	SqueeSAR processing (LOS data)			
2.4	Data calibration (LOS data)	M3	14 Feb 2020	20 Feb 2020
2.5	Vertical measurements generation			
2.6	Draft deliverables			
2.7	Final deliverable	M4	16 Mar 2020	16 Mar 2020

Table 2: Task 2 subtasks and schedule.

2. Task 1: Study Area

The study area covers 101,210 km^2 (39,000 mi^2) and includes the groundwater basins of interest to DWR. The area has increased by 6,737 km^2 (2,600 mi^2) compared to the 2018 study as it now includes additional basins located in the north and in the south of California (Figure 1).

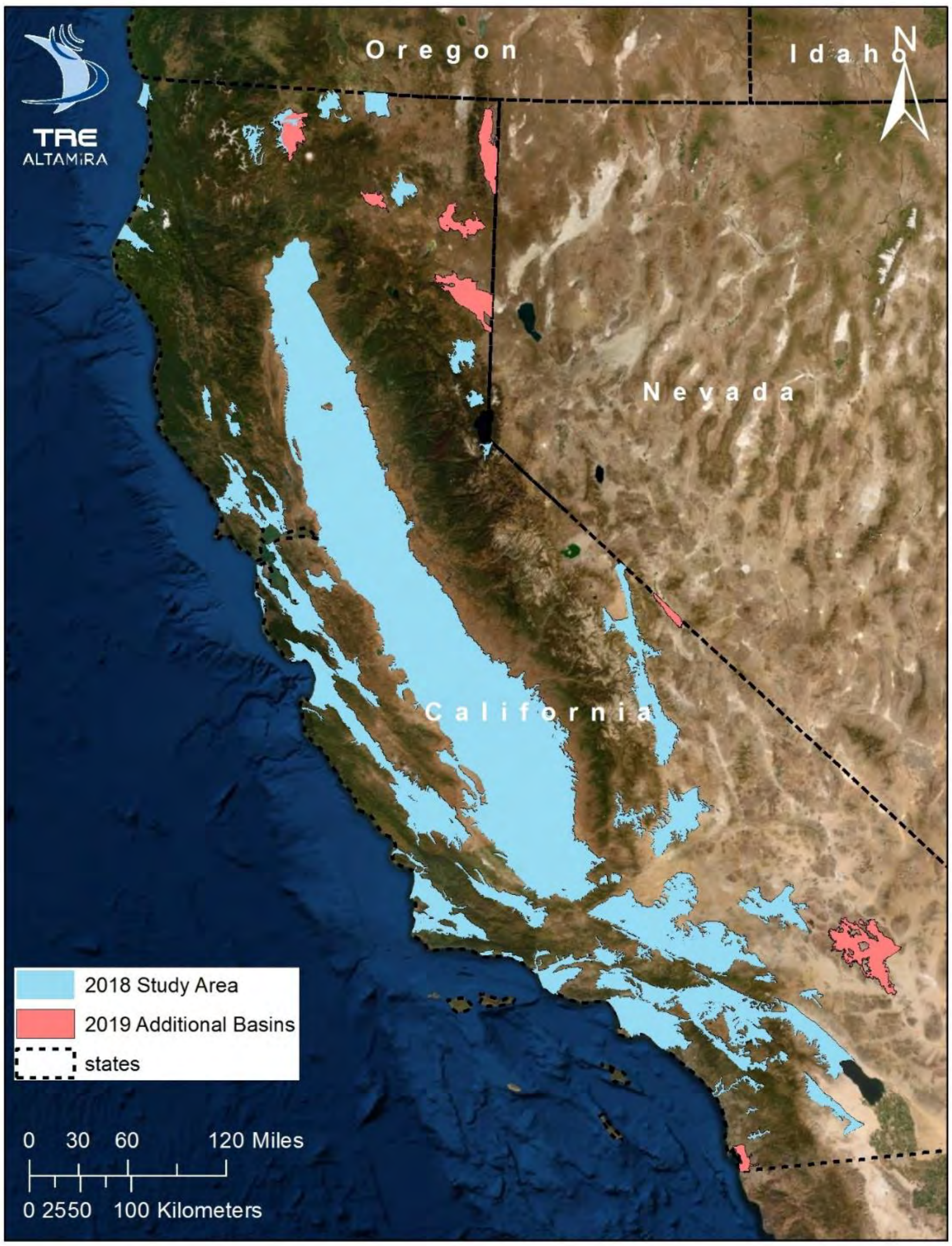


Figure 1: The 2019 study area covers the groundwater basins of the 2018 analysis (light blue) and also includes new basins (light red).

3. Task 2.1: Imagery procurement

The 2019 update included new satellite radar imagery acquired over the study area by the Sentinel-1 (SNT) mission since the end of the 2018 analysis (01 June 2018).

The SNT mission is part of the European Radar Observatory for the Copernicus joint initiative of the European Commission and the European Space Agency and comprises two satellites that share the same orbit, with each satellite acquiring data in the C-band wavelength (5.9 cm), with a 5x20 meter ground resolution. SNT has been collecting radar imagery over California since late 2014 from both ascending and descending orbits (Figure 2), initially with a 24-day revisit frequency and, since early 2017, with a nominal 12-day revisit frequency. The acquisition orbits are denominated ascending (south to north) or descending (north to south) according to the flight direction of the sensor.

The ascending and descending imagery acquired between 1 June 2018 and 30 September 2019 over the previous study area, and from 1 January 2015 and 01 June 2018 over the new basins (Figure 1) consisted of 2,235 images.

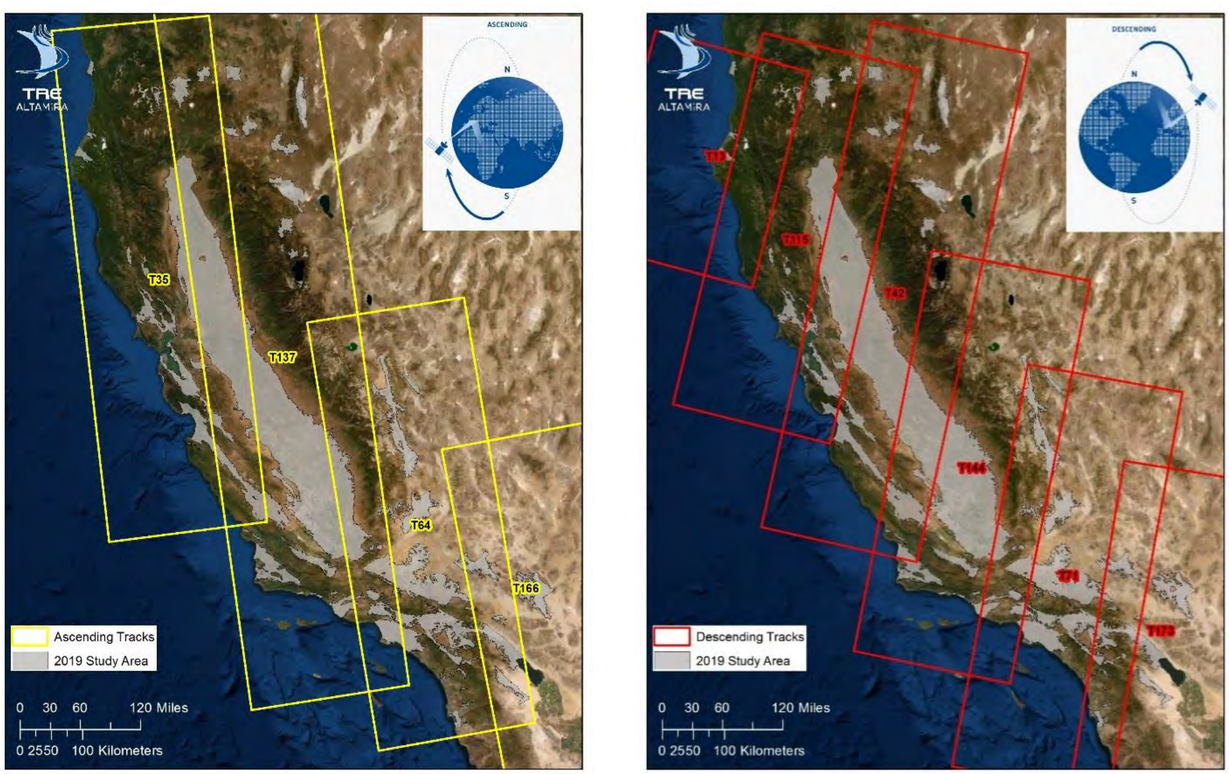


Figure 2: Ascending and Descending SNT acquisition tracks over California.

4. Task 2.2: Processing polygons definition

The downloaded imagery was analyzed to define the number of processing polygons. To maintain maximum consistency with the 2018 results, the 27 processing polygons over the 2018 areas have remained unchanged while 8 new processing polygons were defined for the new 2019 basins, based on their extent, the maximization of the temporal coverage and the optimization of GPS station coverage.

The final data processing includes 18 descending and 17 ascending polygons (Figure 2).

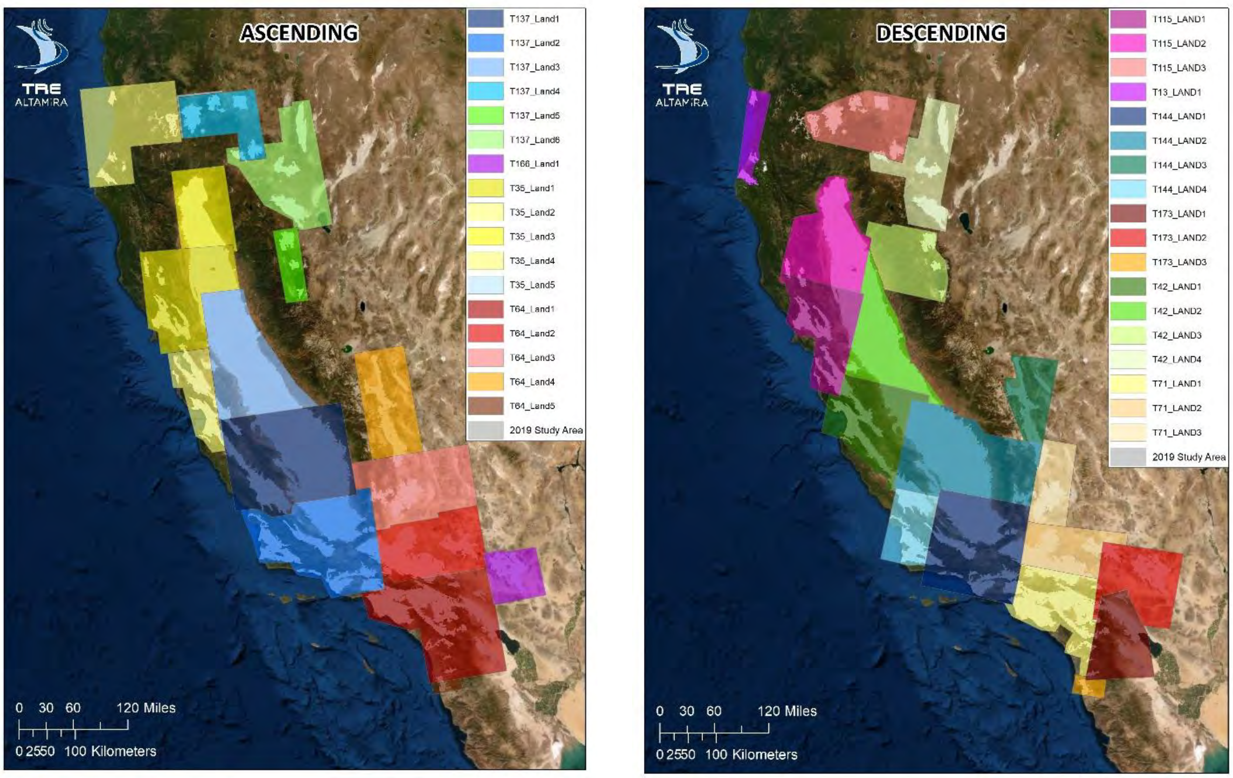


Figure 3: Ascending and Descending processing polygons.

5. Task 2.3: SqueeSAR processing

The SqueeSAR processing for the 27 previous processing polygons produced LOS measurements that cover 01 January 2018 - 30 September 2019, which includes an overlap of 15-20 images with the previous analysis (Figure 4). The overlap was applied in order to maximize the robustness of the integration with the 2018 measurements and minimize the impact of isolated noisy measurements in the time series.

The integration of the new LOS measurements with the 2018 measurements generated uninterrupted deformation time series spanning the period January 2015 – September 2019. Over the new 2019 areas, the SqueeSAR processing was carried out ex novo, using the entire image archive available from January 2015.

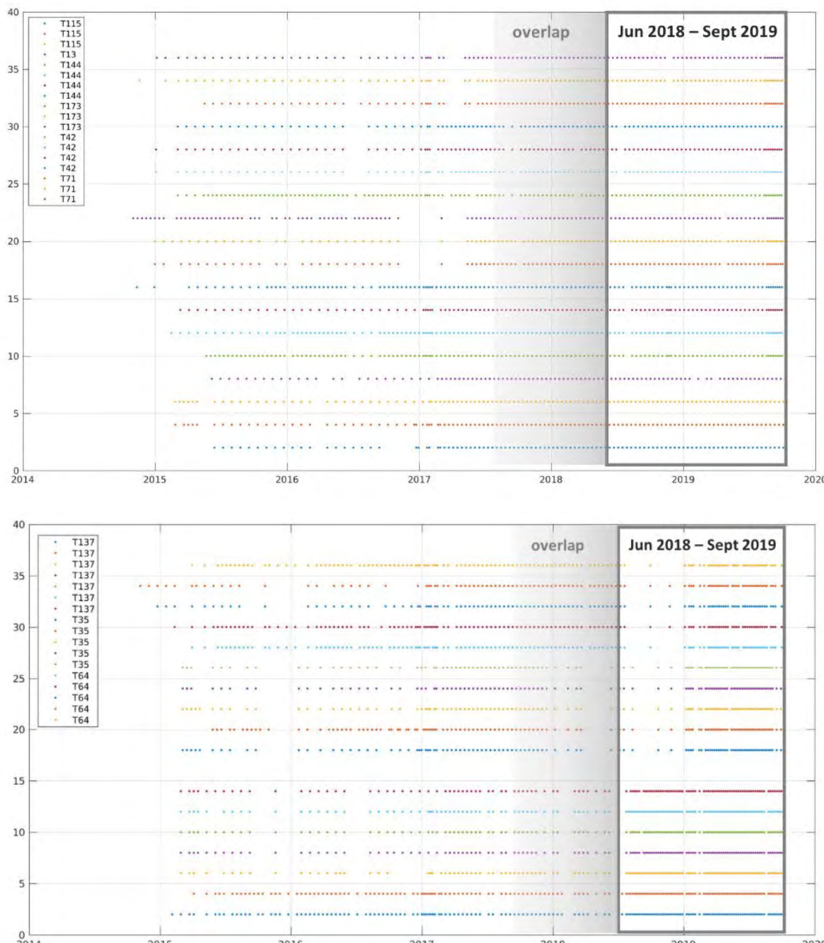


Figure 4: Temporal distribution of the imagery for all ascending and descending processing polygons. The current 2019 analysis used the imagery collected between June 2018 and September 2019 plus an overlap of approximately 15-20 images with the historical imagery.

6. Task 2.4: Data Calibration

A total of 231 GPS stations was selected from the UNAVCO network to perform the calibration of the 2019 measurements. This network included the 200 stations used in the 2018 analysis as well as 31 additional stations to cover the new 2019 areas (Figure 5). The selection criteria for the calibration stations were the same as for the 2018 project: at least 10 stations (when available) with a homogeneous spatial distribution within each processing polygon and absence of long temporal gaps in the time series.

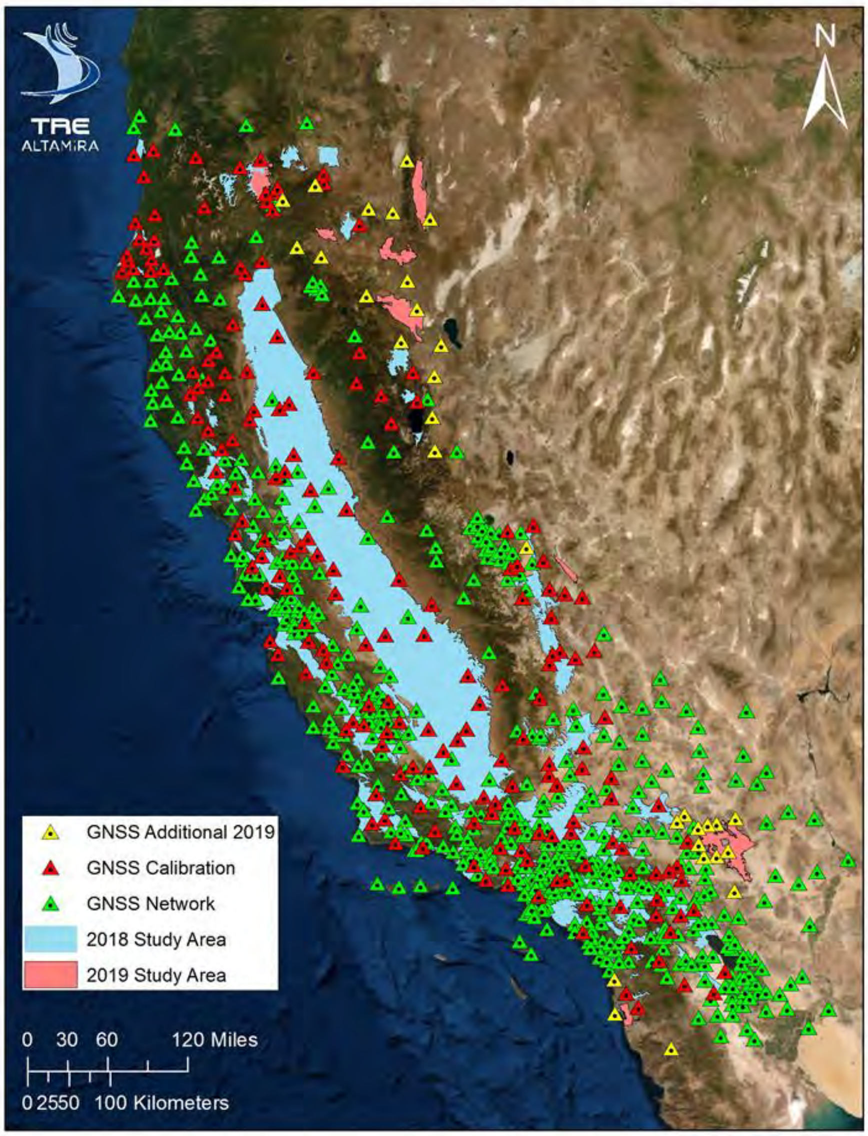


Figure 5: GNSS network over California. The same stations (red) used for the 2018 calibration will be used for the 2019 update, with the addition of 31 stations (yellow) to cover the new areas

The GPS time series have minor differences with the data used for the 2018 analysis within the overlap period (1/1/2015 to 6/30/2018), due to the use of a different file format starting from September 2018 and the removal of NULL values through linear interpolation prior to applying the 31-day moving average (Towill communication).

An analysis of the updated GPS time series by TRE confirmed slight differences with an overall improvement of the quality of the time series (Figure 6). The average differences in rate are within ±2mm for all three motion components (N, E and Vertical) and had a minimal impact on the consistency of the calibration results with the historical data.

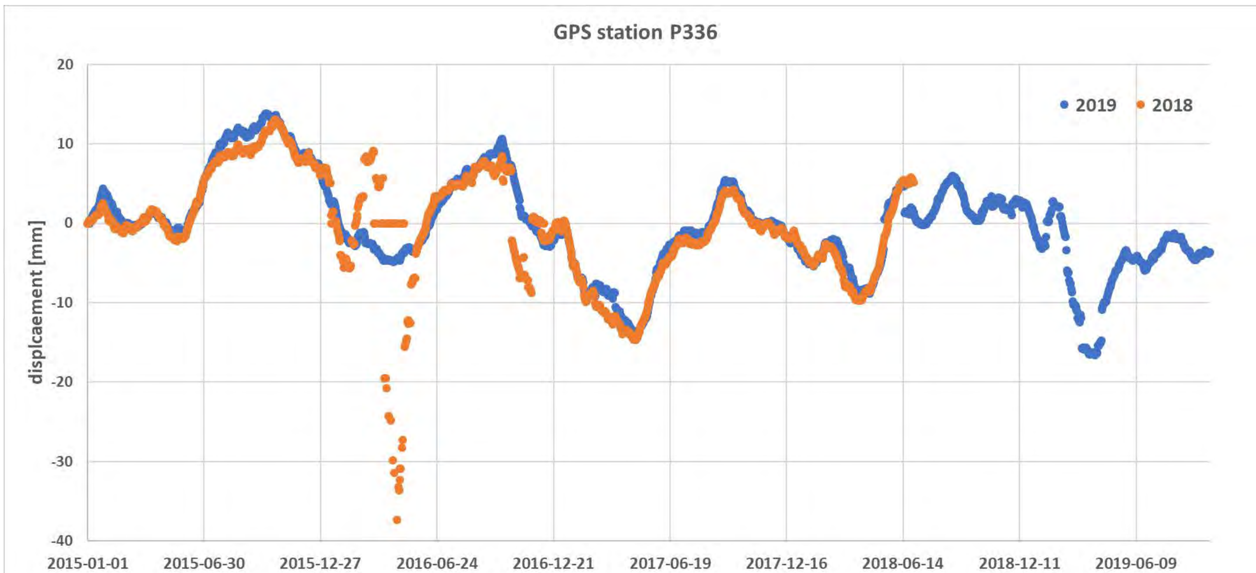


Figure 6: Comparison between the time series of the GPS P336 used for the 2018 analysis (in orange) and the 2019 analysis (in blue).

6.1. Methodology

The calibration of the LOS data was performed using the methodology defined in 2018, which is reiterated below (Figure 7):

- Time series filtering and projection to the satellite LOS:
  - The GNSS 3-D measurements provided by Towill were projected to the satellite 1-D LOS to create a GNSS LOS time series (LTS). This step allows a direct comparison of the two independent measurements (InSAR and GPS).
  - All InSAR measurement points (MP) within a 100-meter radius of each GNSS were selected and used to calculate an average time series (ATS) for the overlapping period with the GNSS

time series (one InSAR ATS for each GNSS). This step allows the comparison of data collected at a same location over a corresponding period of time.

- Plane removal: to remove possible linear errors related to potential satellite orbital inaccuracies, a difference in average velocity (linear trend) was calculated for each ATS and corresponding LTS. The average velocity differences calculated for each ATS and LTS pair were then used to estimate and remove a first order surface (plane) from all InSAR MP. The plane is statistically estimated at regional scale by minimizing the residuals of the differences between the ATS and corresponding LTS.
- Absolute calibration: to tie the two measurement techniques together and convert the relative InSAR measurements to the absolute reference system of the GNSS network, it was necessary to calibrate the local InSAR reference points to the same absolute reference. The procedure involved the generation of an average time series of residuals by comparing the ATS to the corresponding LTS for each GNSS location. All the time series of residuals obtained were then averaged to define a unique common time series of residuals (cRTS) at regional scale. This cRTS represents the movement of the local InSAR reference points with respect to the absolute GNSS reference frame. The cRTS was then removed from every InSAR MP time series.

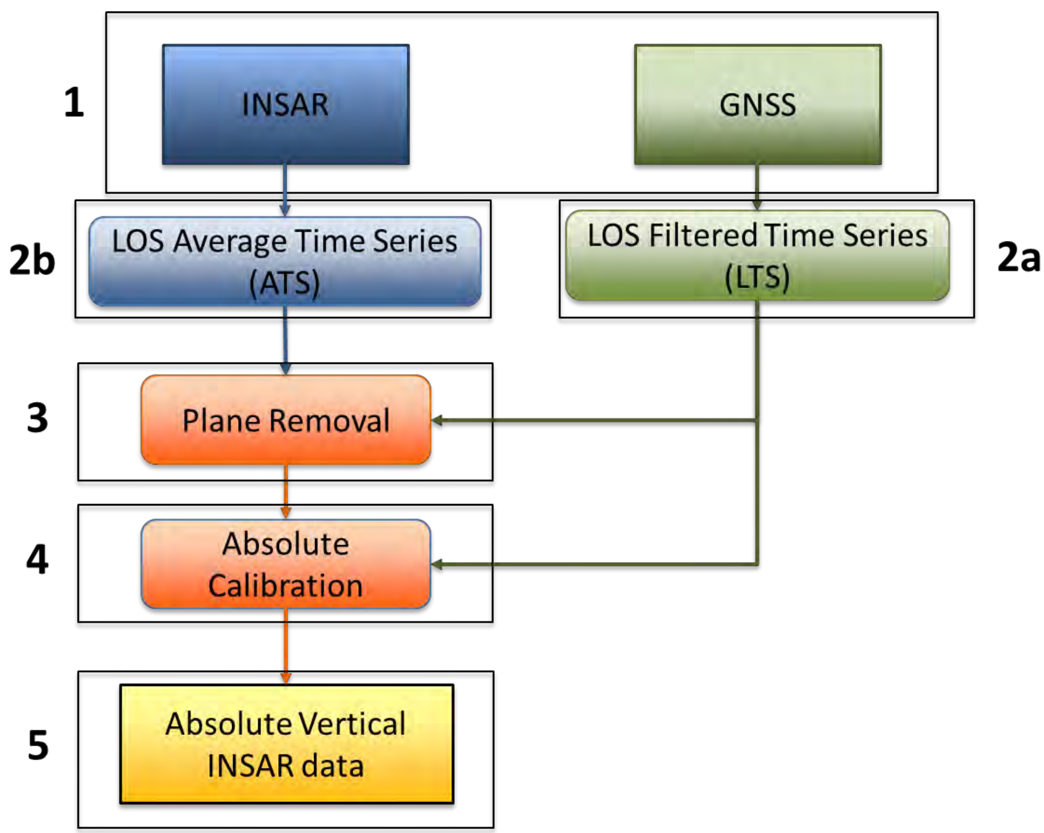


Figure 7: Diagram of the calibration methodology.

7. Task 2.5: Vertical measurements

The ascending and descending calibrated LOS InSAR time series covering the period January 2015 – September 2019, constitute the input for the absolute vertical time series estimation. The vertical measurements are produced using the same assumptions and methodology of the 2018 analysis:

- Satellites from different orbits and tracks identify different objects on the ground. For this reason, the data combination procedure requires the use of a common spatial grid to subsample the full resolution LOS results. The entire area was divided into a lattice of cells, using the same grid of the 2018 analysis (100x100 m square cells with the same code of the 2018 analysis), with the assumption that MPs belonging to the same cell are affected by the same motion.
- The average of all measurements within a same cell are referred to as synthetic measurement points (SMP). Both ascending a descending SMP are calculated for each cell. The resolution of the SMP, and thus of the resulting vertical data, as consequence of the use of the previously mentioned grid, is 100 m. SMP do not correspond to specific radar targets on the ground but instead represent synthetic points positioned at the centre of the cells.
- Since acquisition dates differ for each processing polygon, the LOS displacement time series of each SMP must be interpolated and re-sampled on a common temporal grid. The temporal grid was defined with the same criteria used for the 2018 analysis: one sample at the 1st day of each month and a frequency of approximately 7 days within the same month.
- The vertical time series of deformation for each SMP was calculated by combining all available ascending and descending LOS time series for the period in common to all LOS data (13 June 2015 – 19 September 2019). The data combination is only performed for cells that contain SMP from both ascending and descending orbits.
- Following the same procedure as in 2018, for those areas where either the ascending or descending orbit data were unavailable, the vertical time series were calculated by projecting the available LOS results to the vertical direction. Descending results were selected by default as they are generally less affected by atmospheric noise compared to the ascending data.

This methodology maintains the maximum consistency with the 2018 vertical results. Minimal differences in the point coverage were observed with respect to the 2015-2018 analysis (due to the loss of a few cells stemming from changes to the ground surface) as well as in the time series (due to the changes in the input GNSS time series), with an overall further improvement of the results.

8. Task 2.6: Draft deliverables

The draft deliverables were generated for both the common period and the variable start date results, as for the 2018 results, and made available on the TREmaps web platform and the dedicated SFTP.

Following the delivery of the draft data sets (Milestone 3), TRE received and addressed the following requests from DWR and Towill:

- Include within the final vertical measurements the points that have lost coherence in the 2018-2019 period by padding them with Null values in the database.
- Include an additional cumulative displacement raster map for the last image of the vertical dataset, 19 September 2019, even if it covers a period shorter than 1 month.

9. Task 2.7: Final Deliverables

The following are the final deliverables:

- Common start date measurements
- Cumulative deformation raster maps
- Variable start date measurements
- Annual deformation raster maps
- LOS (ascending and descending) measurements

9.1. Common start date:

- Start date: 13 June 2015
- Period covered: 13 June 2015 - 19 September 2019
- Vertical measurement point database is provided in shapefile format, subdivided into 9 shapefiles to not exceed the file size limitations of current GIS software. Database contents are reported in Figure 8.
- The temporal sampling consists of one measurement every ~7 days with a sample fixed at the first day of each month.
- The reference system is WGS84 and the measurements are in metric units (mm).

Field	Description
CODE	Synthetic Measurement Point (sMP) identification code
VEL_V	sMP average vertical displacement rate in the common period 13 June 2015 - June 2018. Positive values correspond to uplift; negative values correspond t subsidence. Values are expressed in [mm/year]
V_STDEV	Vertical displacement rate standard deviation [mm/year]
ACC	Acceleration [mm/year^2]
SEASON_AMP	Average seasonal amplitude [mm]
Dyyyymmdd	Each field contains the cumulative displacement with respect to the first acquisition. Displacement values are expressed in [mm]

Figure 8: Database contents of the common start date shapefiles.

9.2. Cumulative raster maps

- Cumulative raster maps are generated using the common start date database
- Each map covers an increasing window with monthly increments, starting from 13 June 2015, using the measurement value at the 1st of each month. As required, a final raster map covering the period 13 June 2015-19 September 2019 was added.
- Raster maps are generated using an interpolation radius of 500m, have a geotiff format, are 32-bit and have 100-meter resolution.
- The maps are in WGS84 reference system and measurement unit is U.S. Survey feet.

9.3. Variable start date:

- Variable start date for each point. The temporal coverage of each measurement point depends on the available satellite imagery in that area.
- Period covered: 01 January 2015 - 19 September 2019.
- Vertical measurement point database is provided in
  - shapefile format, subdivided into 10 shapefiles to not exceed the file size limitations of GIS software. Database contents are reported in Figure 9.
  - table format (.csv), subdivided into 10 files to not exceed file size limitations. *Null* values assigned for dates where there is no satellite data or loss of interferometric coherence (i.e. for points that are no longer radar reflectors because of the surface changes occurred with respect to the 2018 analysis). Zero value corresponds to the start date. Database contents are reported in Figure 10.
- The temporal sampling consists of one measurement every ~7 days with a sample mandated to the first day of each month.
- The reference system is WGS84 and the measurements are in metric units (mm).

Field	Description
CODE	Synthetic Measurement Point (sMP) identification code
VEL_V	sMP average vertical displacement rate in the specific period. Positive values correspond to uplift; negative values correspond to subsidence. Values are expressed in [mm/year]
V_STDEV	Vertical displacement rate standard deviation [mm/year]
ACC	Acceleration [mm/year^2]
SEASON_AMP	Average seasonal amplitude [mm]
Dyyyymmdd	Each field contains the cumulative displacement with respect to a variable start date. Zero value assigned for dates where there is no satellite data. Displacemer values are expressed in [mm]

Figure 9: Database contents of the variable start date shapefiles.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	CODE	X	Y	D20150101	D20150107	D20150113	D20150120	D20150126	D20150201	D20150207	D20150212	D20150218	D20150223	D20150301	D20150307
2	ERS5I59	-121.97	42.00544	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	-1.9	-2.8
3	ERS5I5A	-121.969	42.00544	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	-3.2	-5.4
4	ERS5I5C	-121.966	42.00544	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	1	1.6
5	ERS5I5D	-121.965	42.00544	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	2.1	4.2
6	ERS5I5E	-121.964	42.00544	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	-0.1	-0.3
7	ERS5I5F	-121.963	42.00544	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	0.3	0.7
8	ERS5I5G	-121.962	42.00544	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	-0.6	-0.9
9	ERS5I5H	-121.961	42.00544	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	0.2	0.6
10	ERRK2JM	-121.964	42.00454	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	-0.6	-1.3
11	ERRK2JN	-121.963	42.00454	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	-0.2	-0.2
12	ERRK2JO	-121.962	42.00454	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	2.2	3.5
13	ERRK2JP	-121.961	42.00454	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	2	4.2
14	ERRK2JQ	-121.96	42.00454	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	2	3.8
15	ERQYMXV	-121.963	42.00364	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	-2	-4.2
16	ERQYMXW	-121.962	42.00364	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	0	1.4	2.5

Figure 10: Example of the table contents.

9.4. Annual raster maps

- Annual raster maps are generated using the variable start date database
- Each raster map covers a moving one-year period, produced at monthly intervals starting from 01 Jan 2015, using the measurement value at the 1st of each month. The maps contain values for those areas where measurements exist for the full annual interval (other cells have No Data values). As requested, a final raster map covering the period 01 Oct 2018 - 19 September 2019 was added.
- Raster maps are generated using an interpolation radius of 500m, have a geotiff format, are 32-bit and have 100-meter resolution.
- The maps are in WGS84 reference system and measurement unit is U.S. Survey feet.

9.5. LOS measurements

- The full resolution LOS data consist of 40 shapefiles, 20 ascending (Figure 11) and 20 descending (Figure 12), divided into two main groups:
  - OLD AREAS: 30 shapefiles including the 2018-2019 LOS measurements obtained by the 2019 processing of the areas covered in the 2018 analysis.
  - NEW AREAS: 10 shapefiles including the 2015- 2019 LOS measurements over the new basins covered by the 2019 analysis.
- Table 3 describes the parameters included in the database of each LOS shapefile.
- The reference system is WGS84 and the measurements are in metric units (mm).

9.5.1. LOS measurements characteristics

Every measurement point (MP) identified by SqueeSAR corresponds to a radar target on the ground that displays stable reflectivity and coherent phase throughout every image of the processed imagery. The MPs belong to two different families (indicated by the parameter EFF_AREA in Table 3):

- Permanent Scatterers (PS): point-wise radar targets characterized by high stable radar signal return (e.g. buildings, rocky outcrops, linear structures, etc.), with EFF_AREA = 0 in the attribute table.
- Distributed Scatterers (DS): patches of ground exhibiting a lower but homogenous radar signal return (e.g. uncultivated land, debris, deserted areas, etc.), with EFF_AREA > 0 in the attribute table.

The density and distribution of the MPs depends on the land cover. In general, MP density increases with the presence of man-made structures and decreases with the presence of vegetation. The highest density is reached over urban areas and arid ground, while it is lower over vegetated or agricultural areas, which are affected by reflectivity changes over time.

For each MP identified, SqueeSAR provides the ground target's position and the displacement time series (Dyyyymmdd fields in Table 3), representing the evolution of the MP's displacement for each acquisition date measured along the LOS direction.

SqueeSAR displacement measurements are provided with two precision indices:

- Displacement rate standard deviation (V_STDEV in Table 3), which provides an indication of the error bar associated with the annual displacement rate measurements.
- Time series standard deviation (STD_DEF in Table 3), which provides an indication of the error bar associated with the displacement time series.

The displacement rate standard deviation characterizes the error associated with rate measurements. Given the standard deviation (σ), and assuming that the errors are normally distributed (or Gaussian), 95% of the values tend to be included in a ±2σ range

The standard deviation of the deformation time series indicates how well an analytical model fits the deformation time series. The model is selected individually for each measurement point with an advanced Model Order Selection technique that also considers the quality of the image archive (number of processed images, time span covered by the archive and possible gaps in the acquisitions). The lower the standard deviation, the lower the average residual with respect to the analytical model. (i.e. the smaller the error bar of the time series).

In order to facilitate the analysis of non-linear movements, acceleration (ACC in Table 3) and seasonal amplitude (SEASON_AMP in Table 3) parameters are provided within the database of each shapefile.

The acceleration [mm/year^2] is calculated by fitting a displacement polynomial model to the time series:

$$d(t) = a + bt + ct^2$$

The seasonal amplitude [mm] is calculated by fitting a displacement polynomial model with a seasonal component to the time series:

$$d(t) = a + bt + ct^2 + A\cos(\frac{2\pi T}{365} + \varphi)$$

Where A = semi-amplitude, T = time [day] and φ = phase (seasonal amplitude maximum value with respect to the first image acquisition)

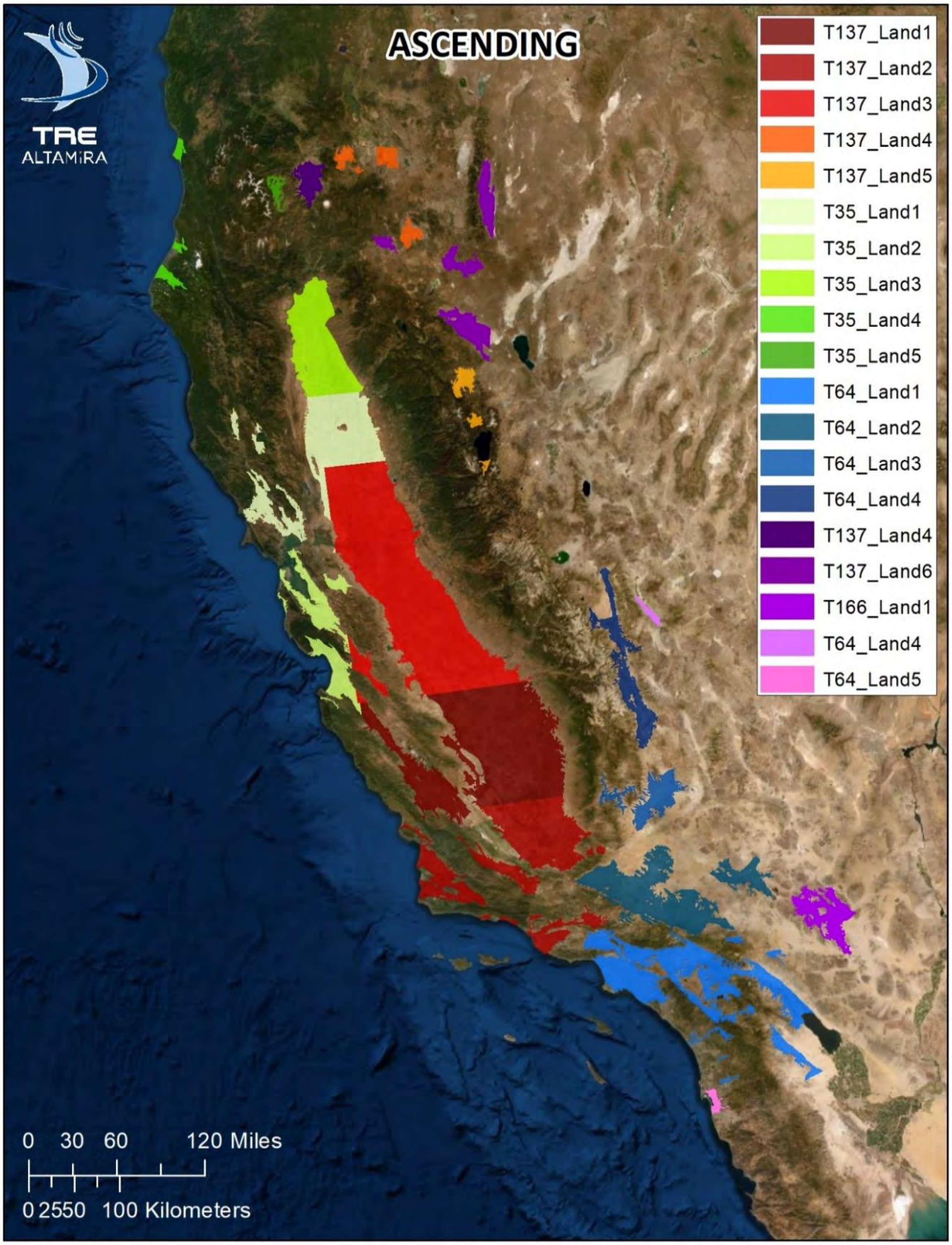


Figure 11: Coverage of the 20 LOS ascending shapefiles.

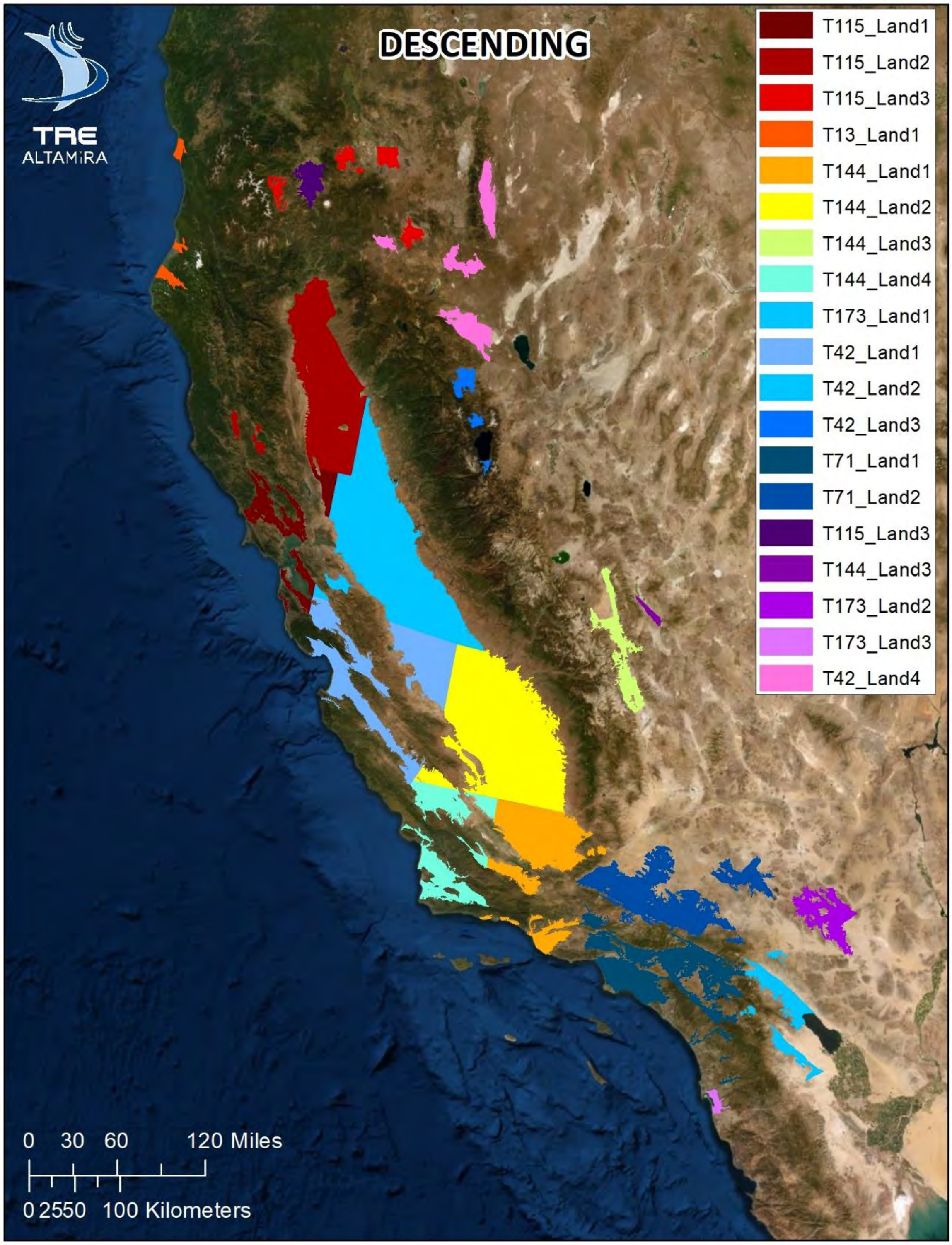


Figure 12: Coverage of the 20 LOS descending shapefiles.

Field	Description
CODE	Measurement Point (MP) identification code
HEIGHT	Topographic Elevation [m] referred to WGS84 ellipsoid
H_STDEV	Height standard deviation [m]
VEL	MP displacement rate. Positive values correspond to motion *toward the satellite;* negative values correspond to motion *away from the satellite* [mm/year]
V_STDEV	Displacement rate standard deviation [mm/year]
ACC	Acceleration [mm/year^2]
SEASON_AMP	Average seasonal amplitude [mm]
COHERENCE	Index varying between 0 and 1, related to the MP phase noise and to the capability of the motion model adopted to cope with the actual MP behaviour
STD_DEF	Average standard deviation of the displacement time series
EFF_AREA	This parameter represents the effective extension of the area [m^2] covered by Distributed Scatterers (DS). For Permanent Scatterers (PS), its value is set to 0
Dyyyymmdd	Fields containing the displacement values of successive acquisitions relative to the first acquisition available. Displacement values are expressed in [mm]

Table 3: Description of the fields contained in the database of a LOS shapefile

9.5.2. Notes for the comparison of LOS data with other 3-D data

InSAR measurements are originally 1-D, corresponding to the projection of real movement onto the satellite Line of Sight (LOS). The schematic of ascending and descending acquisition geometries is reported in Figure 13. θ is the angle between the LOS and the vertical direction. δ is the angle between the LOS and the NS direction.

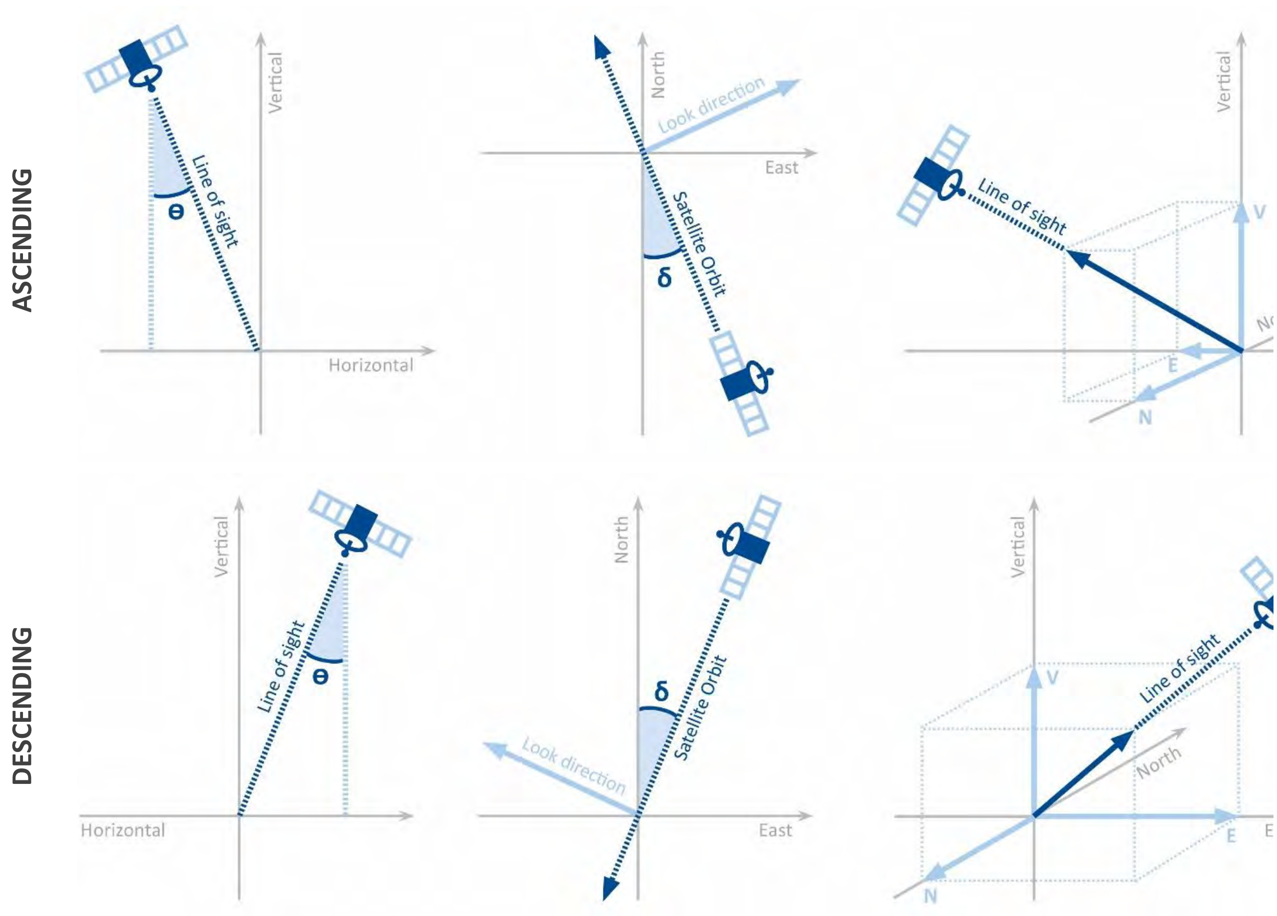


Figure 13: Schematic of the LOS orientation for ascending and descending orbits.

To compare 3-D measurements obtained by other technique such a GNSS network with InSAR LOS data, it is necessary to project the 3-D measurement to the specific LOS according to:

$$D_{LOS} = D_{VERT}*H_{LOS} + D_{EW}*E_{LOS} + D_{NS}*N_{LOS}$$

D_{VERT}, D_{EW} e D_{NS} are the measurements provided by the GNSS along the three directions. H_{LOS}, E_{LOS} e N_{LOS} are the cosine versors of the LOS along the three directions, which are specific for each LOS processing polygon and are reported in the metadata files (xml) attached to the shapefile. D_{LOS} is the GNSS measurement projected to the LOS direction. The cosine versors of each LOS shapefiles are summarized in Table 4.

Orbit	Processing polygon	N_{LOS}	E_{LOS}	H_{LOS}	new/old
ASCENDING	CALIFORNIA_SNT_A_T35_LAND1	-0.117	-0.646	0.753	old
	CALIFORNIA_SNT_A_T35_LAND2	-0.121	-0.649	0.750	old
	CALIFORNIA_SNT_A_T35_LAND3	-0.119	-0.671	0.731	old
	CALIFORNIA_SNT_A_T35_LAND4	-0.102	-0.589	0.801	old
	CALIFORNIA_SNT_A_T35_LAND5	-0.116	-0.669	0.733	old
	CALIFORNIA_SNT_A_T64_LAND1	-0.111	-0.632	0.766	old
	CALIFORNIA_SNT_A_T64_LAND2	-0.109	-0.631	0.767	old
	CALIFORNIA_SNT_A_T64_LAND3	-0.101	-0.593	0.798	old
	CALIFORNIA_SNT_A_T64_LAND4	-0.102	-0.617	0.780	old and new
	CALIFORNIA_SNT_A_T64_LAND5	-0.113	-0.631	0.767	new
	CALIFORNIA_SNT_A_T166_LAND1	-0.118	-0.603	0.788	new
	CALIFORNIA_SNT_A_T137_LAND1	-0.129	-0.611	0.780	old
	CALIFORNIA_SNT_A_T137_LAND2	-0.096	-0.634	0.766	old
	CALIFORNIA_SNT_A_T137_LAND3	-0.125	-0.603	0.787	old
	CALIFORNIA_SNT_A_T137_LAND4	-0.114	-0.577	0.808	old and new
	CALIFORNIA_SNT_A_T137_LAND5	-0.132	-0.647	0.750	old
	CALIFORNIA_SNT_A_T137_LAND6	-0.129	-0.645	0.753	new
	CALIFORNIA_SNT_A_T166_LAND1	-0.604	-0.118	0.789	new

Table 4: Cosine versos of the LOS ascending data.

Orbit	Processing polygon	N_{LOS}	E_{LOS}	H_{LOS}	new/old
DESCENDING	CALIFORNIA_SNT_D_T13_LAND1	-0.115	0.594	0.795	old
	CALIFORNIA_SNT_D_T42_LAND1	-0.100	0.625	0.774	old
	CALIFORNIA_SNT_D_T42_LAND2	-0.095	0.615	0.782	old
	CALIFORNIA_SNT_D_T42_LAND3	-0.095	0.627	0.772	old
	CALIFORNIA_SNT_D_T42_LAND4	-0.094	0.646	0.757	new
	CALIFORNIA_SNT_D_T71_LAND1	-0.115	0.613	0.781	old
	CALIFORNIA_SNT_D_T71_LAND2	-0.115	0.622	0.773	old
	CALIFORNIA_SNT_D_T71_LAND3	-0.121	0.661	0.740	old
	CALIFORNIA_SNT_D_T115_LAND1	-0.105	0.593	0.798	old
	CALIFORNIA_SNT_D_T115_LAND2	-0.103	0.597	0.795	old
	CALIFORNIA_SNT_D_T115_LAND3	-0.101	0.602	0.792	old and new
	CALIFORNIA_SNT_D_T144_LAND1	-0.121	0.587	0.799	old
	CALIFORNIA_SNT_D_T144_LAND2	-0.127	0.624	0.770	old
	CALIFORNIA_SNT_D_T144_LAND3	-0.112	0.558	0.821	old and new
	CALIFORNIA_SNT_D_T144_LAND4	-0.096	0.670	0.735	old
	CALIFORNIA_SNT_D_T173_LAND1	-0.110	0.653	0.748	old
	CALIFORNIA_SNT_D_T173_LAND2	-0.108	0.652	0.750	new
	CALIFORNIA_SNT_D_T173_LAND3	-0.117	0.687	0.717	new

Table 5: Cosine versos of the LOS descending data

10. Data delivery

All deliverables are provided to Towill and DWR through the TREmaps web platform and a dedicated SFTP site (login credentials provided by email).

For ease of use, the deliverables are organized into four different groups: 1) Common start date; 2) Cumulative raster maps; 3) Variable start date; 4) Annual rater maps; 5) LOS data

Cumulative and annual maps are visualized on TREmaps starting from the last map of the 2018 analysis but all the raster files for the entire period 01 January 2015-01 September 2019 can be downloaded.

LOS results are provided only through the SFTP site because of the big size of the files.

11. Summary

Ground deformation measurements over the basins indicated by DWR were updated using the SqueeSAR data processing algorithm for the period June 2018 - September 2019. The results were integrated with the previous 2018 study results to generate uninterrupted vertical deformation time series for the period January 2015 - September 2019. New basins indicated by DWR were processed separately and then included in the final database.

The processing strategy had the aim of providing the most accurate measurements over the entire extent of the area of interest while maintaining the maximum consistency with the results obtained in 2018. This was achieved in several steps that included the minimization of possible sources of noise (e.g. atmospheric variations, satellite orbital errors) and calibrating the InSAR data to the regional GNSS network.

The calibration phase followed the regional scale methodology defined in the 2018 study, using 231 GNSS stations out of 782 available from the UNAVCO network, to remove orbital inaccuracies and to fix the local InSAR reference points to the absolute GNSS network reference system. The results will be validated by Towill in the project Task 4.

Appendix 2-E - Model Documentation

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Executive Summary

This report presents a preliminary version of the model documentation for the Shasta Watershed Groundwater Model (SWGM) v 1.0; this is the first available integrated hydrological model that represents the entire Shasta Valley watershed. This documentation highlights key model components and describes the planned modifications considered for future updates of the SWGM. Many of these modifications and enhancements are already under development requiring the technical team to balance the need to document key model inputs or assumptions and the ongoing refinement of the SWGM. This effort to document an evolving model has therefore required the technical team to incorporate place holders pending further information. Any updates to parametrization, parameter values, or additional observations will be published in SWGM v1.1.

As an important note for the review of the GSP, the model has been actively used only to provide a representation of the water budget of the entire watershed and of the groundwater basin for historical, and current conditions and for future climate change scenarios. All key GSP decision up to this point, including the development of Sustainable Management Criteria (SMCs), have been made using available observed data and not on simulated results from the SWGM. The Advisory Committee that collaborated with the technical team throughout the past three years strongly recommended that the GSP clearly state that the development of the SWGM has been an achievement but, due to the limited time and the limited data availability, the uncertainty in the model is currently too significant to be reasonably used to drive critical decision making for the GSP. The extensive data gap section (Appendix 3-A) and the description of the SMCs in Chapter 3 explain in detail which data will be collected over the next five years to allow the development of a more robust model. For the 5-year GSP update, we envision new definitions of the SMCs that rely on observed data in addition to simulated model results and future scenarios.

A brief history of the development of all the model components is summarized here. The technical team started working on data collection and evaluation in 2018. Following this preliminary assessment, we followed these steps:

- Development of the 3-dimensional geological model: analysis and geolocation of about 1500 well-logs throughout the valley, development of the geological model which serves as the basis for the groundwater model layer definition;
- Development of the crop-demand soil water budget model (Davids Engineering, Appendix 2-I);
- Extensive coordination with the State Water Resource Control Board (SWRCB) environmental flows project technical team to ensure that atmospheric inputs including precipitation, potential evapotranspiration, and temperature align to the extent possible;
- Development of a surface water hydrology model reflecting key elements including precipitation as rain or snow, snow accumulation, snowmelt, and surface runoff using the PRMS software with preliminary sensitivity analysis and calibration;
- Development of the Hydrogeological Conceptual Model;
- Groundwater model (based on MODFLOW) with preliminary sensitivity analysis and calibration; and
- Preliminary coupling in GSFLOW, but not currently used because of runtime limitations.

The PRMS surface water model is expected to be refined and enhanced significantly in coming iterations as additional data and datasets become available. Time series datasets derived from an array of planned stream gages is expected to allow for the validation of surface water flows derived from a currently poorly understood combination of precipitation as rain or snow, snow melt, and spring flow. In the absence of a comprehensive and defensible hydrologic feature or hydrography dataset, the modeled representation of stream channels and springs was derived using a digital elevation model (DEM) and Advisory Committee input. This placeholder dataset is expected to be revised and enhanced using a combination of continued stakeholder outreach, validation using satellite imagery, and potentially additional instrumentation. Streambed location and geometry is expected to revisited and revised with high resolution Light Detection and Ranging (LiDAR) elevation data provided by the SWRCB.

The spatial and temporal dynamics of snowpack hydrology within the Shasta Watershed are currently a notable data limitation with significant variability observed at snow pillows across the region and limited understanding of glacier melt on Mt. Shasta. Future DWR snow surveys are expected to allow for refinement of the snow module within PRMS to more effectively simulate the accumulation and subsequent melting of snowpack across the Shasta Watershed. Additional novel resources in the field of snowpack hydrology, including snowpack modeling from UC Santa

Barbara's Snow Hydrology Research Group is also expected to allow for the refinement of the snowpack in PRMS.

The first iteration of the SWGM includes several atmospheric time series datasets that were developed by Paradigm Environmental, the technical team of consultants developing a parallel model for the SWRCB's environmental flows project. An extensive effort was made to coordinate with the SWRCB's technical team through a series of meetings and follow up conversations allowing for the sharing of model inputs but not yet model input documentation. The SWGM technical team has included a short conceptual overview outlining the origin and development of these datasets and how they were incorporated into the PRMS model in the absence of comprehensive documentation from Paradigm Environmental or a SWRCB environmental flows project work product to reference. The refinement of atmospheric inputs is expected to be a key component of SWGM revisions through a combination of on the ground observed conditions and remote sensing datasets derived from satellites. Key areas of focus are expected to be the spatial and temporal variability of precipitation and temperature as it drives the rain, snow, and snowmelt elements of the model.

SWGM v1.0 should be considered a preliminary effort to characterize the Shasta Watershed and as such the SWGM will continue to be updated to better represent the hydrologic system as new data from continuous groundwater sensors, increased number of stream gages, and agricultural water usage become available. The Model Documentation will continue to be updated as the SWGM is updated.

Introduction / Background

The Shasta Watershed Groundwater Model (SWGM) was developed to calculate historical and projected water budgets and to improve understanding of long-term trends in groundwater levels. The SWGM is a loosely coupled groundwater-surface water interaction model. The groundwater is simulated through USGS' Modular Groundwater Flow Model (MODFLOW) (Harbaugh 2005), climate variables and surface water flows are simulated through the Precipitation-Runoff Modeling System (PRMS) (Markstrom et al. 2008) with the addition of a Daily Root Zone Simulation Model (RSRZ) providing input for irrigated lands (Davids Engineering 2013). The SWGM simulates the entire Shasta Valley HUC8 Watershed (Watershed) with the Bulletin 118 Groundwater Basin located within the domain.

The SWGM was developed to meet the requirements of the Sustainable Groundwater Management Act (SGMA) (Cal. Water Code, Division 6, Part 2.74).

Purpose and Scope

Development of SWGM was done to assist in the development of a water balance within the Shasta Valley Groundwater Sustainability District. In order to estimate subsurface inflows into the District, the entire Watershed is modeled. This iteration of the model should still be considered preliminary. Inflows and outflows within the watershed are accounted for to degree that time and budget allowed. Updates to the model should be conducted as additional data are gathered from the region.

Description of Study Area

Model Software Summary

The SWGM is a combination of multiple models interacting to simulate the entire HUC8 Shasta Watershed. Three models are used to estimate all of the flow components herein. The three models are a Daily Root Zone Simulation Model (RZSM) developed by Davids Engineering, a Precipitation-Runoff Modeling System (PRMS), and MODFLOW-OWHM.

RSRZ

Davids Engineering developed a Daily Root Zone Simulation Model (RSRZ) that calculates the root zone water budget based on the water budget components Figure 1. The RSRZ uses precipitation and evapotranspiration as the driving water budget model inputs, and root zone water balance parameters based on crop and soil type that impact the soil moisture storage. The RSRZ model relies on remote sensing-based estimates of evapotranspiration model derived from imagery collected by LandSat satellties, Parameter-elevation Regressions on Independent Slopes Model (PRISM) rainfall data developed by Oregon State University[1], and root zone parameters based on the crop and soil types (Davids Engineering 2013). The Daily root zone dynamics were modeled from January 1989 to December 2018. Daily water budget components were then upscaled to monthly values by taking the sum of each water budget component (e.g. evapotranspiration). These monthly values were extracted and incorporated into the MODFLOW models as *Applied Water* and *Deep Percolation* which respectively represent the amount of groundwater pumping for cells where irrigation occurs and the amount of groundwater recharge to the aquifer. Complete details of the Daily Root Zone Simulation Model can be found in Appendix 2-I.

Davids Engineering developed a Daily Root Zone Simulation model that uses remote sensing based evapotranspiration model using LandSat, PRISM rainfall data from Oregon State[2], and root zone parameters based on the crop and soil types (Davids Engineering 2013). The Daily RSRZ was ran from January 1989 to December 2018 and provided the calculated *Applied Water* and *Deep Percolation* which respectively represent the amount of groundwater pumping for irrigated cells and the amount of groundwater recharge to the aquifer. The daily water budget components were then upscaled to monthly values by taking the sum of each water budget component (e.g. Evapotranspiration). Complete details of the Daily Root Zone Simulation Model can be found in Appendix 2-I.

PRMS

PRMS is a surface water hydrology model focused on simulating a watershed's response to climatic processes such as precipitation, evaporation, and evapotranspiration. The first iteration of PRMS was released by USGS in 1983 in the FORTRAN programming language where model inputs were incorporated with punch cards and outputs were summarized by line printers. USGS has released five iterations of the model with recent revisions focused on streamlining the integrating PRMS with other computational tools such as USGS' MODFLOW. The surface water component of USGS' coupled Groundwater and Surface Water FLOW (GSFLOW) model developed for the Shasta GSP is the most recent publicly available iteration of PRMS, PRMS-V or version 5, released in late May of 2019. PRMS is comprehensively documented and supported by USGS with a dedicated webpage, release notes, and installation instructions. The PRMS version 4 User's Manual (PRMS

[1]PRISM website: http://prism.oregonstate.edu/
[2]PRISM website: http://prism.oregonstate.edu/

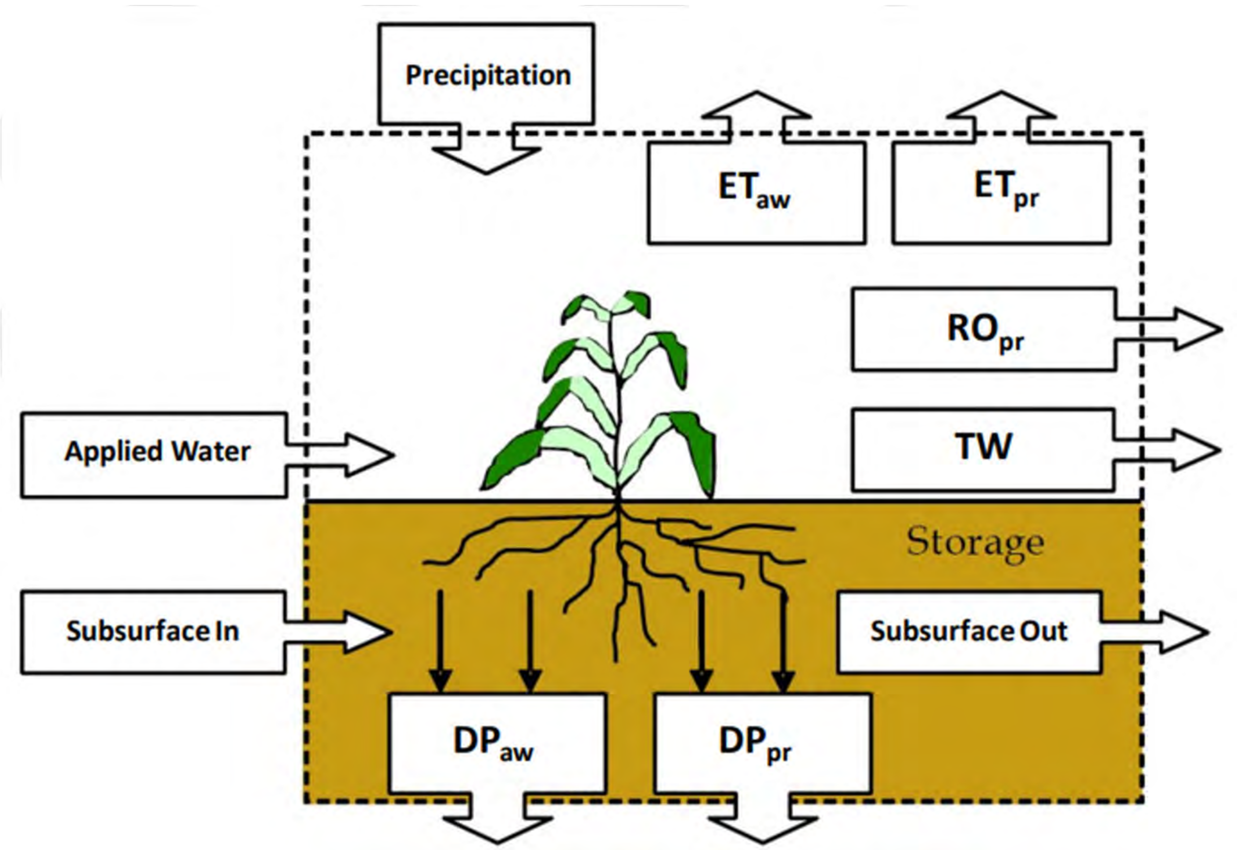

Figure 1: Conceptualization of Fluxes of Water Into and Out of the Crop Root Zone

User's Manual) is the most comprehensive resource outlining model parameters and processes. Table 1 documents the process and modules used within the SWGM.

MODFLOW

MODFLOW is a finite difference groundwater model simulating spatial and temporal groundwater conditions in the watershed. The MODFLOW model simulates the spatially and temporal variable dynamics of groundwater fluxes and groundwater elevations which are sufficient to characterize a water budget for the Basin and determine whether there will be significant changes in water level that may impact groundwater users. Table 2 summarizes the MODFLOW packages used within SWGM.

Table 1: PRMS Modules used

Process	Module
Computation Order	$call\_modules$
Basin Definition	$basin$
Cascading Flow	$cascade$
Common States and Fluxes	$climateflow$
Potential Solar Radiation	$soltab$
Parameter Setup	$setup\_param$
Timestep Control	$prms\_time$
Time Series Data	obs
Potential Evapotranspiration	$climate\_hru$
Temperature Distribution	$temp\_1sta$
Precipitation Distribution	$precip\_1sta$
Solar Radiation Distribution	$ddsolrad$
Transpiration Distribution	$transp\_tindex$
Canopy Interception	$intcp$
Snow Dynamics	$snowcomp$
Surface Runoff	$srunoff\_smidx$
Soilzone Computations	$soilzone$
Groundwater	$gwflow$
Streamflow Routing Init	$routing$
Streamflow Routing	$muskingum$

Table 2: MODFLOW Pachages used to Calculate Groundwater Flows in the Basin

MODFLOW Package	Application
BAS6	Define Active Model Domain
DIS	Define Model Grid and Extent
LAK	Lake Shastina and Grass Lake
SFR	Shasta River, tributaries, and springs
UPW	Geologic model
GHB	Canals
UZF	Recharge and runoff
WEL	Groundwater pumping for irrigation needs
ZONE	Delineate hydrogeologic zones
PVAL	Parameters data
GAGE	Output from SFR and LAK packages
OC	Output control
NWT	Numerical solver
HOB	Head observation package

Hydrologic System

Climate

The Shasta Valley generally has a mixture of warm-summer Mediterranean and high desert environment climates with distinctive seasons of cooler, wetter winters and warm, dry summers. The orographic effect of the mountains to the west and south sides of the Valley creates a rain shadow in eastern areas of the Valley. The higher elevation areas to the west and south of the Valley historically receive greater annual precipitation (30–70 inches [in], or about 76–177 centimeters [cm]) in comparison to annual precipitation on the east side of the Valley (12–15 in). Annual mean precipitation ranges from a low of about 13 to 15 in (33–38 cm) at lower elevations to a high of about 67 in (170 cm) at Mount Shasta; see the summary statistics table for the (out of Watershed but close to the southern border) Mount Shasta rainfall gauge (station ID: 045983; SWRCB 2018). In the City of Yreka, annual precipitation averages range from 19 to 21 in (48–53 cm); see the attached plot of 1960–2005 Yreka annual precipitation (CDWR 2011) and the summary statistics table for the Yreka rainfall gauge (station ID: 049866; SWRCB 2018). Annual precipitation ranges from 25 to 29 in (64–74 cm) at853higher elevations of the Klamath Mountains to the west, and up to 33 in (84 cm) near China Mountain. To the east, higher elevations of the Cascade Range receive from 19 to 27 in (48–69 cm) of precipitation annually. The rainy season, which generally begins in October and lasts through April, accounts for about 80 percent of total annual rainfall. At elevations below 4,000 ft (~1,200 m) amsl, precipitation mostly occurs as rainfall, as is the case on the valley floor. Precipitation accumulates as snow in the surrounding mountains, with a rain-snow transition zone from 4,000 to 5,000 ft (~1,200–1,500 m) amsl. Accumulation of snowfall in the surrounding mountains results in runoff during spring snowmelt.

Surface Water

Elevation across the approximately 800 sq mi (~2,070 sq km) Watershed ranges from just over 2,000 ft (610 m) amsl near the confluence with the Klamath River to over 14,000 ft (4,300 m) near the peak of Mount Shasta. Several smaller watersheds encompassed by the Shasta River watershed; the two most notable being the Little Shasta River and Parks Creek. The Watershed is bounded to the west by the Scott River watershed, to the south by the Sacramento River watershed, to the east by the Butte Creek watershed, and by the Klamath River to the north. Shasta River is approximately 58 miles (93 km) long stretching from the peak of Mount Eddy at about 9,000 ft (2,750 m) amsl to the confluence with the Klamath River. The Little Shasta River drainage basin within the Watershed is bounded by Goosenest Mountain (8,260 ft; 2520 m amsl) to the south, Ball Mountain (7,792 ft; 2,375m amsl) to the east and Willow Creek Mountain (7,828 ft; 2386 m amsl) to the north. Little Shasta River is predominantly spring fed, sustained by a series of springs emerging from Quaternary and Tertiary High Cascade volcanic materials, discussed further in Section 2.2.1.3. Mount Shasta, snow-covered year-round, is the most conspicuous feature of the landscape, visible from all parts of the Valley. Several glaciers stretch along its upper slopes which are the primary source of recharge to the Basin. On its north slope, Whitney, Bolam, and Hotlum Glaciers descend to altitudes of about 10,000 ft (3,048 m) amsl. On the south slope, the Koiiwakiton Glacier descends to an altitude of 12,000 ft (3,658 m) amsl, and the Clear Creek and Winton Glaciers to about 11,000 ft (3,353 m) amsl. Regional climate models generally predict the loss of Mount Shasta's glacier volume over the next 50 years and total loss of the glacier by the year 2100, likely resulting in reduced recharge in the Basin (UCD 2010?).

The Shasta River has a complicated seasonal and longitudinal flow regime due to intricate surface water and groundwater interactions, coupled with extensive agricultural diversion and return flows (Vignola and Deas 2005; Nichols et al. 2010). The Watershed includes a small number of small-scale diversion dams and diversions of the Shasta River or major tributaries, with the two main sources of water being the Shasta River and Parks Creek with storage in Lake Shastina (Dwinnell Reservoir). A number of the small-scale diversion dams have been or are in the process of being removed or modified for fish passage. Water rights dictating usage throughout the Shasta Basin are a combination of riparian and appropriative water rights adjudicated as a part of the 1932 Decree (CDWR 1932). Buck (2013) constructed a groundwater model for a portion of the Watershed and summarized major balance components for the period 2008–2011. The upper Shasta River (i.e., upstream of Dwinnell Dam) originates on the eastern slope of Mt. Eddy and is characterized by a runoff-driven hydrograph derived from rainfall and snowmelt (Nichols et al. 2010). Inflows to Lake Shastina consist of the upper Shasta River, flows diverted from Parks Creek near Edgewood, and Carrick Creek originating from the northwest flank of Mount Shasta. In 1928, construction of Dwinnell Dam was completed, impounding Lake Shastina to primarily serve as a storage reservoir and diversion for agricultural irrigation water throughout the Valley. Lake Shastina is the largest single water source in the Watershed. Outflow from Lake Shastina to the lower Shasta River, regulated by Dwinnell Dam, has reduced mean annual discharge in the reaches immediately downstream of the reservoir by up to 90 percent (Jeffres et al. 2008; Nichols 2008; Nichols et al. 2010). Maximum reservoir storage capacity in Lake Shastina is rarely achieved because of the permeable underlying volcaniclastic rocks which allow impounded water to flow into the underlying aquifer (Vignola and Deas 2005). Mack (1960) reported that multiple springs along the base of the ridge forming the western embankment of Lake Shastina increased in flow following construction of the reservoir. Seepage losses from Lake Shastina have been estimated at 6,500 to 42,000 acre-feet (AF) (~8-52 million cubic meters (m^3)) annually, significant relative to the reservoir's 50,000 AF (~62 million m^3) storage capacity, representing a loss of 13 to 84 percent of storage capacity (Paulsen 1963, NCRWQCB 2006). Flows in the lower Shasta River (i.e., downstream of Dwinnell Dam) are composed of minimal releases from Lake Shastina, tributary creeks (e.g., Parks Creek, Willow Creek, Little Shasta River), multiple discrete groundwater springs (e.g., Big Springs, Little Springs, Clear Springs, Kettle Springs, Bridge Field Springs), and additional diffuse groundwater springs. The lower Shasta River is characterized by a spring-dominated hydrograph primarily sourced from Big Springs Creek, supplied by multiple groundwater springs in the Big Springs Complex vicinity (Jeffres et al. 2008, Nichols 2008, Nichols et al. 2010). Spring-fed baseflows from Big Springs Creek outside the irrigation season (i.e., November to March) are five times those of the lower Shasta River upstream of the Big Springs Creek confluence (including Parks Creek) for the same time period (Jeffres et al. 2009). Approximately 95 percent of baseflows during irrigation season (i.e., April to October) in the lower Shasta River originate from the Big Springs Complex. During irrigation season, Big Springs Creek baseflows are approximately 35 percent lower, caused by temporally variable irrigation diversions and unquantified groundwater pumping (Jeffres et al. 2009). Instream flows downstream of Big Springs Creek confluence quickly rebound to spring-fed baseflow conditions following irrigation season (Nichols et al. 2010). Dwinnell Dam (constructed in 1928) is the largest water storage structure in the Basin, with current1 capacity of 50,000 AF (~62 million m^3), upgraded from 36,000 AF (~44 million m^3) in 1965 (USFWS15422013). Water is delivered to users in Shasta Basin via canals, diversion facilities, pumps, and storage infrastructure (Willis et al. 2013). The largest storage and delivery systems in the Shasta Basin are maintained by water service agencies or private water users which operate in accordance with the Watermaster service requirements (Willis et al. 2013). Major diversions and smaller dams or weirs are located below Dwinnell Dam, along with numerous diversions on tributaries (CDFW15471997; Lestelle

2012; NOAA Fisheries 2014; CDFW 2016). Several diversions and return channels exist largely for agricultural purposes that primarily operate during the irrigation season (April 1-September 30), including the Grenada Irrigation District Ditch, the Shasta River Water Association, and Oregon Slough (Jeffres et al. 2010) (Figure 32). The City of Yreka obtains much of its water supply from Fall Creek (Figure 33), located outside the Watershed near Iron Gate Reservoir (Pace Engineering 2016). The City's treated wastewater, totaling 966 AF (1.2 million m^3) in 2015, is discharged to percolation fields near Yreka Creek (Pace Engineering 2016). Historical instream flow data were collected from the United States Geological Survey (USGS) and California Department of Water Resources (DWR) Water Data Library and California Data Exchange Center (CDEC). Two (2) USGS streamflow gauges (stations SRM and SRY) are present in the Watershed with observed data spanning water years 1958 to 1978, and 2002 to 2016. Five additional gauging stations are maintained by DWR and are associated with sporadic data collection in two to three-year periods. Gauge locations in the Watershed are shown in Figure (Figure33). Data were analyzed to assess quantity and quality of the observed record. Quantity was measured as percent of days with recorded flow data at each gauge, and quality was assessed as percent of days flagged by USGS as having been "edited or estimated by USGS personnel (USGS 2018)."Table (?; Table: Summary of streamflow data quantity and quality in the Shasta Valley Groundwater Basin) provides a summary of USGS data quantity and quality in the Watershed; a continuous flow record of reliable data (in terms of quantity and quality) is present throughout the watershed from 1957 to present. In 2005 and 2009, the Nature Conservancy acquired property in the Watershed, and at this time the University of California at Davis Center for Watershed Science, the Nature Conservancy, and Watercourse Engineering began monitoring streamflow in Big Springs Creek, the mainstem Shasta River, and Little Shasta River (Jeffres et al. 2008, 2009, 2010; Nichols et al. 2016, 2017; Null et al. 2010; Willis et al. 2012, 2013, 2017). Additional sources of flow data include gauges placed on the Shasta River and Parks Creek in 2001 and 2002 (Watercourse Engineering 2006); estimates of unimpaired flows (Deas et al. 2004); a 2016 water balance study (SVRCD 2016); summaries of discrete flow measurements for springs in the Watershed including Little Springs Creek (Deas et al. 2015) and Big Springs Creek (Appendix G of NCRWQCB15752006); measurements of springs, creeks, and diversions on the Shasta Springs Ranch (Chesney et al. 2009, Davids Engineering 2011); and a compilation of data for sites in the Little Shasta River drainage basin (CDFW 2016). Streamflow data from all available sources will be further assessed during hydrologic model development to identify important critical conditions. Data quantity and quality impact both selection of data to be used for calibration and interpretation of model performance during associated time periods. More weight will be given to locations and time periods with higher quantity and quality of data. Instream flows in the Watershed have been significantly affected by water resource management in the Basin. Seasonal low flow and drought conditions naturally occur in the watershed, but are becoming more common. Studies have been conducted to characterize hydrology and hydrologic habitat in the Watershed and to determine interim and minimum instream flow needs in the Watershed (McBain & Trush 2013, CDFW 2017). The Instream Flow Needs study documented historical and current sampling above and below Parks Creek confluence, in the center of the Watershed1588(McBain & Trush 2013). Historical data of unimpaired mean monthly flow in the Upper Shasta River and Parks Creek estimate a maximum of approximately 208 cubic feet per second (cfs) (~6 cubic meters per second (m^3/s)) and a minimum of 6 cfs (~0.2 m^3/s) during spring and summer months. Baseflows in spring and summer 2010 recorded a maximum of 36 cfs (~1 m^3/s) and a minimum of 5.6 cfs (0.16 m^3/s; see Figure: Historic stream flows at notable gauges along the Shasta River and Parks Creek). According to these studies, considerable inter-annual streamflow variability exists along with uniformity and predictability of streamflow between June and late October, consistent with other streams in the region.

Groundwater

The groundwater system is poorly understood in the Shasta Watershed. The complex geology is further discussed in Appendix 2-A In general groundwater flow is consistently towards the Shasta River in the middle of the watershed with an overall trend of flow to the north towards the Klamath River. The groundwater flow is further complicated by fracture flow within fractured basalt in the southeast area of the watershed. Groundwater is known to be connected in the majority of the Shasta River with groundwater daylighting at multiple springs near the Big Springs Complex.

Model Development

Climate Data

The following section provides an overview of the atmospheric time series inputs that drive the simulation of the energy and water balance of hydrologic response units (HRUs) within the PRMS model.

Climate Inputs

Precipitation Precipitation time series were manually processed by Paradigm Environmental using geographic information system (GIS) and software packages before being assigned to each HRU within the Shasta PRMS model domain. Hourly modeled precipitation totals were extracted for the 29-year modeled period of record from the National Aeronautics and Space Administration (NASA) North American Land Data Assimilation System (NLDAS)[3]. NASA developed the NDLAS system to use the best available climatic land surface observations to construct a quality-controlled land surface model (LSM) for the U.S. NLDAS models conditions at a scale of 1.0 degree (approximately 84 kilometers longitude and 111 kilometers latitude) for data from 1979 to present and 0.25 degree (approximately 21 kilometers longitude and 27.75 miles latitude) from 2000 present.

Paradigm Environmental scaled hourly precipitation datasets for each NLDAS grid cell to align with monthly rainfall totals derived from the PRISM model[4], a high-resolution climate model developed and maintained by Oregon State University. PRISM applies a weighted regression scheme to model climatic conditions with a focus placed on complex regimes where factors such as orography (elevation driven), rain shadows, temperature inversions, slope aspect, and coastal proximity yield unique climates. The PRISM dataset is presented in “climatologies” at a scale of 30-arcsec (800 meters) and monthly data are available at 2.5 arcmin (4 km) resolution. NLDAS hourly data were used as relative hyetographs to distribute monthly PRISM totals. Hourly PRISM-scaled NLDAS totals were summed by day and manually assigned to PRMS HRUs corresponding to the centroid of each PRISM grid. The precip_1sta module was used to interpolate and distribute daily precipitation totals to HRUs between PRISM centroid grids using monthly correction factors to account for differences in altitude, spatial variation, topography, and measurement gage efficiency.

[3]Additional information regarding the North American Land Data Assimilation System (NLDAS) can be found at: https://ldas.gsfc.nasa.gov/nldas]

[4]Additional information regarding PRISM model can be found at: https://prism.oregonstate.edu/

Temperature Hourly modeled temperature time series were extracted from NLDAS records and post-processed by Paradigm Environmental to represent maximum and minimum temperatures by day. These daily maximum and minimum temperature timeseries were manually assigned to PRMS HRUs corresponding to the centroid of each NLDAS grid. Daily maximum and minimum temperatures were adjusted based on temperature zones. The temp_1sta module was used to interpolate and distribute daily maximum and minimum temperatures to HRUs between NLDAS grid centroids using an estimated monthly lapse rate.

Potential Evapostranspiration Potential evaporation time series were manually processed by Paradigm Environmental using GIS and software packages. Hourly modeled evapotranspiration time series were extracted from NLDAS records, and manually assigned to PRMS HRUs corresponding to the centroid of each NLDAS grid. The climate_hru module was used to read daily evapotranspiration depths directly into PRMS by HRU.

Internal Climate

Solar Radiation Daily solar radiation was internally calculated based on the ddsolrad module within PRMS. The ddsolrad module distributes solar radiation to each HRU using a maximum temperature per degree-day relationship discussed extensively in the Solar-Radiation Distribution Modules section of the PRMS model documentation. Maximum assumed temperature within the PRMS model is used to establish a degree-day coefficient based on a relationship established by Leavesley and others in 1983. This degree-day coefficient is then used to translate potential short-wave solar radiation to assumed short wave solar radiation with the driving assumption being that higher temperatures correspond to summer months and longer days with higher solar radiation. Conversely, lower maximum temperatures correspond to winter periods with shorter days and lower short-wave solar radiation.

Snow Precipitation falling within the Shasta Watershed is partitioned in rain, snow, or a mix of rain and snow based on internal parameters established within PRMS. Precipitation occurring on a day where both the minimum and maximum daily temperature are above a threshold where all precipitation falling is assumed to be rainfall, parameter tmax_allrain, is simulated as only rainfall. Similarly, precipitation falling on days where both the minimum and maximum daily temperatures are below a threshold where all precipitation falling is assumed to be snow, parameter tmax_allsnow, is simulated as only snowfall.

When the assumed maximum daily air temperature falls between the tmax_allsnow and tmax_allrain thresholds and the minimum daily air temperature is less than or equal to the tmax_allsnow threshold, precipitation is modeled as a mixture of rain and snow. A comprehensive discussion of the simulation of precipitation as rain and snow can be found in the Precipitation-Distribution Modules section of the PRMS Users Manual.

The PRMS model simulates snowpack hydrology processes within the Snow module (snowcomp) including snow initiation, accumulation, and depletion by HRU. The Snow module simulates snowmelt as a function of the daily water and energy balance for each HRU including the accumulation, sublimation, and melt of snowpack. PRMS computes daily snowpack dynamics including snowpack depth, density, snow water equivalent (SWE), snowpack, temperature, albedo, and cover area to allow users to readily compare modeled representations to key on-site snowpack observations from snow pillows or snow courses as well as satellite-derived observations for factors such as snowpack albedo.

Watershed Parameters

PRMS requires users to translate the physical characteristics of a subject watershed and relevant dynamic temporal elements (e.g.; precipitation) into a representation that can be simulated using the quantitative relationships within the modeling platform. The process of translating physical characteristics such as elevation, land use or land cover, geology, and subwatersheds into a set of unique hydrologic units is often referred to as spatial discretization. The process of translating atmospheric conditions into time series that can drive a model is typically referred to as temporal discretization. Both of these processes are discussed below with each section providing an overview and referring readers to more comprehensive discussions in model documentation where available.

A key element of PRMS model development is the parameterization of a network of HRUs, stream segments or reaches, and lakes reflecting the understanding of the watershed model domain. HRUs are developed as a function of land use or land cover, soil, elevation, slope, aspect, and climate patterns and are assumed to be uniform in how they respond to atmospheric time series inputs. While PRMS is capable of integrating irregular or complex (non-rectangle) geometry HRUs, USGS strongly recommends that HRUs reflecting the discretization of the land surface align with the subsurface discretization represented in the coupled MODFLOW groundwater model discussed in Section 3.2.1.

The Shasta PRMS model is comprised of 42,586 18-acre HRUs arranged in 214 rows and 199 columns of a grid. Each HRU is assigned a unique set of land use/landcover and atmospheric inputs during spatial processing using an external GIS. The distribution of HRUs representing the discretized model domain for the Shasta PRMS model is presented in Figure 4.

Elevation and Runoff

A 10-meter resolution digital elevation model (DEM) was extracted from the USGS National Elevation Dataset (NED) to represent topography within the Shasta Watershed. This gridded representation of elevation was translated into mean elevation, slope, and aspect for each HRU and incorporated into the PRMS model.

Soils

The spatial distribution of soils within the Shasta Watershed were extracted from the Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (additional information regarding the SSURGO database can be found at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627). SSURGO presents soil characteristic and soil hydraulic summaries including percent sand, silt, clay, as well as available water holding capacity. Relevant hydraulic parameters were used to parameterize the soil-zone module and the soilzone process within PRMS. A comprehensive discussion of the simulation of precipitation as rain and snow can be found in the Soil Zone Module section of the PRMS Users Manual.

Vegetation

There are 5 types of vegetation cover within PRMS, bare soil, grasses, shrubs, trees, and coniferous correlating to 0 through 4, respectively. The vegetation types are generalized and interact with other variables to account for native vegetation water consumption and use. Distribution of vegetation type is shown on Figure 2.

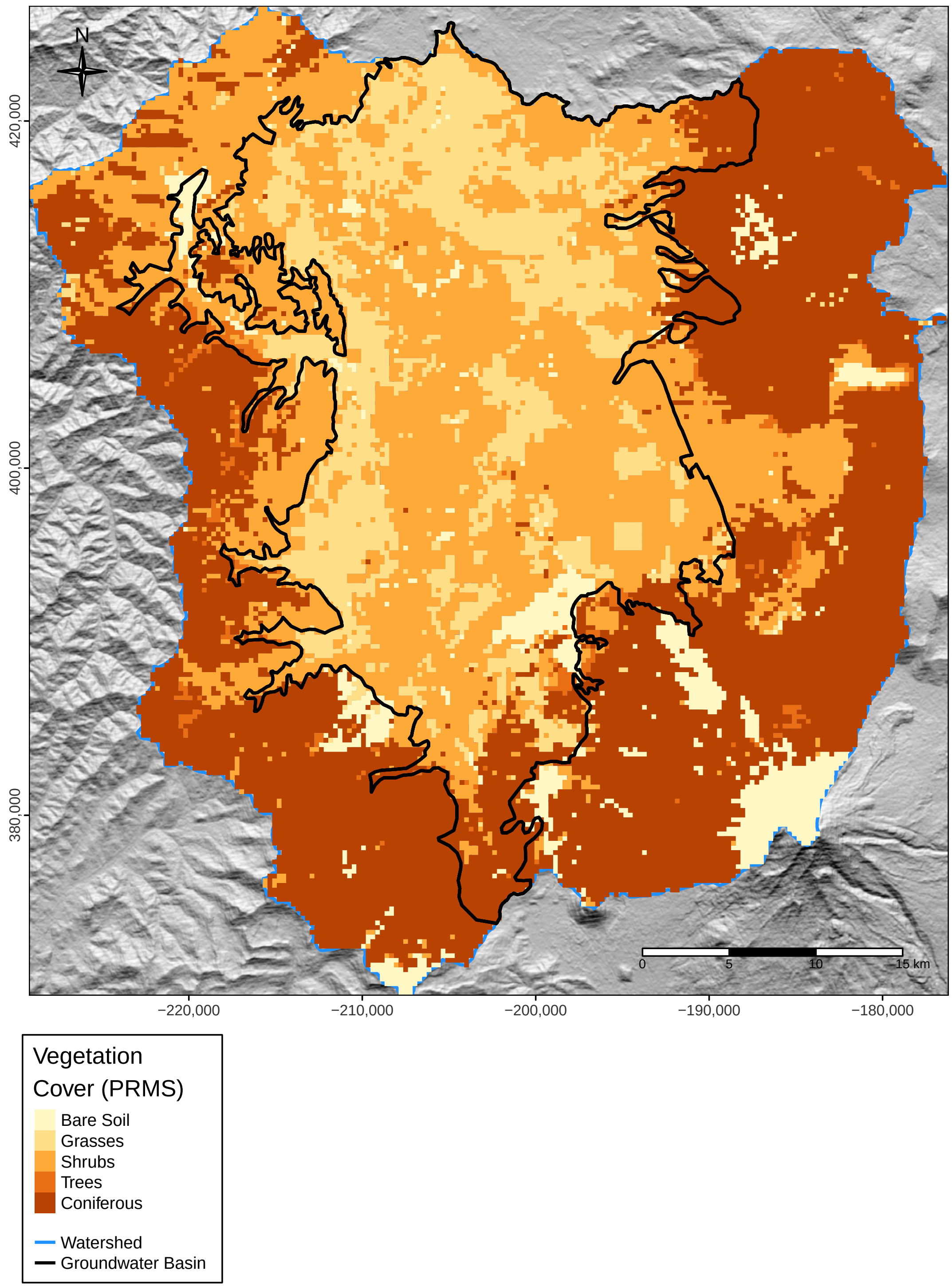

Figure 2: Vegetation type as simulated within PRMS.

Discretization

Spatial Discretization and Layering

The MODFLOW and PRMS models use the same grid consisting of 18 acre (270 meter x 270 meter) grid cells. The active portion of both surface water and groundwater is the HUC8 watershed boundary. Vertical discretization was carried out to keep layer thicknesses consistent throughout the model domain due to the amount of discontinuous volcanic geology. Layer 1 top is defined at land surface and extends 10 meters below land surface. Layers 2 through 4 are 40 meters, 100 meters, and 350 meters thick, respectively.

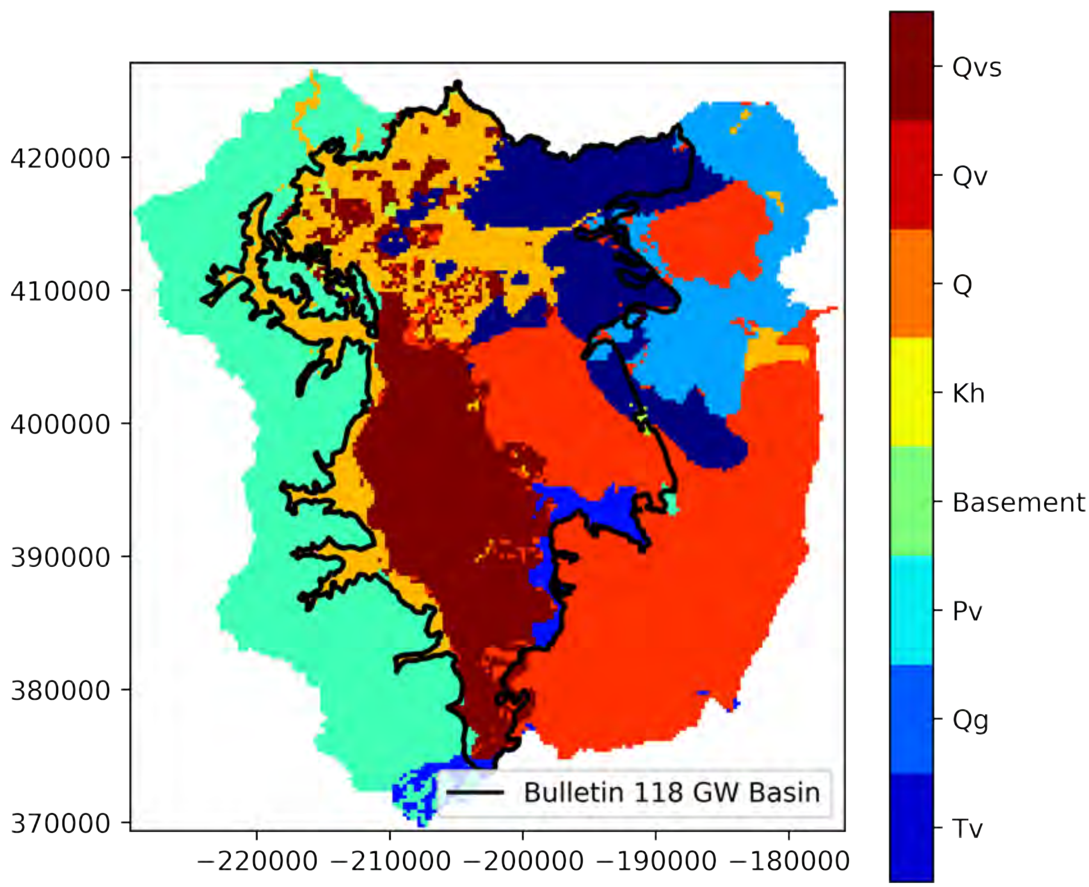

Figure 3: Shasta Valley Geology and model grid discretization

Temporal Discretization

The SWGM MODFLOW model has monthly stress periods with weekly time steps and runs from Water Year (WY) 1991-2018. Monthly stress periods are appropriate for the SWGM as the object of interest is the groundwater budget on the monthly and annual timescale at which groundwater is typically managed. The SWGM PRMS model uses daily time steps to account for the faster reaction time typically found in surface water systems.

Agricultural Water Use

Agricultural water use is estimated through the RSRZ, see Appendix 2-I, in combination with land use maps developed by DWR with assistance by local stakeholders (Davids Engineering 2013).

Groundwater Use

Agricultural groundwater use was estimated through the RSRZ. Land irrigated by groundwater, see attached David's Engineering report, were intersected with the RSRZ polygons to create cell-by-cell estimates of groundwater pumping. Groundwater pumping data and pumping well locations were not sufficiently available to allocate groundwater pumping to individual wells, thus groundwater pumping for each node was assigned based on the *Applied Water* calculated by the RSRZ.

Surface Water Use

Surface water diversion are regulated through the Scott and Shasta Watermaster District (SSWD) and the State Water Resource Control Board (SWRCB). Review of historic SSWD reports was compiled by Davids Engineering.

The SSWD has seven service areas within the Shasta Watershed; Upper Shasta River, Boles Creek, Beaughan Creek, Carrick Creek, Parks Creek, Lower Shasta River, and Little Shasta River. Annual reports between WY 1991-2017 were considered for review, years with sufficient documentation were 1991-1994, 1996-2000, and 2013-2016. Total water rights by service area are shown in Table 3. Table 4 Shows estimated deliveries of water by service region and water year type. For water years with insufficient data, the mean deliveries for that region and water year type were used. The same methodology was used in climate projections when estimating surface water diversions.

Table 3: Total Water Rights by Service Region (shown in cubic feet per second).

Season	Upper Shasta	Lower Shasta	Little Shasta	Parks Creek	Boles Creek	Beaughan Creek	Carrick Creek	Jackson Creek
Irrigation	108.66	146.64	92.32	55.66	17.68	10.30	11.72	3.05
Winter	18.55	10.85	21.93	18.33	6.99	4.47	1.39	0.38

[a] Based on Davids Engineering water rights review.

Table 4: Estimates of water deliveries by service region and water year type.

Month	WY Type	Upper Shasta	Lower Shasta	Little Shasta	Parks Creek	Boles Creek	Beaughan Creek	Carrick Creek	Jackson Creek
April	Normal	100%	98%	70%	100%	100%	98%	100%	100%
April	Wet	100%	100%	98%	100%	100%	100%	100%	100%
April	Dry	58%	93%	27%	50%	100%	100%	100%	100%
August	Normal	28%	90%	31%	16%	100%	98%	92%	100%
August	Wet	59%	98%	41%	15%	97%	100%	100%	100%
August	Dry	16%	82%	26%	10%	78%	100%	94%	100%
July	Normal	50%	93%	37%	31%	100%	98%	97%	100%
July	Wet	91%	100%	47%	34%	100%	100%	100%	100%
July	Dry	42%	83%	29%	16%	91%	100%	97%	100%
June	Normal	84%	97%	47%	83%	100%	98%	100%	100%
June	Wet	100%	100%	67%	85%	100%	100%	100%	100%
June	Dry	43%	87%	41%	64%	100%	100%	100%	100%
March	Normal	100%	98%	71%	100%	100%	98%	100%	100%
March	Wet	100%	100%	100%	100%	100%	100%	100%	100%
March	Dry	99%	97%	28%	50%	100%	100%	100%	100%
May	Normal	100%	98%	66%	98%	100%	98%	100%	100%
May	Wet	100%	100%	91%	100%	100%	100%	100%	100%
May	Dry	73%	87%	55%	60%	100%	100%	100%	100%
October	Normal	6%	90%	33%	3%	97%	98%	88%	100%
October	Wet	13%	100%	39%	5%	90%	100%	100%	100%
October	Dry	15%	82%	26%	7%	74%	100%	94%	100%
September	Normal	7%	90%	33%	5%	97%	98%	90%	100%
September	Wet	15%	99%	39%	7%	90%	100%	100%	100%
September	Dry	15%	82%	26%	7%	74%	100%	94%	100%

[a] Based on Davids Engineering water rights review.

Aquifer Characteristics

Shasta Watershed Geology

A geologic model was developed to represent the complex geology of the Shasta Watershed. The geologic model was digitized and included the analysis of hundreds of DWR well logs along with regional surficial geology maps in Leapfrog[5]. There are 8 hydrogeologic units within the geologic model which are implemented in the MODFLOW model as listed in Table 4 in Chapter 2 Section 2.1.3. While there is evidence of faulting occurring within the watershed, there was insufficient geologic and hydrologic data to include them within the groundwater model geology. In addition, fracture flow is known to occur within Qv formation, but due to sparse information of the orientation, size, and connectivity of the fractures the Qv unit is modeled as equivalent porous media (Appendix 2-A Geologic Modeling Methodology). The hydraulic properties including horizontal hydraulic conductivity, horizontal anisotropy, vertical hydraulic conductivity, specific storage, and specific yield, are detailed in Hydraulic Parameters section. An example cross-section is shown in Figure 4.

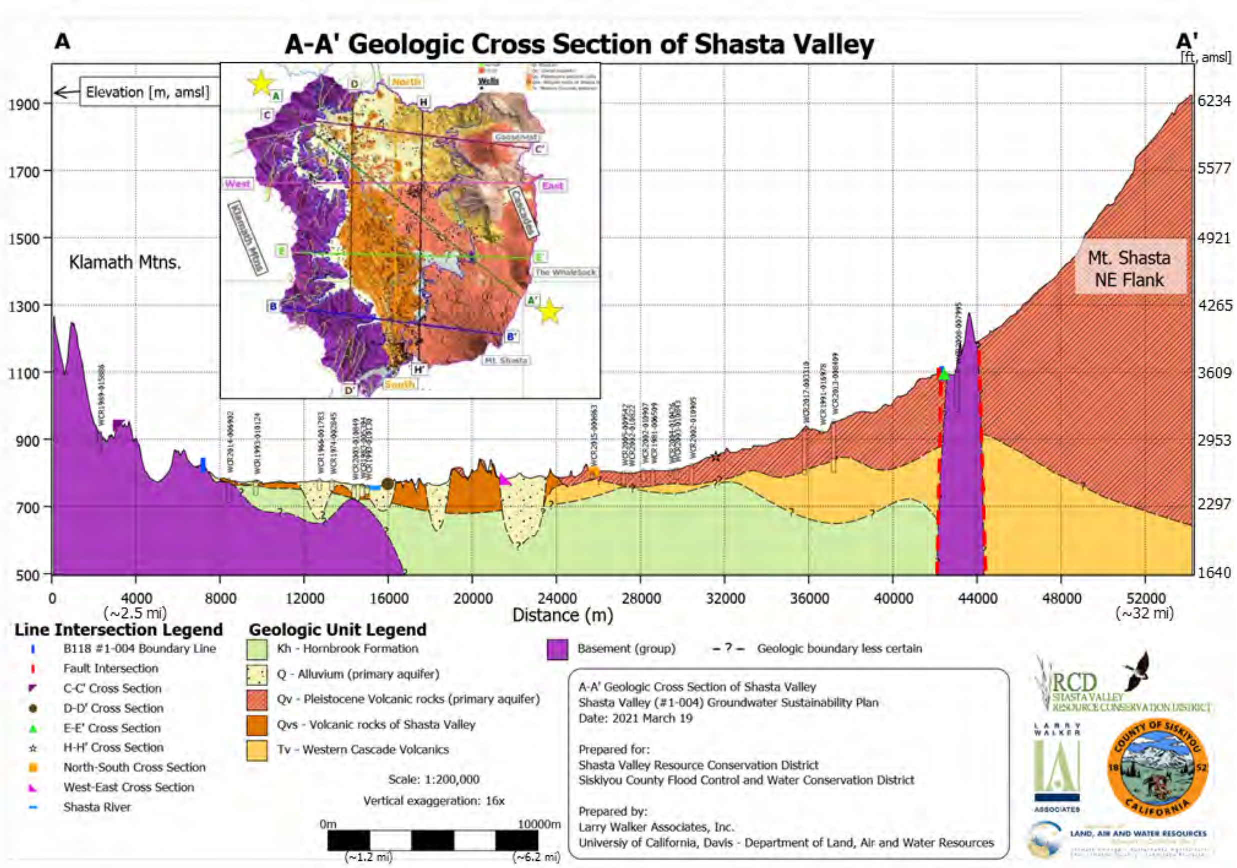

Figure 4: Geologic cross section A-A' from the Shasta Valley Watershed geologic model (inset includes the surface geologic overview map of the Shasta Valley Watershed geologic model.

[5]Sequent, Leapfrog Geo https://www.seequent.com/products-solutions/leapfrog-geo/

Hydraulic Properties

Initial Conditions

The SWGM is initiated with a steady-state model run. Recharge fluxes were estimated using the monthly recharge values before 1997 and averaged. Steady-state flows in the surface water system were estimated using the average flows in September before 1994. Agricultural pumping was estimated based on the first 9 years, from WY1991-WY1999. Steady-state fluxes were adjusted during model calibration.

Surface Water System

The mainstem of the Shasta River as well as major tributaries are modeled within PRMS and MODFLOW. PRMS uses the Muskingum package to route water and MODFLOW uses the Streamflow Routing Package (Niswonger and Prudic 2005). Reach and segment numbering were consistent between PRMS and MODFLOW. The stream network was developed using the same 10-meter resolution DEM from the NED used to establish the topographic setting to derive a representation of the stream system within the Watershed. Stakeholder input was requested to manually correct the DEM-derived stream network due to inaccuracies in elevation as well as the interaction of canal and stream networks.

Water conveyance in the Shasta Valley is typically carried out through a complex canal network. Figure 5 shows the entire mapped canal system and the mapped leaky ditches. Leaky ditch designation and locations were provided by the Shasta Valley Resource Conservation District (SVRCD).

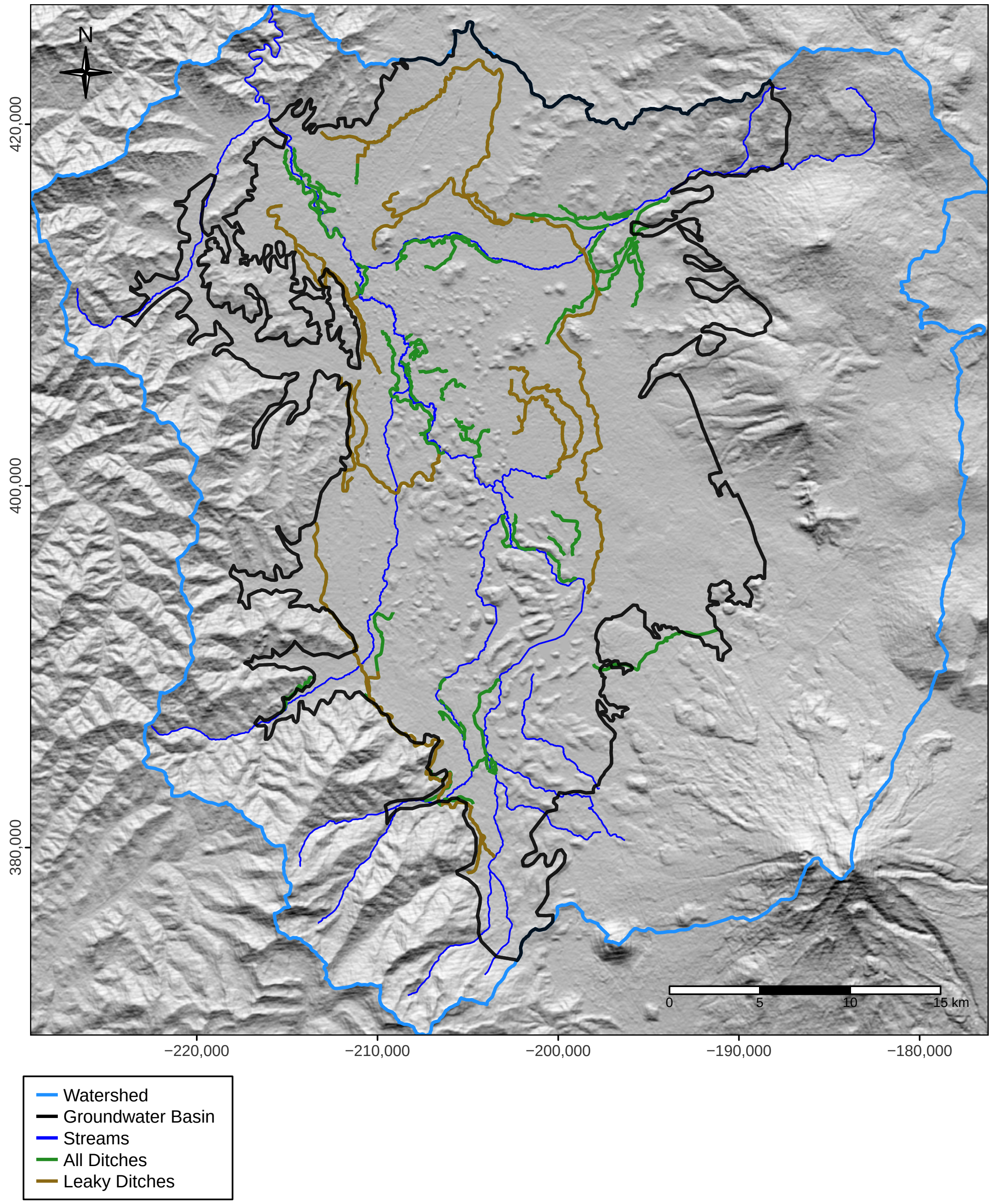

Figure 5: Complete ditch map of Shasta Valley with designation of leaky ditches, as mapped by the SVRCD.

Two lakes are modeled in the SWGM, Dwinnell Reservoir and Grass Lake. Dwinnell Reservoir is a managed reservoir with a total capacity of 50,000 acre-feet of water. Inflows to the reservoir are difficult to measure due to the lack of monitoring upstream of the reservoir. The reservoir is fed by the upper Shasta River and various spring fed tributaries. Releases from Dwinnell Reservoir include instream flow to the Shasta River, prior rights in the Shasta River, and agricultural water demand to the MWCD Canal. Seepage under the dam is also measured and accounted for by MWCD. Releases into the Canal are estimated based on total monthly water deliveries, as submitted to the SWRCB.

The complete surface water system as modeled within MODFLOW is shown in Figure 6.

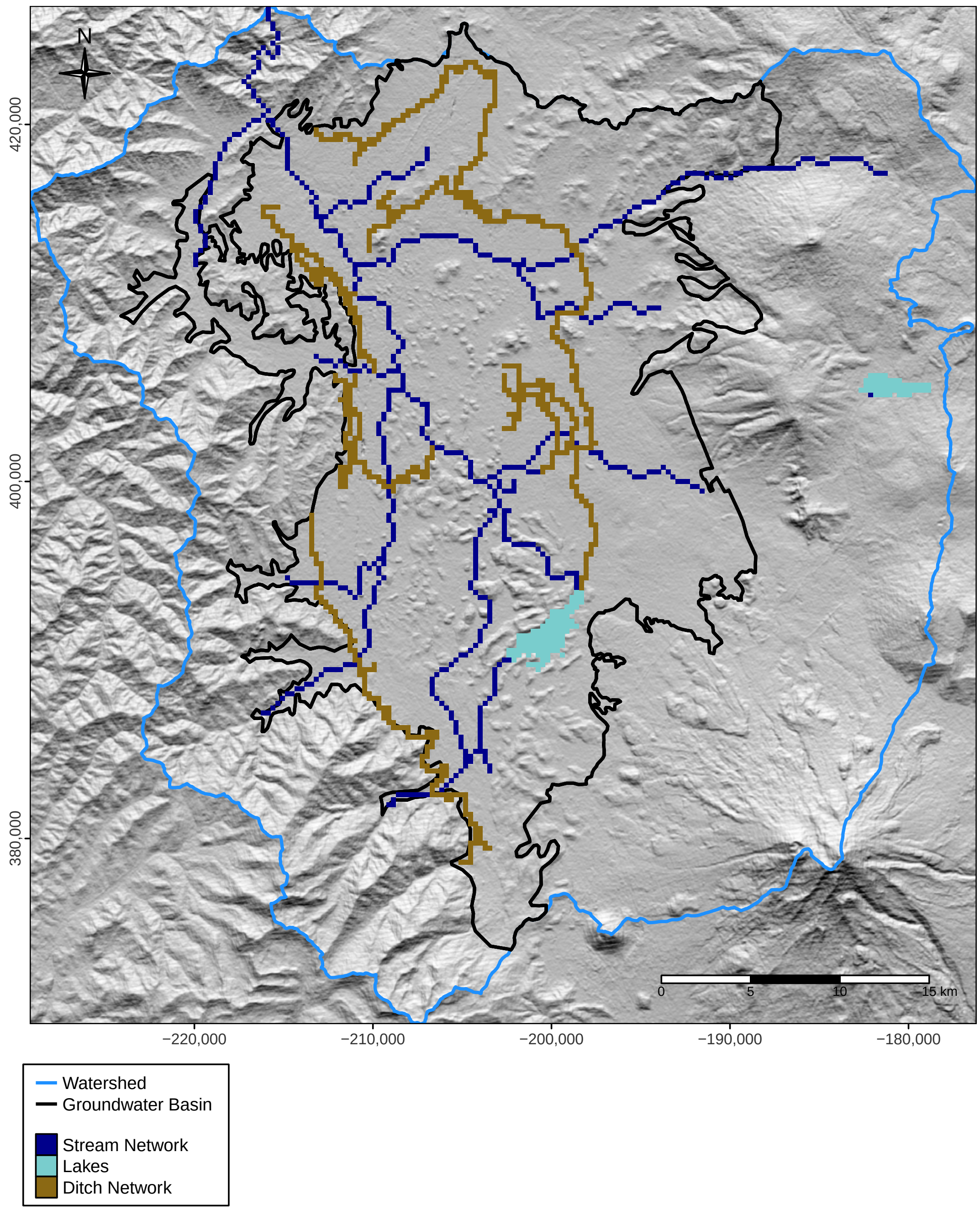

Figure 6: Surface water as modeled within MODFLOW.

Model Calibration and Sensitivity

The SWGM transient model which ran from WY1991-2018 was calibrated with the groundwater elevation and streamflow targets described in this section. The sensitivity analysis and calibration software UCODE2014[6] was applied to the SWGM. UCODE2014 uses the sum of square weighted residuals as the objective function for determining the models ability to match observations. Preliminary calibration was conducted on the groundwater flow system but due to data scarcity additional calibrations will be done for SWGM v1.1. Ongoing recommendations and collaboration with the SWRCB is aiding in constraining the calibration.

Observations Used in Model Calibration

Groundwater Observations

The California Statewide Groundwater Elevation Monitoring (CASGEM) database was filtered and cleaned for the Shasta Valley area and modeled time period to create a database of groundwater observations that were corrected with respect to the model top elevations. In addition to the periodic groundwater level measurements, The Nature Conservatory (TNC) has collected groundwater level data more recently that were included. The groundwater level observations were weighted using an acceptable standard deviation of 0.1 for observation data from CASGEM and 0.15 for observation data from TNC. Each well was given a unique name to identify it within the modeling framework as shown in Table 5. Figures Figure 7, Figure 8, and Figure 9 show the locations of groundwater elevation wells used in calibration of the SWGM.

Table 5: Overview of Groundwater Elevation Observations

MODFLOW ID	ROW	COL	Start Date	End Date	No. of Obs
c_10	151	95	1990-10-01	2018-03-01	54
c_11	148	121	1990-10-01	2008-10-01	34
c_12	139	70	1990-10-01	2018-03-01	55
c_13	139	90	1990-10-01	2017-10-01	55
c_14	120	65	2013-04-01	2018-03-01	10
c_15	115	86	2005-10-01	2018-03-01	26
c_16	101	113	1990-10-01	2017-10-01	54
c_17	95	111	1990-10-01	2018-03-01	53
c_18	43	50	1990-10-01	1992-10-01	5
c_19	127	118	1990-10-01	2007-03-01	31
c_20	124	62	1990-10-01	2018-03-01	56
c_21	113	72	1990-10-01	2018-03-01	51
c_22	108	68	1990-10-01	2018-03-01	55
c_23	108	88	1990-10-01	2011-10-01	40
c_24	105	96	1990-10-01	1997-10-01	14
c_25	104	122	1990-10-01	2005-10-01	29
c_26	91	109	1990-10-01	2018-03-01	52

[6] https://igwmc.mines.edu/wp-content/uploads/sites/117/2018/11/UCODE_2014_User_Manual-version02.pdf

Table 5: Overview of Groundwater Elevation Observations *(continued)*

MODFLOW ID	ROW	COL	Start Date	End Date	No. of Obs
c_27	89	93	1990-10-01	2018-03-01	53
c_28	81	71	1990-10-01	2018-03-01	56
c_29	80	103	1991-03-01	2017-10-01	52
c_30	74	110	1990-10-01	2018-03-01	53
c_31	66	69	1990-10-01	2018-03-01	56
c_32	47	50	1990-10-01	2018-03-01	55
c_34	47	96	1990-10-01	2002-03-01	22
c_35	46	69	1990-10-01	2018-03-01	48
c_36	45	51	2000-09-01	2008-10-01	18
c_37	31	93	1990-10-01	2018-03-01	53
c_38	30	85	1990-10-01	2018-03-01	50
c_39	28	76	1990-10-01	2018-03-01	45
c_40	20	104	1990-10-01	2018-03-01	53
c_41	18	89	1990-10-01	2018-03-01	54
c_42	24	88	2013-04-01	2018-03-01	9
c_43	104	89	2010-04-01	2015-04-01	12
c_44	74	53	2004-10-01	2018-03-01	23
c_45	53	65	2013-04-01	2018-03-01	11
c_46	46	76	2004-09-01	2018-03-01	28
TNC_01	101	98	2010-01-01	2017-10-01	54
TNC_02	104	89	2010-09-01	2017-10-01	86
TNC_03	89	93	2010-03-01	2016-03-01	73
TNC_04	89	93	2010-01-01	2017-12-01	95
TNC_05	92	103	2010-03-01	2013-03-01	37
TNC_06	92	103	2010-01-01	2014-02-01	50
TNC_07	93	103	2010-01-01	2017-09-01	93
TNC_08	92	102	2012-04-01	2013-03-01	12
TNC_09	102	101	2010-04-01	2016-03-01	72
TNC_10	91	99	2014-02-01	2017-09-01	44

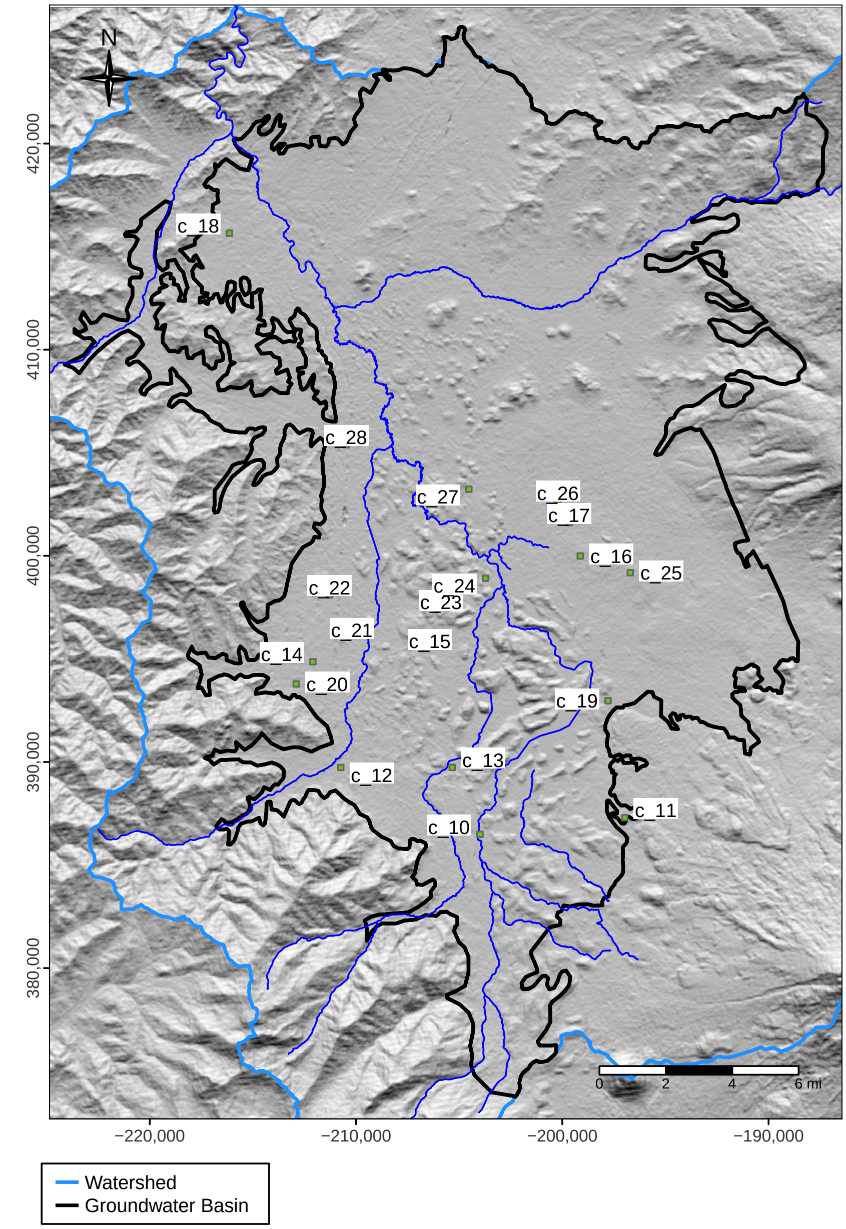

Figure 7: Groundwater Elevation wells used in model calibration, Wells c_10 through c_28.

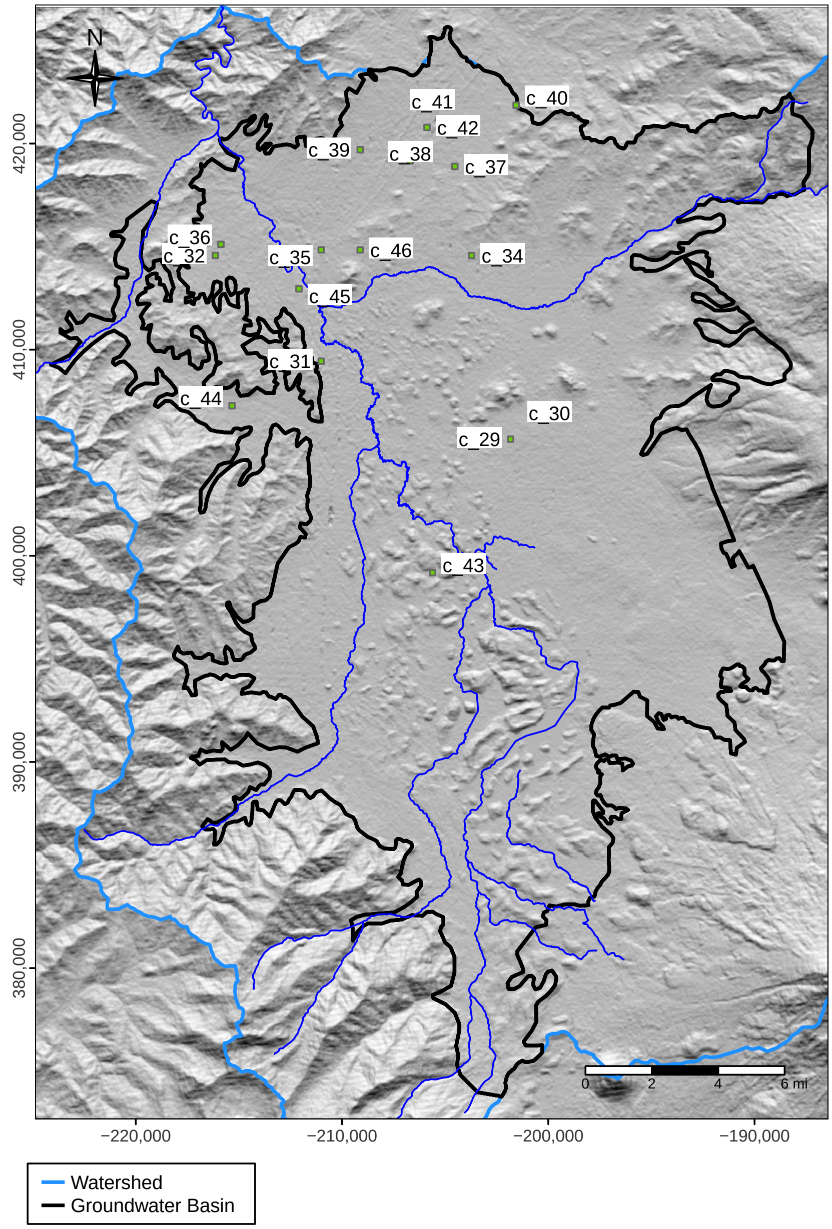

Figure 8: Groundwater Elevation wells used in model calibration, Wells c_29 through c_46.

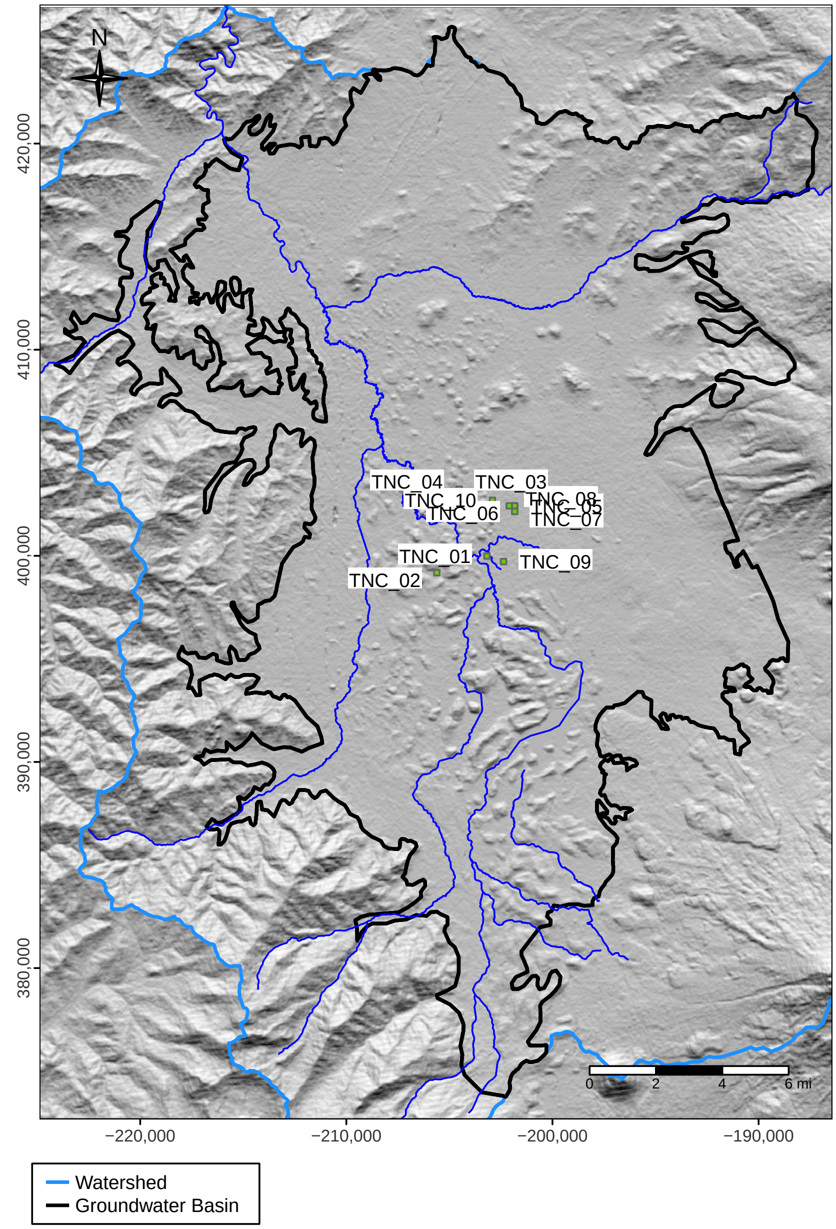

Figure 9: Groundwater Elevation wells used in model calibration, Wells TNC_01 through TNC_10

Surface Water Flow Observations

Several USGS stream gages exist on the Shasta River and its tributaries which were applied to both the PRMS and MODFLOW models to calibrate stream and watershed related parameters. Streamflows measured throughout the upper watershed and Shasta Valley were included as flow observations with a coefficient of variation of 10% as a weighting parameter.

Additional Observations

Precipitation gages were used to manually calibrate rainfall distribution within the PRMS model framework. Remotely sensed snowfall estimations (Bair et al. 2016) were used to examine total snow pack and the relative distribution of snow within the Shasta Watershed.

Model Parameters

Hydraulic Parameters

There are 41 hydraulic parameters in the SWGM. Table 6 shows the the name of the parameters as used within the modeling framework in addition to final values used. These parameters are used exclusively within MODFLOW and control the storage and movement of water through the subsystem.

Table 6: Hydraulic properites descriptions and values used in the SWGM.

Parameter Name	Group Name	Value	Description
an1	HANI	1.0000000	Anisotropy multiplier for Unit 1
an2	HANI	1.0000000	Anisotropy multiplier for Unit 2
an3	HANI	1.0000000	Anisotropy multiplier for Unit 3
an4	HANI	1.0000000	Anisotropy multiplier for Unit 4
an5	HANI	1.0000000	Anisotropy multiplier for Unit 5
an6	HANI	1.0000000	Anisotropy multiplier for Unit 6
an7	HANI	1.0000000	Anisotropy multiplier for Unit 7
an8	HANI	1.0000000	Anisotropy multiplier for Unit 8
DRE_leak	LAK	5.3900000	Lakebed leakance (BDLKNC) for Dwinnell Reservoir
kx1	HK	0.0362000	Horizontal hydraulic conductivity for Unit 1
kx2	HK	1.0920000	Horizontal hydraulic conductivity for Unit 2
kx3	HK	0.0111000	Horizontal hydraulic conductivity for Unit 3
kx4	HK	2.4260000	Horizontal hydraulic conductivity for Unit 4
kx5	HK	0.0063900	Horizontal hydraulic conductivity for Unit 5
kx6	HK	12.8910000	Horizontal hydraulic conductivity for Unit 6

Table 6: Hydraulic properites descriptions and values used in the SWGM. *(continued)*

Parameter Name	Group Name	Value	Description
kx7	HK	17.1500000	Horizontal hydraulic conductivity for Unit 7
kx8	HK	0.0006650	Horizontal hydraulic conductivity for Unit 8
kz1	VK	16.2800000	Vertical hydraulic conductivity for Unit 1
kz2	VK	44.2900000	Vertical hydraulic conductivity for Unit 2
kz3	VK	5.9460000	Vertical hydraulic conductivity for Unit 3
kz4	VK	0.0294000	Vertical hydraulic conductivity for Unit 4
kz5	VK	0.5002000	Vertical hydraulic conductivity for Unit 5
kz6	VK	16.2900000	Vertical hydraulic conductivity for Unit 6
kz7	VK	66.1400000	Vertical hydraulic conductivity for Unit 7
kz8	VK	0.5590000	Vertical hydraulic conductivity for Unit 8
ss1	SS	0.0003520	Specific storage for Unit 1
ss2	SS	0.0004320	Specific storage for Unit 2
ss3	SS	0.0004140	Specific storage for Unit 3
ss4	SS	0.0001670	Specific storage for Unit 4
ss5	SS	0.0004270	Specific storage for Unit 5
ss6	SS	0.0016300	Specific storage for Unit 6
ss7	SS	0.0000374	Specific storage for Unit 7
ss8	SS	0.0000986	Specific storage for Unit 8
sy1	SY	0.7138000	Specific yield for Unit 1
sy2	SY	0.2500000	Specific yield for Unit 2
sy3	SY	0.2500000	Specific yield for Unit 3
sy4	SY	0.1632000	Specific yield for Unit 4
sy5	SY	0.2510000	Specific yield for Unit 5
sy6	SY	0.0115000	Specific yield for Unit 6
sy7	SY	0.5847000	Specific yield for Unit 7
sy8	SY	0.2731000	Specific yield for Unit 8

Soil Parameters

There are 16 soil parameters in the SWGM. Table 7 shows the the name of the parameters as used within the modeling framework in addition to final values used. The soil parameters are spatially variable and are based on SSURGO data. Soil modle parameters are generally multipliers to scale the entire basin values. This was done to maintain the spatial distribution of soil properties. These parameters are used within PRMS.

Table 7: Soil properites descriptions and values used in the SWGM.

Parameter Name	Group Name	Value	Description
carea_max	carea	1.000000	Multiplier for maximum possible area contributing to surface runoff expressed as a portion of the HRU area
fastcoef_lin	Soil_Zone	0.001000	Linear preferential flow routing coefficient

Table 7: Soil properites descriptions and values used in the SWGM. *(continued)*

Parameter Name	Group Name	Value	Description
fastcoef_sq	Soil_Zone	0.549791	Non linear preferential flow routing coefficient
pref_flow_den	Soil_Zone	0.040000	Fraction of the gravity reservoir in which preferential flow occurs for each HRU
sat_threshold	Soil_Zone	4.560000	Multiplier for water holding capacity of the gravity and preferential flow reservoirs
slowcoef_lin	Soil_Zone	6.380000	Multiplier for linear coefficient in equation to route gravity reservoir storage
slowcoef_sq	Soil_Zone	11.020543	Multiplier for nonlinear coefficient in equation to route gravity reservoir storage downslope
smidx_coef	Sroff	0.100000	Coefficient in nonlinear contributing area algorithm
smidx_exp	Sroff	0.100000	Exponent in nonlinear contributing area algorithm
soil_moist_max	Soil_Zone	2.795000	Multiplier for maximum available water holding capacity of capillary reservoir from land surface to rooting depth
soil_rechr_max	Soil_Zone	1.000000	Multiplier for maximum storage for soil recharge zone
soil2gw_max	Soil_Zone	0.001000	Maximum amount of the capillary reservoir excess that is routed directly to the GWR
srain_intcp	Intcp	1.000000	Multiplier for summer rain interception storage capacity for the major vegetation type
ssr2gw_exp	Soil_Zone	2.400000	Multiplier for nonlinear coefficient in equation used to route water from the gravity reservoirs to the GWR
ssr2gw_rate	Soil_Zone	1.000000	Linear coefficient in equation used to route water from the gravity reservoir to the GWR
wrain_intcp	Intcp	3.259831	Multiplier for winter rain interception storage capacity for the major vegetation type

Climate Parameters

There are 103 soil parameters in the SWGM. Table 8 shows the the name of the parameters as used within the modeling framework in addition to final values used. These parameters are used within PRMS.

Table 8: Climate properites descriptions and values used in the SWGM.

Parameter Name	Group Name	Value	Description
adj_rain_apr	adjmix_rain	1.0000000	Multiplier for rain in April
adj_rain_aug	adjmix_rain	1.0000000	Multiplier for rain in August
adj_rain_dec	adjmix_rain	1.2000000	Multiplier for rain in December
adj_rain_feb	adjmix_rain	1.0000000	Multiplier for rain in February
adj_rain_jan	adjmix_rain	1.0000000	Multiplier for rain in January
adj_rain_jul	adjmix_rain	1.0000000	Multiplier for rain in July
adj_rain_jun	adjmix_rain	1.2000000	Multiplier for rain in June
adj_rain_mar	adjmix_rain	1.0000000	Multiplier for rain in March
adj_rain_may	adjmix_rain	1.0000000	Multiplier for rain in May
adj_rain_nov	adjmix_rain	1.0000000	Multiplier for rain in November
adj_rain_oct	adjmix_rain	1.1000000	Multiplier for rain in October
adj_rain_sep	adjmix_rain	1.0000000	Multiplier for rain in September
dday_in_apr	dday_intcp	-7.5759444	Intercept in degree day equation for PRMS solar radiation in April
dday_in_aug	dday_intcp	-34.0000000	Intercept in degree day equation for PRMS solar radiation in August
dday_in_dec	dday_intcp	-8.0000000	Intercept in degree day equation for PRMS solar radiation in December
dday_in_feb	dday_intcp	-7.0000000	Intercept in degree day equation for PRMS solar radiation in February
dday_in_jan	dday_intcp	-12.8721115	Intercept in degree day equation for PRMS solar radiation in January
dday_in_jul	dday_intcp	-37.5030524	Intercept in degree day equation for PRMS solar radiation in July
dday_in_jun	dday_intcp	-13.5515332	Intercept in degree day equation for PRMS solar radiation in June
dday_in_mar	dday_intcp	-7.0000000	Intercept in degree day equation for PRMS solar radiation in March
dday_in_may	dday_intcp	-14.6390135	Intercept in degree day equation for PRMS solar radiation in May
dday_in_nov	dday_intcp	-26.4071231	Intercept in degree day equation for PRMS solar radiation in November
dday_in_oct	dday_intcp	-13.0000000	Intercept in degree day equation for PRMS solar radiation in October
dday_in_sep	dday_intcp	-13.0000000	Intercept in degree day equation for PRMS solar radiation in September
dday_sl_apr	dday_slope	0.1960800	Slope in degree day equation for PRMS solar radiation in April
dday_sl_aug	dday_slope	0.6500000	Slope in degree day equation for PRMS solar radiation in August
dday_sl_dec	dday_slope	0.3100000	Slope in degree day equation for PRMS solar radiation in December
dday_sl_feb	dday_slope	0.1001000	Slope in degree day equation for PRMS solar radiation in February
dday_sl_jan	dday_slope	0.3100000	Slope in degree day equation for PRMS solar radiation in January
dday_sl_jul	dday_slope	0.6989744	Slope in degree day equation for PRMS solar radiation in July

Table 8: Climate properites descriptions and values used in the SWGM. *(continued)*

Parameter Name	Group Name	Value	Description
dday_sl_jun	dday_slope	0.5508728	Slope in degree day equation for PRMS solar radiation in June
dday_sl_mar	dday_slope	0.3900000	Slope in degree day equation for PRMS solar radiation in March
dday_sl_may	dday_slope	0.9583546	Slope in degree day equation for PRMS solar radiation in May
dday_sl_nov	dday_slope	0.6350482	Slope in degree day equation for PRMS solar radiation in November
dday_sl_oct	dday_slope	0.3400000	Slope in degree day equation for PRMS solar radiation in October
dday_sl_sep	dday_slope	0.4000000	Slope in degree day equation for PRMS solar radiation in September
freeh2o_cap	snow	0.0521899	Free water holding capacity of snowpack
pet_adj_apr	Pot_ET	1.1000000	Potential ET adjustment in April
pet_adj_aug	Pot_ET	0.8271625	Potential ET adjustment in August
pet_adj_dec	Pot_ET	1.1252488	Potential ET adjustment in December
pet_adj_feb	Pot_ET	0.9410774	Potential ET adjustment in February
pet_adj_jan	Pot_ET	1.1000000	Potential ET adjustment in January
pet_adj_jul	Pot_ET	0.9000000	Potential ET adjustment in July
pet_adj_jun	Pot_ET	1.1000000	Potential ET adjustment in June
pet_adj_mar	Pot_ET	1.0932620	Potential ET adjustment in March
pet_adj_may	Pot_ET	1.3110423	Potential ET adjustment in May
pet_adj_nov	Pot_ET	0.8000000	Potential ET adjustment in November
pet_adj_oct	Pot_ET	1.2000000	Potential ET adjustment in October
pet_adj_sep	Pot_ET	1.2000000	Potential ET adjustment in September
pet_juniper	Pot_ET	1.3000000	Potential ET adjustment in areas with juniper cover
pet_other	Pot_ET	1.1000000	Potential ET adjustment in areas without juniper cover
ppt_radj_apr	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in April
ppt_radj_aug	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in August
ppt_radj_dec	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in December
ppt_radj_feb	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in February
ppt_radj_jan	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in January
ppt_radj_jul	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in July
ppt_radj_jun	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in June
ppt_radj_mar	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in March
ppt_radj_may	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in May
ppt_radj_nov	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in November
ppt_radj_oct	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in October
ppt_radj_sep	ppt_rad_adj	0.0200000	PRMS ppt_rad_adj factor in September
radj_sppt	Sol_Rad	0.3444511	Adjustment factor for computed solar radiation for summer day with greater than ppt_rad_adj inches of precipitation
radj_wppt	Sol_Rad	0.1277979	Adjustment factor for computed solar radiation for winter day with greater than ppt_rad_adj inches of precipitation

Table 8: Climate properites descriptions and values used in the SWGM. *(continued)*

Parameter Name	Group Name	Value	Description
radmax	Sol_Rad	0.8000000	Maximum fraction of the potential solar radiation that may reach the ground due to haze, dust, smog, and so forth
tmax_in_apr	tmax_index	57.4738530	Index temperature used to determine precipitation adjustments to solar radiation in April
tmax_in_aug	tmax_index	84.3901690	Index temperature used to determine precipitation adjustments to solar radiation in August
tmax_in_dec	tmax_index	42.1902520	Index temperature used to determine precipitation adjustments to solar radiation in December
tmax_in_feb	tmax_index	47.0413480	Index temperature used to determine precipitation adjustments to solar radiation in February
tmax_in_jan	tmax_index	47.5186048	Index temperature used to determine precipitation adjustments to solar radiation in January
tmax_in_jul	tmax_index	85.0927650	Index temperature used to determine precipitation adjustments to solar radiation in July
tmax_in_jun	tmax_index	75.1458640	Index temperature used to determine precipitation adjustments to solar radiation in June
tmax_in_mar	tmax_index	52.1053100	Index temperature used to determine precipitation adjustments to solar radiation in March
tmax_in_may	tmax_index	66.2615090	Index temperature used to determine precipitation adjustments to solar radiation in May
tmax_in_nov	tmax_index	49.2785800	Index temperature used to determine precipitation adjustments to solar radiation in November
tmax_in_oct	tmax_index	64.7301510	Index temperature used to determine precipitation adjustments to solar radiation in October
tmax_in_sep	tmax_index	77.1708690	Index temperature used to determine precipitation adjustments to solar radiation in September
tmax_lap_apr	tmax_lap	11.2936403	Change in maximum air temperature per 1,000 feet elevation change (°F) in April
tmax_lap_aug	tmax_lap	7.0000000	Change in maximum air temperature per 1,000 feet elevation change (°F) in August
tmax_lap_dec	tmax_lap	12.0000000	Change in maximum air temperature per 1,000 feet elevation change (°F) in December

Table 8: Climate properites descriptions and values used in the SWGM. *(continued)*

Parameter Name	Group Name	Value	Description
tmax_lap_feb	tmax_lap	12.0000000	Change in maximum air temperature per 1,000 feet elevation change (°F) in February
tmax_lap_jan	tmax_lap	9.4700610	Change in maximum air temperature per 1,000 feet elevation change (°F) in January
tmax_lap_jul	tmax_lap	7.5693981	Change in maximum air temperature per 1,000 feet elevation change (°F) in July
tmax_lap_jun	tmax_lap	5.6314665	Change in maximum air temperature per 1,000 feet elevation change (°F) in June
tmax_lap_mar	tmax_lap	12.7798857	Change in maximum air temperature per 1,000 feet elevation change (°F) in March
tmax_lap_may	tmax_lap	11.0000000	Change in maximum air temperature per 1,000 feet elevation change (°F) in May
tmax_lap_nov	tmax_lap	13.1165216	Change in maximum air temperature per 1,000 feet elevation change (°F) in November
tmax_lap_oct	tmax_lap	9.6706430	Change in maximum air temperature per 1,000 feet elevation change (°F) in October
tmax_lap_sep	tmax_lap	9.0000000	Change in maximum air temperature per 1,000 feet elevation change (°F) in September
tmax_snow	tmax_snow	32.0000000	Maximum temperature snow can form (°F)
tmin_lap_apr	tmin_lap	7.3058421	Change in minimum air temperature per 1,000 feet elevation change (°F) in April
tmin_lap_aug	tmin_lap	7.0000000	Change in minimum air temperature per 1,000 feet elevation change (°F) in August
tmin_lap_dec	tmin_lap	11.0000000	Change in minimum air temperature per 1,000 feet elevation change (°F) in December
tmin_lap_feb	tmin_lap	11.7491194	Change in minimum air temperature per 1,000 feet elevation change (°F) in February
tmin_lap_jan	tmin_lap	13.2407952	Change in minimum air temperature per 1,000 feet elevation change (°F) in January
tmin_lap_jul	tmin_lap	7.0000000	Change in minimum air temperature per 1,000 feet elevation change (°F) in July
tmin_lap_jun	tmin_lap	8.0000000	Change in minimum air temperature per 1,000 feet elevation change (°F) in June
tmin_lap_mar	tmin_lap	12.9059633	Change in minimum air temperature per 1,000 feet elevation change (°F) in March
tmin_lap_may	tmin_lap	15.5359526	Change in minimum air temperature per 1,000 feet elevation change (°F) in May

Table 8: Climate properites descriptions and values used in the SWGM. *(continued)*

Parameter Name	Group Name	Value	Description
tmin_lap_nov	tmin_lap	2.0000000	Change in minimum air temperature per 1,000 feet elevation change (°F) in November
tmin_lap_oct	tmin_lap	10.0000000	Change in minimum air temperature per 1,000 feet elevation change (°F) in October
tmin_lap_sep	tmin_lap	9.0000000	Change in minimum air temperature per 1,000 feet elevation change (°F) in September

Streamflow Parameters

There are 4 streamflow parameters in the SWGM. Table 9 shows the the name of the parameters as used within the modeling framework in addition to final values used. These parameters are used within the SFR package of MODFLOW.

Table 9: Streamflow properites descriptions and values used in the SWGM.

Parameter Name	Group Name	Value	Description
sfr_hc	SFR	1.2620	Multiplier for streambed hydraulic conductivity
sfr_rough	SFR	0.5721	Multiplier for Manning's roughness coefficient
sfr_thick	SFR	0.9254	Multiplier for streambed thickness
sfr_width	SFR	1.0000	Multiplier for streambed width

Pumping Parameters

There are 13 pumping parameters in the SWGM. Table 10 shows the the name of the parameters as used within the modeling framework in addition to final values used. These are adjustment factors to pumping volumes for the entire watershed. They are used within the WEL package of MODFLOW.

Table 10: Pumping properites descriptions and values used in the SWGM.

Parameter Name	Group Name	Value	Description
WEL_apr	WEL	1.0	Multiplier for all pumping in April
WEL_aug	WEL	1.0	Multiplier for all pumping in August
WEL_dec	WEL	1.0	Multiplier for all pumping in December
WEL_feb	WEL	1.0	Multiplier for all pumping in February
WEL_jan	WEL	1.0	Multiplier for all pumping in January
WEL_jul	WEL	1.0	Multiplier for all pumping in July
WEL_jun	WEL	1.0	Multiplier for all pumping in June
WEL_mar	WEL	1.0	Multiplier for all pumping in March

Table 10: Pumping properites descriptions and values used in the SWGM. *(continued)*

Parameter Name	Group Name	Value	Description
WEL_may	WEL	1.0	Multiplier for all pumping in May
WEL_nov	WEL	1.0	Multiplier for all pumping in November
WEL_oct	WEL	1.0	Multiplier for all pumping in October
WEL_par	WEL	1.1	Multiplier for all pumping in all months
WEL_sep	WEL	1.0	Multiplier for all pumping in September

Recharge Parameters

There are 14 recharge parameters in the SWGM. Table 11 shows the the name of the parameters as used within the modeling framework in addition to final values used. These parameters are adjustment factors to recharge after PRMS and the RSRZ are calculated.

Table 11: Recharge properites descriptions and values used in the SWGM.

Parameter Name	Group Name	Value	Description
RCH_apr	UZF	1.0000	Recharge multiplier for April
RCH_aug	UZF	1.0000	Recharge multiplier for August
RCH_dec	UZF	1.0000	Recharge multiplier for December
RCH_feb	UZF	1.0000	Recharge multiplier for February
RCH_jan	UZF	1.0000	Recharge multiplier for January
RCH_jul	UZF	1.0000	Recharge multiplier for July
RCH_jun	UZF	1.0000	Recharge multiplier for June
RCH_mar	UZF	1.0000	Recharge multiplier for March
RCH_may	UZF	1.0000	Recharge multiplier for May
RCH_nov	UZF	1.0000	Recharge multiplier for November
RCH_oct	UZF	1.0000	Recharge multiplier for October
RCH_sep	UZF	1.0000	Recharge multiplier for September
VKS	UZF	100.0000	Saturated vertical hydraulic conductivity, used for rejected infiltratrion only
strt_rch	UZF	0.5579	Starting recharge multiplier for the steady state stress period

Calibration Results

The hydrographs below present the observed groundwater hydrographs versus the simulated heads (after calibration). The map below shows the location of each observation well in the model domain using the MODFLOW node as the naming convention for observations. This is a preliminary calibration run. Additional work on including additional observations and changing parameterization is currently underway in collaboration with the SWRCB.

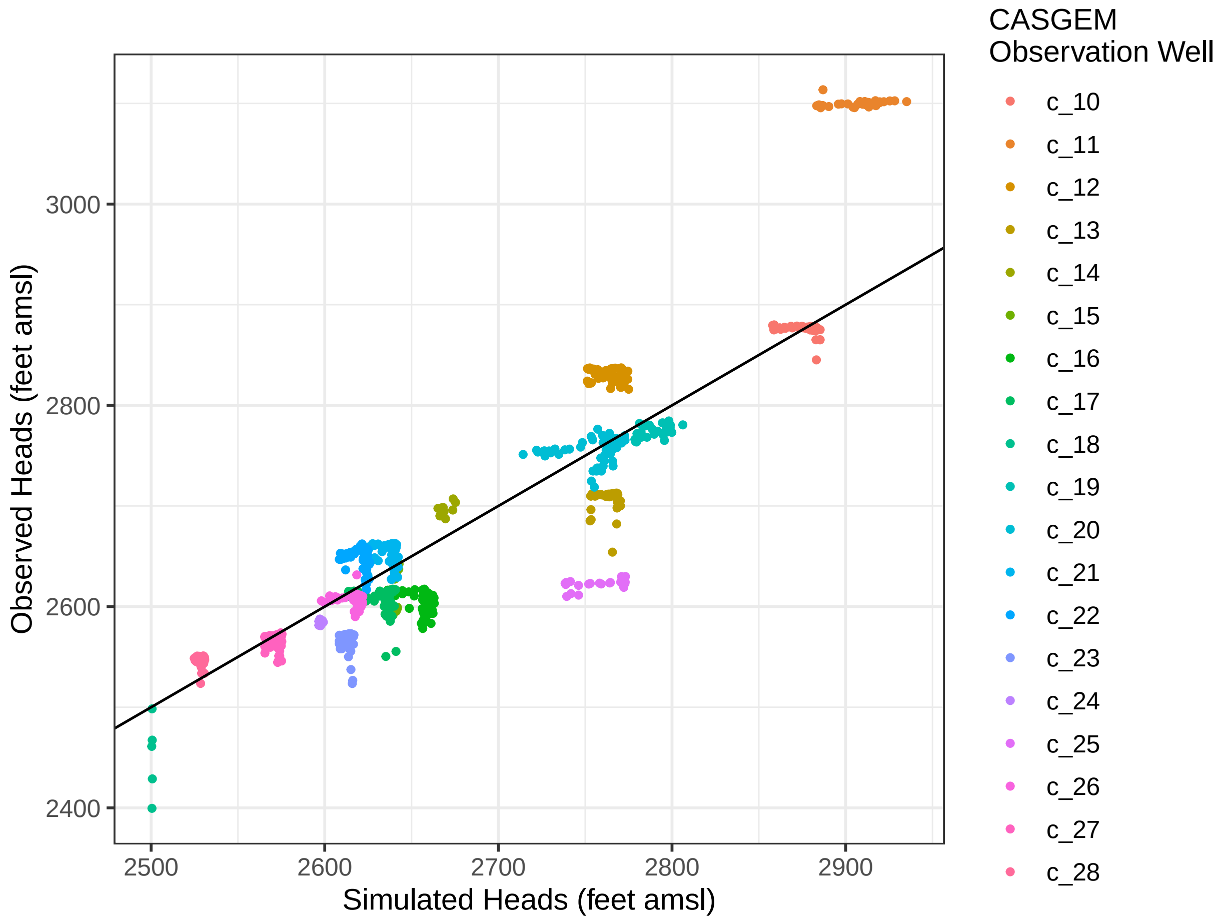

Figure 10: Observed vs. Simulated groundwater elevations in CASGEM Wells (1 of 2).

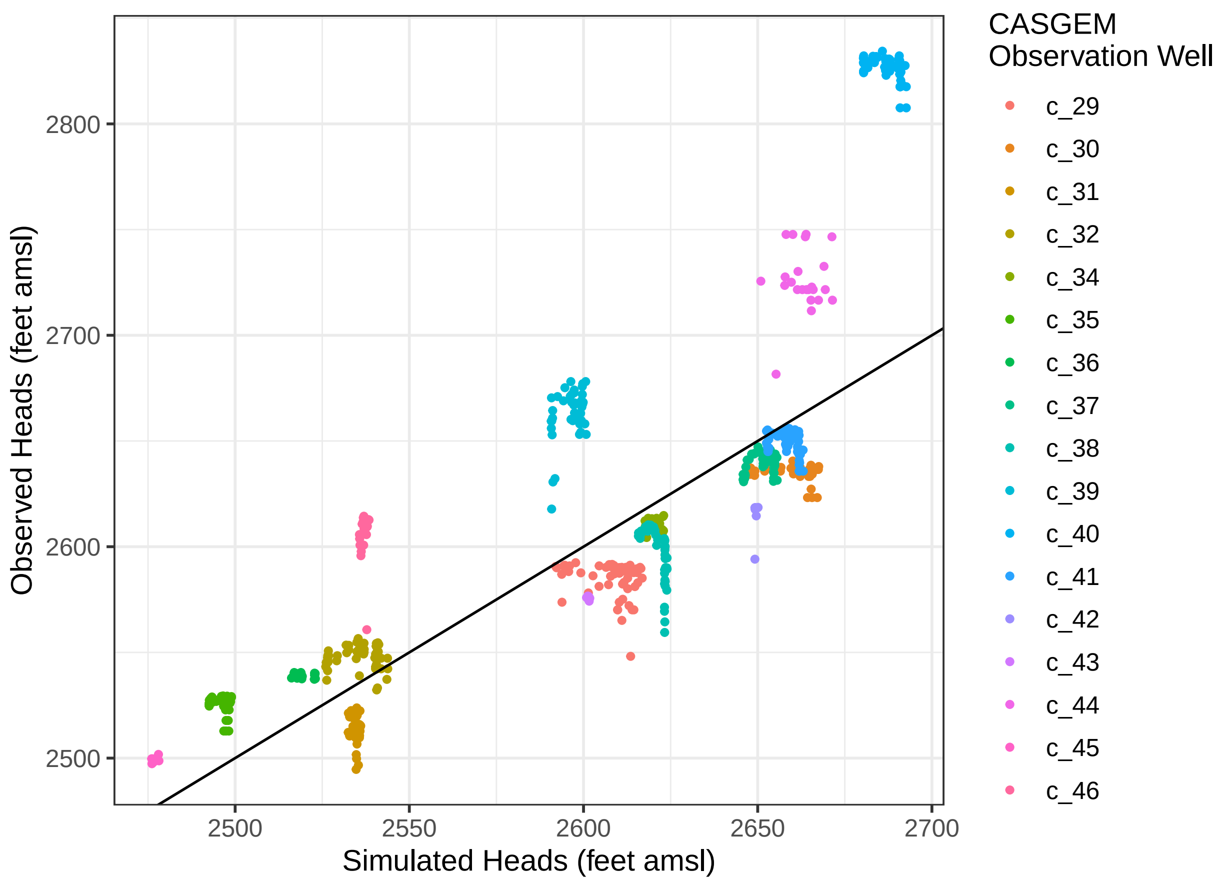

Figure 11: Observed vs. Simulated groundwater elevations in CASGEM Wells (2 of 2).

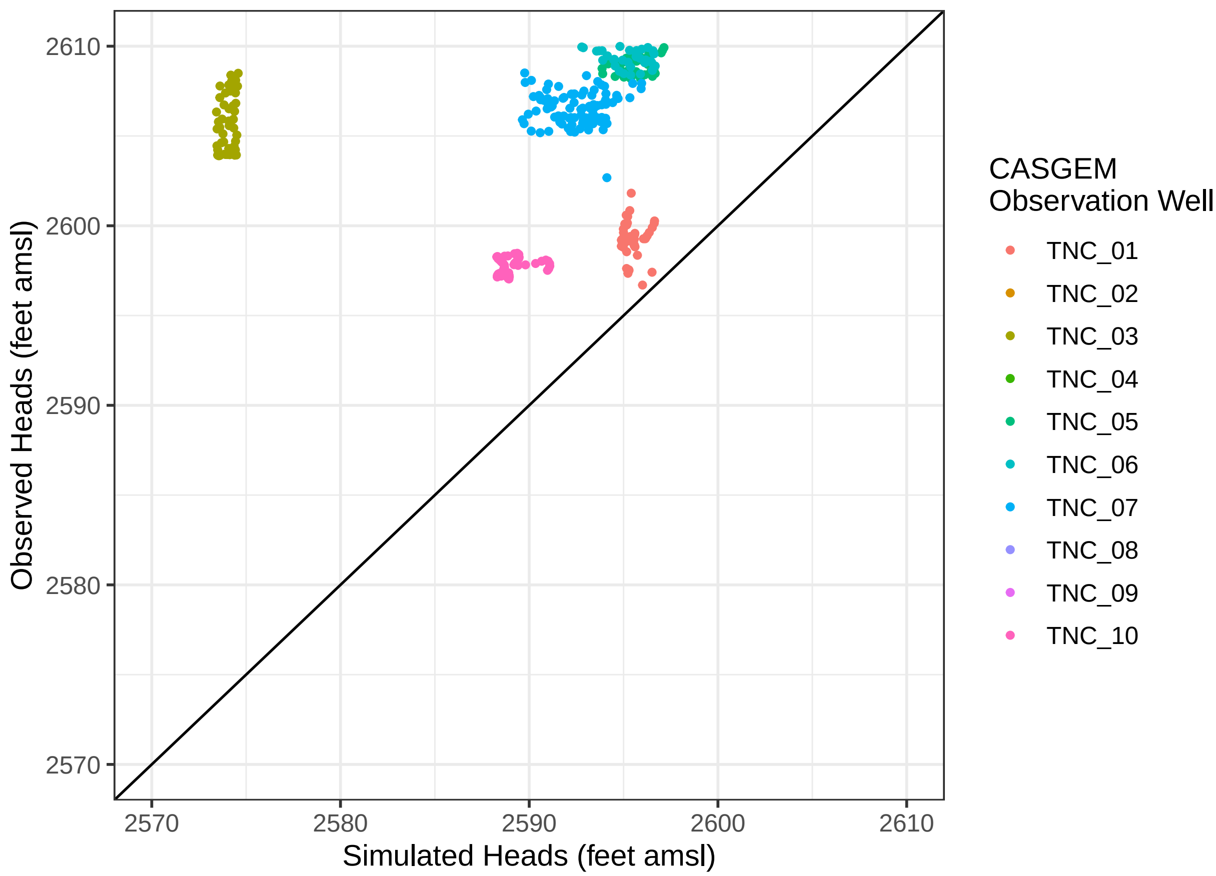

Figure 12: Observed vs. Simulated groundwater elevations in TNC wells near Big Springs.

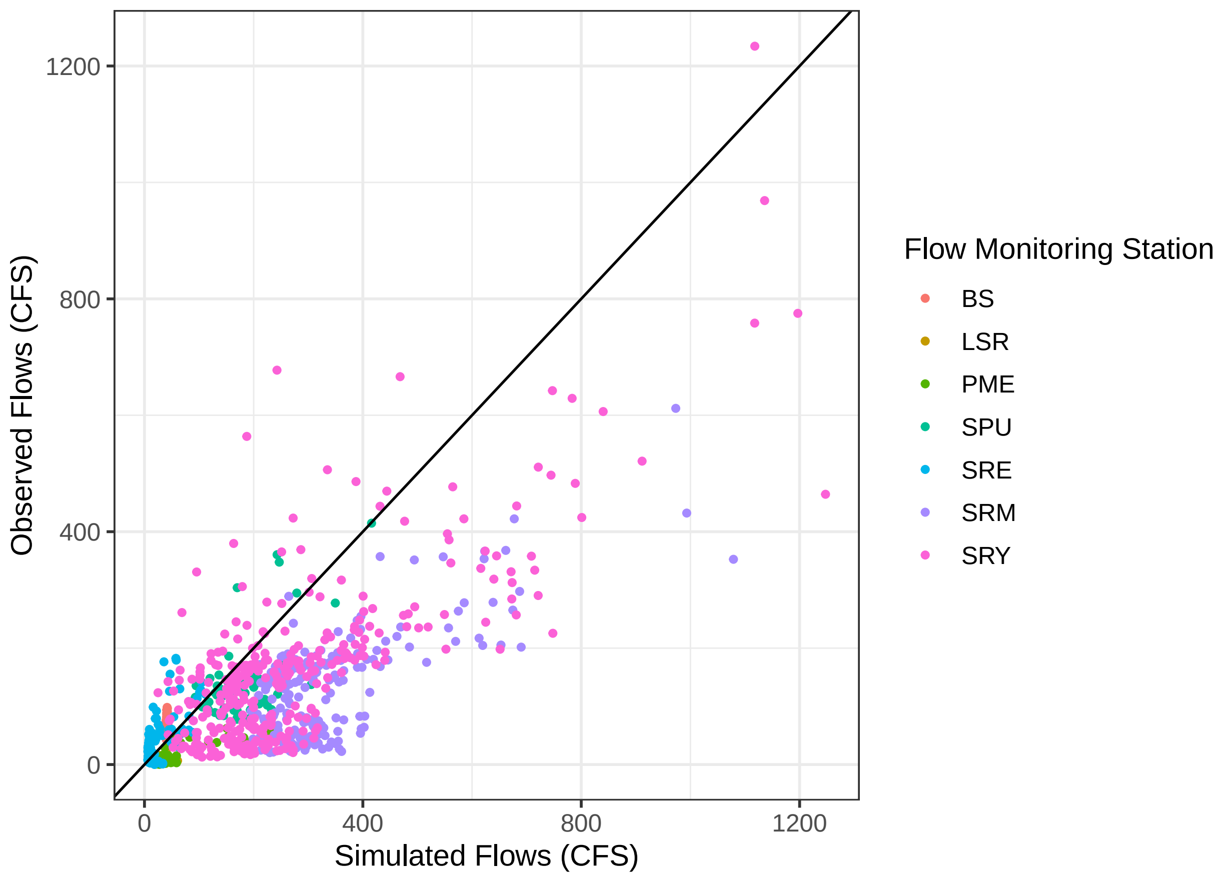

Figure 13: Observed vs. Simulated river flows within Shasta Watershed

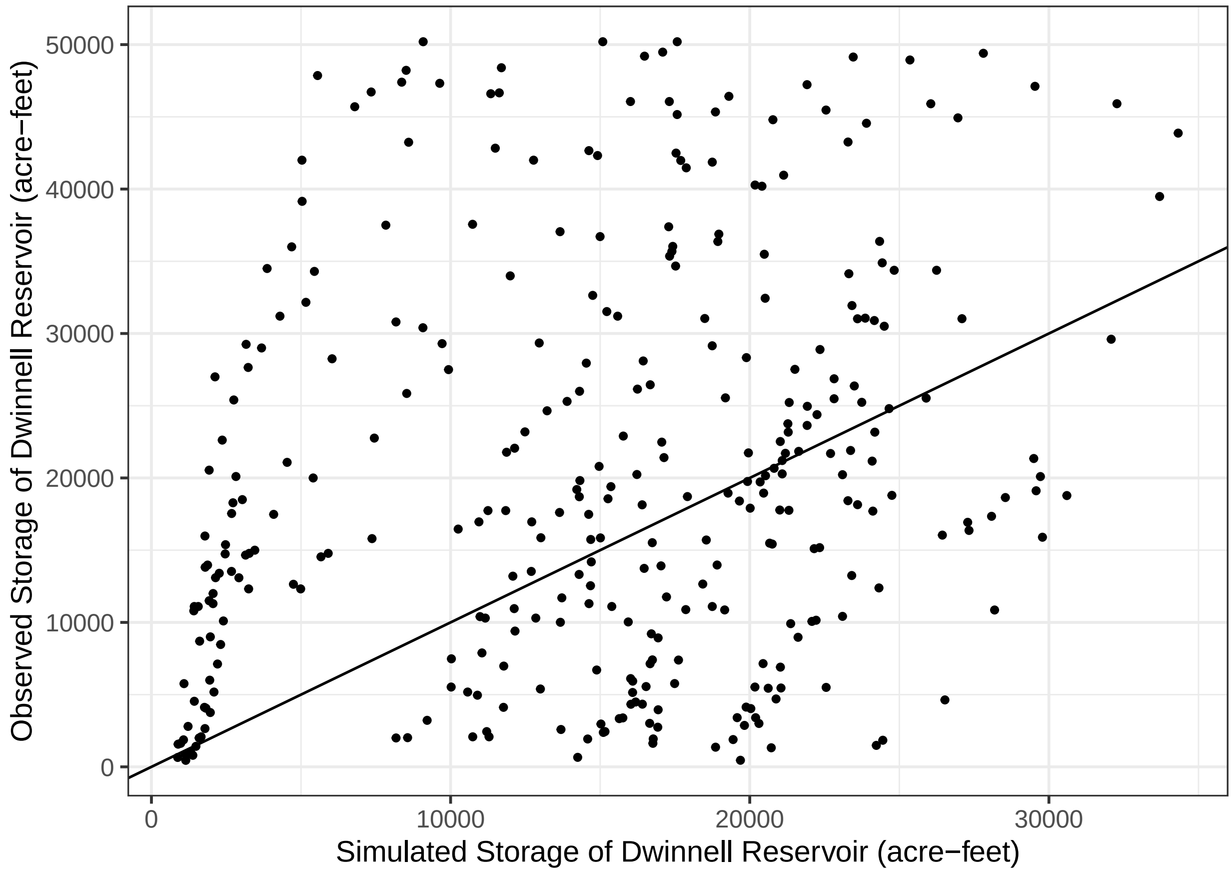

Figure 14: Observed vs. Simulated total storage in Dwinnell Reservoir.

Sensitivity and Uncertainty Analysis

A complete sensitivity and uncertainty analysis will be published in the SWGM v1.1 documentation.

Hydrologic Budget and Flow

Climate Budget

Climatic water budgets are summarized from PRMS modeled output.

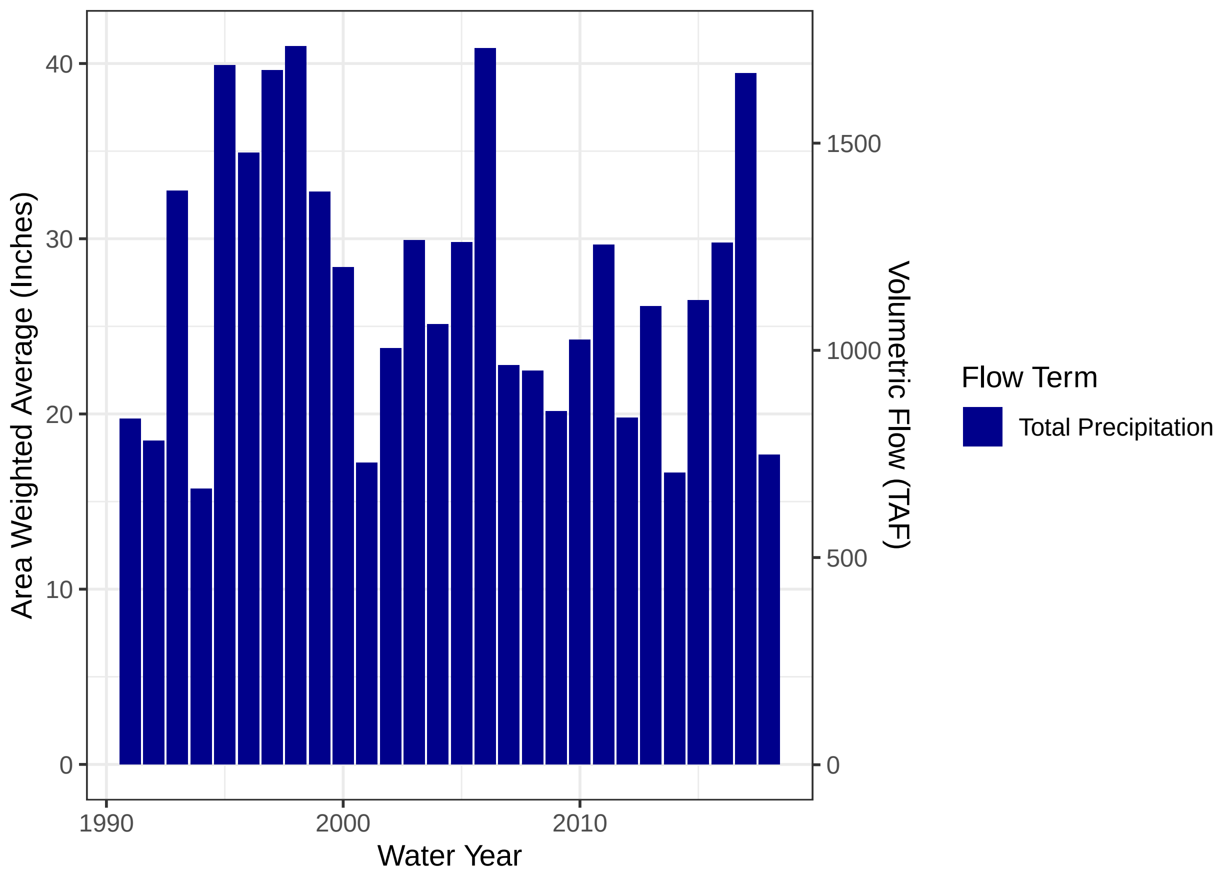

Figure 15: Yearly precipitation within the Shasta Watershed.

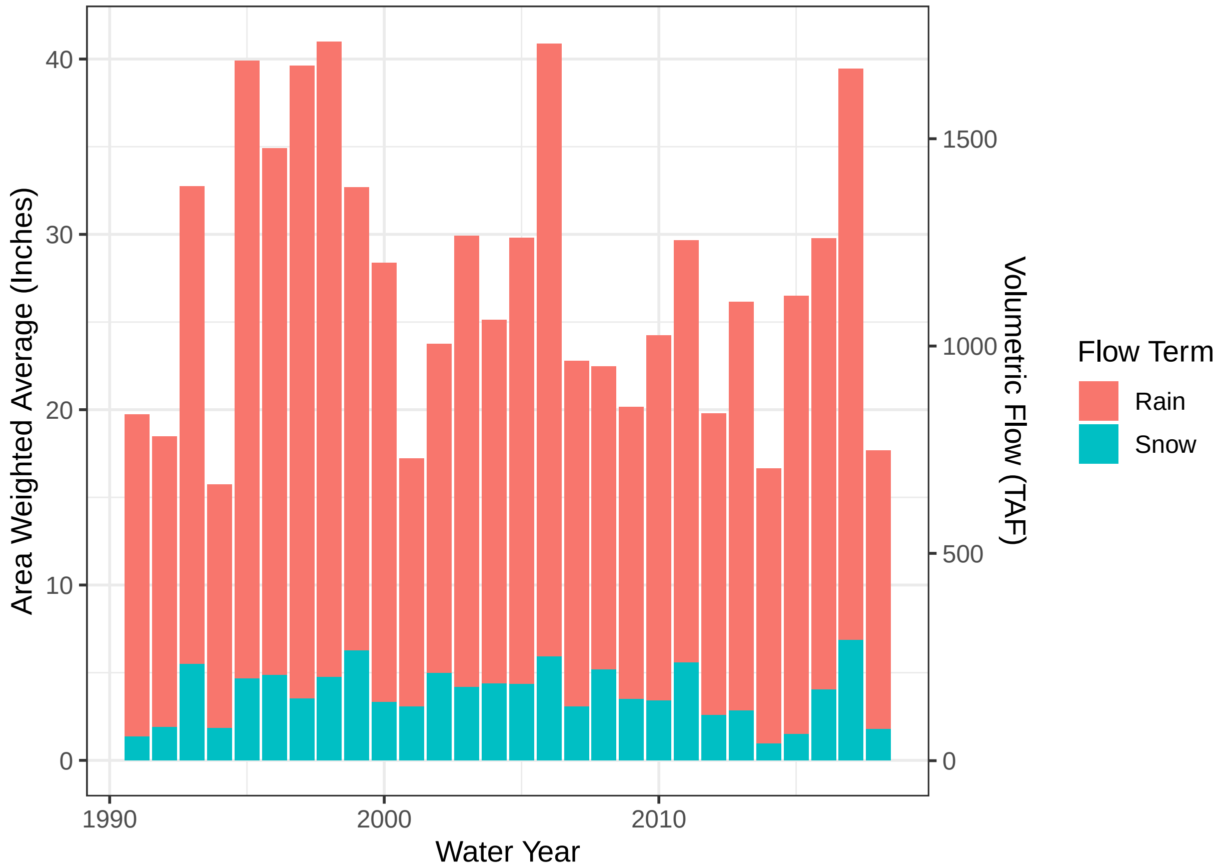

Figure 16: Yearly rain and snowfall within the Shasta Watershed.

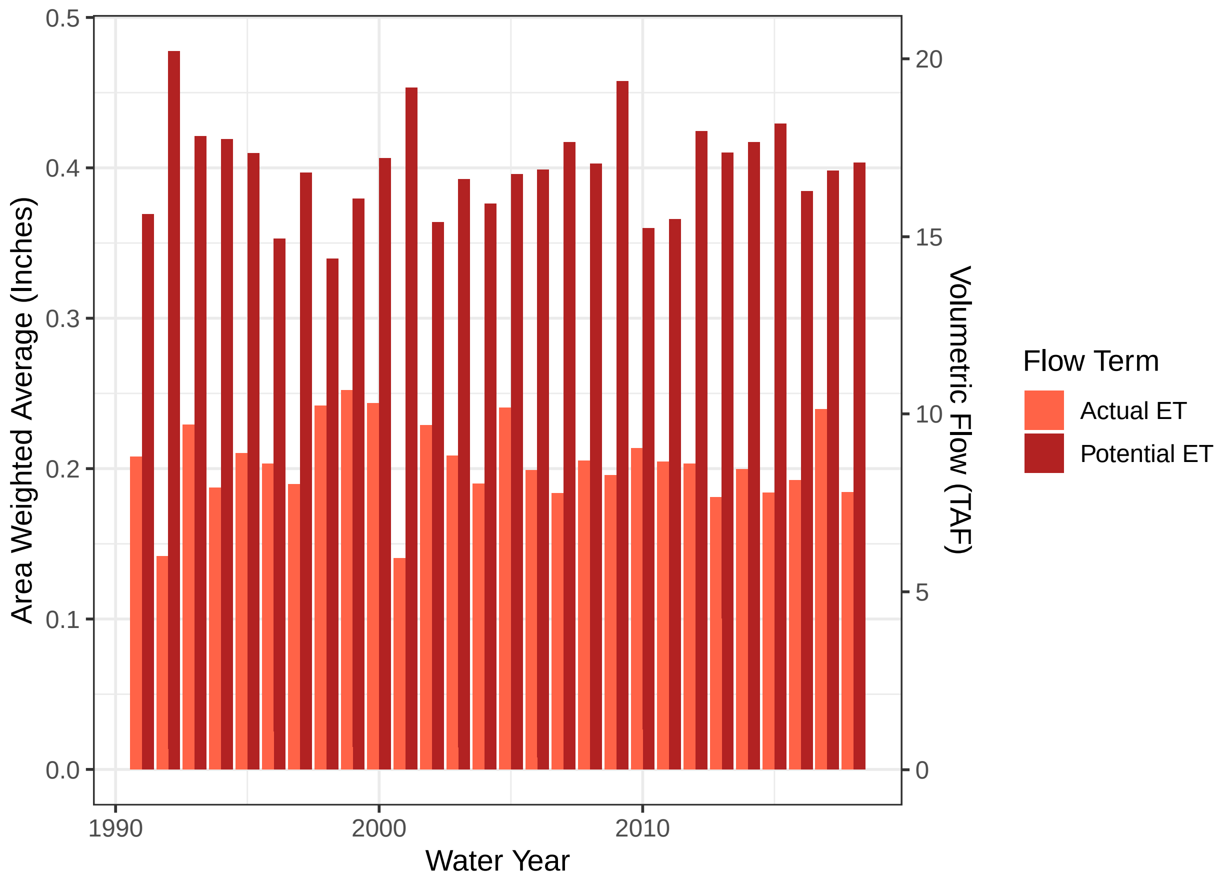

Figure 17: Yearly rain and snowfall within the Shasta Watershed.

Groundwater Budget

Groundwater budgets can be reviewed in Chapter 2 of the Shasta GSP. Updates to the groundwater budget will be presented in the SWGM v1.1 updatted documentation.

Climate Projections

Modeled water balances reflecting a series of climate projections was evaluated with the calibrated SWGM. Water years were selected from the historic time period (WY1991-WY2018) and repeated as needed to make a 50-year climate period. The 50-year climate period is recorded as WY2022-2071. Table 12 shows the sequence of historic climate used to create the projected baseline.

Table 12: Projected climate referenced to historic climate reference years with water year type, as described by DWR, for historic climate.

Projected Climate	Historic Climate	Water Year Type
2022	1994	Dry
2023	1995	Wet

Table 12: Projected climate referenced to historic climate reference years with water year type, as described by DWR, for historic climate. *(continued)*

Projected Climate	Historic Climate	Water Year Type
2024	1996	Wet
2025	1997	Wet
2026	1998	Wet
2027	1999	Wet
2028	2000	Above Normal
2029	2001	Critical
2030	2002	Dry
2031	2003	Above Normal
2032	2004	Above Normal
2033	2010	Below Normal
2034	2006	Wet
2035	2007	Below Normal
2036	2008	Dry
2037	2009	Dry
2038	2011	Above Normal
2039	1991	Critical
2040	1992	Critical
2041	1993	Above Normal
2042	1994	Dry
2043	1995	Wet
2044	1996	Wet
2045	1997	Wet
2046	1998	Wet
2047	1999	Wet
2048	2000	Above Normal
2049	2001	Critical
2050	2002	Dry
2051	2003	Above Normal
2052	2004	Above Normal
2053	2010	Below Normal
2054	2006	Wet
2055	2007	Below Normal
2056	2008	Dry
2057	2009	Dry
2058	2011	Above Normal
2059	1991	Critical
2060	1992	Critical
2061	1993	Above Normal
2062	1994	Dry
2063	1995	Wet
2064	1996	Wet
2065	1997	Wet
2066	1998	Wet
2067	1999	Wet
2068	2000	Above Normal
2069	2001	Critical

Table 12: Projected climate referenced to historic climate reference years with water year type, as described by DWR, for historic climate. *(continued)*

Projected Climate	Historic Climate	Water Year Type
2070	2002	Dry
2071	2003	Above Normal

Four climate scenarios were created using the projected baseline climate data, these four scenarios are labeled as "Far," "Near," "Dry," and "Wet," corresponding to DWR future scenarios "2030," "2070," "2070DEW," and "2070WMW," respectively. Model differencing was used to examine trends in different climate scenarios using the baseline projected data as the differencing base.

DWR's Climate Change Data and Guidance for Use During GSP[7] development contains a dataset of "change factors" which each GSA can use to convert local historical weather data into 4 different climate change scenarios (DWR 2018). Change factors are geographically and temporally explicit. Geographically, a grid of 1/16-degree resolution cells covers the extent of California; for each of these cells, one change factors applies to each month, 1911-2011.

Under their SGMA climate change guidance, DWR provided a dataset of "change factors" which each GSA can use to convert local historical weather data into 4 different climate change scenarios (DWR 2018). Change factors are geographically and temporally explicit. Geographically, a grid of 1/16-degree resolution cells covers the extent of California; for each of these cells, one change factors applies to each month, 1911-2011.

The 2030 (Near) and 2070 central tendency (Far) scenarios predict similar rainfall conditions to the Base case, while the 2070 DEW (Dry) and 2070 WMW (Wet) scenarios show less and more cumulative rain, respectively. Conversely, all scenarios predict higher future ET than the Base case.

Additional information, water budgets, and further discussion on the climate scenario water budgets will be presented in SWGM v1.1.

Model Limitations and Future Improvements

Potential Improvements

SWGM v1.0 should be considered a preliminary effort to characterize the Shasta Watershed. Data from continuous groundwater sensors, increased number of stream gages, and agricultural water usage will provide updates to the calibrated values of the system. There are a number of updates that are under consideration for the base model:

- Updates to glacier melt and snow dynamics on Mount Shasta. Updates to the PRMS code, v 5.2, include a more robust characterization of glacier dynamics. Increased data collection on precipitation, solar radiation, air temperature, and other climate variables should also be included in PRMS updates.

[7] https://groundwaterexchange.org/wp-content/uploads/2020/09/Resource-Guide-Climate-Change-Guidance_v8_ay_19.pdf

- Geologic updates to include fracture flow within basalt geology.
- Hydrogeologic updates to refine anisotropy, storage, and model layer thicknesses.
- Agricultural demands should be internally calculated within the code. Both Ag package within GSFLOW and FMP package with OWHM are possible codes that can be used.
- Update to stream geometry using LiDAR data from SWRCB.
- Representation of the canal network using SFR.
- Update the model simulation period through 2021 to include new continuous groundwater level data collected as part of the GSP.
- Surface water diversions can be dynamically linked with priorities to the SFR package to meet surface water demand.

Model Archiving

The SWGM will be released to the public after the public comment period and after consulting DWR about best management practices for model release.

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Report

Date
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GEOPHYSICAL INVESTIGATIONS FOR SUBSURFACE CHARACTE-RIZATION IN SHASTA VALLEY

tTEM & WalkTEM SURVEYS

RAMBOLL Bright ideas. Sustainable change.

GEOPHYSICAL INVESTIGATIONS FOR SUBSURFACE CHARACTE-RIZATION IN SHASTA VALLEY
TTEM & WALKTEM SURVEYS

Project name	**LWA: TTEM and WalkTEM in Shasta Valley**
Project no.	**1690018915**
Date	**05/27/2021**
Prepared by	**Ahmad-Ali Behroozmand**
Approved by	**Max Halkjær**
Description	**Geophysical investigations for subsurface characterization in Shasta Valley**

RAMBOLL

WATER

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Geophysical tTEM and WalkTEM Investigations for Subsurface Characterization in Shasta Valley

May 27, 2021

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Dear Dr. Gooch,

Ramboll is pleased to submit this report of the results of the geophysical investigations conducted in the eastern part of Shasta Valley.

Ramboll has completed geophysical investigation of the study area where the main purpose was to improve understanding of the recharge process in the area.

We appreciate staff from Larry Walker Associates, Inc. (LWA) and County of Siskiyou for obtaining site permits, support during the field operation and for providing information from previous studies in the area. It has been a pleasure to conduct the study and we will remain available at your convenience to discuss this report or to answer any questions.

Yours sincerely,

A. A. Behroozmand

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WalkTEM Results

ABBREVIATIONS

ATV	All-Terrain Vehicle
BGS	Below Ground Surface
DOI	Depth of Investigation
EM	Electro-Magnetics
GERDA	Geophysical Relationship Database
GIS	Geographic Information System
GPS	Global Positioning System
HM	High Moment
Hz	Hertz
IP	Induced Polarization
LCI	Laterally Constrained Inversion
LM	Low Moment
M	Meter
TEM	Transient Electro Magnetics
tTEM	Towed-TEM

1. INTRODUCTION

The main purpose of this project was to improve understanding of the subsurface geology and recharge process in the area. We used Towed-TEM (tTEM) and WalkTEM geophysical techniques. The tTEM survey was conducted along pre-planned paths. The WalkTEM data were acquired at pre-planned locations in the study area.

Through geophysical inversion, the time-domain electromagnetic (TEM) data provided by the two methods were interpreted to smooth (multi-layer) electrical resistivity models. The tTEM method provides a high-resolution representation of the variations in electrical resistivity along the paths where an all-terrain vehicle (ATV) pulled the sensor. The WalkTEM method provides a detailed representation of the variations in electrical resistivity at specific measuring locations.

The main sections of this report describe the field operation and the results of the tTEM and WalkTEM surveys in the study area. Appendix 1 contains a general introduction to the TEM method. Appendix 2 contains detailed documentation of the tTEM and WalkTEM systems, including calibration of the system, repeated data acquired along a test line, complete configuration of the systems and information about processing and inversion parameters. Appendix 3 provides mean resistivity plan-view maps at different elevation intervals across the study area. Appendix 4 contains cross sectional illustrations of the results. Appendix 5 contains the data from WalkTEM soundings and how they were modelled.

Figure 1 The tTEM system in operation at the site.

Figure 2 The WalkTEM system in operation at the site.

2. FIELD WORK

The fieldwork consisted of two (2) days of tTEM and WalkTEM surveying. The surveys were carried out by Ahmad-Ali Behroozmand of Ramboll between September 23-24, 2020. The tTEM data collection was performed by towing the tTEM system behind an ATV using a specially designed sled frame with non-metallic parts to avoid potential interferences as seen in Figure 3. The equipment was transported to and from the site with a cargo van.

The tTEM system went through a detailed test and documentation process at the National Danish Test site. The results are shown in Appendix 2. The test results demonstrate that the tTEM system reproduces the Danish Test and Reference site accurately.

The WalkTEM data collection was performed by laying out a 40 m x 40 m (130 ft x130 ft) square-shaped transmitter loop, along with a receiver loop placed in the center of the transmitter loop for each measurement at pre-planned locations across the study area. These measurements are called 'soundings'. The WalkTEM setup can be seen in Figure 4.

Detailed information about the TEM methods and the tTEM & WalkTEM specifications can be found in Appendix 1 and Appendix 2, respectively.

Figure 3 The tTEM transmitter sled setup.

Figure 4 The WalkTEM instrument in operation.

2.1 tTEM Data Collection

Prior to data acquisition, GIS layers containing geographic locations of the study area and tTEM lines were loaded into the tTEM navigation software, which enabled real-time tracking of the paths. This also allowed the operator to view the density of the data being collected and facilitate proper coverage of the site with the tTEM. During the tTEM survey, data quality and the entire system functionality were checked by the operator.

A location map of the tTEM survey lines is shown in Figure 5. The tTEM data were acquired in two areas within the valley. The near-surface geology of area 1 consists of both rocks and sediments, while the geology of area 2 consists mainly of volcanic rocks.

2.2 WalkTEM Data Collection

Prior to data collection, each pre-planned location was assessed carefully to ensure minimal EM noise interference from overhead powerlines, powered cables etc. Whenever the sounding locations were not optimal, it was moved to the nearest optimal location.

Location of the WalkTEM soundings is shown with squares in Figure 5.

2.3 Instrumentation issues

No instrument issues were encountered during the survey.

2.4 Weather

The weather was sunny, cool and dry in the morning and warm during the day.

2.5 Quality control during surveying

During start-up in the morning, Ramboll personnel carefully inspected the tTEM system to ensure that all parts, including wires and bolts & knots, were intact and secure. When the system was fully up and running, the GPS and TEM transmitter and receiver were checked.

At the end of each survey day, the data were quality controlled and a simple data processing and inversion was performed. The results demonstrated consistency and good signal to noise ratio.

A segment of the tTEM lines (test line) was repeated during the survey. The results of the repeated survey lines are shown in Appendix 2, which demonstrate high repeatability of the system and consistency of the inversion schemes.

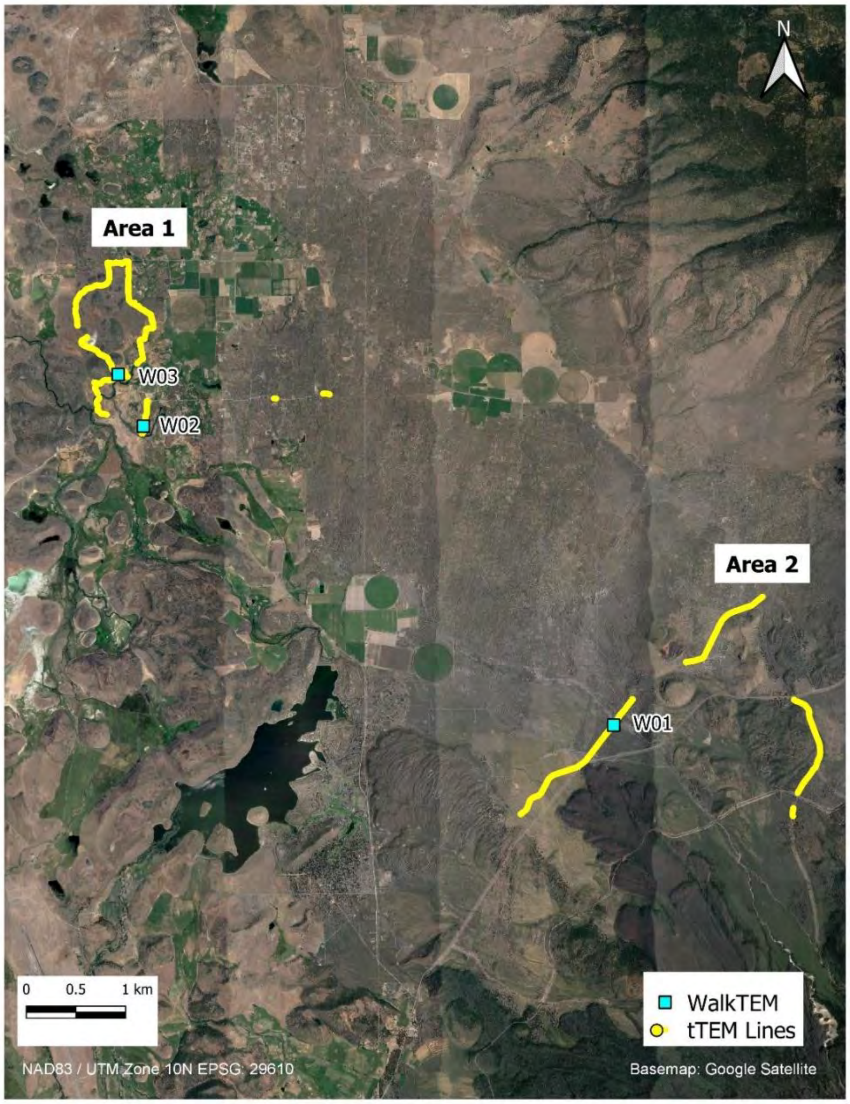


Figure 5 Location map of the Surveyed Area.

3. PROCESSING AND INVERSION

The processing and inversion of the tTEM data were completed with the software package, Aarhus Workbench (https://hgg.au.dk/software/aarhus-workbench/ https://www.aarhusgeosoftware.dk/workbench-viewer). The workbench is a well-documented and technically sound software package used for processing and inversion of electromagnetic and geoelectrical data. We utilized an application that is specifically designed for processing and inversion of the tTEM data.

The tTEM data were collected with 282 Hz repetition frequency equivalent to 282 decay curves per second. The high number of data points allows for an advanced data processing scheme to achieve the best possible signal to noise ratio.

The processing and inversion of the WalkTEM data were completed with the software package, Aarhus SPIA (https://hgg.au.dk/software/spia/). The SPIA is a well-documented and technically sound software package used for processing and inversion of ground-based electromagnetic and geoelectrical data. We utilized an application that is specifically designed for processing and inversion of the WalkTEM data.

3.1 tTEM data processing steps

The collected tTEM data underwent the following processing steps:

1. Check if useful data have been mistakenly masked during the data acquisition process.
2. Import data to a Geophysical Relationship database (GERDA).
3. Check if data are masked at turning points to avoid data where the system is not aligned properly.
4. Check all secondary data to ensure they are within specifications and do not vary significantly along the lines.
5. Process GPS data.
6. Assign a standard uniform 3% noise to all data.
7. Define a standard processing scheme to automatically reject data and assign noise to the data.
8. Manually inspect each survey line. Data determined noisy that has not already been rejected in the previous step are removed. The noise can be due to overhead powerlines, buried power cables, metal fences, and other man-made sources. This is done for the individual soundings, as well as for a sequence of soundings along the survey line.
9. Assign elevation from a digital elevation model grid to each data point.
10. Average data along the lines using a trapezoidal filter, where more data from the late time gates are averaged compared to fewer data at the early time gates. This is to improve the signal to noise ratio for the data representing the deeper parts and to maintain the high resolution near-surface features along the line.
11. Develop a final processed dataset with an average sounding distance of approximately 5 m (~ 16 ft).

More information about the tTEM data processing can be found in Appendix 2.

3.2 tTEM inversion steps

The entire processed tTEM data were then used together during the inversion and underwent the following steps:

1. Define horizontal and vertical constrains on the resistivities as well as the number of model layers and layer thicknesses.
2. Invert the processed data using the laterally-constraint (LCI) approach (Auken et al., 2005).
3. Present the data as depth slices. In case the depth slices reveal some distinct anomalies, the processing of the corresponding data is revisited (Step 3.1.1-8) and the data are re-inverted.

4. Calculate the depth of investigation (DOI) for each resistivity model, based on a sensitivity analysis of the model.

More information about the inversion process can be found in Appendix 2.

3.3 WalkTEM data processing steps

The collected WalkTEM data underwent the following processing steps:

1. Manually inspect each dataset for both low-moment (LM) and high-moment (HM) sounding curves.
2. Remove noisy data. The noise can be due to overhead powerlines, buried power cables, metal fences, and other man-made sources.
3. Assign a standard uniform 3% noise to all data.
4. Assign the transmitter loop center coordinate (acquired in the field) to the sounding.

3.4 WalkTEM inversion steps

The processed WalkTEM data were then used in the following inversion scheme:

1. Define vertical constrains on the resistivities as well as the number of model layers and layer thicknesses.
2. Invert the processed data for smooth (multi-layer) and layered resistivity models.
3. Present the data as line models. In case the results are not satisfactory, the inversion setup is revisited, and the data are re-inverted.
4. Calculate the DOI, based on a sensitivity analysis of the model.

4. RESULTS

This section describes the results of the geophysical surveys. The measured data are modelled to represent the electrical resistivities at different depths, which can then be interpreted as lithology to get an understanding of the site geology.

The results are presented as mean resistivity plan-view maps, cross sections and 3D fence diagrams. Figure 6 shows a location map of the tTEM accepted and rejected data for inversion in area 1. Results from area 2 are discussed in section 4.5.

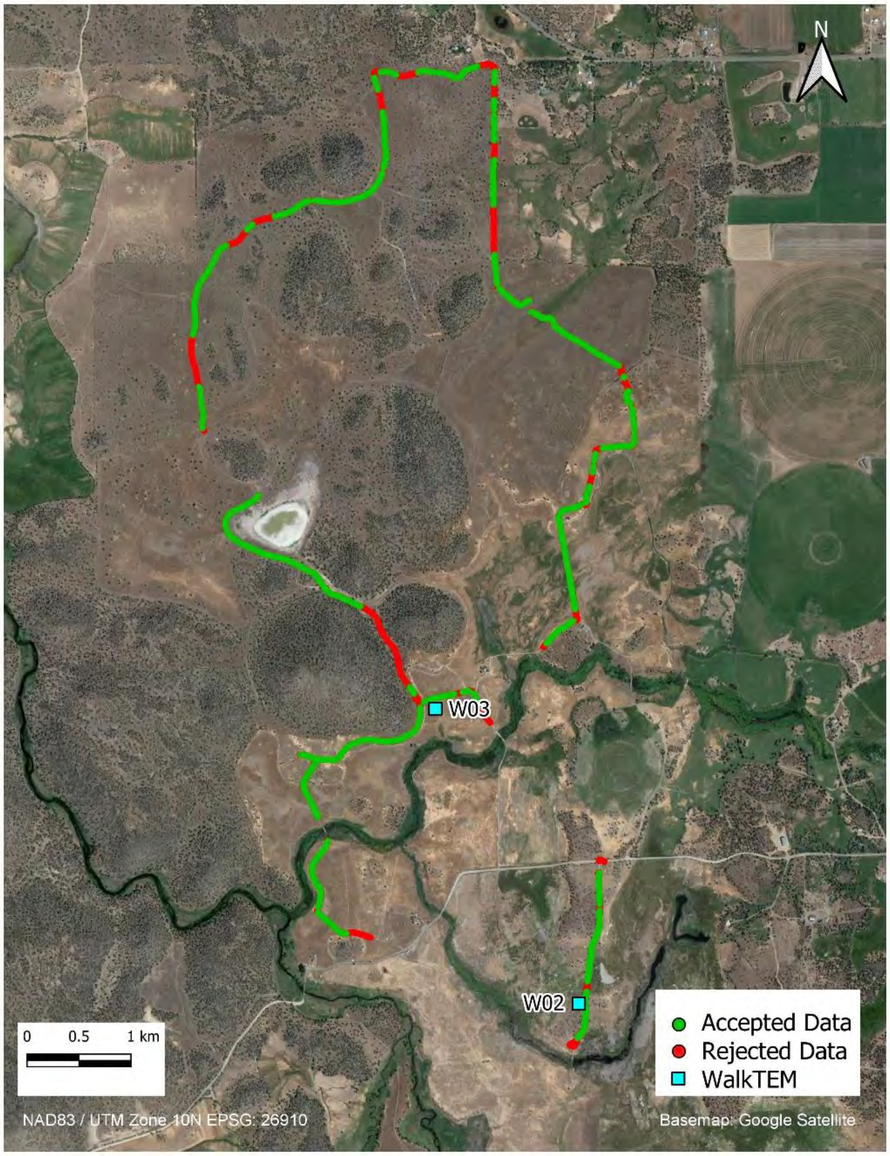


Figure 6 Location map of the tTEM accepted and rejected data for inversion in area 1.

4.1 Correlation between resistivity and lithology

The tTEM and the WalkTEM methods measure the electrical resistivity of the earth. To obtain the subsurface lithologic information, the measured electrical resistivities must be transformed into lithologies. Transforming resistivities to lithology is based on a general correlation between resistivity and sediment type. Figure 7 shows a general correlation, where low permeability clay has a low resistivity, sandy clay typically has a medium-range resistivity, and sand to coarse sand has a relatively large resistivity value. This correlation is a general assumption and the range of resistivity for each lithologic unit can vary between locations. The water quality within the vadose zone or in the aquifer can also impact the resistivity, i.e. the more saline the water, the lower the formation resistivity. Therefore, correlation with additional data sources (such as information from boreholes and water quality) and general geologic knowledge of the study area are crucial to obtain the most accurate description of the subsurface.

In this project, the resistivity colormap was adjusted to represent the geologic variations across the study area. The adjusted scale, used for all presentations in this report, is shown in Figure 8.

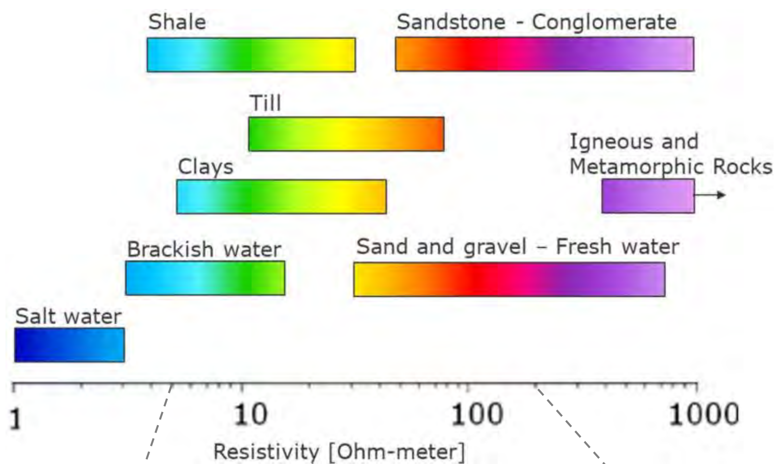


Figure 7 General correlation between resistivity, type of sediments and rocks, and water of varying quality.

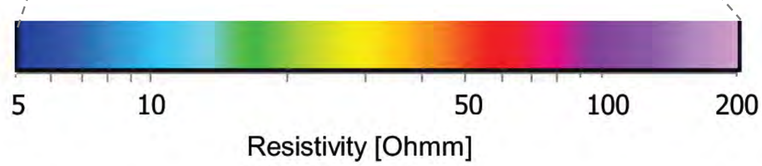


Figure 8 Resistivity color scale used for all presentations in the report.

4.2 Mean resistivity maps

Appendix 3 presents mean resistivity plan-view maps at different elevation intervals. The mean resistivity maps illustrate detailed structures and provide insight about variations across the surveyed area at each interval. The tTEM vertical resolution is high in the shallow subsurface and decreases with depth.

A fine depth discretization has been chosen to enable illustration of the lithologic variations across the study area and hence avoid oversimplified representation of the lithology. The depth of investigation (DOI) depends on the variations in data quality and geology. The DOI varies for each inverted model. Data below the determined DOI have been removed on the horizontal mean resistivity slices, which may cause the appearance of missing data, particularly in the lowest elevation intervals. In the highest elevation intervals data are only presented where the terrain elevation is high.

4.3 Vertical sections

Vertical sections are presented in Appendix 4. Detailed structural variations are observed along each section. The WalkTEM resistivity models are shown as bars on the sections and are in good agreement with the tTEM models. Data below the determined DOI have been made semitransparent.

4.4 Fence diagrams

In the following figures, selected vertical sections from area 1 are stitched together and visualized from different angles. This serves to provide a three-dimensional visualization of the results.

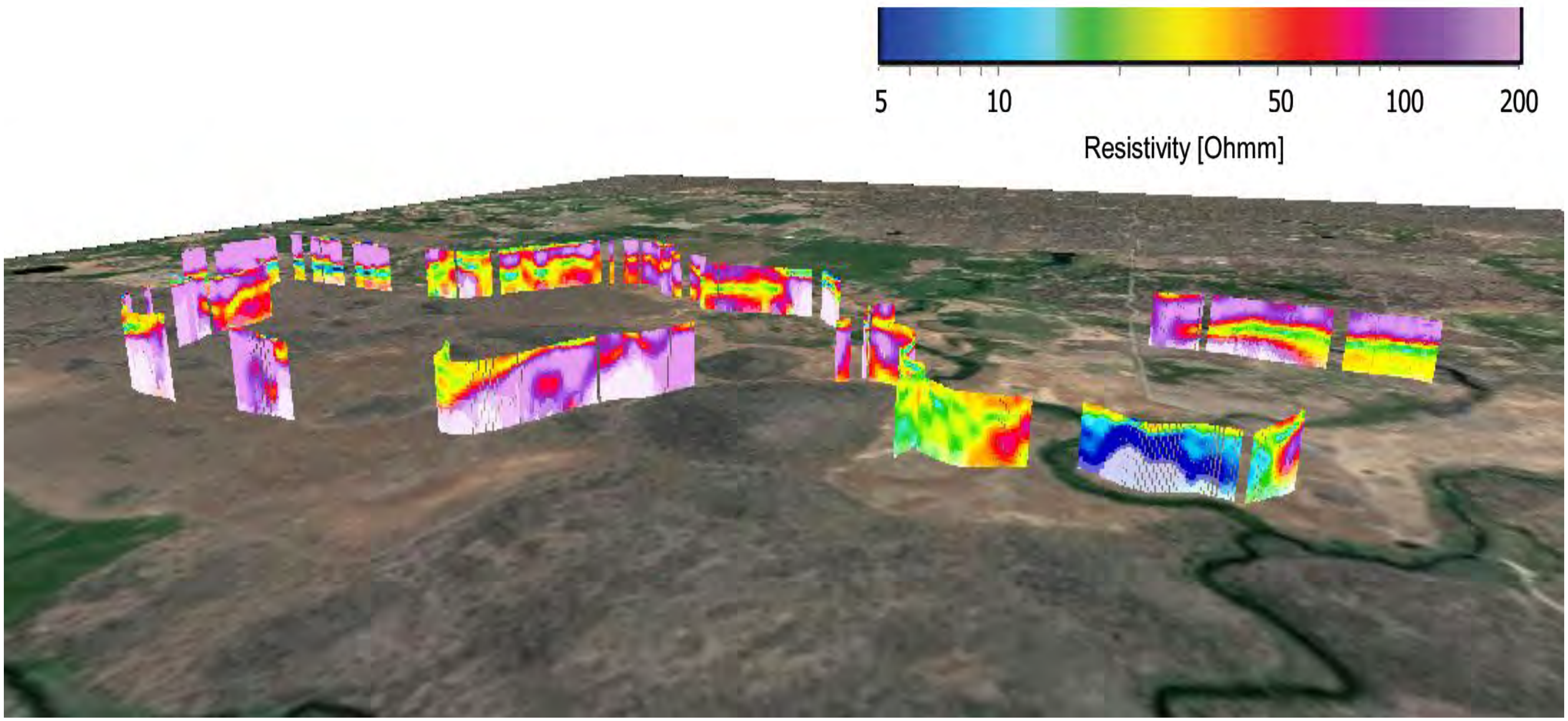


Figure 9 The model results presented as a 3D fence diagram. Seen from the west of area 1.

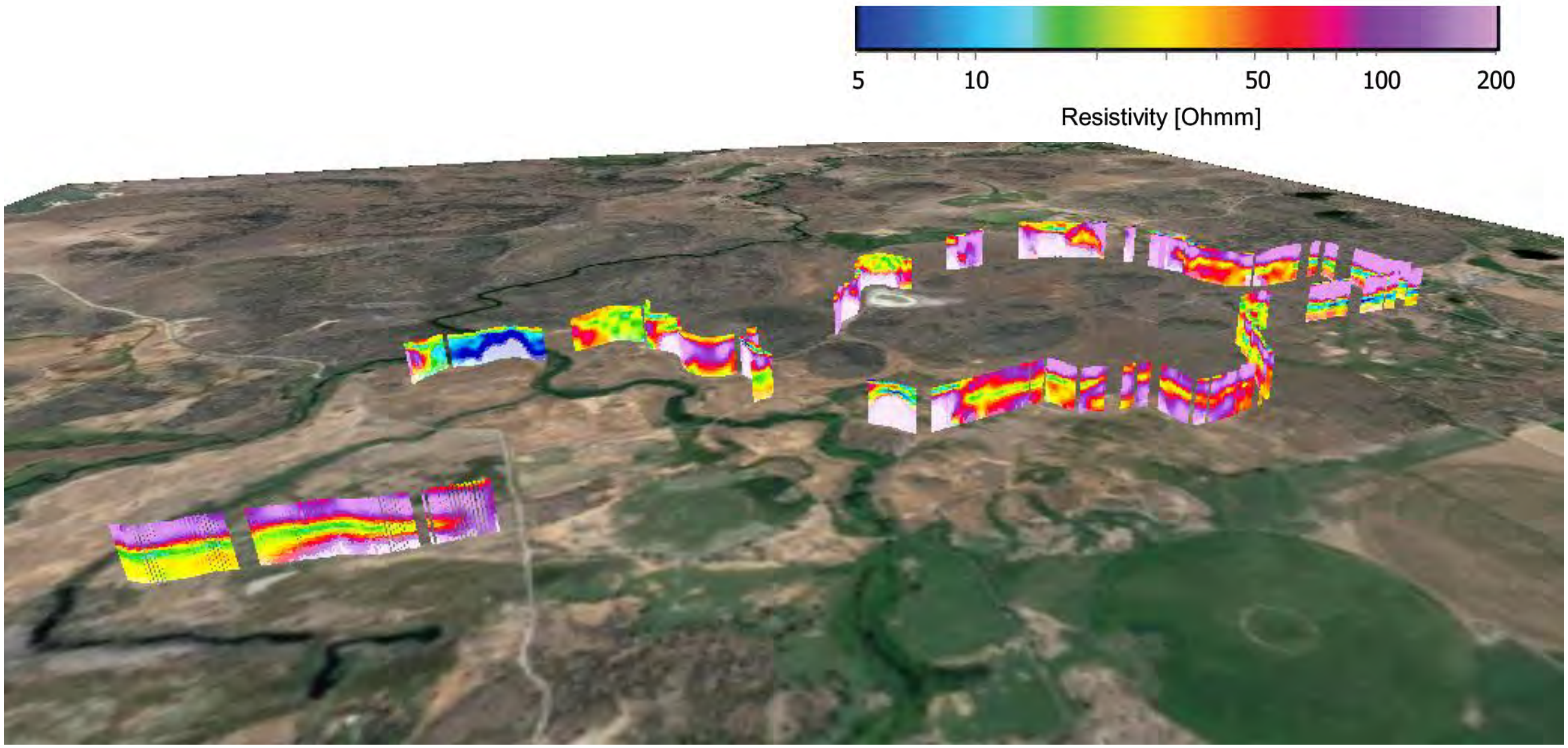


Figure 10 The model results presented as a 3D fence diagram. Seen from the south east of area 1.

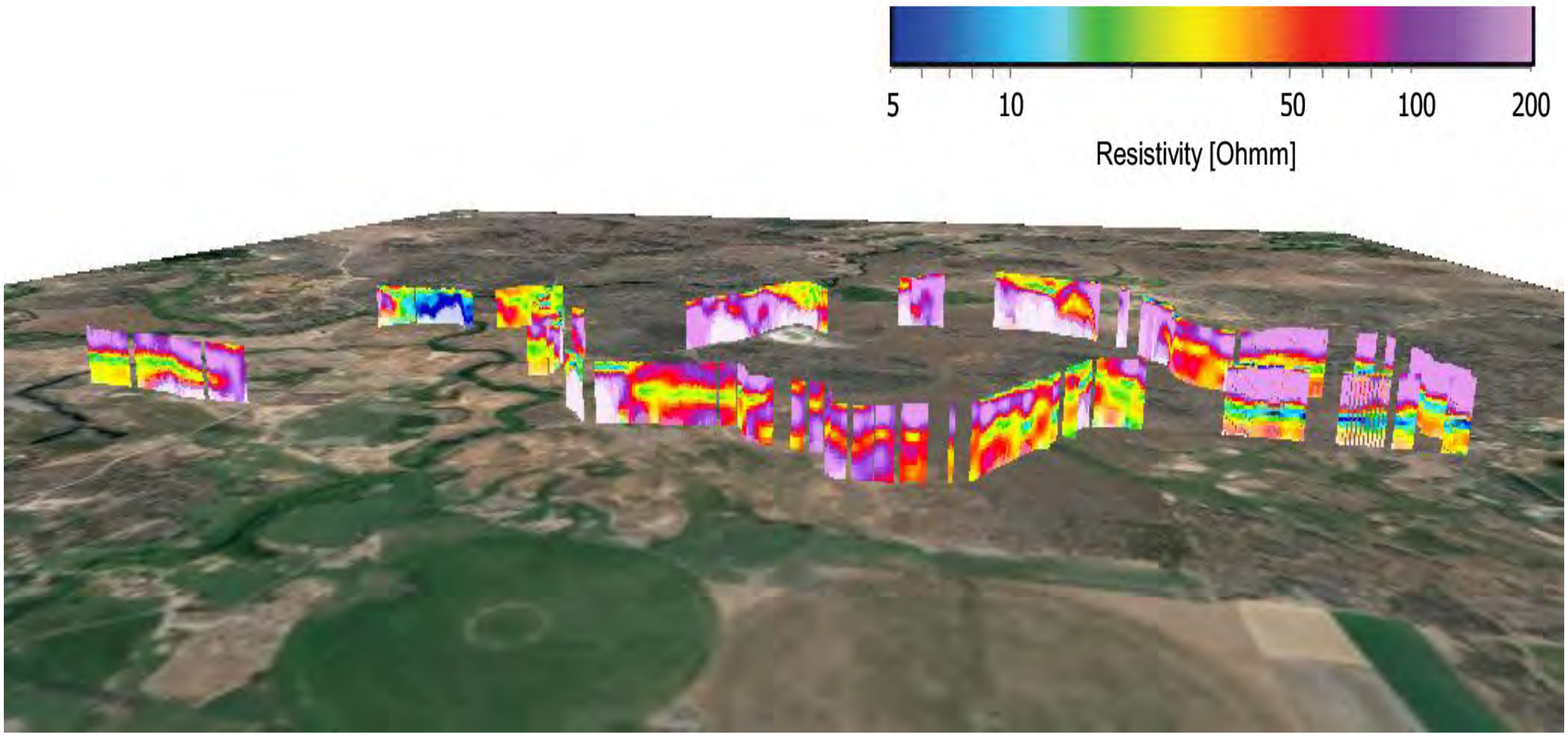


Figure 11 The model results presented as a 3D fence diagram. Seen from the east of area 1.

4.5 Results from Area 2

Figure 12 shows a location map of the tTEM surveyed lines in area 2.

In area 2, the earth TEM signal level was found to be extremely low. The weak TEM signal in volcanic environments can be interpreted to be due to

1. The very high resistivity of the volcanic rocks. The resistivity of the volcanic rocks can be more than 1,000 Ohm-m; the higher the resistivities of the subsurface geology, the weaker the earth TEM response,
2. Induced polarization (IP) effects. The IP effects in volcanic environments could arise from deposited clay minerals, or metals such as massive sulphides mineralization. Such formations tend to be chargeable. The decaying IP response can have an opposite sign compared to the ordinary TEM response, which reduces or sometimes takes over the weak TEM response measured in a resistive environment. As a result, the IP-effects in TEM data are observed as abnormally quick decay curves (with different decay curve characteristics than the TEM decay curve) and can alter the shape of the TEM curves. When the IP effect is strong, and the resistivity of the rock is high the measured TEM signals can have a sign change along the decay curve. In certain cases, the entire decay curve can change sign.

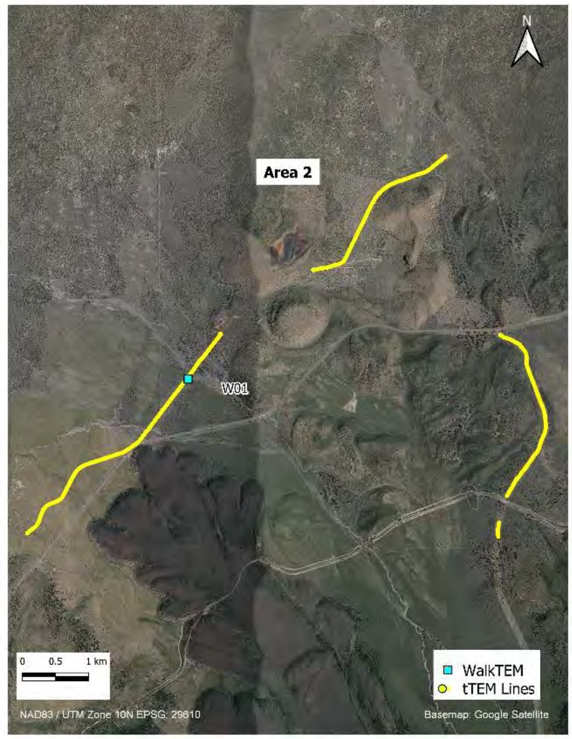


Figure 12 Location map of surveyed area 2.

Another issue when working in such high resistivity environments is that the signal level may drop down to or close to the system response level.

We are confident that the tTEM and the WalkTEM instruments worked properly throughout the project because we observed typical TEM signal by returning to area 1, and during subsequent projects. Both tTEM and WalkTEM signals were weak in area 2 as shown in Figure 13 and Figure 14. We conclude that the weak signal is due to the highly resistive subsurface geology, with a combined effect of negatively signed IP and system responses.

As an example, Figure 13 compares representative tTEM data (dB/dt curves) from areas 1 and 2. The left panel shows a few neighbouring signals from area 1, which represent a typical TEM response. In this case, the signals reach the noise level (gray) at ~ 200 microseconds. The right panel shows similar data acquired in area 2. The curves represent fast decaying (negative) system responses that take over the weak earth signals. The signals reach the noise level at ~ 30 microseconds. In terms of signal level, the signals from area 2 are more than two orders of magnitudes weaker than the signals from area 1. For comparison, in each panel red circles show signal levels at 10 and 30 microseconds.

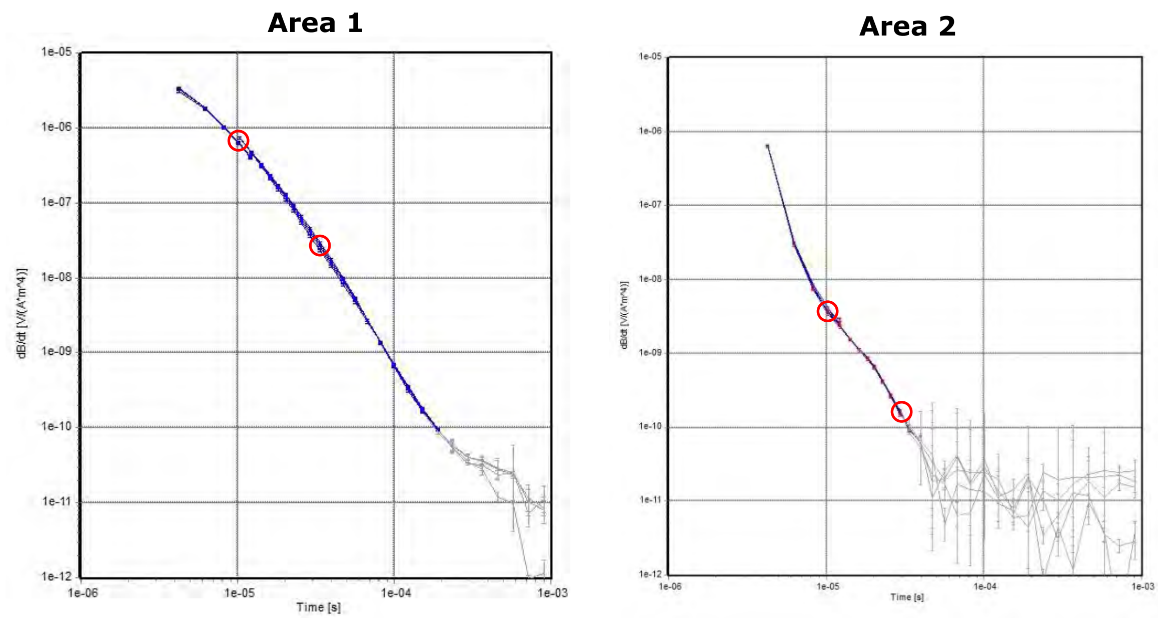


Figure 13 Representative tTEM curves from area 1 (left) and area 2 (right). Gray color indicates rejected data for inversion. Red circles show signal levels at 10 and 30 microseconds.

Figure 14 compares representative WalkTEM curves from area 1 (left) and area 2 (right). The left panel represents a typical WalkTEM response. The right panel shows similar data acquired in area 2. Again, the curves from area 2 decay faster and the signals are much weaker than the signals from area 1. In each panel, red circles show signal levels at 10 and 100 microseconds.

Since the IP effects on the tTEM data from area 2 are combined with the system response, it is not possible to invert the data in a reliable manner. The WalkTEM data may only be inverted for high moment signals. The WalkTEM results at location W01 are shown in Figure 15. The inverted model suggests very high resistivities (> 1,000 ohm-m) in the top section. In deeper parts, i.e. depths larger than 150-200 m, resistivities decrease to values ~ 10 ohm-m.

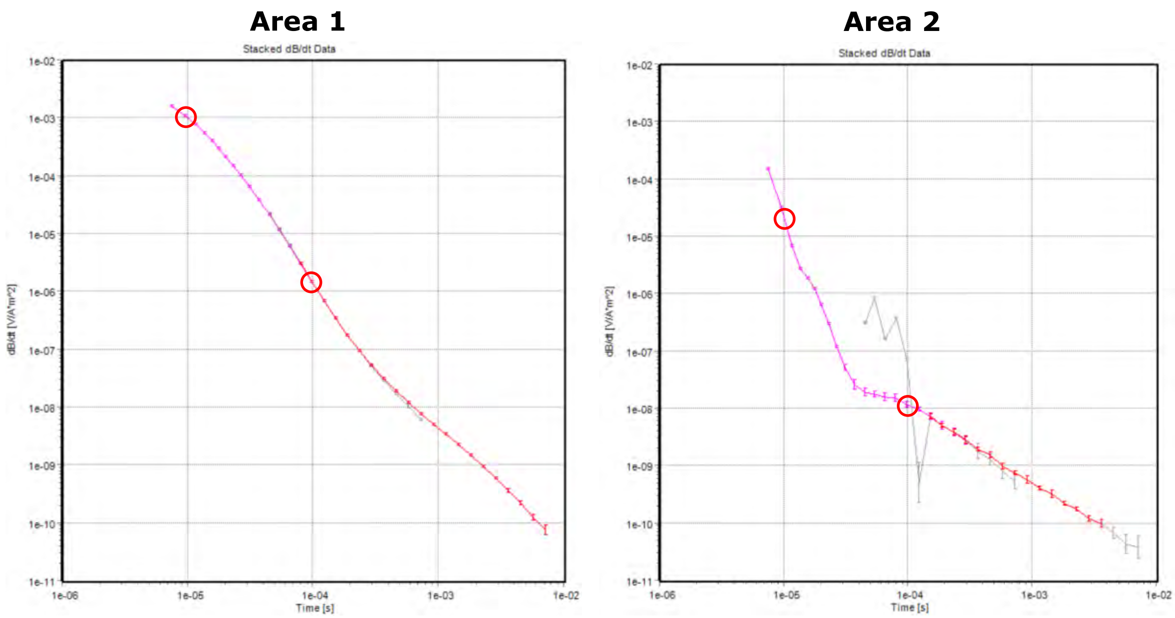


Figure 14 Representative WalkTEM curves from area 1 (left) and area 2 (right). Gray color indicates rejected data for inversion. Red circles show signal levels at 10 and 100 microseconds. Pink and red curves show low-moment and high-moment data, respectively.

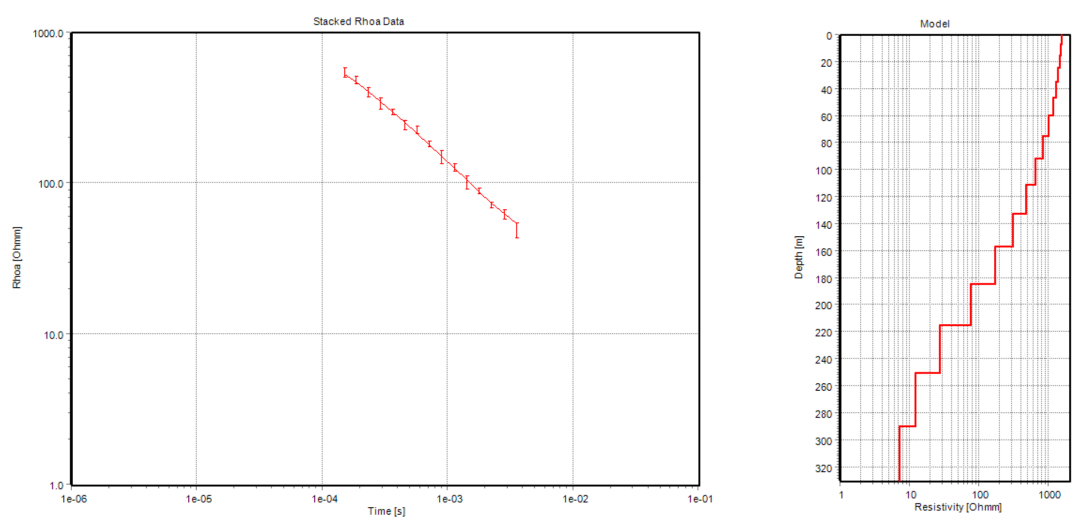


Figure 15 WalKTEM results at location W01. (left) High moment data, (right) inverted resistivity model.

5. DATA DELIVERABLES

The project deliverables consist of the following files:

1. Raw data as extracted from the instrument, including:
   A. Ascii files with information about the geographical coordinates, transmitted current and many other supporting data. All files are named YYYYMMDD_HHMMSS_MMM followed by three letters as an extension. The more crucial files have a filename extension SPS. Other files are primarily LOG files. One file with a filename extension LIN describes the start and end of each survey line.
   B. Binary data files with the electromagnetic decay measurements. These files have a filename extension SKB. The top section of the binary file is an ascii section with all information about measurement cycles and settings in the instrument.
2. A GERDA Firebird database containing all collected data, processed data, as well as the inverted model results.
3. ArcGIS layers including:
   A. *Boreholes*. An ArcGIS shape file (xxx.shp) containing location of boreholes, terrain elevation and drill depth.
   B. *Layout*. Several ArcGIS shape files containing general information about the surveyed area (project area outline, powerlines etc.), location of tTEM survey lines for each production day and locations of the remaining data after processing.
   C. *Mean Resistivity Maps*. Geo-referenced TIF files (xxx.tif) illustrating average resistivities within different horizontal intervals. Each file name includes information about the top and bottom of the interval.
   D. *Model Sections*. ArcGIS shape files containing locational information for the vertical sections presented in this report.
4. Model outputs. Ascii files (with a filename extension XYZ) containing exported models from the GERDA database in two different file formats.
5. A project report including appendices. The report is delivered as a PDF file.

The project deliverable folder tree diagram is shown in Figure 16. In each folder, a text file (Readme.txt) describes detailed information of the files within the folder.

```
├──1.Raw_Data_From_Instrument
│   ├──20200923
│   └──20200924
├──2.GERDA_Firebird_Database
│   ├──tTEM
│   └──WalkTEM
├──3.GIS
│   ├──Layout
│   │   ├──tTEM_Lines
│   │   ├──tTEM_Lines_Accepted
│   │   └──WalkTEM_Locations
│   ├──Mean_Resistivity_Maps
│   └──Model_Sections
├──4.XYZ_Model_Outputs
└──5.Report
```

Figure 16 Project deliverable folder tree diagram.

6. CONCLUSIONS

The acquired tTEM and WalkTEM data provide detailed subsurface information of the study area. The tTEM and WalkTEM models are in good agreement with each other and map out the geologic layering and provide detailed information about homogeneity and extent of each layer.

The collected tTEM and WalkTEM data in area 1 reveal detailed subsurface structures at different depths along the survey lines and sounding locations. The tTEM models delineate high resistivity (hard rock) and medium-to-low resistivity (sedimentary) structures. A noticeable observation is the discontinuity of the structures along the tTEM lines, which indicates the complex geology of the area. The two WalkTEM models in area 1 suggest a deep conductive structure below the tTEM depth of investigation.

In area 2, the acquired tTEM signal is weak because of the very high resistivity of the volcanic rocks and the IP effects. The WalkTEM data in this area are weak too, and it is only possible to invert the high-moment data. The inverted model suggests very high (> 1,000 ohm-m) resistivities in the top section. In depths larger than 150-200 m, resistivities decrease to values ~ 10 ohm-m.

APPENDIX 1
THEORY - TEM

TEM Introduction and Theory

Upon acquisition of the first ground based TEM instrument in the early 1990's, Ramboll has been among the global pioneers when it comes to applying TEM methods for subsurface mapping. Over the last 20 years, the accuracy of the instruments and their ability to obtain information about aquifers and hydrogeological properties has improved significantly. The TEM method is now one of the most efficient geophysical technologies for groundwater investigations.

Within the last 15 years, airborne TEM systems have been developed and introduced. Using the airborne systems, the ability to survey large areas has been significantly improved. The towed TEM (tTEM) and WalkTEM systems are basically a downscaled version of the TEM system on an airborne platform named SkyTEM.

TEM Theory

A direct current is injected in a transmitter loop. When the current stabilizes, the transmitter is abruptly turned off. By abruptly turning off the transmitter current, short-duration eddy currents are induced in the ground. The receiver coil located in the center of the transmitter loop (central loop configuration like WalkTEM) or outside the transmitter loop (off-set configuration like tTEM), measures the decaying magnetic field derived from the eddy currents.

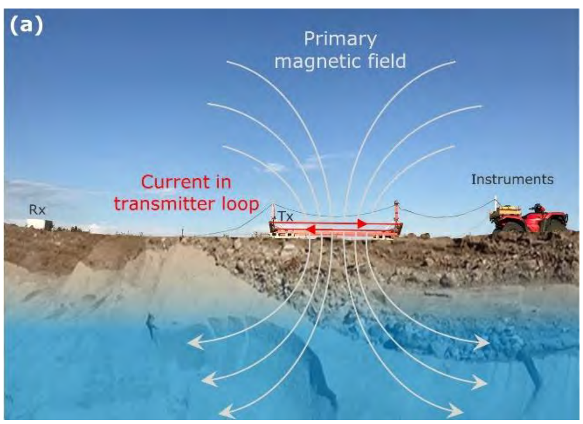


Figure A1- 1 The primary EM field generated by the current in the transmitter loop.

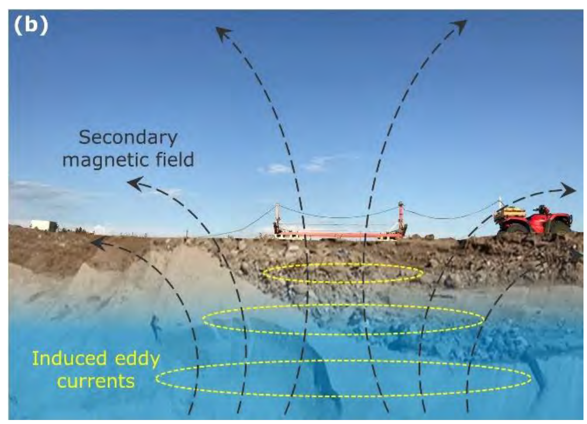


Figure A1- 2 When the current is turned off in the transmitter loop (no primary field), eddy currents are generated in the subsurface. The eddy currents create secondary magnetic fields that are measured with the receiver.

Noise in TEM Data

TEM data are comprised of different type of noise components. Noise can cause bias signals and affect the depth of investigation and if not properly identified and removed, can result in incorrect geological and hydrological interpretations. The different sources of noise are described below:

1. Galvanic coupling is caused by the electromagnetic signal induced in a metal object, such as a metal pipe, metal fence or the loop, following the ground-wire through the power-masts to

the ground as sketched below. The challenge is that the signal component caused by a galvanic coupling can be hard to detect as the nature of the decay is similar to the response from the ground as illustrated Figure A1- 3. Galvanically-coupled data are identified by looking at the data along the survey lines while paying attention to the signal level and its correlation with potential coupling sources on the GIS map.

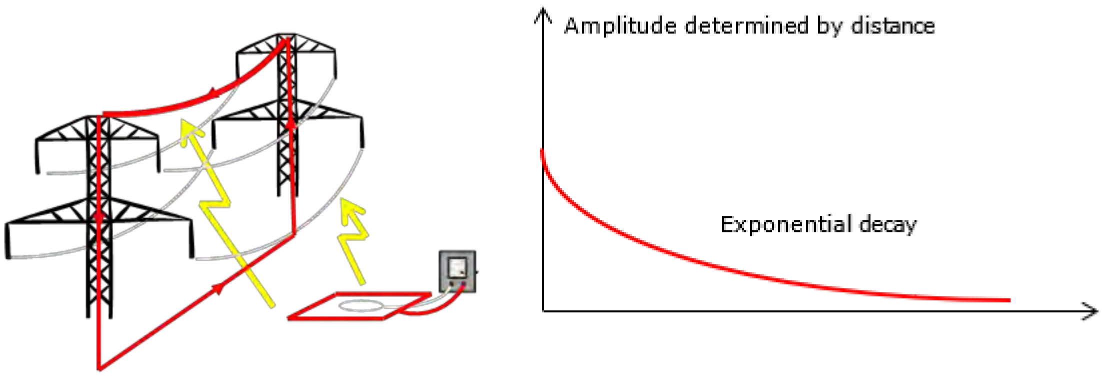


Figure A1- 3 Illustration showing the effects of galvanic coupling.

2. Capacitive coupling is caused by the induced electromagnetic signal in an insulated installation such as a power cable. The noise creates an oscillating signal as illustrated in Figure A1- 4. It is normally easy to distinguish capacitive coupling noise from the ground response.

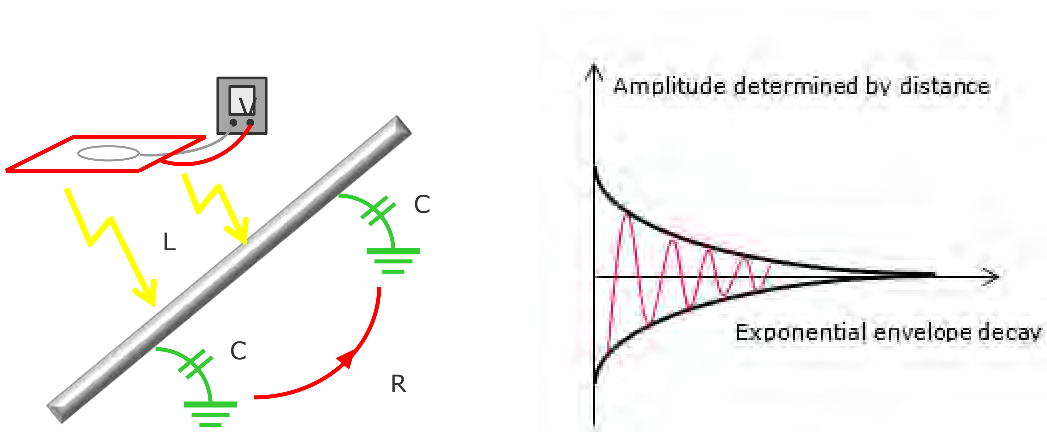


Figure A1- 4 Illustration showing the effects of capacitive coupling.

3. Coherent noise from electrical powerlines has the same pattern as sketched for the capacitive coupling. It is often easy to identify these features during processing of the data.
4. Atmospheric noise is more random in nature and is typically handled by none-spike filtering and by simple averaging of the data. In case of a strong lightning or an electromagnetic

storm the background noise can prevent the collection of data with satisfactory signal-to-noise ratio.

5. Motion induced noise due to vibrations in the receiver coil. Vibration of the receiver coil in the earth magnetic field will create a noise component. It is only a problem for moving systems, such as SkyTEM (airborne) or the tTEM system. This noise is minimized by suspending the receiver coil and keeping the survey speed within recommended limits (Figure A1- 5).
6. Internal noise in the instrumentation.

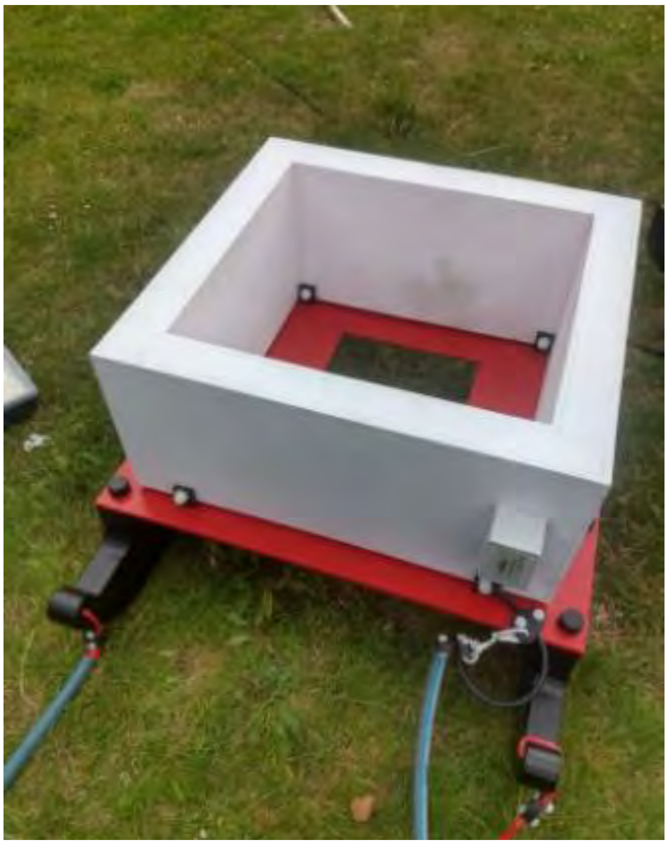


Figure A1- 5 The TEM Receiver coil is suspended to reduce motion induced noise.

Depth of Investigation

The depth of investigation (DOI) depends on the geological and hydrogeological settings within the survey area and the signal-to-noise ratio determined by the power of the transmitted electromagnetic field, internal noise in the instrumentation and the actual ambient noise during the survey.

The length of the TEM decay curves, i.e. how late in time the signal can be measured before reaching the noise level, determines the DOI. In Figure A1- 6, the earth response (the green curves) reaches the noise floor for the system at ~ 500 μs. The depth of investigation can be increased by increasing the induced signal. This is typically done by injecting higher current, increasing the size of the transmitter loop and/or increasing the number of decay curves being averaged (stack size).

The DOI for the tTEM system is typically 60-80 m bgs. The DOI for the WalkTEM system is typically 200-300 m bgs. The DOI will be larger when the ground is more resistive and smaller when the ground is more conductive. During the inversion, the DOI is estimated for each resistivity model.

Inversion

The inversion process is the step where the measured voltage values are fitted with the TEM response of the geophysical model. The model is described by its layer thicknesses and corresponding electrical resistivities. The results are typically presented as smooth (multi-layer) resistivity models.

The processed data were inverted by applying a laterally constrained inversion (LCI) approach, where neighboring soundings are constrained in a multi-layered inversion scheme.

An in-depth description of the modelling scheme can be found in the references listed below.

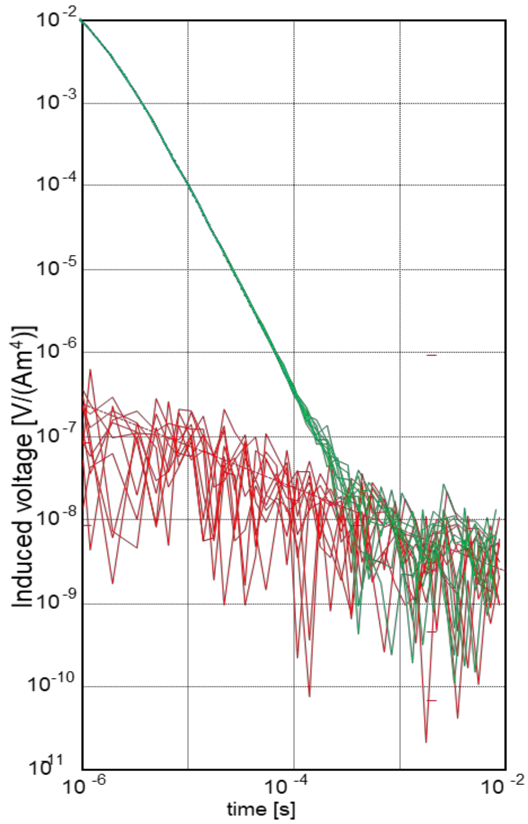


Figure A1- 6 An Example of decay curves created by a TEM system (Green curves) and the background noise floor (Red curves).

References

Selected references describing TEM systems like the tTEM and WalkTEM systems, the calibration of a TEM system at the national Danish Test site and the applied modeling technique.

Auken, E., Foged, N., Larsen, J. J., Lassen, K. V. T, Kumar Maurya, P, Dath, S. M., and Eiskjær, T. T., 2019, tTEM — A towed transient electromagnetic system for detailed 3D imaging of the top 70 m of the subsurface, Geophysics, Vol. 84, NO. 1 (Jan-Feb 2019); P. E13–E22, 11 Figs., 1 Table. 10.1190/GEO2018-0355.1

Auken, E., Foged, N. and Sørensen, K., 2002, Model recognition by 1-D laterally constrained inversion of resistivity data: Proceedings – New Technologies and Research Trends Session, 8th meeting, EEGS-ES.

Auken, E., Christiansen, A. V., Jacobsen, B. H., Foged, N., and Sørensen, K. I., 2005, Piecewise 1D Laterally Constrained Inversion of resistivity data: Geophysical Prospecting, 53, 497–506. Christiansen, A.V. and Auken, E., 2012, A global measure for depth of investigation: Geophysics, vol 77, No. 4, 171-177.

Auken, E., A.V. Christiansen, C. Kirkegaard, G. Fiandaca, C. Schamper, A.A. Behroozmand, et al. 2015. An overview of a highly versatile forward and stable inverse algorithm for airborne, ground-based and borehole electromagnetic and electric data. Explor. Geophys. 46:223–235. doi:10.1071/EG13097

Foged, N., E. Auken, A. V. Christiansen, and K. I. Sørensen, 2013, Test site calibration and validation of airborne and ground based TEM systems: Geophysics, 78, no. 2, E95–E106, doi: 10.1190/geo2012-0244.1.

McNeill, J. Electromagnetic Terrain Conductivity Measurement at Low Induction Numbers; Technical Report TN-6; Geonics Limited: Mississauga, ON, Canada, 1980

Sørensen, K. I., and Auken, E., 2004, SkyTEM – A new high-resolution helicopter transient electromagnetic system.: Exploration Geophysics, 35, 191–199.

Sørensen, K. I., 1997, The pulled array transient electromagnetic method: Proceedings of the 3rd Meeting of the Environmental and Engineering Geophysical Society, European Section, 135–138

Viezzoli, A., A. V. Christiansen, E. Auken, and K. I. Sørensen, 2008, Quasi-3D modeling of airborne TEM data by Spatially Constrained Inversion, Geophysics, 73, 3, F105-F113

APPENDIX 2
INSTRUMENTATION, PROCESSING & INVERSION SETTINGS, REPEAT LINES

The towed-TEM (tTEM) and WalkTEM instruments are time-domain electromagnetic systems designed for hydrogeophysical and environmental investigations. The instruments were developed based on many years of research at Aarhus University in Denmark. The experience dates back to the development of the pulled-array TEM (PATEM) system and later the SkyTEM airborne system.

tTEM Instrument

This section describes the tTEM instrument, documentation for calibration, results of repeated lines within the survey area and the settings being applied for this specific survey. The information is provided to give an in-depth understanding of the data collection, processing and inversion.

Instrument Setup

The tTEM system measures continuously while towed on the ground. It is designed to provide a very high near-surface resolution with very early time gates and a fast repetition frequency. The tTEM is based on an off-set loop configuration, with the receiver coil (Rx-coil) pulled ~ 8.0 m behind the transmitter coil (Tx-coil). The Rx-coil is horizontal, i.e. measuring the z-component of the magnetic fields.

An ATV or similar vehicle tows the tTEM-system. The distance between the ATV and the Tx coil is 3.0 m. The Tx-coil is a 2 m x 4 m loop suspended by the red beams, as shown on the photo in Figure A2-1. A GPS is located at the front of the Tx-frame for accurate positioning of the system. The Rx-coil is placed on a small sled. The transmitter electronics, receiver instrument, power supply etc. are carried on the back of the ATV.

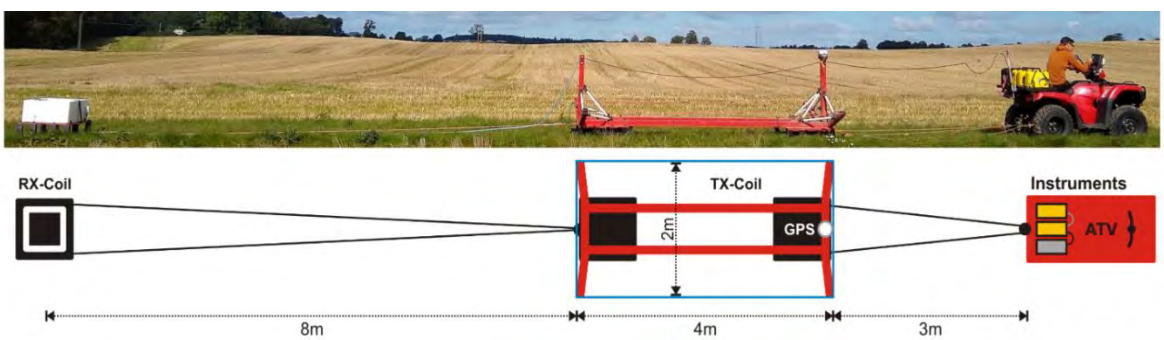


Figure A2- 1 The tTEM system configuration.

tTEM Instrument IDs

For this survey, the instruments with ID's shown in Table A2- 1 were used.

Unit	ID1	ID2
TIB Receiver instrument	13	20180843
RC20 Receiver coil		20200217
tTEM Transmitter	TX11	20200209
Novatel Agstar GPS		20200640

Table A2- 1 ID's for the instrumentation used in this survey.

Device Positions, Nominal

The positions and the geometry of the main components are listed in Table A2- 2 and used in the processing and inversion scheme. As an example, the GPS coordinate is measured in the front of the transmitter frame, and then during the processing of the GPS data, the coordinates are shifted to reflect the actual focus point of the system. The geometry of the transmitter frame and the exact off-set of the receiver coil are used during the inversion of the data.

Unit	X (m)	Y (m)	Z(m)
GP_Tx (GPS)	2.00	0.00	-1.20
RxZ (Z-receiver coil)	-10.28	0.00	-0.30
Tx-Coil, center	0.00	0.00	-0.50
Tx-Coil corner 1	-2.00	-1.00	-0.50
Tx-Coil corner 2	2.00	-1.00	-0.50
Tx-Coil corner 3	2.00	1.00	-0.50
Tx-Coil corner 4	-2.00	1.00	-0.50

Table A2- 2 Nominal equipment, receiver and transmitter coils positioning. The origin is defined as the center of the transmitter coil. Z is positive downwards.

Transmitter Waveform

The current in the transmitter loop is turned on and off in pulses. The direction of the current shifts from positive to negative in between each pulse. The two graphs below show the waveform for the low moment (LM) and the high moment (HM) as the current is turned off very rapidly. During the off times, i.e. when the current is turned off, the secondary magnetic fields from the eddy currents are measured in the receiver coil.

Figure A2- 2 Close-up photo showing the transmitter frame mounted on the sled

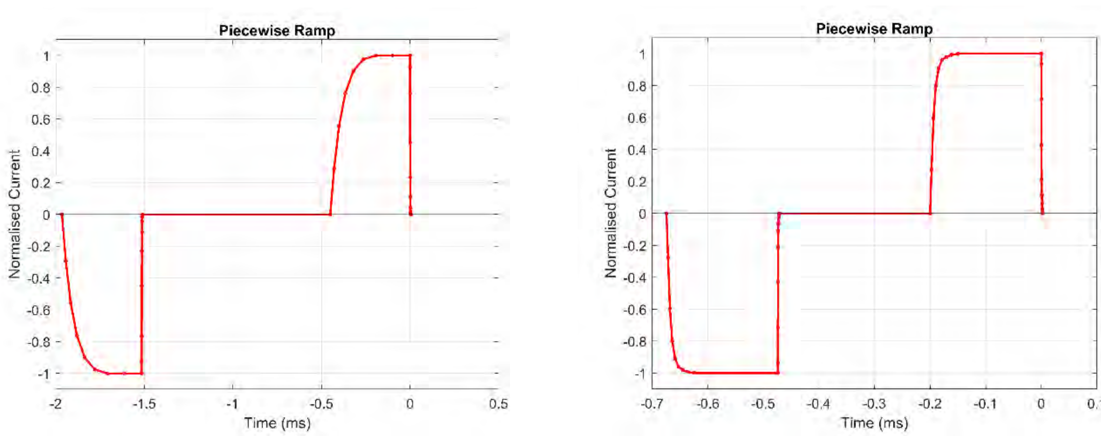


Figure A2- 3 Waveforms for the LM (left) and the HM (right). The red line segments indicate the piecewise linear modelling of the waveforms.

The speed of the turn-off ramp of the low moment is critical for the resolution of the shallow subsurface. Table A2- 4 shows a closeup view of the ramp down on the low moment; the current is turned off within approximately 2 microsecond (μS).

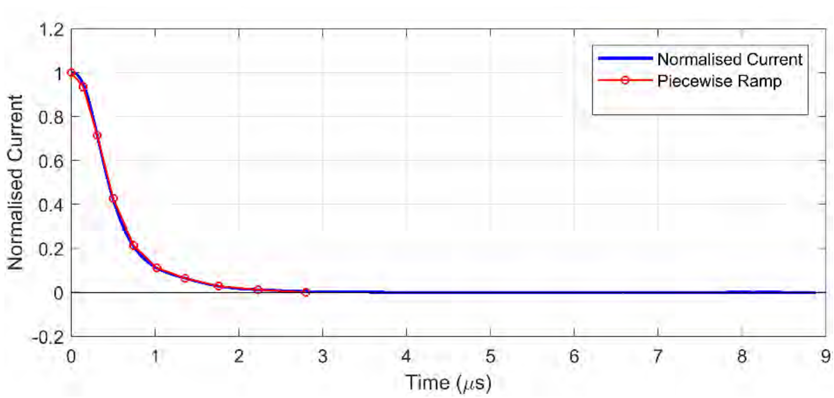


Figure A2- 4 Close-up on ramp down for LM. The red line segments indicate the piecewise linear modelling of the waveform.

The transmitter waveforms for LM and HM, are listed as time and nominal amplitude. On-times are negative, and off-times are positive. The shape of the waveform is used in the inversion scheme. The actual waveforms are scaled by the current measurement just before the current is turned off.

LM time	LM amplitude	HM time	HM amplitude
-6.7400e-04 s	-0.000	-1.9650e-03 s	-0.000
-6.7250e-04 s	-0.496	-1.9483e-03 s	-0.316
-6.7071e-04 s	-0.658	-1.9279e-03 s	-0.532
-6.6859e-04 s	-0.784	-1.9030e-03 s	-0.710
-6.6605e-04 s	-0.865	-1.8725e-03 s	-0.845
-6.6303e-04 s	-0.925	-1.8351e-03 s	-0.933
-6.5944e-04 s	-0.963	-1.7894e-03 s	-0.981
-6.5516e-04 s	-0.978	-1.7334e-03 s	-1.001
-6.5007e-04 s	-0.989	-1.6650e-03 s	-1.000
-6.4400e-04 s	-1.000	-1.5150e-03 s	-1.000
-4.7400e-04 s	-1.000	-1.5148e-03 s	-0.967
-4.7387e-04 s	-0.953	-1.5146e-03 s	-0.859
-4.7373e-04 s	-0.812	-1.5143e-03 s	-0.662
-4.7355e-04 s	-0.559	-1.5139e-03 s	-0.381
-4.7334e-04 s	-0.332	-1.5135e-03 s	-0.155
-4.7309e-04 s	-0.175	-1.5131e-03 s	-0.053
-4.7279e-04 s	-0.086	-1.5125e-03 s	-0.017
-4.7243e-04 s	-0.041	-1.5118e-03 s	-0.007
-4.7200e-04 s	-0.016	-1.5110e-03 s	-0.000
-4.7150e-04 s	-0.000	-4.5000e-04 s	0.000
-2.0000e-04 s	0.000	-4.3333e-04 s	0.316
-1.9850e-04 s	0.496	-4.1294e-04 s	0.532
-1.9671e-04 s	0.658	-3.8799e-04 s	0.710
-1.9459e-04 s	0.784	-3.5745e-04 s	0.845
-1.9205e-04 s	0.865	-3.2009e-04 s	0.933
-1.8903e-04 s	0.925	-2.7438e-04 s	0.981
-1.8544e-04 s	0.963	-2.1844e-04 s	1.001
-1.8116e-04 s	0.978	-1.5000e-04 s	1.000
-1.7607e-04 s	0.989	0.0000e+00 s	1.000
-1.7000e-04 s	1.000	2.0384e-07 s	0.967
0.0000e+00 s	1.000	4.3584e-07 s	0.859
1.2589e-07 s	0.953	7.2384e-07 s	0.662
2.6989e-07 s	0.812	1.0598e-06 s	0.381
4.5389e-07 s	0.559	1.4598e-06 s	0.155
6.6189e-07 s	0.332	1.9398e-06 s	0.053
9.0989e-07 s	0.175	2.5078e-06 s	0.017
1.2139e-06 s	0.086	3.1878e-06 s	0.007
1.5659e-06 s	0.041	4.0000e-06 s	0.000
1.9979e-06 s	0.016		
2.8000e-06 s	0.000		

Table A2- 3 Transmitter waveforms LM and HM.

Measurement Cycle

The basic settings of the instrumentation are shown in Table A2- 4.

Parameter	LM	HM
Moment ID	2	1
No. of turns	1	1
Transmitter area (m2)	8 m2	8 m2
Tx Current	~ 3 A	~ 30 A
Tx Peak moment	~ 24 Am2	~ 240 Am2
Repetition frequency	1008 Hz	282 Hz
Raw Data Stack size	366	282
Raw Moment cyclus time	0.22 s	0.40 s
Tx on-time	200 μs	450 μs
Duty cycle	42%	30%
Turn-off time	2.6 μs at 3 Amp	4.5 μs at 30 Amp
Number of gates	5	25
Gate time interval (gate center time)	4 μs – 30 μs	10 μs – 900 μs
Front-gate time (nominal)	2 μs	4 μs
Front-gate delay	2 μs	2 μs

Table A2- 4 Basic settings of the instrumentation.

Receiver Coil

The receiver coil can be described by the following parameters. The parameters are used in the inversion scheme.

Parameter	Value
Low pass filter frequency	300 kHz
Low pass filter order	1
Effective area	$20m^2$

Table A2- 5 Receiver coil parameters.

Instrument Firmware Versions

The firmware in the instruments have the version numbers described in the table below.

Software	Version
PaPC	4.1.1.8
Navsys	2.1.0.4
TxProc	2.10.0.30
tTEM Log	5.0.4.8
NAV	5.2.0.2

Table A2- 6 Instrument firmware versions.

Documentation of Test and Calibration

At the Danish national geophysical test-site near Aarhus, Denmark, the tTEM instrumentation described above was tested and calibrated. The purpose for the test and calibration is to document the performance of the instrument and to defined absolute calibration parameters. The calibration is performed to establish the absolute time shift and data level to facilitate precise modeling of the data. No additional levelling or drift corrections are applied. To perform the calibration, all system parameters (transmitter waveform, low pass filters, etc.) must be known to allow accurate modeling of the tTEM setup. The calibration constants are determined by comparing a recorded tTEM response on the test site with the reference response. The reference response is calculated from the test site reference model for the used tTEM configuration.

Acceptable calibration was achieved with the calibration constants stated in Table A2- 7. The calibration was performed on June 9, 2019. Calibration plots for both moments are shown in Figure A2- 5 and Figure A2- 6. The scale factors of 1.01 and 1.03 (1% and 3%) are very acceptable. The time shift is deemed due to the delays in the electronics and inaccurately modelled waveforms. The obtained time shifts are very acceptable.

Moment	Time Shift	Scale Factor
LM	-0.80 µs	1.01
HM	-0.70 µs	1.03

Table A2- 7 Calibration constants.

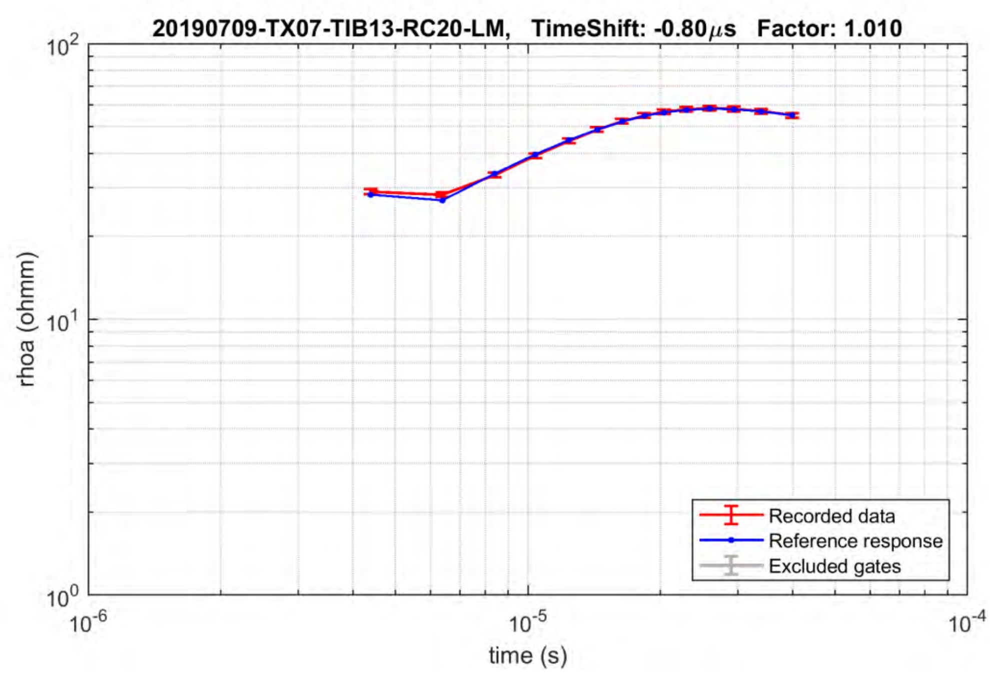


Figure A2- 5 Calibration plot for the LM. The red curve is the recorded data with calibration factors applied, and the blue curve is the forward response from the national geophysical test-site in Denmark.

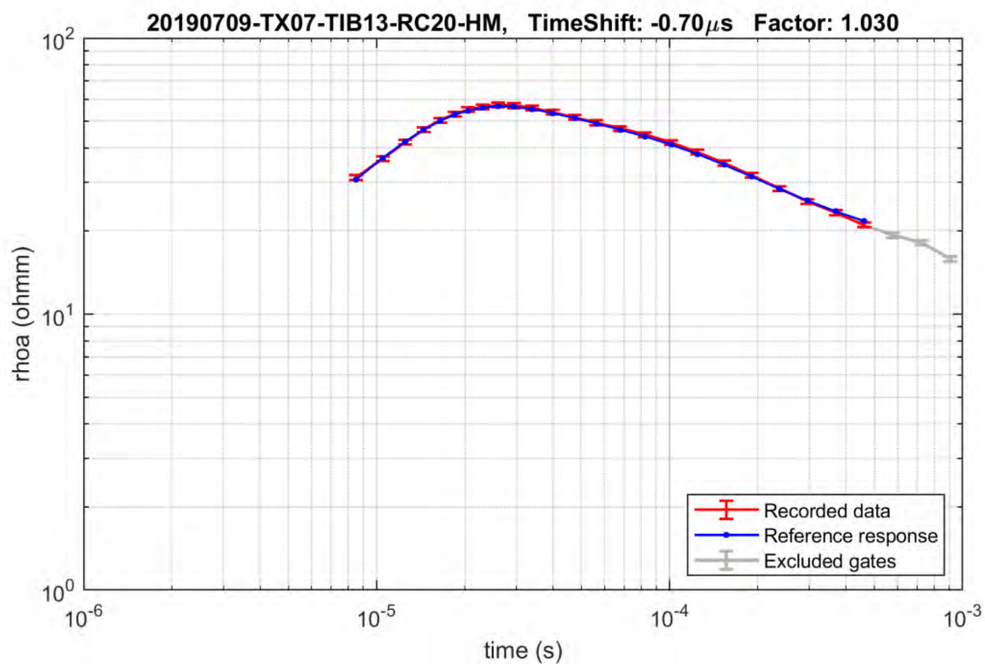


Figure A2- 6 Calibration plot for the HM. The red curve is the recorded data with calibration factors applied, and the blue curve is the forward response from the national geophysical test-site in Denmark.

Processing and Inversion Software Settings

The processing and inversion are based on the Aarhus Workbench software, version 6.4.0.0. A 30-layer model has been applied. Table A2- 8 **Outline of the 25-layer model.** lists the fixed layer thicknesses, depth to bottom of layer and the initial resistivity assigned to the model layers (a homogenous half space). For this survey, the initial resistivity values were obtained by first inverting each tTEM sounding data with homogeneous half-space earth model and the resulting values were used during the inversion.

Layer	Thickness [Meter]	Depth [Meter]	Start value [Ohm-m]
1	1.00	1.00	Auto
2	1.10	2.10	Auto
3	1.20	3.20	Auto
4	1.30	4.50	Auto
5	1.30	5.80	Auto
6	1.50	7.30	Auto
7	1.60	8.90	Auto
8	1.70	10.6	Auto
9	1.80	12.4	Auto
10	2.00	14.3	Auto
11	2.10	16.5	Auto
12	2.30	18.7	Auto
13	2.50	21.2	Auto
14	2.60	23.8	Auto

Layer	Thickness [Meter]	Depth [Meter]	Start value [Ohm-m]
15	2.90	26.7	Auto
16	3.10	29.8	Auto
17	3.30	33.1	Auto
18	3.60	36.7	Auto
19	3.90	Auto.5	Auto
20	4.20	44.7	Auto
21	4.50	49.1	Auto
22	4.80	53.9	Auto
23	5.20	59.1	Auto
24	5.60	64.7	Auto
25	6.00	70.8	Auto
26	6.50	77.3	Auto
27	7.00	84.3	Auto
28	7.60	91.9	Auto
29	8.10	100	Auto
30	--		Auto

Table A2- 8 Outline of the 25-layer model.

GPS Settings
The settings and the position of the GPS is shown in Table A2- 9.

Parameter	Value
Beat Time	0.5 sec
Filter length	7.0 sec
Polynomial order	2
Shift in x-direction	-4.965 m

Table A2- 9 GPS processing.

Repeat Lines Within the Survey Area
Within the survey area, a test line was surveyed repeatedly. This is done to document that the system is not affected by drift or other problems with the instrumentation. It also shows that the processing and inversion schemes are robust and consistent.

The modelling results along the test lines are shown in the following figures. The results show high repeatability of the tTEM system and the inversion approach.

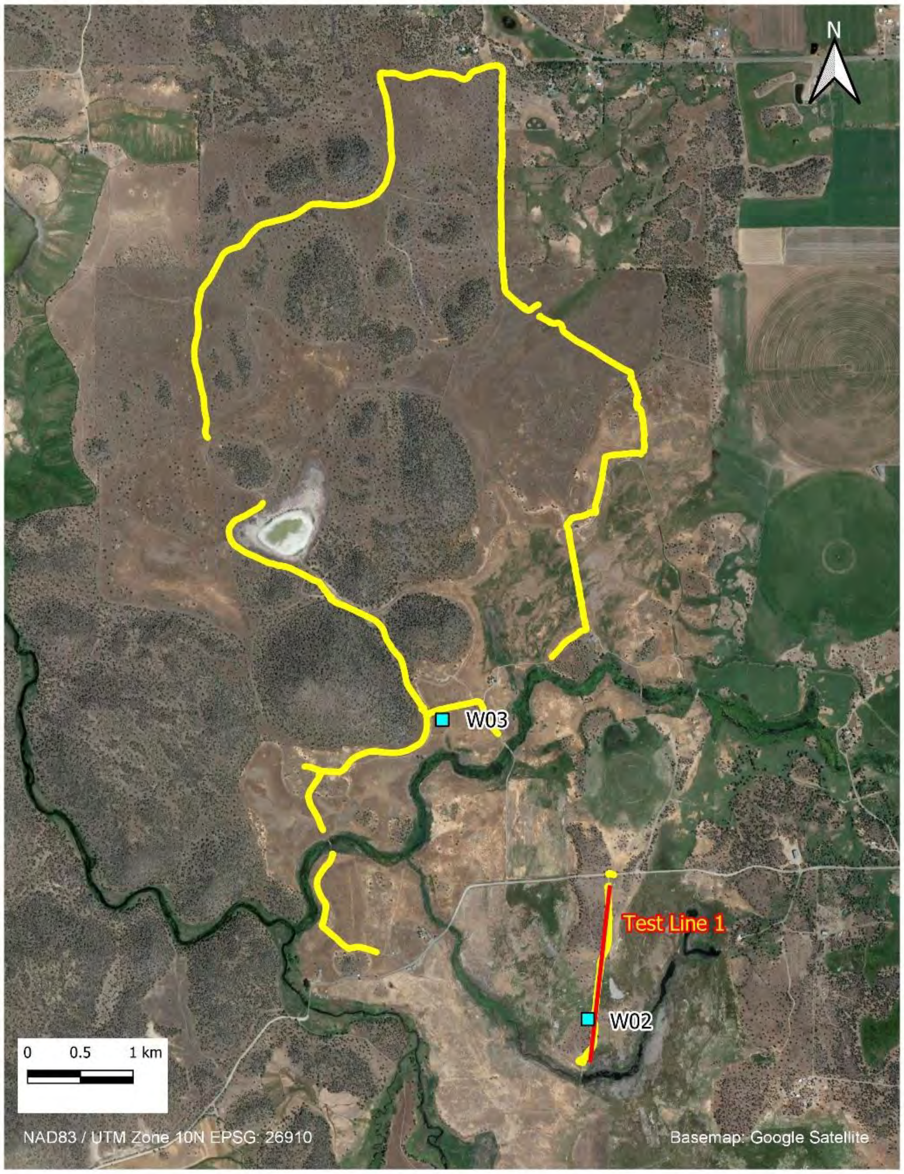


Figure A2- 7 Location map of the test line conducted on the 23rd of September 2020.

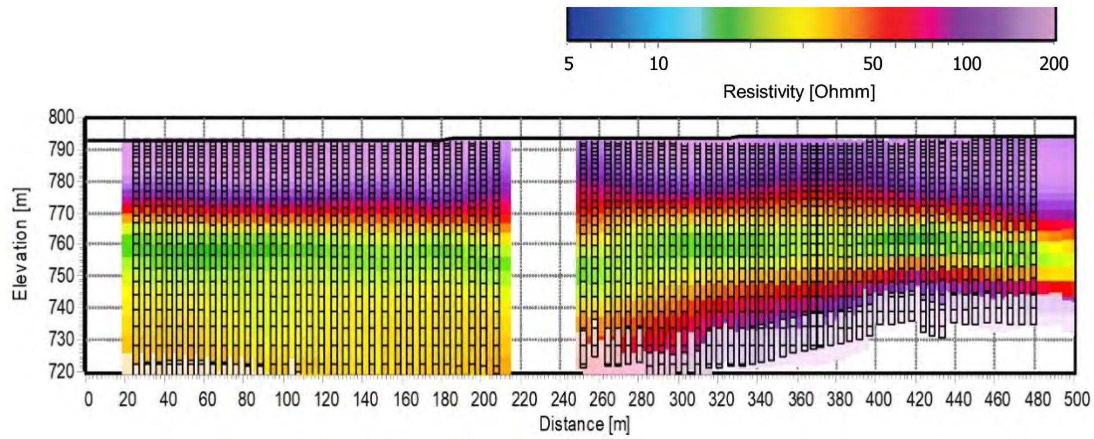


Figure A2- 8 Modeled soundings along test line 1 (500 m). The data were measured on September 23rd 2020 from 12:32:37 to 12:37:04.

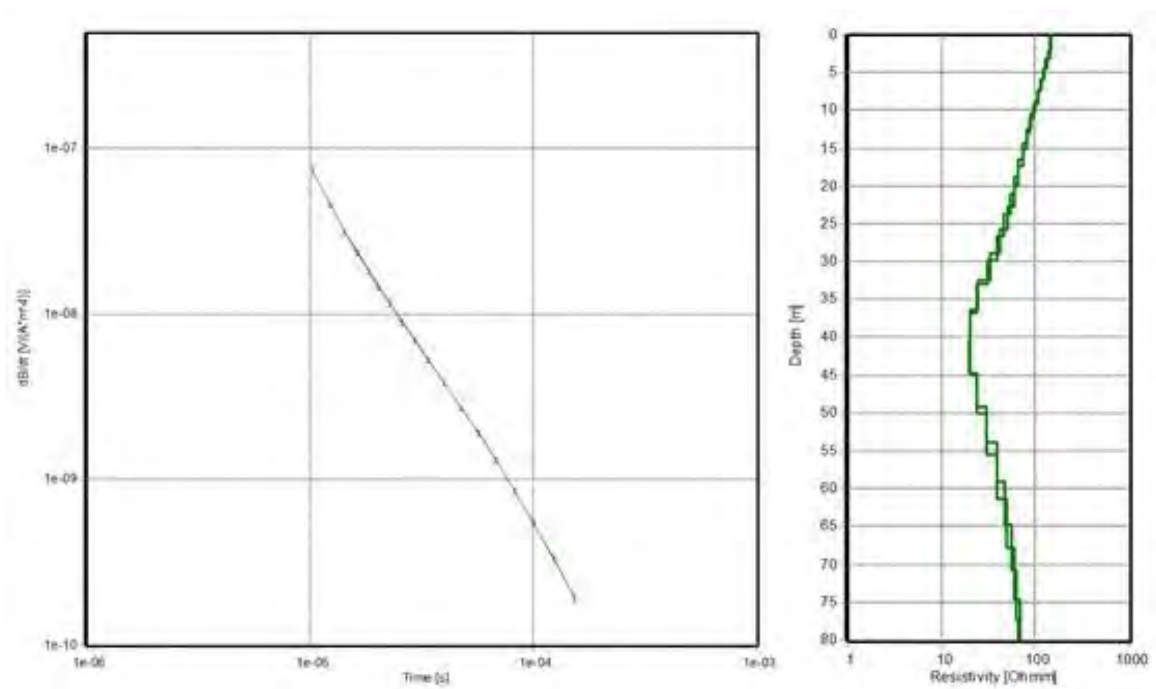


Figure A2- 9 Two co-located sounding curves (left; red - 2x LM, green – 2 x HM) and the corresponding resistivity models (right) along test line 1. The sounding curves show excellent repeatability, which is also reflected in the model curves. Both data sets are from September 23rd, 2020.

WalkTEM Instrument

This section describes the WalkTEM instrument setup and system specifications. The information is provided to give an in-depth understanding of the data collection, processing and inversion.

WalkTEM Instrument Setup

The WalkTEM field configuration used in this survey is named "central loop" configuration. It comprises a 40 m x 40 m (130 ft x 130 ft) square-shaped transmitter (Tx) loop, along with a 10 m x 10 m (33 ft x 33 ft) 2-turn receiver (Rx) loop placed in the center of the transmitter loop. The Tx and Rx loops are connected to the WalkTEM instrument, which is placed at the corner of the Tx loop. The instrument is supplied with a 12V external battery (Figure A2-13).

The instrument runs on a built-in windows computer. It also has a built-in keypad to ease operation of the system. The acquisition software is linked to a simplified inversion program that enables quick analysis of the data at the site.

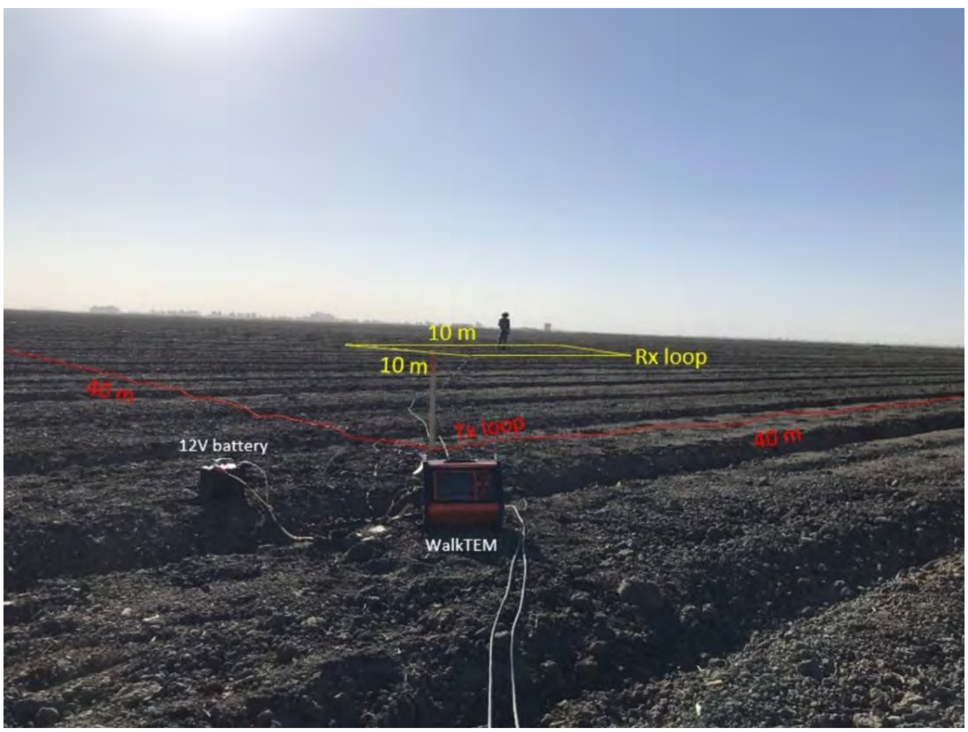


Figure A2- 10 The WalkTEM system configuration.

Measurement Cycle

The basic settings of the instrumentation are shown in Table A2- 10. In this study, a measuring script consisting of 45 time gates was used to achieve maximum depth of investigation.

Parameter	LM	HM
Moment ID	2	1

No. of turns	1	1
Transmitter area (m2)	1600 m2	1600 m2
Tx Current	~ 1 A	~ 8 A
Tx Peak moment	~ 1600 Am2	~ 12800 Am2
Number of gates	25	32
Gate time interval (gate center time)	9.19 μs – 706 μs	35 μs – 22.16 μs

Table A2- 10 Basic settings of the instrumentation.

System Calibration

The WalktTEM instrumentation described above was tested and calibrated at the Danish national geophysical test-site near Aarhus, Denmark. The purpose for the test and calibration is to document the performance of the instrument and to defined absolute calibration parameters.

The calibration is performed to establish the absolute time shift and data level to facilitate precise modeling of the data. No additional levelling or drift corrections are applied. To perform the calibration, all system parameters (transmitter waveform, low pass filters, etc.) must be known to allow accurate modeling of the WalkTEM setup. The calibration constants are determined by comparing a recorded WalkTEM response on the test site with the reference response. The reference response is calculated from the test site reference model for the used WalkTEM configuration.

Acceptable calibration was achieved with the calibration constants stated in Table A2- 11. The scale factors of 1.04 and 1.02 (4% and 2%) are very acceptable. The time shift is deemed due to the delays in the electronics and inaccurately modelled waveforms. The obtained time shifts are very acceptable.

Moment	Time Shift	Scale Factor
LM	-1.70 μs	1.04
HM	-1.60 μs	1.02

Table A2- 11 Calibration constants.

Processing and Inversion Software Settings

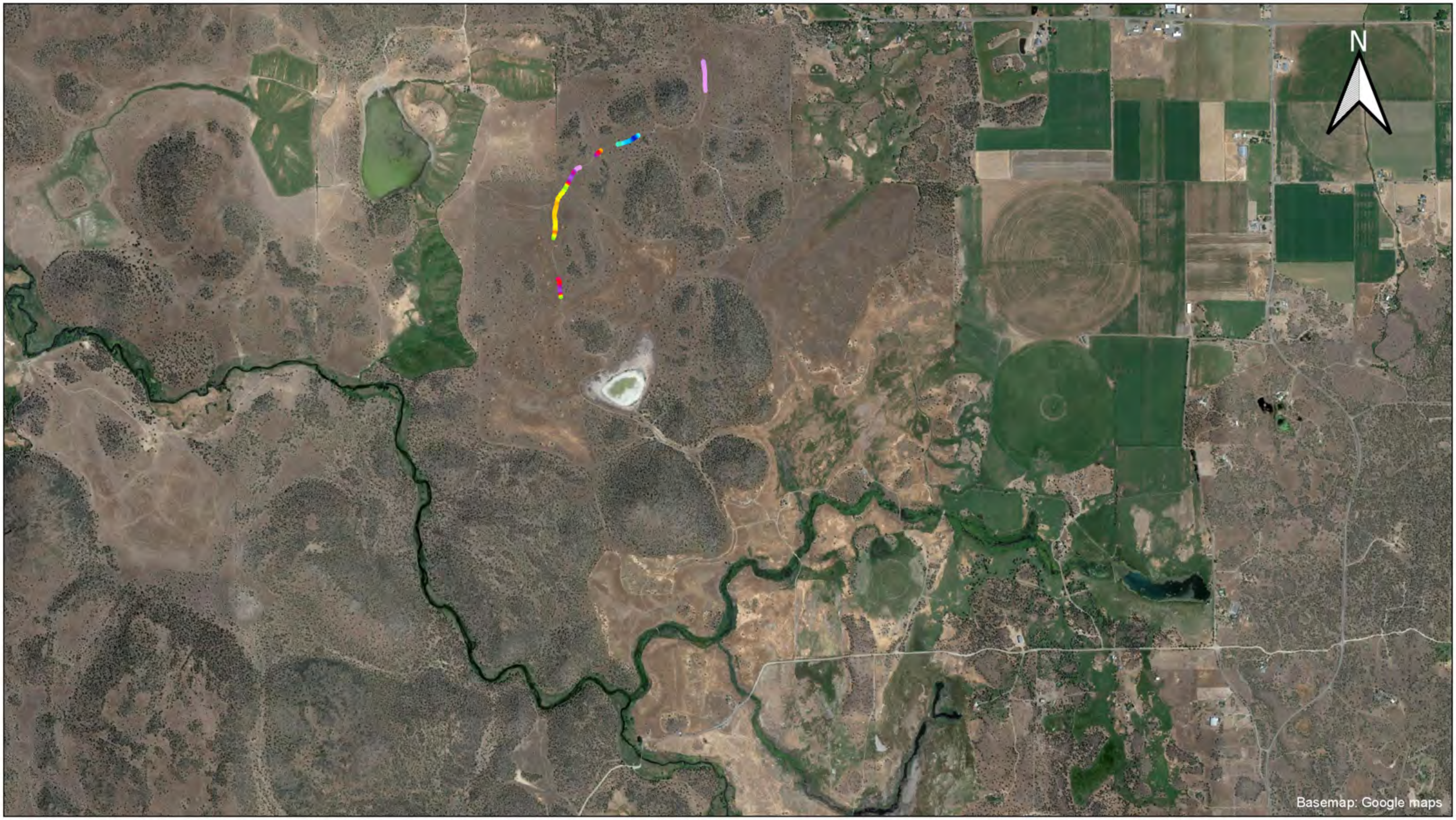
The processing and inversion are based on the Aarhus SPIA software, version 3.5.1.0. A 20-layer model has been applied. Table A2- 12 lists the fixed layer thicknesses, depth to bottom of layer and the initial resistivity assigned to the model layers (a homogenous half space).

Layer	Thickness [Meter]	Depth [Meter]	Start value [Ohm-m]
1	4.30	4.30	50
2	4.86	9.16	50
3	5.48	14.64	50
4	6.19	20.84	50
5	6.99	27.83	50
6	7.89	35.72	50
7	8.91	44.63	50

Layer	Thickness [Meter]	Depth [Meter]	Start value [Ohm-m]
8	10.06	54.69	50
9	11.36	66.05	50
10	12.82	78.87	50
11	14.48	93.35	50
12	16.34	109.69	50
13	18.45	128.14	50
14	20.83	148.97	50
15	23.52	172.49	50
16	26.55	199.04	50
17	29.98	229.02	50
18	33.84	262.86	50
19	38.21	301.07	50
20	--	--	50

Table A2- 12 Outline of the 25-layer model.

APPENDIX 3
TTEM MEAN RESISTIVITY PLAN-VIEW MAP RESULTS



Mean resistivity map, elevation interval 805 m to 810 m a.m.s.l

5 10 50 100 200

Resistivity [Ohmm]

0 0.5 1 km

WGS84 / UTM zone 10N EPSG: 32610

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Mean resistivity map, elevation interval 800 m to 805 m a.m.s.l

5 10 50 100 200

Resistivity [Ohmm]

0 0.5 1 km

WGS84 / UTM zone 10N EPSG: 32610

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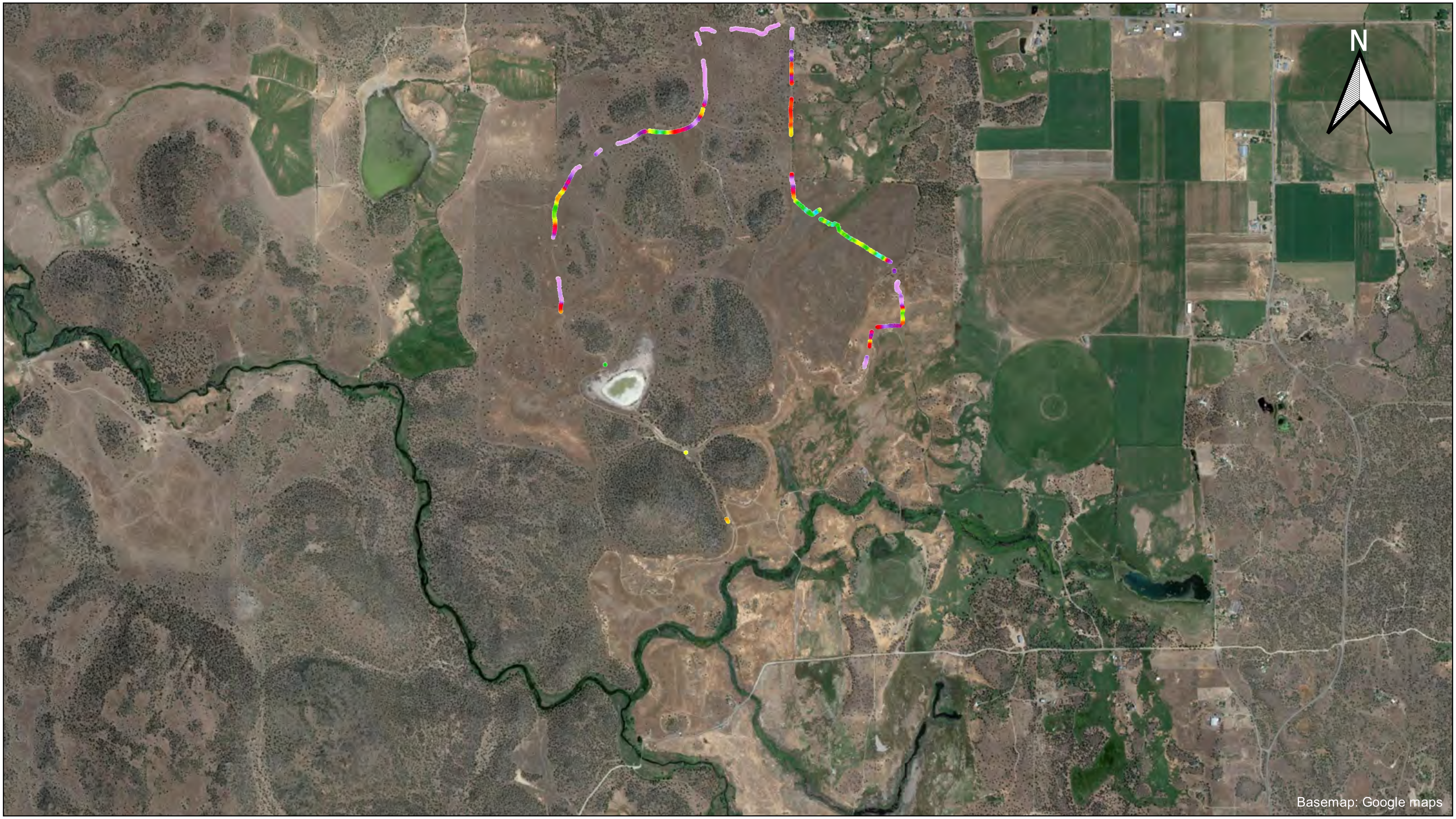
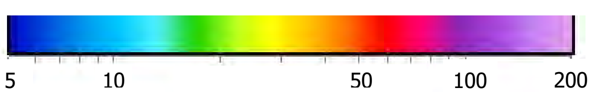


Mean resistivity map, elevation interval 795 m to 800 m a.m.s.l



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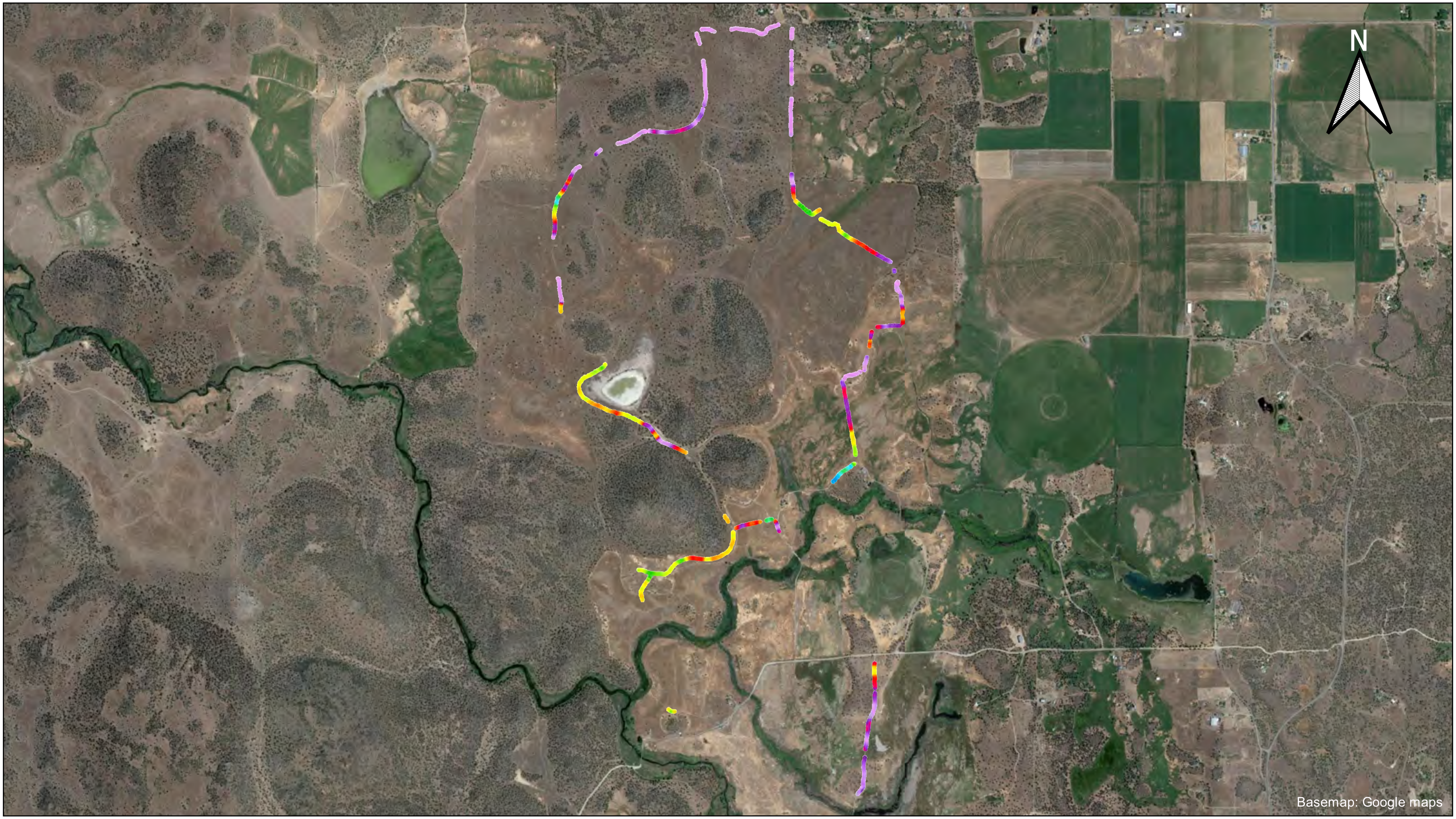
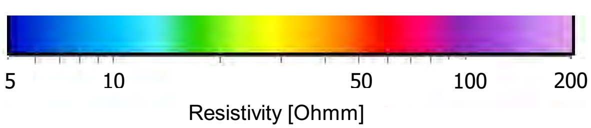


Mean resistivity map, elevation interval 790 m to 795 m a.m.s.l



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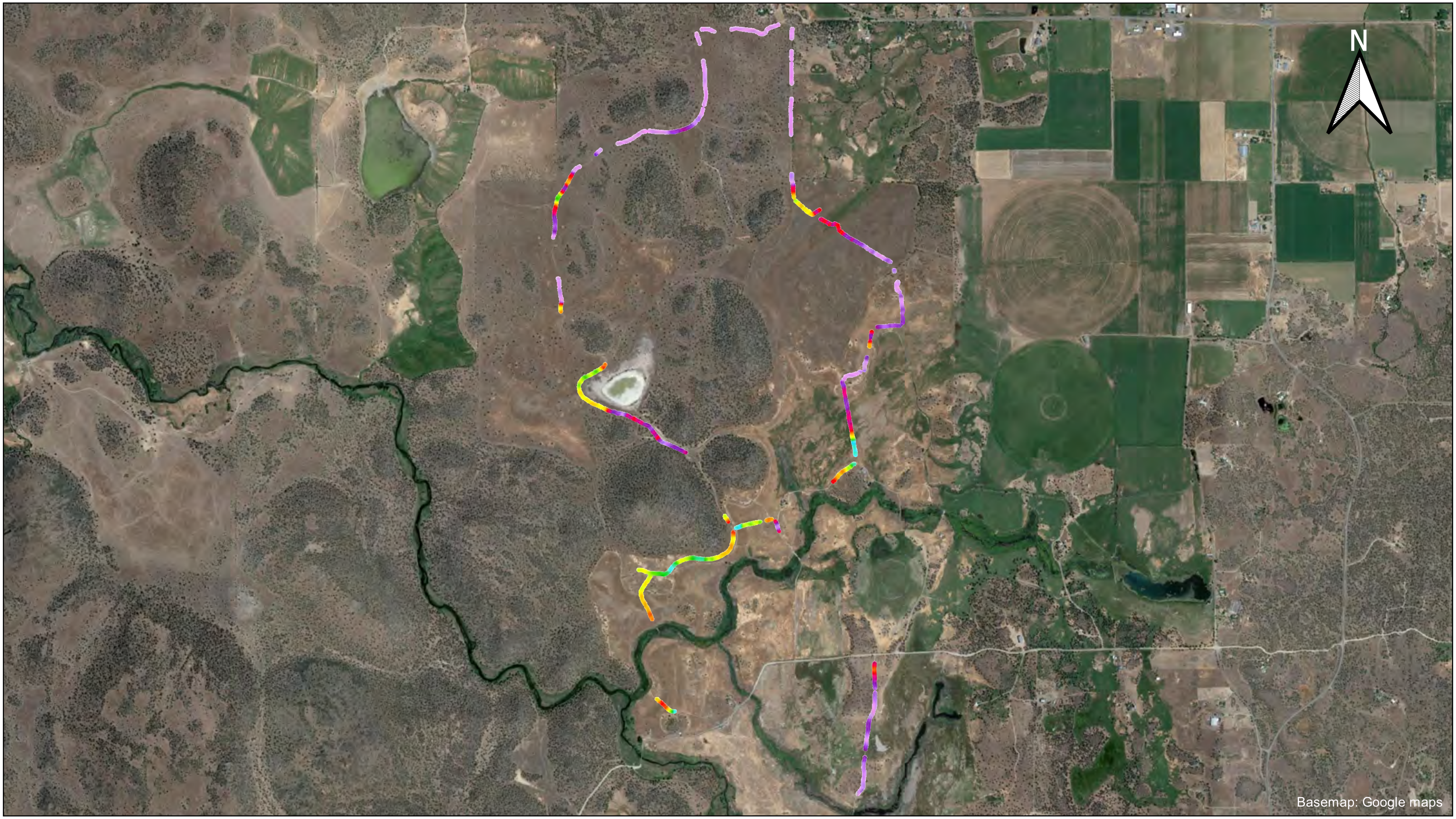

Mean resistivity map, elevation interval 785 m to 790 m a.m.s.l

5 10 50 100 200

Resistivity [Ohmm]

0 0.5 1 km

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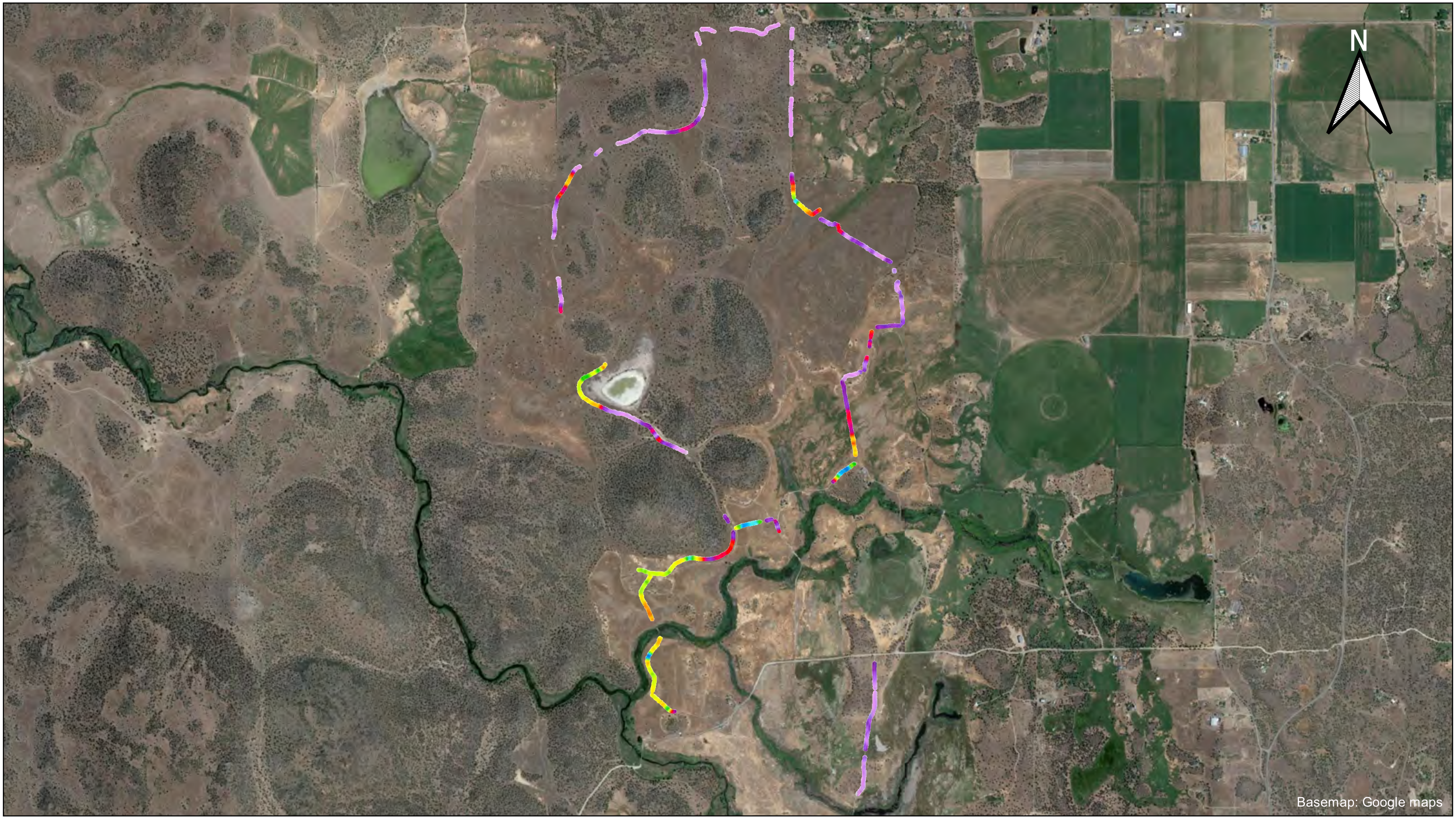
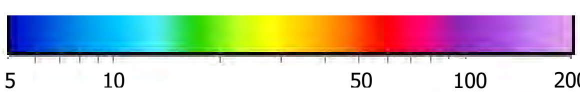


Mean resistivity map, elevation interval 780 m to 785 m a.m.s.l



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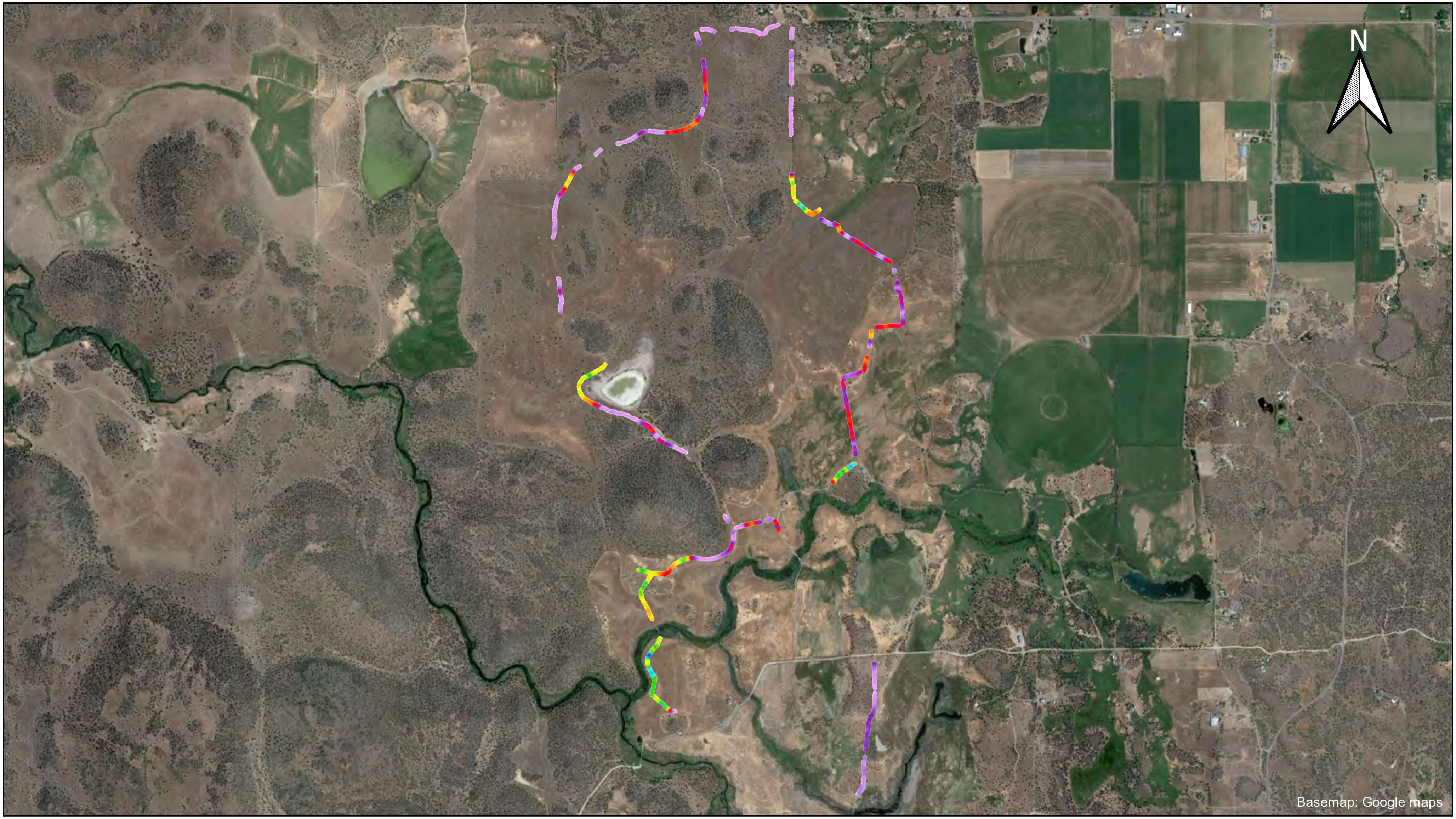

Mean resistivity map, elevation interval 775 m to 780 m a.m.s.l

5 10 50 100 200

Resistivity [Ohmm]

0 0.5 1 km

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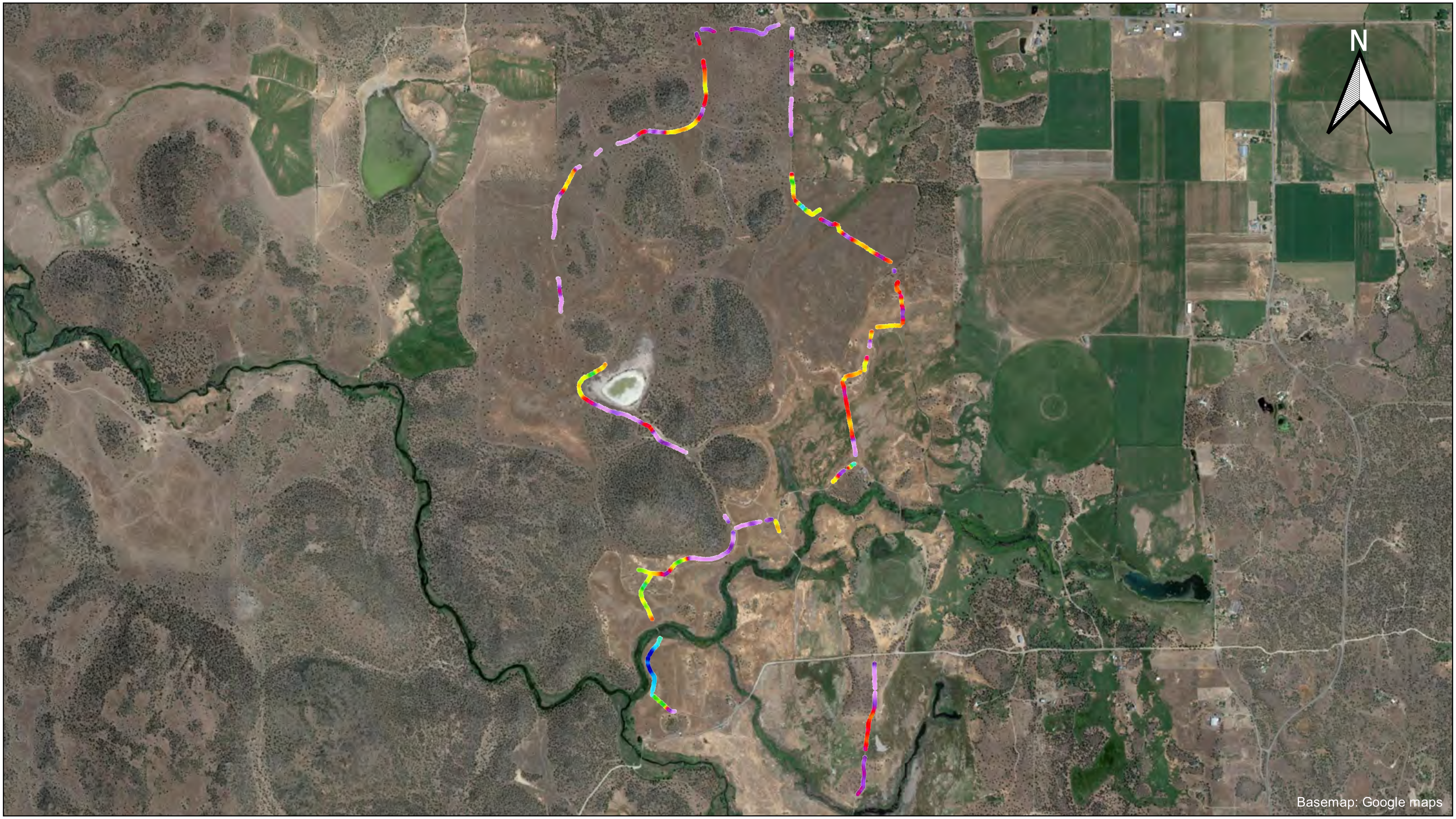

Mean resistivity map, elevation interval 770 m to 775 m a.m.s.l

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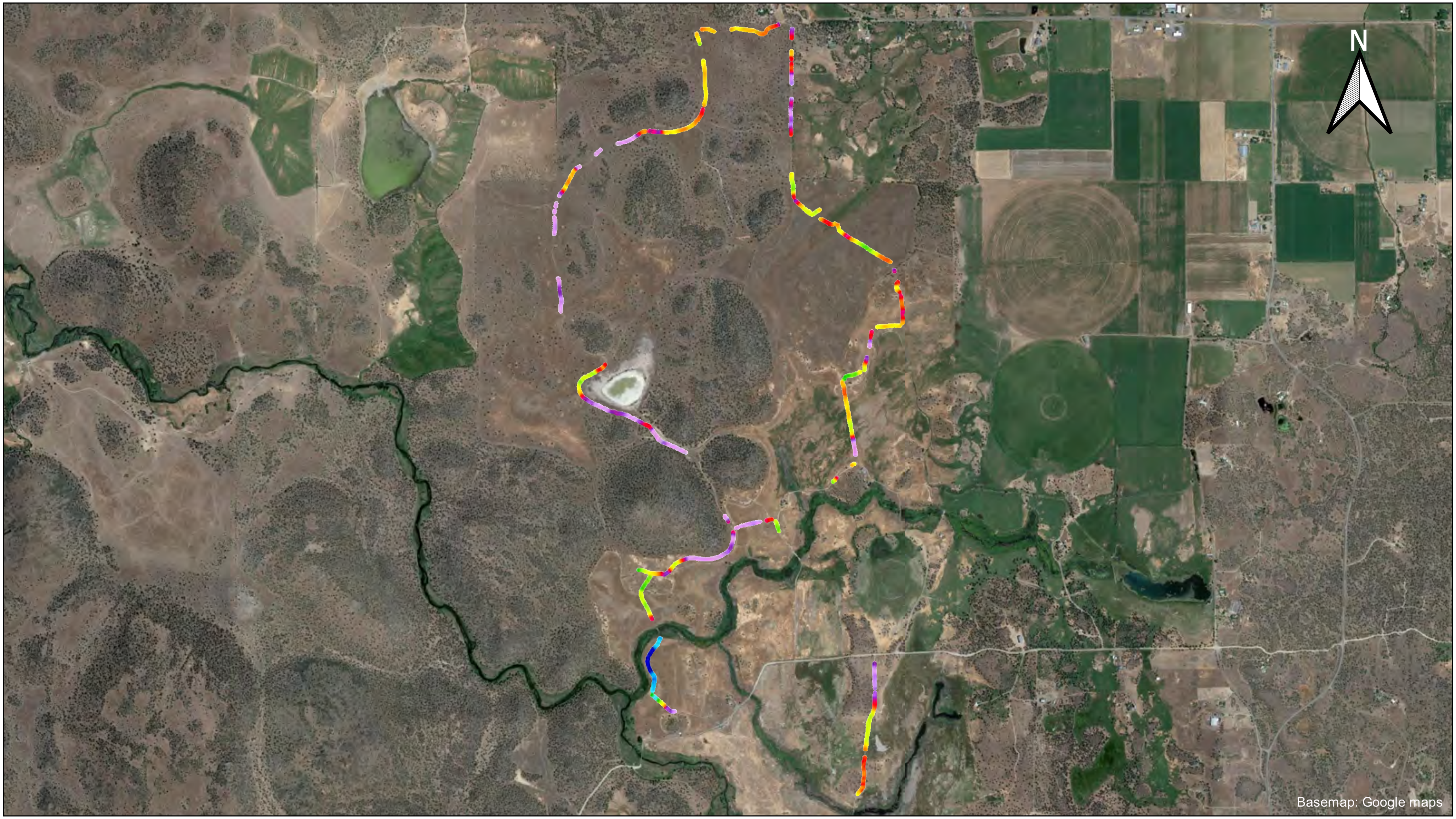

Mean resistivity map, elevation interval 765 m to 770 m a.m.s.l

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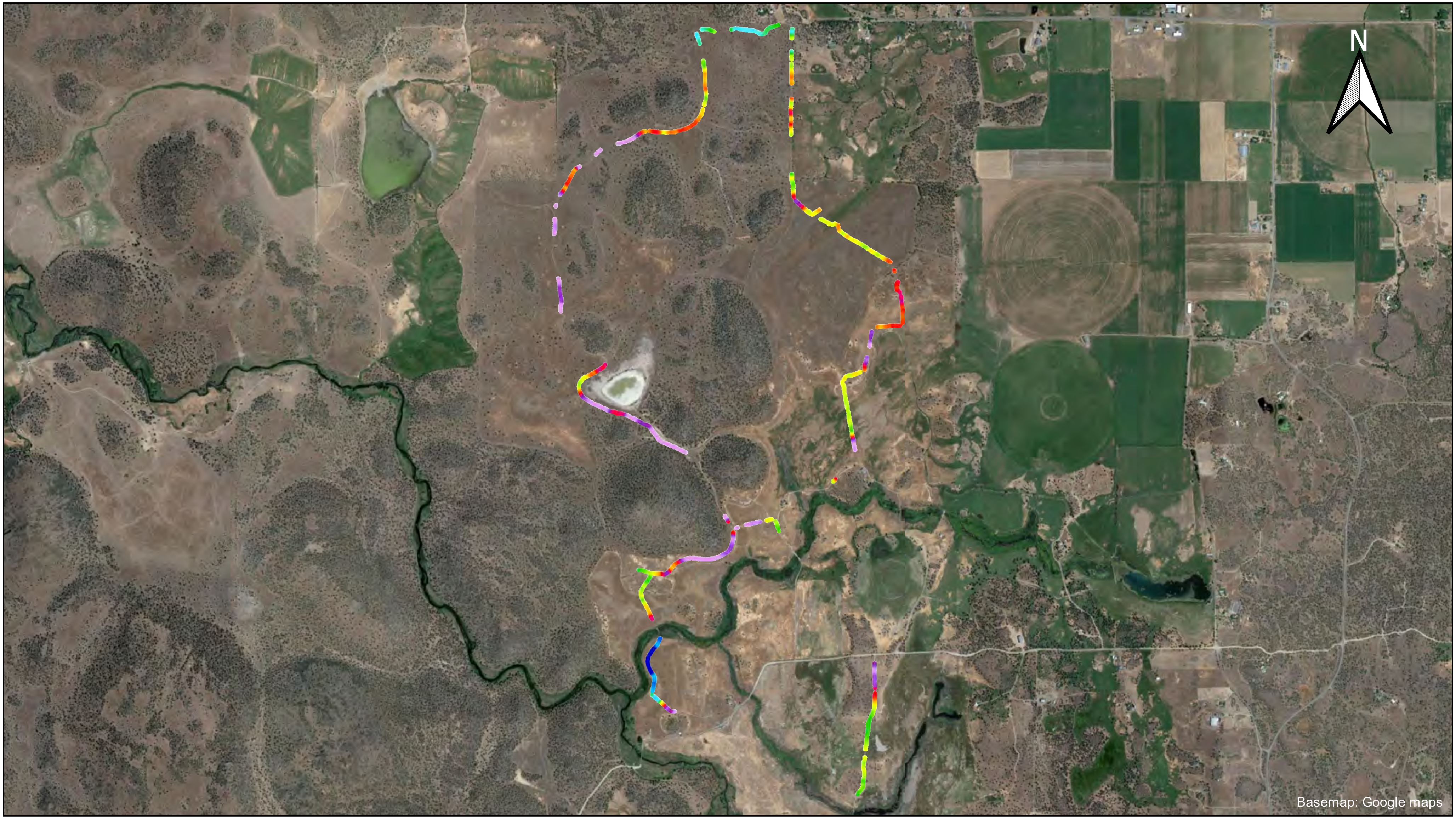
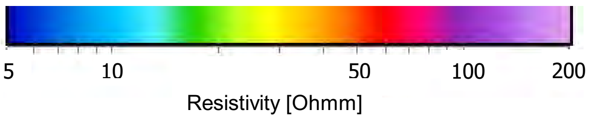


Mean resistivity map, elevation interval 760 m to 765 m a.m.s.l



0 0.5 1 km

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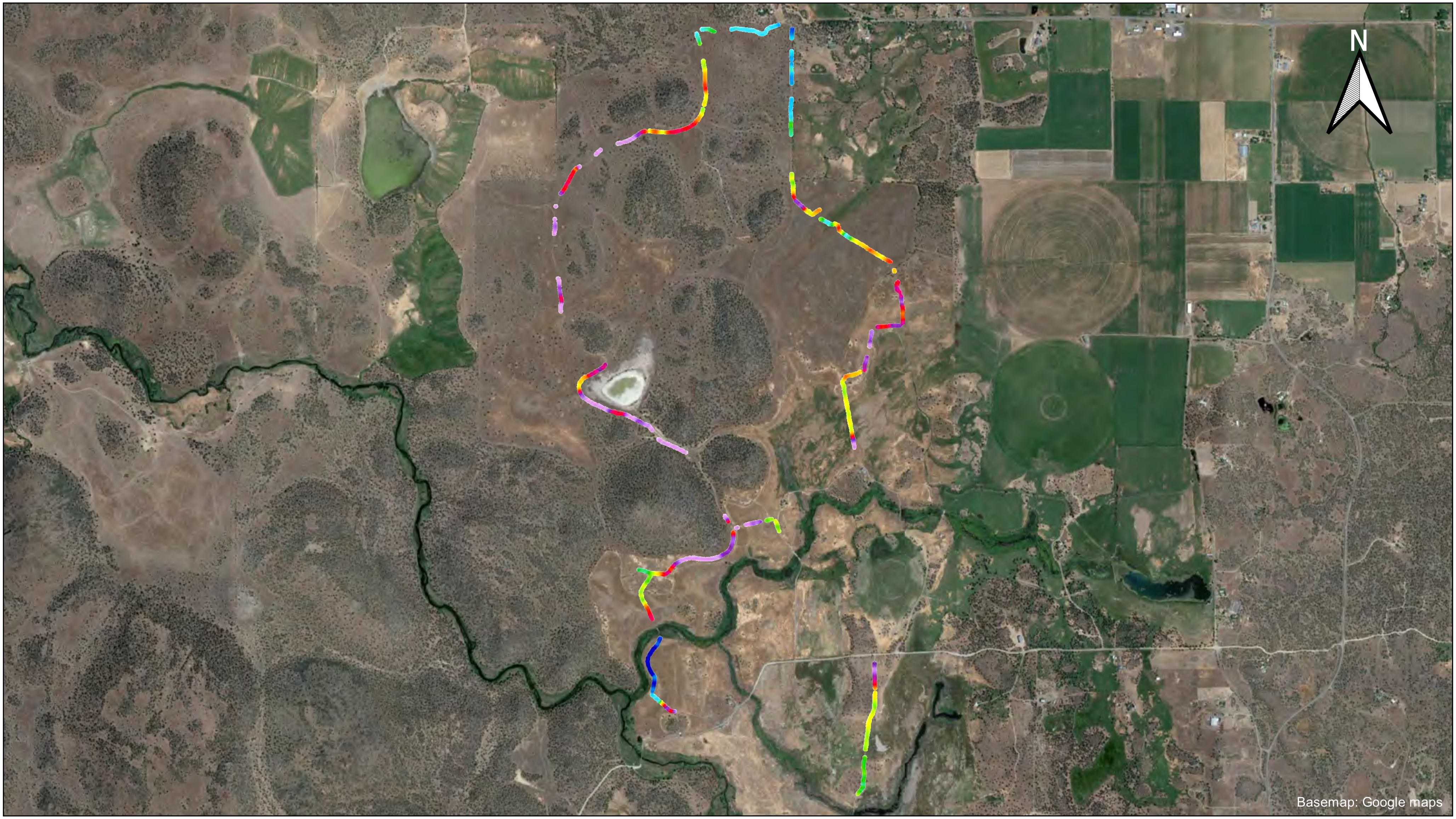
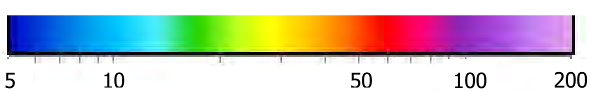


Mean resistivity map, elevation interval 755 m to 760 m a.m.s.l



0 0.5 1 km

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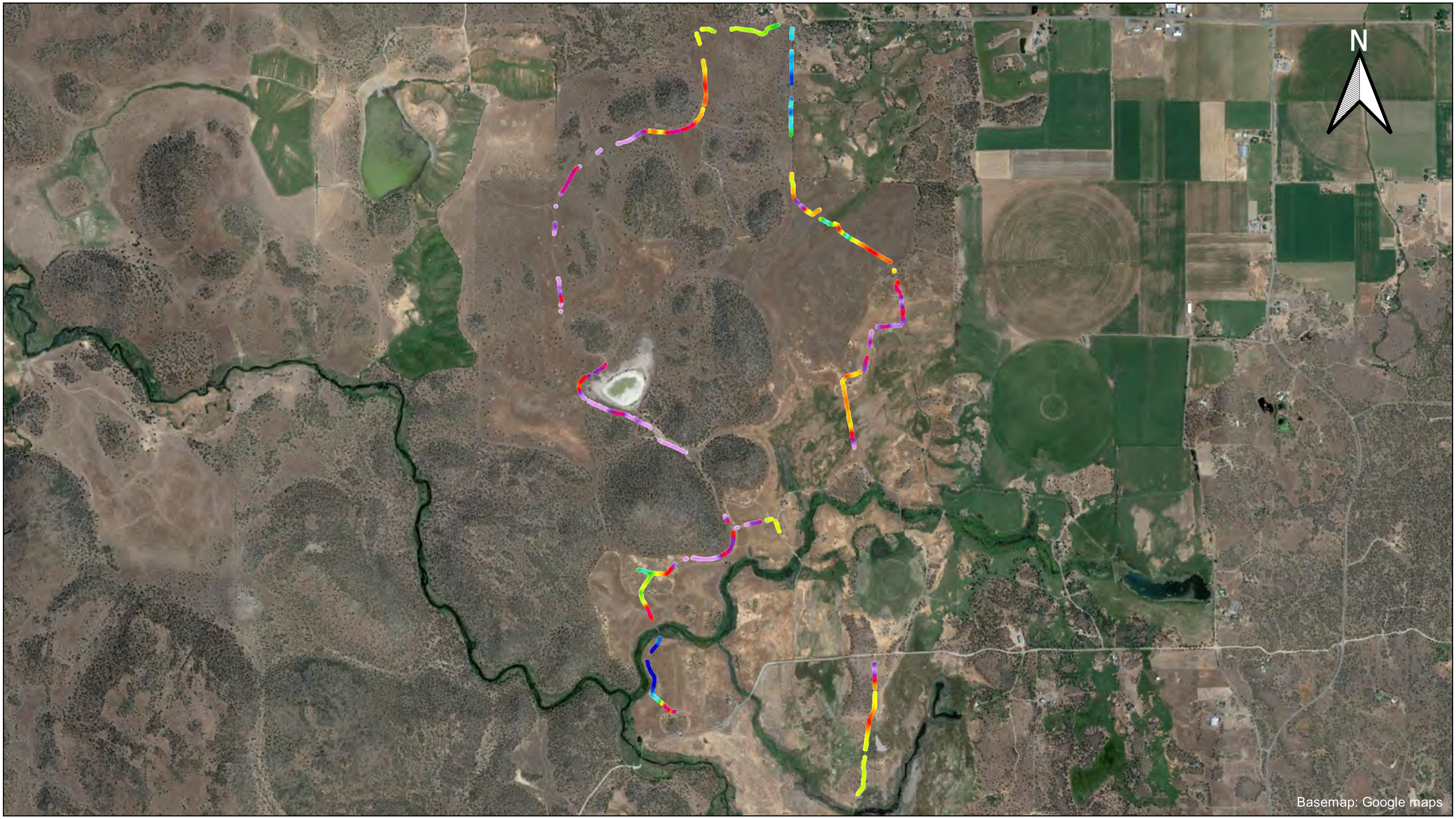

Mean resistivity map, elevation interval 750 m to 755 m a.m.s.l

5 10 50 100 200

Resistivity [Ohmm]

0 0.5 1 km

WGS84 / UTM zone 10N EPSG: 32610

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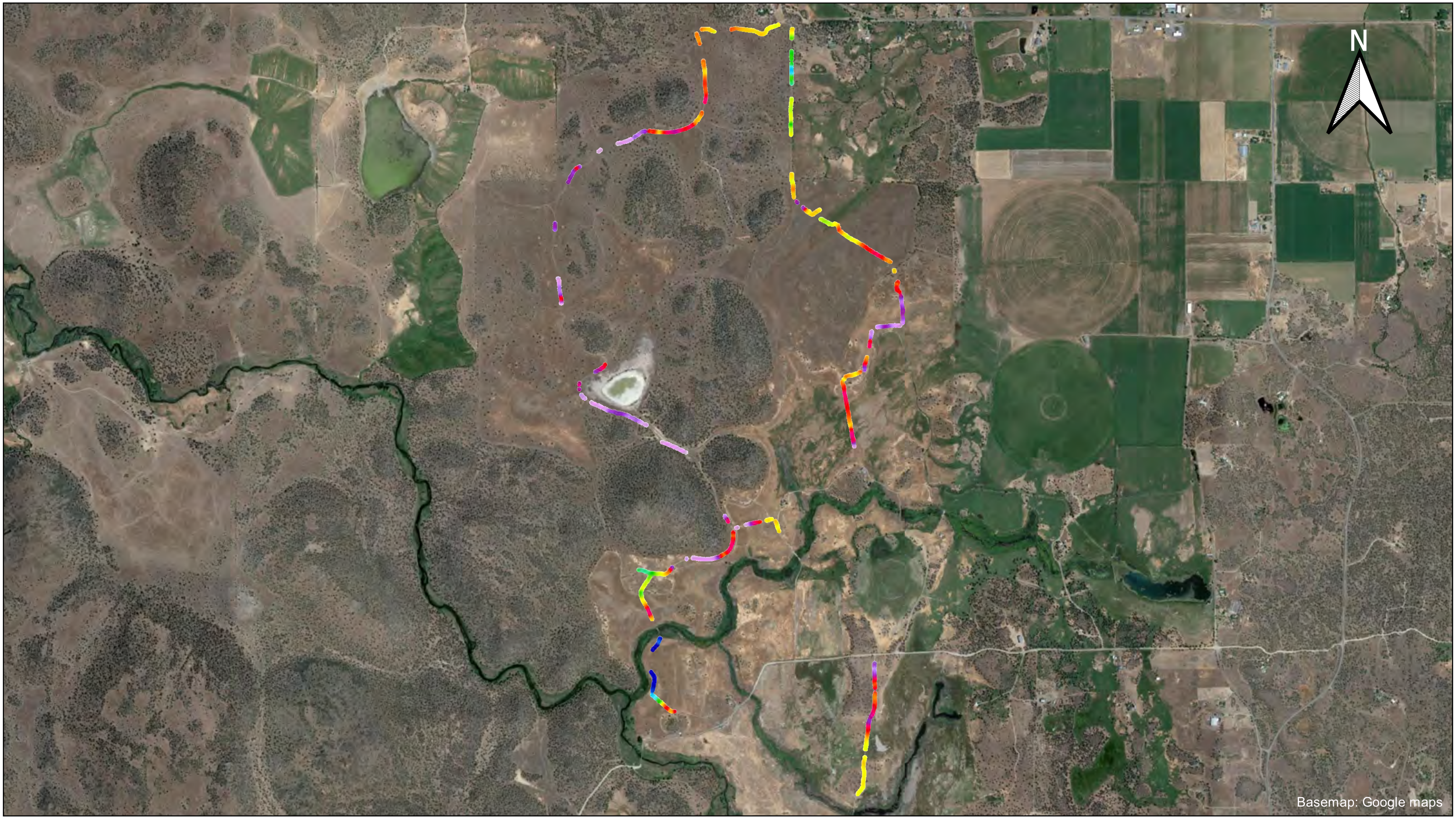

Mean resistivity map, elevation interval 745 m to 750 m a.m.s.l

0 0.5 1 km

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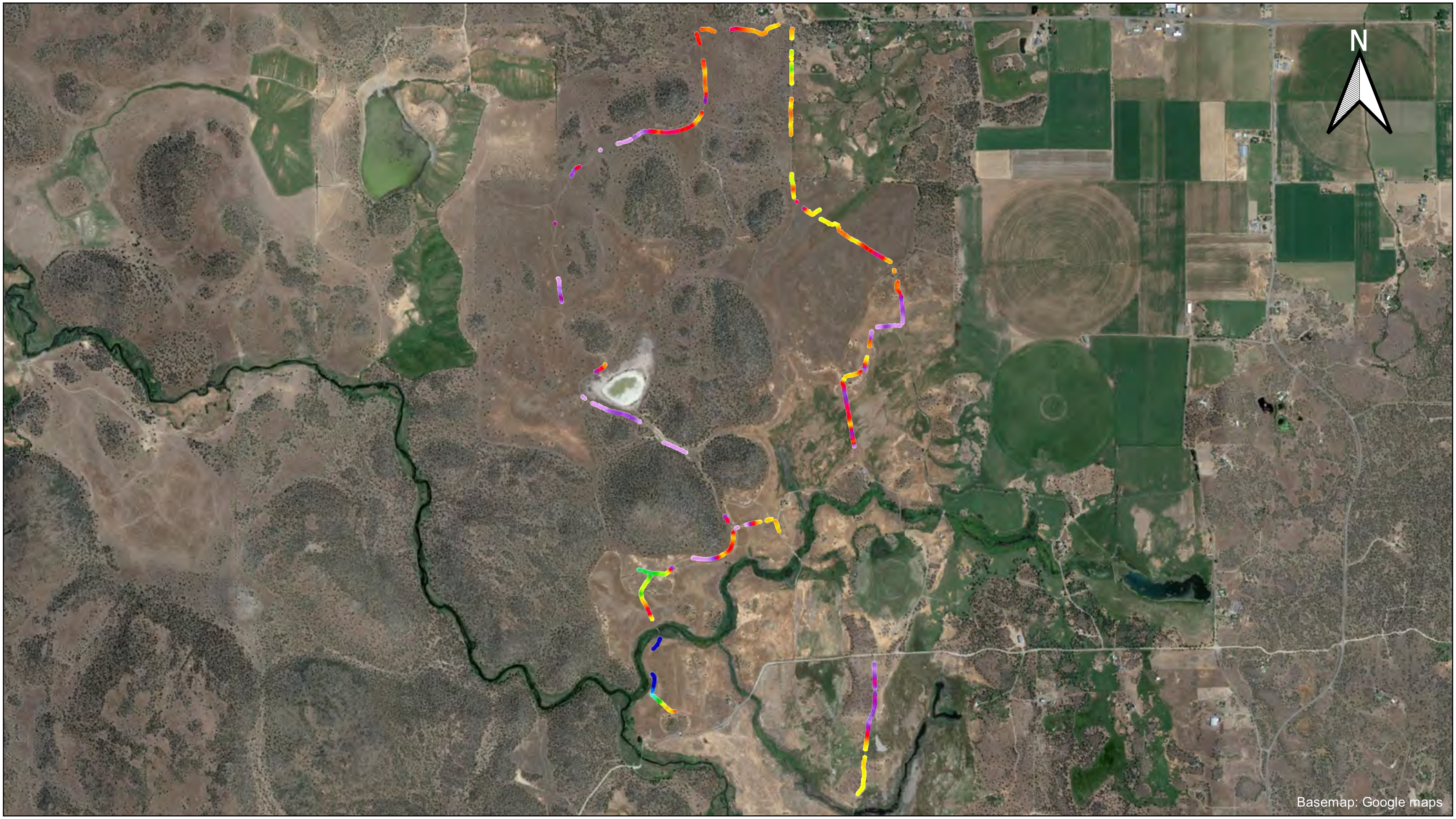
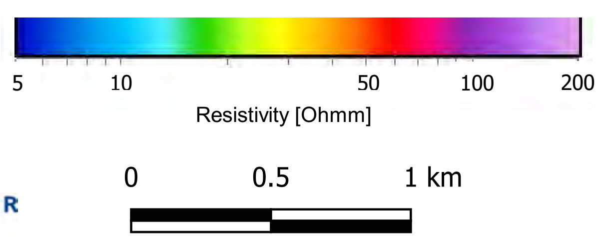


Mean resistivity map, elevation interval 740 m to 745 m a.m.s.l



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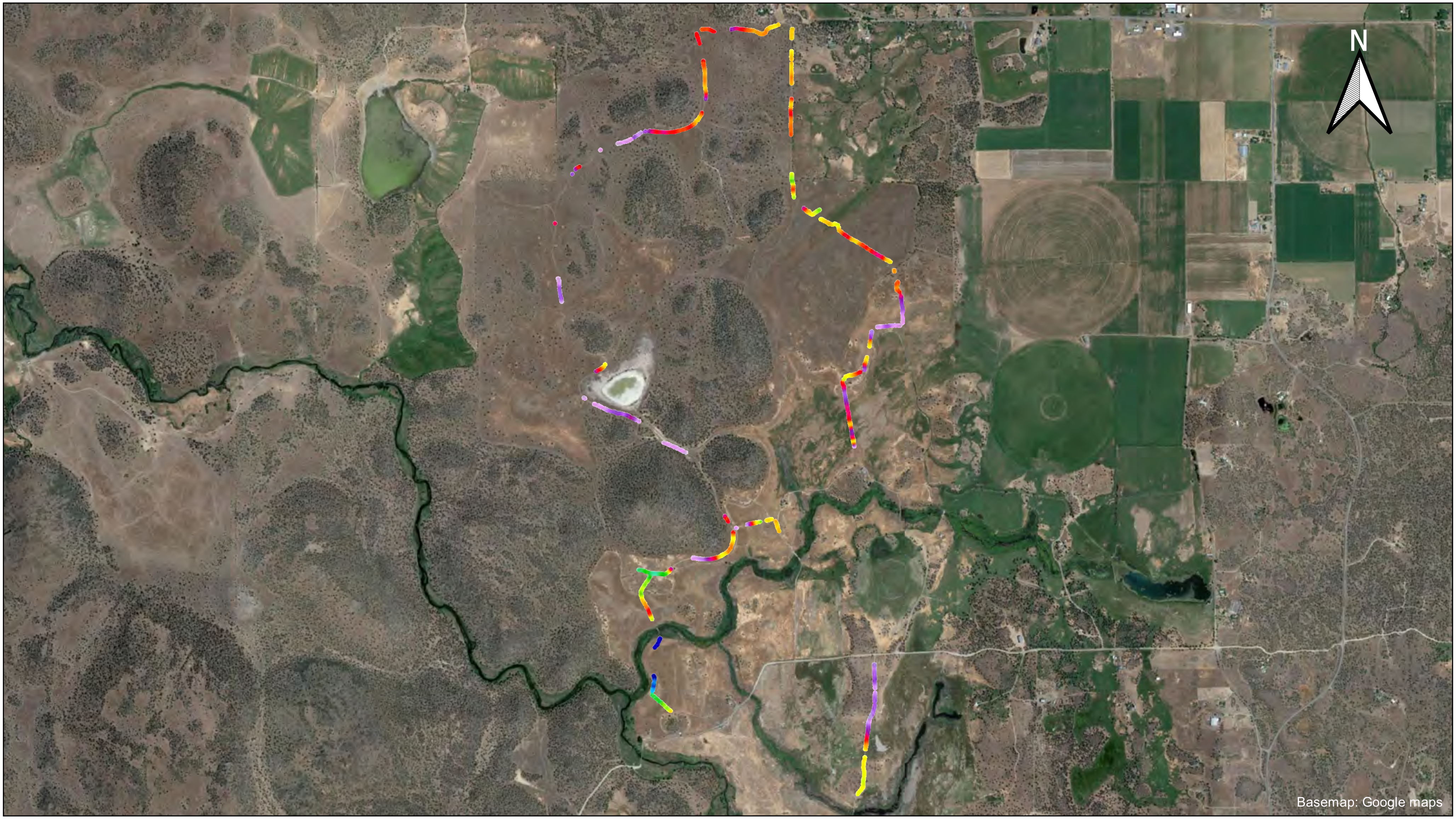
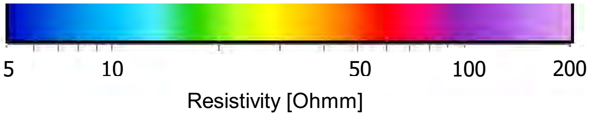
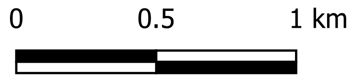


Mean resistivity map, elevation interval 735 m to 740 m a.m.s.l





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Approved by: MAXH

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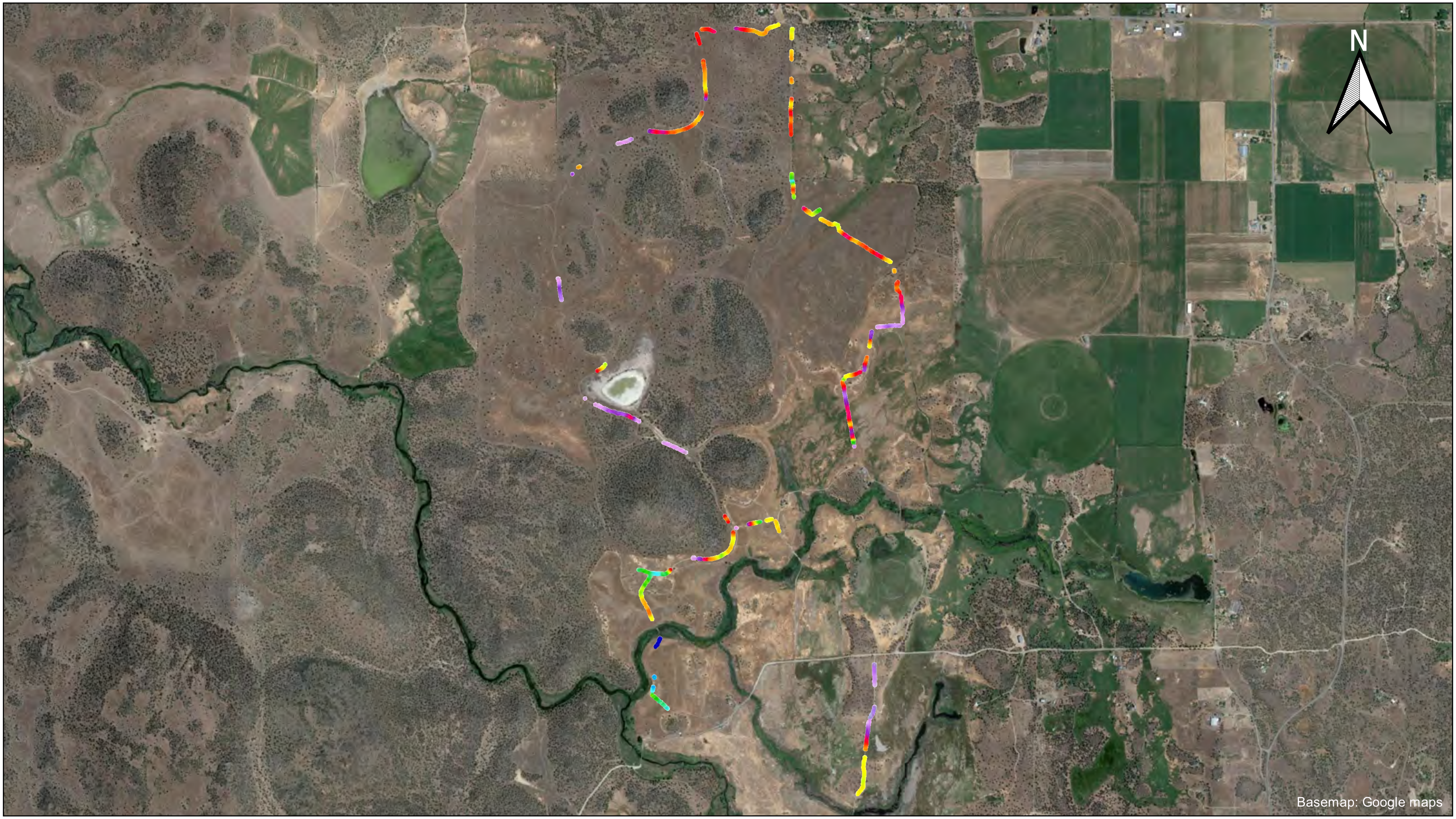

Mean resistivity map, elevation interval 730 m to 735 m a.m.s.l

5 10 50 100 200

Resistivity [Ohmm]

0 0.5 1 km

WGS84 / UTM zone 10N EPSG: 32610

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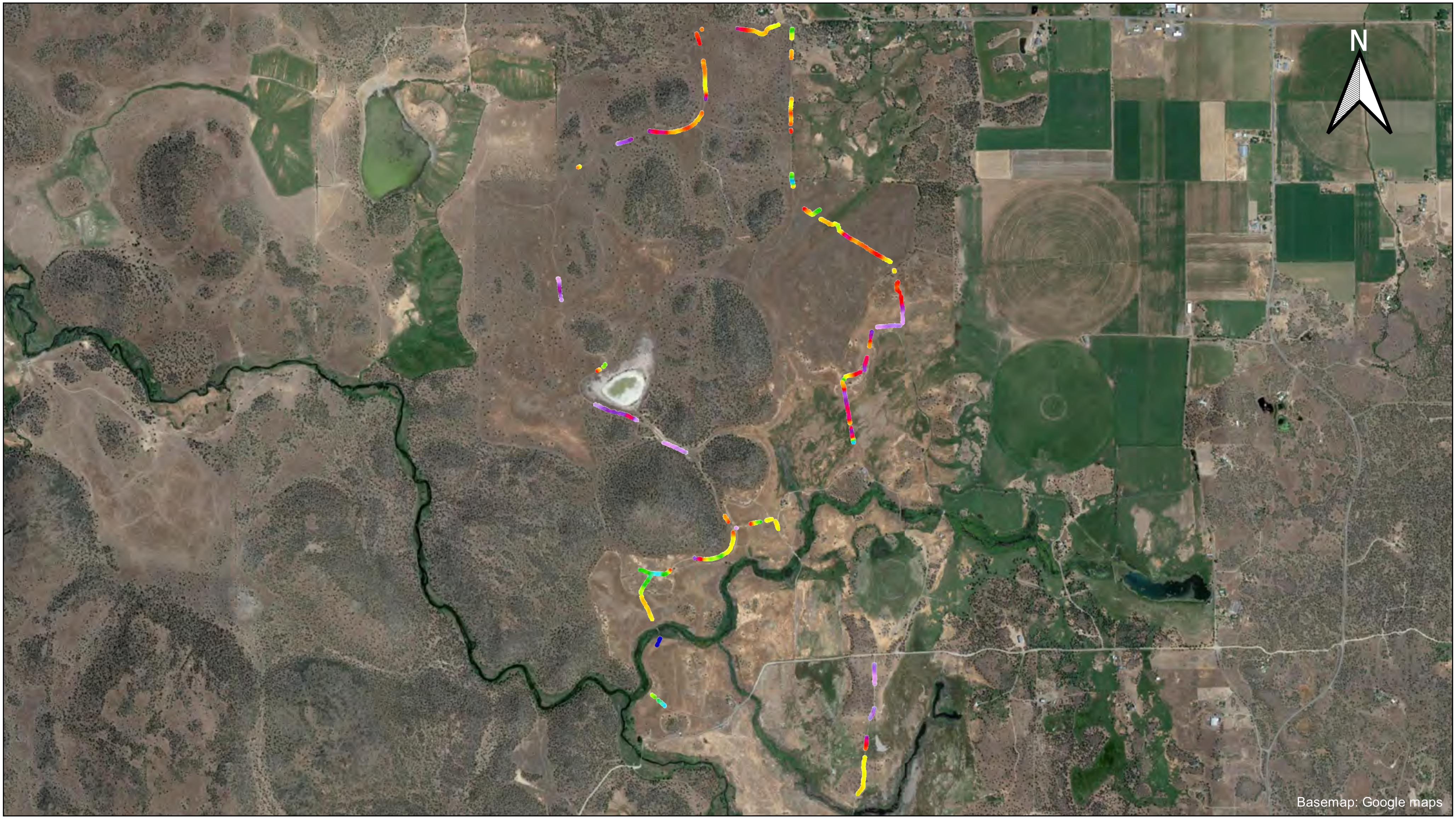
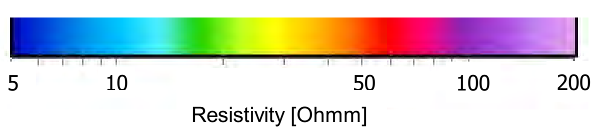
Date: 4/5/2021
Created by: PRT
Checked by: ABB
Approved by: MAXH

RAMBOLL



Mean resistivity map, elevation interval 725 m to 730 m a.m.s.l



WGS84 / UTM zone 10N EPSG: 32610

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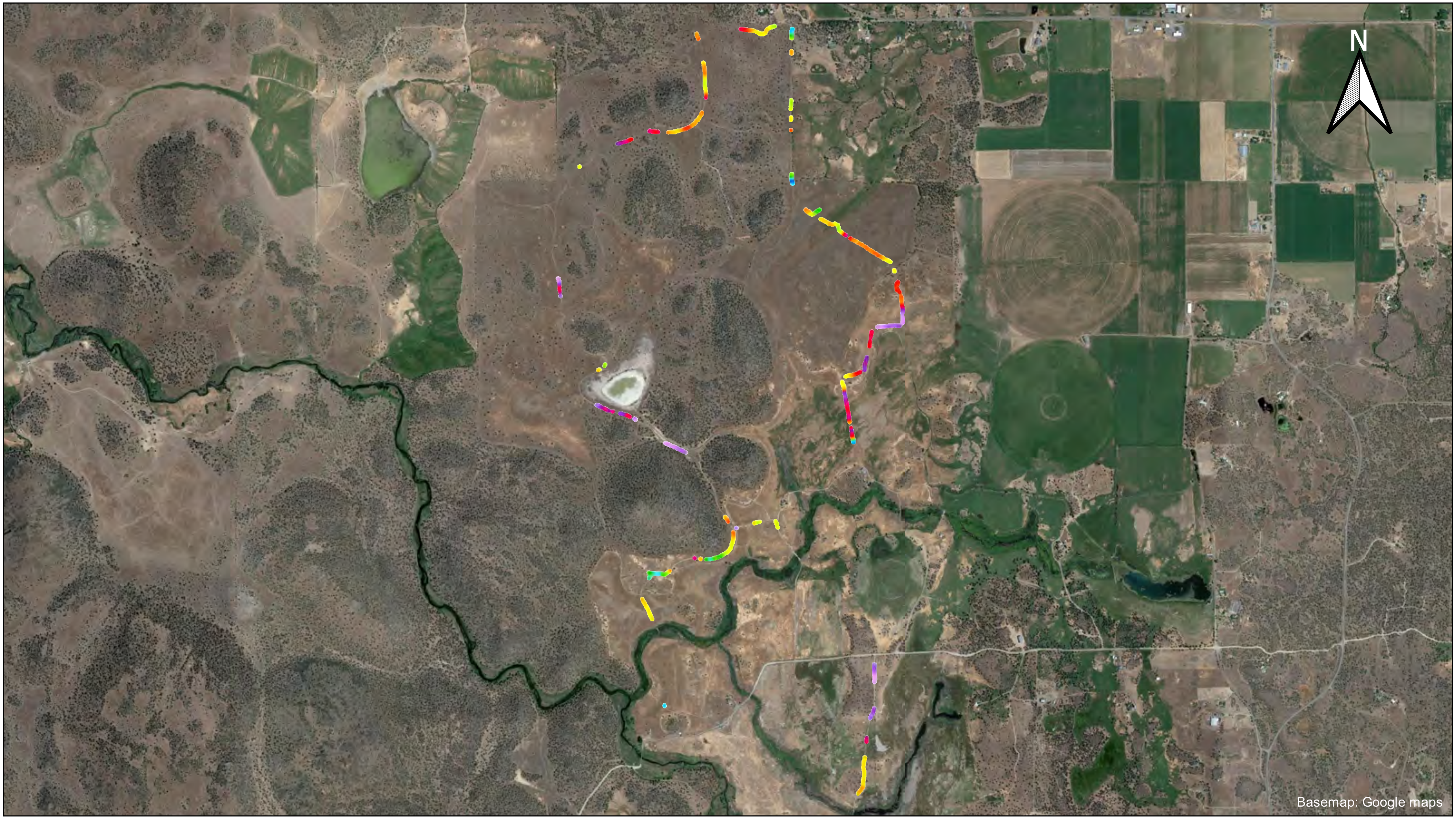

Mean resistivity map, elevation interval 720 m to 725 m a.m.s.l

5 10 50 100 200
Resistivity [Ohmm]

0 0.5 1 km

WGS84 / UTM zone 10N EPSG: 32610

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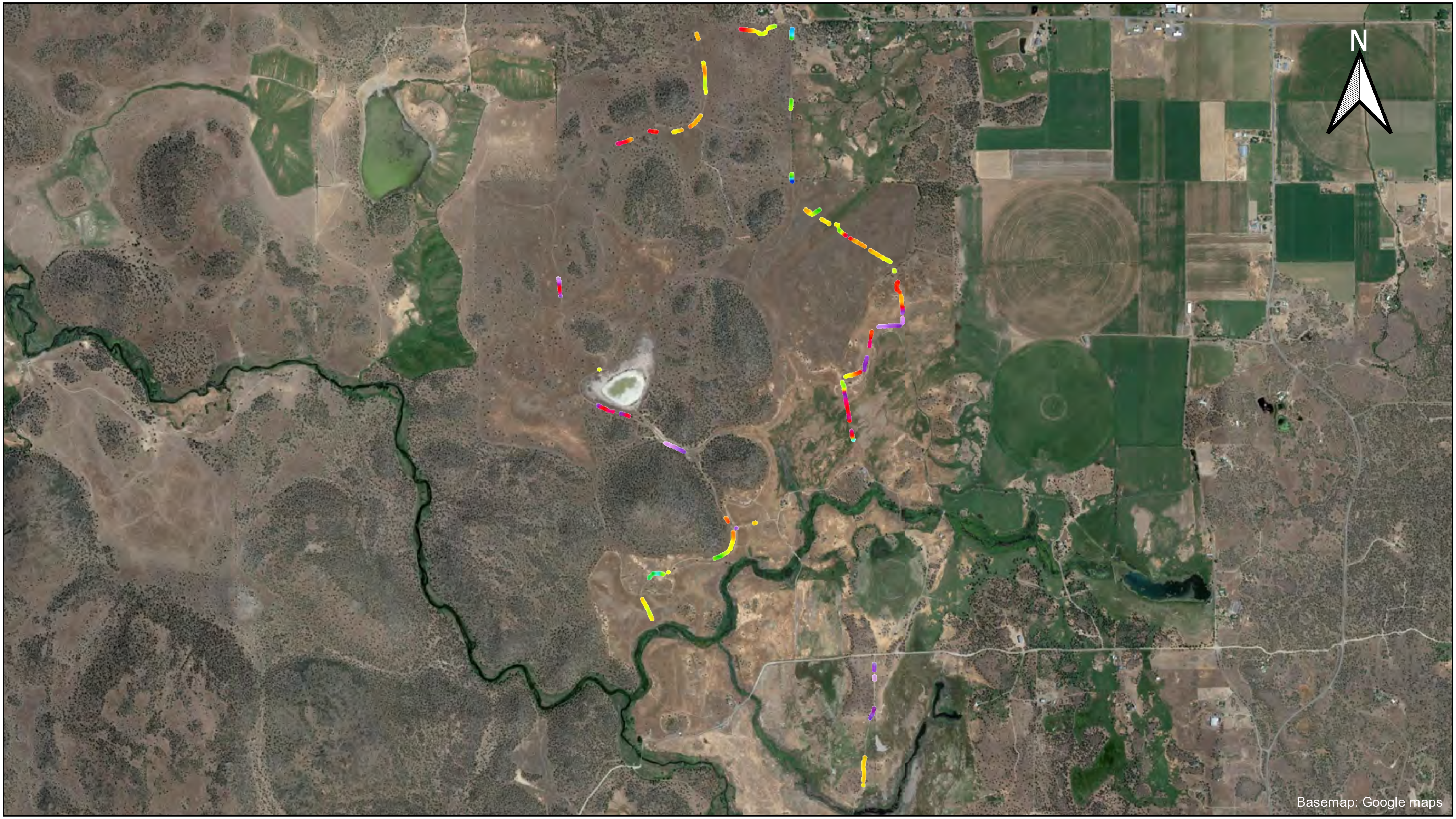
Date: 4/5/2021
Created by: PRT
Checked by: ABB
Approved by: MAXH

RAMBOLL



Mean resistivity map, elevation interval 715 m to 720 m a.m.s.l

5 10 50 100 200
Resistivity [Ohmm]

0 0.5 1 km

WGS84 / UTM zone 10N EPSG: 32610

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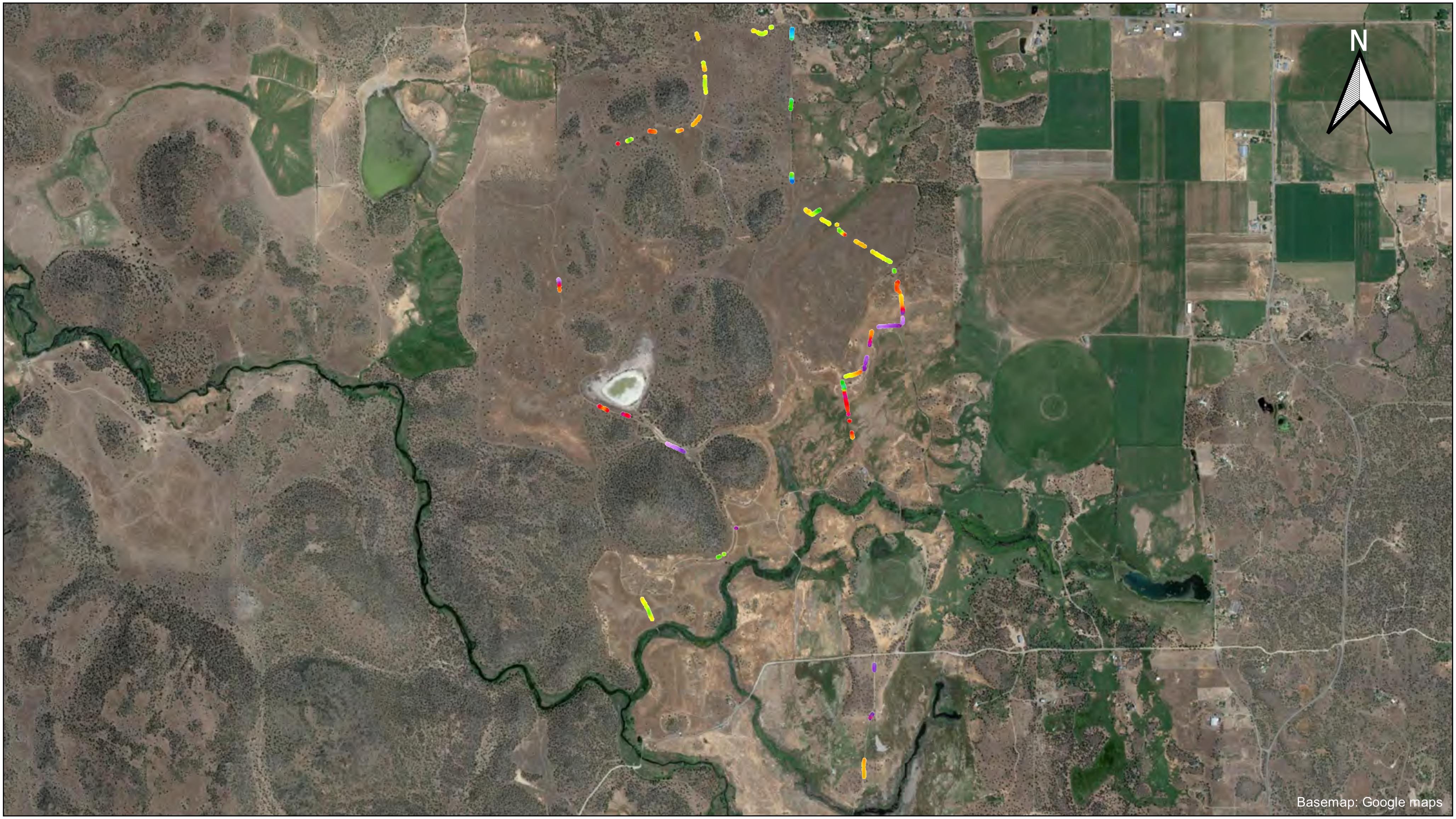
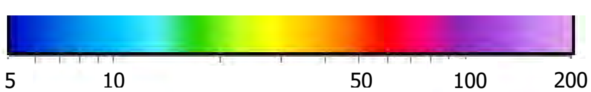
Date: 4/5/2021
Created by: PRT
Checked by: ABB
Approved by: MAXH

RAMBOLL



Mean resistivity map, elevation interval 710 m to 715 m a.m.s.l



0 0.5 1 km

WGS84 / UTM zone 10N EPSG: 32610

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Created by: PRT
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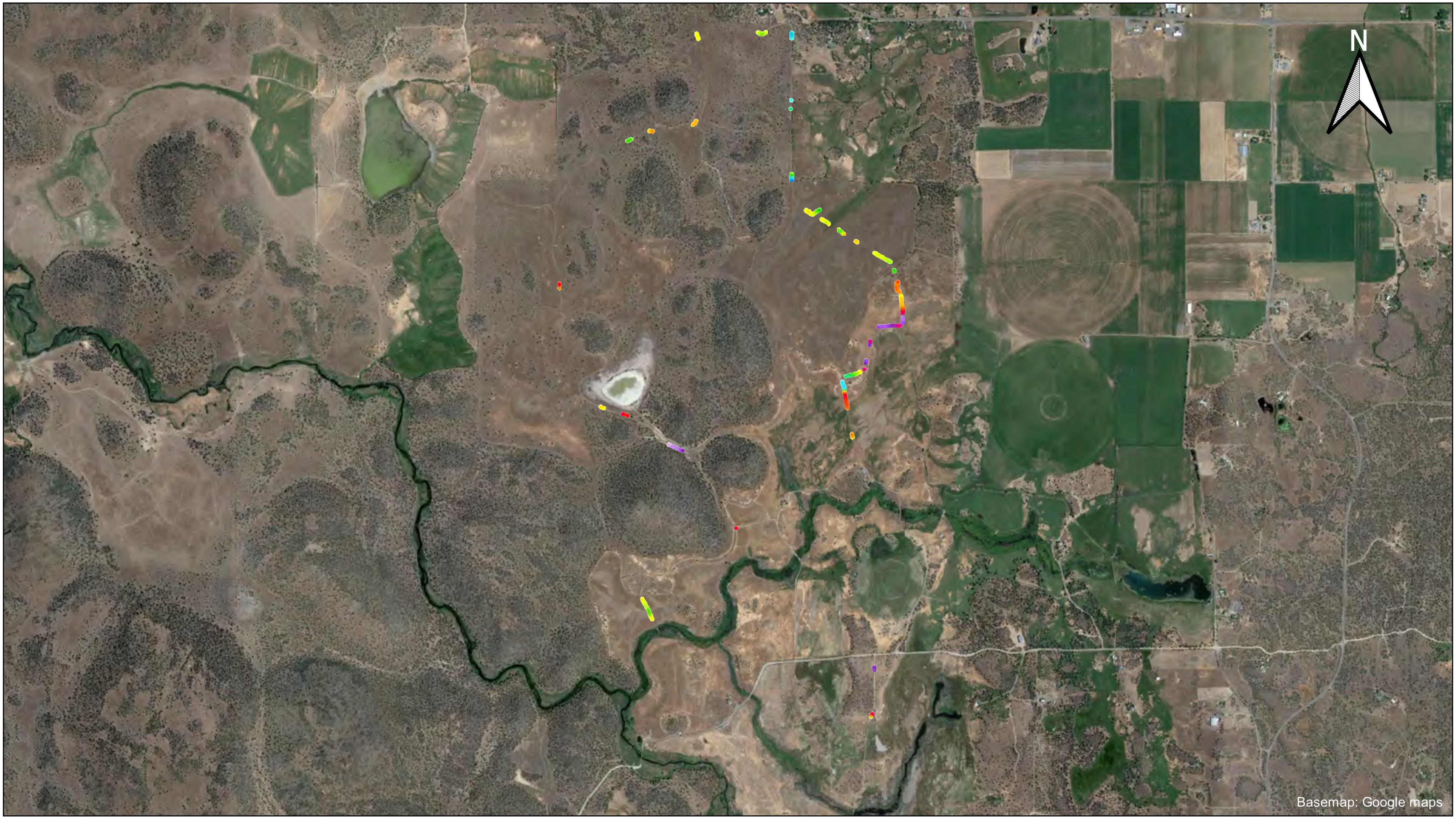
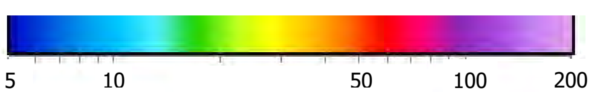


Mean resistivity map, elevation interval 705 m to 710 m a.m.s.l



WGS84 / UTM zone 10N EPSG: 32610

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Date: 4/5/2021
Created by: PRT
Checked by: ABB
Approved by: MAXH

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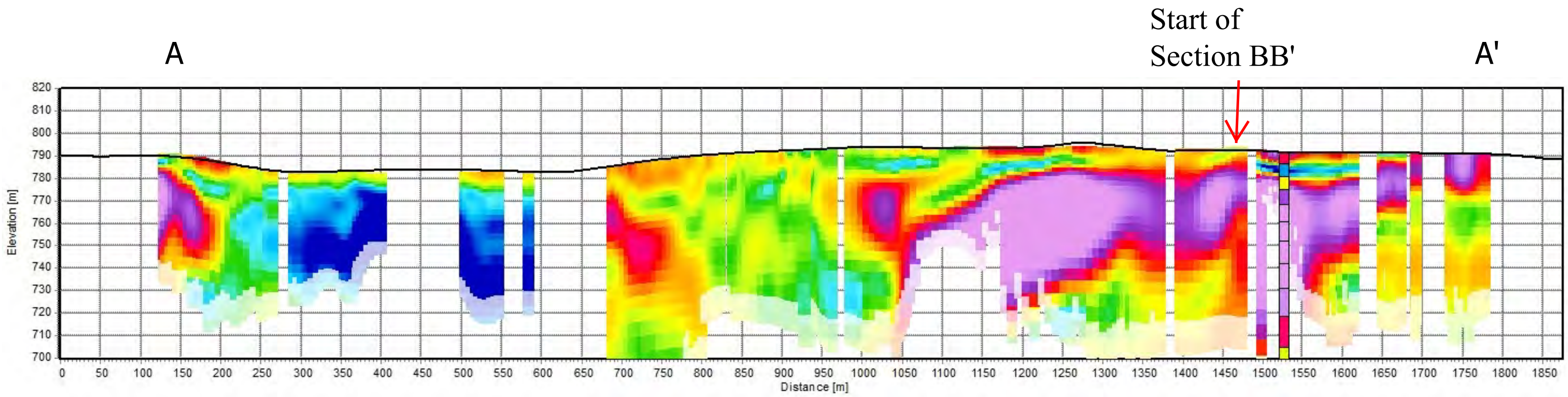
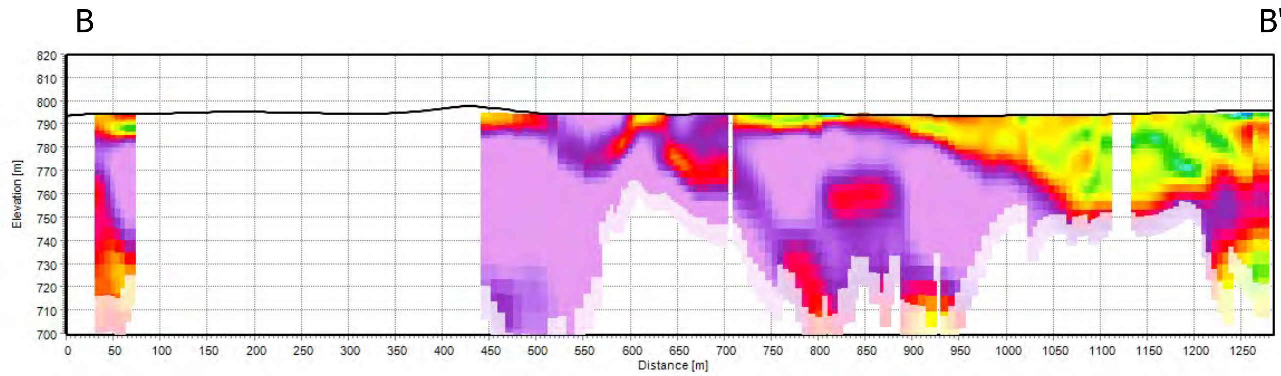
APPENDIX 4
TTEM VERTICAL SECTION RESULTS





Model Sections A and B

Visualized section
tTEM models

Date: 4/5/2021
Created by: PRT
Checked by: AAB
Approved by: MAXH

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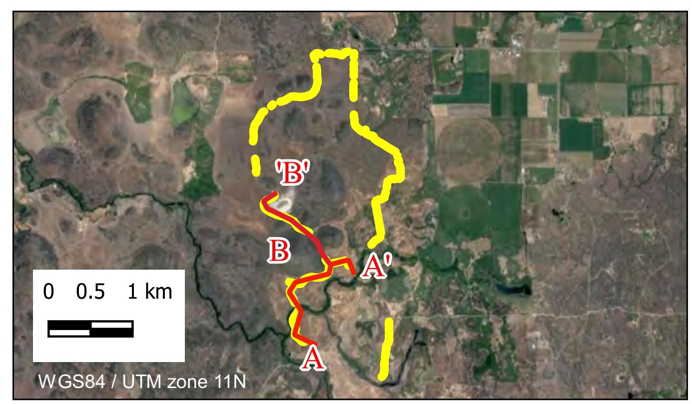
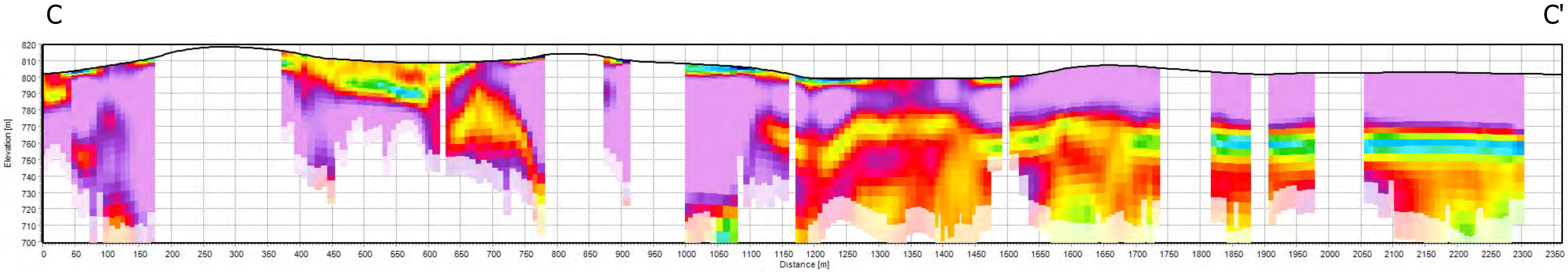
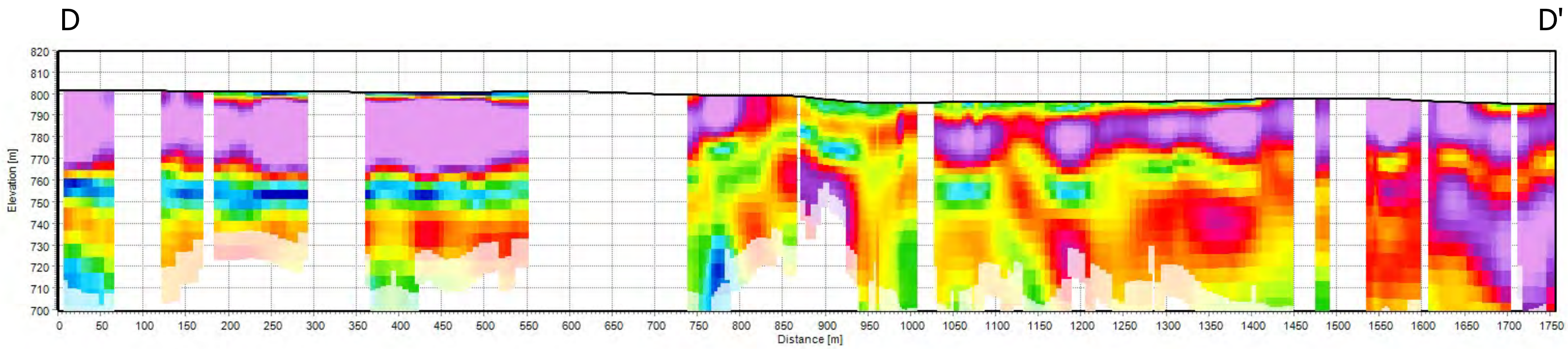




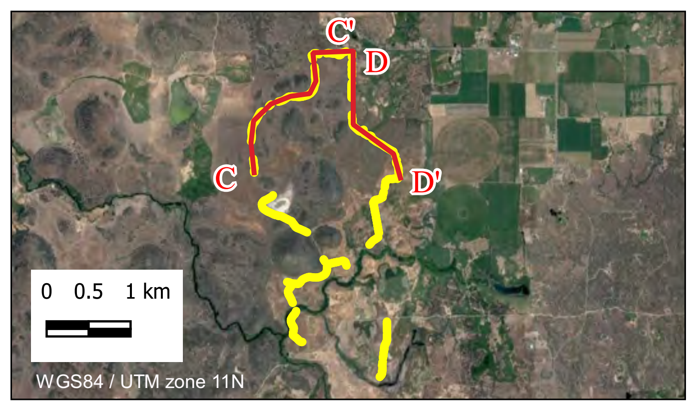


Model Sections C and D

Visualized section

tTEM models

Date: 4/5/2021
Created by: PRT
Checked by: AAB
Approved by: MAXH



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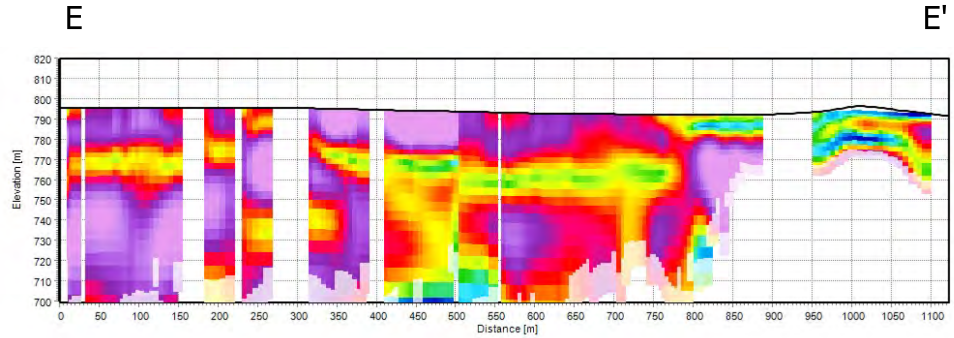
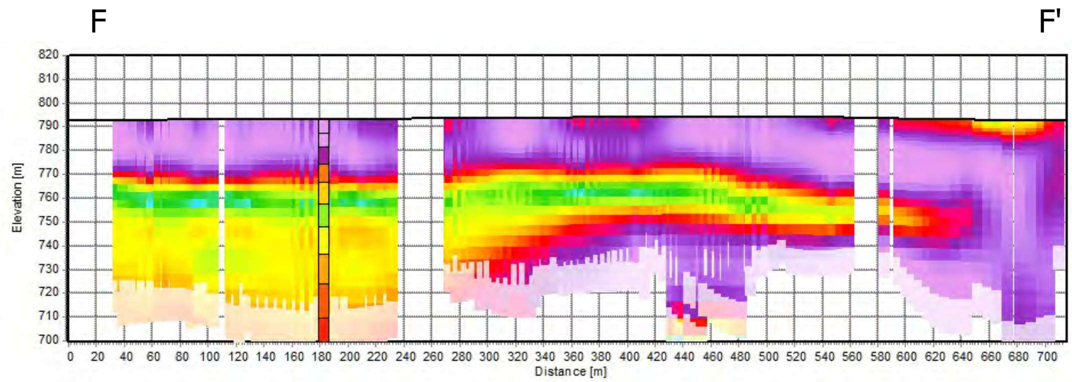
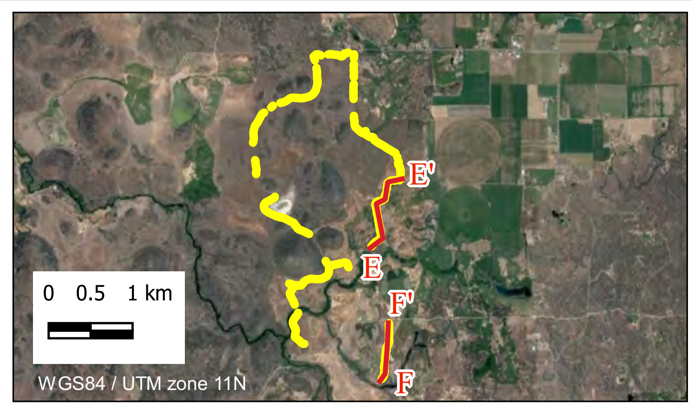


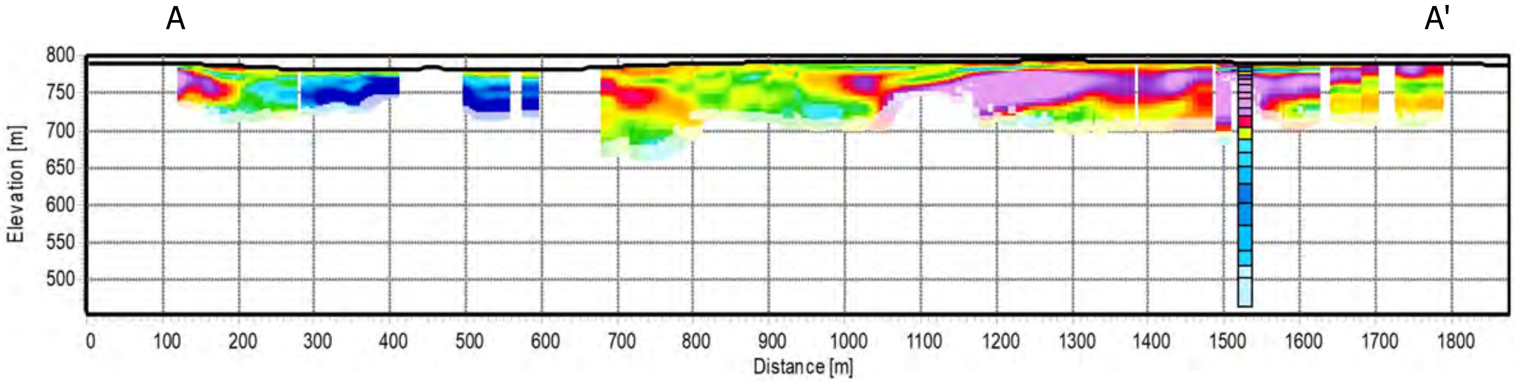


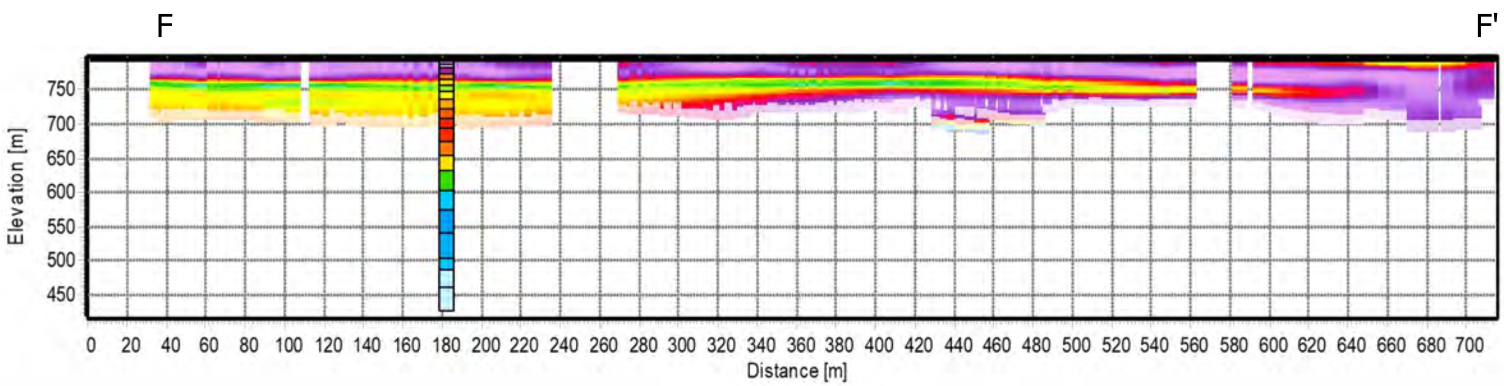
Model Sections E and F

Visualized section
tTEM models

Date: 4/5/2021
Created by: PRT
Checked by: AAB
Approved by: MAXH





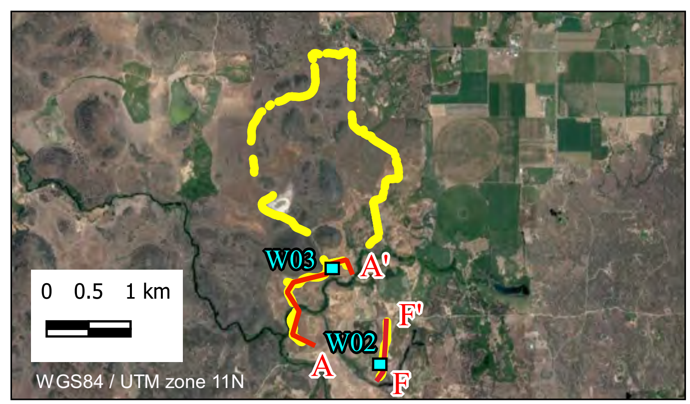


Model Sections A and F

Visualized section
tTEM models

Date: 4/5/2021
Created by: PRT
Checked by: AAB
Approved by: MAXH

RAMBOLL



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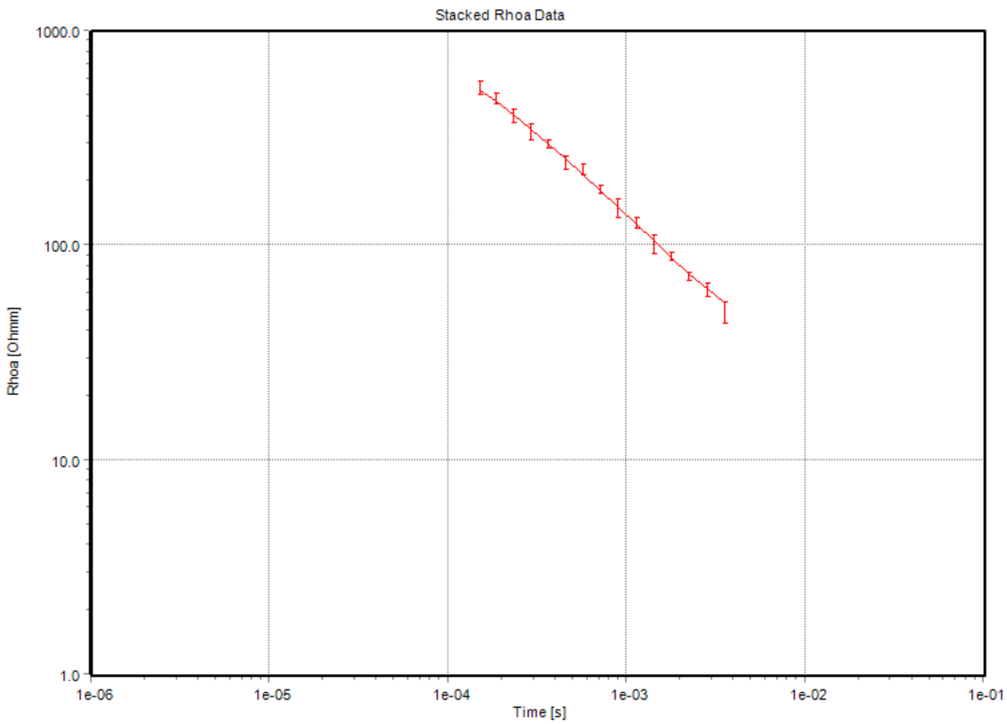
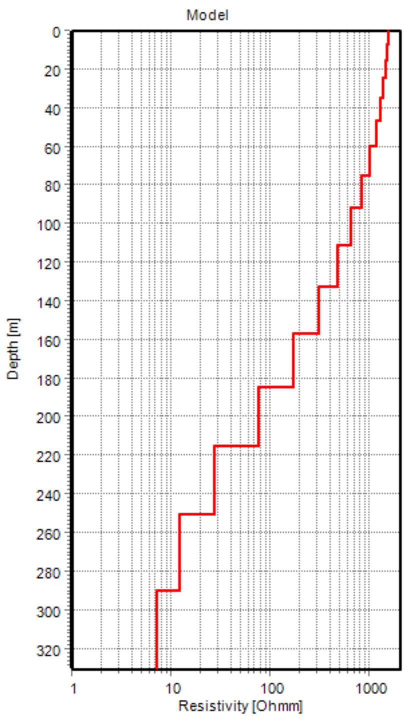
APPENDIX 5
WALKTEM RESULTS

WalkTEM Station: W01

UTMX: 558615 **Data Residual:** 0.4 **Database Name:** Project45.gdb

UTMY: 4597634 **DOI:** 401 m **EPSG:** WGS 84 UTM zone 10N (epsg: 32610)

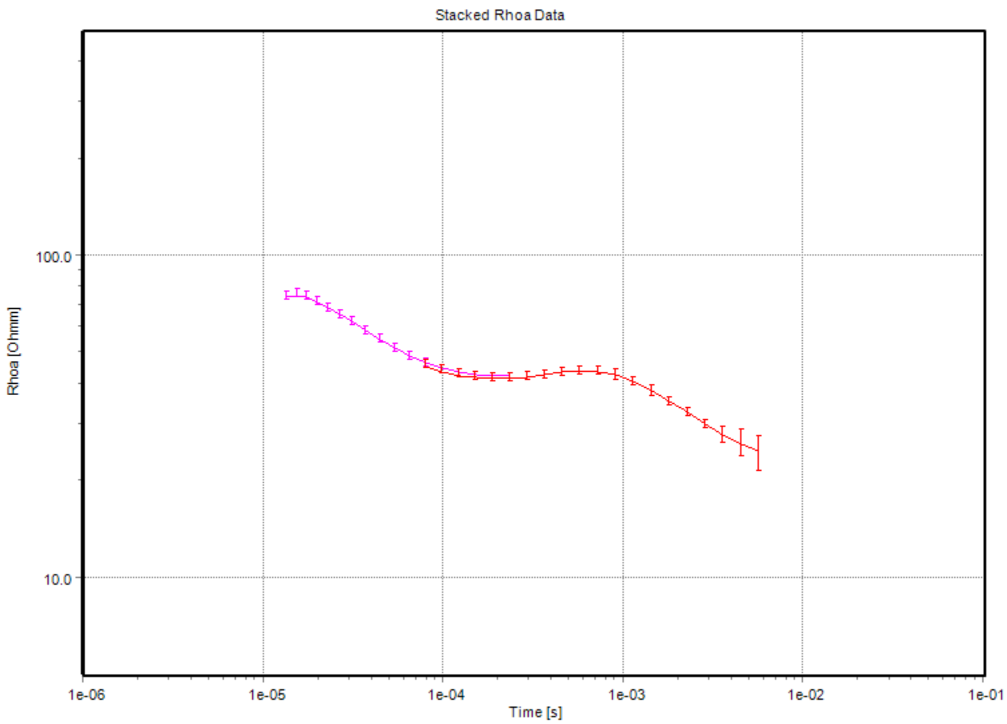


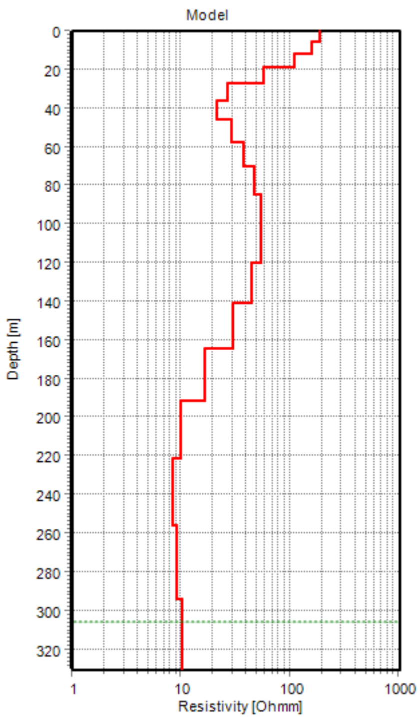


WalkTEM Station: W02

UTMX: 547930 **Data Residual:** 0.25 **Database Name:** Project45.gdb

UTMY: 4604434 **DOI:** 306 m **EPSG:** WGS 84 UTM zone 10N (epsg: 32610)

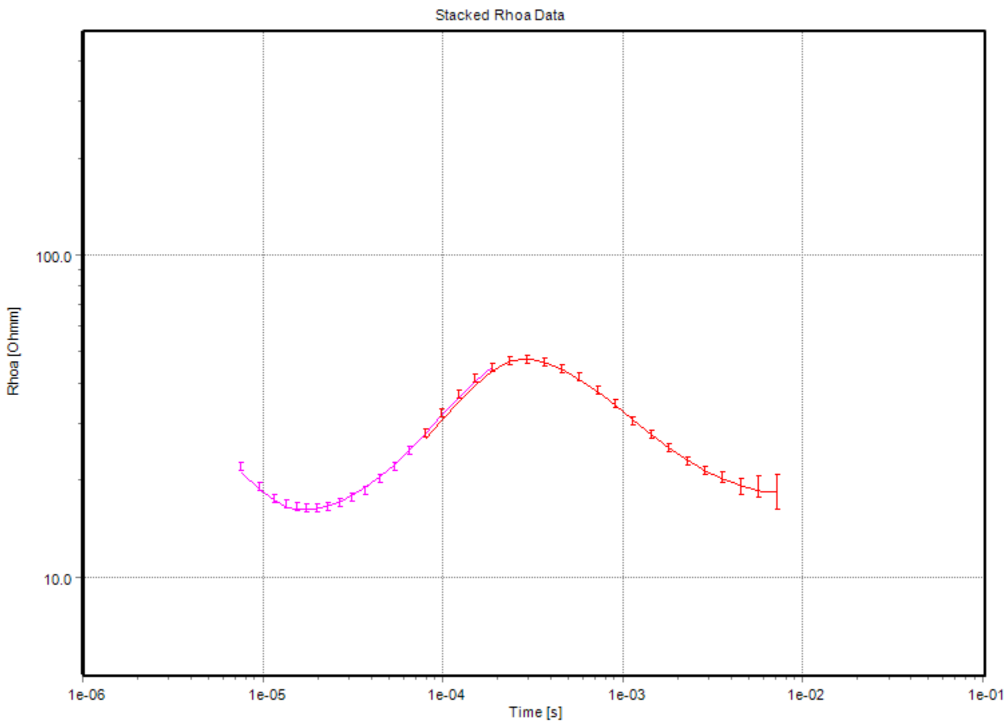


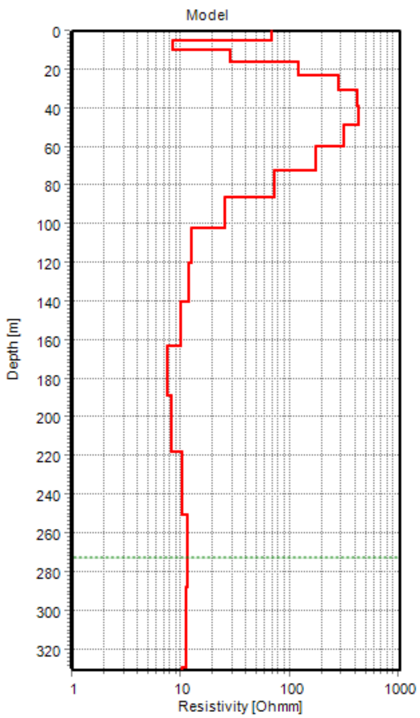


WalkTEM Station: W03

UTMX: 547359 **Data Residual:** 0.57 **Database Name:** Project45.gdb

UTMY: 4605611 **DOI:** 273 m **EPSG:** WGS 84 UTM zone 10N (epsg: 32610)





Appendix 2-G. Groundwater Dependent Ecosystem Assessment

Contents

Additional Tables and Figures for the Identification of Groundwater Dependent Ecosystems

The following section provides additional tables and figures that are mentioned in the main text of Section 2.2.2.7.

Water Levels

Representations of depth to groundwater for each of the 23 representation of depth to groundwater are presented from Figure 1 to Figure 16. The raster size is 0.41 mi (0.66 km) by 0.31 mi (0.5 km).

Tables

The union of the NCCAG vegetation and wetland layers and adapted 2016 Siskiyou County LU/LC dataset created several tables.

- New fields created by combining or concatenating the relevant fields in each dataset is identified in Table 1.
- Descriptions of classes in the NCCAG Wetland Dataset is shown in Table 2.
- A summary of relationships between combined fields and assumed actions is presented in Table 4.
- Siskiyou County LU/LC classes are presented in Table 3.

Table 1: Field Used to Create a Combined Representation of Mapped Potential GDE Coverage.

Dataset	Field Used
NCCAG Vegetation	Vegetation
NCCAG Wetland	ORIGINAL_C
DWR Siskiyou County	LABEL

Table 2: NCCAG Wetland Dataset Field Descriptions.

Class	Classification Description
PEM1C	Palustrine, Emergent, Persistent, Seasonally Flooded
PSSC	Palustrine, Scrub-Shrub, Seasonally Flooded

Table 2: NCCAG Wetland Dataset Field Descriptions. *(continued)*

Class	Classification Description
R5UBF	Riverine, Unknown Perennial, Unconsolidated Bottom, Semipermanently Flooded
PFOC	Palustrine, Forested, Seasonally Flooded
PUSC	Palustrine, Unconsolidated Shore, Seasonally Flooded
R2UBH	Riverine, Lower Perennial, Unconsolidated Bottom, Permanently Flooded
R3UBH	Riverine, Upper Perennial, Unconsolidated Bottom, Permanently Flooded
PEM1F	Palustrine, Emergent, Persistent, Semipermanently Flooded
45800	Seep or Spring

Table 3: Siskiyou County Land Use and Land Cover Field Descriptions.

Land Use/Land Cover Class	Description
G	Grain and Hay Crops
G1	Barley
G2	Wheat
G3	Oats
G3-H	Oats - harvested crop
G6	Miscellaneous grain and hay
G6-H	Miscellaneous grain and hay - harvested crop
G6-X	Miscellaneous grain and hay - partially irrigated
G-T	Grain and Hay Crops - tilled
I1	Idle but cropped within the past three years
I1-T	Idle but cropped within the past three years - tilled
I2	New land being prepared for crop production
NB	Barren and wasteland
NR4	Riparian vegetation - seasonal duck marsh
NR4-X	Riparian vegetation - seasonal duck marsh - partially irrigated
NR5	Riparian vegetation - permanent duck marsh
NV	Native vegetation
NW1	Water surface - river or stream (natural fresh water channels)

Table 3: Siskiyou County Land Use and Land Cover Field Descriptions. *(continued)*

Land Use/Land Cover Class	Description
NW2	Water surface - water channel for delivering water for irrigation and urban use
NW3	Water surface - water channel for removing on-farm drainage water
NW4	Water surface - freshwater lake, reservoir, or pond
P	Pasture
P1	Pasture - alfalfa & alfalfa mixtures
P3	Mixed pasture
P3-X	Mixed pasture - partially irrigated
P4	Native pasture
P4-X	Native pasture - partially irrigated
P6	Pasture - miscellaneous grasses
S1	Semiagricultural & incidental to agriculture - farmsteads (with farm residence)
S5	Semiagricultural & incidental to agriculture - farmsteads (with no farm residence)
S6	Semiagricultural & incidental to agriculture - miscellaneous semi-ag
T10	Onions and garlic
T12	Potatoes
T18	Miscellanous truck crops
T20	Strawberries
UC	Commercial
UC1	Offices, retailers, etc.
UC4	Recreation vehicle parking and camp sites
UC5	Commercial institutions
UC6	Schools
UC7	Municipal auditoriums, theaters, churches, buildings and stands
UI	Industrial
UI1	Manufacturing, assembling, and general processing
UI14	Waste accumulation sites
UI2	Extractive industries
UI3	Storage and distribution
UI6	Saw mills
UL1	Law area - irrigated
UR	Residential
UR1	Single family dwellings with lot sizes greater than 1 acre up to 5 acres
UV	Vacant

Table 3: Siskiyou County Land Use and Land Cover Field Descriptions. *(continued)*

Land Use/Land Cover Class	Description
UV1	Vacant unpaved areas
UV3	Railroad right of way
UV4	Paved areas
UV6	Airport runways

Table 4: Master Vegetation Lookup Summary.

VEGETATION	ORIGINAL_C	LABEL	join_field	Possible_Action
	45800	NV	_45800_NV	Retain_Natural
	PEM1C	S5	_PEM1C_S5	Retain_Check
	PEM1C	NW2	_PEM1C_NW2	Retain_Check
	PEM1C	NW4	_PEM1C_NW4	Retain_Check
	PEM1C	NR4	_PEM1C_NR4	Retain_Natural
	PEM1C	P3	_PEM1C_P3	Retain_Check
	PEM1C	NV	_PEM1C_NV	Retain_Natural
	PEM1C	P4-X	_PEM1C_P4-X	Retain_Natural
	PEM1C	S1	_PEM1C_S1	Retain_Check
	PEM1C	P3-X	_PEM1C_P3-X	Retain_Check
	PEM1C	NR5	_PEM1C_NR5	Retain_Natural
	PEM1C	UR	_PEM1C_UR	Remove Ag.
	PEM1C	P1	_PEM1C_P1	Retain_Check
	PEM1C	P4	_PEM1C_P4	Retain_Natural
	PEM1C	UV1	_PEM1C_UV1	Retain_Check
	PEM1C	G6	_PEM1C_G6	Remove Ag.
	PEM1C	G	_PEM1C_G	Remove Ag.
	PEM1C	I1	_PEM1C_I1	Retain_Check
	PEM1C	UV4	_PEM1C_UV4	Remove Ag.
	PEM1C	P	_PEM1C_P	Retain_Check
	PEM1F	NV	_PEM1F_NV	Retain_Natural
	PFOC	NV	_PFOC_NV	Retain_Natural
	PFOC	P4-X	_PFOC_P4-X	Retain_Natural
	PSSC	NW2	_PSSC_NW2	Retain_Check
	PSSC	NV	_PSSC_NV	Retain_Natural
	PSSC	NW4	_PSSC_NW4	Retain_Check
	PSSC	P4-X	_PSSC_P4-X	Retain_Natural
	PSSC	UV1	_PSSC_UV1	Retain_Check
	PSSC	UV4	_PSSC_UV4	Remove Ag.
	PUSC	NV	_PUSC_NV	Retain_Natural
	R2UBH	NR4	_R2UBH_NR4	Retain_Natural

Table 4: Master Vegetation Lookup Summary. *(continued)*

VEGETATION	ORIGINAL_C	LABEL	join_field	Possible_Action
	R2UBH	NW2	_R2UBH_NW2	Retain_Check
	R2UBH	NV	_R2UBH_NV	Retain_Natural
	R3UBH	NV	_R3UBH_NV	Retain_Natural
	R3UBH	NW2	_R3UBH_NW2	Retain_Check
	R3UBH	UV4	_R3UBH_UV4	Remove Ag.
	R5UBF	NW2	_R5UBF_NW2	Retain_Check
	R5UBF	NV	_R5UBF_NV	Retain_Natural
	R5UBF	NR4	_R5UBF_NR4	Retain_Natural
	R5UBF	NW4	_R5UBF_NW4	Retain_Check
	R5UBF	P4-X	_R5UBF_P4-X	Retain_Natural
	R5UBF	UV1	_R5UBF_UV1	Retain_Check
	R5UBF	P4	_R5UBF_P4	Retain_Natural
	R5UBF	I1	_R5UBF_I1	Retain_Check
	R5UBF	UV4	_R5UBF_UV4	Remove Ag.
Wet Meadows		NV	Wet Meadows_ _NV	Retain_Natural
Wet Meadows		NR4	Wet Meadows_ _NR4	Retain_Natural
Wet Meadows		NW2	Wet Meadows_ _NW2	Retain_Check
Wet Meadows		P4-X	Wet Meadows_ _P4-X	Retain_Natural
Wet Meadows		NW4	Wet Meadows_ _NW4	Retain_Check
Wet Meadows		P3-X	Wet Meadows_ _P3-X	Retain_Check
Wet Meadows		UR	Wet Meadows_ _UR	Remove Ag.
Wet Meadows		UV4	Wet Meadows_ _UV4	Remove Ag.
Wet Meadows		G6	Wet Meadows_ _G6	Remove Ag.
Wet Meadows		UV1	Wet Meadows_ _UV1	Retain_Check
Wet Meadows	PEM1C	NW2	Wet Meadows_PEM1C_NW2	Retain_Check
Wet Meadows	PEM1C	NR4	Wet Meadows_PEM1C_NR4	Retain_Natural
Wet Meadows	PEM1C	P4-X	Wet Meadows_PEM1C_P4-X	Retain_Natural

Table 4: Master Vegetation Lookup Summary. *(continued)*

VEGETATION	ORIGINAL_C	LABEL	join_field	Possible_Action
Wet Meadows	PEM1C	UR	Wet Meadows_PEM1C_UR	Remove Ag.
Wet Meadows	PEM1C	UV4	Wet Meadows_PEM1C_UV4	Remove Ag.
Wet Meadows	PEM1C	NV	Wet Meadows_PEM1C_NV	Retain_Natural
Wet Meadows	PSSC	P4-X	Wet Meadows_PSSC_P4-X	Retain_Natural
Wet Meadows	R5UBF	NR4	Wet Meadows_R5UBF_NR4	Retain_Natural
Wet Meadows	R5UBF	P4-X	Wet Meadows_R5UBF_P4-X	Retain_Natural
Willow (Shrub)		NW2	Willow (Shrub)_ _NW2	Retain_Check
Willow (Shrub)		NV	Willow (Shrub)_ _NV	Retain_Natural
Willow (Shrub)		NR4	Willow (Shrub)_ _NR4	Retain_Natural
Willow (Shrub)		UV4	Willow (Shrub)_ _UV4	Remove Ag.
Willow (Shrub)		G6	Willow (Shrub)_ _G6	Remove Ag.
Willow (Shrub)		UV1	Willow (Shrub)_ _UV1	Retain_Check
Willow (Shrub)		I2	Willow (Shrub)_ _I2	Retain_Check
Willow (Shrub)	PEM1C	NW2	Willow (Shrub)_PEM1C_NW2	Retain_Check
Willow (Shrub)	PEM1C	G6	Willow (Shrub)_PEM1C_G6	Remove Ag.
Willow (Shrub)	PEM1C	NR4	Willow (Shrub)_PEM1C_NR4	Retain_Natural
Willow (Shrub)	R3UBH	NV	Willow (Shrub)_R3UBH_NV	Retain_Natural
		NR4	_ _NR4	Retain_Natural
		NR4-X	_ _NR4-X	Retain_Natural
		NR5	_ _NR5	Retain_Natural
		NW1	_ _NW1	Retain_Natural
		NW2	_ _NW2	Retain_Check

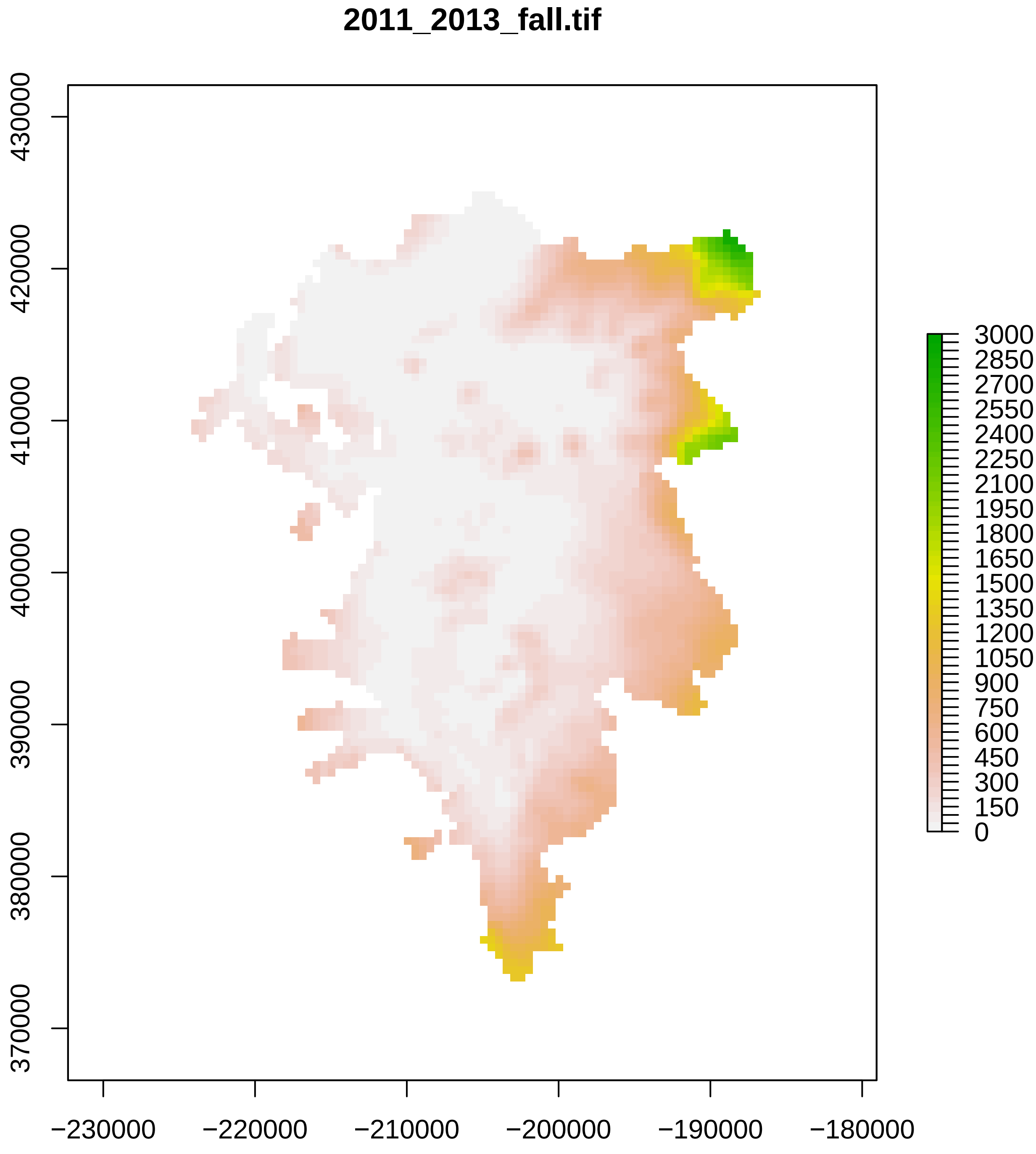


Figure 1: Depth to water, in feet below ground surface.

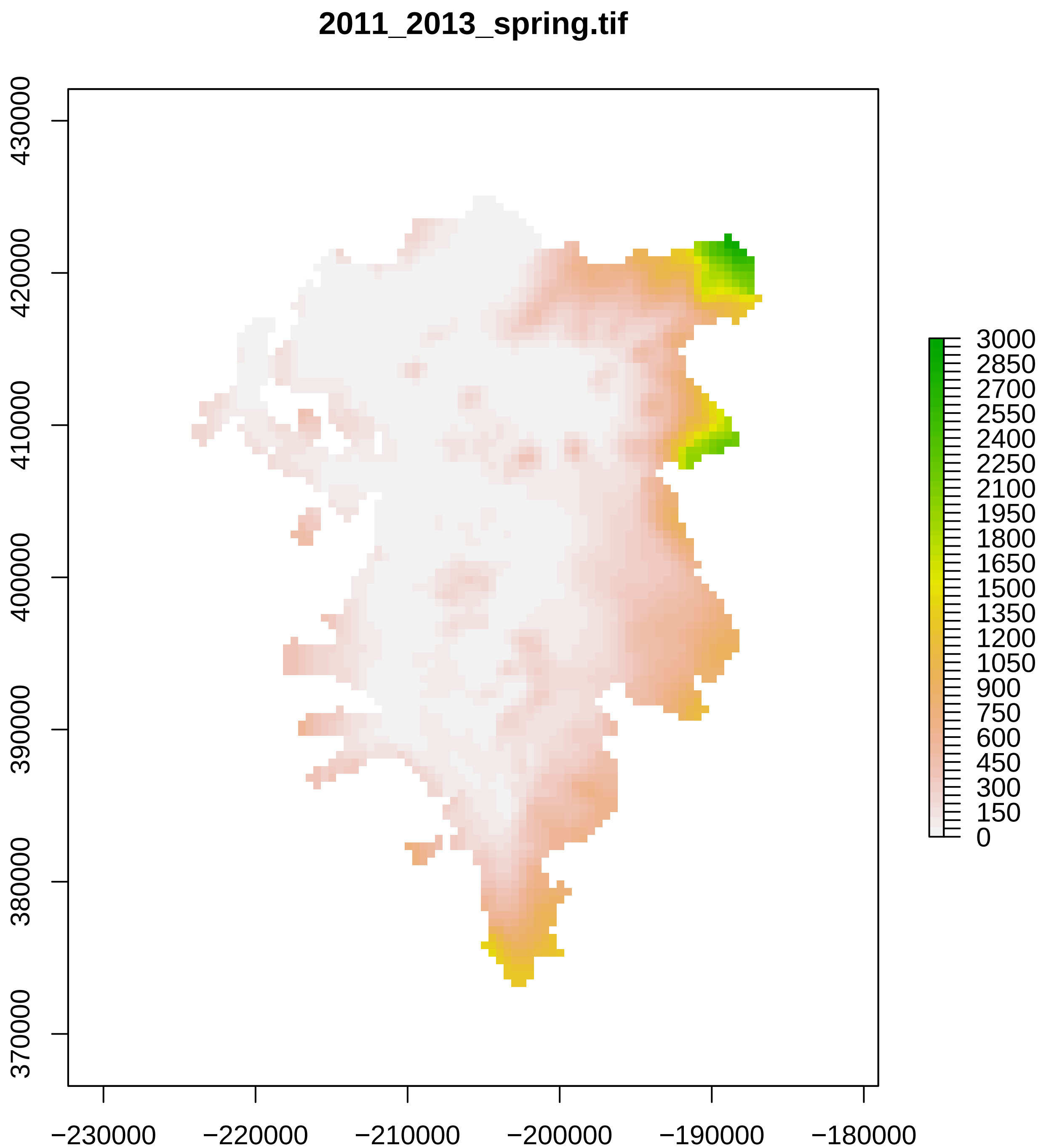


Figure 2: Depth to water, in feet below ground surface.

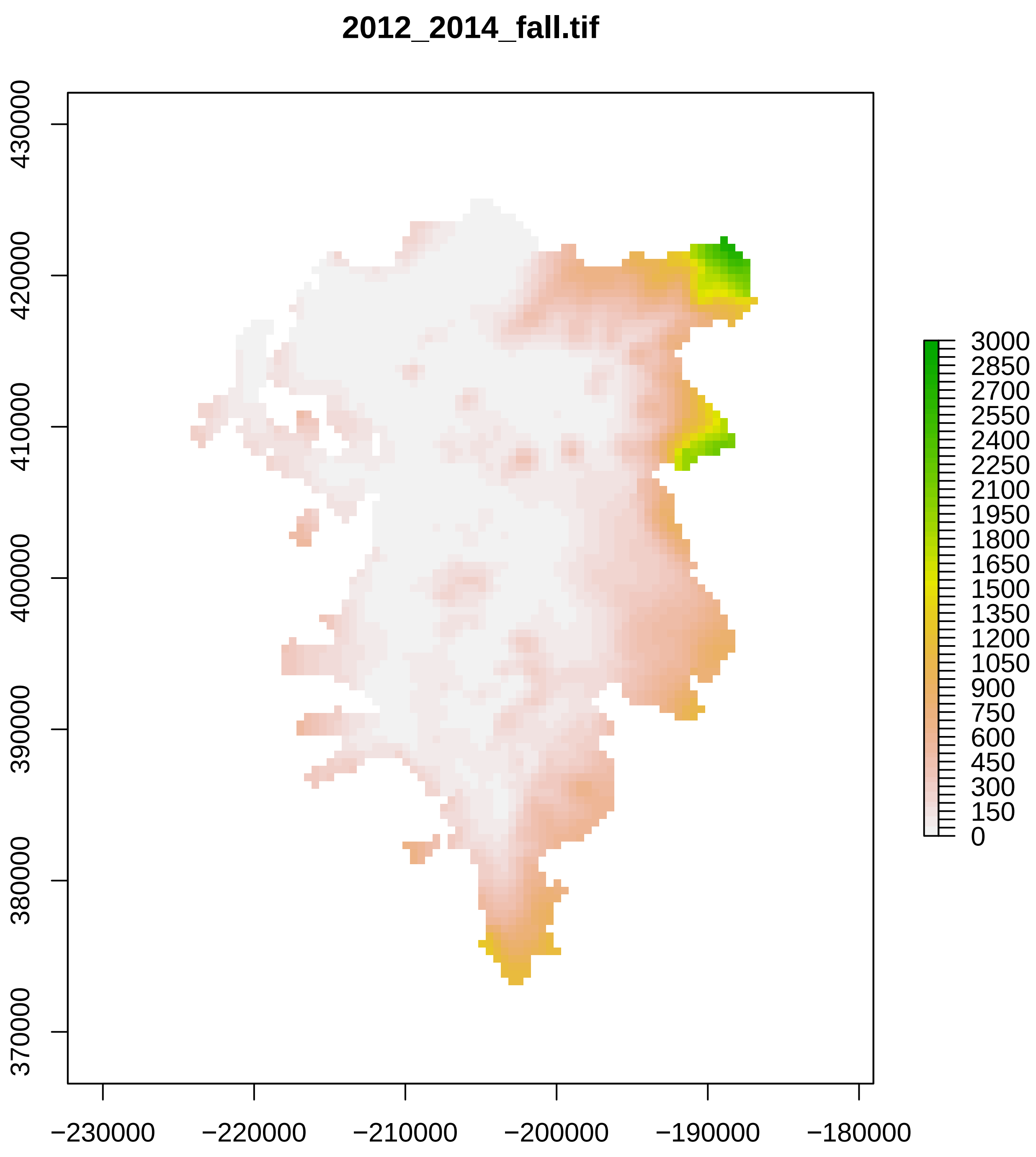


Figure 3: Depth to water, in feet below ground surface.

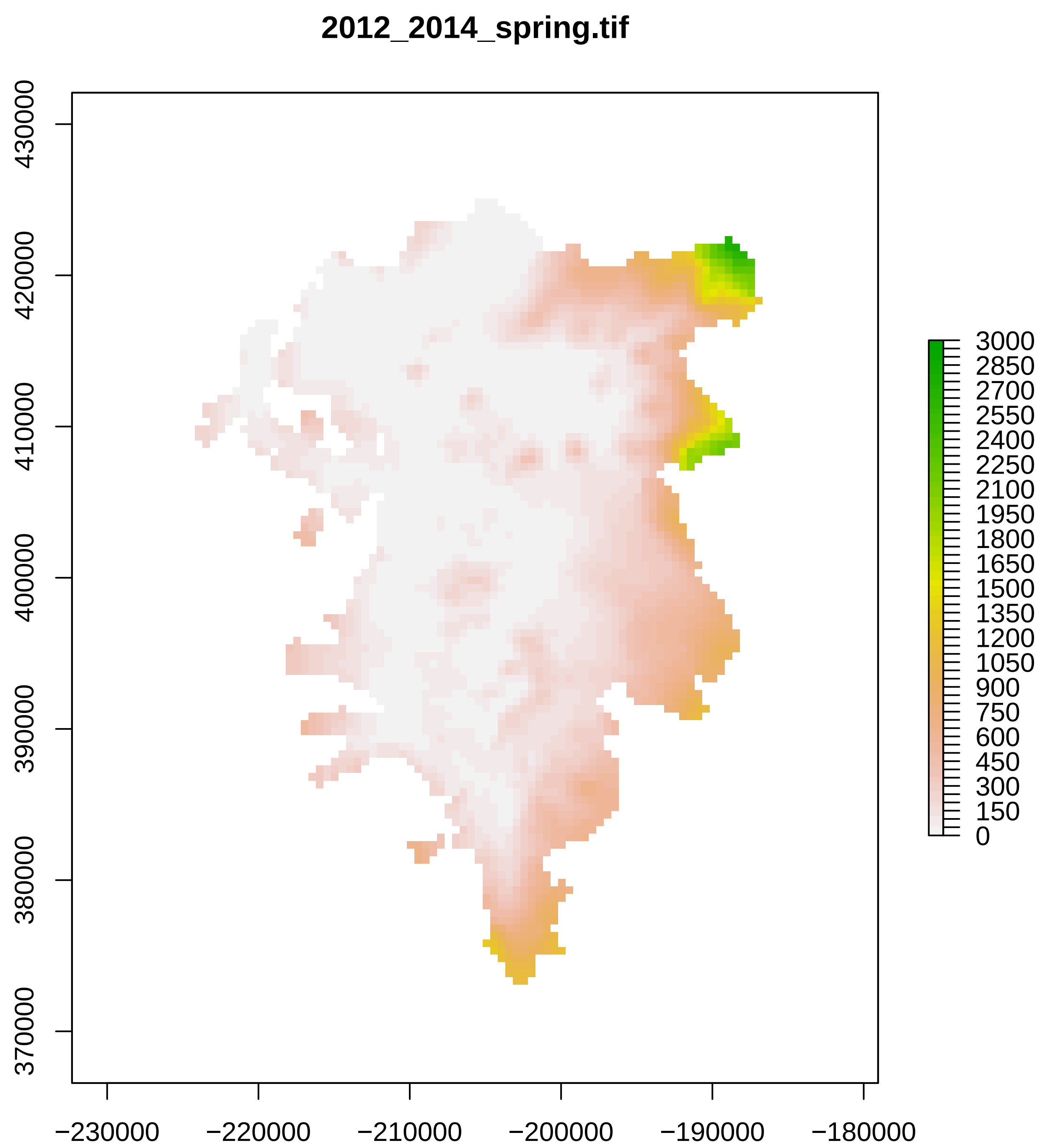


Figure 4: Depth to water, in feet below ground surface.

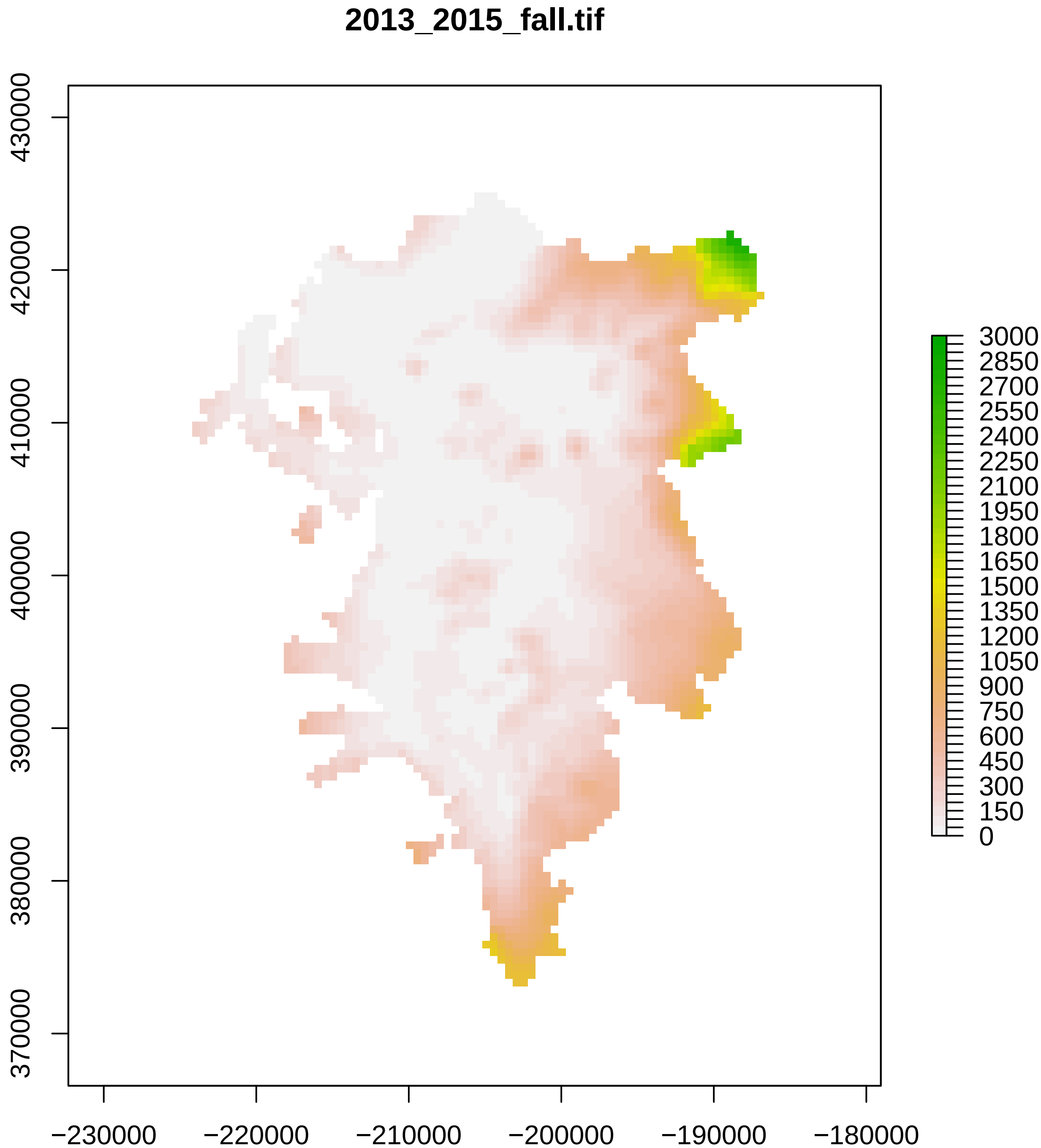


Figure 5: Depth to water, in feet below ground surface.

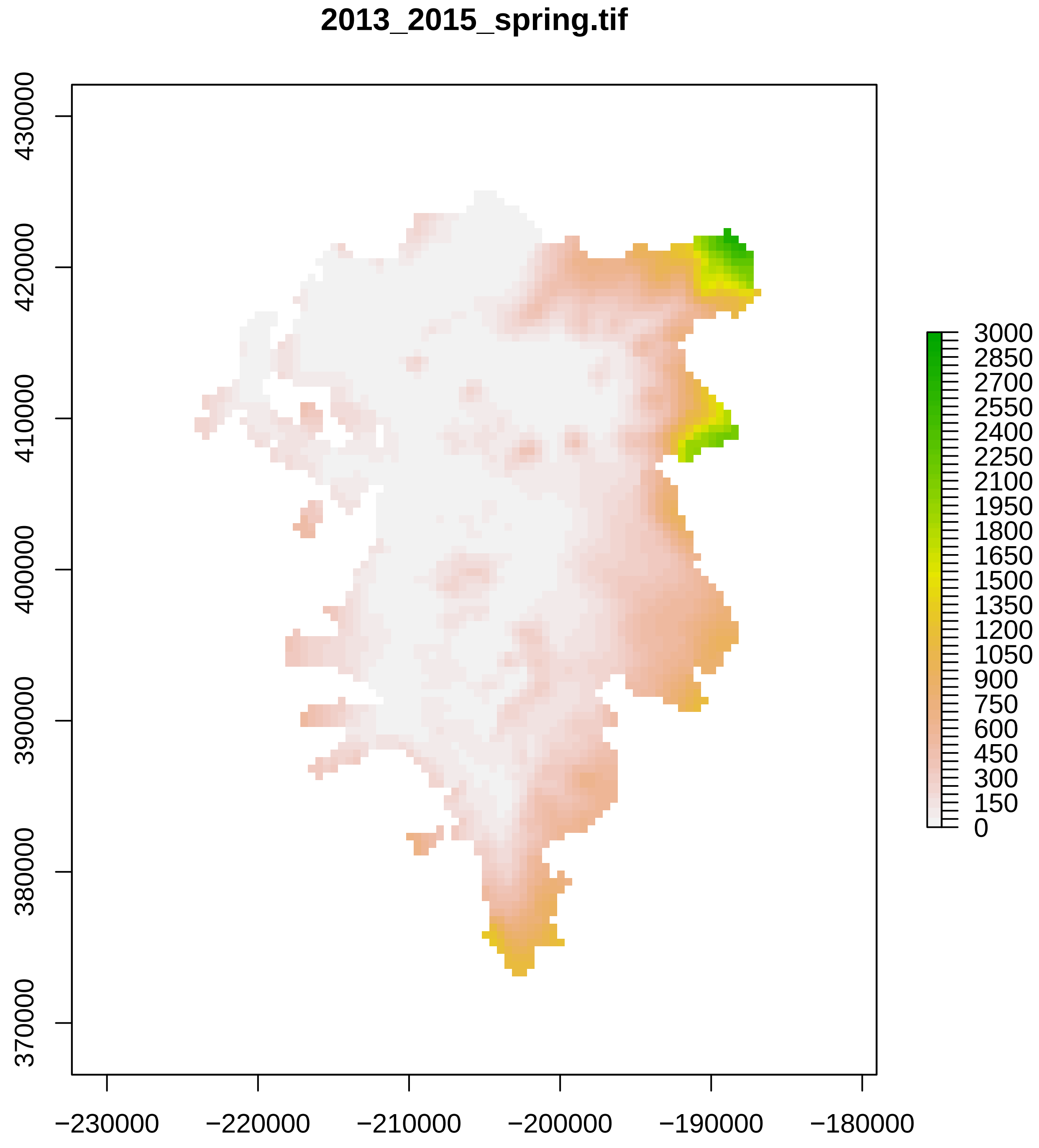


Figure 6: Depth to water, in feet below ground surface.

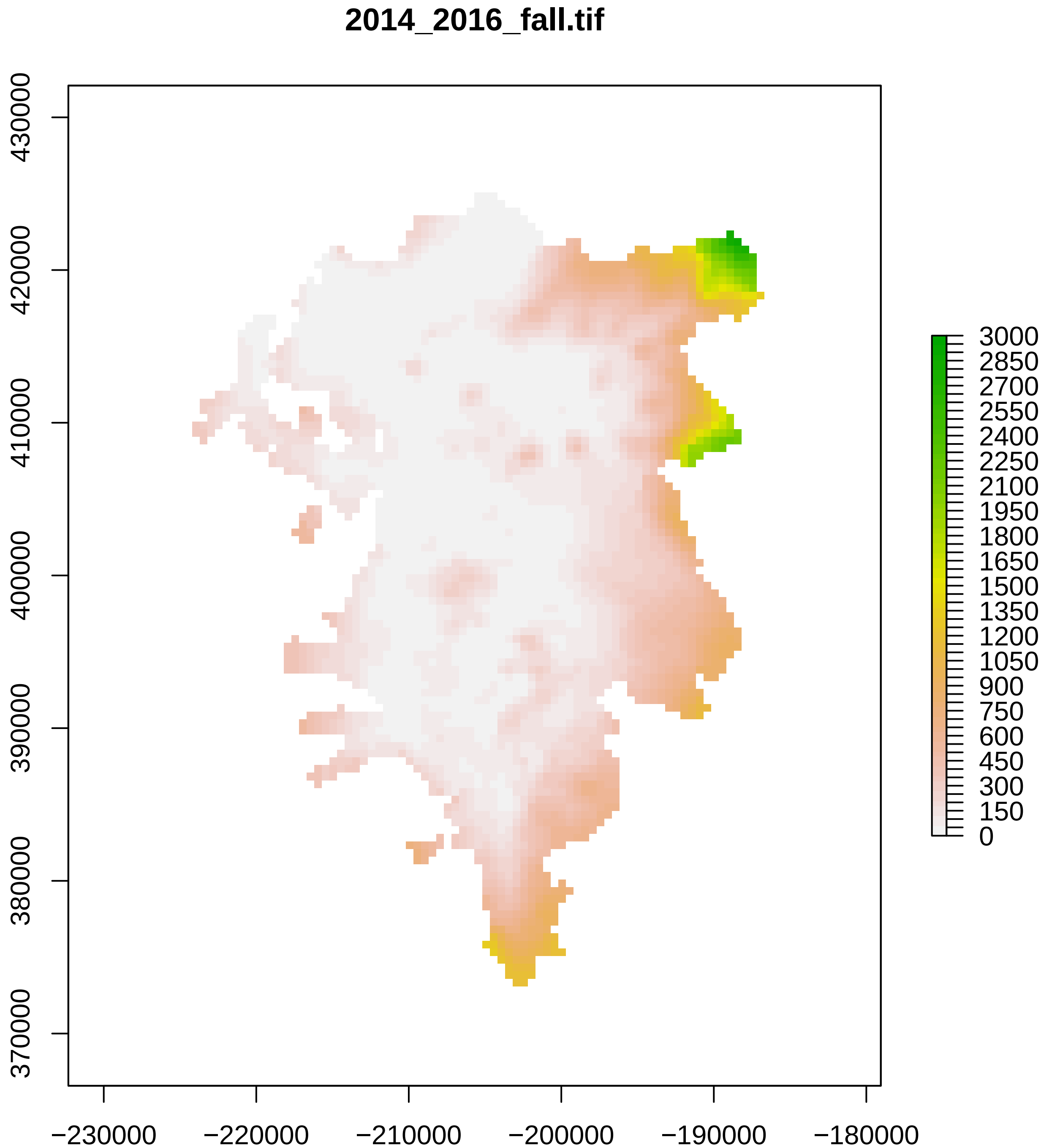


Figure 7: Depth to water, in feet below ground surface.

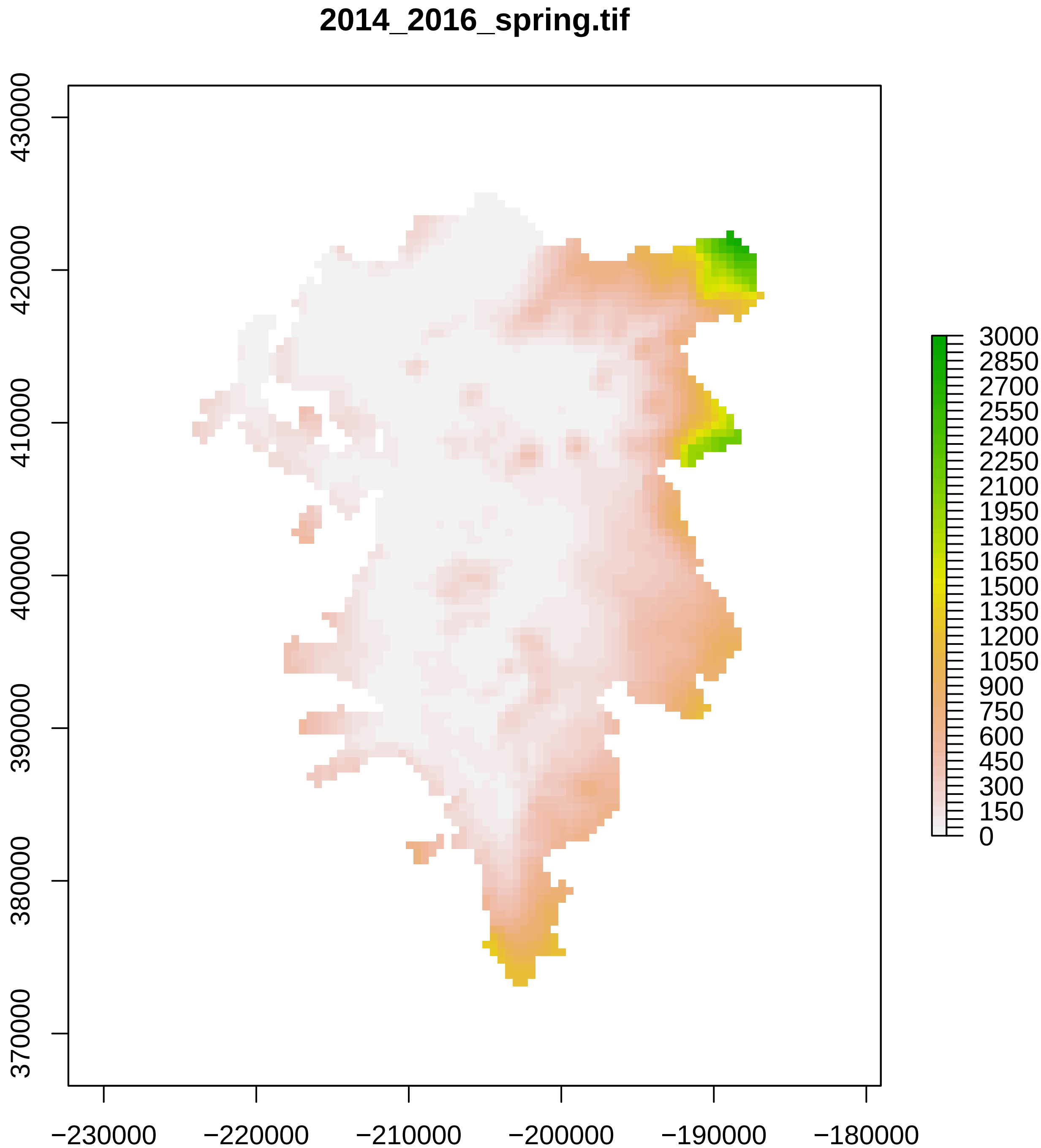


Figure 8: Depth to water, in feet below ground surface.

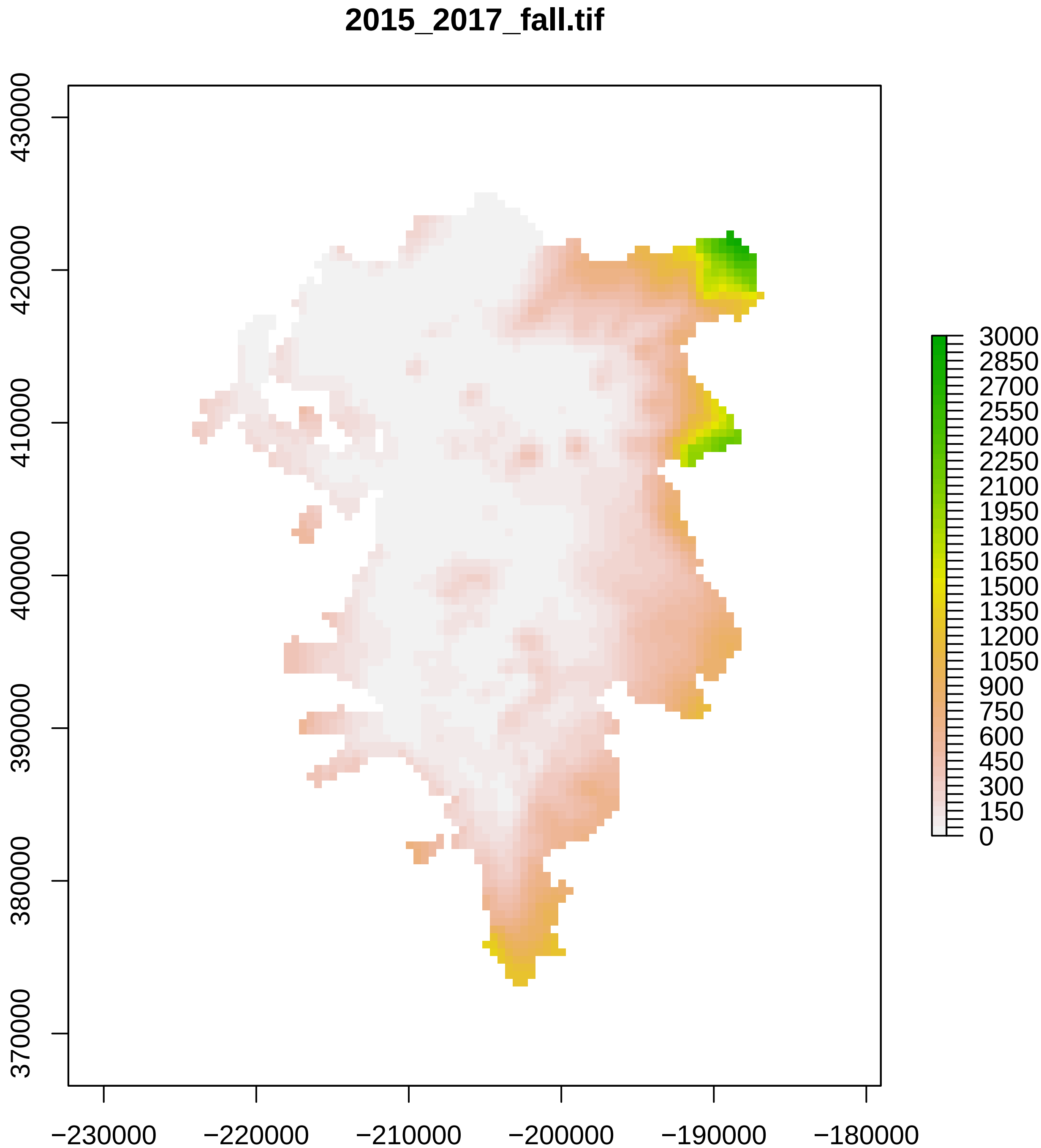


Figure 9: Depth to water, in feet below ground surface.

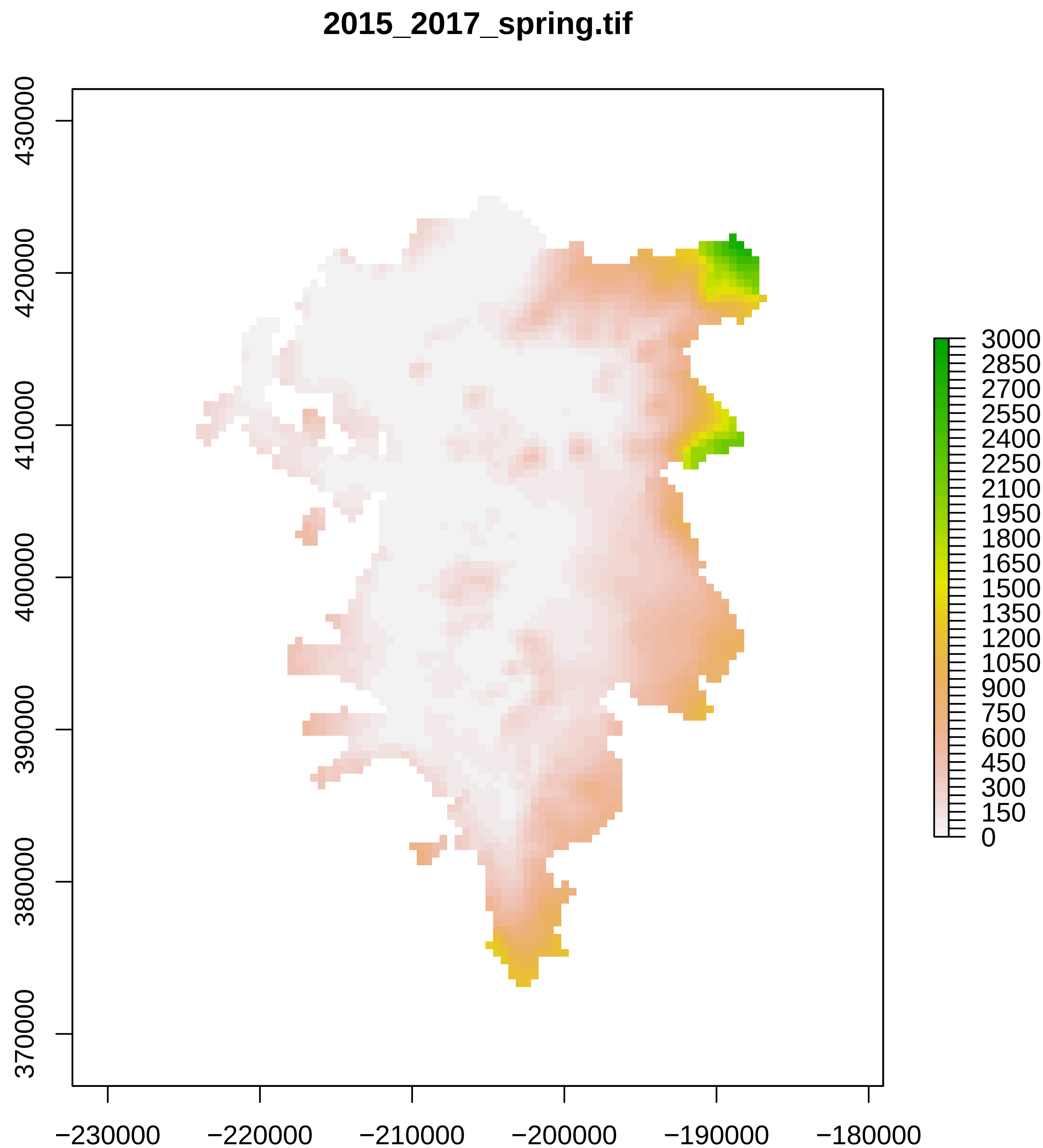


Figure 10: Depth to water, in feet below ground surface.

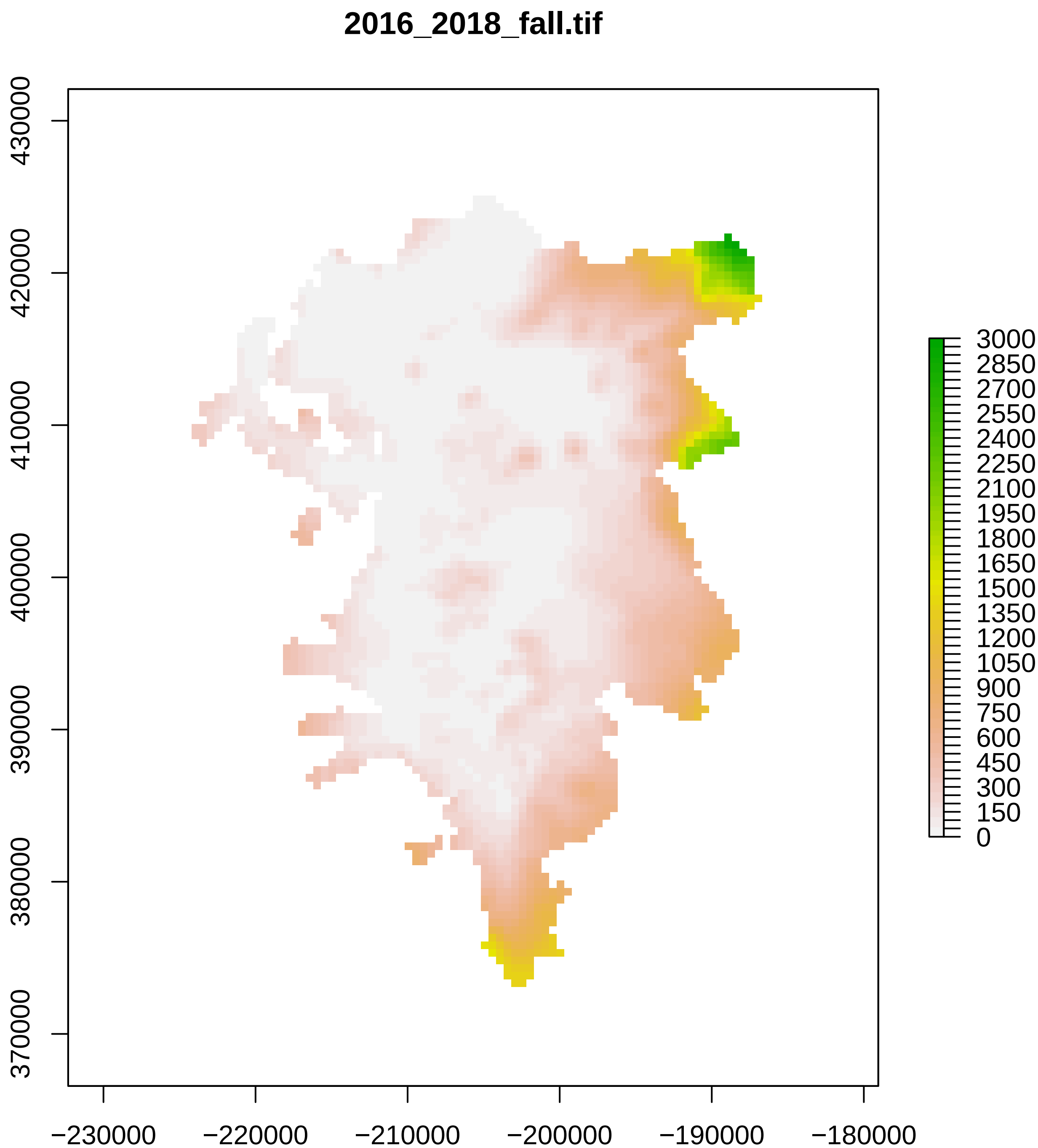


Figure 11: Depth to water, in feet below ground surface.

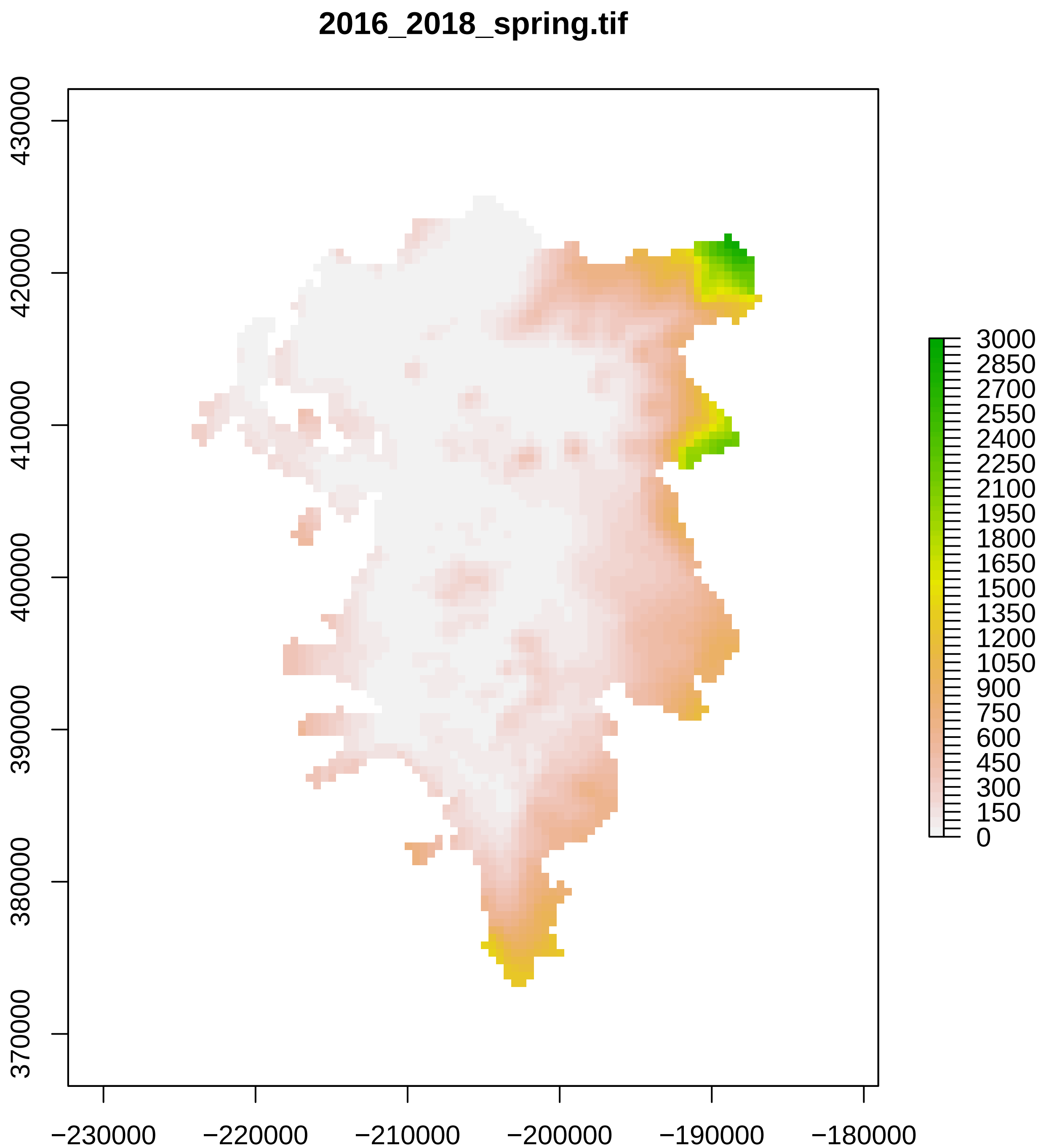


Figure 12: Depth to water, in feet below ground surface.

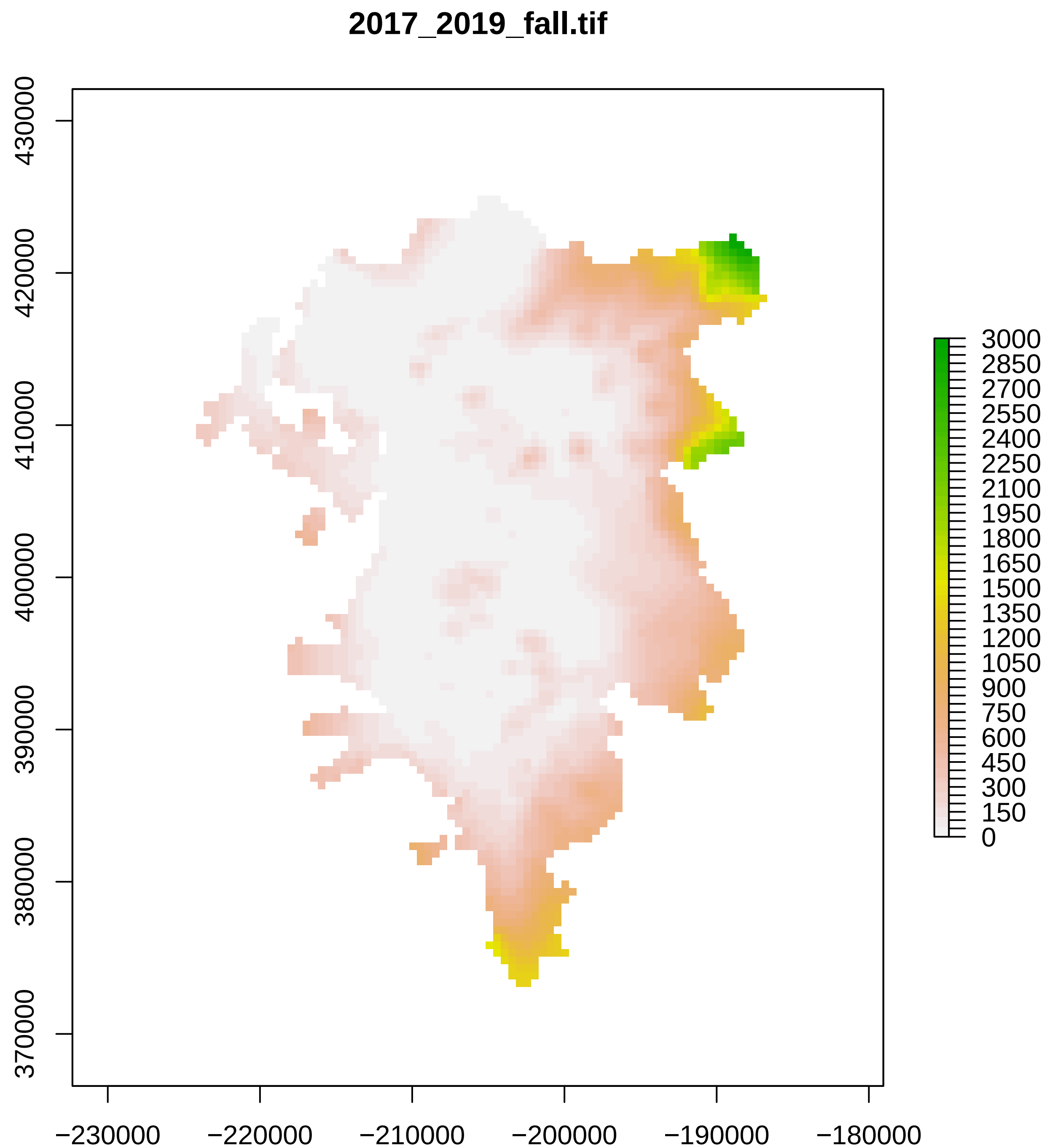


Figure 13: Depth to water, in feet below ground surface.

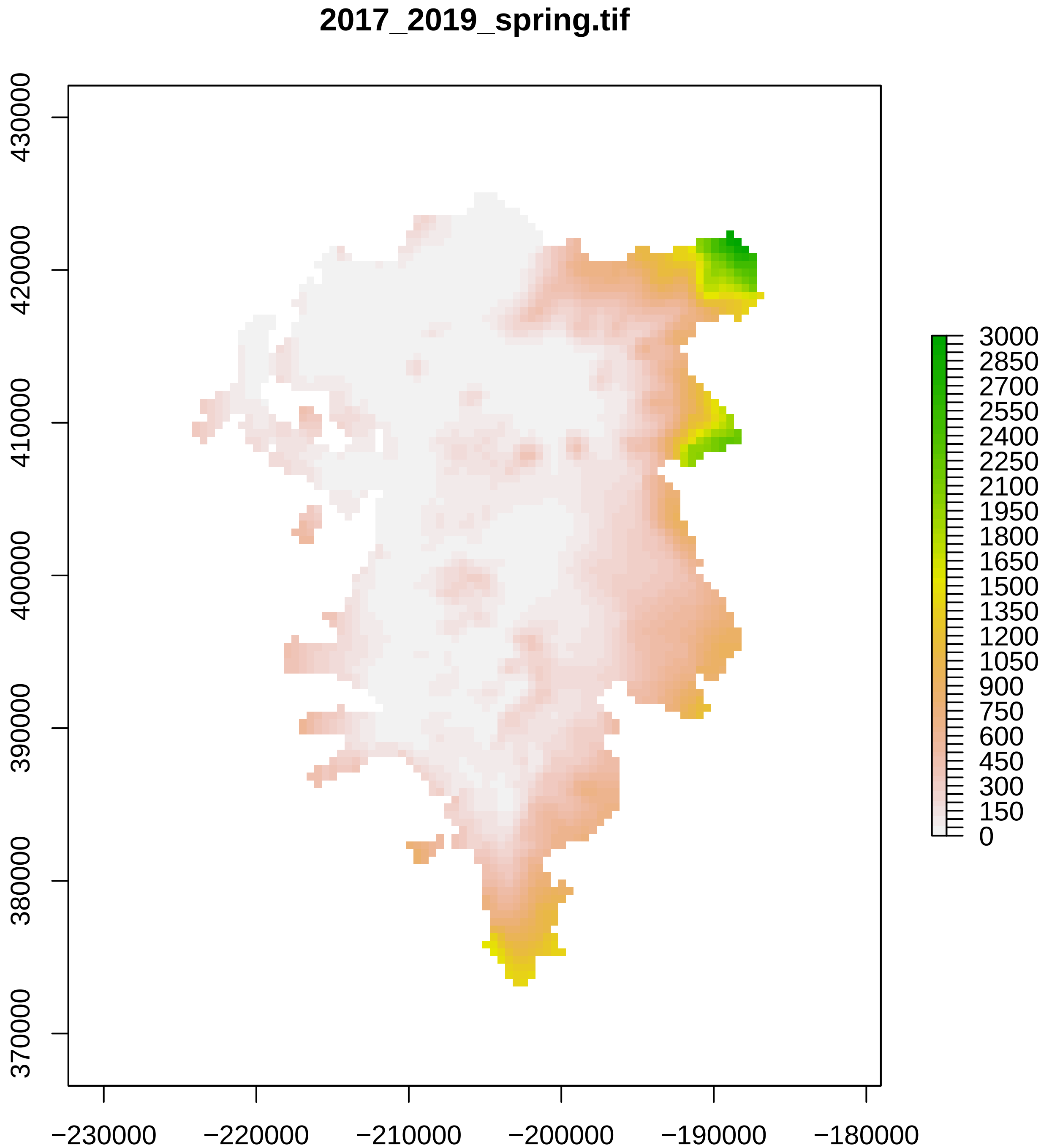


Figure 14: Depth to water, in feet below ground surface.

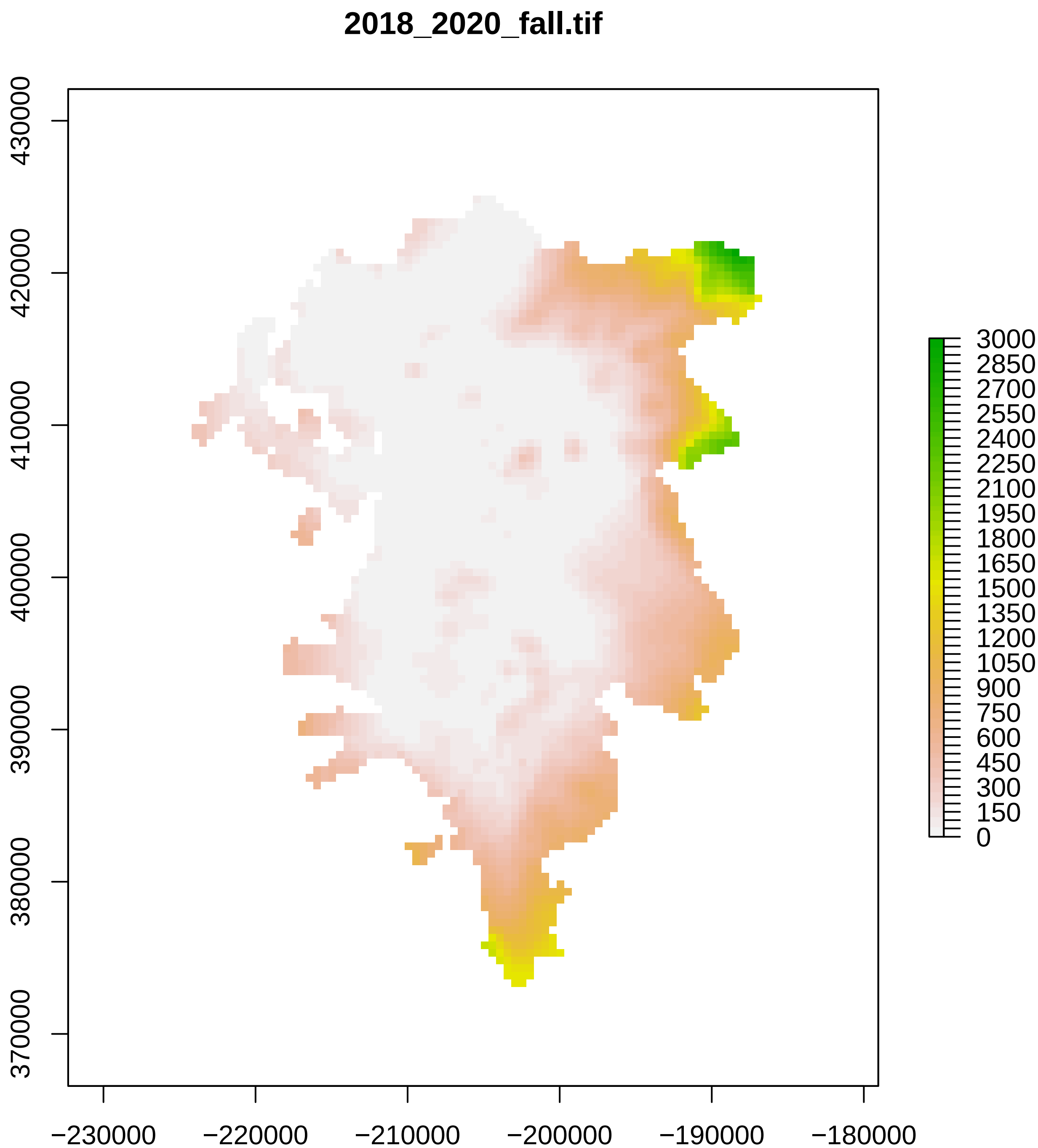


Figure 15: Depth to water, in feet below ground surface.

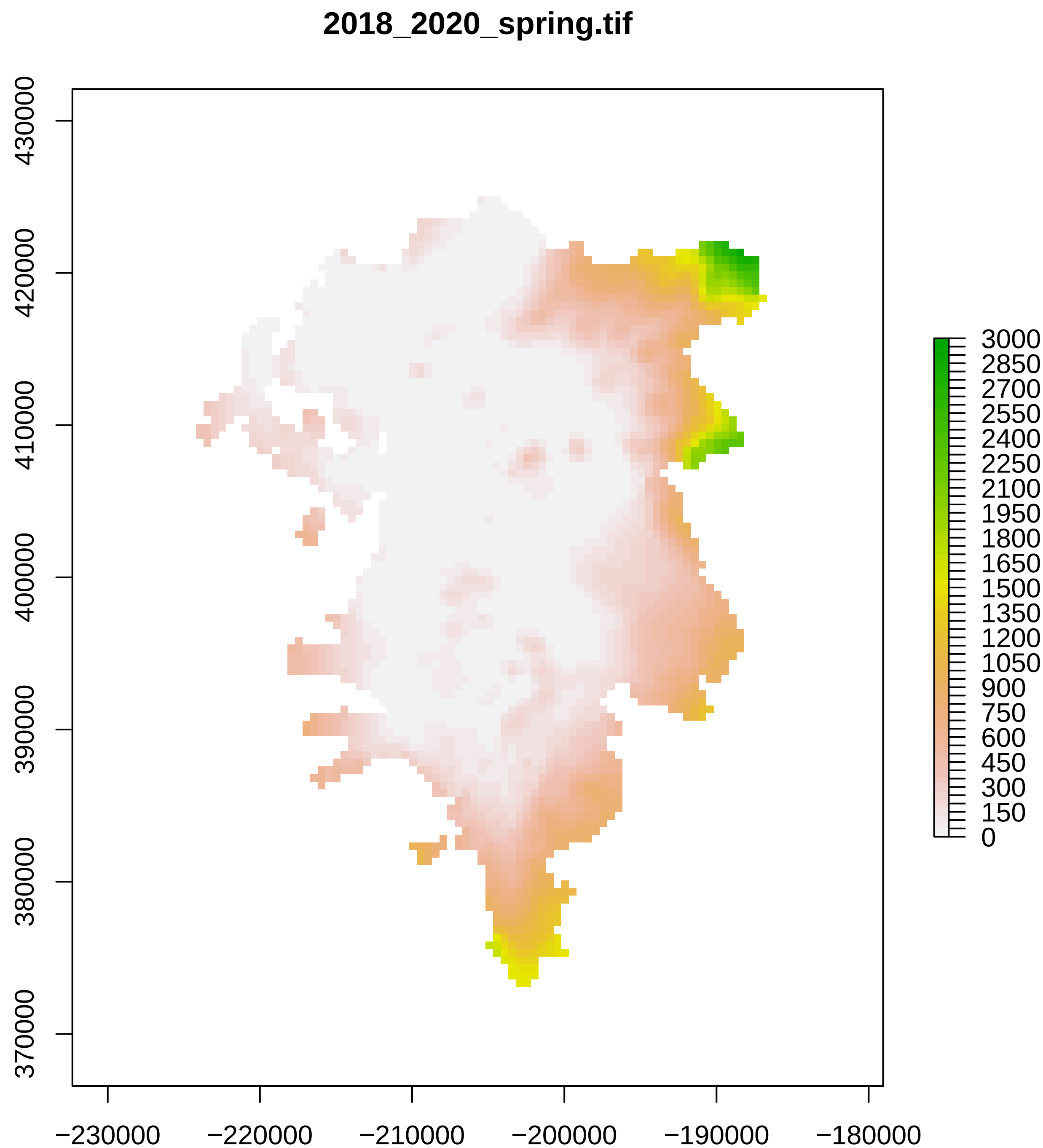


Figure 16: Depth to water, in feet below ground surface.

Technical Memorandum

Date:	11/22/2021
To:	Larry Walker Associates
From:	Davids Engineering, Inc.
Topic:	**Monitoring Results of Shallow Piezometer Transect Study from May 2020 through November 2021 in the Shasta Valley, Siskiyou County, CA**

Executive Summary

Shallow piezometers were installed in three transects across the Shasta Valley in late April 2020: two transects along different reaches of the Shasta River and one along the Little Shasta River. One of the transects on the Shasta River was upstream of the confluence with the Little Shasta River (SRU), and the other was downstream of the confluence with the Little Shasta River (SRD). The transect along the Little Shasta River (LSR) is within the alluvial portion of the Little Shasta Valley. These piezometers, along with the stilling wells installed in the rivers, were instrumented to continuously monitor water surface elevations and temperatures in and adjacent to surface water features. The goal of monitoring shallow groundwater elevations and temperatures adjacent to surface water features was to identify the direction and gradient of groundwater flow near stream-aquifer boundaries, manifesting as either accretions to or depletions from surface water features. The monitoring results from May 2020 through November 2021 indicated that the Shasta River was primarily gaining in both transect locations during this period, while the Little Shasta River was losing at its transect location during this period. Current funding will allow the study to continue through December 2021, but it is recommended that monitoring continue beyond this date and potentially be expanded to include new areas of the Shasta Valley. Multiple years of data and additional sites will provide useful insights into how changing weather conditions, river stage and flow, water use and water management practices, and water availability (e.g., wet years vs. dry years) influence stream-aquifer interactions in the Shasta Valley.

1 Introduction

Davids Engineering (DE) was subcontracted under Larry Walker Associates (LWA) in an effort for the Shasta Valley Resource Conservation District (SVRCD) to better understand hydrological processes in the Shasta Valley[1]. DE focused primarily on surface water monitoring and focused studies for additional data collection to support Groundwater Sustainability Plan (GSP) development for the Shasta Valley (Valley) groundwater basin under the Sustainable Groundwater Management Act (SGMA). Funding for this project was provided in full or in part from the Water Quality, Supply, and Infrastructure Improvement Act of 2014 and through an agreement with the State Department of Water Resources (DWR). One of the studies by DE included the installation and continuous monitoring of piezometer transects along surface water features in the Shasta Valley to evaluate stream-aquifer interactions over space and time. Despite the diversity of geologic formations in the Shasta Valley and while there are instances of dry wells nearby to productive wells in many parts of the Valley, the valley wide groundwater system

[1] Although this study is currently ongoing, all work in this document is presented in the past tense.

appears to be hydrologically continuous across the extent of the Valley (Mack, 1960; DWR, 2015). Monitoring shallow groundwater elevations and temperatures adjacent to surface water features can help identify the direction and gradient of groundwater flow near stream-aquifer boundaries, manifesting as either accretions to or depletions from surface water features.

Shallow piezometers were installed in three transects across the Shasta Valley: two transects along different reaches of the Shasta River and one along the Little Shasta River (Figure 1). One of the transects on the Shasta River was upstream of the confluence with the Little Shasta River (SRU), and the other was downstream of the confluence with the Little Shasta River (SRD). The transect along the Little Shasta River (LSR) was within the alluvial portion of the Little Shasta Valley. All three transects were located within the boundary of the Shasta Valley groundwater basin. Each transect consisted of five measurement sites: four shallow piezometers and a temporary stilling well in the river; two piezometers were located on each riverbank, with one nearer and one further from the river, and the stilling well in the center of the transect. The five measurement sites were established in a line roughly perpendicular to the flow of the river and were instrumented with pressure transducers to measure temperature and water surface elevation. The piezometer boreholes were drilled, and the sites were instrumented in late April 2020. This TM presents monitoring results for the period from May 2020 through November 2021 along with a discussion of results and recommendations.

2 Methods

2.1 Conceptual Study Design

The installation of piezometer transects to evaluate stream-aquifer interactions was previously identified as a prioritized monitoring activity that would be beneficial for water management in the Shasta Valley (SVRCD, 2013). The measurement of shallow groundwater levels in the aquifer adjacent to a stream, through the installation and instrumentation of piezometers and measured relative to surface water levels in the stream, allows for the determination of hydraulic gradient and whether the stream is gaining or losing at the location of the piezometer transect (Figure 2). If water levels in the aquifer adjacent to the stream are at a higher elevation than stream water levels, it indicates that the stream is gaining at the location of the piezometer transect. Conversely, if water levels in the aquifer adjacent to the stream are at a lower elevation than stream water levels, it indicates that the stream is losing at the location of the piezometer transect. Continuous monitoring of these water levels over time allows for evaluation of seasonal changes or long-term trends.

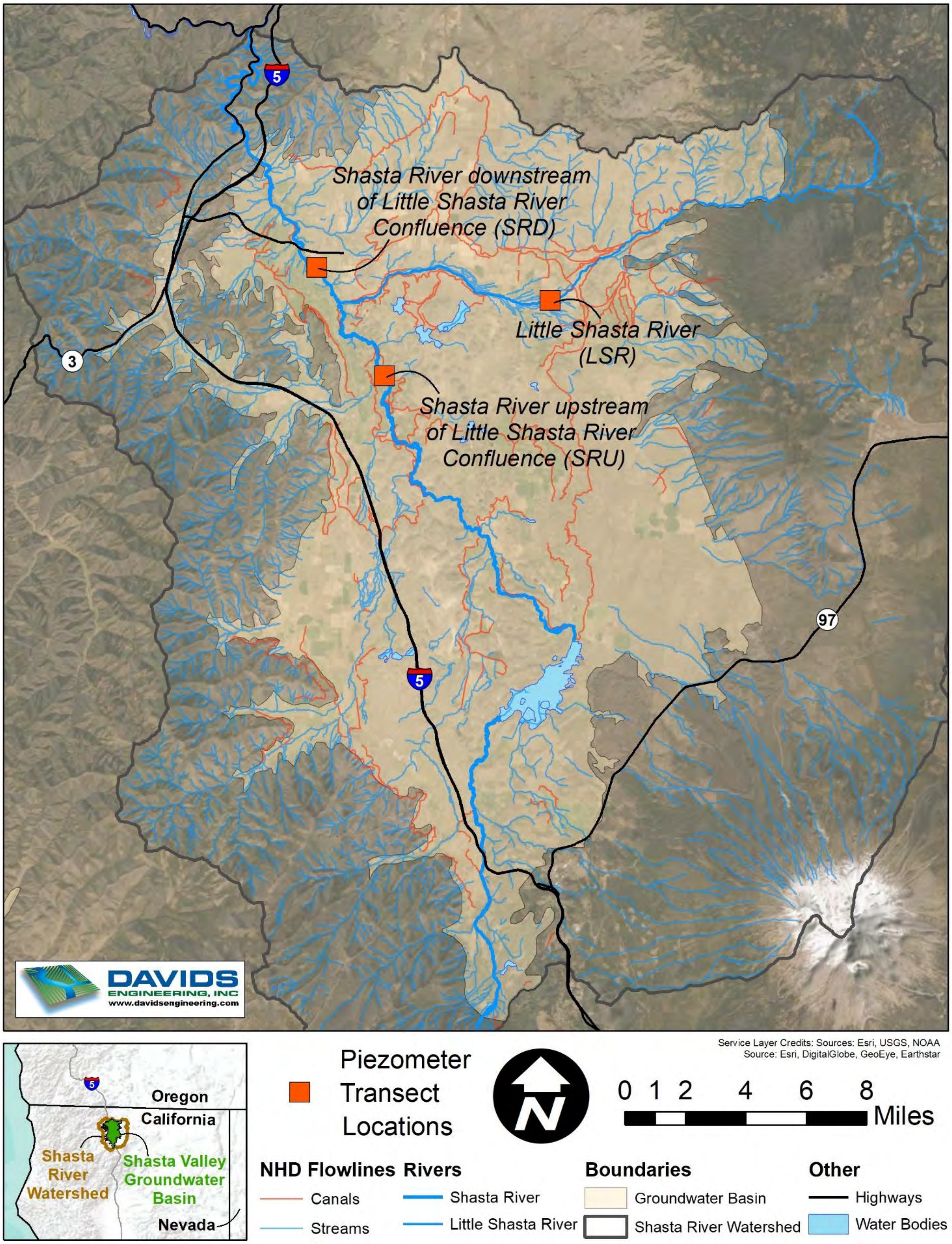


Figure 1. Approximate Location of Piezometer Transects within Shasta Valley.

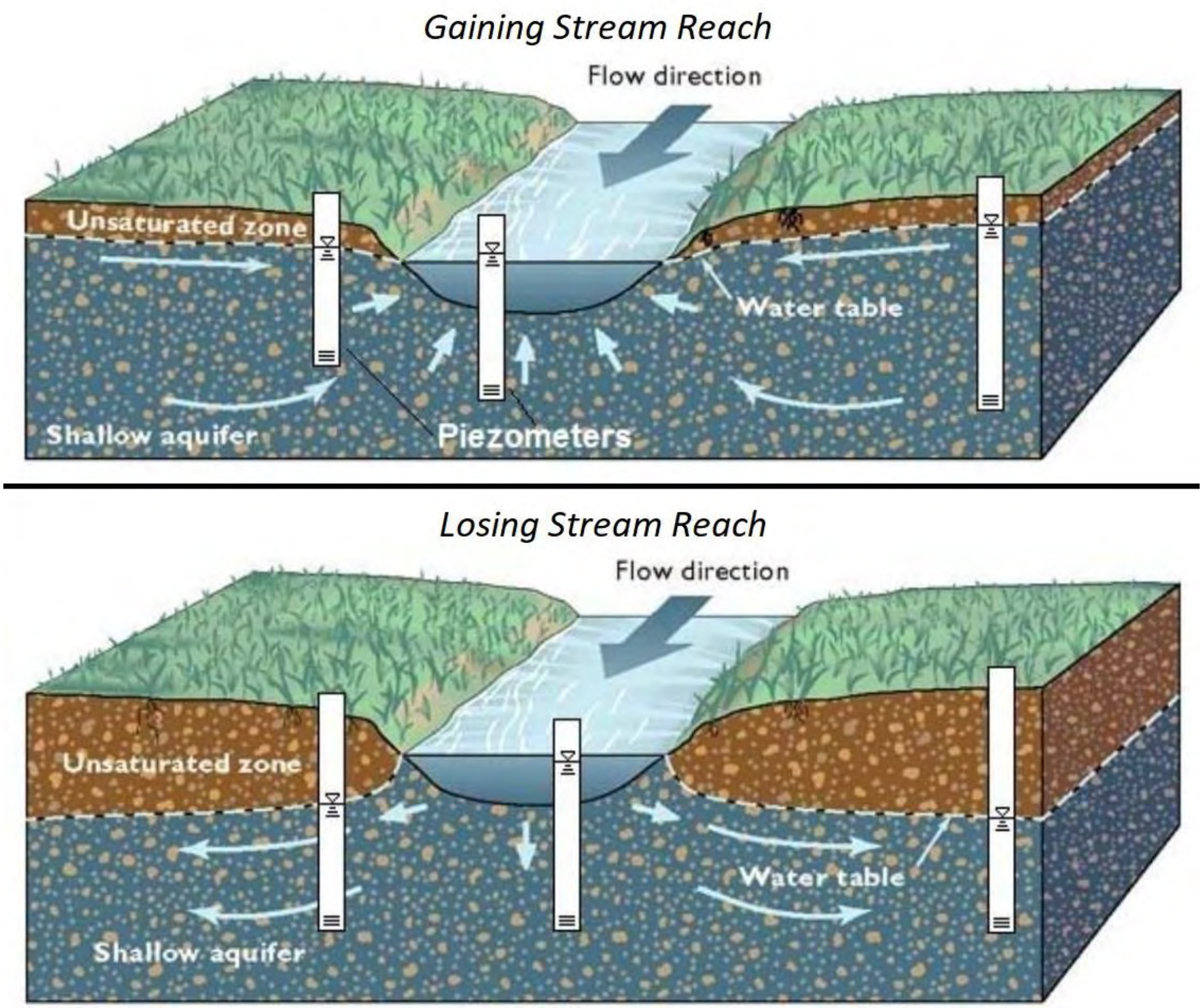


Figure 2. Conceptual Diagram of Piezometers in Gaining and Losing Stream Reaches (Modified from Winter et al., 1999).

Also, temperatures can be measured and monitored in the aquifer and stream to provide additional insight into stream-aquifer interactions (Constantz, 2008). Surface water is exposed to four heat-transfer mechanisms, most notably radiative heat input from the sun and convective heat transfer as water flows downstream and mixes. Although the influence of these is highly dependent on location, riparian conditions, and weather conditions, these typically lead to both higher temperatures in surface water than groundwater in summer months and more fluctuation in surface water temperature than groundwater temperature as the conditions influencing heat-transfer change. In a losing reach, the temperature in the shallow aquifer adjacent to the stream will more closely mirror surface water temperatures in the stream as surface water flows from the stream into the adjacent groundwater system. Conversely, in a gaining reach, the temperature in the shallow aquifer adjacent to the stream will remain more constant, not following surface water temperature trends as closely, as groundwater flows from the aquifer into the stream.

Both water levels, or water surface elevations, and temperature were contrasted and compared between shallow groundwater in piezometers and surface water features to evaluate stream-aquifer interactions at the three transects.

2.2 Study Design, Initiation, and Implementation

2.2.1 Piezometer Construction, Equipment Installation, Site Commissioning and Maintenance

The piezometer transect locations were determined through coordination between DE, LWA, and SVRCD staff and local stakeholders and landowners. A total of 12 piezometer boreholes were drilled, along with installation of screens, standpipes, filter pack, surface seals, and well caps, by Lawrence & Associates during April 2020. Each transect consists of four shallow piezometers and a temporary stilling well installed in the river in the center of the transect to measure surface water elevations. All piezometers and stilling wells were instrumented with Onset pressure transducers (Part # U20-001-04), and each transect has an additional pressure transducer installed in the open air to measure and account for atmospheric pressure, for a total of 18 pressure transducers. Measurement of water levels with these pressure transducers has a typical error of 0.01 ft and a maximum error of 0.02 ft (Onset, 2020). Pressure transducers were configured to log data on a 15-minute timestep. Following the installation of instrumentation, elevation surveys of each transect site were completed to determine water surface elevations relative to other locations in the transect[2]. These data were compiled and reviewed to determine site characteristics at the outset of the study at the beginning of May 2020.

After study initiation, SVRCD staff completed monthly site visits for data download and site maintenance activities. Data were organized, compiled, and processed using Onset's Hoboware Pro software, Python scripting, and a custom-built Microsoft Access database. The dataset presented in this TM from the start of the study through early November 2021 also underwent additional review and QA/QC measures.

2.2.2 Site Naming Convention

The naming convention used for this study was comprised of a Transect ID used to designate the transect, followed by a Pressure Transducer Location Code used to designate the location within the transect. The Transect ID used to distinguish each of the three transect locations is shown below in Table 1.

[2] During the elevation survey, elevation at the top of each piezometer was surveyed relative to a local benchmark and the depth-to-water in each piezometer standpipe was measured using a well sounder to determine relative water surface elevations for each piezometer transect.

A Leica Disto 20x automatic optical level and 16 ft aluminum telescoping Philadelphia rod were used by a two-man team to survey the well cap elevations and water surface elevation in the river at each transect; the elevation of the north rim of the well cap at the Left Bank Near (LBN) location was used as the local benchmark. The distance from the well cap to the top of the piezometer standpipe was measured using a tape measure, and the depth-to-water from the top of the piezometer standpipe was measured using a Global Water WL500-100M water level sounder to determine water surface elevations relative to other locations in the transect. Latitude and longitude for each transect location were recorded using a GPS-enabled device, and the water surface elevation above mean sea level at the local benchmark was determined by entering the coordinates into Google Earth Pro.

Table 1. Transect Name and ID.

Transect ID	Transect Name
SRU	Shasta River upstream of the Little Shasta River confluence
SRD	Shasta River downstream of the Little Shasta River confluence
LSR	Little Shasta River in Little Shasta Valley

Each transect includes six pressure transducers: one measuring atmospheric pressure[3], one installed in a temporary stilling well in the river to measure surface water levels, and four installed in piezometers (two on each bank of the river) to measure shallow groundwater levels. The codes shown below in Table 2 are descriptors to uniquely identify each pressure transducer at each transect site. The codes below (individually or combined) are added to the right of the Transect ID to create a SiteID to uniquely identify each pressure transducer of the 18 total installed as part of the study (Table 3).

Table 2. Pressure Transducer Location Codes.

Code	Description
LB	Left bank, looking D/S
RB	Right bank, looking D/S
N	Near, Closer to stream/river
F	Far, Further to stream/river
SWE	Surface Water Elevation
ATC	Atmospheric Compensation

[3] The pressure transducer measuring atmospheric pressure was installed in the open air just beneath the well cap in the Left Bank Near (LBN) piezometer standpipe.

Table 3. SiteID, Site Description, Associated Atmospheric Compensation Site (i.e. ATC SiteID).

SiteID	Site Description	ATC SiteID
SRU-LBN	Shasta River upstream of the Little Shasta River confluence, Left Bank near River	SRU-ATC
SRU-LBF	Shasta River upstream of the Little Shasta River confluence, Left Bank further from River	SRU-ATC
SRU-RBN	Shasta River upstream of the Little Shasta River confluence, Right Bank near River	SRU-ATC
SRU-RBF	Shasta River upstream of the Little Shasta River confluence, Right Bank further from River	SRU-ATC
SRU-SWE	Shasta River upstream of the Little Shasta River confluence, Surface Water Elevation	SRU-ATC
SRU-ATC	Shasta River upstream of the Little Shasta River confluence, Atmospheric Pressure Compensation	SRU-ATC
SRD-LBN	Shasta River downstream of the Little Shasta River confluence, Left Bank near River	SRD-ATC
SRD-LBF	Shasta River downstream of the Little Shasta River confluence, Left Bank further from River	SRD-ATC
SRD-RBN	Shasta River downstream of the Little Shasta River confluence, Right Bank near River	SRD-ATC
SRD-RBF	Shasta River downstream of the Little Shasta River confluence, Right Bank further from River	SRD-ATC
SRD-SWE	Shasta River downstream of the Little Shasta River confluence, Surface Water Elevation	SRD-ATC
SRD-ATC	Shasta River downstream of the Little Shasta River confluence, Atmospheric Pressure Compensation	SRD-ATC
LSR-LBN	Little Shasta River in Little Shasta Valley, Left Bank near River	LSR-ATC
LSR-LBF	Little Shasta River in Little Shasta Valley, Left Bank further from River	LSR-ATC
LSR-RBN	Little Shasta River in Little Shasta Valley, Right Bank near River	LSR-ATC
LSR-RBF	Little Shasta River in Little Shasta Valley, Right Bank further from River	LSR-ATC
LSR-SWE	Little Shasta River in Little Shasta Valley, Surface Water Elevation	LSR-ATC
LSR-ATC	Little Shasta River in Little Shasta Valley, Atmospheric Pressure Compensation	LSR-ATC

3 Results

This section presents the results of monitoring water surface elevations and temperature at each of the transect locations, along with some observations and a discussion of the results. Finally, a comparison of the results at the different transects is included. Attachment A includes a spreadsheet with daily average water surface elevations and temperatures for all 15 measurement sites.

3.1 Shasta River Upstream of Little Shasta River Confluence (SRU)

Figure 3 is a heatmap depicting the daily average values of water surface elevation and temperature for the five monitoring sites at the SRU transect. Figure 4 is a heatmap depicting the daily average difference between the water surface elevation and temperature for each of the shallow piezometers in reference to the surface water location (calculated as surface water subtracted from groundwater)[4]. Although the heatmaps depict transect location results directly alongside one another, the distances between piezometers varies. For this transect, the Right Bank Near (RBN) piezometer was located roughly 160 feet from the river edge and located within an inside bend of the river, and the Right Bank Far (RBF) piezometer was located roughly 520 feet from the river edge (e.g., roughly 360 feet further from the river than RBN location). The LBN piezometer was located roughly 140 feet from the river edge, and the LBF piezometer was located roughly 510 feet from the river edge. The Shasta River had continuous flow past the transect location throughout the study period from May 2020 through November 2021. The text below includes observations based on the study results seen in Figures 3 and 4.

The river stage remained relatively stable during the monitoring period, with total fluctuations in stage of typically less than two feet. River stage remained steady from May through September 2020, after which there was an increase in stage from late September 2020 through mid-November 2020. This increase coincides with the end of the irrigation season and cessation of upstream diversions and pumping and the beginning of the winter season with increased precipitation. The river stage remained steady from mid-November 2020 through April 2021, when it decreased to and remained at levels similar to the 2020 spring and summer. This decrease coincided the start of the 2021 irrigation season. The river stage in November 2021 was the highest during the entire monitoring period.

Groundwater elevations in the piezometers on both sides of the river tended to be higher than the surface water elevation, or stage, in the river, with elevations increasing with distance from the river. In the further piezometers on both sides of the river, there were sharp increases in water surface elevation periodically during the 2020 and 2021 irrigation seasons. At the RBF location, there was a similar sharp decrease shortly after the increase; at the LBF location, there was a decrease immediately after the increase peaked, but it tended to be a more gradual decrease than seen at the RBF location. At the nearer piezometers on both sides of the river, similar increase/decrease trends were seen with smaller changes in water surface elevation, although the connection is more obviously seen along the left bank. The temporal trends in water surface elevations for LBF and LBN were closely correlated (i.e., when one when up or down, the other did as well), while the correlation between RBF and RBN was less

[4] Roughly one month of data was lost due to equipment failure during February 2021 at the LBN site, and two months of data were lost due to equipment malfunction from August through October 2021 at all transect sites.

pronounced. The lands on either side of the river in this transect location were irrigated, and these periodic pulses of water observed in piezometers were likely reflective of deep percolation from irrigation events reaching the water table. Because the groundwater elevations are higher than the stream during these periods, recharge from applied irrigation water appears to be returning to the Shasta River. Additionally, there is the potential for surface and subsurface inflows along Julien Creek as it flows east towards its confluence with the Shasta River corridor to influence the higher groundwater elevations seen along the left bank in the vicinity of this transect location.

As expected, the surface water temperature in the Shasta River showed the greatest fluctuations with seasonal highs and lows that are more extreme than seen in the adjacent shallow groundwater system. Although fluctuating with weather conditions, sun exposure, and ambient air temperature, it generally increased to a seasonal peak around 70˚F in July 2020, and then decreased to a seasonal low around 45˚F in December 2020. The seasonal peak temperature in July 2021 was around 65˚F, noticeably cooler than July 2020. Groundwater temperatures were more stable, with seasonal lows of around 50˚F in May 2020 and 2021 and seasonal peaks of around 60˚F in October and November 2020 and 2021. The piezometers along the left bank of the river showed more minimal temperature fluctuations than those along the right bank of the river. The RBN temperature was noticeably different than other piezometer sites, with relatively higher temperatures. This may be due to its location on an inside bend of the Shasta River, where it may be more influenced by surface water conditions than the other piezometers. During the irrigation season, periodic increases in temperature are also observed, which may be indicative of relatively warmer irrigation water moving through the shallow groundwater system.

With the exception of the RBN piezometer in late July and early August in 2020 and sporadic intervals during the 2021 irrigation season, all piezometers showed higher groundwater elevations than surface water elevations during the study period. Groundwater temperatures also did not show strong responses or similarities to surface water temperatures. These results indicate that the Shasta River was gaining in the transect location over the study period.

Interestingly, changes in groundwater levels due to irrigation events on the left bank do not seem to correlate strongly with changes in groundwater temperatures as might be expected due to relatively warm irrigation-related deep percolation reaching the water table. This may be due to the integrated pressure and temperature sensors being installed at a depth that did not experience the thermal changes from deep percolation that the top of the water table may have experienced.

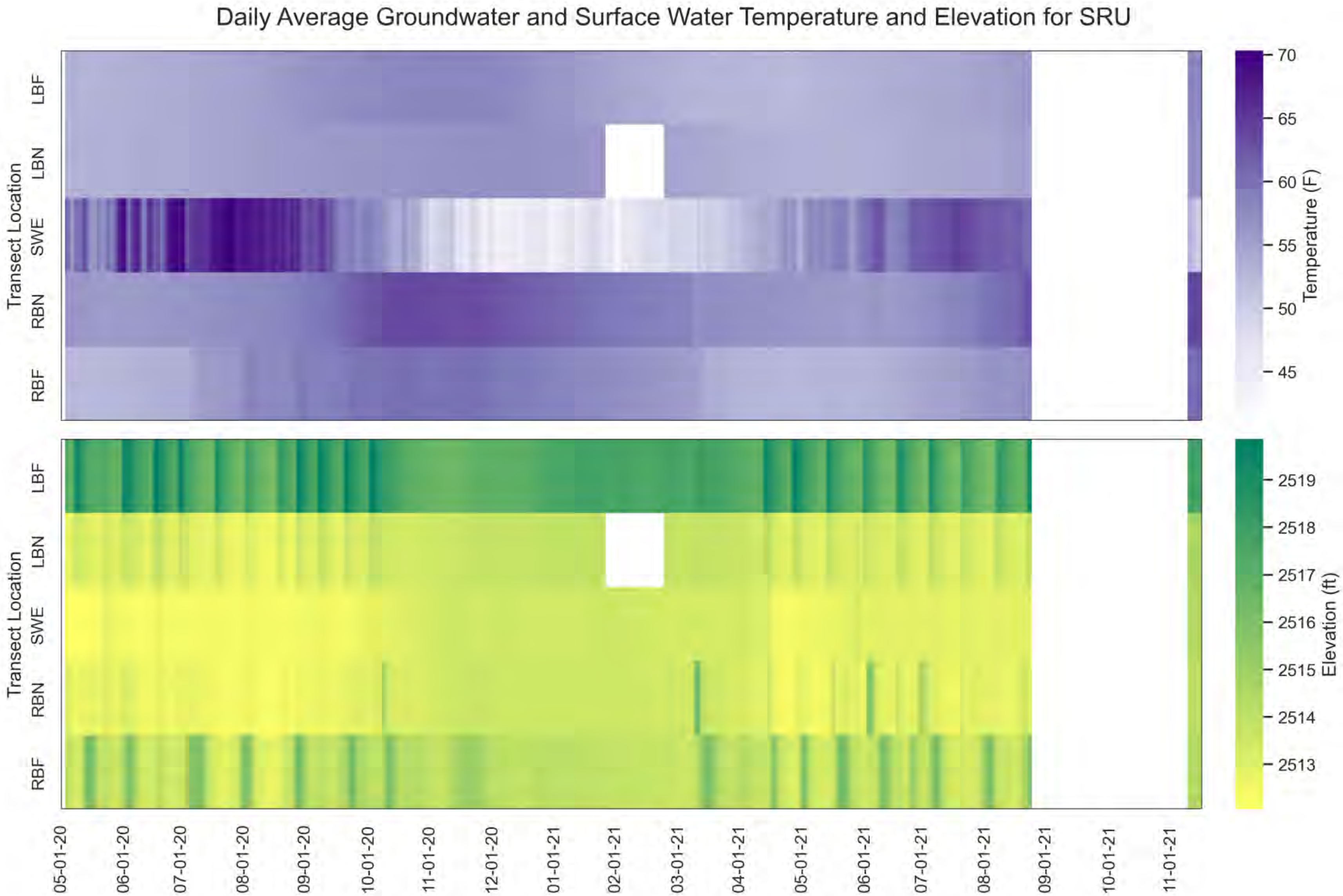


Figure 3. Daily average groundwater and surface water elevations and temperatures for the Shasta River Upstream (SRU) transect; monitoring locations are the left bank far (LBF), left bank near (LBN), surface water elevation (SWE), right bank near (RBN), and right bank far (RBF).

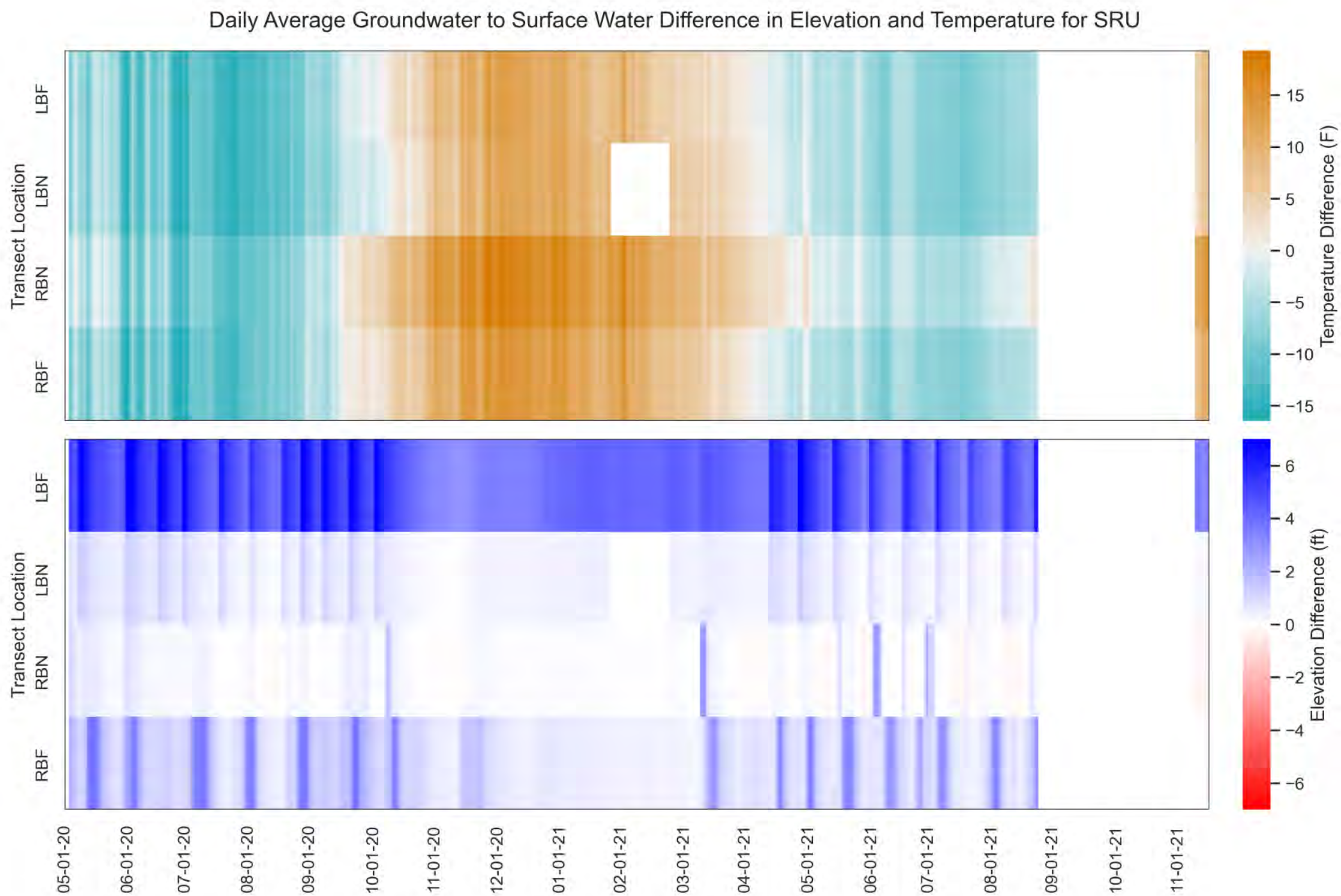


Figure 4. Daily average difference in groundwater and surface elevations and temperatures (Groundwater – Surface Water) for the Shasta River Upstream (SRU) piezometers installed at left bank far (LBF), left bank near (LBN), right bank near (RBN), and right bank far (RBF).

3.2 Shasta River Downstream of Little Shasta River Confluence (SRD)

Figure 5 is a heatmap depicting the daily average values of water surface elevation and temperature for the five monitoring sites at the SRD transect, and Figure 6 is a heatmap depicting the daily average difference between the water surface elevation and temperature for each of the shallow piezometers in reference to the surface water location (calculated as surface water subtracted from groundwater)[5]. Although the heatmaps depict transect location results directly alongside one another, the distances between piezometers varies. For this transect the Right Bank Near (RBN) piezometer was located roughly 170 feet from the river edge, and the Right Bank Far (RBF) piezometer was located roughly 360 feet from the river edge (e.g. roughly 190 feet further from the river than RBN location). The LBN piezometer was located roughly 70 feet from the river edge, and the LBF piezometer was located roughly 260 feet from the river edge. The Shasta River had continuous flow past the transect location throughout the study period from May 2020 through November 2021. The text below includes observations based on the study results seen in Figures 5 and 6.

The river stage remained relatively stable during the monitoring period, with total fluctuations in stage of less than two feet. Apart from fluctuations in late May 2020, river stage remained steady from May through mid-September 2020. The second half of September showed increasing stage, culminating in a roughly 6 inch increase from September 30th to October 1st. This final increase coincides with the end of the irrigation season and cessation of upstream diversions and pumping. The river stage remained relatively steady from October 2020 through April 2021, when it decreased to and remained at levels similar, but slightly lower, than to the spring and summer of 2020. This decrease coincided with the start of the 2021 irrigation season. The river stage in November 2021 was at a similar elevation as in November 2020.

Groundwater elevations in the piezometers on both sides of the river tended to be higher than the surface water elevation, or stage, in the river through most of the study period, with elevations increasing with distance from the river. At the LBF location, there were periodic sharp increases in water surface elevation followed by a more gradual decrease after the increase peaked during the 2020 and 2021 irrigation seasons. During the late summer in 2020 and 2021, the left bank also had periods with groundwater elevations similar to or slightly lower than surface water elevations. Groundwater levels along the right bank tended to be higher in elevation than along the left bank and had fewer and less extreme fluctuations both day-to-day and seasonally. Groundwater elevations increased on both sides of the river from late September through December 2020, similar to surface water elevation trends, and elevations in November 2021 were similar to those in November 2020 at all transect locations. At the nearer piezometers on both sides of the river, the fluctuations seen appeared to align with fluctuations at the further piezometers, indicating a strong hydrological connection. Although lands directly adjacent to the river and immediately surrounding the piezometers were not irrigated on either bank, there was irrigation of upgradient lands resulting in periodic tailwater or seepage inflows towards the river in the vicinity in this transect location; increases in groundwater levels observed in piezometers were likely reflective of irrigation events on these upgradient lands. Additionally, there is the potential for surface

[5] Two months of data were lost due to equipment malfunction from August through October 2021 at all transect sites.

and subsurface inflows along the Little Shasta River corridor to influence higher groundwater elevations seen along the right bank in this transect location.

As expected, the surface water temperature in the Shasta River showed the greatest fluctuations with seasonal highs and lows that are more extreme than seen in the adjacent shallow groundwater system. Although fluctuating with weather conditions, sun exposure, and ambient air temperature, it generally increased to seasonal peaks around 75˚F in July 2020 and 2021, and decreased to a seasonal low temperature around 40 ˚F in December 2020 and January 2021. Groundwater temperatures were more stable but showed differences between the right and left banks. The temperatures at the two piezometer locations along the right bank were very similar to one another and noticeably higher than along the left bank; the right bank piezometers increased to seasonal peaks around 60˚F from September through November and seasonal lows between 50˚F and 55˚F from March through May in 2020 and 2021. Along the left bank, the two piezometers showed different seasonal trends. Although both had seasonal lows between 45˚F and 50˚F from January through May, the LBF temperature increased more rapidly and has a higher seasonal peak around 60˚F in August while the LBN temperature increased more slowly and had a seasonal peak around 55˚F from September through November. The differences in temperature along each bank of the river in this location are indicative of different sources and influences.

With the exception of groundwater elevations along the left bank during the late summer period, piezometers showed higher groundwater elevations than surface water elevations during the study period. Groundwater temperatures also did not show strong responses or similarities to surface water temperatures, although differences are seen between the piezometer locations within the transect. These results indicate that the Shasta River was generally gaining in the transect location over the study period, with some potential losses to the shallow groundwater system adjacent to the left bank in the late summer.

Interestingly, changes in groundwater levels due to irrigation events do not seem to correlate with changes in groundwater temperatures as might be expected due to relatively warm irrigation-related deep percolation reaching the water table. This may be due to the integrated pressure and temperature sensors being installed at a depth that did not experience the thermal changes from deep percolation that the top of the water table may have experienced.

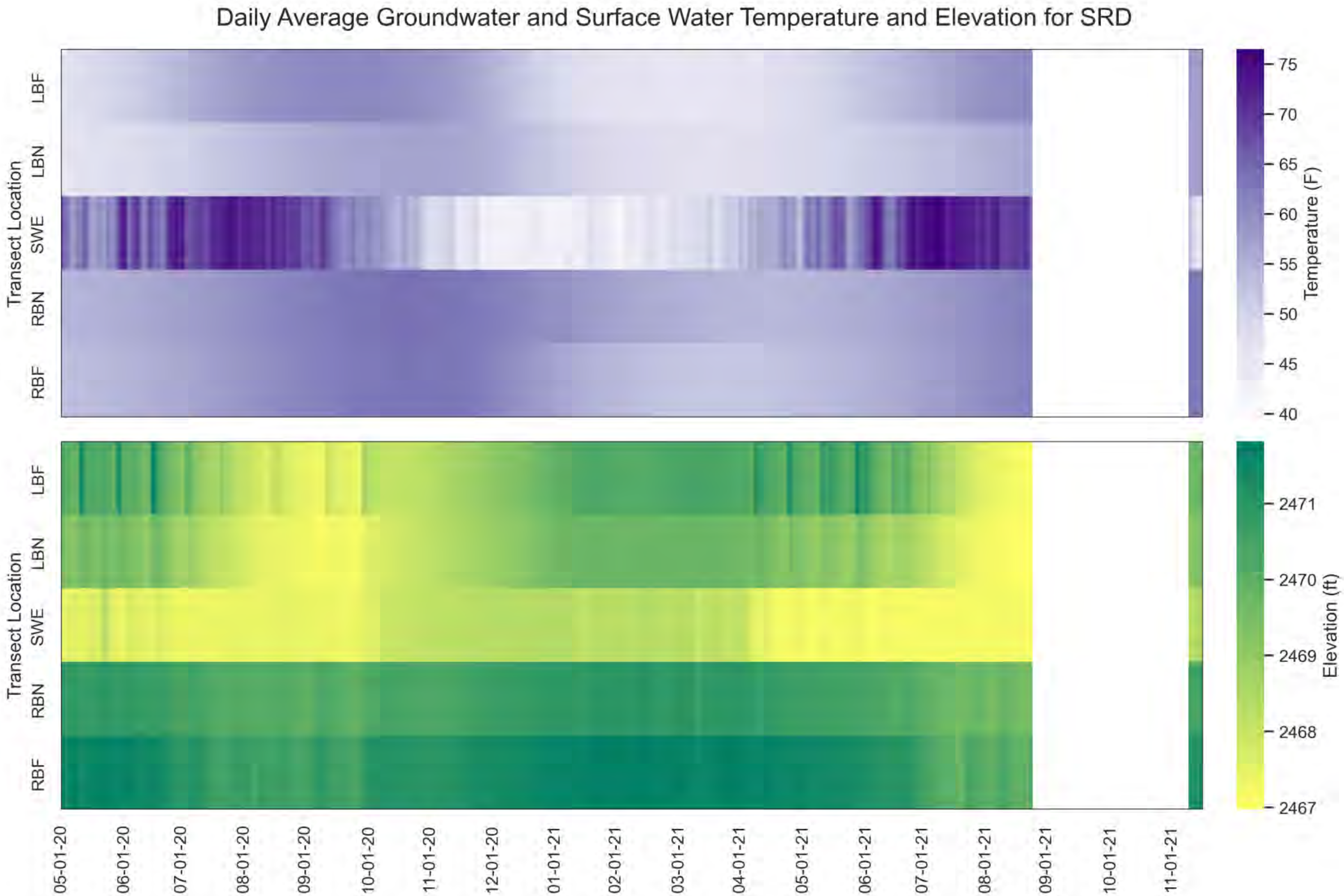


Figure 5. Daily average groundwater and surface water elevations and temperatures for the Shasta River Downstream (SRD) transect; monitoring locations are the left bank far (LBF), left bank near (LBN), surface water elevation (SWE), right bank near (RBN), and right bank far (RBF).

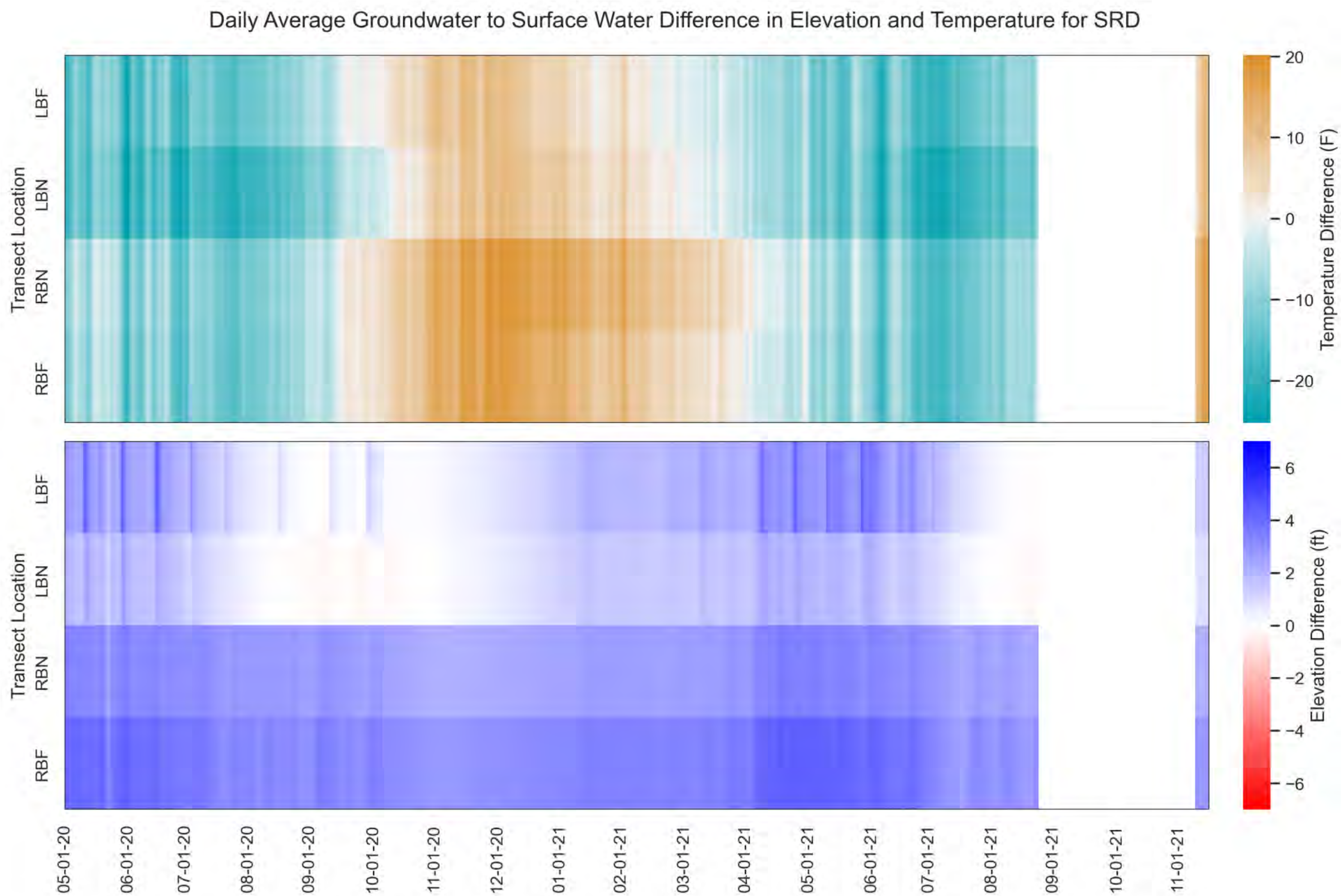


Figure 6. Daily average difference in groundwater and surface elevations and temperatures (Groundwater – Surface Water) for the Shasta River Downstream (SRD) piezometers installed at left bank far (LBF), left bank near (LBN), right bank near (RBN), and right bank far (RBF).

3.3 Little Shasta River in the Little Shasta Valley (LSR)

Figure 7 is a heatmap depicting the daily average values of water surface elevation and temperature for the five monitoring sites at the LSR transect, and Figure 8 is a heatmap depicting the daily average difference between the water surface elevation and temperature for each of the shallow piezometers in reference to the surface water location (calculated as surface water subtracted from groundwater)[6]. Although the heatmaps depict transect location results directly alongside one another, the distances between piezometers varies. For this transect the Right Bank Near (RBN) piezometer was located roughly 120 feet from the river edge, and the Right Bank Far (RBF) piezometer was located roughly 520 feet from the river edge (e.g., roughly 400 feet further from the river than RBN location). The LBN piezometer was located roughly 70 feet from the river edge, and the LBF piezometer was located roughly 420 feet from the river edge. The Little Shasta River did not have continuous flow throughout the study period. The text below includes observations based on the results seen in Figures 7 and 8.

Apart from a few spikes in stage likely associated with precipitation events, the river stage remained relatively steady from the start of the study in May 2020 until beginning to decline in late June 2020. During a monthly site visit on 6/16/20 the river was noted to have continuous flow, but during the next site visit on 7/17/20 it was noted that surface water was only present in isolated pools. On 8/22/20 the water level in the isolated pool where surface water elevations were monitored fell below the level where the pressure transducer was installed, making further data collection at this site impossible until levels rise. This was a decline in stage of roughly three feet. Water level increased above the pressure transducer again in mid-October 2020, and in early November the river stage rapidly increased more than three feet as winter flows returned to the Little Shasta River. River stage remained relatively stable from November 2020 through late June 2021, although a modest decrease is seen in February and March 2021. After late June 2021, the stage in the river steadily declines at a similar rate to that seen during the same period in 2020. An equipment malfunction in mid-August stopped the data record, although water levels were close to dropping below the pressure transducer elevation. The river stage in November 2021 was at a similar elevation as in November 2020, having increased over three feet in elevation from the prior measurement in August 2021.

Unfortunately, due to underlying geological conditions (primarily the presence of large cobbles) the piezometer boreholes were not able to be drilled as deeply in this transect as the other two transects. Groundwater levels in three of the four piezometers dropped below the level where the pressure transducer was installed at the bottom of the standpipe during the study period:

- At LBF (the shallowest piezometer borehole) this occurred on 6/19/20 and the only period where groundwater levels were higher than the pressure transducer again was during March and April 2021 at the seasonal high.
- At RBN this occurred on 9/12/20, but levels increased above the pressure transducer elevation again in late October 2020.
- At LBN this occurred on 10/10/20. but levels increased above the pressure transducer elevation again in late October 2020.

[6] Two months of data were lost due to equipment malfunction from August through October 2021 at all transect sites.

Data collection at these sites was not possible while groundwater levels were lower than the pressure transducer elevations, and these transect locations would benefit from deepened boreholes, which would allow pressure transducers to be installed at a greater depth and lower elevation.

Groundwater elevations in the piezometers on both sides of the river were consistently lower than the surface water elevation throughout the study period, with elevations decreasing with distance from the river. In contrast to the other two transects along the Shasta River, the lands on either side of the river in this transect location were not irrigated. During May and early June 2020, there were short periods of increased stage in the Little Shasta River, and the groundwater levels in the piezometers (at lower elevation than river stage) also showed increased water levels following increased stage in the Little Shasta River. This was potentially reflective of water flow from the river into the adjacent groundwater system on either bank in the location of the transect. Generally, groundwater levels at each piezometer all roughly followed the seasonal trends seen in surface water elevation in the Little Shasta River. Seasonal declines in shallow groundwater elevation began in late spring 2020 and 2021 (preceding declines in river stage, which began in late June) and continued until fall or early winter, when they began to increase as or after stage increased in the Little Shasta River. Although the general trends at each location are similar, there are still noticeable differences in groundwater elevations and trends between piezometers in the transect. The LBN location typically most closely parallels the surface water elevation in the Little Shasta River, both in changes over time and in elevation, suggesting a closer hydrological connection than other transect locations. The RBN location was typically to be lower in elevation than LBN, although it has similar seasonal high and low elevations; its elevations changes tend to be more gradual than the LBN location. The LBF location had a similar groundwater elevation to the other transect sites in May 2020, but did not recover to the same seasonal high in the spring of 2021. Finally, the RBF location showed the least decline and overall fluctuation of all measurement sites in the transect. For the several days in mid-August 2020 and 2021 prior to the end of the SWE data record, the RBF site showed higher water level than the SWE location. This indicates potential groundwater inflows from upgradient sources to the RBF transect location that were not present at other piezometer locations in this transect.

As expected, the surface water temperature in the Little Shasta River showed the greatest fluctuations with seasonal highs and lows that are more extreme than seen in the adjacent shallow groundwater system. Although fluctuating with weather conditions, sun exposure, and ambient air temperature, it generally increased to seasonal peaks between 70˚F and 75˚F in July and August 2020 and 2021, and decreased to a seasonal low temperature around 40 ˚F from December 2020 through February 2021. Groundwater temperatures were more stable, with seasonal lows of around 50˚F in March and April and seasonal peaks of around 60˚F in September and October. The trends at each site were similar, although the RBF temperature was slightly higher than the other locations. Groundwater temperatures tended to be higher than the surface water temperature in the winter months and lower in the summer months.

Piezometers consistently showed lower groundwater elevations than surface water elevations during the study period; these results indicate that the Little Shasta River was losing in the transect location during the study period.

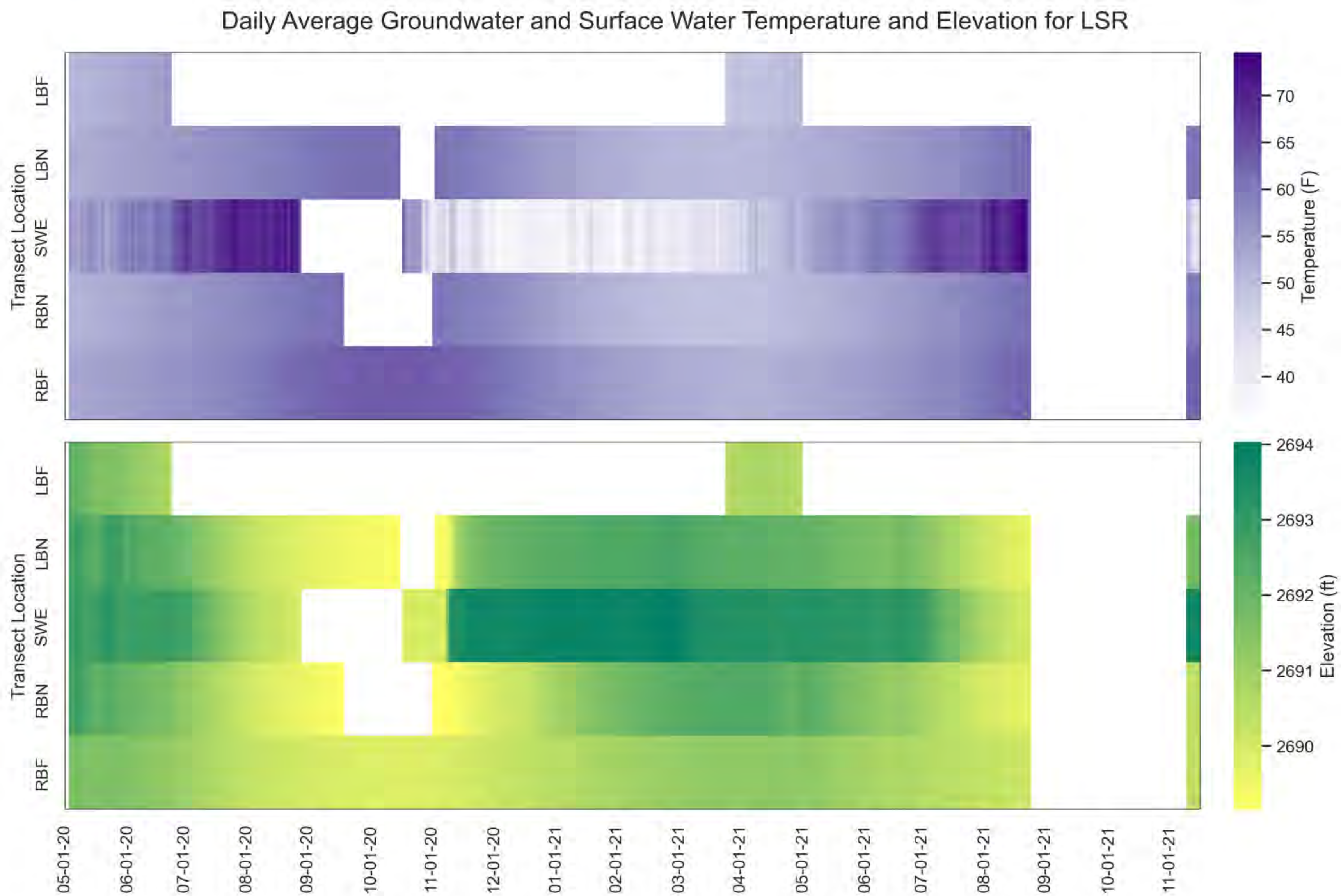


Figure 7. Daily average groundwater and surface water elevations and temperatures for the Little Shasta River (LSR) transect; monitoring locations are the left bank far (LBF), left bank near (LBN), surface water elevation (SWE), right bank near (RBN), and right bank far (RBF).

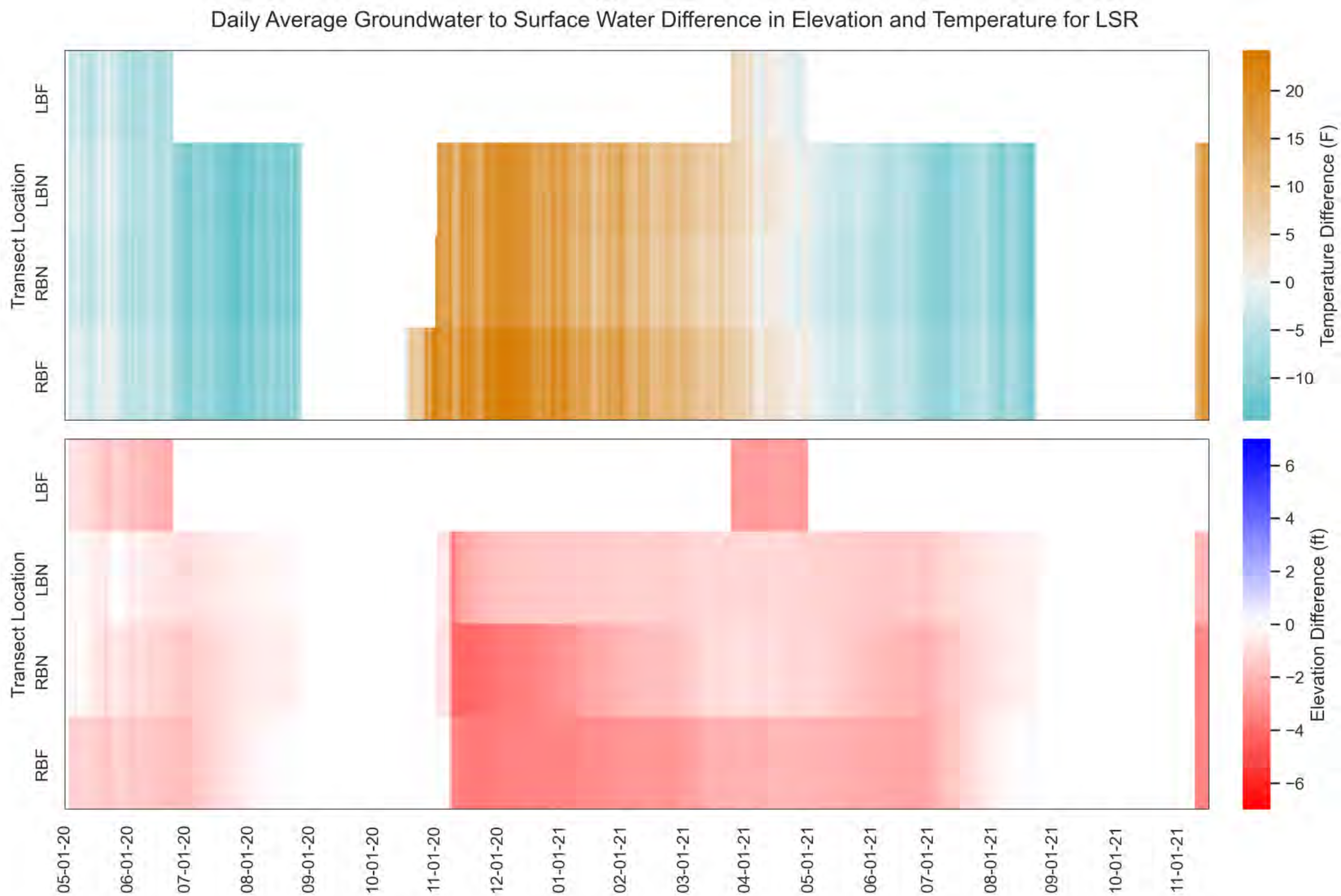


Figure 8. Daily average difference in groundwater and surface elevations and temperatures (Groundwater – Surface Water) for the Little Shasta River (LSR) piezometers installed at left bank far (LBF), left bank near (LBN), right bank near (RBN), and right bank far (RBF).

3.4 Average Monthly Water Elevations

Figure 9 is a heatmap showing average monthly water elevations for the three piezometer transects using data from both 2020 and 2021, which provides a sense of monthly trends at each site. The monitoring locations within each transect are shown equally spaced in the figures, which is not representative of actual distances between locations in the field. The results show that the surface water elevations for the two Shasta River transects (SRU and SRD) were generally lower than the shallow groundwater elevations on either bank of the river, indicating potential gains in the transect location. In contrast, the Little Shasta River transect (LSR) show that surface water elevations were generally higher than the shallow groundwater elevations on either bank of the river, indicating potential losses in the transect location. The blank, white values for the LSR transect are months during which data are unavailable due to water levels dropping below the elevation of the pressure transducers for those transect locations.

3.5 Summary of Average Stream-Aquifer Differences and Comparison of Transects

Figure 10 is a heatmap depicting the daily average water surface elevations for the five monitoring sites at each of the three transects, and Figure 11 is a heatmap depicting the daily average difference between the water surface elevations for each of the shallow piezometers in reference to the surface water location (calculated as surface water subtracted from groundwater)[7]. Figures 12 and 13 are similar heatmaps to Figures 10 and 11 that depict the daily average temperature values instead of water surface elevations. The difference calculations for Figures 11 and 13 mean that a positive water surface elevation or temperature difference indicates a higher average water surface elevation or temperature in the piezometers than in the surface water, and vice versa. These results were shown in Sections 3.1 through 3.3 for each individual transect but are included here for ease of comparison between transects to review overall trends and results across the monitoring locations.

Overall, shallow groundwater levels relative to surface water showed relatively consistent trends during the study period, and the 2021 irrigation season results were similar to the 2020 irrigation season results. The shallow groundwater levels in the two transects along the Shasta River tended to be higher in elevation and have a hydraulic gradient towards the river, while in the Little Shasta River they tend to be lower in elevation and have a hydraulic gradient away from the river. While these trends were influenced by a variety of factors, one that may contribute to differences is the irrigation of lands on either side of the river, as the lands along the Shasta River in the vicinity of or upgradient of the transect were irrigated while lands along the Little Shasta River were unirrigated for a larger area around and upgradient of the transect. For the two transects along the Shasta River, the effects of irrigation are clearly seen through periodic spikes in shallow groundwater elevations during the irrigation season.

[7] Two months of data were lost due to equipment malfunction from August through October 2021 at all transect sites.

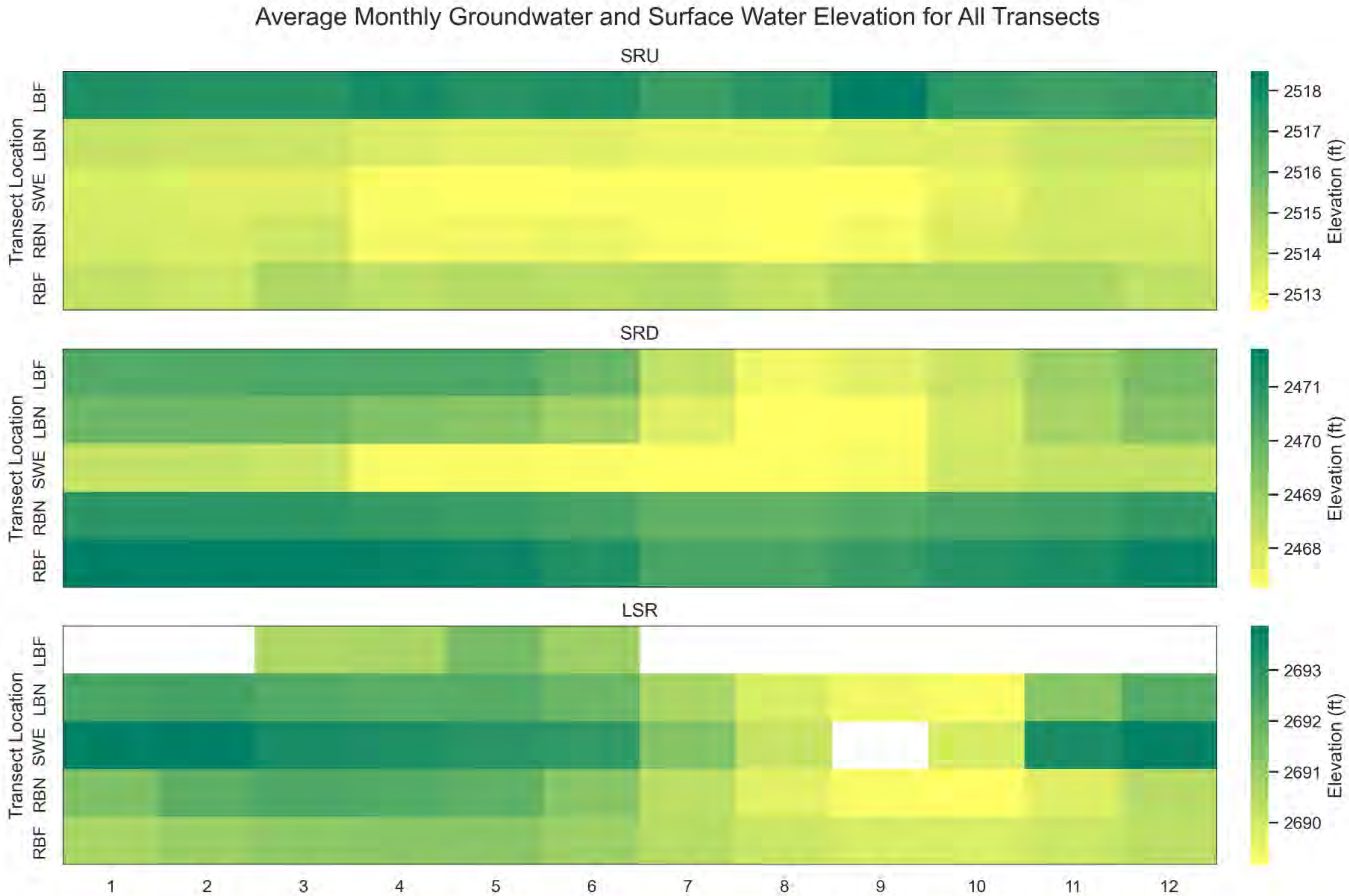


Figure 9. Average monthly groundwater and surface water elevations for the Shasta River Upstream (SRU), Shasta River Downstream (SRD) and Little Shasta River (LSR) transects. Monitoring locations are left bank far (LBF), left bank near (LBN), surface water elevation (SWE), right bank near (RBN), and right bank far (RBF). Months are represented by numbers 1 through 12 (i.e. January through December).

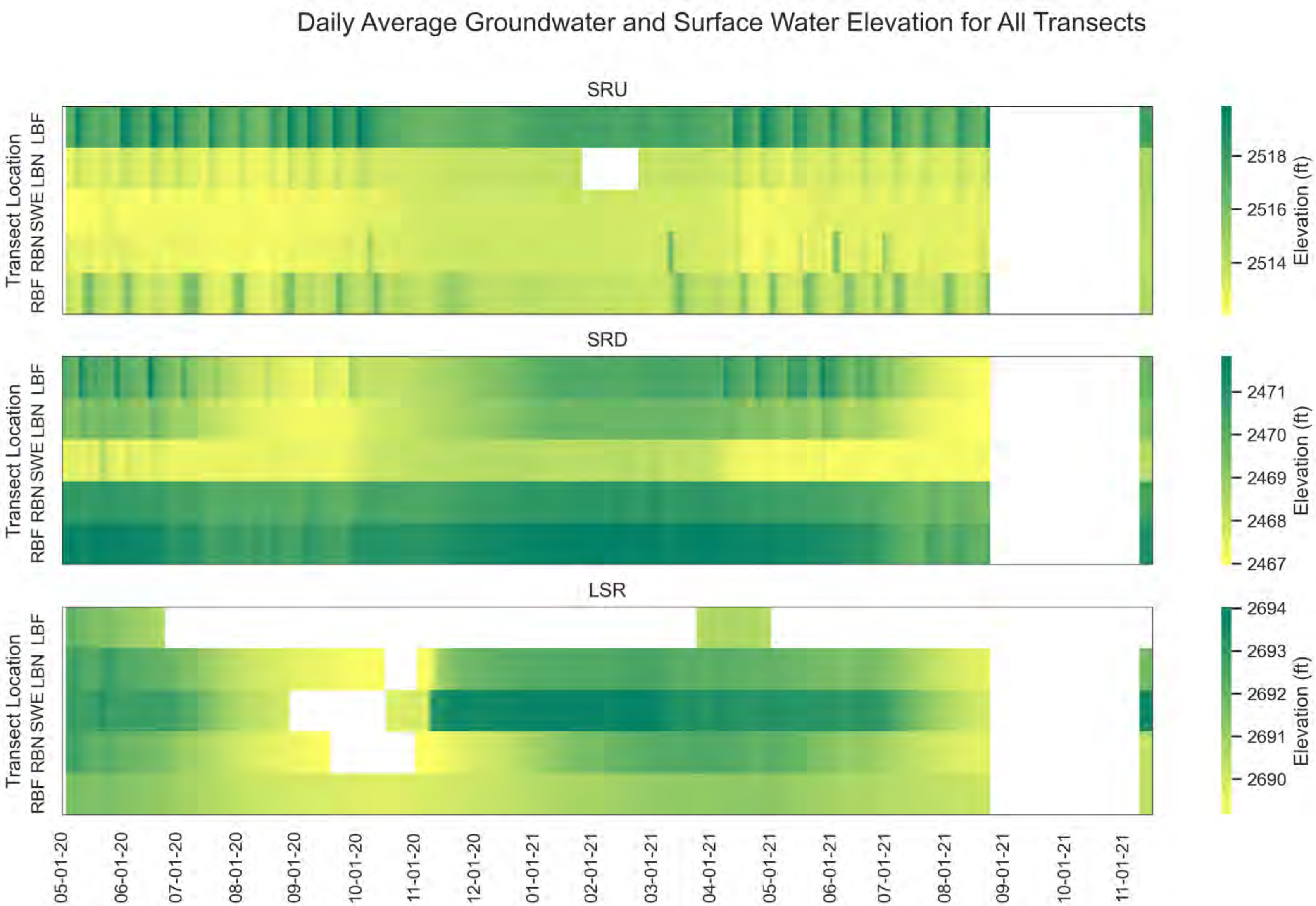


Figure 10. Daily average groundwater and surface water elevations for the Shasta River Upstream (SRU), Shasta River Downstream (SRD) and Little Shasta River (LSR) transects. Monitoring locations are left bank far (LBF), left bank near (LBN), surface water elevation (SWE), right bank near (RBN), and right bank far (RBF).

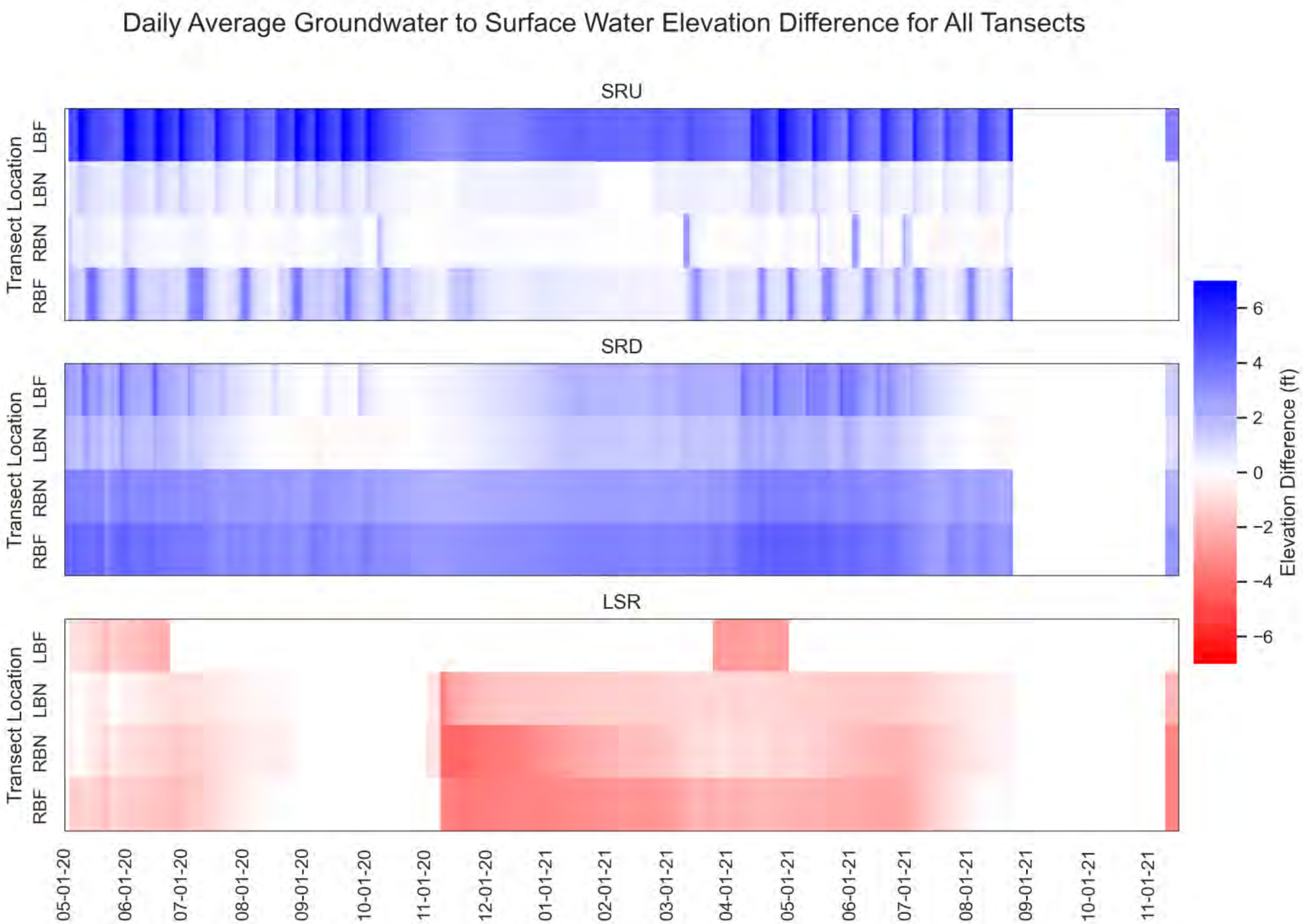


Figure 11. Daily average difference in groundwater and surface elevations (Groundwater – Surface Water) for the Shasta River Upstream (SRU), Shasta River Downstream (SRD) and Little Shasta River (LSR) transects. Monitoring locations are left bank far (LBF), left bank near (LBN), surface water elevation (SWE), right bank near (RBN), and right bank far (RBF).

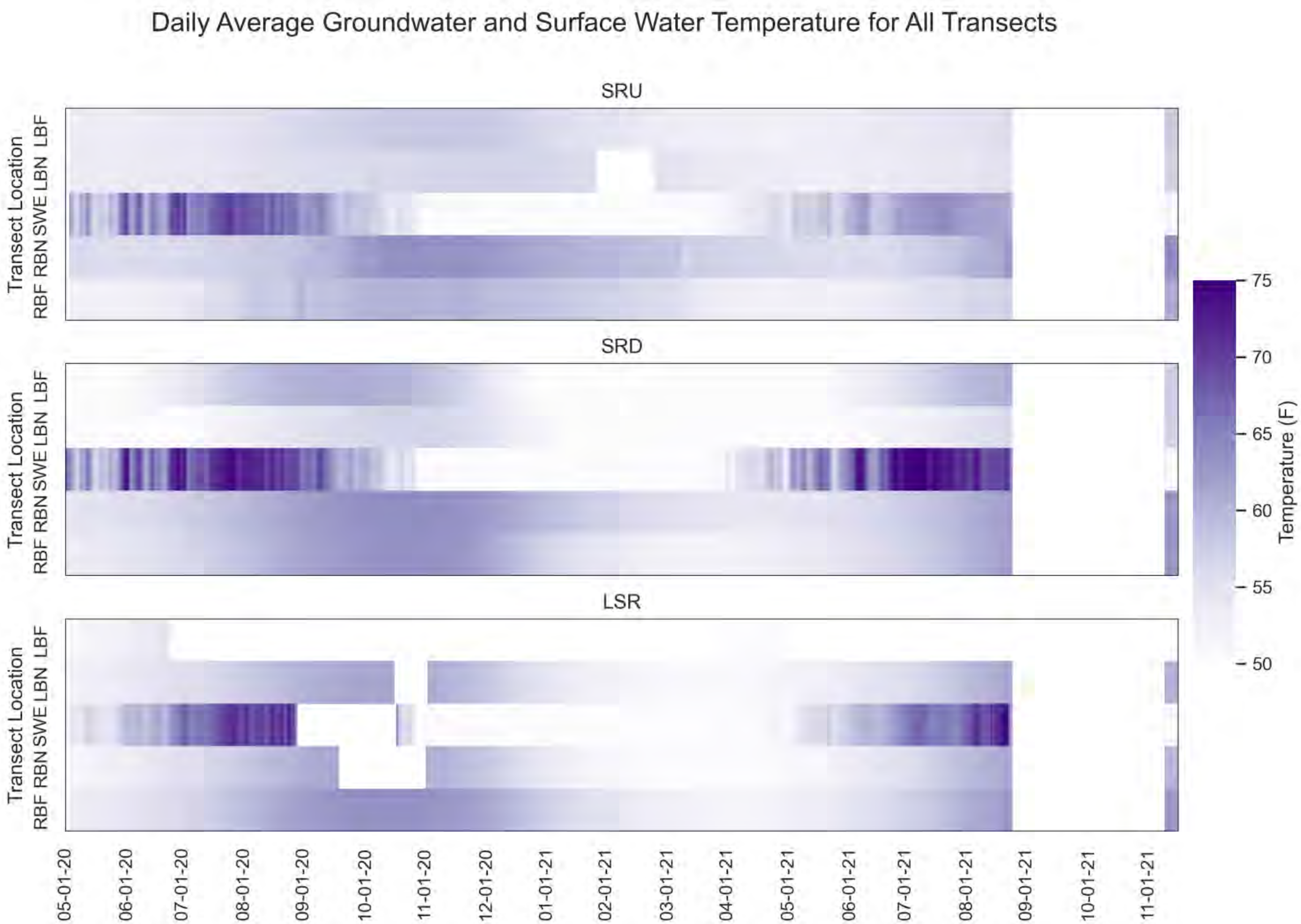


Figure 12. Daily average groundwater and surface water temperatures for the Shasta River Upstream (SRU), Shasta River Downstream (SRD) and Little Shasta River (LSR) transects. Monitoring locations are left bank far (LBF), left bank near (LBN), surface water elevation (SWE), right bank near (RBN), and right bank far (RBF).

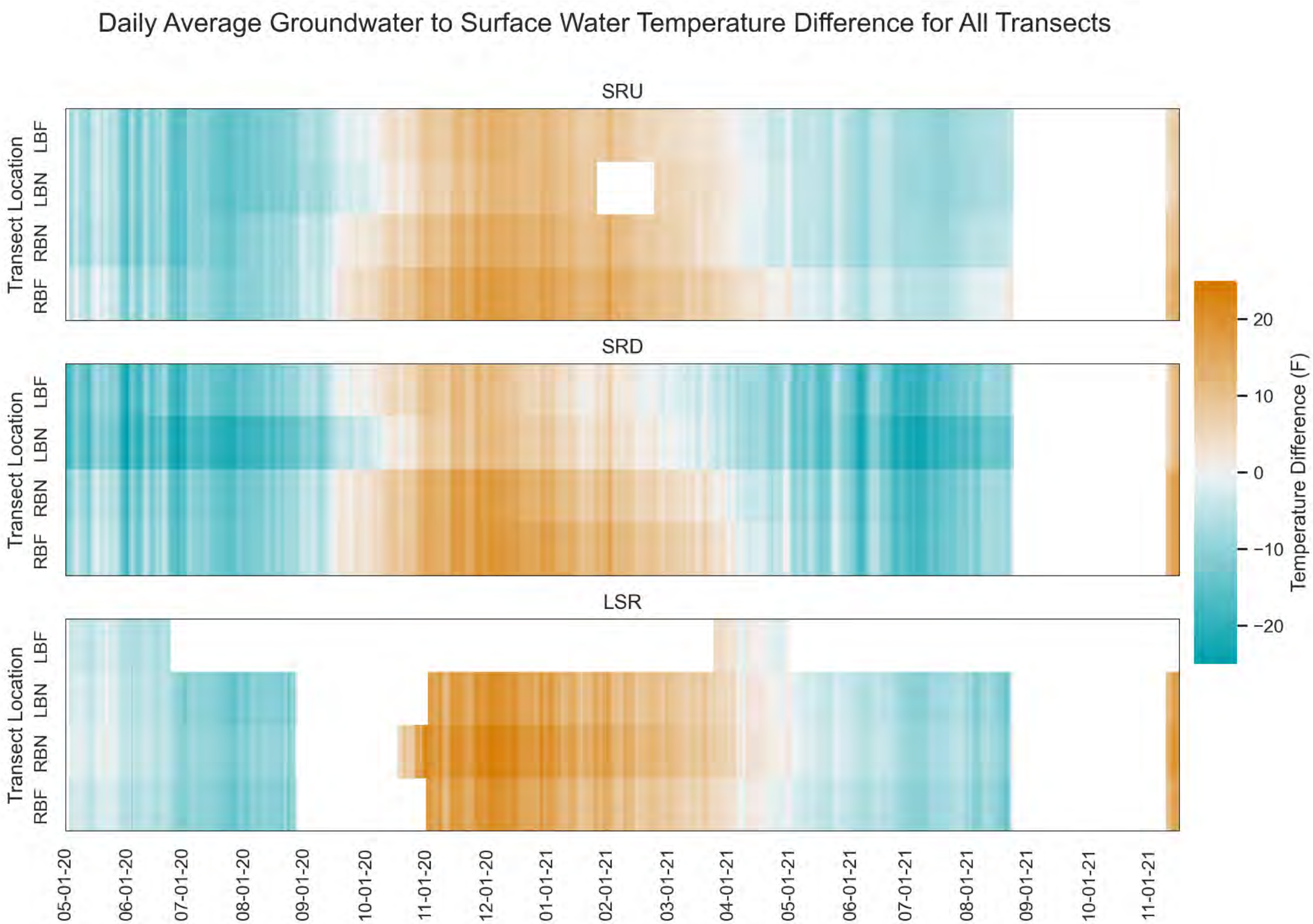


Figure 13. Daily average difference in groundwater and surface temperatures (Groundwater – Surface Water) for the Shasta River Upstream (SRU), Shasta River Downstream (SRD) and Little Shasta River (LSR) transects. Monitoring locations are left bank far (LBF), left bank near (LBN), surface water elevation (SWE), right bank near (RBN), and right bank far (RBF).

Temperatures differed across the transects, but overall showed the same general trends. The shallow groundwater was lower in temperature at the start of the study in May 2020 (e.g., negative values) with greater differences from surface water temperatures at the SRU and SRD transects than at the LSR transect. Initially, the differences increased into the summer months of 2020 as surface water temperatures increased more rapidly than groundwater temperatures. However, in late summer and early fall, as groundwater temperatures continued to slowly rise and surface water temperatures began falling, the trend reversed. The differences decreased and then became positive in September or October 2020 for all the piezometers; this is reflective of surface water temperatures decreasing below shallow groundwater temperatures. This trend continued into the winter and spring of 2021, until decreasing groundwater temperatures and increasing surface water temperatures again cause the trend to reverse. Temperature trends during the 2021 irrigation season were similar to those observed during the 2020 irrigation season.

Surface water temperatures during the spring and summer months were greater at the SRD transect than the SRU transect, which was potentially caused by surface warming in the Shasta River as it flowed downstream. With relatively similar groundwater temperatures in each transect location, this resulted in greater temperature differences observed at the SRD transect than the SRU transect. Interestingly, the surface water temperatures in the in the SRU transect during the 2021 irrigation season were not as high as during the 2020 irrigation season, although they were similar during both irrigation seasons at the SRD transect. The temperature difference comparison at all transects reflected the slower changes in shallow groundwater temperatures relative to changes in surface water temperatures.

4 Discussion and Conclusions

The study provides valuable information about stream-aquifer interactions in the Shasta Valley along the Shasta River and Little Shasta River. Monitoring results indicating the Shasta River was primarily gaining in both transect locations during this period, while the Little Shasta River was losing at its transect location during this period. Current funding allows the study to continue through December 2021. Included below are recommendations based on the data collected thus far over the study period from May 2020 through November 2021:

- The study and data collection should continue beyond December 2021 for as long as possible. Multiple years of data will provide useful insight into how changing weather conditions, river stage and flow, water use and water management practices, and water availability (e.g., wet years vs. dry years) influence stream-aquifer interactions in the Shasta Valley. As the GSP is implemented between 2022 and 2042, these data also have potential to reveal responses of stream-aquifer interactions to GSP implementation.
- Additionally, if possible or feasible due to funding and other water monitoring or management priorities in the basin, it is recommended that the piezometer boreholes in the transect along the Little Shasta River be deepened so that the pressure transducers can be installed further below ground to record data on changing water surface elevations and temperatures in case groundwater levels continue to consistently drop below the current bottom of the piezometer borehole and elevation where the pressure transducers are installed.

- Additionally, depending on funding and other priorities, further evaluation of the piezometer transects could be completed through additional data collection and data analysis. This includes, but is not limited to, the following:
    - Quantification of accretions or depletions in stream reaches that include the piezometer transects through flow measurements of upstream and downstream surface water flow.
    - Addition of a floating temperature sensor in each piezometer so that the temperature records are reflective of first encountered groundwater, instead of deeper groundwater that might not be influenced by deep percolation from applied water.
    - Water quality sampling of shallow groundwater and surface water.
    - Analysis of flow gradients, saturated flow thickness, and hydraulic conductivity and detailed investigation into the groundwater and surface water conditions in the vicinity of the piezometer transects.
- Finally, depending on funding and other priorities, it is recommended that additional piezometer transects be installed, commissioned, and monitored in other locations distributed across the Shasta Valley to provide additional insight into stream-aquifer interactions. High priority locations for additional transects include:
    - Shasta River downstream of the confluence with Big Springs Creek.
    - Shasta River near the confluence with Parks Creek.
    - Shasta River downstream of Lake Shastina.
    - Shasta River upstream of Lake Shastina.

5 References

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6 Attachments

- SV_Shallow_Piezometer_Transect_Study_Daily_Avg_May_20_Nov_21.xlsx
    - Spreadsheet with daily averages for water surface elevation and temperature at all sites.

7 Acknowledgements

This project would not have been possible without the facilitation, technical expertise, and leadership of SVRCD and the voluntary partnership and participation of private landowners.

Funding for this project has been provided in full or in part from the Water Quality, Supply, and Infrastructure Improvement Act of 2014 (Proposition 1) and through an agreement with the State Department of Water Resources.

Technical Memorandum

To: Larry Walker Associates

From: Davids Engineering

Date: January 23, 2020; revised October 20, 2021

Subject: **Shasta Valley Basin Evapotranspiration and Applied Water Estimates**

1 Summary

The purpose of this effort is to develop time series estimates of agricultural water use for the Shasta Valley groundwater basin from January 1989 through December 2018. The approach builds upon estimates of actual evapotranspiration (ETa) developed using remotely sensed information from the Landsat satellite.

The consumptive use of water (i.e., evapotranspiration) is the primary destination of infiltrated precipitation and applied irrigation water within the Valley. Quantification of consumptive use was achieved by performing daily calculations of evapotranspiration (ET) for individual fields for the study period. ET was separated into its evaporation (E) and transpiration (T) components. Transpiration was quantified using a remote sensing approach where Landsat satellite images acquired from USGS were used to calculate the Normalized Difference Vegetation Index (NDVI), which was subsequently translated to a basal crop coefficient and combined with reference ET (ETo) to calculate transpiration over time.

A spatial coverage of field boundaries was developed for the Basin, and agricultural fields (primarily pasture) were identified based on available data. Field boundaries were delineated primarily based on polygon coverages in GIS format from the California Department of Water Resources (DWR).

ET was calculated based on a combination of remote sensing data and simulation of irrigation events in a daily root zone water balance model. Due to the remote sensing approach, crop ET estimates are relatively insensitive to specific crop type and irrigation method. As a result, detailed, accurate assignment of crop types and irrigation methods to each field is not critical to developing relatively reliable estimates of crop ET. For purposes of this study, irrigated pasture was assigned as a representative crop type for agricultural lands.

The amount of green vegetation present over time was estimated for each field polygon based on NDVI, which is calculated using a combination of red and near infrared reflectances as measured using multispectral satellite sensors onboard Landsat satellites. Following the preparation of NDVI imagery spanning the analysis period all images were quality controlled to remove pixels affected by clouds.

Mean daily NDVI values for each field were converted to basal crop coefficients. Daily precipitation was estimated based on assembly and review of data from the PRISM Climate Group at Oregon State

University[1]. Daily reference evapotranspiration (ET_o) was estimated based on information from California Irrigation Management Information System (CIMIS) and from National Oceanic and Atmospheric Administration (NOAA) weather stations. Root zone parameters that influence the amount of available soil moisture storage were estimated based on soils present in the Shasta Valley.

A summary for the analysis period of the annual ET of applied water (ET_{AW}), ET_c (synonymous with ET_a), applied water (AW), deep percolation of applied water (DP_{AW}) and deep percolation of precipitation (DP_{pr}) estimates based on the root zone water balance model is given in the Results section.

Application of remote sensing combined with daily remote sensing based root zone water balance modeling (RS-RZ model) provides a reliable methodology in the absence of more detailed, ground-based information for estimation of surface interactions with the groundwater system including net groundwater depletion through estimation of ET of applied water and other fluxes.

2 Introduction

The purpose of this effort is to develop time series estimates of agricultural, urban, and native vegetation water use for the Shasta Valley groundwater basin from 1989 to 2018. Demand has been quantified at the field scale using a remote-sensing based daily root zone water balance model. This effort is primarily focused on agricultural water use, and as such, only results for this are presented. Although results for urban and native vegetation are also available through the model, they have not been quality-controlled or reviewed as extensively as the agricultural water use results.

3 Methodology

3.1 Daily Root Zone Simulation Model

A conceptual diagram of the various surface layer fluxes of water into and out of the crop root zone is provided in Figure 3.1. The consumptive use of water (i.e., evapotranspiration or ET) is the primary destination of infiltrated precipitation and applied water for irrigation within the Shasta Valley. Quantification of consumptive use was achieved by performing daily calculations of ET for individual fields from January 1989 through December 2018. Evapotranspiration was separated into its evaporation (E) and transpiration (T) components. Additionally, each component was separated into the amount of E or T derived from precipitation or applied water.

[1] PRISM website: http://prism.oregonstate.edu/

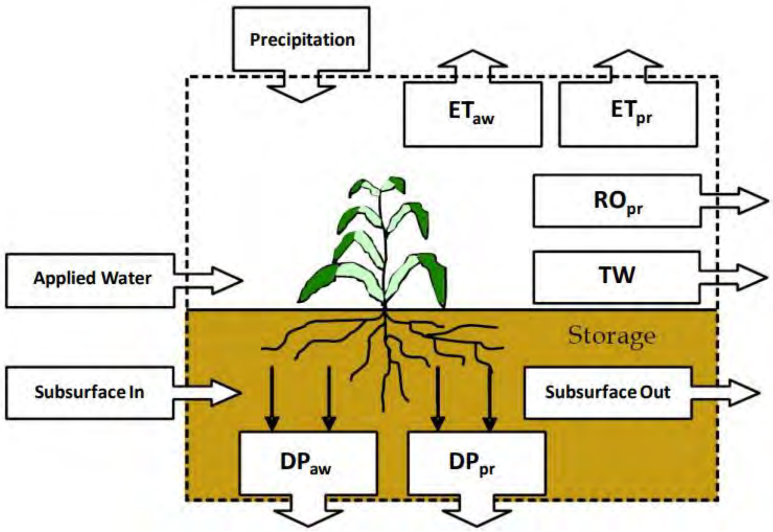

Figure 3.1. Conceptualization of Fluxes of Water Into and Out of the Crop Root Zone.

In estimating applied water for irrigation, the daily root zone simulation model simulates individual irrigation events on a field-by-field basis to meet ET demands in excess of what can be met by precipitation. While the large majority of this demand is truly met through applied irrigation water, some of the demand may also be met by other water sources such as shallow groundwater or seepage from nearby canals. The model does not differentiate between these potential sources of water but designates all demands as met through applied water. An estimated 10% of applied irrigation water is assumed as tailwater, flowing to a nearby stream and leaving the model area[2]. This percentage was based on a review of prior studies in the Shasta Valley and professional judgment regarding tailwater outflows in this context.

Transpiration was quantified using a remote sensing approach whereby Landsat satellite images acquired from USGS were used to calculate the Normalized Difference Vegetation Index (NDVI), a measure of the amount of green vegetation present. NDVI values were calculated and interpolated for each field over time. NDVI values were then converted to transpiration coefficients that were used to calculate transpiration over time by multiplying daily NDVI by daily reference evapotranspiration (ET_o). Evaporation was quantified by performing a surface layer water balance for the soil based on the dual crop coefficient approach described in FAO Irrigation and Drainage Paper 56 (Allen et al. 1998). On a daily basis, evaporation was calculated based on the most recent wetting event (precipitation or irrigation) and the evaporative demand for the day (ET_o). This methodology is described in greater detail in Davids Engineering (2013).

3.2 Development of Field Boundaries

A spatial coverage of field boundaries was developed for the analysis area, and individual agricultural field polygons were identified. For each polygon, daily water balance calculations were performed for the analysis period, and irrigation events were simulated to estimate the amount of water applied to meet crop irrigation demands. This section describes the development of the field polygon coverage and assignment of cropping and irrigation method attributes. Field boundaries were delineated based on a polygon coverage in GIS format from the California Department of Water Resources (DWR) from 2009.

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[2] This tailwater estimate does not include tailwater that may be recaptured and reused, either on the same field or a downstream field in the model area.

Non-agricultural areas were filled using a grid of approximately 40-acre tracts based on the Public Land Survey System (PLSS).

3.3 Assignment of Land Use Type and Irrigation Method

As described previously, crop evapotranspiration (ET) was calculated based on a combination of remote sensing data, precipitation data, and simulation of irrigation events in a daily root zone water balance model. A result of the remote sensing approach is that crop transpiration was estimated with little influence from the assigned crop type for each field. Additionally, crop transpiration is the dominant component of ET, meaning that ET estimates are likewise largely independent of the assigned crop type.

Crop evapotranspiration is driven to some extent by the characteristics of the irrigation method and its management, including the area wetted during each irrigation event and the frequency of irrigation. Surface irrigation methods typically wet more of the soil surface than micro-irrigation methods; however, surface irrigated fields are typically irrigated less frequently than their micro-irrigated counterparts. As a result, evaporation rates can be similar among surface and micro-irrigated fields, and estimates of evaporation are likewise somewhat independent of the assigned irrigation method. Parameters related to irrigation method were assigned based on the assumption that most irrigated lands in the Shasta Valley are irrigated using surface irrigation methods as indicated by the 2009 DWR land and water use survey.

A key result of the relative insensitivity of the crop ET estimates to crop type or irrigation method (due to the remote sensing approach), is that detailed, accurate assignment of crop types and irrigation methods to each field is not critical to developing reliable estimates of crop ET at the field scale and, more importantly, at coarser scales due to the cancellation of errors in individual field estimates as they are aggregated (Davids Engineering 2013).

3.4 NDVI Analysis

The amount of green vegetation present over time was estimated for each field polygon based on the Normalized Difference Vegetation Index (NDVI), which is calculated using a combination of red and near infrared reflectances, as measured using multispectral satellite sensors onboard Landsat satellites. NDVI can vary from -1 to 1 and typically varies from approximately 0.15 to 0.2 for bare soil to 0.8 for green vegetation with full cover. Negative NDVI values typically represent water surfaces.

3.4.1 Image Selection

Landsat images are preferred due to their relatively high spatial resolution (30-meter pixels, approx. 0.2 acres in size). A total of 428 raw satellite images were selected and converted to NDVI spanning the study period (Table 3.1). Of the images selected, 217 were from the Landsat 5 satellite, 128 were from the Landsat 7 satellite (first available in 2001), and 83 were from the Landsat 8 satellite (first available in 2013). These images were used to process and download surface reflectance (SR) NDVI from the USGS Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA)[3].

The number of days between image dates ranged from 8 to 160, with an average of 25 days. Generally, there was at least one image selected for each month, with less images available during winter months when cloudy conditions are more likely to occur[4].

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[3] USGS ESPA website: https://espa.cr.usgs.gov/

[4] The winter months have lower evapotranspiration, greater precipitation, and very low to negligible irrigation demands. As a result, they are not as influential for model results as the summer months during the irrigation season.

3.4.2 Extraction of NDVI Values by Field and Development of Time Series NDVI Results

Following the preparation of NDVI imagery spanning the analysis period, NDVI for water surfaces (such as lakes or some wetlands) was adjusted to a higher value to more accurately estimate ET. All images were then masked using the Quality Assessment Band (BQA) provided by ESPA to remove pixels affected by snow, clouds and cloud shadows. Then, mean NDVI was extracted from the imagery for each field for each image date. These NDVI values were interpolated across the full analysis period from January 1, 1989 to December 31, 2018 to provide a daily time series of mean NDVI values for each field.

3.4.3 Development of Relationship to Estimate Basal Crop Coefficient from NDVI

Basal crop coefficients (K_{cb}) describe the ratio of crop transpiration to reference evapotranspiration (ET_o) as estimated from a ground-based agronomic weather station. By combining K_{cb}, estimated from NDVI, with an evaporation coefficient (K_e), it is possible to calculate a combined crop coefficient ($K_c = K_{cb} + K_e$) over time[5]. By multiplying K_c by ET_o, crop evapotranspiration (ET_c) can be calculated. For this analysis, ET_o, K_{cb}, K_e, and ET_c (synonymous to actual ET, ET_a) were estimated for each field on a daily time step for the full analysis period.Mean daily NDVI values for each field were converted to basal crop coefficients using a relationship following Er-Raki et al. (2007) And as described in greater detail by Davids Engineering (2013)[6].

[5] The estimation of Ke is based on a daily 2-stage evaporation model described in FAO Irrigation and Drainage Paper No. 56 (Allen et al. 1998).

[6] This relationship is developed based on comparison of the combined crop coefficient to NDVI for individual fields but represents only the transpiration component of ET. Thus, the relationship developed predicts the basal crop coefficient, Kcb.

Table 3.1. Landsat Image Selection by Month and Year for Study Period.

Year	Month												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
1989	0	0	1	1	1	2	2	1	2	2	0	2	14
1990	1	1	1	2	1	2	0	1	1	2	0	0	12
1991	0	0	1	2	0	2	0	2	2	2	0	0	11
1992	0	0	1	1	2	1	2	2	2	2	2	1	16
1993	1	1	0	0	2	2	1	1	2	1	1	1	13
1994	2	1	1	2	1	1	2	2	2	1	1	0	16
1995	0	0	0	1	1	2	2	2	2	2	1	1	14
1996	1	1	1	2	2	1	2	2	1	2	1	0	16
1997	1	1	2	2	2	1	1	2	2	2	1	1	18
1998	0	1	2	2	0	2	2	1	2	2	0	2	16
1999	0	0	1	1	1	1	2	1	1	1	1	1	11
2000	0	0	1	0	2	2	1	2	1	1	0	1	11
2001	1	0	1	1	1	1	2	1	1	0	1	0	10
2002	1	1	0	1	1	2	1	1	1	1	1	0	11
2003	1	2	1	0	1	1	1	1	1	1	1	0	11
2004	0	1	1	1	1	1	2	1	1	0	1	1	11
2005	1	0	2	1	2	1	2	1	1	1	1	0	13
2006	0	1	0	1	2	1	2	1	1	1	1	0	11
2007	1	0	2	1	1	2	2	1	1	1	1	0	13
2008	0	0	1	1	1	2	2	2	0	1	1	0	11
2009	1	0	1	2	1	1	2	2	2	0	1	1	14
2010	0	1	1	2	1	1	2	1	2	0	1	0	12
2011	1	0	1	1	1	1	1	1	2	1	0	1	11
2012	1	1	0	1	2	0	1	2	2	0	1	1	12
2013	0	1	0	1	1	2	3	1	2	2	1	0	14
2014	1	0	0	1	1	2	2	1	1	2	0	0	11
2015	3	2	2	2	0	2	2	1	1	2	2	0	19
2016	4	1	4	2	3	2	2	3	3	1	3	2	30
2017	2	2	3	3	3	2	2	2	3	2	1	2	27
2018	1	2	0	1	2	2	2	2	2	2	2	1	19
Total	25	21	32	39	40	45	50	44	47	38	28	19	428

3.5 Precipitation

Daily precipitation was estimated based on assembly and review of data from the PRISM Climate Group at Oregon State University. Specifically, each field was assigned estimated daily precipitation from the 4km PRISM grid cell within which its centroid fell. The study area is represented by 90 individual grid cells.

Annual precipitation totals, averaged over the agricultural fields in the study area for water years 1990 to 2018, are shown in Figure 3.2. Water year precipitation over the study period varied from 66 taf in 1994 to 184 taf in 2006, with an annual average of 120 taf.

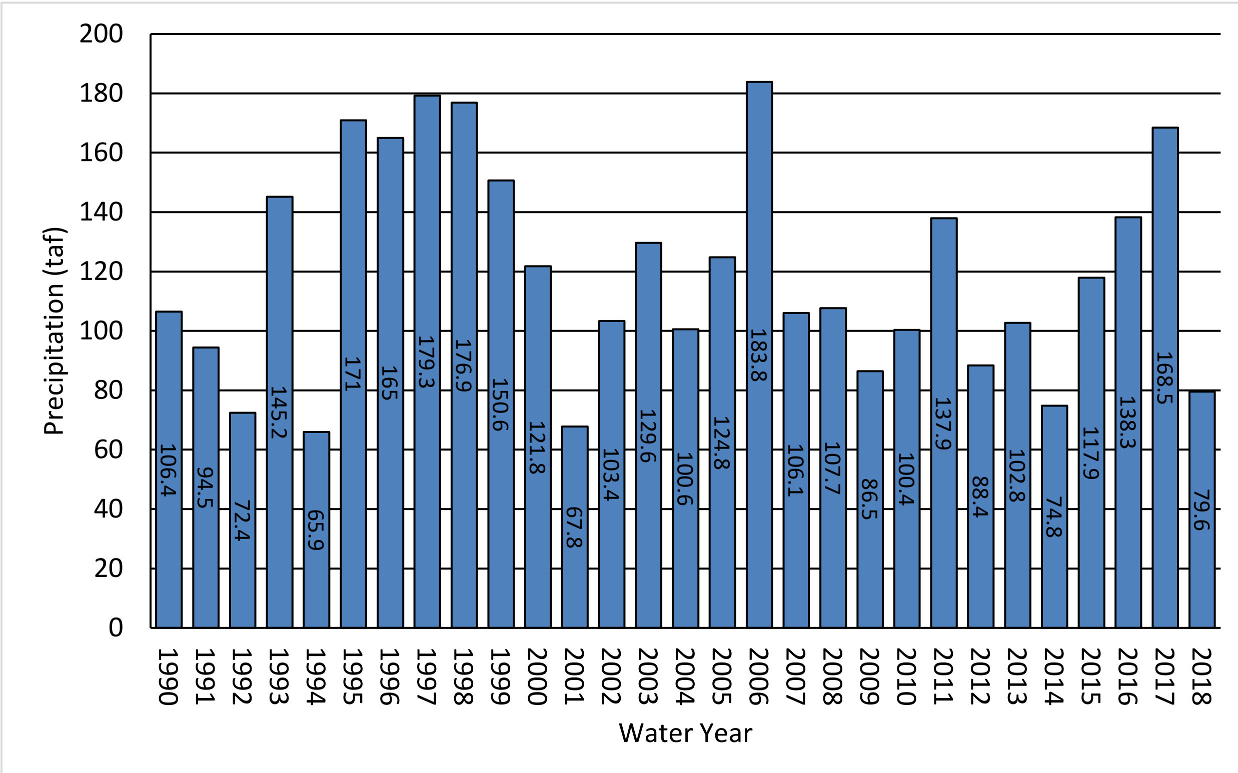

Figure 3.2. Annual Precipitation Totals.

3.6 Estimation of Daily Reference Evapotranspiration

Daily reference evapotranspiration (ET_o) was estimated based on information from the McArthur CIMIS weather station (Station No. 43) and air temperature at the Yreka NOAA[7] station location. ET_o provides a means of estimating actual crop evapotranspiration over time for each field. Based on review of nearby weather stations with data available during the period of analysis, the McArthur station was selected based on it being located relatively near the Shasta Valley, having relatively good fetch, and having available data during the analysis period. The Yreka NOAA station was selected based on it being within the Shasta Valley.

Individual parameters from the available CIMIS data including incoming solar radiation, air temperature, relative humidity, and wind speed were quality-controlled according to the procedures of Allen et al. (2005). The quality-controlled data were then used to calculate daily ET_o for the available period of record. The resulting daily ET_o and quality controlled NOAA temperature data were used to estimate the final time series of daily ET_o at Yreka using the method of Hargreaves and Samani (1985).

[7] https://www.ncdc.noaa.gov/cdo-web/search

ET_o zones were developed to account for the variability in elevation, slope, and aspect (and therefore ET) found in the study area based on long-term average spatially distributed ETo from Spatial CIMIS[8]. One ET_o zone was created for each PRISM precipitation grid cell, resulting in the creation of 90 ET_o zones. Daily ETo values for Yreka were multiplied by an adjustment factor for each zone to derive a spatially distributed ETo time series for each zone.

3.7 Estimation of Root Zone Water Balance Parameters

Root zone parameters that influence the amount of available soil moisture storage were estimated based on soils present in the Shasta Valley. Crop parameters of interest include root depth, NRCS curve number[9], and management allowable depletion (MAD). Root depth was estimated based on published values. Curve numbers were estimated based on values published in the NRCS National Engineering Handbook, which provides estimates based on crop type and condition. MAD values by crop were estimated based on values published in FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998).

Soil hydraulic parameters of interest include field capacity (% by vol.), wilting point (% by vol.), saturated hydraulic conductivity (ft/day), total porosity (% by vol.), and the pore size distribution index (λ, dimensionless). These parameters were estimated by first determining the depth-weighted average soil texture (sand, silt, clay, etc.) based on available NRCS soil surveys. Next, the hydraulic parameters were estimated using hydraulic pedotransfer functions developed by Saxton and Rawls (2006). Then, hydraulic parameters were adjusted within reasonable physical ranges for each soil texture so that the modeled time required for water to drain by gravity from saturation to field capacity agreed with typically accepted agronomic values. Unsaturated hydraulic conductivity (e.g. deep percolation) within the root zone was modeled based on the equation developed by Campbell (1974) for unsaturated flow.

[8] Spatial CIMIS is a gridded ETo product available from DWR. Long-term average gridded ETo was estimated based on daily ETo grids for the years 2004 to 2018.

[9] The curve number runoff estimation method developed the Natural Resources Conservation Service (NRCS) was used to estimate runoff from precipitation in the model. For additional information, see NRCS NEH Chapter 2 (NRCS, 1993).

4 Results

4.1 Evapotranspiration

Estimated annual evapotranspiration volumes for agricultural fields in the study area are shown in Figure 4.1. Estimated volumes of ET derived from applied water (ETaw) and precipitation (ETpr) are shown in thousands of acre-feet (taf). Annual ETaw ranged from 103 taf to 147 taf, with an average of 128 taf. Annual ETpr ranged from 46 taf to 107 taf, with an average of 70 taf. Total ET ranged from 167 taf to 219 taf, with an average of 198 taf.

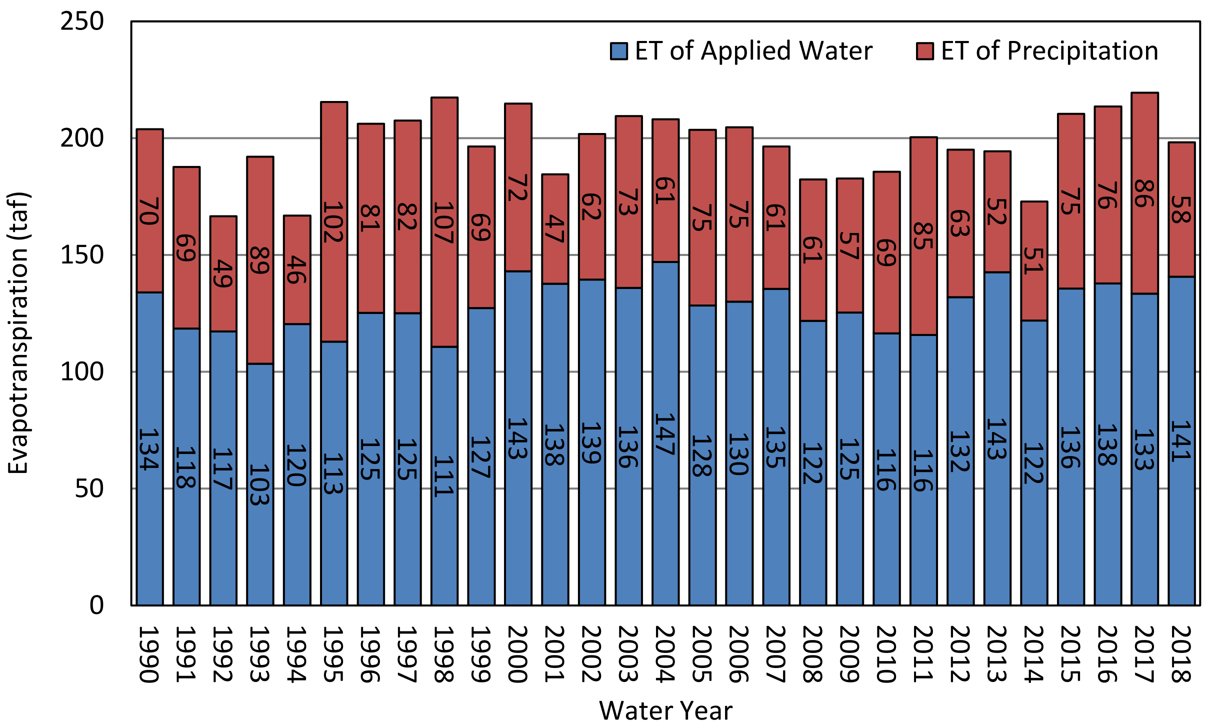

Figure 4.1. Total ET by Water Year.

4.2 Irrigation Demands

Annual estimated irrigation demands for agricultural fields within the study area are shown in Figure 4.2 in thousands of acre feet. Annual demands ranged from 168 taf to 229 taf, with an average of 199 taf.

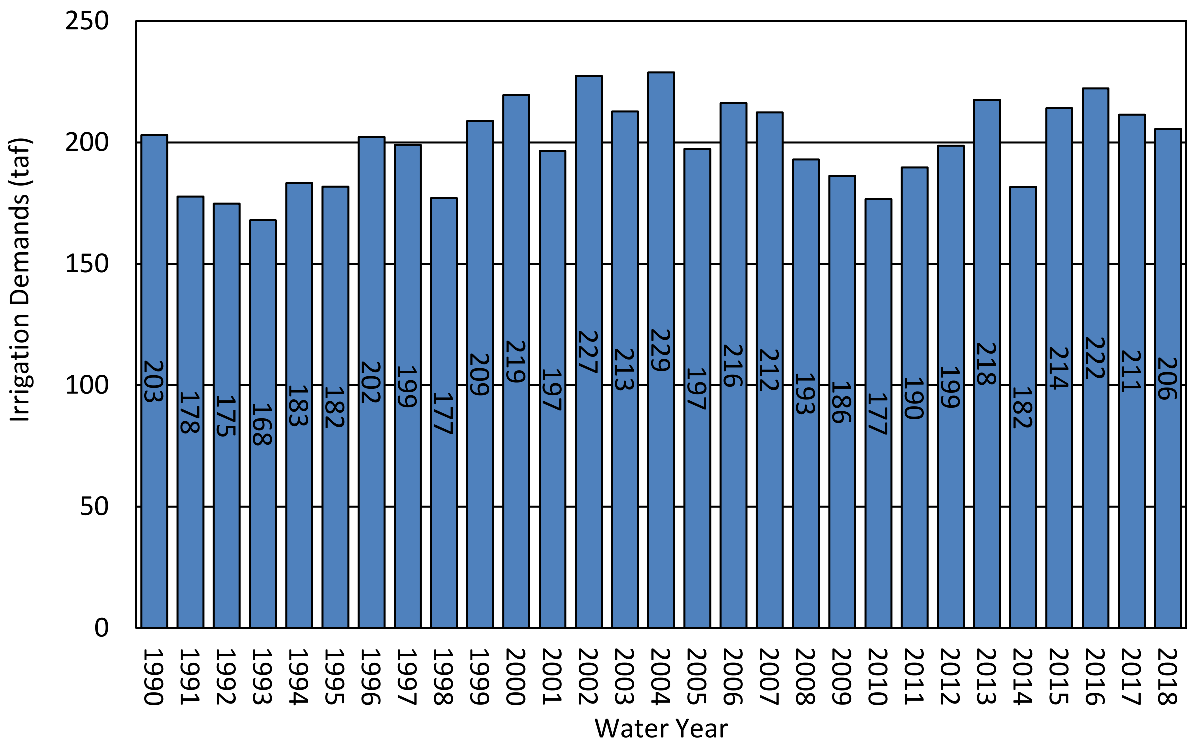

Figure 4.2. Irrigation Demands by Water Year.

4.3 Deep Percolation

Estimated annual deep percolation volumes for agricultural fields within the study area are shown in Figure 4.3. Estimated volumes of deep percolation derived from applied water (DPaw) and precipitation (DPpr) are shown in thousands of acre-feet. Annual DPaw ranged from 40 taf to 62 taf, with an average of 51 taf. Annual DPpr ranged from 15 taf to 82 taf, with an average of 40 taf. Total deep percolation ranged from 60 taf to 144 taf, with an average of 191 taf.

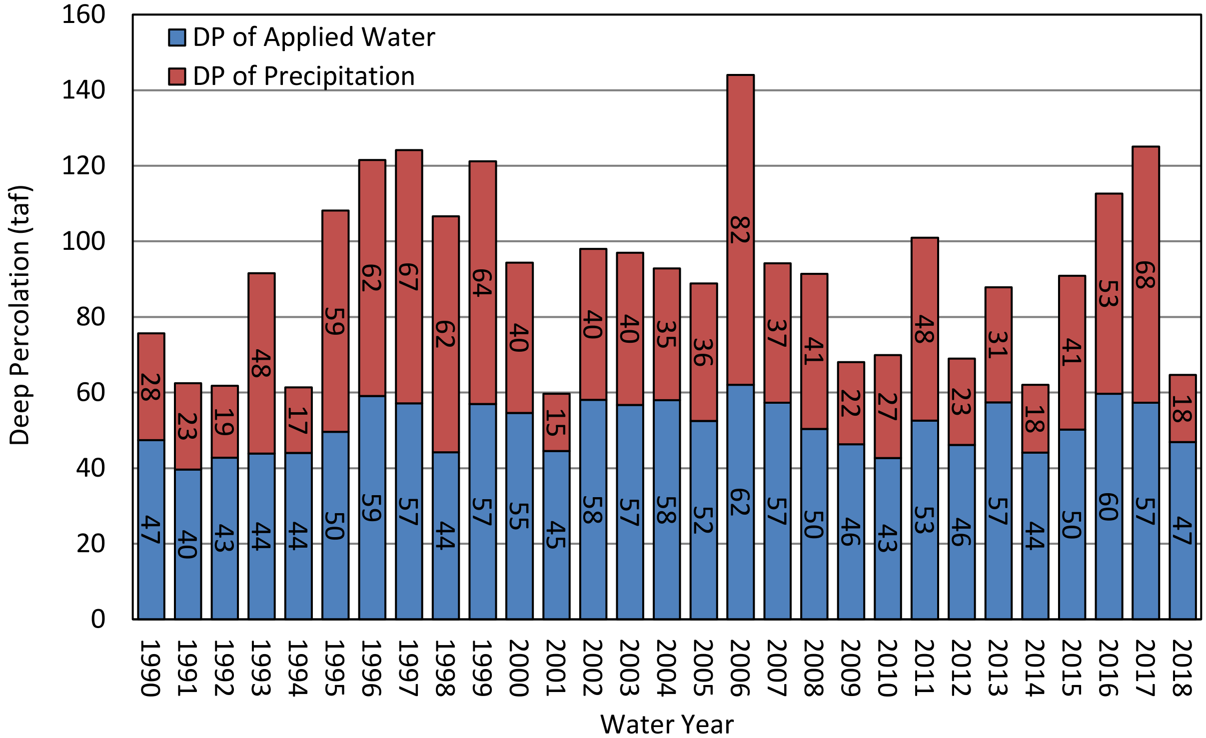

Figure 4.3. Deep Percolation by Water Year.

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Technical Memorandum (TM)

To: Larry Walker Associates

From: Davids Engineering, Inc.

Date: March 16, 2020

Subject: **Estimation of Historical Surface Water Diversions in the Shasta Valley**

Introduction

Davids Engineering (DE) was subcontracted by Larry Walker Associates (LWA) to assist in the development of a Groundwater Sustainability Plan (GSP) as part of implementation of the Sustainable Groundwater Management Act (SGMA) in the Shasta Valley. One task under this effort was to estimate historical surface diversions within the Valley based on available information from the watermaster service, which was established following the 1932 Shasta River Decree to supervise the distribution of water to the land areas included in the Decree. For a long time, the watermaster service was provided by the California Department of Water Resources (DWR); in recent years, it has been provided by the Scott Valley and Shasta Valley Watermaster District (SSWD).

Methodology

The Watermaster Key table[1] was used to identify watermaster service area, diversion number and location, winter and summer diversion rights (given in cubic feet per second, or cfs), and diversion priority; these stem from the 1932 Shasta River Decree. The eight watermaster service areas in the Shasta Valley are Beaughan Creek, Boles Creek, Carrick Creek, Jackson Creek, Little Shasta River, Lower Shasta River, Parks Creek, and Upper Shasta River. For each watermaster service area the total flow volume on record were summed by priority to determine total possible diversions. The Shasta Valley and surface water features corresponding to each watermaster service area are depicted in Figure 1.

[1] The Watermaster Key table is a dataset of decreed water rights that are under the supervision of the Scott Valley and Shasta Valley Watermaster District. It represents only the diversions serving adjudicated lands that are defined in the Orders Creating/Changing Watermaster Service Areas. This dataset does not represent actual diversion volumes and does not guarantee the accuracy of water rights. This dataset contains flow volumes used for developing the annual service fees and billing calculation. A brief presentation describing Service Area Orders can be found on the District's Homepage (sswatermaster.org), select *Responsibility of the Watermaster*. The Watermaster Key table does not include water rights that are outside the Watermaster Service Area or the subject of third-party agreements requiring the bypass of water or otherwise changing the operations and use of a diversion.

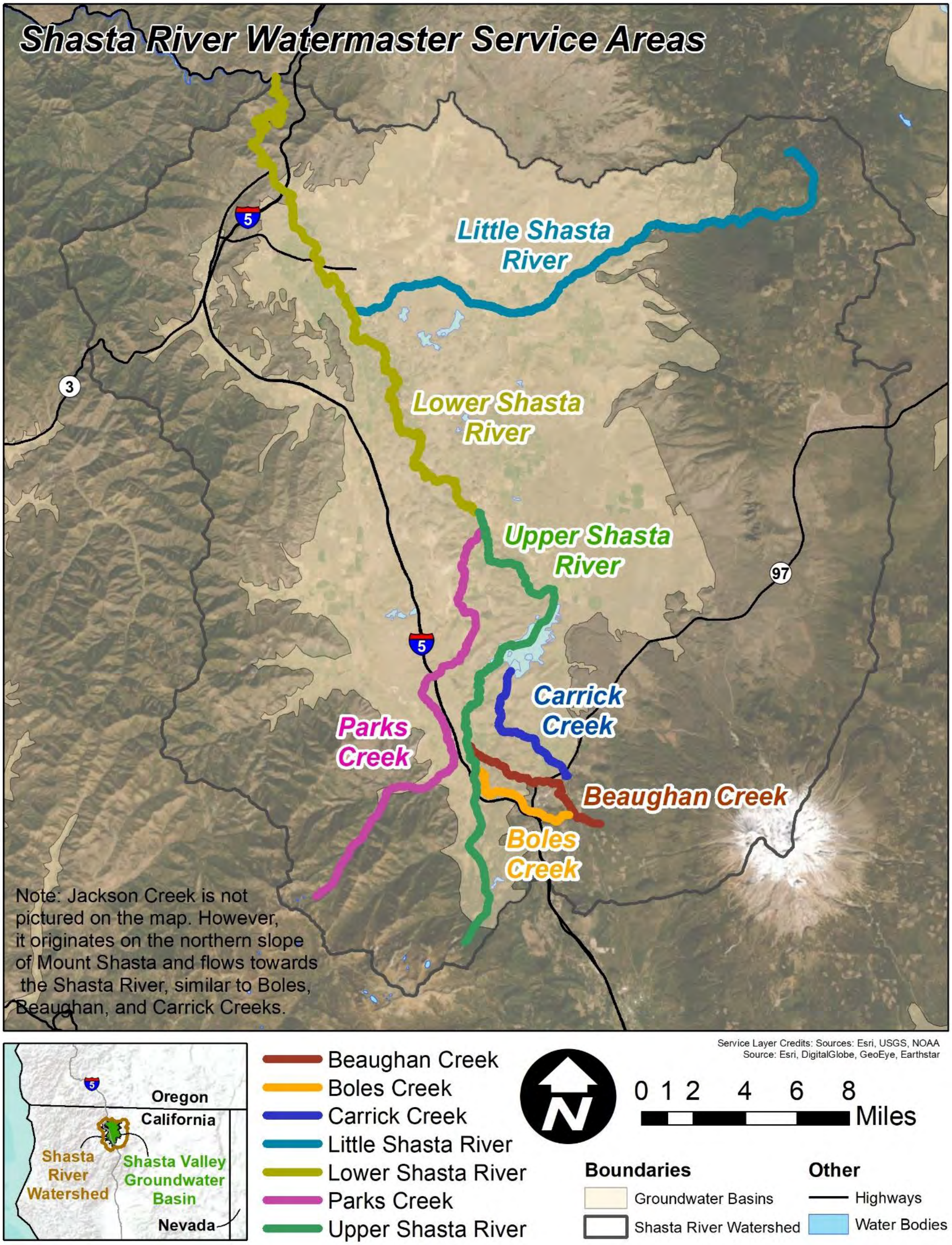

Figure 1. Shasta River Watermaster Service Areas.

Following this, years were selected to characterize Dry, Normal, and Wet conditions in the Shasta Valley. This selection was based on annual average precipitation[2], availability of information from the watermaster service in any given year, and two wet/dry water year indices for nearby areas.

One water year index referenced was the Surface Water Supply Index (SWSI) for the Klamath Basin in southern Oregon. Although the Shasta River watershed is part of the larger Klamath River watershed, the Klamath Basin SWSI is prepared by the state of Oregon and applies to the portions of Klamath Basin within Oregon. The northern portion of the Shasta Valley watershed is roughly 15 miles south of the California-Oregon border. The other water year index referenced was that for the Sacramento Valley, which lies approximately 100 miles to the south of the Shasta Valley.

For each selected year, the Summary of Operations report from the watermaster service was reviewed[3]. The report contains a narrative description of water availability, including a description of the amount of diversions possible throughout the season (typically described by priority, with reductions expressed as a percentage of a specific priority). These narrative descriptions for three of the service areas in the 2000 report are included in Figure 2 as an example. These descriptions were utilized in conjunction with the Watermaster Key table to estimate diversion flow rates on a monthly basis for each of the eight watermaster service areas. These in turn can be summed to determine overall diversions for the Shasta Valley on a monthly timestep for each selected year. The selected years can then be evaluated individually or can be averaged to determine results for Dry, Normal, and Wet Years to estimate diversions in years for which the watermaster reports were not available.

Results and Discussion

In addition to the presentation and discussion of results below, a spreadsheet is included as Attachment A with analysis calculations and results.

Year Selection

Years between 1991 and 2017 were considered for selection to characterize Dry, Normal, and Wet years. Table 1 shows the water year, average annual precipitation, the Klamath Basin SWSI value and category, the Sacramento Valley Water Year Index, whether a report was available from the watermaster service, and whether or not they year was selected as a Dry, Normal, or Wet year. The table is sorted to show average annual precipitation in ascending order.

The years selected to represent Dry years were 1991, 1992, 1994, and 2014; the years selected to represent Normal years were 2000, 2013, and 2016; and the years selected to represent Wet years were 1993, 1996, 1997, 1998, and 1999. The average water year[4] precipitation in the Shasta Valley for the years selected to characterize Dry, Normal, and Wet years was 17.8, 28.8, and 35.7 inches, respectively.

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[2] Annual average precipitation was calculated as the average of the 162 grid cells that represent the overall Shasta River watershed in the Parameter-elevation Regressions on Independent Slopes Model (PRISM) dataset. More information about PRISM is available at: http://www.prism.oregonstate.edu

[3] For years 2011 and prior, this report was produced by DWR and was titled 'Summary of Operations for Watermaster Service in Northern California: 2011 Season'. It included a report for every adjudicated watershed with watermaster service provided by DWR, of which the Shasta Valley was one. It is also not available for most years in the decade between 2001 and 2011. For years 2013 onwards, GEI Consultants, Inc. prepared this report for the SSWD and was titled 'Summary of Watermaster Services for the 2013 Season'. All the reports evaluated, both DWR and SSWD, were very similar in format and content.

[4] A water year represents the period from October 1 to September 30. For example, the 2010 water year corresponds from the period October 1, 2009 to September 30, 2010.

Parks Creek

Flows were above normal with all rights being filled until the middle of June. Flows decreased and third priorities were discontinued by the last week of July. Flows continued to decrease with less than 6 cfs by September.

Upper Shasta River

Upper Shasta River, Dale Creek, and Eddy Creek are on the same order of priorities. The flow was enough to fill all priorities until August 22. Flow decreased to 40 percent of second priorities in August and remained near that level until the end of September. Lower priorities below the Yreka Ditch received return flow and inflow from springs after August 22.

Little Shasta River

There was above-average snowmelt runoff this season on the Little Shasta River. The flows started at 100 percent of all priorities and decreased gradually to 80 percent of fifth priority on July 15. Flows decreased to 70 percent of fifth priority on August 1 and remained that way until the season's end.

Figure 2. Narrative Description Sample from Summary of Operations for Watermaster Service in Northern California: 2000 Season for Parks Creek, Upper Shasta River, and Little Shasta River Service Areas.

2015 was also initially selected to represent Normal years based on annual precipitation records. Preliminary review of this analysis questioned whether the year 2015 (in midst of a period of drought) was suitable for characterization of Normal years. The average annual precipitation record shows that this year experienced more precipitation than Dry years and less than Wet years; however, it does not address the timing of precipitation throughout the water year. In particular, reviewers noted that the 2015 water year had intense storms and greater precipitation early in the year and dry conditions later in the year. Also, the two water indices for this year indicate drier than average conditions. Based on this information, as noted above, the year 2015 was not included in the characterization of Normal years. However, since the analysis has been completed for this year, it is recommended that the efforts requiring diversion estimates for 2015 use the estimated diversions from the 2015 watermaster service records, rather than the Dry, Normal, or Wet year characterization.

The year 2002 could potentially also be reviewed and incorporated into the characterization of Normal years, but it is the only other year in this range for which watermaster service records are available.

The year selection data, analysis, and results are shown in the tab titled 'Precip_WY_Index' in the spreadsheet included as Attachment A.

Table 1. Dry, Normal, and Wet Year Criteria and Selections.

Water Year	Precip-itation (in)	Klamath Basin SWSI Category	Klamath Basin SWSI Value	Sacramento Valley Water Year Index	Watermaster Service Records Available	Selection
2014	15.90	Slightly Dry	-1.64	Critical	Yes	Dry
1994	16.23	Slightly Dry	-1.70	Critical	Yes	Dry
2001	18.16	Slightly Dry	-1.31	Dry	No	
1992	19.55	Moderately Dry	-2.57	Critical	Yes	Dry
1991	19.59	Slightly Dry	-1.88	Critical	Yes	Dry
2009	21.55	Near Average	-0.76	Dry	No	
2012	21.59	Near Average	-0.31	Below Normal	No	
2007	22.46	Near Average	-0.52	Dry	No	
2008	23.64	Near Average	0.04	Critical	No	
2002	24.56	Near Average	-0.78	Dry	Yes	
2013	25.28	Slightly Dry	-1.07	Dry	Yes	Normal
2004	26.48	Slightly Dry	-1.03	Below Normal	No	
2015	26.53	Slightly Dry	-1.35	Critical	Yes	
2010	26.54	Near Average	-0.94	Below Normal	No	
2000	29.88	Near Average	0.83	Above Normal	Yes	Normal
2005	30.92	Slightly Dry	-1.45	Above Normal	No	
2016	31.21	Near Average	-0.54	Below Normal	Yes	Normal
2003	31.63	Slightly Dry	-1.52	Above Normal	No	
2011	31.84	Near Average	0.93	Wet	No	
1999	32.55	Slightly Wet	1.89	Wet	Yes	Wet
1993	34.39	Near Average	0.12	Above Normal	Yes	Wet
1996	36.34	Near Average	0.54	Wet	Yes	Wet
1997	39.34	Slightly Wet	1.15	Wet	Yes	Wet
1995	41.89	Near Average	-0.31	Wet	Yes	
2017	41.96	Near Average	-0.12	Wet	Yes	
2006	42.00	Near Average	0.84	Wet	No	
1998	43.04	Slightly Wet	1.29	Wet	Yes	Wet

Estimated Surface Water Diversions

The total flow volume on record for the Shasta Valley for the summer (or irrigation) season, summed from the Watermaster Key table, was 446 cfs. For each of the years selected, the narrative description for each of the eight service areas was reviewed and used to estimate water diversions on a monthly basis by priority. As an example, if a report said that the flows decreased to 50% of the 5th priority on June 15th for a service area, then all 1st to 4th priority diversions would have an assumed 100% diversion value for the month of June. All 6th or higher priorities would have an assumed 50% diversion value for the month of June (unless prior comments indicated other, earlier diversion flow reductions), and the 5th priority diversion would have an assumed diversion value of 75% (e.g. 100% for the first half of the month, and 50% for the second half). These monthly estimates were then summed for each service area to develop total monthly estimated diversion for each selected year, and the average results for each year type were determined. The monthly results from March through October can be seen below in Figure 3. As expected, monthly diversions tend to increase from Dry to Normal to Wet years.

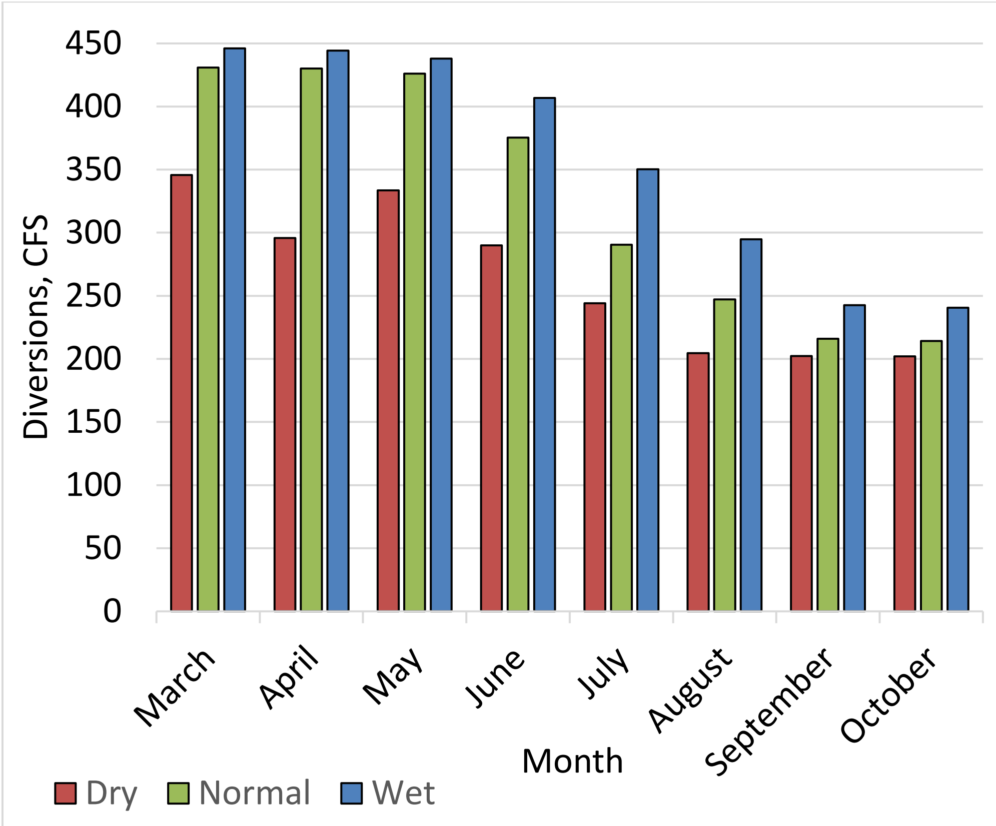

Figure 3. Estimated Average Monthly Surface Water Diversions in Dry, Normal, and Wet Years.

On a monthly pattern, also as expected, diversions tend to decrease as the irrigation season continues, representing decreasing water availability. The exception to this is from April to May during dry years, where an increase in diversions is seen. This could be explained by snowmelt at the end of spring resulting in higher surface water flows and higher diversions during the month of May. Figure 4 shows the average monthly diversions in Dry, Normal, and Wet years, but also includes the monthly diversions in the individually selected years as well. This demonstrates the variability from year to year in estimated monthly diversion volumes.

For the winter period (November through February), the total flow volume on record was calculated using the Watermaster Key table and totaled roughly 83 cfs (19% of the 446 cfs total for the summer period). Due to lesser diversion rates and greater water availability, it was assumed that 100% of winter diversions were possible in all year types[5].

A summary of the data, analysis, and results are included in Attachment A, a Microsoft Excel spreadsheet. It includes estimated monthly diversions for each priority water right in each of the eight service areas, which are then aggregated and summarized for the selected Dry, Normal, and Wet years as described in the spreadsheet.

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[5] During review by SSWD Staff, it was noted that not all diversion rights are exercised during the winter period. As a result, this assumption overestimates historical diversions for the winter period.

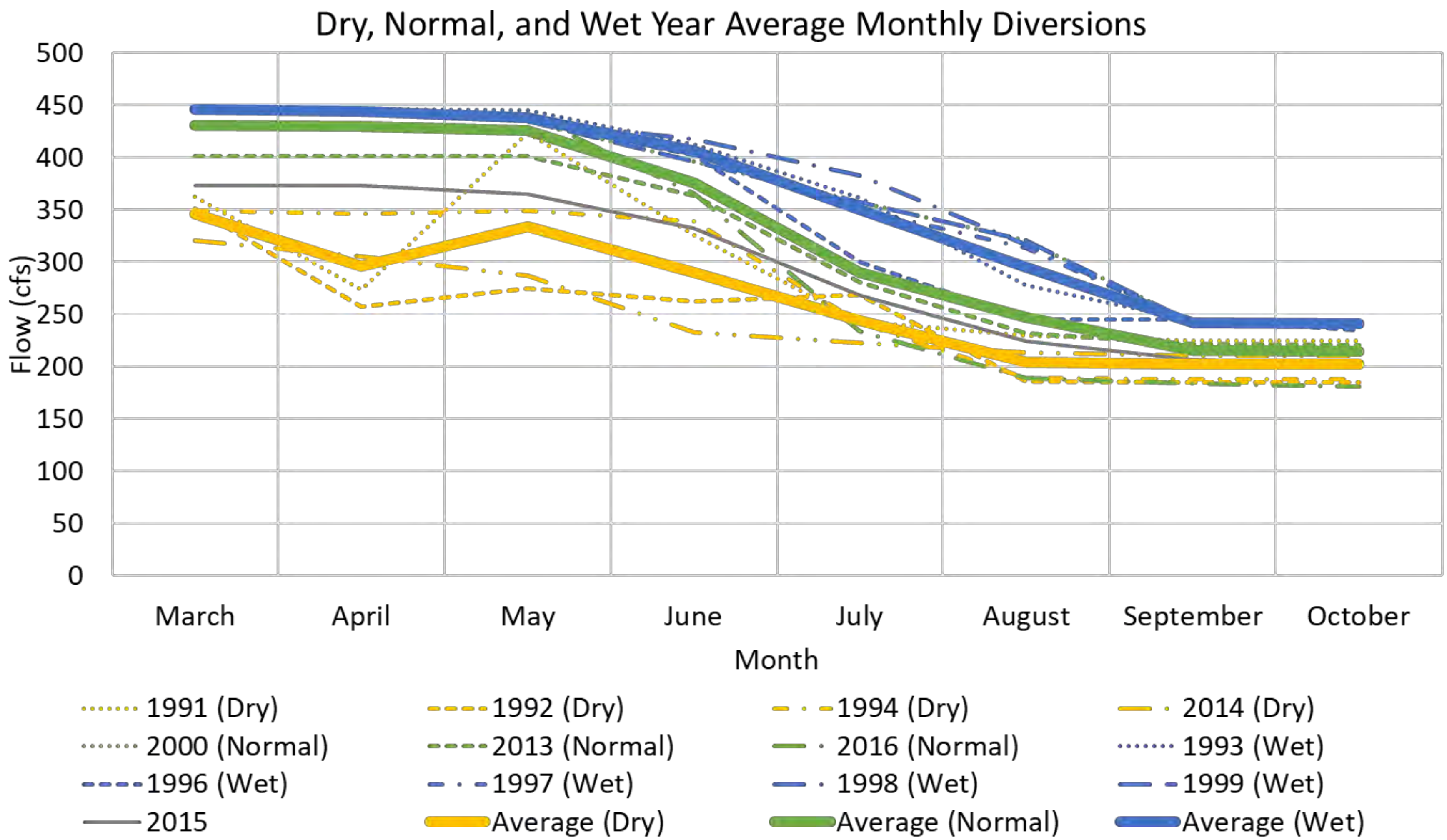

Figure 4. Estimated Monthly Surface Water Diversions in Individually Selected and Average Dry, Normal, and Wet Years.

Comparison to Other Data Sources

Two studies completed in 2009 and 2010 included actual measurements of diversions in the Shasta Valley. One included diversions from the Little Shasta River[6], and the other includes diversions from Parks Creek and the Shasta River (in the Upper Shasta River service area)[7]. Unfortunately, watermaster service records are not available for these years. However, the results from these studies can be compared to the Dry, Normal, and Wet year estimated diversions to evaluate how reasonable the results are[8].

The years 2009 and 2010 years had average annual precipitation of 21.6 and 26.5 inches, respectively. Both of these values are between the average annual precipitation values for the selected dry years (17.8 inches) and the selected Normal years (28.2 inches). Correspondingly, the results for the Musgrave Ditch show diversion volumes from March through October that are greater than estimated diversions during Dry years, but less than estimated diversions during Normal years. Figure 5 below shows the total March through October diversion volumes from these different sources for comparison.

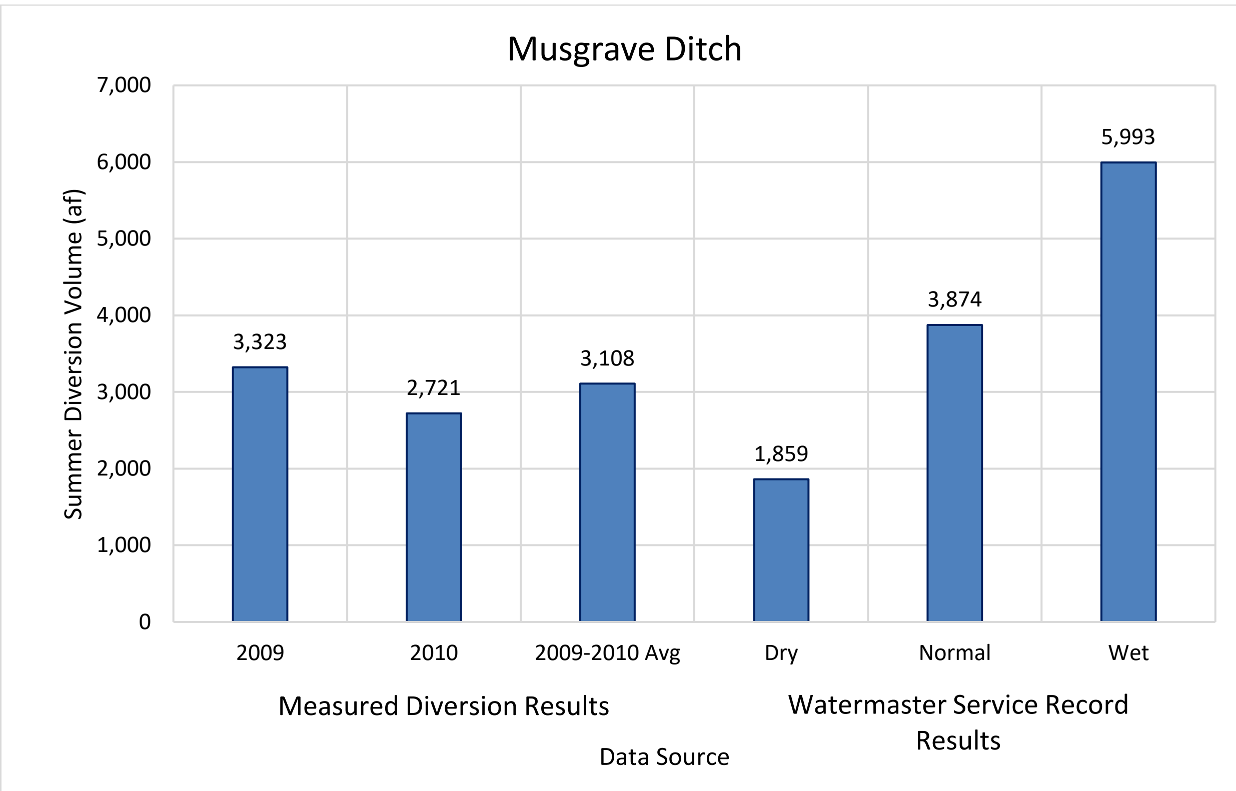

Figure 5. Musgrave Ditch Diversion Volume Comparison.

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[6] Little Shasta River Water Efficiency Study: A Cooperative Investigation Undertaken by the California Department of Fish and Game and the Cowley and Hart Ranches, Little Shasta, CA. February 2012

[7] Shasta Springs Ranch Irrigation Efficiency Study: A Cooperative Investigation Undertaken by the California Department of Fish and Game and Emmerson Investments. September 2011.

[8] Additional available measurement data from the SSWD that can be compared to Dry, Normal, and Wet year estimated diversions include documented measurement information from GEI Consultants, Inc. for specific locations and measurement records kept by the SSWD from July 2018 onwards.

Interestingly, although there was more precipitation in 2010 as compared to 2009, there was a smaller volume of measured diversions. This comparison was also completed for Shelly Ditch and Hart-Haight Ditch with similar results: measured diversions in 2009 and 2010 were between estimated diversion in Dry and Normal years, and measured diversion volumes were smaller in 2010 than 2009. This comparison was also done for the Shelly Ditch and Hart-Haight Ditch diversions from the Little Shasta River, yielding similar results for each of those sites.

The comparison was also done for the Evans Spring Ditch, which holds 1st priority diversion rights estimated to be 100% filled in Dry, Normal, and Wet years. However, actual measured diversions show that this number fluctuates from year to year and in both 2009 and 2010 was lower than the estimated diversions for all year types. This may reveal some of the limitations and uncertainty of using watermaster service records to estimate surface water diversions. Figure 6 below shows the Evans Spring Ditch comparison.

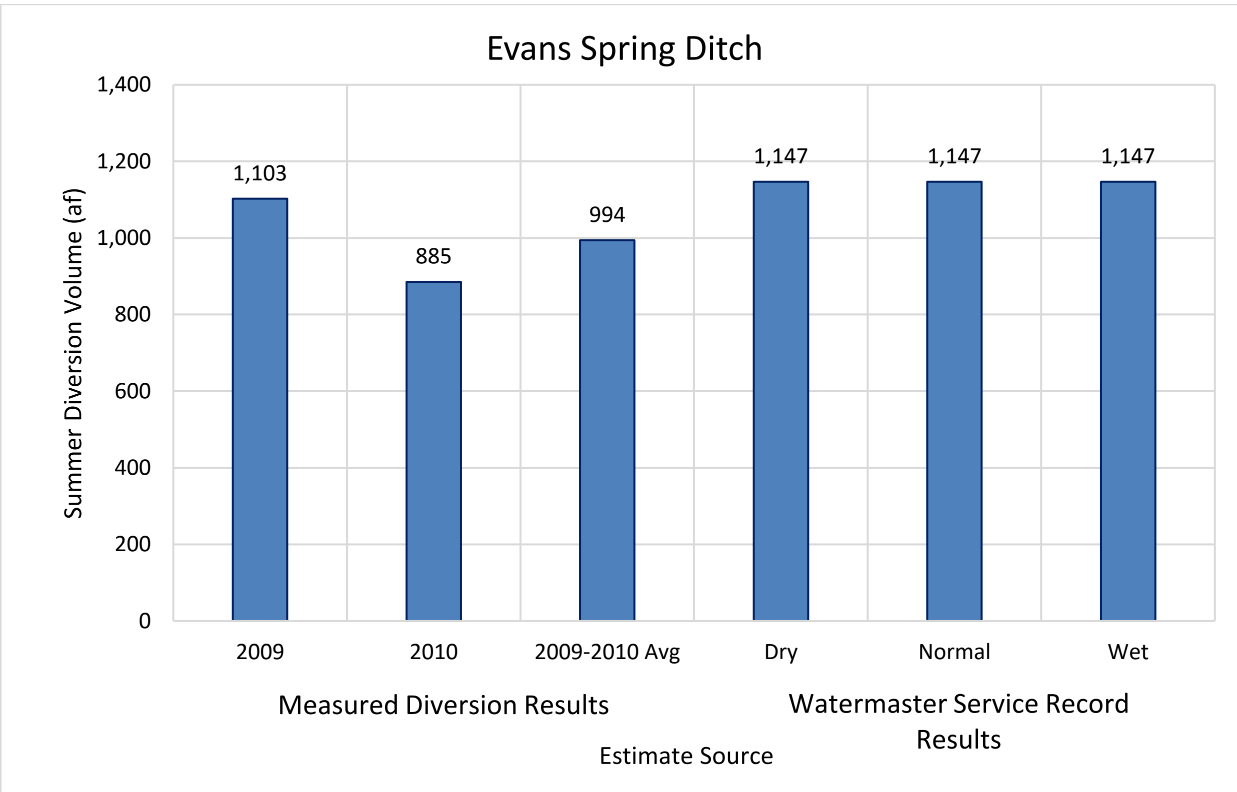

Figure 6. Evans Spring Ditch Diversion Volume Comparison.

In 2010, diversions were measured at five points along lower Parks Creek and the Shasta River below Lake Shastina and upstream of the Parks Creek confluence. A similar comparison was made between measured diversions and estimate diversions during Dry, Normal, and Wet years. At two of the diversion points, the results were the same as those for the Musgrave Ditch, Shelly Ditch, and Hart-Haight Ditch, in which the two datasets aligned relatively well. For the other three diversion points, the measured diversions in 2010 were greater than the estimated diversions in all year types. To illustrate this, Figure 7 below shows the comparison for the HIG Pump diversion.

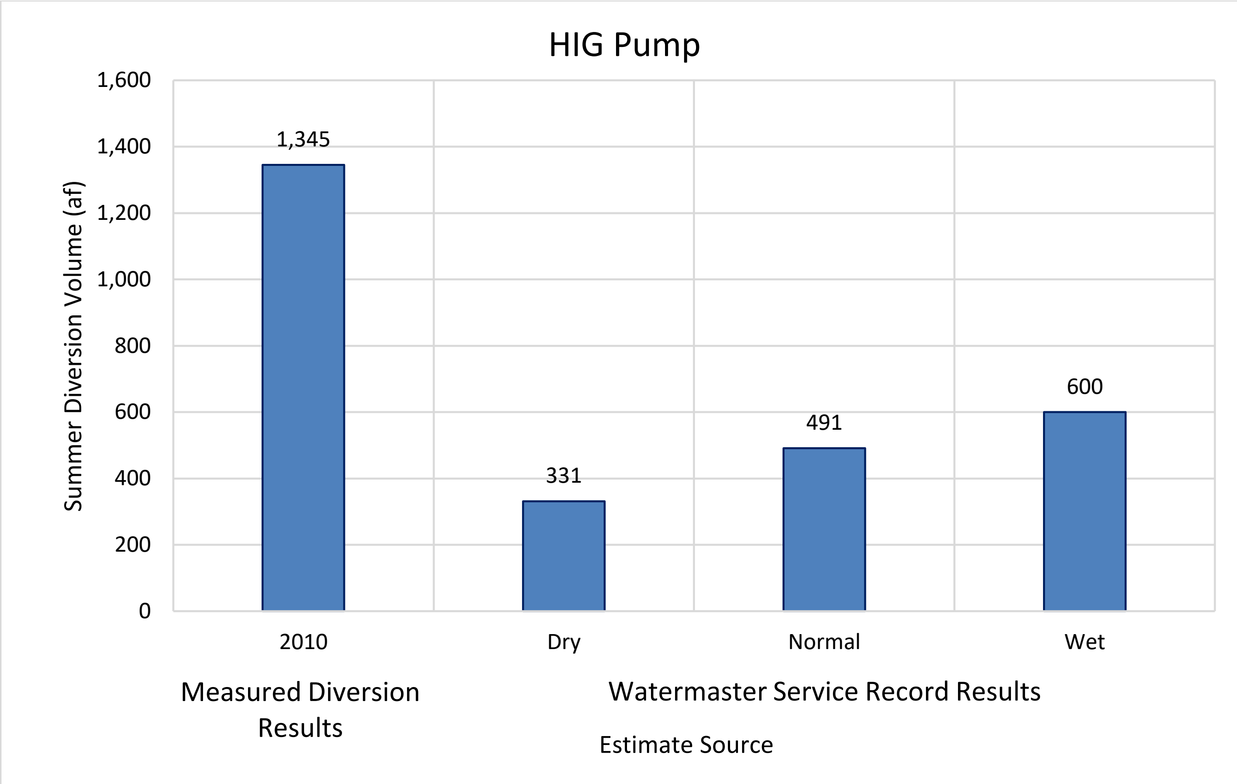

Figure 7. HIG Pump Diversion Volume Comparison.

There are cases in the Shasta Valley where water rights under the Decree and riparian rights use the same diversion location and infrastructure, which is a potential explanation for the greater volume of measured diversions than estimated diversions. Additionally, although this diversion is in the Upper Shasta River service area, it is located below Lake Shastina and Dwinnell Dam. The Upper Shasta River service area tends to have decreasing water availability and decreasing diversions as the irrigation season continues (based on watermaster service records). However, it is theorized that this diversion and other diversions below Lake Shastina are able to be met consistently throughout the year through releases from Dwinnell Dam. The watermaster service records state that releases from Lake Shastina to water users directly downstream of the reservoir are the responsibility of the watermaster.

The three sites with higher measured diversions as compared to estimated diversions may reveal other limitations and uncertainties with using watermaster service records to estimate surface water diversions.

In total, results for nine diversions included in the two studies were compared to the corresponding Dry, Normal, and Wet year estimated diversions. A summary is shown below in Table 2, with the detailed comparison and comments for three of the nine diversions presented previously.

Table 2. Comparison of Measured Diversions to Estimated Diversions.

Location	Measured Diversion Results (af)			Watermaster Reports (af)		
	2009	2010	2009-2010 Avg	Dry	Normal	Wet
Shelly Ditch	888	623	778	581	1,279	2,007
Musgrave Ditch	3,323	2,721	3,108	1,859	3,874	5,993
Hart-Haight Ditch	2,084	2,181	2,203	1,508	3,329	5,012
Evans Spring Ditch	1,103	885	994	1,147	1,147	1,147
HIG Gravity	-	1,133	-	98	146	178
HIG Pump	-	1,345	-	331	491	600
Parks Creek 2	-	354	-	293	549	591
Parks Creek 3&4	-	614	-	346	756	736
Parks Creek 5	-	519	-	94	194	189

Conclusions and Recommendations

These results were presented and discussed with SSWD staff to determine whether the interpretation of the watermaster service records was reasonable, and whether there were better data sources to utilize to estimate historical surface water diversions. SSWD staff shared that flow volumes from the Decree are used for billing purposes for watermaster service but are not always reflective of historical diversion flow rates or the resulting volumes. Actual diversion amounts at a specific diversion point can differ from year to year, even in times of similar water availability. The methodology also does not account for diversions that may be temporarily inactive (e.g. if a field is fallowed in a particular year and surface water is not diverted). SSWD staff anticipated that the methodology used likely overestimated diversions. Through discussion with SSWD staff, it was determined that watermaster service records utilized are the most readily available data source for estimating historical diversions.

For future water accounting efforts or water budgets, more accurate data sources should be identified or developed. In recent years, the SSWD has been collecting more reliable and accurate diversion data that could be used in place of estimated diversions based on the methodology described here. Also, recent legislation in Senate Bill 88 (SB 88) requires surface water diverters statewide to measure and report diversions. This legislation does not apply to adjudicated water rights under the Decree, since the watermaster service already regulates and reports on the timing and quantity of diversions. However, this legislation does apply to riparian water rights (and potentially other water rights) not covered under the Decree and included in the SSWD watermaster service area. There are cases in the Shasta Valley where water rights under the Decree and riparian rights use the same diversion location and infrastructure. SB 88 will provide additional data concerning diversion timing and volume that will be valuable for improving surface water diversion estimates for future water accounting purposes. Additional data collection or coordination with diverters could also be completed to better understand diversion timing and volumes moving forward.

Attachment A: Shasta_Valley_Watermaster_Diversion_Summary.xlsx

Attachment A is a Microsoft Excel spreadsheet used determine and present results of an analysis to estimate historical surface water diversion in the Shasta Valley under the 1932 Shasta River Decree. The datasets used in the analysis were the watermaster key table and watermaster service records (which include narrative descriptions of how much water was available for diversion, and if supplies are limited, approximately when surface diversions were reduced or ended). Based on annual precipitation and water year indices for the Sacramento Valley and Klamath Basin (and Watermaster Report availability), years were selected for evaluation to represent Dry, Normal, and Wet conditions.

The tabs in the spreadsheet are described below:

- Readme – this tab explains the contents of the spreadsheet.
- Summary - this tab presents average irrigation season diversions in cfs and as a percentage of total water rights for the valley as a whole and for the different service areas; it also includes summary figures.
- Aggregated - this tab contains monthly data for the years selected for evaluation of watermaster reports to estimate surface water diversions.
- Precip_WY_Index - this tab presents the data used to select years for evaluation and characterization of Dry, Normal, and Wet years.
- BeaughanCreek_EstDivs – this tab presents estimated monthly diversions for select years for the Beaughan Creek service area.
- BolesCreek_EstDivs – this tab presents estimated monthly diversions for select years for the Boles Creek service area.
- CarrickCreek_EstDivs – this tab presents estimated monthly diversions for select years for the Carrick Creek service area.
- JacksonCreek_EstDivs – this tab presents estimated monthly diversions for select years for the Jackson Creek service area.
- LittleShasta_EstDivs – this tab presents estimated monthly diversions for select years for the Little Shasta River service area.
- LowerShasta_EstDivs – this tab presents estimated monthly diversions for select years for the Lower Shasta River service area.
- ParksCreek_EstDivs – this tab presents estimated monthly diversions for select years for the Parks Creek service area.
- UpperShasta_EstDivs – this tab presents estimated monthly diversions for select years for the Upper Shasta River service area.

Appendix 3-A. Data Gap Assessment

Contents

Introduction

Multiple datasets were utilized during development of this GSP to characterize current and historical Basin conditions. Monitoring networks were designed to support the evaluation of Basin conditions throughout GSP implementation, particularly with respect to the six sustainability indicators. The representative monitoring points (RMPs) in these monitoring networks are sites at which quantitative values for minimum or maximum thresholds, measurable objectives, and interim milestones are defined. New RMPs will be considered for the 5-years update based on the suggested expanded monitoring network. Data gaps that were identified throughout the GSP development process can be categorized into:

I. Data gaps in information used to characterize current and historical basin conditions.
II. Data gaps in monitoring networks developed to evaluate future Basin conditions which will be used in reporting and tracking Basin sustainability.
III. Additional data or information valuable for measuring progress towards the Basin's sustainability goal. This information has been identified as information that may be useful but has not been confirmed as a data gap.

These data gaps were identified based on spatial coverage of data, the period for which data are available, frequency of data collection, and representativeness of Basin conditions. An overview of data gaps in the first category is provided in Chapter 2, as part of the characterization of past and current Basin conditions, and the data gaps in the second and third categories are in Chapter 3 as part of descriptions of the monitoring networks. This appendix details the identification of data gaps and uncertainties in each of the categories and the associated strategies for addressing them. The process of data gap identification, and development of strategies to fill data gaps is illustrated in Figure 1 below, sourced from the Monitoring Networks and Identification of Data Gaps Best Management Practice (BMP), provided by DWR (2016). Data gaps and monitoring networks may be revised during continued development of the numerical model.

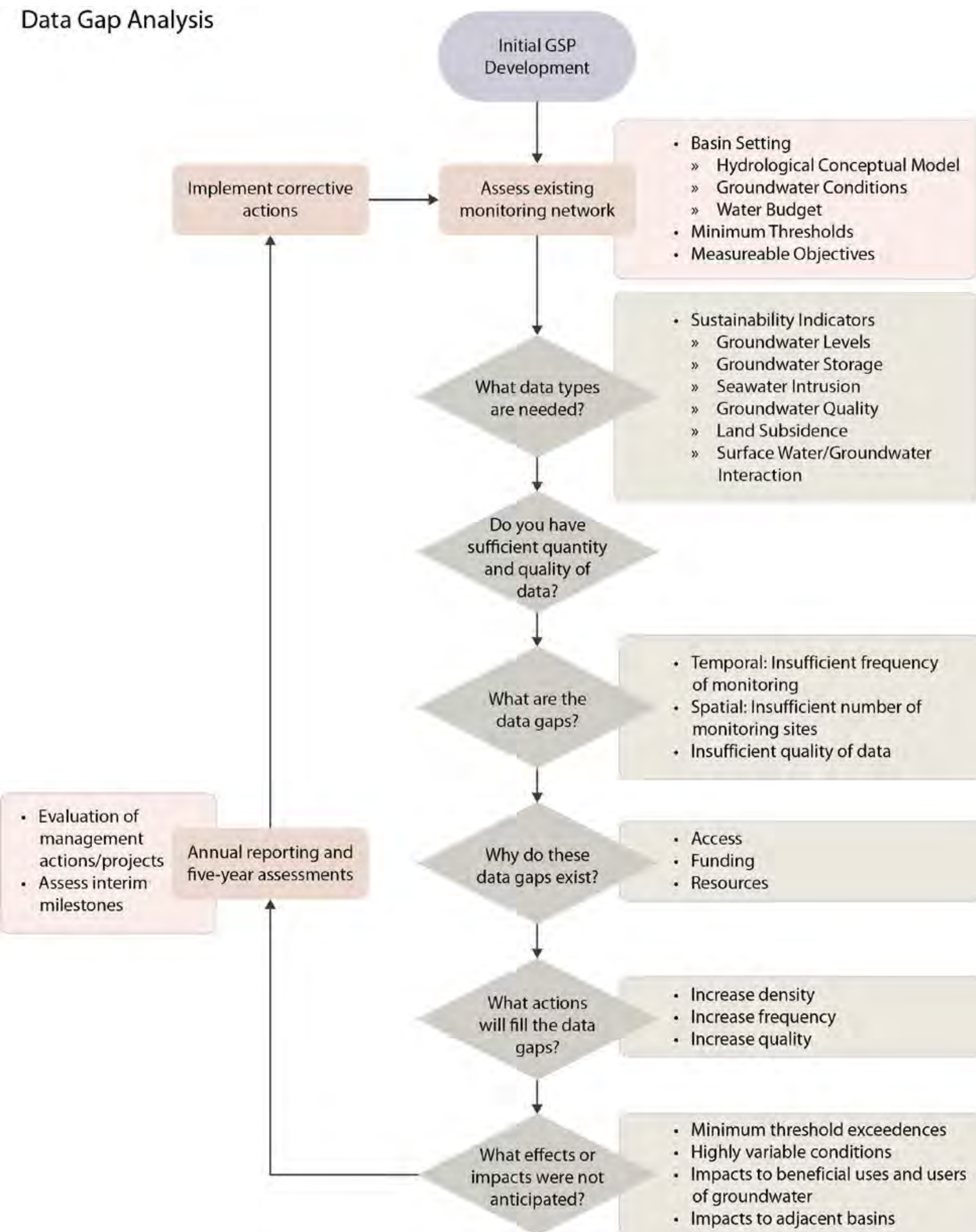

Figure 1: Data Gap Analysis Flowchart (DWR 2016).

I. Data Gaps in Existing Information Used for Basin Characterization

Definition of the hydrogeological conceptual model (HCM) is a key requirement for understanding the Basin setting and characterizing existing and historical Basin conditions. An accurate assessment of the physical setting and processes that control groundwater occurrence in the Basin is foundational to development of the sustainable management criteria and monitoring networks in Chapter 3 and identification of projects and management actions in Chapter 4.

Identification of data gaps and uncertainty within the HCM is a requirement per 23 CCR 354.14 (b)(5) and is important to choosing locations and types of additional monitoring that reduce these gaps and uncertainties.

Identification of Data Gaps

The HCM is detailed in Chapter 2 of this GSP. Data gaps and uncertainties were identified throughout development of the HCM and are briefly discussed in Chapter 2 under applicable subsections. A discussion of the components of the HCM for which key datasets were used, associated data gaps, and uncertainties is provided below. The following sections also discuss the current data networks (Table 1).

Table 1: All monitoring locations and data in Shasta Valley Groundwater Basin.

Site ID	Network	Station Name	Operator
BZR	Atmosphere	BRAZIE RANCH	CA Dept of Forestry and Fire Protection
CIMIS_260	Atmosphere	260	SVRCD
CIMIS_261	Atmosphere	261	SVRCD
LSH	Atmosphere	LITTLE SHASTA	Goosenest Ranger District
PRK	Atmosphere	PARKS CREEK	Mount Shasta Ranger District
SVB	Atmosphere	BOLAM	Shasta Valley Resource Conservation District
SVG	Atmosphere	GOOSENEST	Shasta Valley Resource Conservation District
SWT	Atmosphere	SWEETWATER	Mount Shasta Ranger District
WED	Atmosphere	WEED AIRPORT	CA Dept of Forestry and Fire Protection
YRK	Atmosphere	YREKA	US Forest Service
MPD	Diversion	MWCD PARKS CK DIVERSION NR EDGEWOOD	CA Dept of Water Resources/North Region Office
SHA_01	GWL - continuous	WestOfWeed	GSA

Table 1: All monitoring locations and data in Shasta Valley Groundwater Basin. *(continued)*

Site ID	Network	Station Name	Operator
SHA_02	GWL - continuous	BigSprings Rockhouse	GSA
SHA_03	GWL - continuous	AirportSouth	GSA
SHA_04	GWL - continuous	OberlinRd	GSA
SHA_05	GWL - continuous	Justin Holmes	GSA
SHA_06	GWL - continuous	LSCSD	GSA
SHA_08	GWL - continuous	Steve Mains	GSA
SHA_09	GWL - continuous	Ray Casterline	GSA
SHA_10	GWL - continuous	Blair Hart	GSA
SHA_11	GWL - continuous	A28	GSA
SHA_17	GWL - continuous	OldWestsideRd	GSA
SHA_172	GWL - continuous	FrontierRd	GSA
SHA_174	GWL - continuous	Ginger	GSA
SHA_18	GWL - continuous	BigSpringsStockWell	GSA
SHA_24	GWL - continuous	EastOfBigSprings	GSA
SV01	GWL - continuous	417660N1224811W001	GSA
SV02	GWL - continuous	417096N1225453W001	GSA
27D002M	GWL - periodic	417258N1225337W001	GSA
42N05W08E001M	GWL - periodic	415017N1224564W001	GSA
42N05W20J001M	GWL - periodic	414719N1224394W001	GSA
42N06W10J001M	GWL - periodic	414987N1225202W001	GSA
43N05W07K001M	GWL - periodic	415867N1224630W001	GSA
43N05W11A001M	GWL - periodic	415952N1223848W001	GSA
43N05W19F002M	GWL - periodic	415601N1224718W001	GSA
43N06W15F003M	GWL - periodic	415748N1225300W001	GSA
43N06W22A001M	GWL - periodic	415637N1225176W001	GSA
43N06W33C001M	GWL - periodic	415351N1225474W001	GSA
44N05W14M002M	GWL - periodic	416595N1223971W001	GSA
44N05W21H001M	GWL - periodic	416462N1224190W001	GSA
44N05W32C002M	GWL - periodic	416237N1224524W001	GSA
44N05W34H001M	GWL - periodic	416191N1223997W001	GSA
44N06W10F001M	GWL - periodic	416774N1225301W001	GSA
44N06W18Q001M	GWL - periodic	416563N1225813W001	GSA
44N06W27B001M	GWL - periodic	416397N1225224W001	GSA
45N05W07H002M	GWL - periodic	417638N1224574W001	GSA
45N06W10A001M	GWL - periodic	417704N1225126W001	GSA
45N06W26C002M	GWL - periodic	417258N1225083W001	GSA
45N06W30E001M	GWL - periodic	417220N1225928W001	GSA

Table 1: All monitoring locations and data in Shasta Valley Groundwater Basin. *(continued)*

Site ID	Network	Station Name	Operator
46N05W31F001M	GWL - periodic	417941N1224710W001	GSA
46N05W33J001M	GWL - periodic	417916N1224217W001	GSA
SV03	GWL - periodic	415444N1225387W001	GSA
SV03A	GWL - periodic	416083N1223932W001	GSA
SV04	GWL - periodic	414686N1222830W001	GSA
A12-LBF	GWL - transects	SR-A12-LBF	SVRCD
A12-LBN	GWL - transects	SR-A12-LBN	SVRCD
A12-RBF	GWL - transects	SR-A12-RBF	SVRCD
A12-RBN	GWL - transects	SR-A12-RBN	SVRCD
A12-SWE	GWL - transects	SR-A12-SWE	SVRCD
A28-LBF	GWL - transects	SR-A28-LBF	SVRCD
A28-LBN	GWL - transects	SR-A28-LBN	SVRCD
A28-RBF	GWL - transects	SR-A28-RBF	SVRCD
A28-RBN	GWL - transects	SR-A28-RBN	SVRCD
A28-SWE	GWL - transects	SR-A28-SWE	SVRCD
LL-LBF	GWL - transects	LSR-LL-LBF	SVRCD
LL-LBN	GWL - transects	LSR-LL-LBN	SVRCD
LL-RBF	GWL - transects	LSR-LL-RBF	SVRCD
LL-RBN	GWL - transects	LSR-LL-RBN	SVRCD
LL-SWE	GWL - transects	LSR-LL-SWE	SVRCD
DWN	Lake Storage	DWINNELL	US Bureau of Reclamation
BS	Monthly Spring Discharge	Big Springs Creek	SVRCD
Clear	Monthly Spring Discharge	Clear Spring	SVRCD
Evans	Monthly Spring Discharge	Evans Spring	SVRCD
HIG	Monthly Spring Discharge	Hole in the Ground Spring	SVRCD
Kettle	Monthly Spring Discharge	Kettle Spring	SVRCD
LS	Monthly Spring Discharge	Little Springs Creek	SVRCD
LSR	River Flow	LITTLE SHASTA R NR MONTAGUE	Nature Conservancy
SPU	River Flow	SHASTA R AT GRENADA PUMP PLANT	CA Dept of Water Resources/North Region Office
SRE	River Flow	SHASTA R NR EDGEWOOD	CA Dept of Water Resources/North Region Office
SRM	River Flow	SHASTA RIVER NEAR MONTAGUE	US Geological Survey

Table 1: All monitoring locations and data in Shasta Valley Groundwater Basin. *(continued)*

Site ID	Network	Station Name	Operator
SRY	River Flow	SHASTA RIVER NEAR YREKA	US Geological Survey
WW	River Flow	Water Wheel	NA
PBS	River Stage	PARKS CK NR BIG SPRINGS	CA Dept of Water Resources/North Region Office
PME	River Stage	PARKS CK BLW MWCD DIVERSION NR EDGEWOOD	CA Dept of Water Resources/North Region Office
SAG	River Stage	SHASTA R ABV CTY RD A-12 NR GRENADA	CA Dept of Water Resources/North Region Office
SBG	River Stage	SHASTA R BLW CTY RD A-12 NR GRENADA	CA Dept of Water Resources/North Region Office
SRG	River Stage	SHASTA R NR GRENADA	CA Dept of Water Resources
DFB	Superceded	DWINNELL DAM INSTREAM FLOW RELEASES	CA Dept of Water Resources/North Region Office
DRE	Superceded	DWINNELL RESERVOIR NEAR EDGEWOOD	CA Dept of Water Resources/North Region Office
DSW	Superceded	DWINNELL DAM SEEPAGE WEIR	CA Dept of Water Resources/North Region Office
SRX	Superceded	SHASTA R CROSS CNL WEIR AT DWINNELL DAM	CA Dept of Water Resources/Div of Environmental Services
YCK	Superceded	YREKA CREEK AT ANDERSON GRADE ROAD	Shasta Valley Resource Conservation District

Climate

Long-term records are available from National Oceanic and Atmospheric Administration (NOAA) weather stations in and around Shasta Valley. A list of the applicable NOAA weather stations used in development of the climate component of the HCM can be found in Section 2.2.1.2. Data from these stations were used to evaluate historical and current precipitation (including snow pack measurements) and evaluate spatial and temporal (seasonal and long-term) trends in precipitation. The new HyDAS station installed through contribution of the SVRCD will provide the missing information about snow pack on the Shasta mountain.

Current and historical climate data is readily available for the Shasta watershed (Watershed) and has sufficient spatial coverage, frequency of measurement and length of record to evaluate current and historical conditions and identify trends. Based on an initial assessment of the data, a rainfall gradient is suspected but not confirmed in the Watershed.

Geology

Gaps in geological information are the largest component of the data gap for the HCM. As fully described in Chapter 2, geology of the Shasta valley is extremely complex and more data are critical to fully understand flow path in the aquifer. Through an effort by DWR, AEM surveys were conducted in Fall 2021, the geophysical analysis by DWR will be complete in six months, and will complement the geophysical study presented in Appendix 2-G.

Aquifer tests and isotopes data collection will further support the refinement of the geological understanding of the basin.

Soils

A 1983 soil survey of central Siskiyou County (USDA 1983) was the primary source used for development of this component of the HCM. Additionally, soil properties as they relate to groundwater recharge were characterized through the Soil Agricultural Banking Index (SAGBI) ratings for the soil series in the Shasta Valley area can be viewed on a web application, developed by the California Soil Resource Lab at the University of California at Davis and University of California Agriculture and Natural Resources (UC Davis Soil Resource Lab and University of California Agriculture and Natural Resources 2019).

No data gaps were identified in the development of this section.

Hydrology and Identification of Interconnected Surface Water Systems

Significant data gaps have been identified regarding the hydrology of the Basin, including limited streamflow and spring flow data, which severely limit the ability to simulate surface waters in the Shasta Watershed Groundwater Model (SWGM) and to define sustainability management criteria (SMCs) for interconnected surface waters (ISWs). New stream gages will be installed along the main stem of the Shasta River and its tributaries, particularly in the upper watershed. Continuous monthly spring flow monitoring, completed by the Shasta Valley Resource Conservation District in conjunction with the GSA, began in July 2020 at six springs (see Section 2.2.2.6 and Figure 3). Establishing a historical record at all new stream gages and spring flow monitoring is critical for improving hydrology data gaps. The number of new instruments and frequency and length of measurements will depend on funding. Current instrumentation is shown in Figure 2. Improved communication and cooperation between the GSA and agencies operating within the Basin should lead to the release of additional relevant streamflow data.

While interconnected surface water systems were identified in Section 2.2.2.6, there are uncertainties in this identification. A continuous saturated zone between the stream and aquifer is assumed for all locations that were identified as interconnected surface waters, as no locations are known to be separated from the water table by thick unsaturated zones, but this has not been physically confirmed. Data gaps concern the connection of Big Springs, how quickly it responds to groundwater pumping, and day to day variations are attempting to be addressed before setting SMC criteria on Big Springs Creek. New stream gages and monitoring wells with continuous data collection at springs and tributaries may allow additional ISWs SMCs to be set and enable better calibration of the Shasta Watershed Groundwater Model (SWGM). The Big Springs Complex will be the primary target of improved monitoring and data collection.

The current data set only allows for preliminary ISW SMCs on the main Shasta River. For other locations (springs and tributaries) there is insufficient groundwater and surface water monitoring data. The numerical groundwater-surface water model cannot be used for this calculation because there is insufficient surface water and groundwater monitoring data near the river to calibrate the model to better represent the flow exchange. After calibration the SWGM will also be used to evaluate groundwater contributions during the entire year.

The current ISW SMC temporary approach will be updated with new surface water, spring, and groundwater data that started collection in 2019 to quantify baseflow over more reaches and times. This will be combined with the updated model to create new SMCs for Big Springs and Shasta River tributaries. The UC Davis Center for Watershed Sciences (CWS) is in the process of developing an in-stream flow assessment of the Little Shasta River (LSR) and have been sharing information that will support the GSA in eventually creating ISW criteria for the LSR as currently there is insufficient data to quantify streamflow depletions or more specifically streamflow depletions due to groundwater extraction. A PMA in Chapter 4 addresses the ISW data gap.

Identification of Groundwater Dependent Ecosystems

Data from the The Nature Conservancy, and other sources (as detailed in Section 2.2.2.7) was used to identify groundwater dependent ecosystems (GDEs) in the Basin. While the results of the initial GDE inventory were evaluated by the Surface Water Ad-Hoc Committee, physical verification has not been completed. Uncertainty exists regarding habitat maps and presence of certain species in the Basin. Additionally, groundwater levels near the GDEs are poorly constrained and the groundwater level monitoring network must be expanded appropriately. There is therefore some uncertainty between riparian and non-riparian GDEs that were mapped and the existence and extent of these GDEs on the ground.

A PMA in Chapter 4 addresses the GDE data gap. Satellite images evaluated twice per year would provide information on the health of GDEs over time and would be critical to fully understand their seasonal cycles.

Current and Historical Groundwater Conditions

Groundwater Elevation Data

Groundwater elevation data is sourced primarily from the California Statewide Groundwater Elevation Monitoring Program (CASGEM), and from DWR. Well data is available dating back to the 1960s and wells have adequate spatial coverage of the Basin, measurement frequency and period of record Figure 4. There are three water level networks: continuous, periodic, and transects. Continuous wells are measured at 10 minute intervals continuously all year, and provide the best data sets for monitoring and model calibration Figure 5. Periodic wells are measured bi-annually. Generally these frequencies are sufficient to enable determination of seasonal, short-term, and long-term trends Figure 6. However they do not provide insights on season high and low values

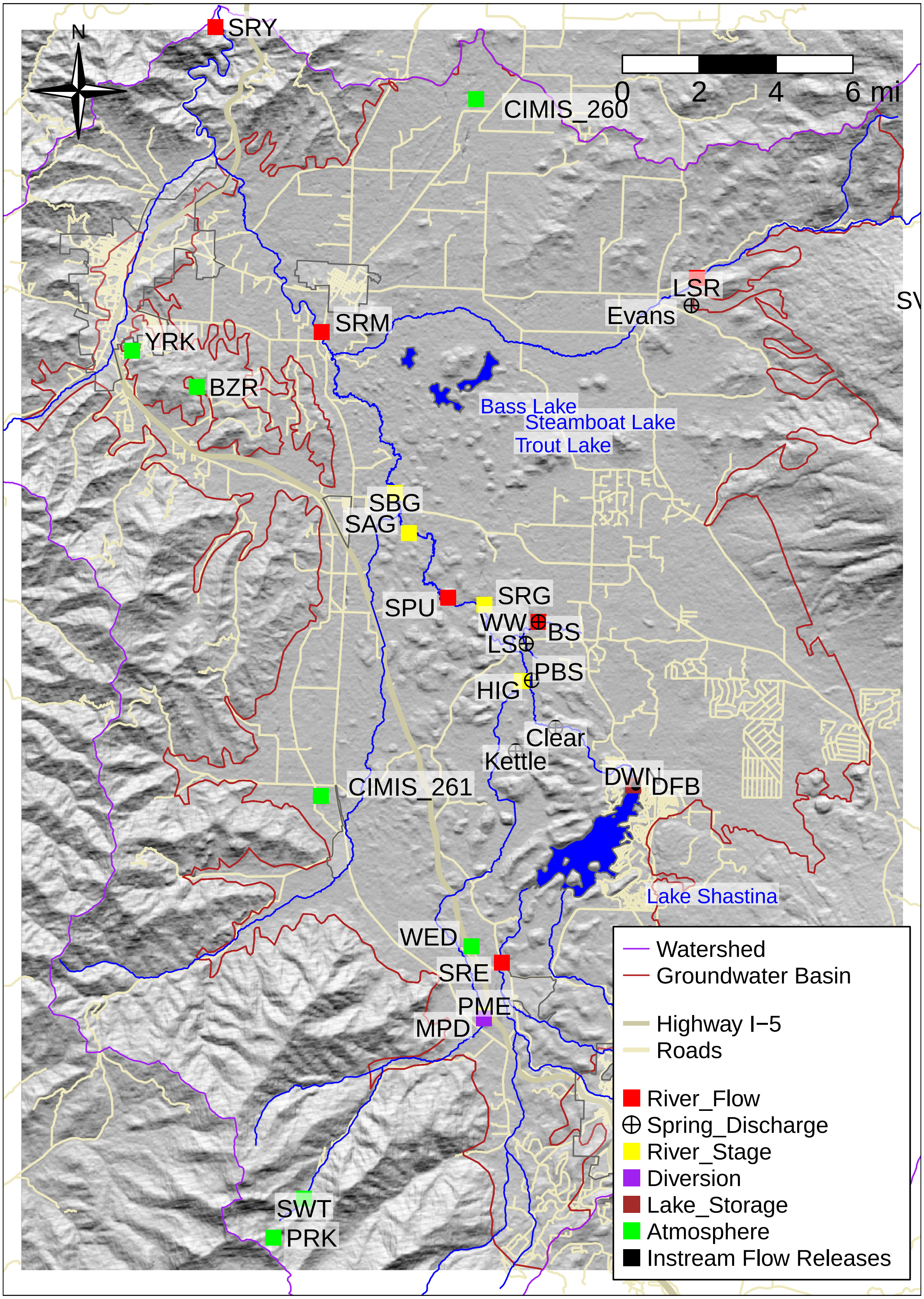

Figure 2: Hydrology and Surface Water Monitoring Networks.

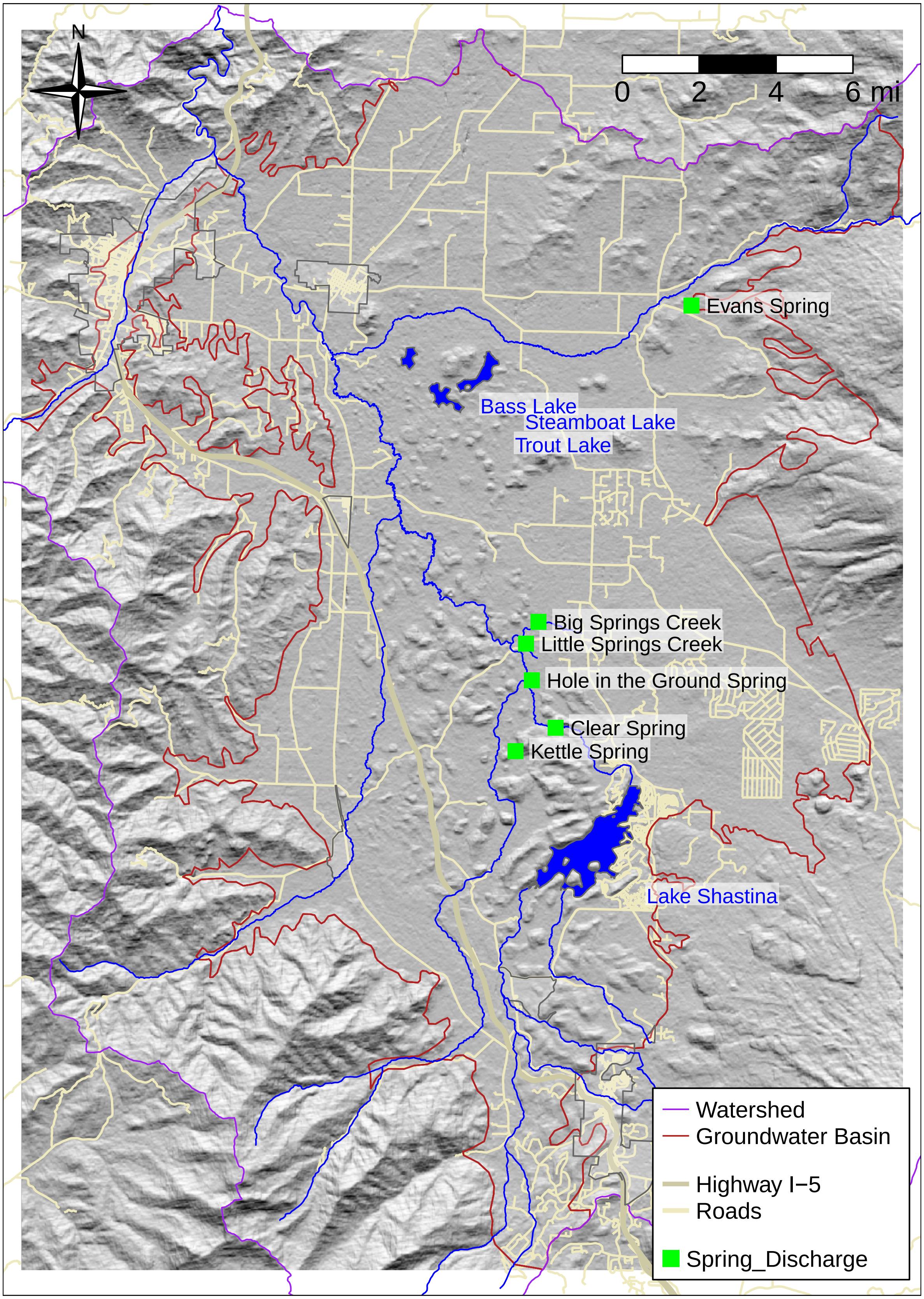

Figure 3: Monthly Spring Monitoring Networks.

and on the response of the system to precipitation, the start of the irrigation season, and seasonal changes to ISWs and GDEs. Transect wells are part of the piezometer transect program for measuring interconnections between surface waters and groundwater (see ISW section) (Figure 7.

Estimate of Groundwater Storage

Groundwater storage data is available from the foundational geological report (Mack 1960) and specific yield and storativity were estimated using the Shasta Watershed Groundwater Model (SWGM).

Groundwater Extraction Data

No pumping monitoring program currently exists in the Basin and this data is not available for any of the wells with groundwater elevation data. This has been identified as a data gap.

Groundwater Quality

Groundwater quality data was obtained from the California Groundwater Ambient Monitoring and Assessment (GAMA) Program Database. As detailed in Appendix 2-B, available water quality data were compared to regulatory standards and locations mapped within the Basin. Constituents of concern were identified through visual analysis of recent data (within the past 30 years) of the generated maps and timeseries for each constituent (available in Appendix 2-B). As seen on these maps, and noted in Section 2.2.2.3, there are multiple data gaps in the groundwater quality information used to develop the HCM. Spatially, groundwater quality data is not equally distributed throughout the Basin, with a general lack of data in the eastern side of the valley. Additionally, most of the groundwater quality data used in the assessment did not have a long record with consistent measurements, or measurements with a frequency that would be sufficient for determination of historical trends in groundwater quality. Further data gap discussion and the strategy for filling these data gaps is discussed with the groundwater quality monitoring network and Chapter 3.

In the North Coast Hydrologic Region, dairy operators are required to monitor and report groundwater data to the NCRWQCB, making them good candidates for network expansion. Annual groundwater monitoring of nitrate was first required in 2012 as a part of Waste Discharge Requirements for Dairies (Order No. R1-2012-0002). Order No. R1-2019-0001 extends the monitoring program but increases sampling frequency to every three years after the year 2022.

Land Subsidence Conditions

Land subsidence data is entirely sourced from the DWR contracted TRE Altamira Interferometric Synthetic Aperture Radar (InSAR) dataset, which provides estimates of vertical displacement from January 2015 to June 2015. Data gaps include the short historical record.

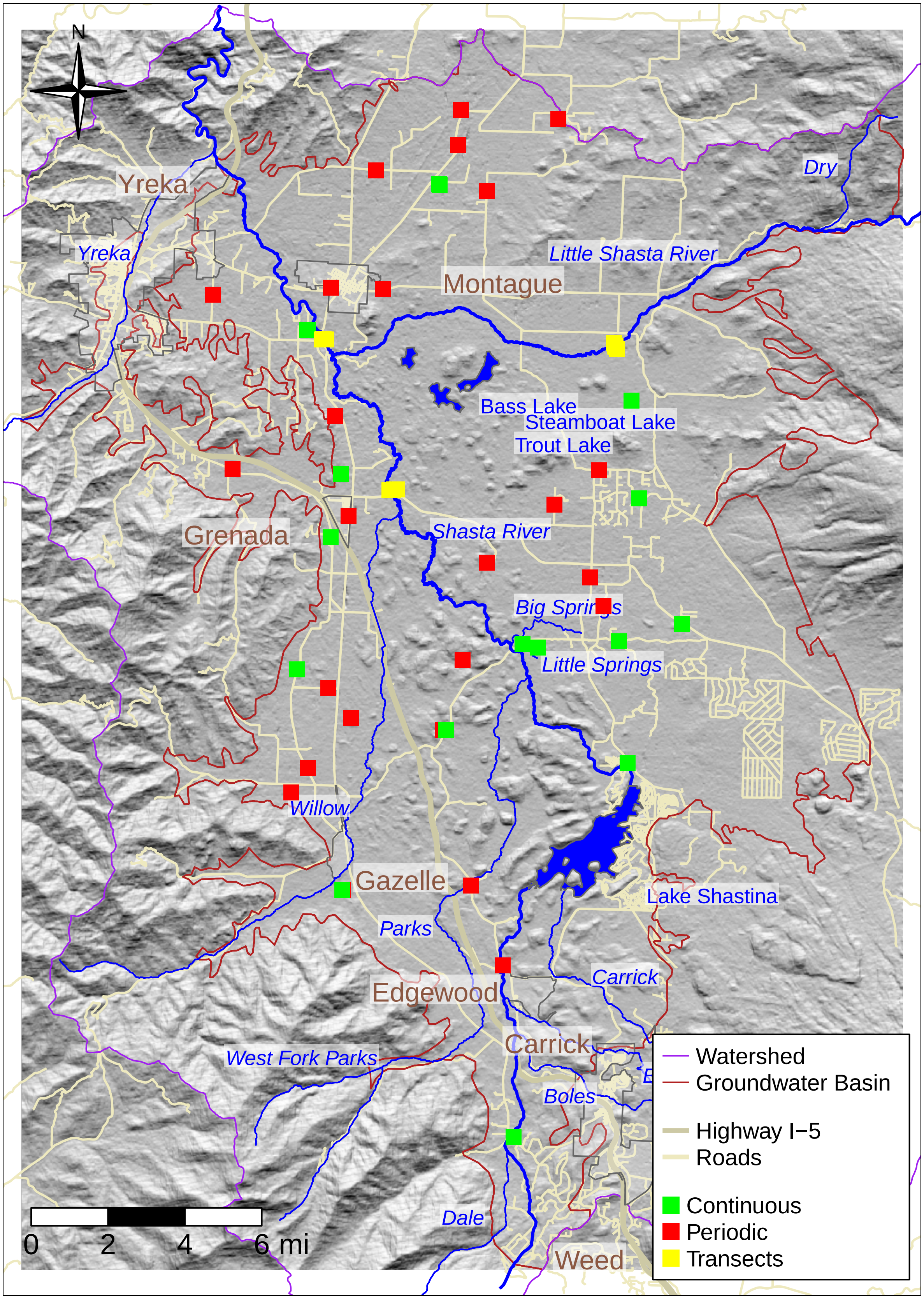

Figure 4: Groundwater Level Monitoring Network.

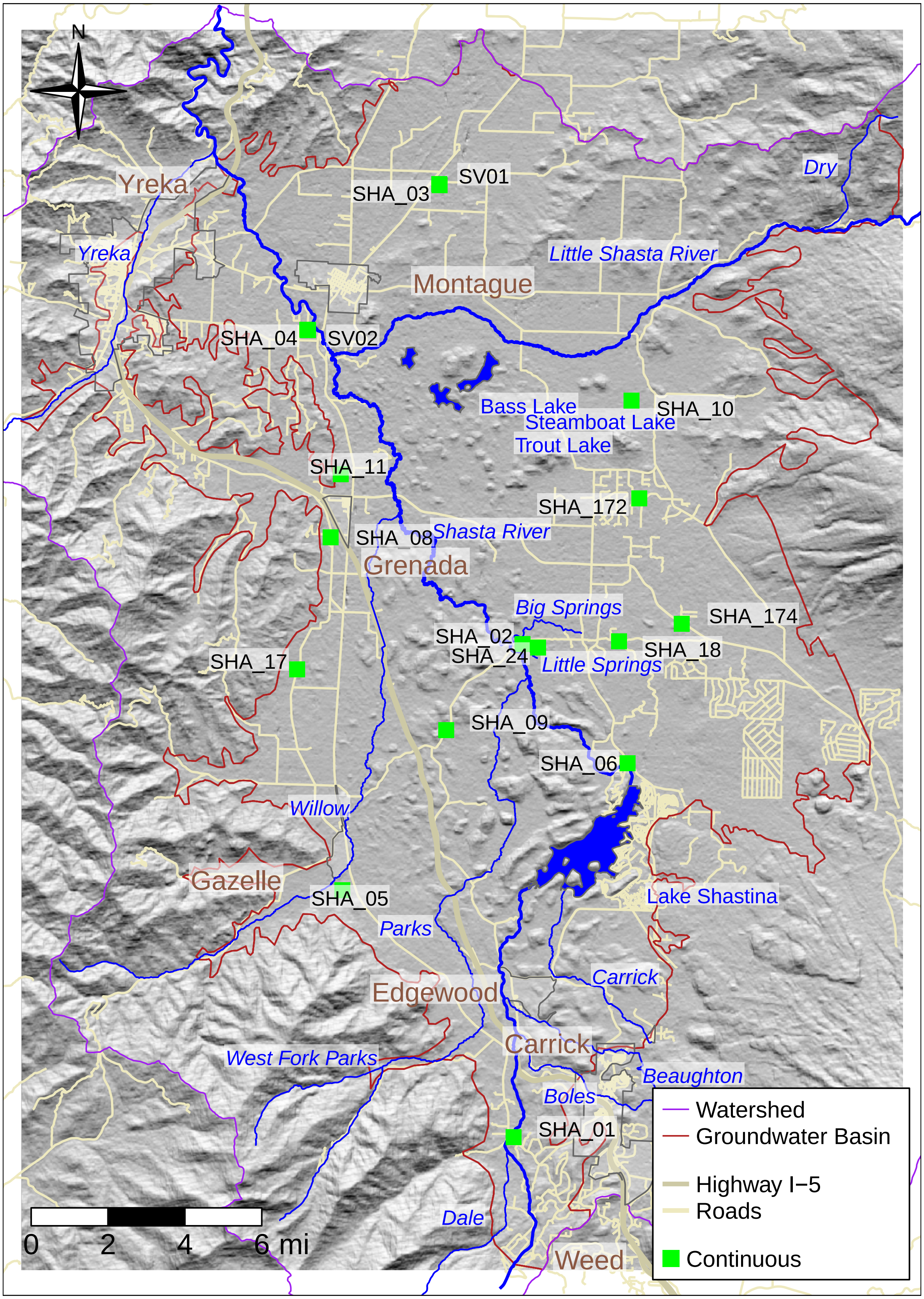

Figure 5: Groundwater Level Continuous Monitoring Network.

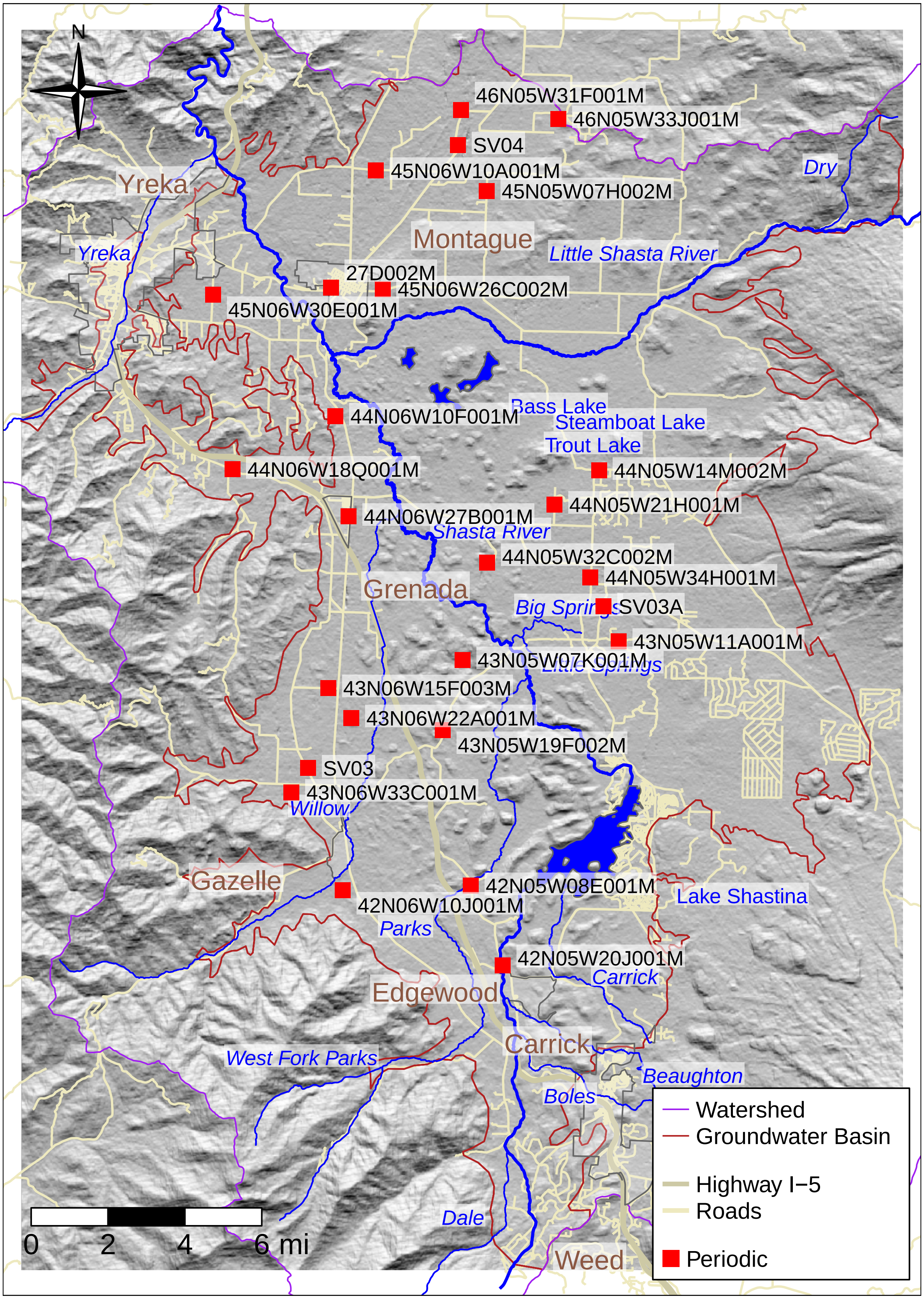

Figure 6: Groundwater Level Periodic Monitoring Network.

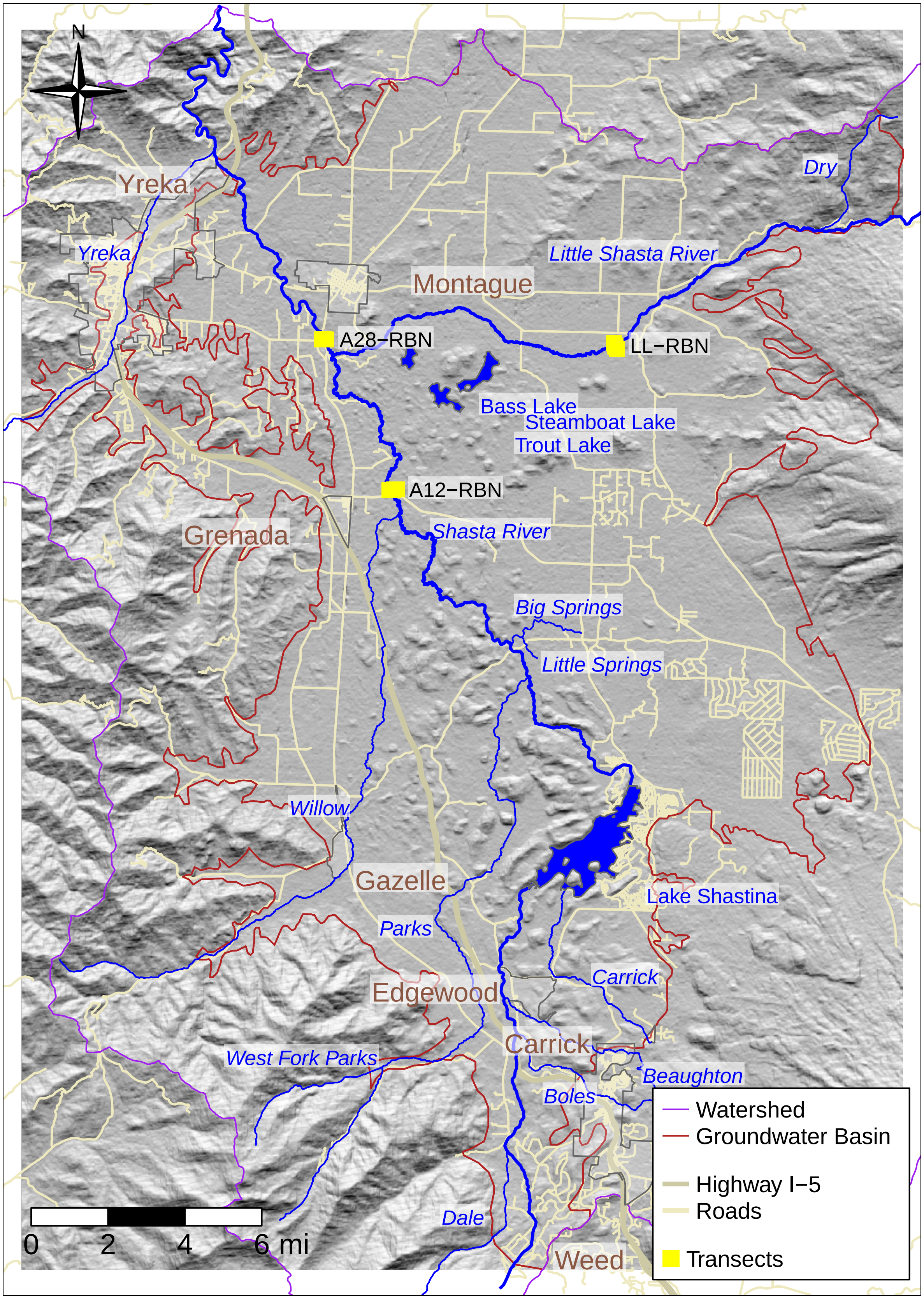

Figure 7: Groundwater Level Transect Monitoring Network.

Water Budget

The water budget is dependent on monitoring data inputs. For data gaps in the water budget see previous sections on climate and hydrology data gaps.

II. Data Gaps Monitoring Networks

Requirements

Multiple data gap requirements are relevant to the definition of monitoring networks for sustainability indicators. Per 23 CCR 354.38 (“Assessment and Improvement of Monitoring Network”):

(a) Each Agency shall review the monitoring network and include an evaluation in the Plan and each five-year assessment, including a determination of uncertainty and whether there are data gaps that could affect the ability of the Plan to achieve the sustainability goal for the basin.

(b) Each Agency shall identify data gaps wherever the basin does not contain a sufficient number of monitoring sites, does not monitor sites at a sufficient frequency, or utilizes monitoring sites that are unreliable, including those that do not satisfy minimum standards of the monitoring network adopted by the Agency

(c) If the monitoring network contains data gaps, the plan shall include a description of the following:

   i. The location and reason for data gaps in the monitoring network
   ii. Local issues and circumstances that prevent monitoring

(d) Each Agency shall describe steps that will be taken to fill the data gaps before the next five-year assessment, including the location and purpose of newly added or installed monitoring sites.

The following discussion summarizes the identified data gaps, description, and strategy to fill the identified data gaps.

Groundwater Level and Storage Monitoring Network

The current network is dominated by bi-annually sampled monitoring wells with a handful of continuous monitored wells (Figure 8 and Table 1). Data gaps in network coverage include the Basin edges such as near Weed, Yreka, Lake Shastina, Little Shasta River, and Pluto’s Cave, additional continuous continuous monitoring wells, and groundwater temperature. Continuous monitoring in particular would support the evaluation of changes in storage and with model calibration. Additional data gaps include representation of domestic wells and vulnerable drinking water users. Expansion of the monitoring network and filling of data gaps will depend on grant funding.

Through the partnership with the SVRCD and through a Water Smart grant obtained from the Bureau of Reclamation, 14 wells have been already instrumented with continuous data and telemetry throughout the Basin Figure 5. Continuous groundwater level data will be used to refine the SWGM and to further improve SMC definition.

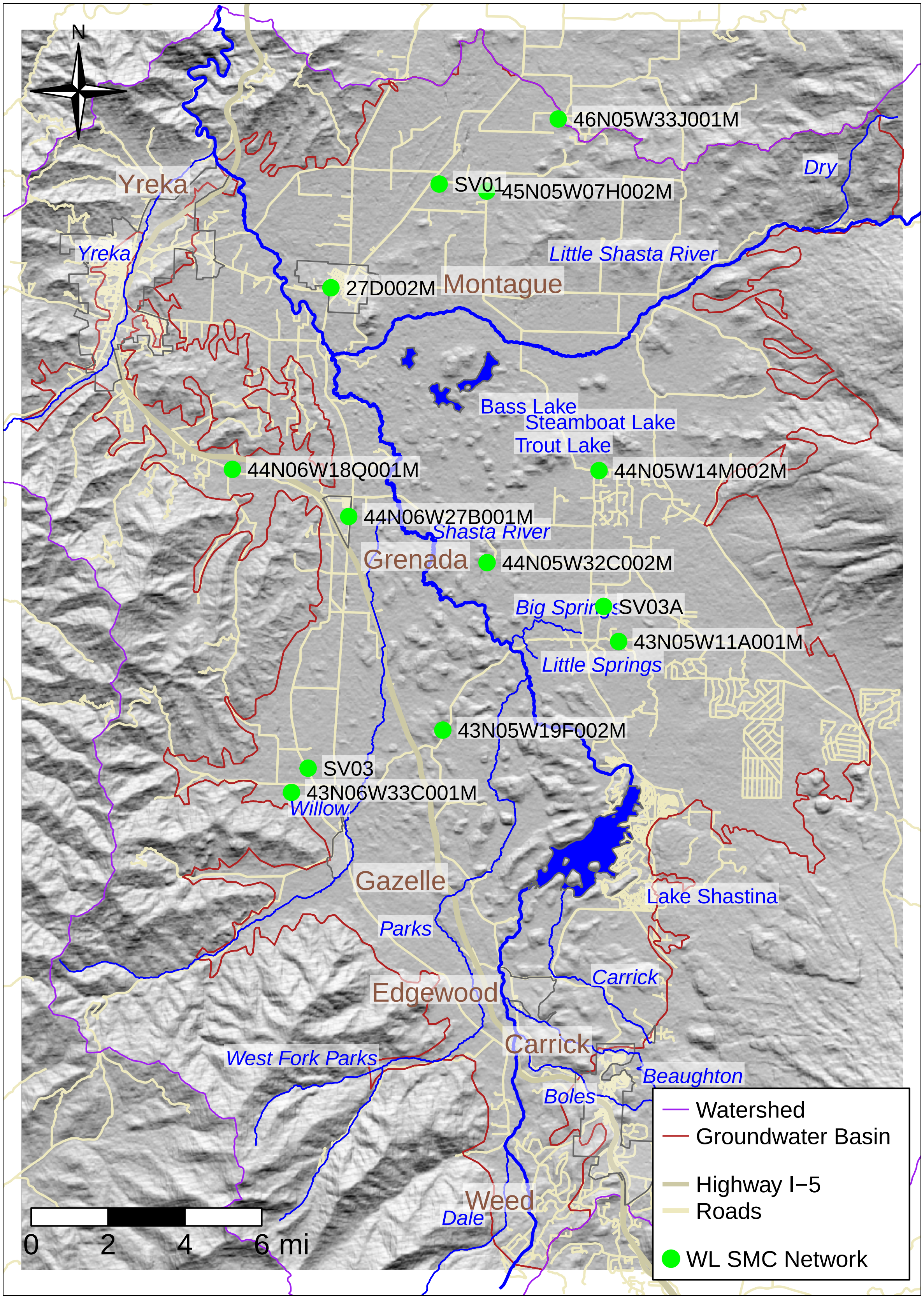

Figure 8: Water Level Monitoring Network.

Groundwater Quality Monitoring Network

Requirements

Requirements for the monitoring network for the degraded water quality sustainability indicator are outlined in 23 CCR 354.34 (c)(4):

Degraded Water Quality. Collect sufficient spatial and temporal data from each applicable principal aquifer to determine groundwater quality trends for water quality indicators, as determined by the Agency, to address known water quality issues.

Data Gaps

Data gaps in the groundwater quality monitoring network were identified due to inadequate spatial coverage, monitoring frequency, and/or lack of representativeness of Basin conditions and activities. The sites with existing and ongoing groundwater quality monitoring are public supply wells and are therefore concentrated near population, or seasonal population, centers, leaving much of the Basin without representative monitoring data. The location of these data gaps is shown on the map of the existing groundwater quality monitoring locations (see Figure 9, reprinted from Chapter 3). These data gaps are due to the limited number of wells that conduct current and ongoing monitoring for the identified constituents of concern, all public supply wells. The wells in the existing groundwater quality network also have a temporal data gap with a frequency of measurement annually or greater, corresponding to the public water supply system sampling frequency. A higher frequency of sampling, at minimum biannually, is necessary to enable determination of trends in groundwater quality on an intra-annual scale. No local issues or circumstances are expected to prevent monitoring. As discussed in Section 3.3.3, the groundwater quality monitoring network will be expanded with a minimum addition of five wells within the first five years of plan implementation to address this data gap. Possible candidate wells for inclusion in this expansion including wells used by dairy operators to report groundwater data to NCRWQCB, domestic wells, and wells included in the monitoring network for groundwater levels.

Depletions of Interconnected Surface Water Monitoring Network

Requirements

The requirements for the depletion of interconnected surface water monitoring network, as part of § 354.34. Monitoring Network, are detailed below:

(A) Flow conditions including surface water discharge, surface water head, and baseflow contribution.
(B) Identifying the approximate date and location where ephemeral or intermittent flowing streams and rivers cease to flow, if applicable.
(C) Temporal change in conditions due to variations in stream discharge and regional groundwater extraction.
(D) Other factors that may be necessary to identify adverse impacts on beneficial uses of the surface water.
(E) Changes in gradient between river and groundwater system.

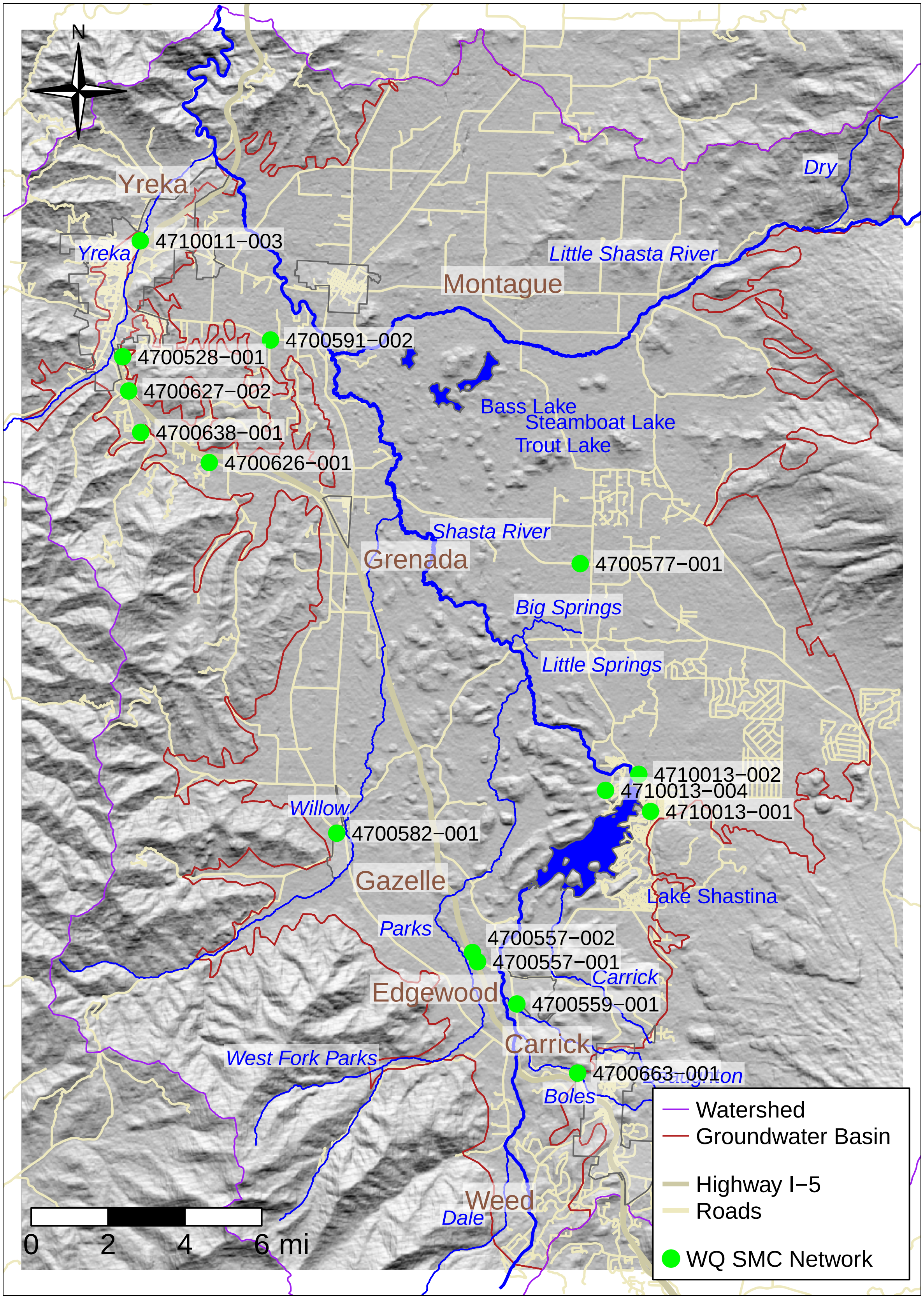

Figure 9: Water Quality Monitoring Network.

Data Gaps

The Shasta Watershed Groundwater Model (SWGM) will be the primary tool for estimating depletions of interconnected surface water after sufficient additional data has been collected at springs, particularly the Big Springs Complex, and Shasta River tributaries. The proposed implementation schedule (see Chapter 5) aims to obtain a better calibrated model over the next 5 years. Spring and flow monitoring is necessary not only for inputs and calibration of the model, but also to create new ISW SMCs and demonstrate sustainability. Wells to be used in observation of long-term trends in the hydraulic gradient between the aquifer and stream were identified as a data gap for the monitoring network associated with the depletions of interconnected surface water sustainability indicator. Two transects of shallow piezometers instrumented with continuous pressure transducers across the Shasta River, and one on the little Shasta have already been installed and will provide critical information to fully understand the relationship between the river and the aquifer. More transects may be considered in the next 5 years pending funding availability. Additional spring and tributary monitoring sites will also depend on funding. Reprinted from Chapter 3, tentative additional ISW sites will include the sites in Table 2, with locations shown in Figure 2.

The GDE monitoring network currently has one single well, leaving no coverage for all other potential GDEs (see Chapter 3). The GDE monitoring network must expand to additional shallow wells.

Table 2: Future monitoring locations for monitoring interconnected surface water, dependent on funding.

Monitoring Location	Monitoring Type	Agency
Shasta River near Yreka (SRY)	Stream Gage	USGS
Shasta River at Grenada Pump Plant (SPU)	Stream Gage	DWR
Big Spring Creek (Water Wheel)	Stream Gage	CDFW
Parks Creek	Stream Gage	–

III. Additional Data or Information Valuable for Measuring Progress Towards the Basin Sustainability Goal

Additional data has been identified that may be valuable to evaluations of progress towards the Basin's sustainability goal. This is primarily additional monitoring information that may be useful to identify adverse impacts on biological uses of surface water, in addition to existing biological monitoring in the Basin.

These include evaluation of streamflow depletion impacts on juvenile salmonids and use of satellite imagery for monitoring riparian and non-riparian vegetation. The GSA may consult other entities or specialists, as feasible, to determine the value of this data.

IV. Data Gap Prioritization

The identified data gaps are prioritized for actions to be taken to resolve them. Data gaps are categorized into "high," "medium," and "low" prioritization statuses based on the value to understanding basin setting or in comparison to the defined SMCs to evaluate Basin sustainability. Filling data gaps can be achieved through increasing monitoring frequency, addition of monitoring sites to increase spatial distribution and density of the monitoring network or adding or developing new monitoring programs or tools. Summaries of the data gaps discussed in this appendix, associated prioritizations, and strategies to fill the data gap are shown in Table 2.

Note: Prioritization to be refined and discussion of added monitoring for continuous groundwater and temperature, isotopes, and soil moisture after preliminary evaluation of the new data that have been collected since 2021. Expansion expected in 2022.

Table 3: Data gap prioritization

Priority	Data Gap Summary	Strategy to Fill Data Gap
High	Groundwater quality monitoring network	Planned expansion of groundwater quality monitoring network in the first five years. Additional expansion will be evaluated at the five-year update.
High	Expand the groundwater level network to cover current data gaps, particularly near surface waters (potential ISWs) and potential groundwater dependent ecosystems.	The GSA will seek local volunteers with historical groundwater level data and seek funding for installation of additional monitoring wells.
High	Depletions of interconnected surface water monitoring network	Dependent on funding, additional stream gages and spring monitoring, with particular focus on Big Springs. Also continued or additional piezometer transects with continuous groundwater level and temperature measurements near the river to determine the gradient between the aquifer and stream. All additional data will assist in the calibration of SWHM, to evaluate the baseflow SMC defined in Chapter 3 for ISW, and potentially redefine the ISW SMCs in a future GSP update.
High	Identification and evaluation of Groundwater-Dependent Ecosystems	Using satellite imagery to confirm location and extent of GDEs and evaluate twice per year to assess GDE health over time.
Medium	Groundwater extraction data	A PMA in Chapter 3 proposes voluntary measures to gather extraction data, with public outreach to encourage participation.
Low	Additional precipitation data to confirm presence of rainfall gradient.	No strategy has been defined yet to fill this data gap.

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Appendix 3-B. Monitoring Protocols

Contents

Monitoring Protocols

This Appendix provides the monitoring protocols for the monitoring networks described in Chapter 3.

Groundwater Levels

Groundwater level data collection may be conducted remotely via telemetry equipment or with an in-person field crew. The following section provides the monitoring protocols for groundwater level data collection. Establishment of these protocols will ensure that data collected for groundwater levels are accurate, representative, reproducible, and contain all required information. All groundwater level data collection in support of this GSP is required to follow these established protocols for consistency throughout the Basin and over time. These monitoring protocols will be updated as necessary and will be re-evaluated every five years. The reference for the following text is the groundwater level monitoring protocols in the Santa Cruz Mid-County Sustainability Plan (MGA GSP), with modifications.

All groundwater elevation measurements are referenced to a consistent elevation datum, known as the Reference Point (RP), surveyed to the National Geodetic Vertical Datum of 1988 (NGVD 88). For monitoring wells, the RP consists of a mark on the top of the well casing while most production wells have the RP at the top of the well's concrete pedestal. State requirements for surveying the RP is a measurement within 0.1 ft (3 cm) horizontally and 0.01 ft (0.3 cm) vertically. Groundwater level measurements are taken to the nearest 0.01 ft (0.3 cm) relative to the RP.

Groundwater elevation is measured by subtracting the depth to water from the reference point:

$GWE = RPE - DTW$,

where:

- GWE = groundwater elevation
- RPE = reference point elevation
- DTW = depth to water

Sample Collection:

- Equipment must be operated and maintained in accordance with manufacturer's instructions.
- Water level measurements must use units of feet, tenths of feet, and hundredths of feet.
- Measurements must include a record of the date, well name/identifier, time (in 24-hour military format), RPE, DTW, and GWE.
- Comments must be included regarding factors which may influence the recorded measurement such as nearby production wells pumping, weather, flooding, or well condition (including oil and other foreign bodies floating on the water surface).

Manual Groundwater Level Measurement

Groundwater level data collected by an in-person field crew will follow the following general protocols:

- Prior to sample collection, all sampling equipment and the sampling port must be cleaned.
- Manual groundwater level measurements are made with electronic sounders or steel tape. Electronic sounders consist of a long, graduated wire equipped with a weighted electric sensor. When the sensor is lowered into water, a circuit is completed and an audible beep is produced, at which point the sampler will record the depth to water. Some production wells may have lubricating oil floating on the top of the water column, in which case electric sounders will be ineffective. In this circumstance, steel tape may be used. Steel tape instruments consist of simple graduated lines where the end of the line is chalked to indicate depth to water without interference from floating oil.
- All equipment is used following manufacturer specifications for procedure and maintenance.
- Measurements must be taken in wells that have not been subject to recent pumping. At least two hours of recovery must be allowed before a hand sounding is taken.
- For each well, multiple measurements are collected to ensure the well has reached equilibrium such that no significant changes in groundwater level are observed.
- Equipment is sanitized between well locations to prevent contamination and maintain the accuracy of concurrent groundwater quality sampling.

Data Logger Groundwater Level Measurement

Telemetry equipment and data loggers can be installed at individual wells to record continuous water level data, which is then remotely collected via satellite to a central database and accessed on the Water Level Portal in a web browser.

Installation and use of data loggers must abide by the following protocols:

- Prior to installation the sampler uses an electronic sounder or steel tape to measure and calculate the current groundwater level in order to properly install and calibrate the transducer. This is done following the protocols listed above.
- All data logger installations must follow manufacturer specifications for installation, calibration, data logging intervals, battery life, and anticipated life expectancy.
- Data loggers are set to record only measured groundwater level to conserve data capacity; groundwater elevation is calculated after data are downloaded.
- In any log or recorded datasheet, the well ID, transducer ID, transducer range, transducer accuracy, and cable serial number are recorded.
- The sampler notes whether the pressure transducer uses a vented or non-vented cable for barometric compensation. If non-vented units are used, data are properly corrected for natural barometric pressure changes.
- All data logger cables are secured to the well head with a well dock or another reliable method. This cable is marked at the elevation of the reference point to allow estimates of future cable slippage.
- Data logger data are periodically checked against hand-measured groundwater levels to monitor electronic drift, highlight cable movement, and ensure the data logger is operating correctly. This check occurs at least annually, typically during routine site visits.

For wells not connected to a supervisory control and data acquisition (SCADA) system, transducer data are downloaded as necessary to ensure no data are overwritten or lost. Data are entered into the data management system as soon as possible after download. After the transducer data are successfully downloaded and stored, the data are deleted or overwritten to ensure adequate data logger memory.

Groundwater Quality

Sample collection will follow the USGS National Field Manual for the Collection of Water Quality Data (Wilde, 2005) and Standard Methods for the Examination of Water and Wastewater (Rice et al., 2012), as applicable, in addition to the general sampling protocols listed below.

The following section provides a brief summary of monitoring protocols for sample collection and testing for groundwater quality. Establishment of these protocols will ensure that data collected for groundwater quality are accurate, representative, reproducible, and contain all required information. All sample collection and testing for water quality in support of this GSP are required to follow the established protocols for consistency throughout the Basin and over time. All testing of groundwater quality samples will be conducted by laboratories with certification under the California Environmental Laboratory Accreditation Program (ELAP). These monitoring protocols will be updated as necessary and will be re-evaluated every five years.

Wells used for sampling are required to have a distinct identifier, which must be located on the well housing or casing. This identifier will be included on the sample label to ensure traceability.

Event Preparation:

- Before the sampling event, coordination with any laboratory that will be used to test the samples is required. Coordination must include scheduling laboratory time for sample testing and reviewing the applicable sample holding times and preservation requirements that must be conducted before the sampling event.
- Sample labels must include the sample ID, well ID, sample date and time, personnel responsible for sample collection, any preservative, analyte, and analytical method. Sample containers may be labelled before or during the sampling event.

Sample Collection and Analysis:

- Collection of a raw sample must occur at, or close to, the wellhead for wells with dedicated pumps and may not be collected after any treatment, from tanks, or after the water has travelled through long pipes. Prior to sample collection, all sampling equipment and the sampling port must be cleaned. The sample equipment must also be cleaned between use at each new sample location or well.
- Sample collection in wells with low-flow or passive sampling equipment must follow protocols outlined in EPA's Low-flow (minimal drawdown) ground-water sampling procedures (Puls and Barcelona, 1996) and USGS Fact Sheet 088-00 (USGS, 2000), respectively. Prior to sample collection in wells without low-flow or passive sampling equipment, at least three well casing volumes should be purged prior to sample collection to make sure ambient water is tested. The sample collector should use best professional judgement to ensure that the sample is representative of ambient groundwater. If a well goes dry, this should be noted, and the well should be allowed to return to at least 90% of the original level before a sample is collected.
- Sample collection should be completed under laminar flow conditions, which is defined as follows: the pump rate during sampling should produce a smooth, constant (laminar) flow rate, and should not produce turbulence during the filling of bottles.

- Samples must be collected in accordance with appropriate guidance and standards and should meet specifications for the specific constituent analyzed and associated data quality objectives.
- In addition to sample collection for the target analytes, field parameters, including temperature, pH and specific conductivity, must be collected at every site during well purging. Field parameters should stabilize before being recorded and before samples are collected. Field instruments must be calibrated daily and checked for drift throughout the day.
- Samples should be chilled and maintained at a temperature of 4 C degrees and maintained at this temperature during transport to the laboratory responsible for analysis.
- Chain of custody forms are required for all sample collection and must be delivered to the laboratory responsible for analysis of the samples to ensure that samples are tested within applicable holding limits.
- Laboratories must use reporting limits that are equivalent to, or less than, applicable data quality objectives.
- Quality control samples will be taken to confirm accuracy, replication, confidence, and robustness of the testing protocols procedures. Quality control samples will be collected during each monitoring event based on a schedule dependent on monitoring frequency. Quality control samples may include field blanks, field duplicates, lab duplicates or matrix spike/matrix spike duplicates. Field-generated quality control samples (field duplicates and field blanks) will be submitted “blind” to the laboratory, with an identifier different from the sampled sites. Issues with quality control samples that are flagged either by the laboratory or GSP QA/QC Officer will be used to correct any issues with the monitoring or lab testing protocol.

Subsidence

The subsidence monitoring network currently depends on data provided by DWR through the TRE ALTAMIRA InSAR Subsidence Dataset. The following describes the data collection and monitoring completed by DWR contractors to develop the dataset. The GSA will monitor all subsidence data annually. If any additional data become available, they will be evaluated and incorporated into the GSP implementation. If the annual subsidence rate is greater than minimum threshold, further study will be needed.

The statewide InSAR subsidence dataset was acquired by DWR to provide important SGMA relevant data to GSAs for GSP development and implementation. TRE ALTAMIRA processed InSAR data collected by the European Space Agency (ESA) Sentinel-1A satellite. Statewide data was collected between January 1, 2015 and September 19, 2019 and calibrated to data from 232 stations in the regional network of Continuous Global Positioning System (CGPS) stations. TRE ALTAMIRA compiled time series data of vertical displacement values for point locations on a grid with 100 m spacing, with values representing averages of vertical displacement measurements within the immediate 100 by 100 m square areas of each point. Gaps in the spatial coverage of the point data are areas with insufficient data quality. TRE ALTAMIRA also created two sets of GIS rasters: annual vertical displacement and total vertical displacement relative to the common start date of June 13, 2015, both in monthly time steps. An inverse distance weighted (IDW) method with a maximum search radius of 500 meter was used to interpolate the rasters from the point data.

Under contract with DWR, Towill Inc. conducted an independent study to ground truth and verify the accuracy of the InSAR dataset. In the study, variation in vertical displacement of California’s ground surface over time, as measured from interferometric synthetic aperture radar (InSAR) satellites, was statistically compared to available ground-based continuous global positioning systems (CGPS) data. The study compared the InSAR-based vertical displacement point time series data to data from 160 CGPS stations that were not used for calibrating the InSAR data, as well as 21 CGPS stations that were used for calibrating InSAR data in Northern California. For the statewide dataset, the study provides statistical evidence that InSAR data accurately measured vertical displacement in California's ground surface to within 16 mm for the period January 1, 2015 through September 19, 2019. The statement of accuracy may vary for regional or localized area subsets (DWR 2020).

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Appendix 3-C Water Level Sustainability Management Criteria

Shasta Valley Well Failure Discussion

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11/30/2021

Contents

Introduction

This analysis seeks to determine the number of wells that may be dewatered due to declining groundwater levels. In the Shasta Valley, groundwater elevations are highly seasonal. The highest risk of dewatering occurs in the late summer and early fall, when water levels are at their seasonal low.

A thorough assessment would involve a comparison of historic and current water levels against well construction details across all or a representative subset of wells in Shasta Valley. However, two key data limitations inhibit a comparison of well construction details with water levels where they have been measured in wells:

- Well depth and perforated intervals, on one hand, and water level observations on the other have been collected by multiple organizations/agencies.

- For most wells associated with water level measurements, the corresponding well construction information is not readily available, making a direct comparison of water levels and depth to top of perforation (or well depth) impossible without significant further reconnaisance.

Consequently, rather than comparing groundwater elevations with depth to top of perforations, this analysis focuses on interpolated groundwater elevation data to assess the aggregated risk of wells not being able to pump water due to low water levels (“well outages”). The risk analysis necessarily utilizes basic information that is readily available and is therefore limited in its specificity. Future analysis may provide a more refined risk assessment.

Methods

Shasta Well Data Statistics

A total of 1148 well logs were analyzed in the Shasta Valley Bulletin 118 basin boundary. These wells were classified by the dominant geologic formation identified at the bottom of the perforated interval during geologic model development. Formations are described in greater detail in the Basin Setting section of the GSP. Major formations and the number of wells identified are the Volcanic Rocks of Shasta Valley (Qvs), Western Cascade Volcanics (Tv), Pleistocene Volcanic Rocks (Qv), Alluvium (Q), Duzel Formation (SOd), with 416, 166, 166, 144, and 79 wells each respectively. Formations with fewer than 10 wells or where the formation was unknown were not considered for this analysis due to the sparsity of data. In total, 943 wells out of 1148, or 86% of the available wells, belong to one of the major formations. Well locations are shown in Figure 1.

Paired top of well perforation and water level measurements were not available in most wells. Table 1 shows wells in the California Statewide Groundwater Elevation Monitoring Program (CASGEM) dataset with associated top of perforation data. This data is not sufficiently spatially distributed or representative of well type, depth, and construction to be used alone in establishing well failure risk. Similarly, Table 2 shows the number of wells in each major formation.

Table 1: Available information for Shasta Valley wells.

Depth, Obs., Perf. Available?	Well Info Source	No. of Wells
None (location only)	LWA GWO	1
Total Depth Only	LWA GWO	1
Observations Only	DWR	8
Observations Only	LWA GWO	8
Perforation Only	–	0
Observations and Depth	DWR	17
Observations and Depth	LWA GWO	7
Depth, Obs. and Perf.	DWR	13
Depth, Obs. and Perf.	–	0

Table 2: Wells used in Shasta Valley Well Outage Analysis

Bottom Formation	Top of Perforation (Depth in Feet)
Q- Alluvium	166
Qv- Pleistocene Volcanic rocks	144
Qvs- Volcanic rocks of Shasta Valley	416
SOd- Duzel Formation	79
Tv- Western Cascade Volcanics	166

Well Outage Risk Analysis

Estimating the elevation datum for each well is based on the USGS reported elevation at the location of the well reported by the respective program agency (mostly DWR). The accuracy of the elevation is estimated to be within 3% of one-half mile, i.e., 80 feet, where 3% represents a general maximum landscape slope within the Shasta Valley groundwater basin and one-half mile represents the maximum distance of the actual well location from the reported well location. Some areas within the Shasta Valley basin have steeper slopes. There, estimated well elevations may be even less accurate. For comparison of estimated water level elevation with well construction information, not being able to determine elevation of a well at its approximate location with an accuracy much better than 10 feet is potentially very problematic.

Unfortunately, a direct comparison of water levels to screened interval or well depth is not currently possible for the overwhelming majority of Shasta Valley wells. A future effort to match water level data with well construction information will help connect some of the wells (from Well Completion Reports) with wells that have recent water level observations. This will provide an aggregated analysis of well outage risk within the network of wells with known water levels.

Instead, the analysis here focuses a) on a review of overall well construction information in Shasta Valley and b) a preliminary, highly approximative estimate of the depth of water above the top of well perforations below the water table and its statistical distribution.

This second step relies on comparing the interpolated water level at the reported well location, obtained by mapping measured water levels in Shasta Valley, against the elevation of the top of perforations at each well for which construction information is available, at the reported location. The estimate of the elevation of the top of perforations is obtained from the estimated elevation of the well at the reported location and well construction information (depth to top of perforations). The difference between estimated water level elevation and estimated elevation of the top of perforations is herein referred to as the “wet depth to top of perforations”:

```
[reported depth to top of perforations] - [interpolated depth to groundwater
at reported location] = [wet depth to top of perforations]
```

Note: By using the USGS reported elevation at the reported well location as the reference elevation for both terms on the left-hand-side, the wet depth to top of perforations can also be expressed as:

```
[interpolated water table elevation at reported location] - [reported elevation
of top of perforations] = [wet depth to top of perforations]
```

For the interpolated depth to water table two maps were constructed: from measured depth to groundwater: in the fall of 2015 (dry year) and in the fall of 2017 (wet year). Water level maps were constructed using spline interpolation. The maps of depth to water table were used to digitally determine the interpolated depth to water table at the reported location of each well considered.

Results and Discussion

Well Construction Information

Well types show different depths to the bottom of the well below ground surface as shown in figure Figure 2. Domestic wells in the Western Cascade Volcanics (Tv) have deeper bottom of perforated intervals relative to other major Shasta Valley domestic well supplying formations. Domestic well top of screens for wells in the Duzel Formation (SOd) are mostly shallower, however some deep screens also exist. The Western Cascade Volcanics (Tv) well screen tops are overall slightly deeper as shown in Figure 3. Domestic, agricultural, and public wells in the Duzel Formation (SOd) all appear to have longer screen lengths than other formations (Figure 4). Geologic Formation plays an important role in determining the top of well screen for domestic and agricultural wells (Figure 8). Relatively shallow top of screen occur among agricultural wells in the Volcanic Rocks of Shasta Valley (Qvs). Some relatively deep domestic wells are present in the Duzel Formation (SOd) and Western Cascade Volcanics (Tv).

Based on pumping test data provided on Well Completion Reports submitted to the Department of Water Resources, agricultural wells in the Pleistocene Volcanic Rocks (Qv) and Volcanic Rocks of Shasta Valley (Qvs) house a greater proportion of higher production wells as shown in Figure 5. In the case of the Pleistocene Volcanic Rocks (Qv) this could be due to a higher proportion of large diameter wells however the distribution of well diameter sizes appear similar among the Alluvium (Q), Volcanic Rocks of Shasta Valley (Qvs), Duzel Formation (SOd), and the Western Cascade Volcanics (Tv) (Figure 6). During pump testing the Pleistocene Volcanic Rocks (Qv) also exhibited lower drawdown than other formations while the Western Cascade Volcanics (Tv) and the Duzel Formation (SOd) both exhibited a relatively high number of large drawdowns during pumping as shown in Figure 7.

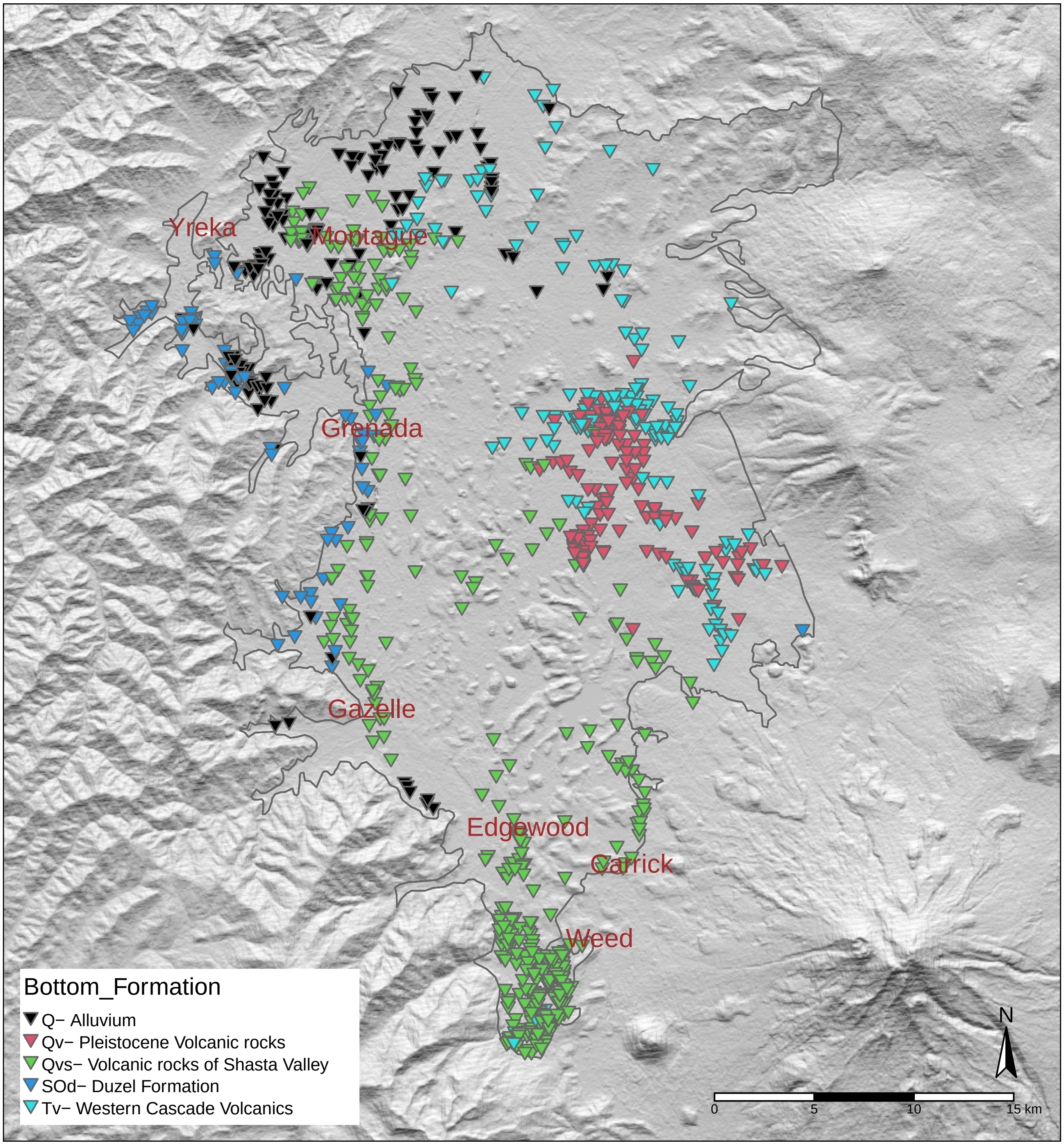

Figure 1: Shasta Valley well map of domestic, public supply, and agricultural wells colored by major formation with locations of water wells are given as colored triangles.

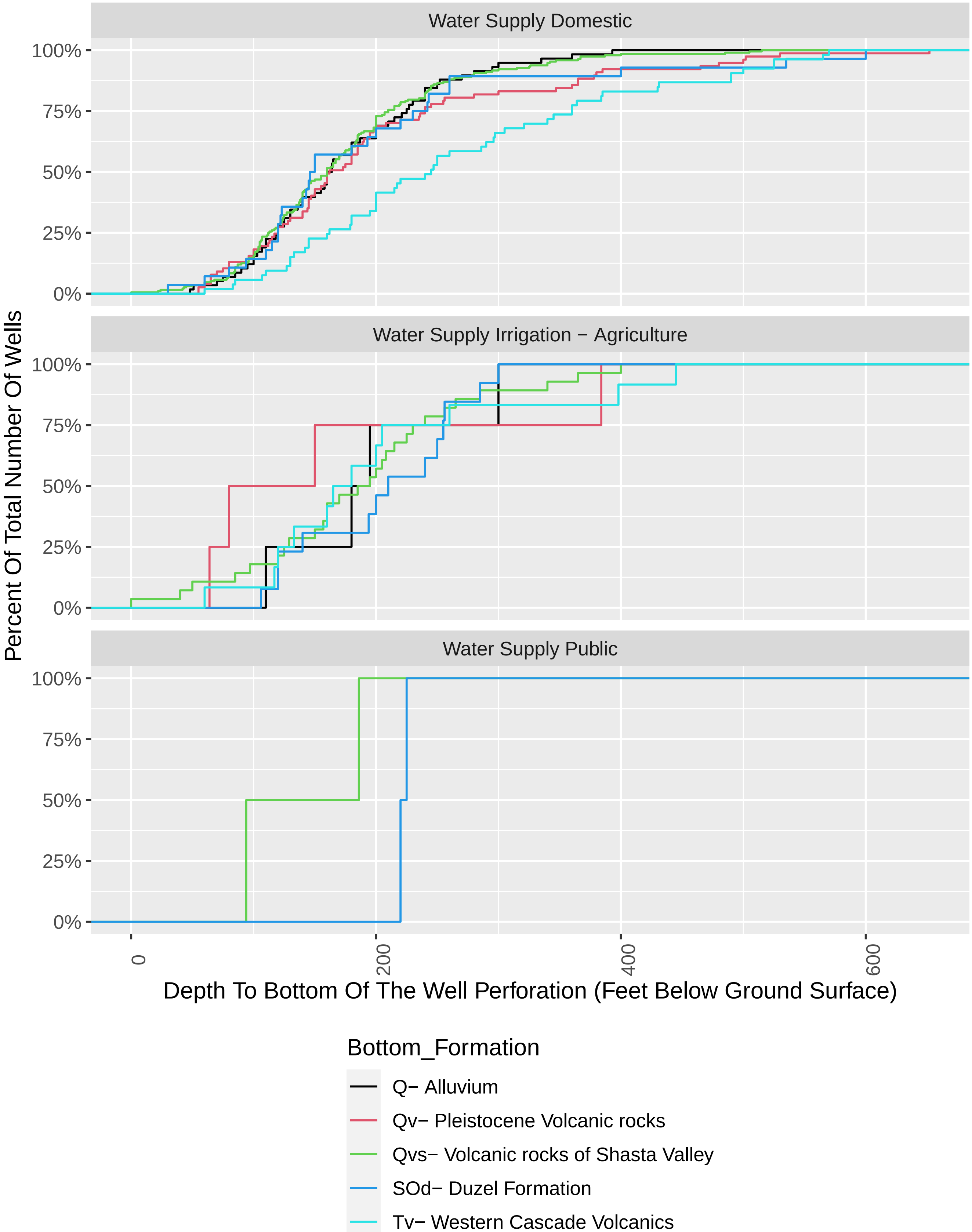

Figure 2: Shasta Valley well perforation bottom. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations. Note that agricultural wells in the Pleistocene Volcanic Rocks have shallower bottom of screens and domestic wells in the Western Cascade Volcanics have deeper bottom of screens.

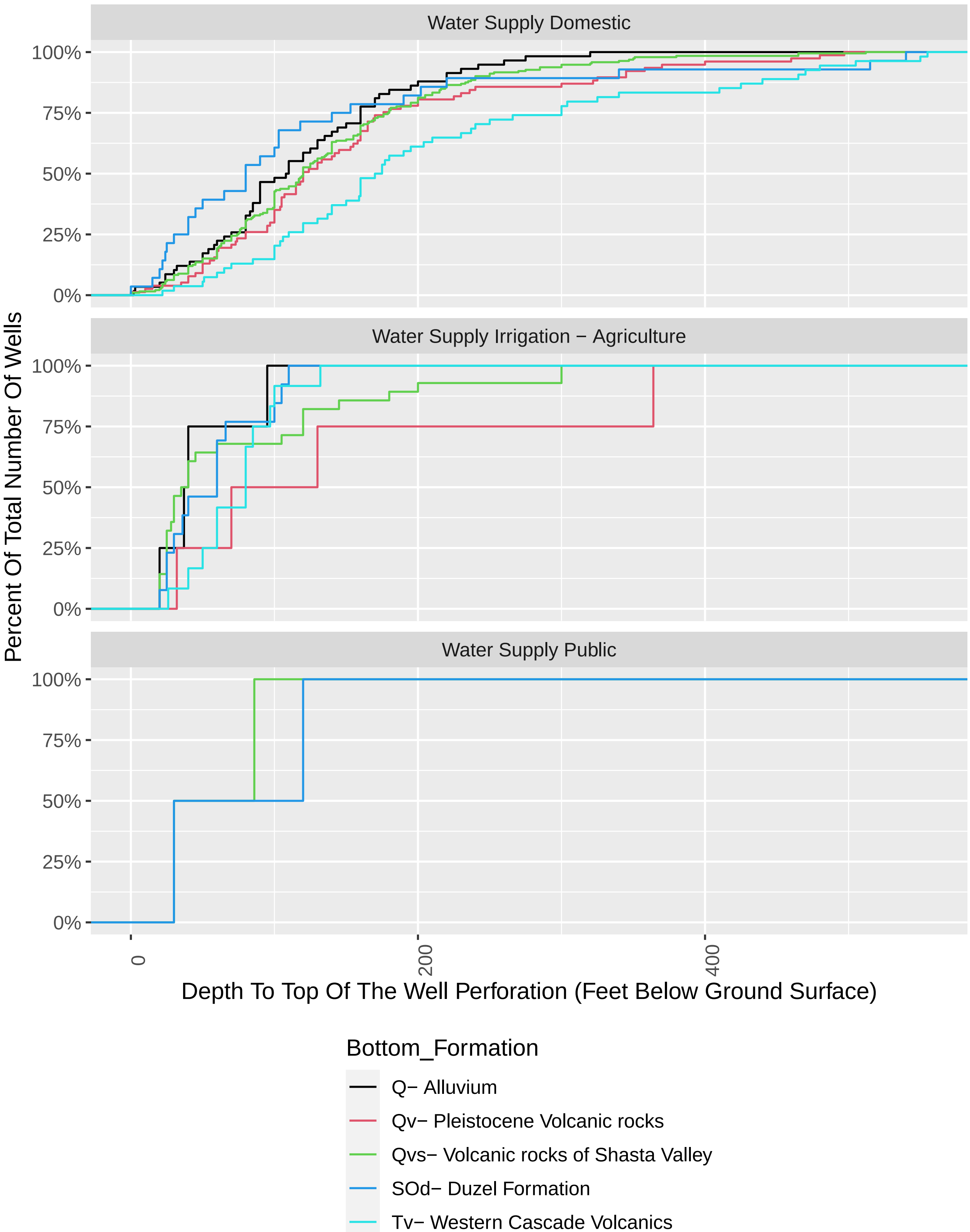

Figure 3: Shasta Valley well perforation top. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations.

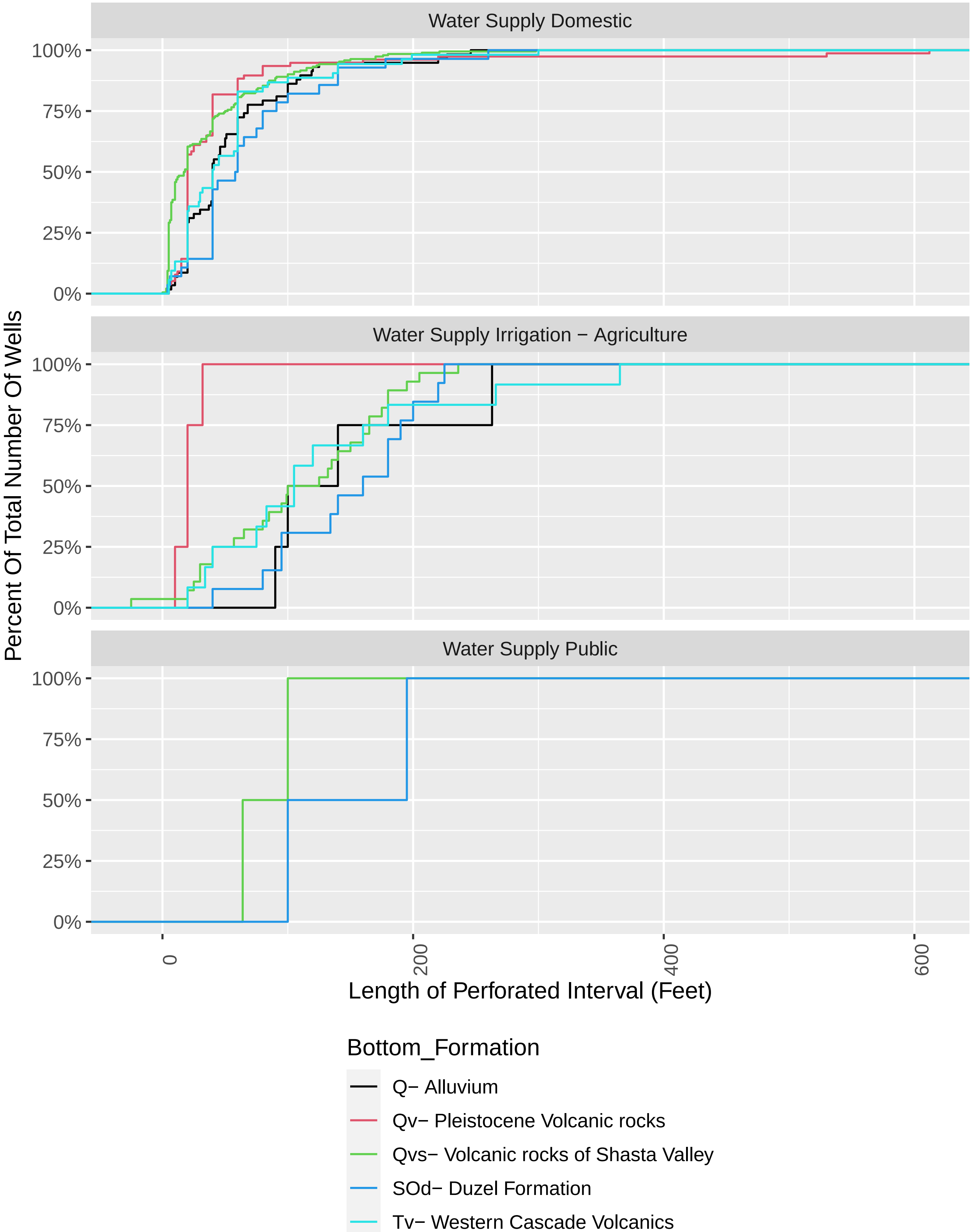

Figure 4: Shasta Valley well perforation length. Sub-graphs show cumulative distribution graphs by well type and each graph shows major formations. Irrigation wells in the Pleistocene Volcanic Rocks have an extremely small range of values and are typically short.

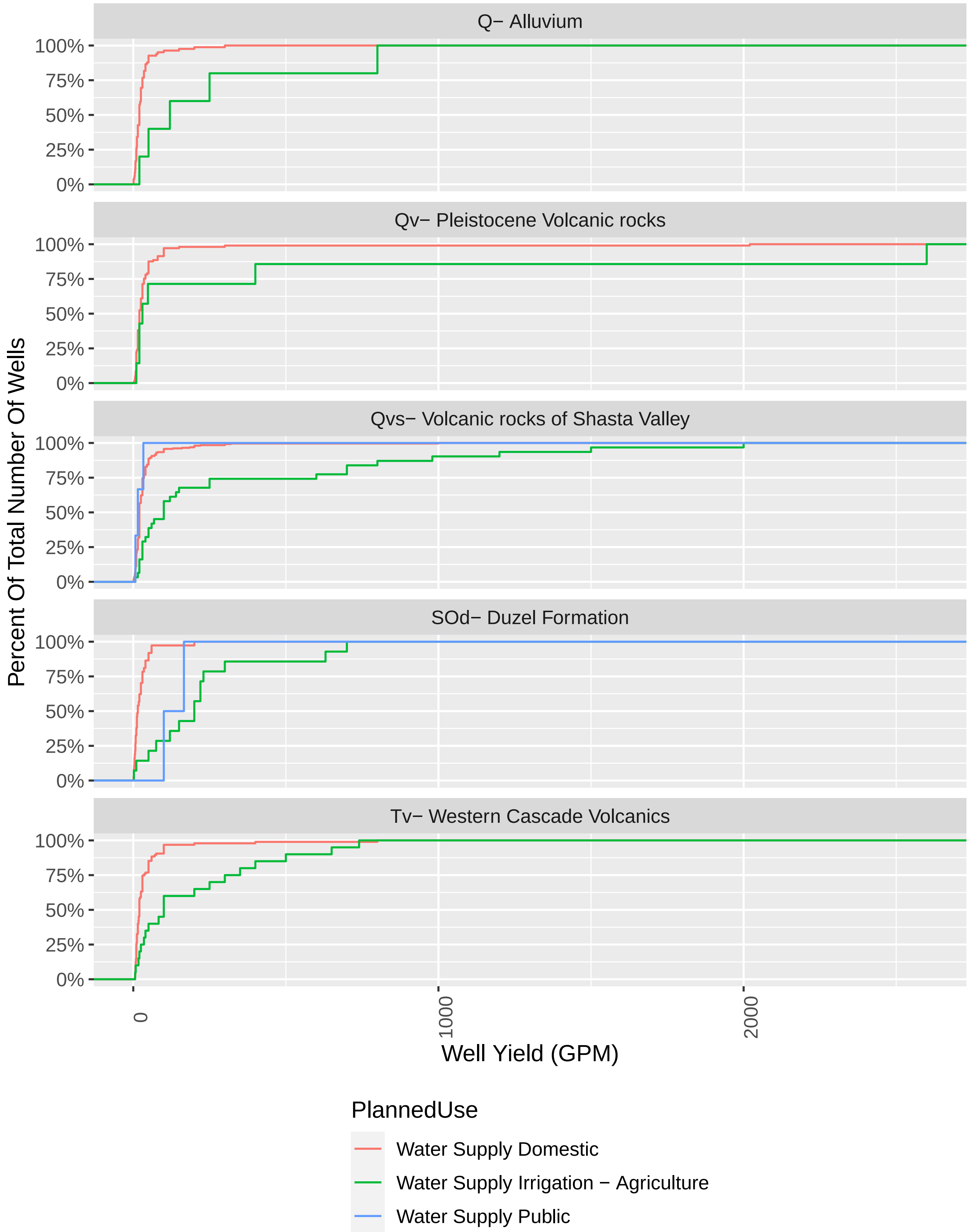

Figure 5: Shasta Valley well yield by formation at the bottom of the well comparing major well types

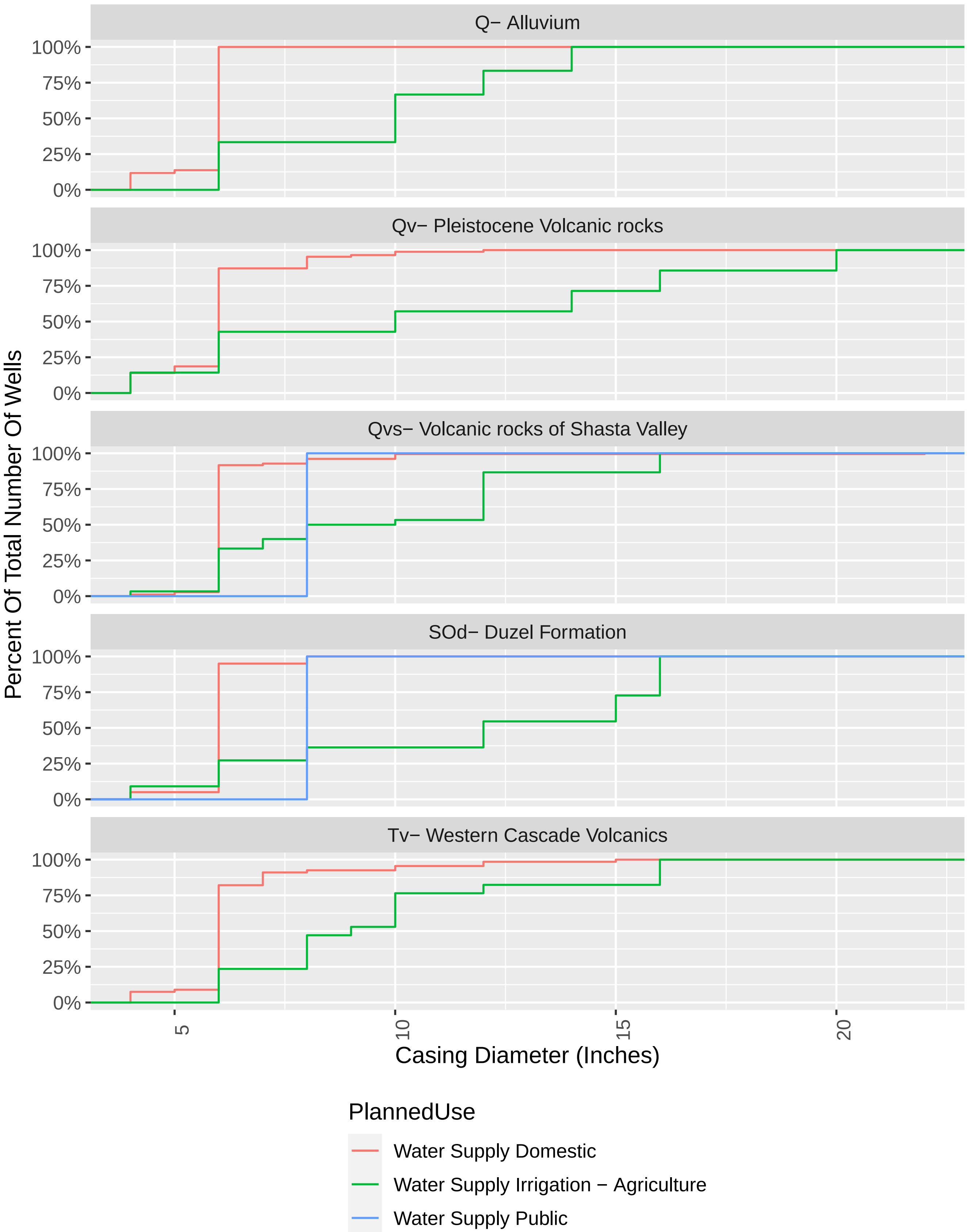

Figure 6: Shasta Valley well casing diameter by formation at the bottom of the well comparing major well types

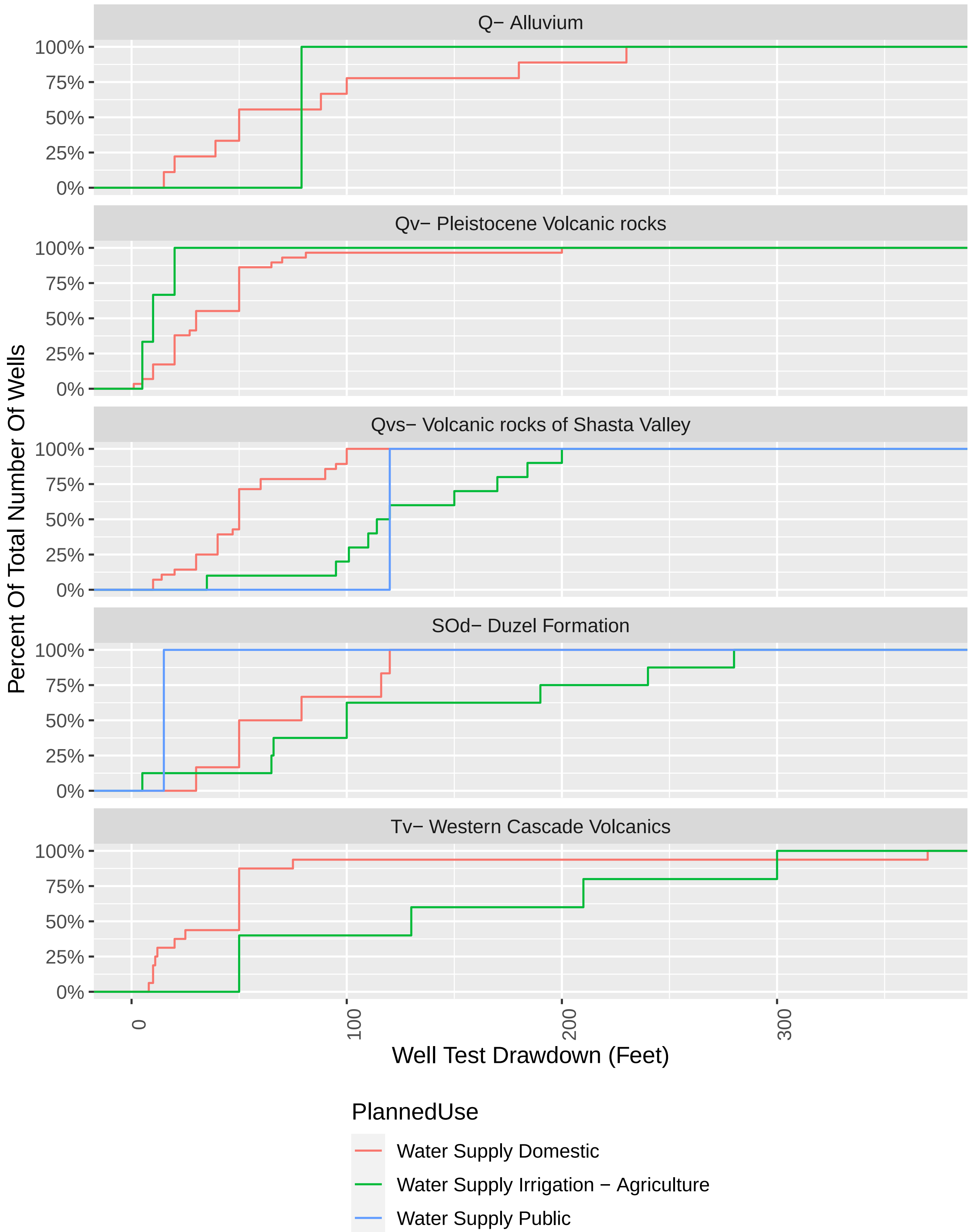

Figure 7: Shasta Valley well test drawdown by formation at the bottom of the well comparing major well types

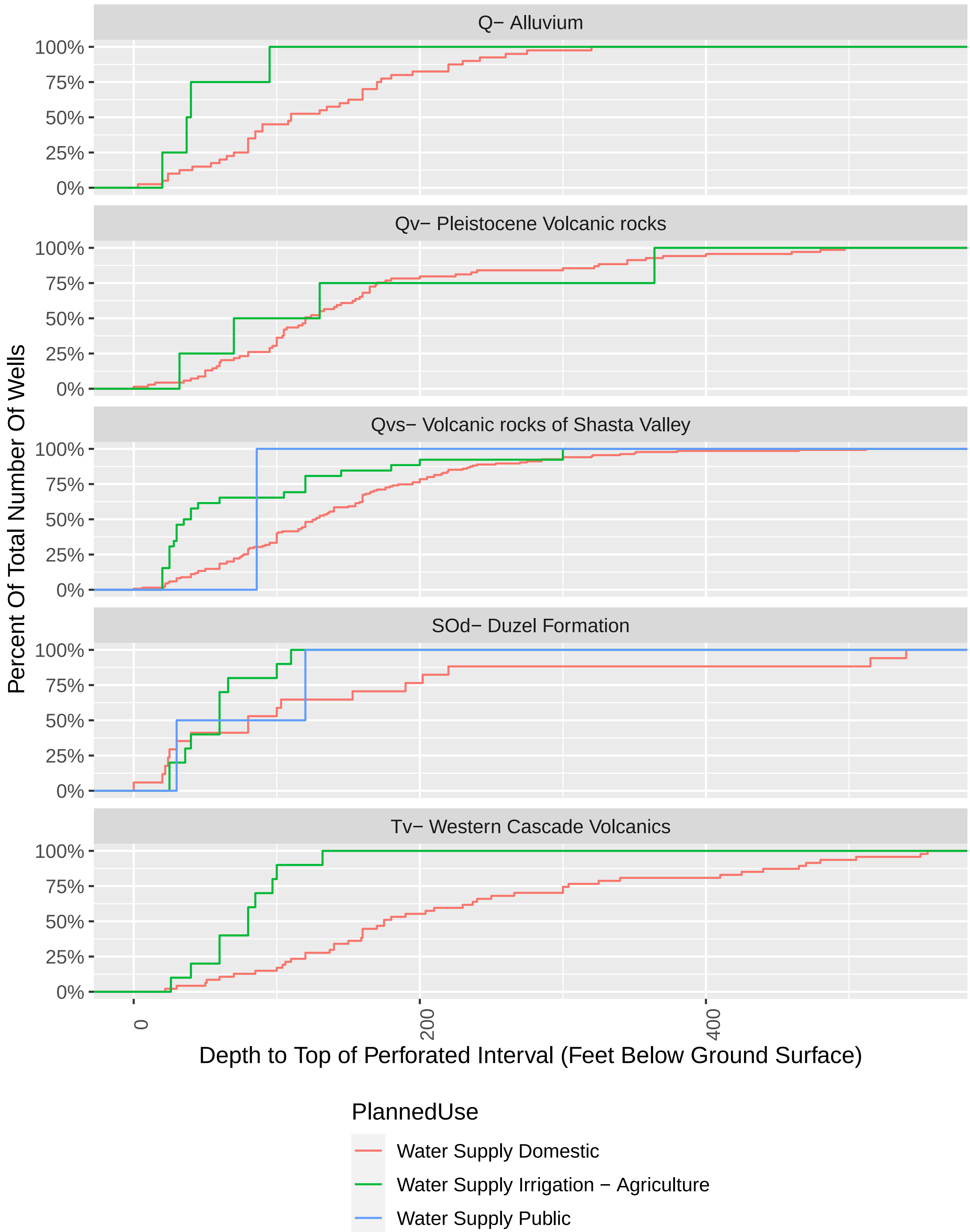

Figure 8: Shasta Valley well top of perforation below ground surface by formation at the bottom of the well comparing major well types

Estimated Wet Depth to Top of Perforations

The interpolated, contoured water table depth in fall of 2015 is shown in Figure 9, together with the location of those wells with water level measurements that are used for the water table depth interpolation. Estimates of water table depths are most accurate near the locations of the measured wells. The accuracy of estimates deteriorates with distance from a measured well (also see Chapter 2 in the Shasta Valley Groundwater Sustainability Plan).

The estimated wet depth to top of perforations is shown in the following map (Figure 10). If the interpolated elevation of the water table was above the top of perforations, the wet depth to top of perforations is positive. If the interpolated water level elevation was below the top of perforations, the difference shown is a negative number, and these wells are color-coded yellow in Figures 10 and 11. About one-quarter of wells have an estimated wet depth to top of perforations that is negative. About half of wells are estimated to have a wet depth to top of perforations of less than 100 feet (but not negative). Slightly more than one-quarter of wells are estimated to have a wet depth to top of perforations of more than 100 feet. The wells most vulnerable to well outage are those with the least (or negative) wet depth to top of perforations. Approximately 93 percent of wells have between negative 100 and positive 200 feet of water predicted above the well perforations.

A negative wet depth to top of perforations may be the result of a real event, e.g., the well is old and has been dry for some time, or the well is pumping from below the top of perforations. A negative wet depth to top of perforations may also be the result of estimation errors:

1) the interpolated water table depth used to estimate wet depth to top of perforations can be associated with significant error, from few feet to few tens of feet, due to limitations of the interpolation algorithm. The algorithm cannot account for localized changes in water table depth, especially in hilly terrains, where depth to water table may change rapidly as a function of terrain and well location.
2) depth to top of perforations is inaccurately reported.

The absolute value of the wet depth to top of perforations is therefore thought to be of poor accuracy. However, its cumulative distribution is indicative of the relative distribution of wet depth to top of perforations across wells in Shasta Valley. The cumulative distribution of the wet depth to top of perforations is shown in Figure 12 for both years, 2015 and 2017. A zoomed-in version of this Figure, focused on wet depth to top of perforations from 0 feet to 200 feet is shown in Figure 13. Wet depth to top of perforations are shown for fall 2015, following a dry winter and fall 2017, following a wet winter, for comparison purposes. The cumulative distribution of wet depth to top of perforations indicates that fall 2017 water level conditions actually had less wet depth to top of perforation across many wells in Shasta Valley than 2015 (in other words, the brown curve is above - shallower than - the green curve). This is consistent with the observation that water levels in 2015 were higher in many wells than in 2017. The difference between the two years is least where (estimated) wet depth to top of perforations is very shallow or negative. From -20 feet to 80 feet wet depth to top of perforations, the difference between fall of 2015 and fall of 2017 is about 10 - 20 feet (most of wells).

When comparing 2015 and 2017 cumulative distributions of wet depth to top of perforations by individual geologic formations, a more differentiated assessment emerges: wells in the Duzel and the Pleistocene volcanic formations show the inverse behavior, with wet depths being shallower in 2015, but deeper in 2017, consistent with the water year type (Figures 14, 15, 16, 17, 18).

The absolute value of the wet depth to top of perforations is, as indicated, highly uncertain. However, the slopes of the cumulative distributions shown are relatively uniform at either end of the distribution and are therefore much less sensitive to the above listed uncertainties. Figure 13 indicates that the slope of the CD is approximately 5% to 9% (in x-axis direction) per 10 feet (in y-axis direction), for the 5th to 35th percentile of shallowest wells. Hence, this slope is representative for the approximately one-third of Shasta Valley wells that have the least estimated wet depth to top of perforations and would be most susceptible to well outages. Given the range over which the slope applies, the slope value is much less sensitive to the specific estimated wet depth to top of perforations at a well. Rather, it applies to all wells with shallow (or negative) values. If we further assume that the minimum wet depth to top of perforations needed for proper pumping is similar for most domestic wells (or most agricultural wells), then the slope can be interpreted as the risk for well outage with additional water level decline below historically low values: the slope indicates that 5% to 9% of Shasta Valley wells are likely to experience well outage for every 10 feet of water level decline below the historically lowest measured water levels. Figure 14, 15, 16, 17, and 18 similarly show the cumulative distribution of "wet depth to top of perforations" for the one-third shallow-most wells completed in the Western Cascade Volcanics, Duzel Formation, Qvs volcanic rocks, alluvium, and Pleistocene Volcanic rocks, respectively.

Importantly, this approach to estimating well outage risk does not require knowledge of specific well information about pumping bowl elevation relative to the screen location, or about a minimum wet water level depth needed to pump properly. It only assumes that some well outages occur if water levels fall below historic lows and, hence, the selected slope is representative of the one-third of wells at most risk to well outage.

This allows for an estimate of the undesirable result that would occur if water levels declined to the minimum threshold. The depth to water level at the minimum threshold is defined as 110% of the deepest depth to water level observed, but never more than 10 ft below the deepest observed water level. In most areas of the groundwater basin, the deepest depth to the water level observed over time is less than 100 feet (see above), hence the minimum threshold in most areas would allow 3 to 8 feet, at most 10 feet of additional lowering of water levels. On average across the RMP network, the minimum threshold is 5 ft below historically observed low water levels. If the entire basin were to fall to the minimum threshold water level, approximately 2.5% to 4.5% of wells, or 25 to 45 wells out of approximately 1,000 wells in the Basin are at risk of well outage (based on 5% to 9% of wells at risk of well outage for every 10 feet decline in water levels, see Figure 13).

The well outage risk may be unevenly distributed across Shasta Valley (Figures 14, 15, 16, 17, 18): The slopes indicate a lower risk for wells in the Western Cascade Volcanics and Pleistocene Volcanics, but higher risks elsewhere.

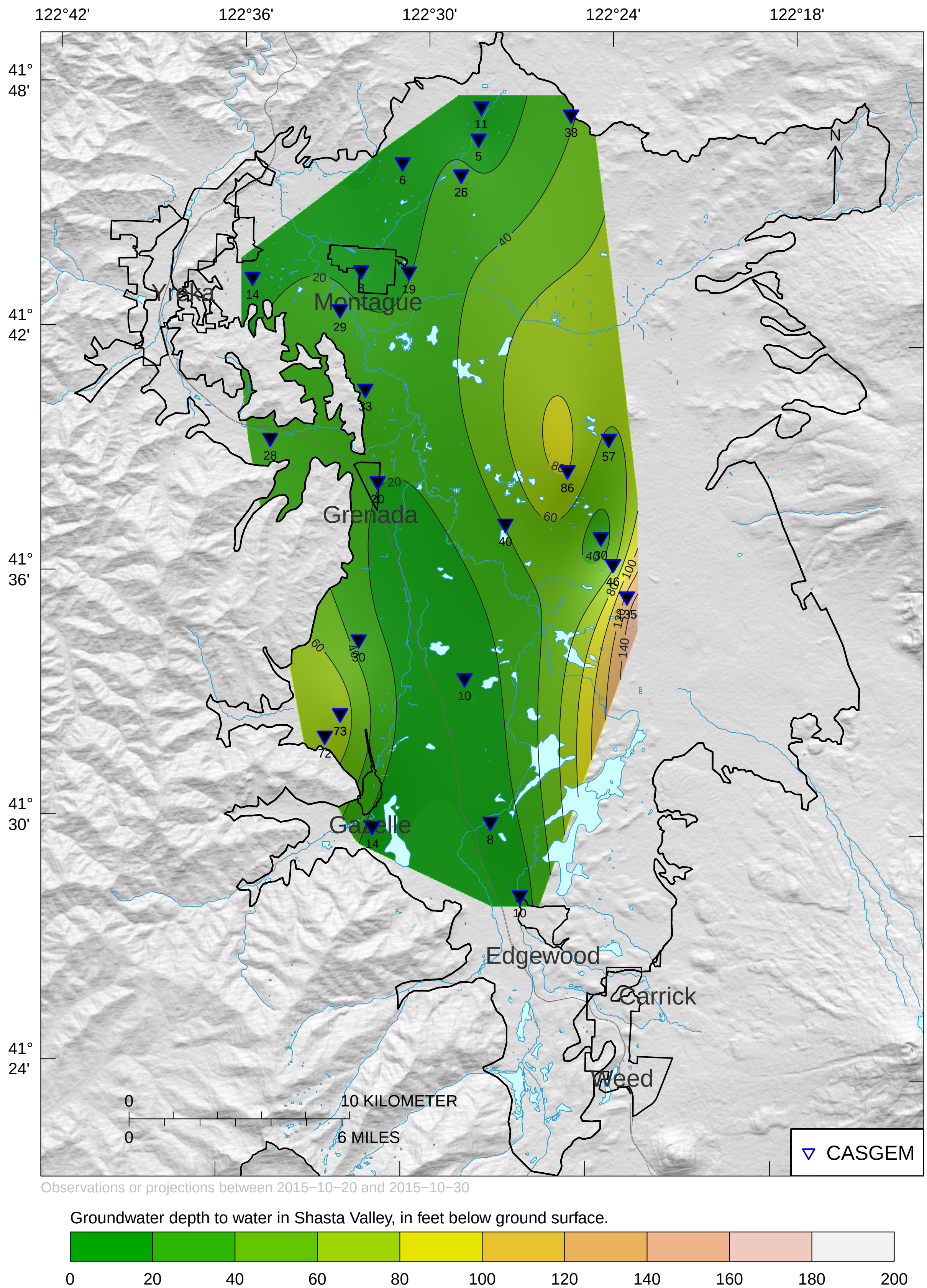

Figure 9: Shasta Valley groundwater elevations reported as approximate depth to groundwater, fall 2015 and well failure estimates based on recent water level observations. Approximate basin-scale groundwater depths are shown.

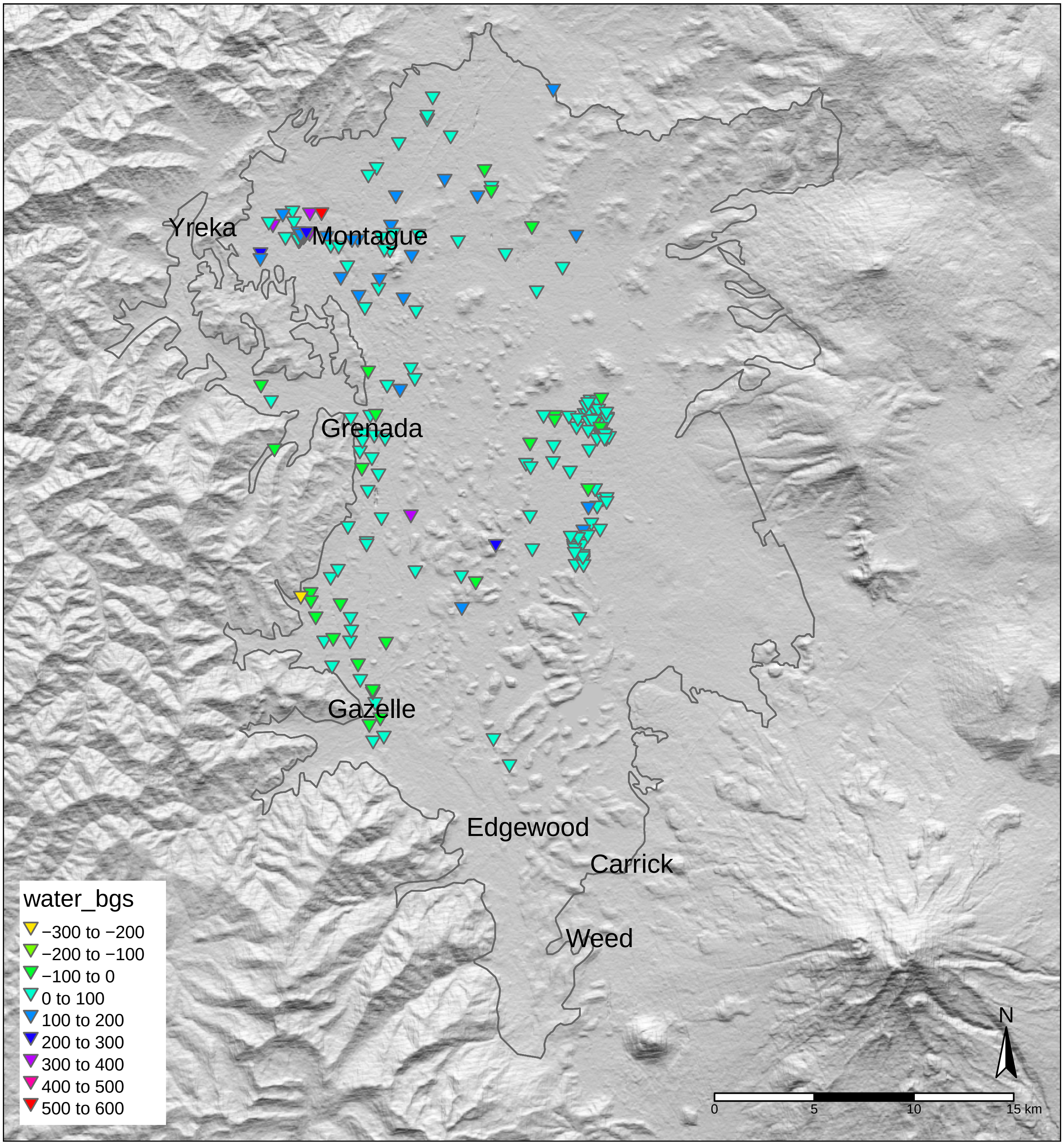

Figure 10: Shasta Valley wet depth to top of perforations based on contoured groundwater elevations, October 2015.

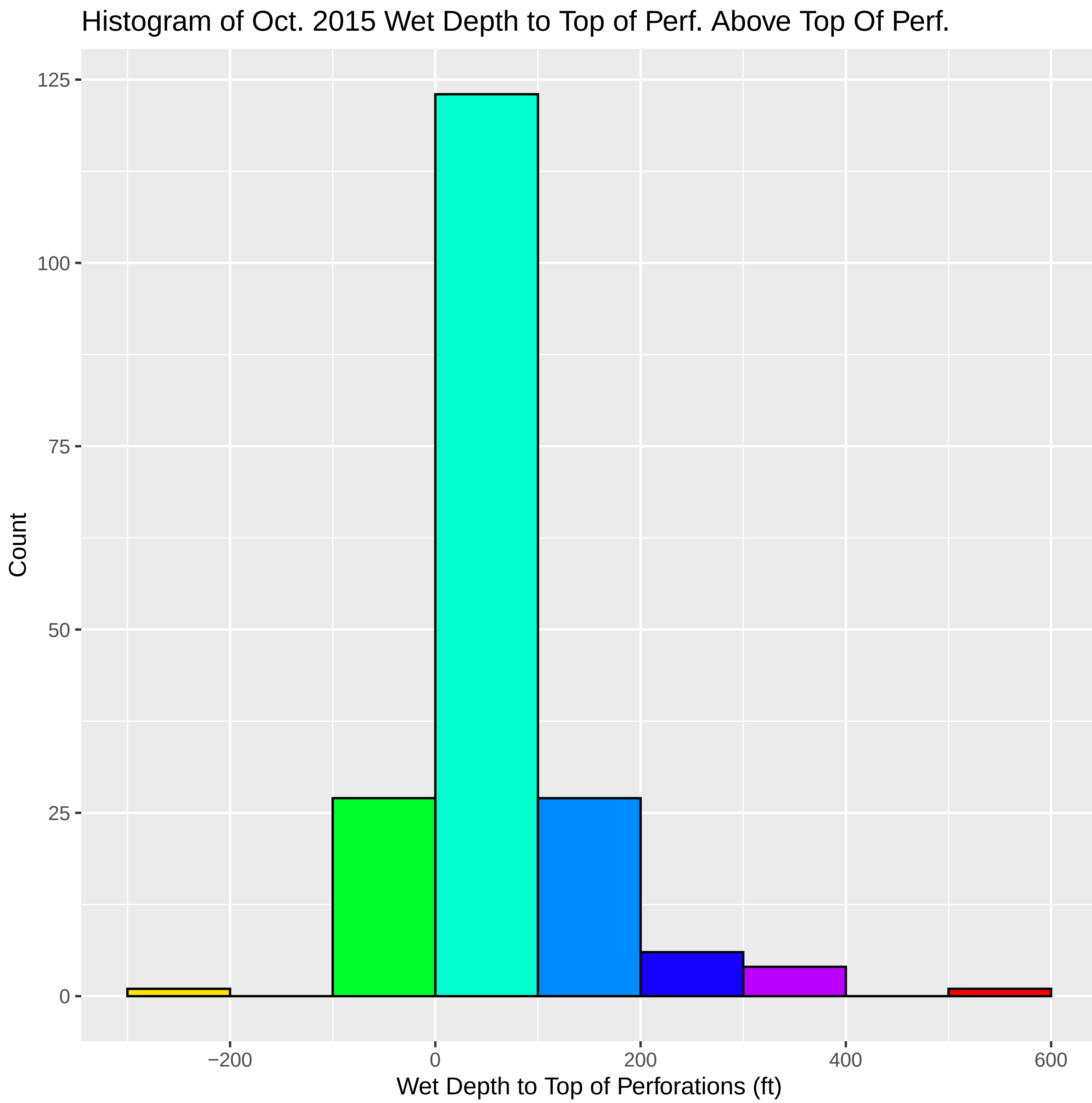

Figure 11: Histogram of wet depth to top of perforations based on contoured groundwater elevations, October 2015.

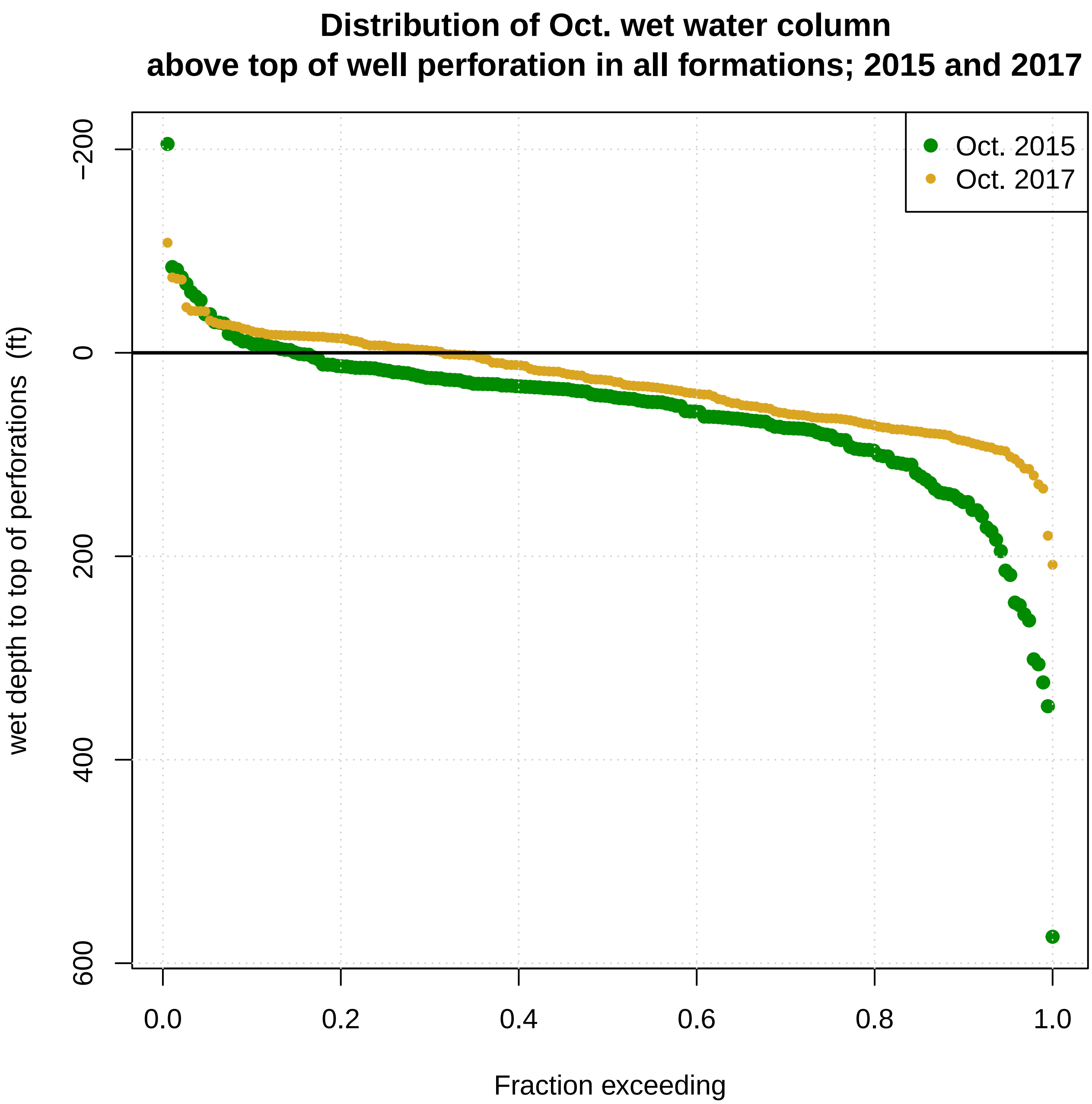

Figure 12: Cumulative distribution function of all well wet depth to top of perforations based on contoured groundwater elevations, Octobers of 2015 and 2017.

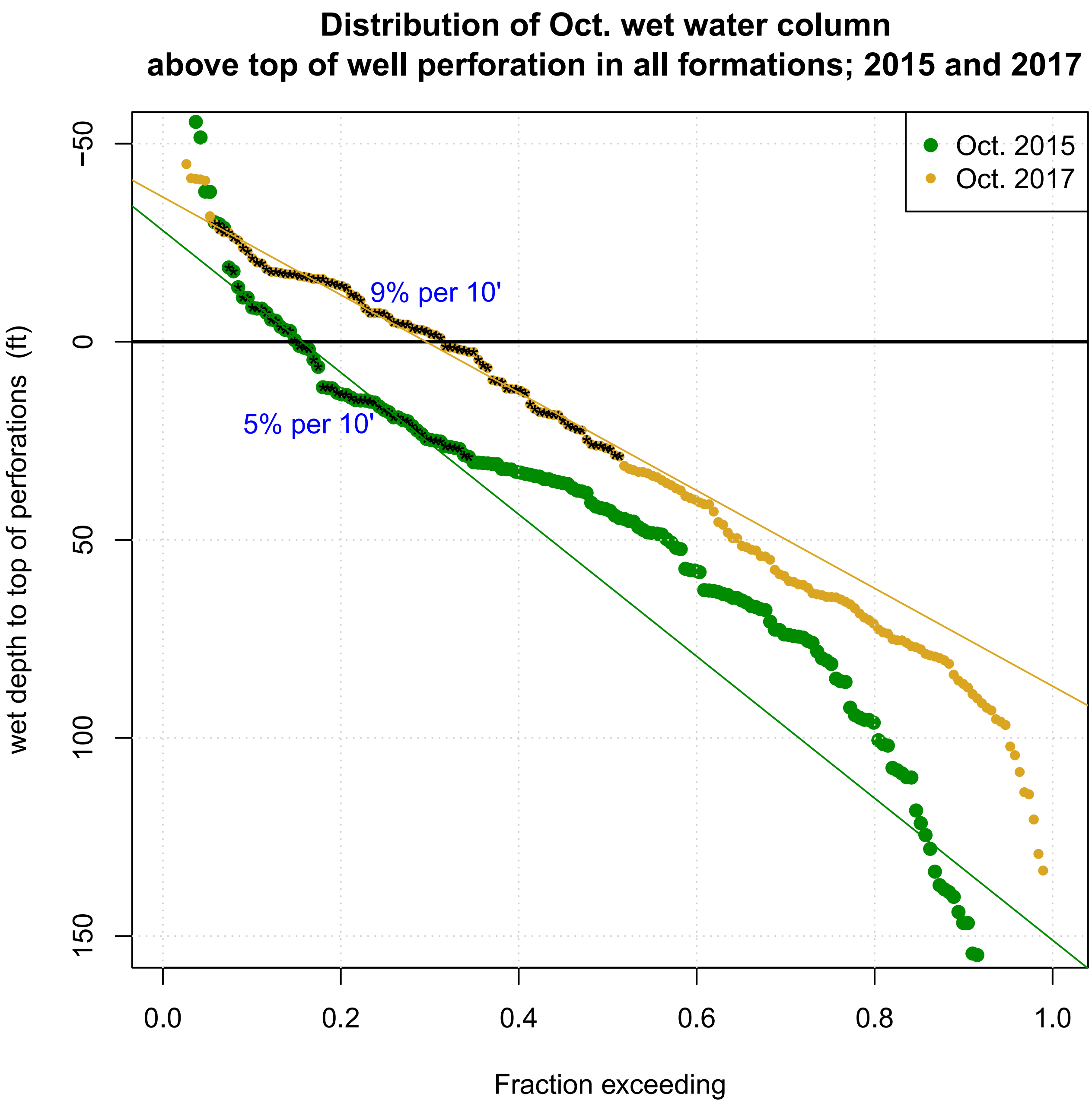

Figure 13: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well failure slope. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (LINEST function in Excel: 10* LINEST (fraction range, feet range).

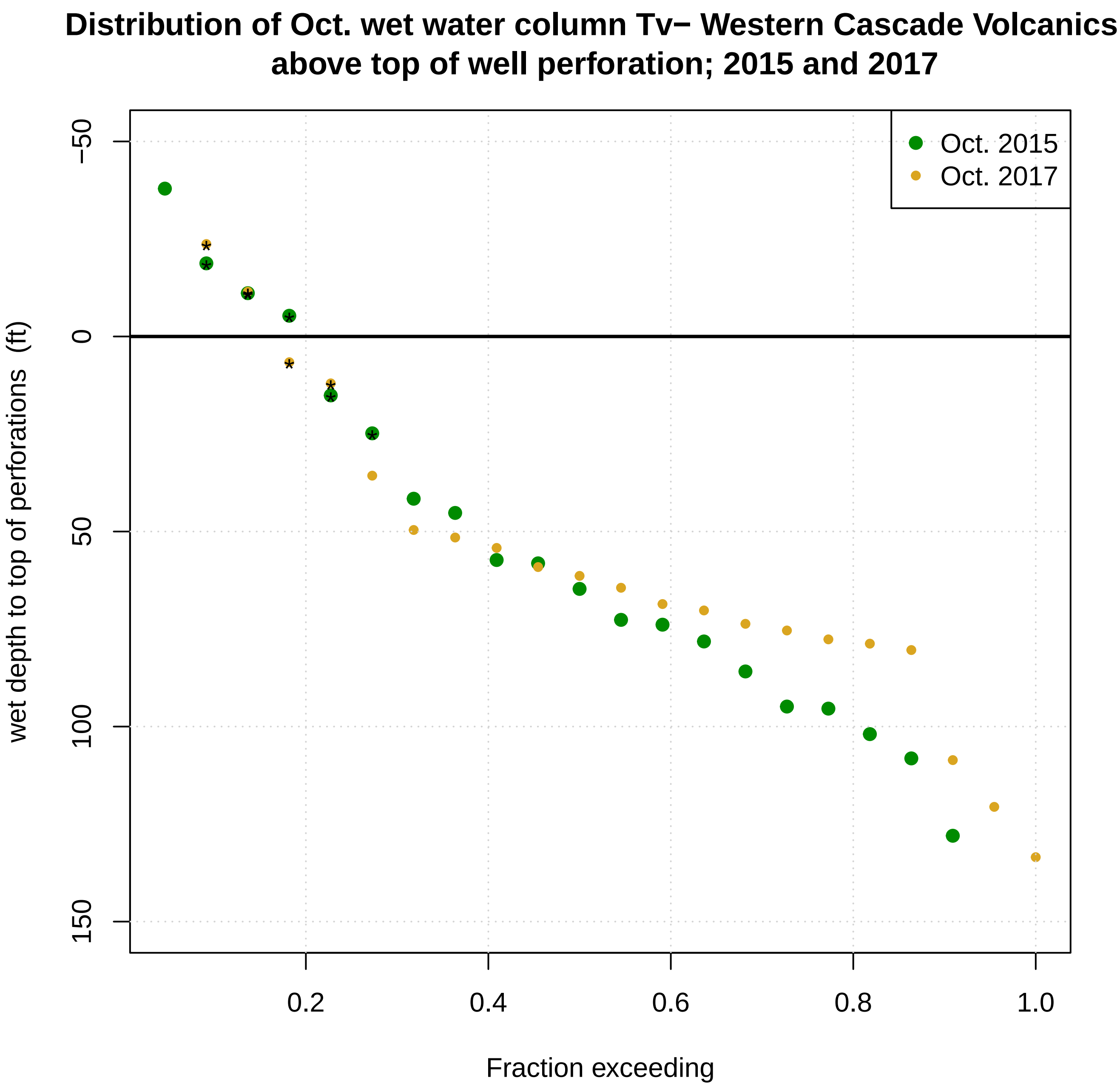

Figure 14: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well failure slope. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (LINEST function in Excel: 10* LINEST (fraction range, feet range).

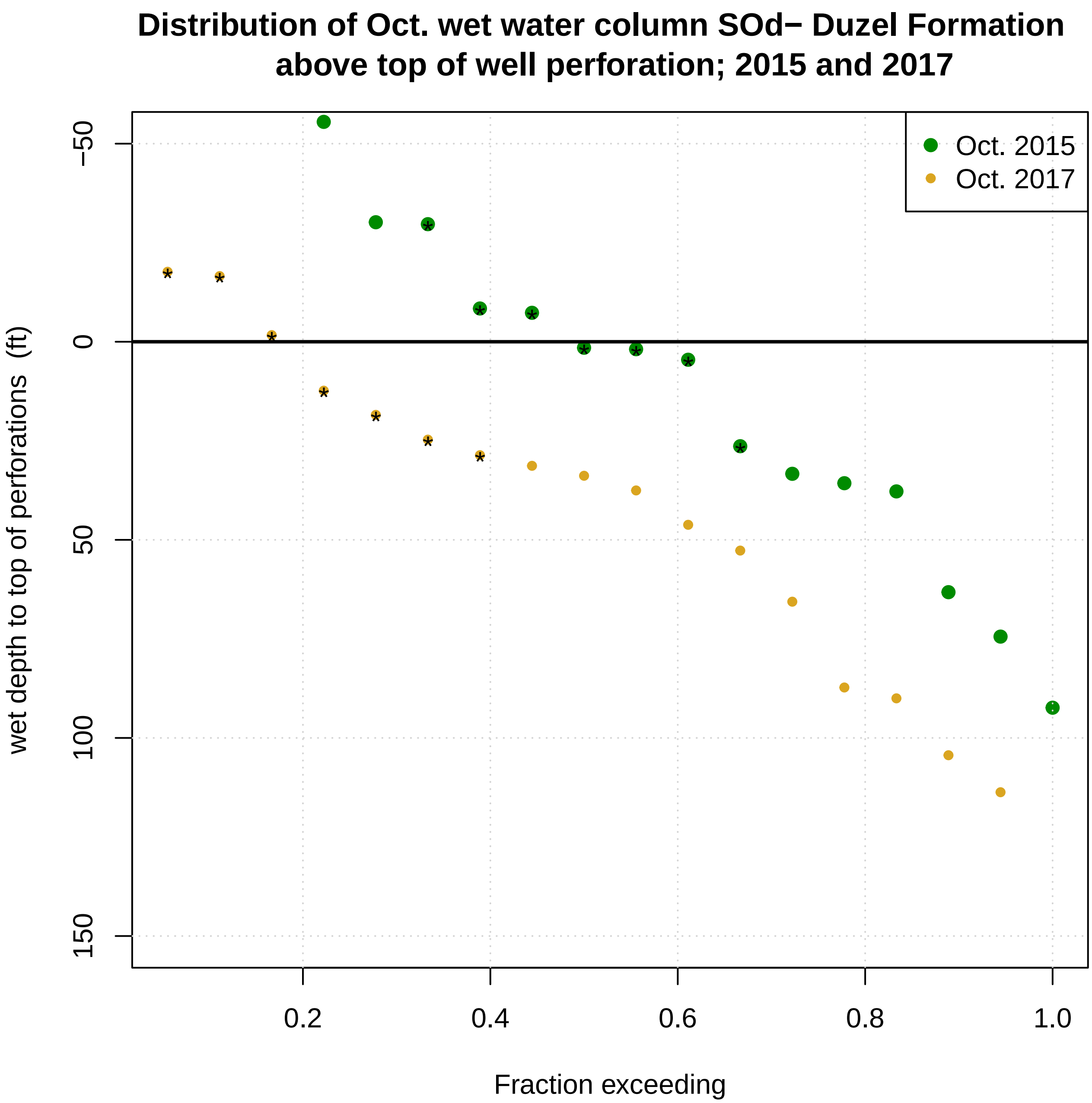

Figure 15: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well failure slope. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (LINEST function in Excel: 10* LINEST (fraction range, feet range).

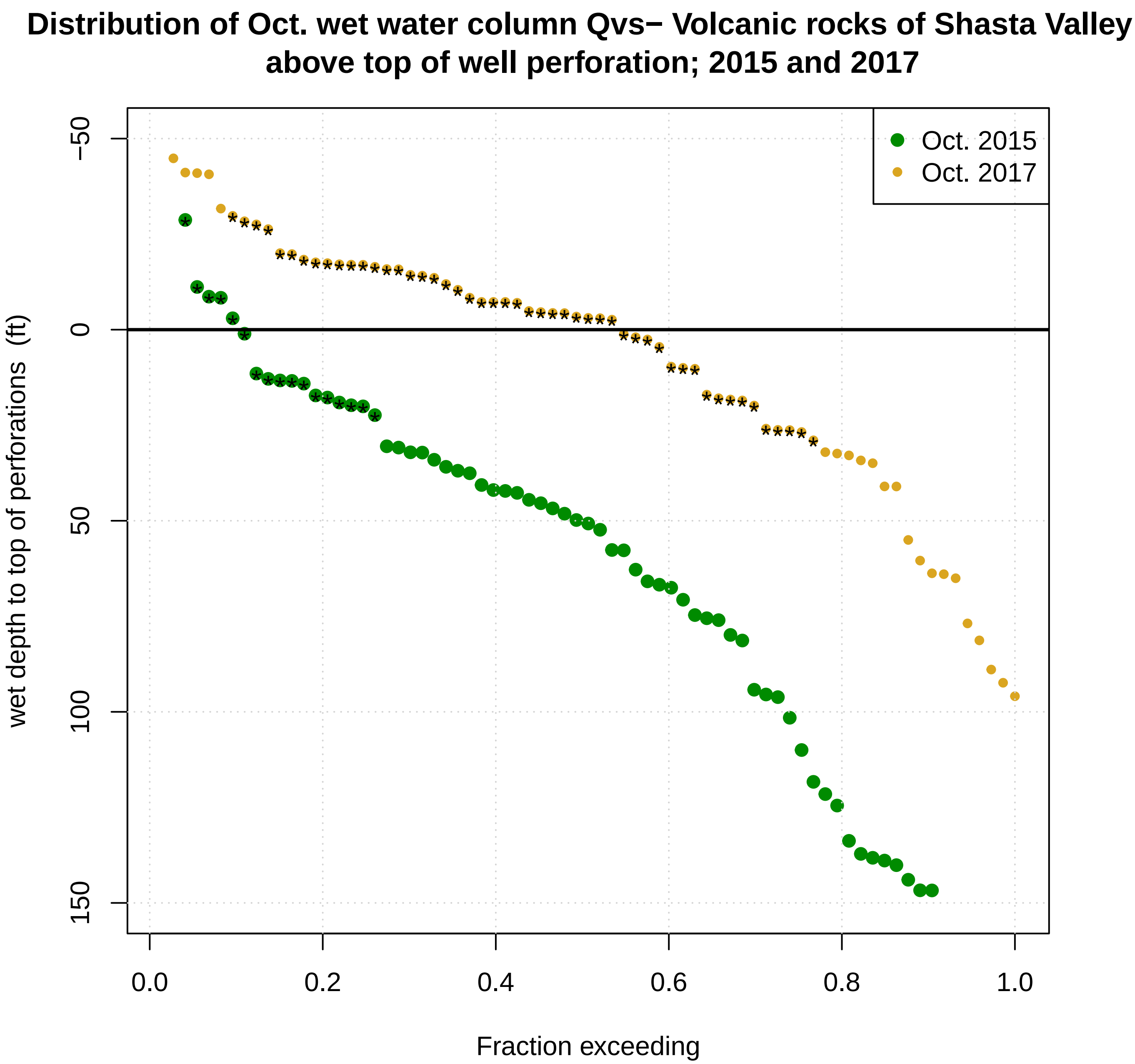

Figure 16: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well failure slope. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (LINEST function in Excel: 10* LINEST (fraction range, feet range).

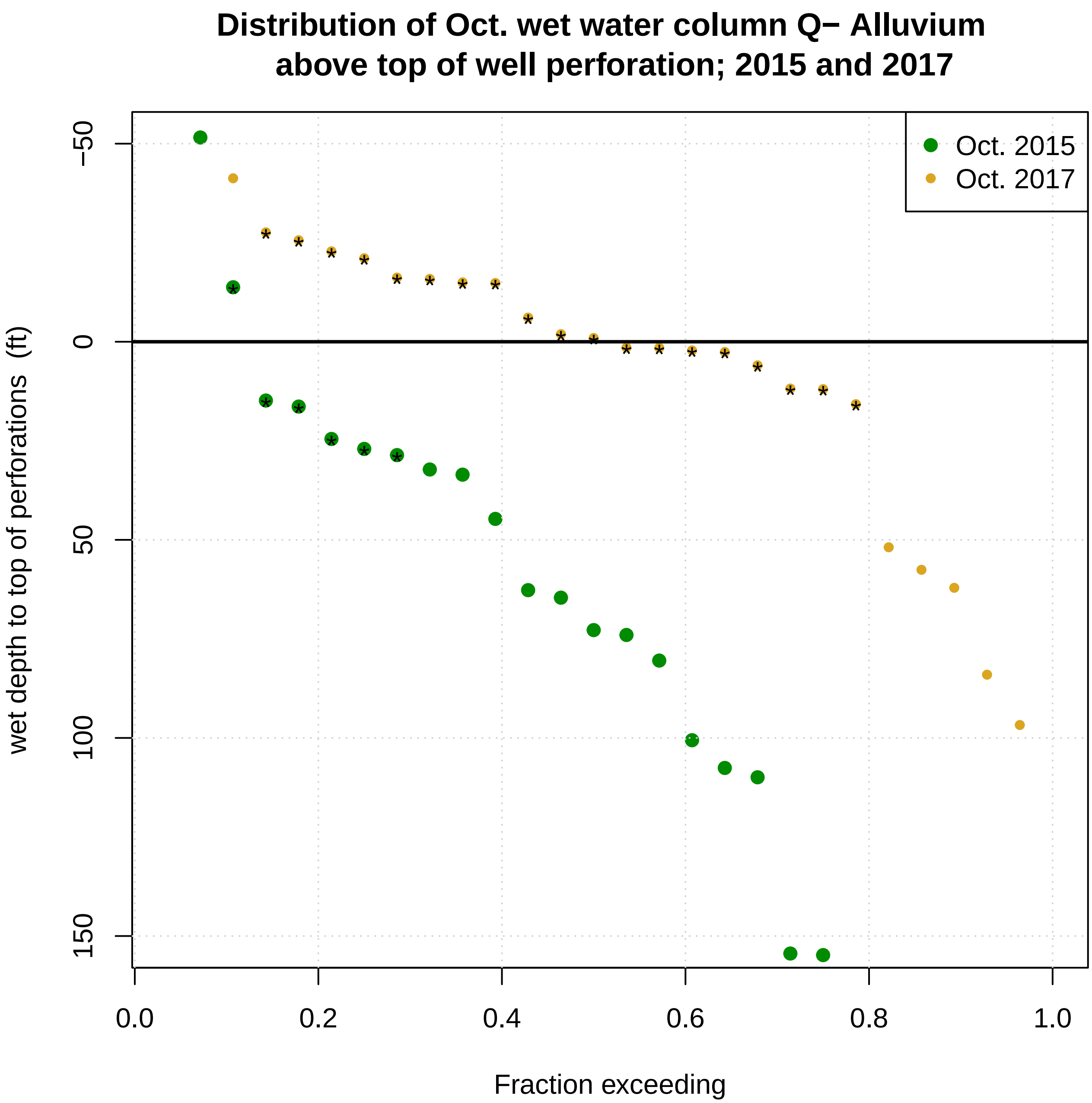

Figure 17: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well failure slope. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (LINEST function in Excel: 10* LINEST (fraction range, feet range).

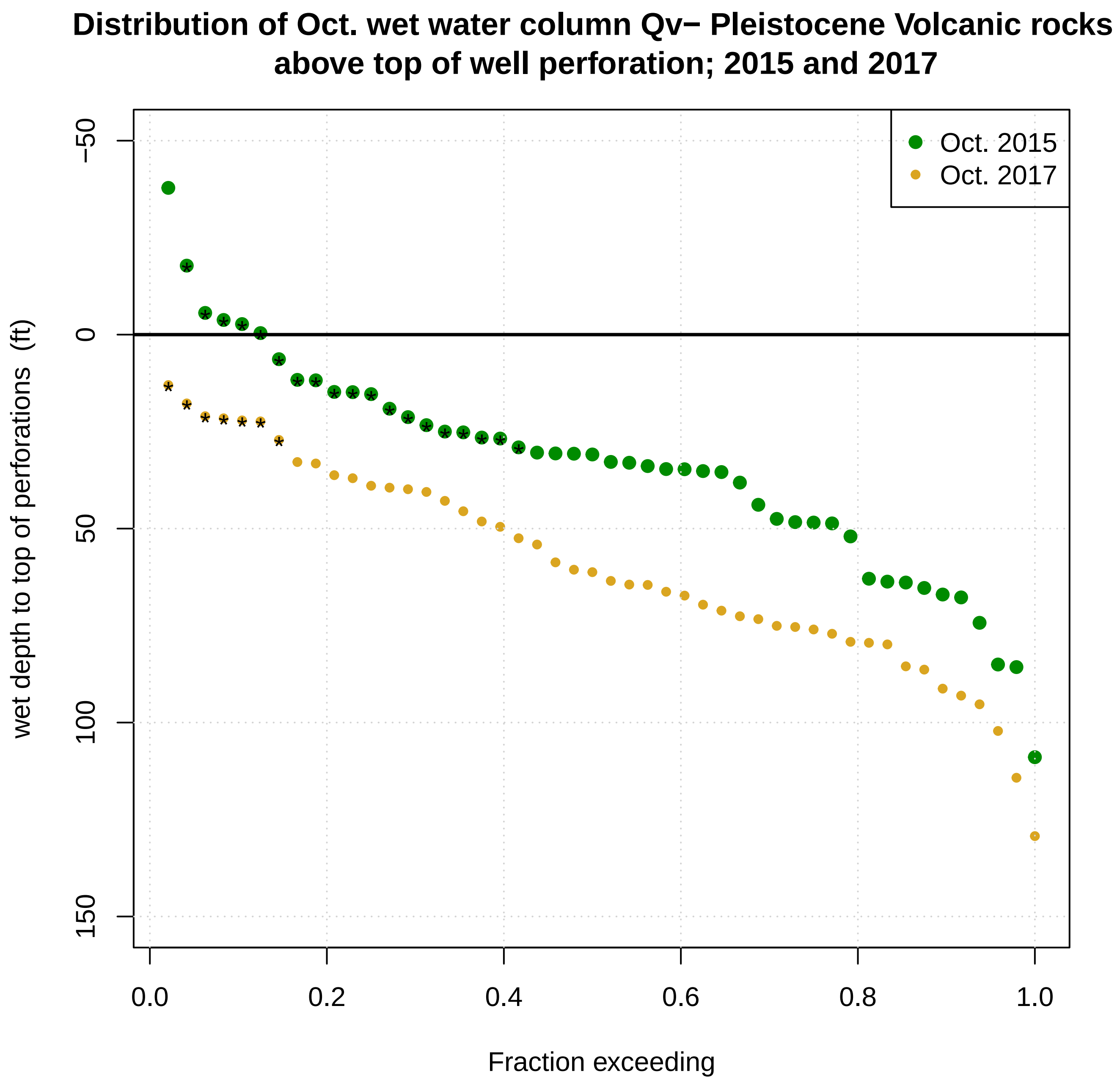

Figure 18: Focused graph of cumulative distribution function of all well wet depth to top of perforations feet based on contoured groundwater elevations, Octobers of 2015 and 2017, -50 to 150 feet. Black dots indicate the wells with water columns betwen -30 and 30 feet used for interpolating the well failure slope. Interpolation computed as a best fit linear slope to the data between the 5th and 35th percentile (LINEST function in Excel: 10* LINEST (fraction range, feet range).

Conclusion

We identified three key findings with respect to well outages:

Majority of wells unlikely to be affected by dewatering. Most wells in Shasta Valley have well depths of 50 feet or more below the interpolated groundwater elevations depths of 2015 (at least 65%).

Uncertainty affects analysis quality. The analysis is relatively uncertain due to the lack of wells with both water level measurements and known well construction. Hence, we relied on interpolated water level data, which may be several feet or even tens of feet incorrect in some areas. This may be the case regarding the ~25% of wells with top of perforations above the interpolated water level depth (Figure 13) in 2015 (dry year) and 2017 (wet year).

In wells for which the wet depth to top of perforations is negative or exceedingly shallow, either:

1) the well goes dry in the fall, regardless of water year type, or,
2) the well pumps from below the top of perforations, or
3) the depth to water table interpolation is erroneous (most likely in hilly areas), or
4) well depth is inaccurately reported.

Due to the uncertainties arising from (3) and (4), we relied instead on the slope of the cumulative distribution of estimated wet water column depth, which is a more stable indicator of how many additional wells fall dry per 10 foot decline in water levels below historically low water levels. We find that:

The number of wells affected by groundwater elevations at the Minimum Threshold is small but not insignificant. The minimum threshold is 10% lower than the minimum measured depth to the water table (see Chapter 3). In most Shasta Valley areas, where water depth of groundwater is less than 70 feet, water levels at the minimum threshold would be less than 7 feet lower than at their historic low. A small number of wells would be affected by that, as shown in Figure 13. Considering Chapter 3, the minimum threshold is, on average, 5 feet below the historically deepest measured water level. Based on Figure 13, a 5 foot lowering of the water level would affect about 2.5% to 4.5% of wells (about 25 to 45 wells), if water level conditions reached minimum threshold levels throughout the basin.

Appendix 3-D. Interconnected Surface Water Sustainability Management Criteria

Contents

Interconnected Surface Water Sustainability Measurable Criteria

The Sustainability Measurable Criteria (SMCs) were primarily based on the attached reports by the Shasta Valley Resource Conservation District and public records from the Scott Valley and Shasta Valley Watermaster District.

LOWER SHASTA RIVER WATER BALANCE: SEPTEMBER 2016

LOWER SHASTA RIVER WATER BALANCE: SEPTEMBER 2016

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

January 2017

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FIGURES

TABLES

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. Water that is forgone and left in river is tracked as well as possible by the Watermaster to ensure it is kept in river, but not all water transacted under these forbearance agreements is accounted for in lower reaches of the Shasta River.

The objectives of this study were to quantify the effects of the Fall Flow Transaction Program by:

I. Measuring flow at strategic locations within the Shasta River, tributaries, and limited tailwater inputs all below the confluence with Big Springs Creek (hereafter referred to as "Lower Shasta River"),
II. Tracking diversion quantities and shutoff times during the study period, and
III. Assessing flow from existing USGS gages.

River inputs and outputs were tracked in a spreadsheet and accretion/depletion was assessed for four subreaches within the study area. Results from this study will be used to inform future transactions and flow studies.

B. BACKGROUND

I. SHASTA RIVER WATERSHED

The Shasta River watershed covers 793 square miles within Siskiyou County, California as part of the larger Klamath Basin. The Shasta River originates from snowmelt in the Klamath Mountains on the western side of the basin, while receiving substantial flow from springs from Mt. Shasta discharging on the eastern side. 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 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, and rearing for coho and Chinook prior to their migration to the ocean as well as 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. The Shasta River TMDL, adopted in 2007, identifies flow alterations due to irrigation withdrawals and return flows (tailwater) as a primary factor 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. Reduced flows, tailwater return flows to the river, along with reduced stream shade are listed as factors that can affect water quality and consequently affect the beneficial uses. While substantial progress has been documented in the Shasta River Watershed through efforts such as pulsed flows in the spring and 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 studied in this document. 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 with that subduction process scraping off a variety of ocean sediments and island arcs which now form the Klamath Mts. In addition, that subduction 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. Those volcanic deposits most notably include an extensive lahar or debris avalanche (~350,000 years before present), forming the bulk of the relatively flat central portion of the Shasta Valley, and the Plutos Cave Basalt (~100,000-300,000 years before present in the southwesterly portion of the valley, comprised of a fractured surface and subsurface lava formation that serves to transmit the bulk of the water that ultimately discharges as springs to form the flows constituting the Shasta River investigated in this study. Lesser portions of the Shasta Valley include more recent alluvial deposits around its perimeter, derived from the surrounding mountains. These geologic features are displayed in Figure 1 and related hydrologic zones in Figure 2.

FIGURE 1. GEOLOGIC MAP OF THE SHASTA VALLEY. GRAPHIC FROM: (CALIFORNIA DEPARTMENT OF WATER RESOURCES, 2008)

FIGURE 2. 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 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. 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 strategy is designed to provide water instream to benefit the migration of spawning Fall Chinook into the Lower Shasta during the month of September. The bulk of summer irrigation 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 of water instream, which tripled the amount of water that would otherwise have been available for these fish in September. In 2016, the program secured 36 cubic feet per second 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.

The outpouring of support by the agricultural community to provide water instream to benefit these fish has been truly 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. 2016 FALL FLOW PROGRAM

In 2016, the Shasta River Water Transaction Program assisted the Shasta Valley agricultural community with completing the eighth year of a community-wide Fall Flow Program. Funding provided was utilized for the 2016 Fall Flow Program to secure 752 acre-feet of water instream through short-term forbearance agreements in September 2016. In support of the 2016 Fall Flow Program, The Nature Conservancy and the Shasta Valley Resource Conservation District completed this Fall Flow Study report to begin developing a target water budget for the month of September for future years, and to better understand in what reaches of the Shasta River the system may be gaining or losing water which can confound needed flow management while short-term forbearance agreements are donating water instream. This water balance is important to help better understand earlier qualitative observations that anywhere from 10-30 cubic feet per second of water was being lost as it traveled downstream to the Lower Shasta during the month of September. Recommendations from this report will inform future phases of this study to refine the study area and begin identifying causes of accretion or depletion of water along the lower 33 miles of the Shasta River.

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Summary 2016 Fall Flow Program and Study Goals and Objectives

Goal:	To gain a better understanding about where the Shasta River may be losing or gaining water during the month of September to maximize the benefits that added flows have to salmon habitat.
Objectives:	Secure flow instream during September 2016 to benefit the return of adult Fall Chinook to the Shasta River and implement Phase 1 of a water budget study.

II. STUDY PERIOD

The study period lasted from late-August through early October 2016. Equipment was installed by August 23rd, 2016 and removed on October 21st, 2016. To meet the goal and objectives of the study, flows in the Lowers Shasta River (below Big Springs Creek confluence) through the Shasta River canyon - including major tributaries, limited tailwater inputs, and diversion amounts - were assessed on select measurement days in August 2016 through early October 2016.

III. METEOROLOGICAL DATA

Within the assessment area, there are two meteorological stations, one at the Weed Airport (WED) which is available through California Data Exchange Center (CDEC) and operated by CAL Fire and the second at Brazie Ranch which is available through the Western Regional Climate Center's Remote Automatic Weather Stations (RAWS) and operated by S&PF. Air temperature, precipitation, and solar radiation data was analyzed from WED due to its closer proximity to the study area. These data are displayed below in Figure 3.

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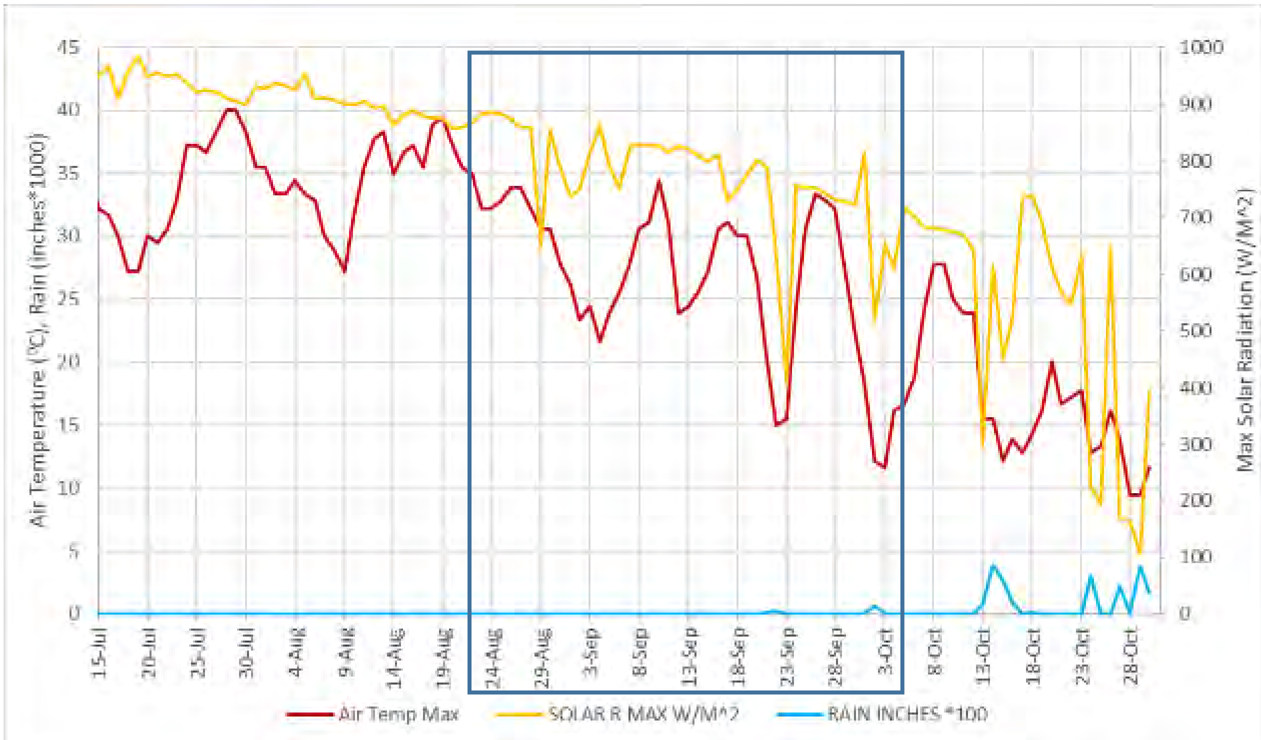

FIGURE 3. METEOROLOGICAL DATA INCLUDING MAXIMUM AIR TEMPERATURE, SOLAR RADIATION, AND PRECIPITATION DURING LATE SUMMER AND FALL 2016 WITH STUDY PERIOD HIGHLIGHTED. DATA SOURCE CDEC STATION WED (WEED AIRPORT): JULY 15, 2016 - OCT. 31, 2016.

Solar radiation and maximum air temperatures decreased consistently through the study period which included a few cloudy days as well as minimal rain on September 21-22nd (0.03 and 0.04 in) and again on October 2nd (0.15 in).

IV. STUDY AREA

The study area spans roughly 33 river miles and includes approximately 21 diversions/diversion points with a diversion potential of up to 143 CFS. The study area was broken up into four reaches. The study area, reaches, and flow measurement stations are identified on Figure 4. Detailed maps of reaches 1 through 4 including diversion locations are provided in Section v. Study Area: Reach Descriptions. Flow measurement station locations were chosen so that: 1) they were spread throughout the study area; 2) they provided relatively easy access; and the cross-sectional area was ideal for a flow measurement.

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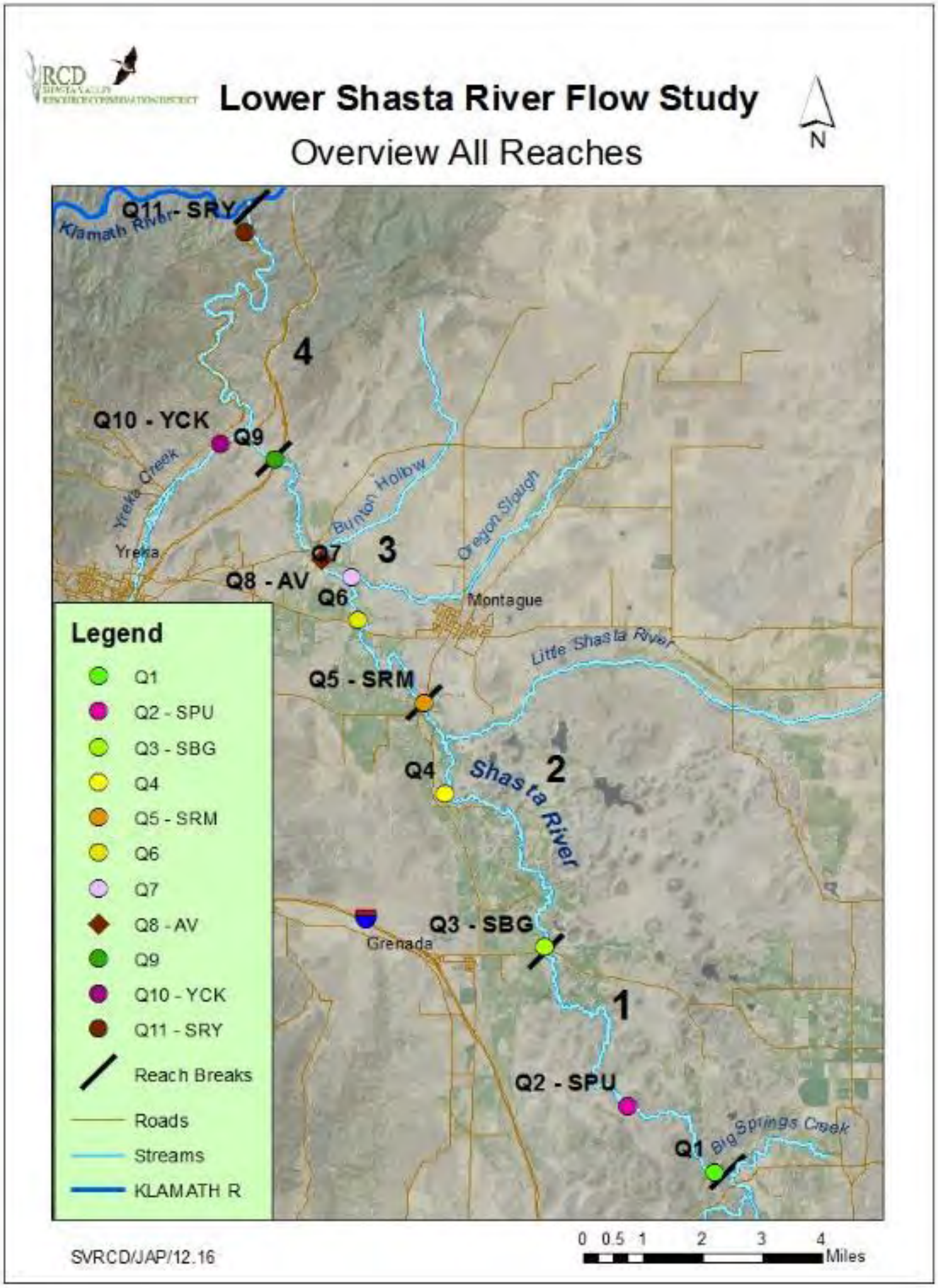

FIGURE 4. MAP OF LOWER SHASTA RIVER AND MAJOR TRIBUTARIES WITH ALL MEASUREMENT SITES INCLUDING DISCHARGE TRANSECTS, INSTALLED AREA-VELOCITY METERS, AND EXISTING GAGES.

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Flow measurement stations within each reach, river mile, and type of flow (Shasta River flow or inflow) are provided in Table 1.

TABLE 1. FLOW MEASUREMENT STATIONS, RIVER MILE, AND TYPE OF FLOW [SHASTA R. FLOW (Q), OR INFLOW].

Station Name	Station ID	River Mile	Type
REACH 1: Below Big Springs Creek to A- 12			
Below Big Springs Creek	Q1	34.8	Shasta R. Q
Above Grenada Irrigation District	Q2-SPU[1]	32.3	Shasta R. Q
Below County Road A-12, SBG - DWR	Q3-SBG	24.8	Shasta R. Q
REACH 2: A-12 to Montague Grenada Weir			
Below County Road A-12, SBG - DWR	Q3-SBG	24.8	Shasta R. Q
Below Shasta Water User's Association	Q4	18.0	Shasta R. Q
Shasta R. near Montague – USGS 11517000	Q5-SRM[2]	15.7	Shasta R. Q (USGS gage)
REACH 3: Montague Grenada Weir to Interstate 5			
Shasta R. near Montague – USGS 11517000	Q5-SRM[2]	15.7	Shasta R. Q (USGS gage)
Below Hwy 3	Q6	12.7	Shasta R. Q
Oregon Slough	Q7	11.4[4]	Inflow
Bunton Hollow	Q8-AV[3]	11.8[4]	Inflow
Upper Canyon	Q9	8.7	Shasta R. Q
REACH 4: Interstate 5 to Klamath River			
Upper Canyon	Q9	8.7	Shasta R. Q
Yreka Ck. at Anderson Grade - SVRCD	Q10-YCK[1]	7.3[4]	Inflow
Shasta R. near Yreka – USGS 11517500	Q11-SRY[2]	0.6	Shasta R. Q (USGS gage)

[1]Station rated prior to study period. Rating verified during study period.
[2]Existing USGS gage. Did not independently verify rating.
[3]Continuously recording area-velocity meter installed.
[4]River mile for inflow measurements indicate the Shasta mainstem location corresponding to their confluence with the Shasta River.

V. STUDY AREA: IRRIGATION DEVELOPMENT

The diversion of Shasta River water for agriculture is the primary water use in the Shasta River Watershed. While the Shasta River adjudication allows for diversion of water in varying quantities year-round depending on each water right holder's specific beneficial uses, only hot season (irrigation) water use has the major short term impacts on water quality and salmonid survival. The summer irrigation season runs from April 01 through October 01 for nearly all diversions on the mainstem Shasta[1]. Beginning early in the irrigation season, surface water has been formally declared as "fully appropriated" for most of the irrigation season and streamflows in the lower portions of the river are drastically reduced until the end of the mainstem irrigation season on October 01.

Although many farmers own and operate their own individual irrigation systems within the Shasta Valley, there are 4 major water districts or associations [Grenada Irrigation District (GID), Montague Water Conservation District (MWCD), Huseman Water Users, and Shasta River Water Association (SWA)] that

[1] Winter diversions from October 01 through April 01 are primarily small and for stock water in the study area.

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operate and manage large irrigation systems using surface water, and one additional district using groundwater (Big Springs Irrigation District). 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: BIG SPRINGS CREEK TO COUNTY ROAD A-12

<u>Reach Length:</u> 10.4 miles

<u>Discharge Measurement locations:</u>

I. **Q1** – below Big Springs Creek at RM 34.8
II. **Q2** – SPU above Grenada Irrigation District pumps at RM 32.3
III. **Q3** – Below county road A-12 at RM 24.8

A total of approximately 67 cfs is potentially diverted within reach 1 (split between 5 diversion points). Of this, one large diversion (40 cfs) was turned off during the entire study period. Reach 1 is displayed in Figure 5.

Investigations by TNC have shown numerous small springs discharging underwater in the bed of the river immediately upstream of this reach, indicating a likelihood of more currently unknown small springs occurring within the reach. Additionally, there are multiple small spring visibly discharging near the river bank between Q1 and Q2, the largest nearing 1 cfs in flow.

The McCloud Slough and one other apparently unnamed slough drain to the river in this reach on river left, although no surface flows are usually apparent. In addition, leakage from the GID canal (up to about 10 cfs, along with any deep percolation from GID irrigation, less any transpiration enroute) may in part return to the river sub-surface in this reach and/or the next reach downstream if GID has been diverting recently.

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. No other accretion sources are known in this reach.

Interestingly, investigations by DWR in the 1950's of a potential dam site in the middle of this reach found evidence of a 130' deep lava canyon completely buried by the lahar covering the bottom of the Shasta valley, yet completely invisible in terms of surface features (California Department of Water Resources, 1964). Such re-sculpting of the landscape provides ample opportunity for unpredictable hydrology throughout this area.

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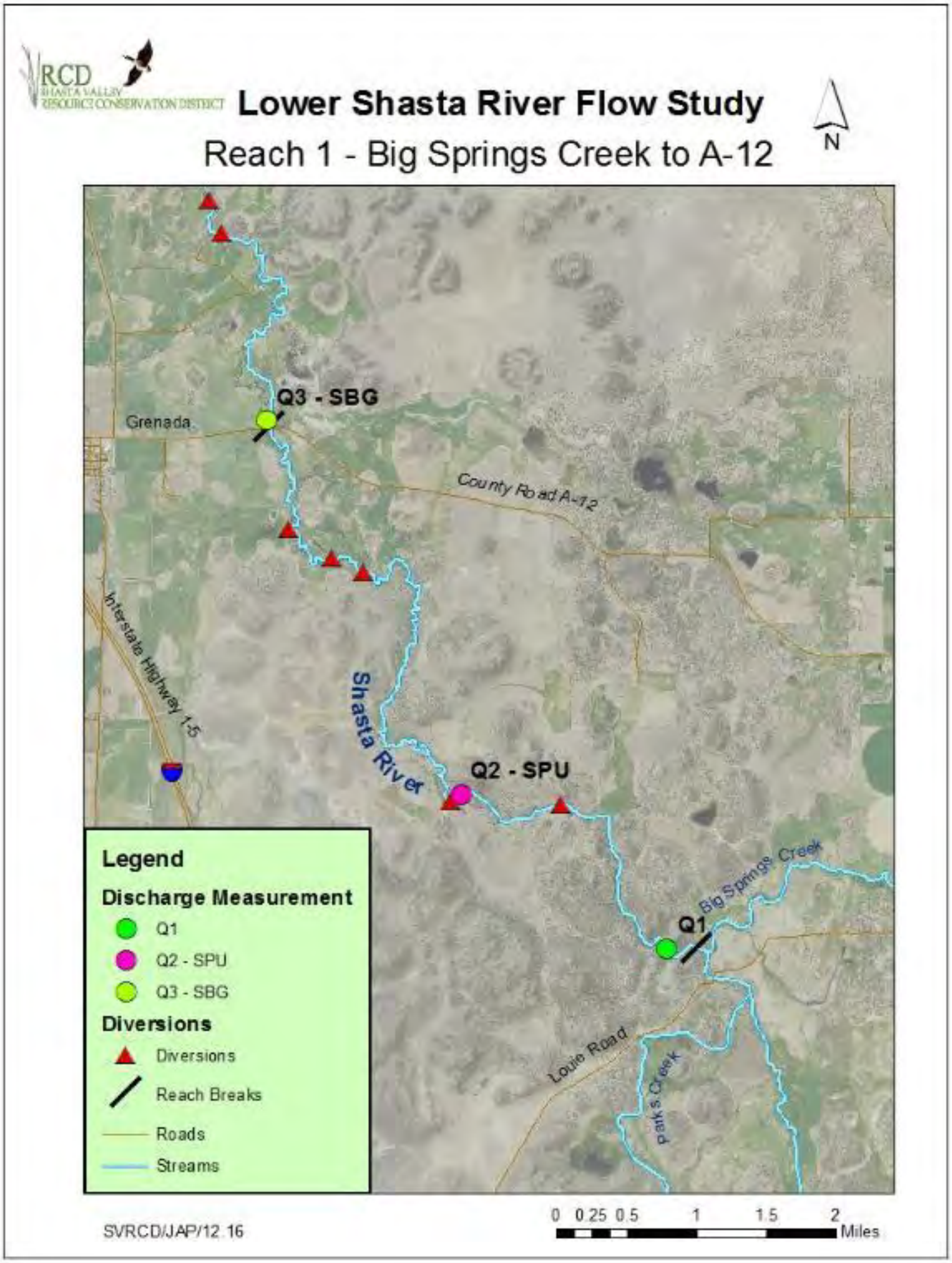

FIGURE 5. MAP OF REACH 1: BIG SPRINGS CREEK TO COUNTY RD. A-12, WITH FLOW MEASUREMENT SITES, REACH BREAKS, AND DIVERSIONS.

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REACH 2: COUNTY RD. A-12 THROUGH MONTAGUE-GRENADA RD. WEIR

Reach Length: 9.1 miles
Discharge Measurement Locations:

I. **Q3** – Below county road A-12 at RM 24.8
II. **Q4** - Below Shasta River Water Association at RM 18.0
III. **Q5** - Shasta R. near Montague – USGS at RM 15.7

A total of approximately 53 CFS is potentially diverted within Reach 2 (split between 7 diversion points). Of this, one large diversion (42 CFS) was turned on for most of the study period (until October 1st) and assumed to be diverting the full right. Reach 2 is displayed in Figure 6.

Within this reach geologic complications continue. A narrow branch of the Plutos Cave Basalt overlays and bisects the Lahar, 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 - although much of it is hidden below irrigated improved pasture. That alluvial fan likely provides a conduit for Julien underflow, spring flow from springs visible and not visible adjoining the Julien Creek channel, along with sub-surface tailwater returning from GID and/or SWA.

Further downstream, leakage from storage reservoirs and/or irrigation tailwater can reach the Shasta from the Calif DFW wildlife area, joining the river at river mile 18.8.

Below SWA (diversion just upstream of Q4 on river left), substantial amounts of SWA tailwater crosses Breceda Lane (just downstream of Q4 on river left) when irrigation is occurring uphill from that area and is either caught in a tailwater re-use system, or returns to the river as tailwater or subsurface.

At the reach breakpoint at Q5-SRM on river right is a large wetland area where an upwelling of water is apparently contributing water to the stream via sub-surface gravel old river channels, even though no surface flows are apparent.

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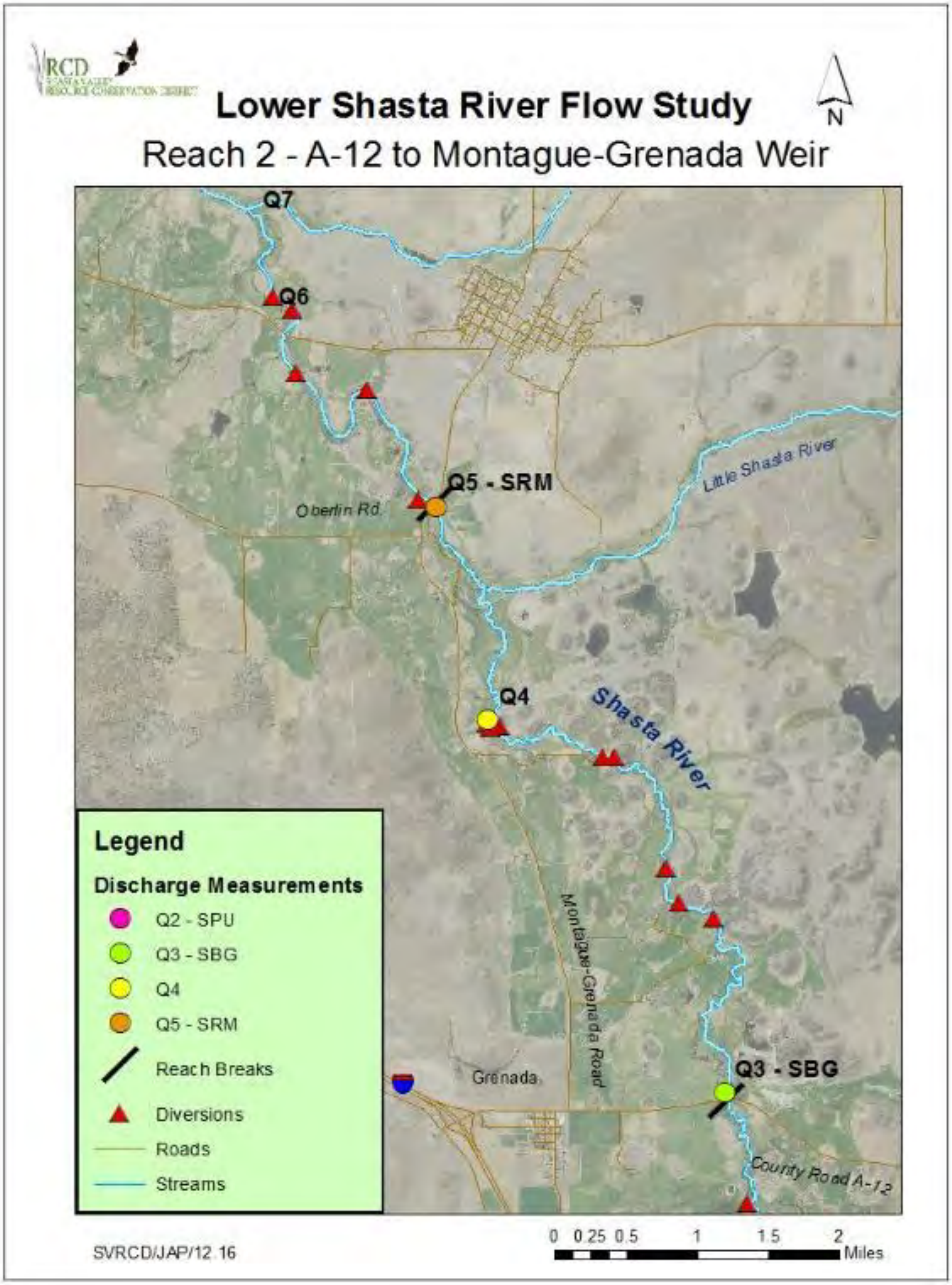

FIGURE 6. MAP OF REACH 2: COUNTY RD. A-12 TO MONTAGUE GRENADA RD. WEIR WITH FLOW MEASUREMENT SITES, REACH BREAKS, AND DIVERSIONS.

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Reach 3: Montague-Grenada Rd. weir to above I-5 crossing

Reach Length: 7.0 miles

Discharge Measurement locations:

I. **Q5** - Shasta R. near Montague – USGS at RM 15.7
II. **Q6** – Below Hwy 3 at RM 12.7
III. **Q7** – Oregon Slough at RM 11.8 (inflow)
IV. **Q8-AV** – Bunton Hollow at RM 11.4 (inflow)
V. **Q9** – Above Interstate 5 crossing at RM 8.7

A total of approximately 22 CFS is potentially diverted within reach 3 (split between 9 diversions/diversion points). Two known inflows enter the Shasta River within this reach including Oregon Slough and Bunton Hollow (measurement stations Q7 and Q8-AV, respectively). Reach 3 is displayed in Figure 7.

Immediately downstream of Q5, periodic pulses of SWA irrigation water and tailwater can return to the river. Downstream of them on river left begins the Lewis Ditch, now essentially abandoned, but still capable of intercepting overland flowing SWA tailwater, which it is believed to eventually deliver to the irrigation pumps immediately downstream of Highway 3.

Beginning about ½ mile downstream of Highway 3, and continuing for about 2½ miles farther are several draws on river left that periodically deliver SWA tailwater towards the river. It is unknown whether that water is being intercepted and directed into an irrigation pipeline, intercepted by an abandoned irrigation ditch, or returning to the river.

More or less opposite this amphitheater is the Oregon Slough, which drains a large area to the north and east of Montague, most of which is within the MWCD. The heavy clay soils in this area infiltrate slowly, leading to increased potential for tailwater creation if water is not managed carefully. Any tailwater not captured reaches the Oregon Slough, along with naturally present water, of which there is some, as the name indicates. A small spring is found just below the Montague-Ager Rd Bridge, and there may be additional water joining the channel in that general area, as there is sufficient water to justify a pumped diversion a little farther downstream. Approximately 1 mile downstream of the Montague-Ager Rd. bridge are the Montague secondary wastewater treatment ponds, immediately adjacent to the stream. Some minor leakage may occur there, flowing into Oregon Slough. Another ¾ mile downstream of those ponds along the Oregon Slough is a small wetland area with a small but visible spring on river right of the Oregon Slough. Despite those various inputs, by the time the slough reaches the Shasta, little water remains in it.

Back on the mainstem Shasta, Bunton Hollow Creek (Q8) joins the river just above the Yreka Western Railroad bridge. All summer the lower end of this intermittent stream has a trickle of water in it, likely mostly originating almost entirely from irrigation adjacent to its channel. Beginning about 1/3 mile upstream of the Yreka-Ager Rd., at approximately the Yreka Western RR bridge, begins an area where significant amounts of apparent ditch leakage can often be found returning to the river on river right via several small draws. Similar amounts have not been observed on river left.

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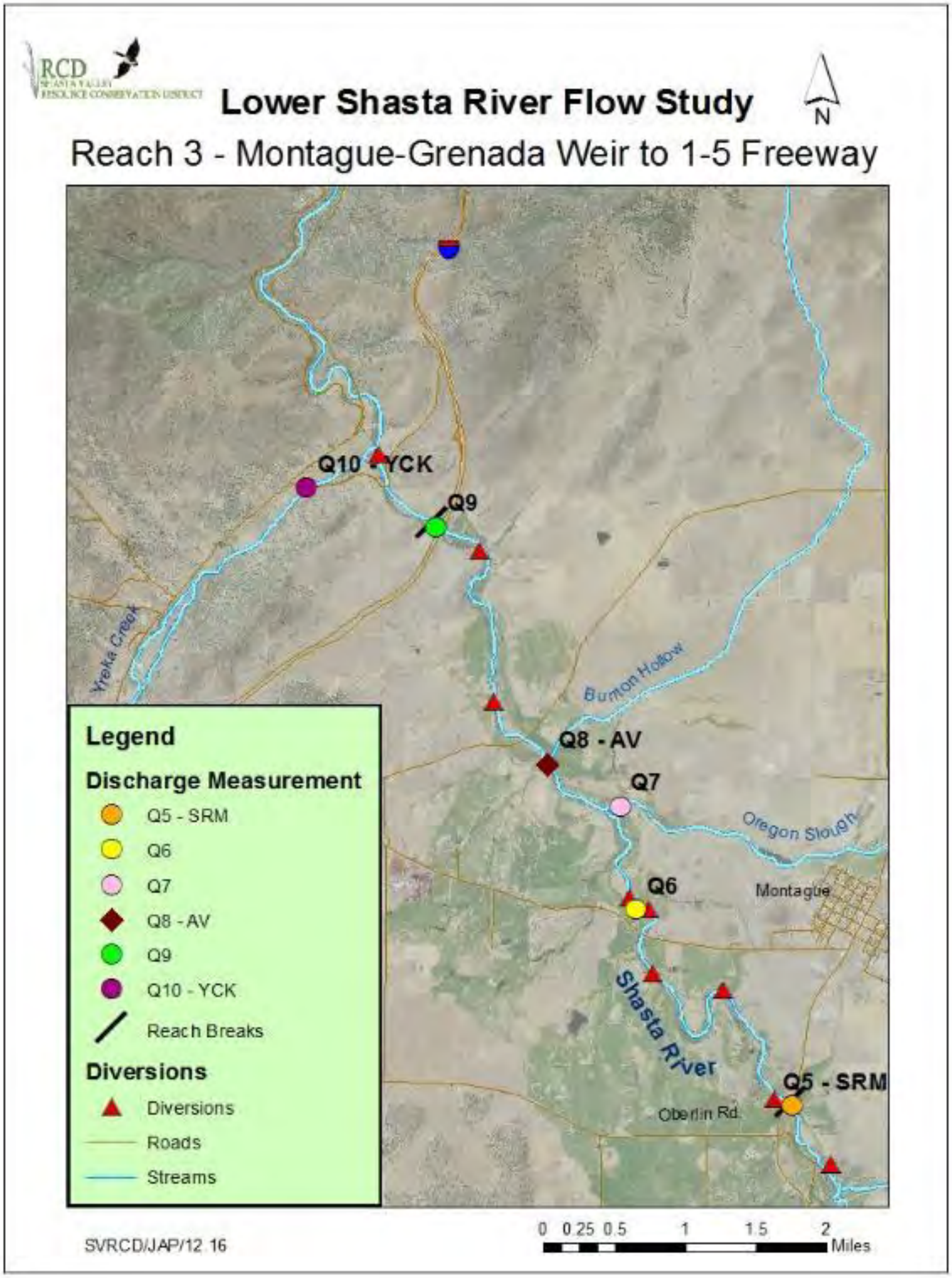

FIGURE 7. MAP OF REACH 3: MONTAGUE GRENADA RD. WEIR TO ABOVE I-5 FREEWAY CROSSING WITH FLOW MEASUREMENT SITES, REACH BREAKS, AND DIVERSIONS.

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Reach 4: Above I-5 freeway crossing to Shasta River Canyon at River Mile 0.6

Reach Length: 8.1 miles

Discharge Measurement Locations:

I. **Q9** – Upper Canyon at RM 8.7
II. **Q10-YCK** - Yreka Ck. at Anderson Grade at RM 7.3 (inflow)
III. **Q11** – SRY - Shasta R. near Yreka USGS at 0.6 miles

No active diversions exist within reach 4. One inactive diversion exists just downstream of the Anderson Grade Rd. bridge. Yreka Creek enters the Shasta River within this reach (measurement station Q10-YCK). Reach 4 is displayed in Figure 8.

As the Shasta River leaves the agricultural portion of the Shasta Valley, it is joined by Yreka Creek, and soon thereafter enters the Shasta Canyon, an area where it flows primarily on bedrock, with periodic patches of gravel. During summer, no surface flows can be found to join the river here, although a few very small springs do apparently provide minute accretions to the river. One active hydro diversion is found in mid-canyon, but its operations do not change river volume. Finally, near the mouth of the Shasta is a currently dormant small domestic diversion, along with a small amount of likely accretion from springs joining the river from river right, but flowing into the river sub-surface. Here again, any additional flow will be negligible.

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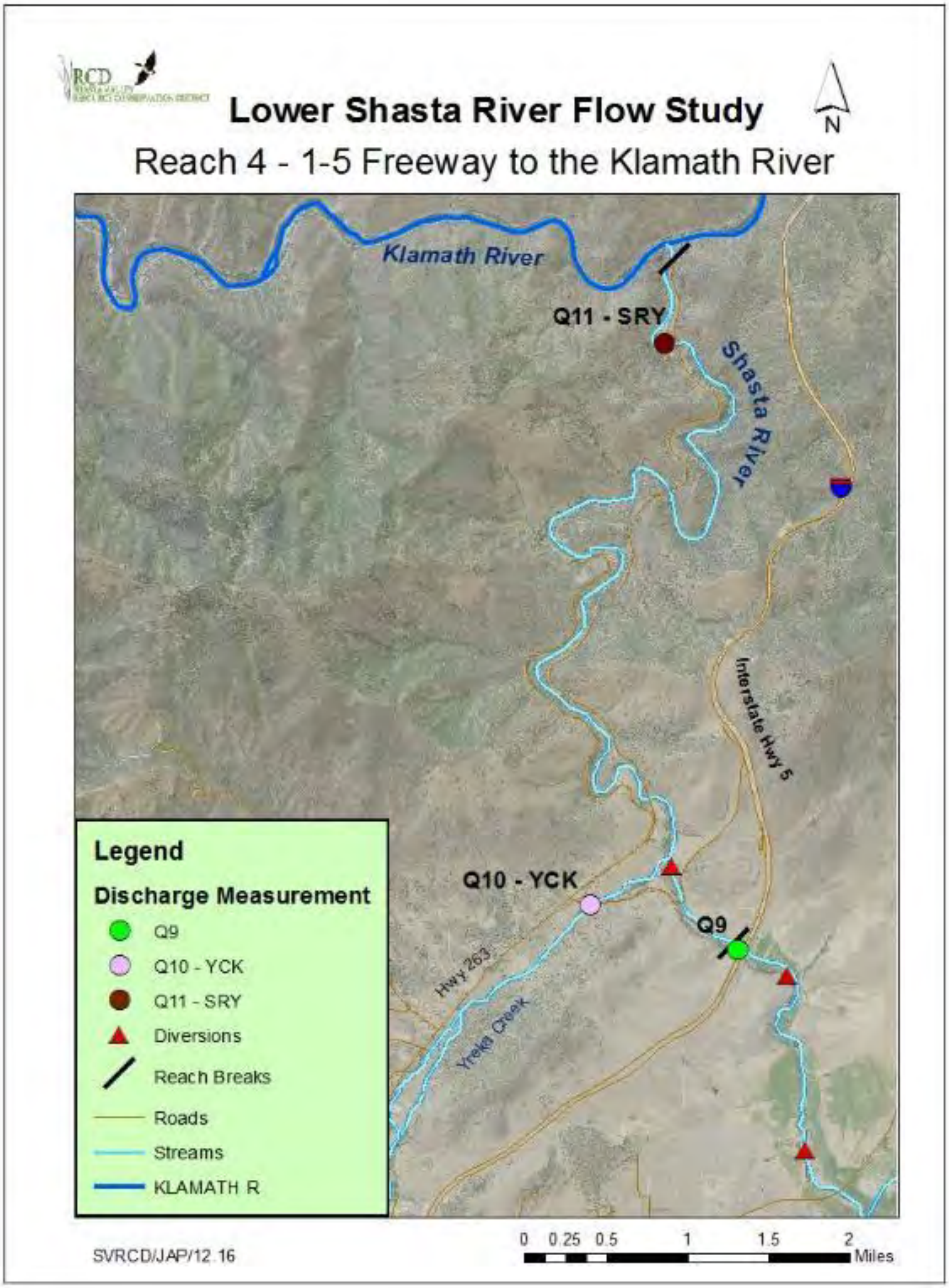

FIGURE 8. ABOVE INTERSTATE 5 FREEWAY CROSSING TO SHASTA RIVER CANYON AT RM 0.5 WITH FLOW MEASUREMENT SITES, REACH BREAKS, AND DIVERSIONS.

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D. METHODS

The purpose of tracking stream flow during the assessment was to better understand accretions and depletions within four subreaches on the five measurement days during the study period from River Mile 34 to the confluence of the Shasta River with the Klamath River.

Flow in the Lower Shasta River was assessed on specific days in September and October by:

1) Installation of level loggers at six (6) measurement stations (Q1, Q3, Q4, Q6, Q7, Q9)
2) Three to five (3-5) flow measurements with an ADV flow meter at six (6) measurement stations,
3) Creation of stage-discharge rating curves for six (6) measurement stations,
4) Two to three (2-3) flow measurements and assessment of existing stage-discharge rating curves at two (2) measurement stations (Q2-SPU and Q10-YCK).
5) Acquisition of flow data from two (2) existing USGS flow gages [Shasta River near Montague (SRM) and Shasta River near Yreka (SRY)]
6) Creation of 15-minute hydrographs for the entire study period using stage-discharge rating curves,
7) Continuous flow measurements at one (1) inflow measurement station with area-velocity (AV) meter (Bunton Hollow),
8) Tracking when diversions were on or off,
9) Calculation of transit times between measurement stations (subreaches),
10) Comparison of flows between measurement stations (accounting for transit times),
11) Calculation of unaccounted accretions or depletions.

Measurement days and assessment days were selected to occur during a range of flows (i.e. low flows, high flows, and before and after select diversions were turned off to participate in the Fall Flow Program). Measurement days at each site and days that diversions were tracked are marked with an “X” while assessment days are highlighted in blue in Table 2.

TABLE 2. FLOW MEASUREMENTS AND AREA-VELOCITY WATER LEVEL VERIFICATIONS ARE INDICATED WITH AN X, AND DAYS THAT DIVERSIONS WERE TRACKED ARE INDICATED WITH A D DURING THE STUDY PERIOD. ASSESSMENT DAYS ARE HIGHLIGHTED IN BLUE.

Site ID	24-Aug	26-Aug	8-Sep	13-Sep	14-Sep	15-Sep	19-Sep	21-Sep	22-Sep	23-Sep	26-Sep	27-Sep	1-Oct	2-Oct	3-Oct
Q1 (coho)	X		X		X		X				X				
Q2-SPU[1]		X	X												
Q3-SBG	X		X		X		X				[4]				
Q4 (SWA)	X		X		X		X				X				
Q5-SRM[2]															
Q6 (arauj)	X		X		X		X				X				
Q7 (org sl)	X			X											
Q8-AV[3]				X											
Q9 (peters)	X		X		X		X				X				
Q10-YCK[1]	X			X											
Q11-SRY[2]															
Diversions Checked	D[5]		D[5]	D	D	D	D	D	D	D	D	D	D[5]	D[5]	D[5]

[1]Station rated prior to study period. Only two measurements were performed during the study period to verify existing rating.
[2]Existing USGS gage. Did not independently verify rating.
[3]Continuously recording area-velocity meter installed. Water level was verified during installation on August 22nd and again on September 13th and October 21st.
[4]Site was not wadable.
[5]Diversion information was obtained from irrigators post- study period.

I. FLOW MEASUREMENTS AND RATING DEVELOPMENT

LEVEL LOGGERS

Onset U20-001-04 level loggers (level loggers) were deployed at each flow measurement site. These level loggers are accurate within ± 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. Therefore, 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 in the middle and at the end of the study period. Water level was measured directly during deployment and equipment removal and compared to logged values.

ADV FLOW MEASUREMENTS

Flow measurements were measured with a 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

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1969). For each flow measurement, 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® records velocity every second and averages it over a period of 40 seconds. Station location and stream depth are input by the hydrographer and used to calculate area for each station. The current-meter method sums 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 are 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 are available to the hydrographer instantaneously, allowing the measurement to be repeated in the case of poor data quality. This substantially reduces error within the various components of the discharge measurement and overall discharge uncertainty is kept to less than 5%.

Days that flow measurements were performed with the FlowTracker® are provided in Table 2.

RATING CURVE DEVELOPMENT AND COMPUTED DISCHARGE

A stage-discharge rating curve was produced at flow measurement sites as described in Rantz et al. (1982). Using the stage-discharge rating curve and 15-minute stage data from level loggers, 15-minute discharge hydrographs were created for each measurement station.

AREA-VELOCITY FLOW MEASUREMENTS

Hach Submerged area velocity meters (FL900AV) with Hach 910 data loggers were deployed at one measurement site and set to record continuously (15-min intervals) during the study period. These area-velocity meters utilize acoustic Doppler technology to measure velocity combined with a pressure transducer to measure water depth. Area, velocity, and water depth measurements are used to calculate total flow. These area-velocity meters were deployed at Bunton Hollow, a tailwater and runoff input that flows into the Shasta River in Reach 3. Area-velocity meters were installed in two culverts that capture the entirety of Bunton Hollow flow at a location approximately 0.17 miles upstream from its confluence with the Shasta River. Water level was checked periodically throughout the study period (Table 2).

II. IRRIGATION DEMANDS

Irrigation demands at diversions throughout the study area were generally tracked by the Watermaster on flow measurement days. On days that diversions were not tracked but a flow measurement occurred, diversion information was obtained directly from irrigators after the study period. Days that diversions were tracked are provided in Table 2.

III. TRANSIT TIMES

Transit time was estimated to determine the time it takes for the water to travel from the top of the measurement area (Q1 – Below Big Springs Creek) through 34.2 miles to the Canyon (Q11 – SRY), and to each measurement location in between. To estimate transit time, hydrographs for each assessment day were plotted together and trends between hydrograph shapes were assessed. The time that each related flow reached each successive measurement location was noted and transit time was assumed to equal the difference between these times. Transit times were important to include in this assessment due to the large (up to approximately 20 cfs) fluctuations in flows which occur over 2- to 4-day cycles. These flow cycles start above reach 1 and are translated all the way through the study area. Therefore, flow on each assessment day was assessed using calculated flows from rating curves at the time that a specific unit of water reached each subsequent station as it travelled downstream. The average transit time through the study area (from Q1 to Q11-SRY) was 25 hours. Transit times are provided in Table 3.

TABLE 3. REACH LENGTHS AND AVERAGE TRANSIT TIMES THROUGH EACH SUBREACH AS WELL AS TOTAL AVERAGE TRANSIT TIME THROUGH THE STUDY AREA.

Subreach	Subreach Length (mi)	Average Estimated Transit time (hr)
Q1 to Q2-SPU	2.5	1.4
Q2-SPU to Q3-SBG	7.5	4.5
Q3-SBG to Q4	6.8	4.7
Q4 to Q5-SRM	2.3	1.7
Q5-SRM to Q6	3.0	4.2
Q6 to Q9	4.0	3.1
Q9 to Q11-SRY	8.1	5.5
Total: Q1 to Q11-SRY	34.2	25.0

IV. UNACCOUNTED ACCRETION/DEPLETION CALCULATIONS

Unaccounted accretions/depletions were attributed to unmeasured distributed or point inflows or outflows and may be affected by variations in actual versus reported diversion amounts and error in discharge values reported at each measurement station.

The unaccounted accretions/depletions were calculated for each reach and subreach 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)

E. RESULTS AND DISCUSSION

Rating curves developed with flow measurements measured periodically throughout the study period (Table 2), and are provided in Appendix A: Rating Curves. Flows calculated from rating curves at specified dates/times (assessment days) at each measurement location (Table 3) are provided in Table 4 and displayed in Figure 9. Rating curves were only created for the range of flows that were encountered during the study period. Therefore, if calculated flows fell above the maximum flow value associated with each rating curve, flow values were displayed as greater than this maximum flow value.

TABLE 4. FLOW CALCULATED FROM RATING CURVES AT EACH MEASUREMENT LOCATION FOR EACH ASSESSMENT DAY.

Station ID	River Mile	24-Aug	8-Sep	13-Sep	14-Sep	19-Sep	26-Sep	1-Oct	2-Oct	3-Oct
Q1	34.8	84.4	103.1	105.6	92.5	100.7	89.1	108.8	96.6	98.8
Q2-SPU	32.3	92.9	109.6	112.2	102.2	110.9	104.6	121.7	112.2	112.2
Q3-SBG	24.8	75.2	80.5	82.7	79.2	88.8	91.4	> 95.0	94.2	93.2
Q4	18.0	39.1	43.1	54.2	40.5	59.9	63.0	> 65.0	> 65.0	> 65.0
Q5-SRM	15.7	49.0	55.0	67.0	55.0	74.0	78.0	99.0	99.0	103.0
Q6	12.7	39.8	38.7	62.2	48.1	67.6	67.3	> 75.0	> 75.0	> 75.0
Q7[1]	11.8	0.1	0.3	0.2	0.1	0.2	0.2	0.2	0.3	0.3
Q8-AV[2]	11.4	0.3	0.9	0.2	0.1	0.5	0.8	0.3	0.3	0.2
Q9	8.7	36.5	40.2	61.8	50.6	64.1	66.2	> 75.0	> 75.0	> 75.0
Q10-YCK	7.7	1.7	1.6	1.8	1.8	1.4	1.7	2.1	2.2	2.2
Q11-SRY	0.6	39.0	44.0	64.0	52.0	68.0	69.0	128.0	118.0	110.0

[1]A rating was not developed for Q7 because only two measurements were performed. Instead, measured depth and width in the confined channel were used with average velocities measured within the channel to calculate flow for each measurement day. Flow in this tributary was minimal and did not change much throughout the study period.

[2]A rating was not developed for area-velocity measurements at Q8-AV. Instead, continuous data were utilized for the associated date/time for each measurement day.

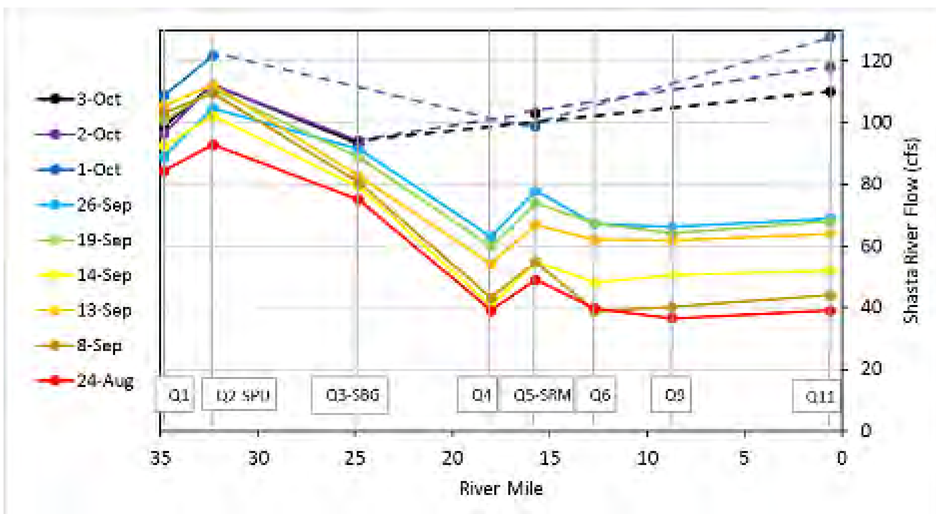

FIGURE 9. SHASTA RIVER FLOWS BY RIVER MILE ON DATE/TIMES ASSOCIATED WITH EACH MEASUREMENT DAY DURING THE STUDY PERIOD.

Spatial and temporal changes in flows as displayed in Figure 9 can be attributed to both known accretion and depletion (diversions) as well as unknown accretion and depletion. Flows generally decreased from upstream to downstream in September. Starting October 1st, flows at the bottom of the study reach (Q11-SRY) were roughly equal to or greater than flows at the top of the study reach (Q1) suggesting no net depletion over the study area. In general, flows increased at each measurement location over the length of the study period. This can be associated with flows increasing at the top of the reach (Q1) on each successive assessment day, reduced irrigation demands through the study period, and potentially other factors (e.g. reduced air temperatures and evapotranspiration).

Flows increased consistently between Q4 and Q5-SRM on assessment days (average of +13 cfs). Although tailwater enters the Shasta River within this subreach, tailwater is generally sporadic in nature

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and unlikely to result in consistent accretion across all assessment days. The Little Shasta River enters in the Shasta between Q4 and Q5-SRM. Although the Little Shasta River was dry or near dry at its confluence with the Shasta River during the study period, 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, Little Shasta River subsurface flows may contribute most of the accretion within this reach. Tailwater inflows, variation in actual versus reported diversion amounts, and/or uncertainty in discharge values likely contributed to variation in accretion values between assessment days (standard deviation of 1.8 cfs).

Flows also increased consistently between Q9 and Q11 on assessment days (average of +2.8 cfs). Most of this was due to Yreka Creek adding an average of 1.7 cfs to the Shasta River within this subreach.

I. REACH 1: BELOW BIG SPRINGS CREEK TO HIGHWAY A-12 BRIDGE (Q1 TO Q3-SBG)

Reach 1 spans from measurement location Q1 to Q-SBG and includes Q1, Q2-SPU, and Q3-SBG. Rating curves for each site are provided in Appendix A and 15-minute discharge hydrographs with associated stage values are displayed in below.

Q1: DISCHARGE AND STAGE BELOW BIG SPRINGS CREEK AT RM 34.8

Q1 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 10. Discharge measurements are lacking to define the upper end of the rating and therefore, flows greater than 110 cfs could not be calculated. Flow ranged from approximately 70 cfs to >110 cfs with large fluctuations in flow (approximately 5 to 20 cfs) over 1 to 4 day cycles, and a general trend of increasing flows over the study period.

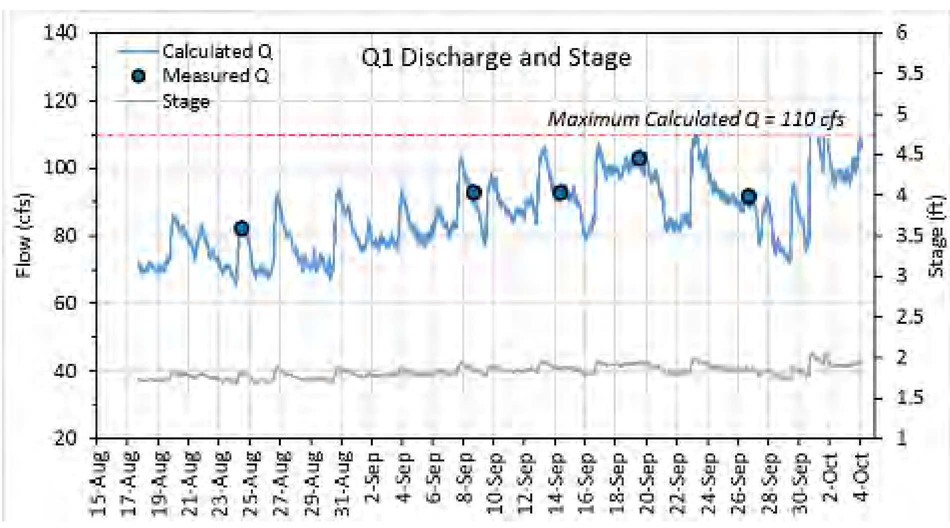

FIGURE 10. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q1 THROUGHOUT THE STUDY PERIOD: AUGUST 17TH THROUGH OCTOBER 4TH, 2016.

A preliminary assessment of gages upstream of Q1 was performed to determine where fluctuations in flow originated. Big Springs Creek at the waterwheel did not have this signal, nor did Parks Creek above the Shasta River [CDEC station Parks Creek near Big Springs (PBS)]. Flows released from Dwinnell Reservoir (CDEC stations DFB and SRX, not shown) also did not display this signal. Therefore, fluctuations

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in flow appear to originate from the Shasta River at an unknown location between Dwinnell Reservoir and the Parks Creek confluence.

The fractured surface and subsurface volcanic deposits and prolific springs in the upper Shasta River watershed suggests that groundwater and river hydrology are intricately related. Therefore, groundwater pumping in these upper reaches may contribute to the cyclic fluctuations in flow that propagate through the study area. Rough back-of-the-envelope calculations utilizing crop type, acreage, and soil type estimate that 15 cfs (continuous) might be utilized in this area. If pumping occurs on a timer, one can assume that greater than 15 cfs may be pumped punctuated by periods of no pumping. Cyclic changes in surface water irrigation demands may also play a role.

Q2: DISCHARGE AND STAGE AT SPU – GRENADA IRRIGATION DISTRICT AT RM 32.3

Q2-SPU 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 11. Flow ranged from approximately 80 cfs to 135 cfs during the study period, with large fluctuations in flow (approximately 5 to 20 cfs) over 1 to 4 day cycles, and a general trend of increasing flows over the study period.

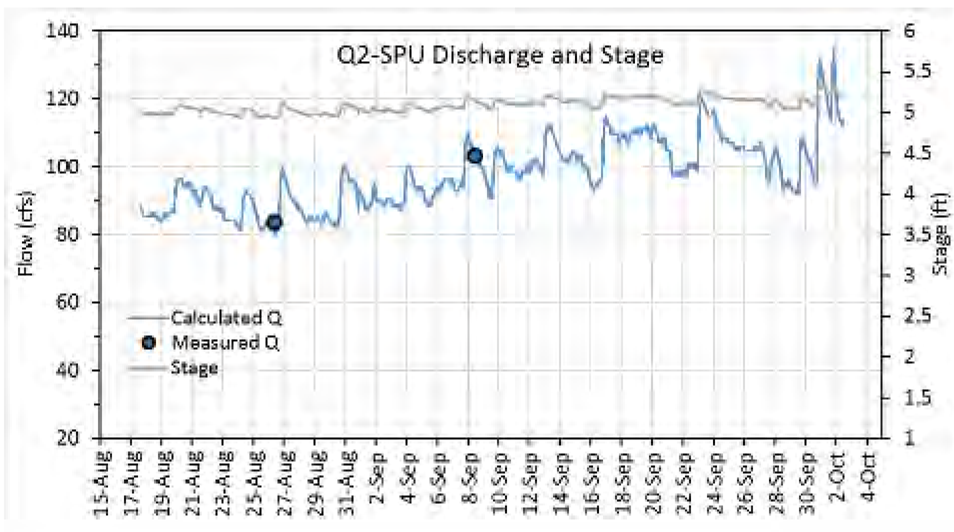

FIGURE 11. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q2-SPU THROUGHOUT THE STUDY PERIOD: AUGUST 17TH THROUGH OCTOBER 3RD, 2016. FLOWS WERE LESS THAN THE MAXIMUM CALCULATED FLOW VALUE OF 140 CFS FOR THE ENTIRE STUDY PERIOD.

Q3: DISCHARGE AND STAGE AT BELOW HIGHWAY A-12 AT RM 24.8

Q3-SBG 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 12. Discharge measurements are lacking to define the upper end of the rating and therefore, flows greater than 95 cfs could not be calculated. Flow ranged from approximately 70 cfs to >95 cfs during the study period, with large fluctuations in flow (approximately 5 to 10 cfs) over 1 to 4 day cycles, and a general trend of increasing flows over the study period.

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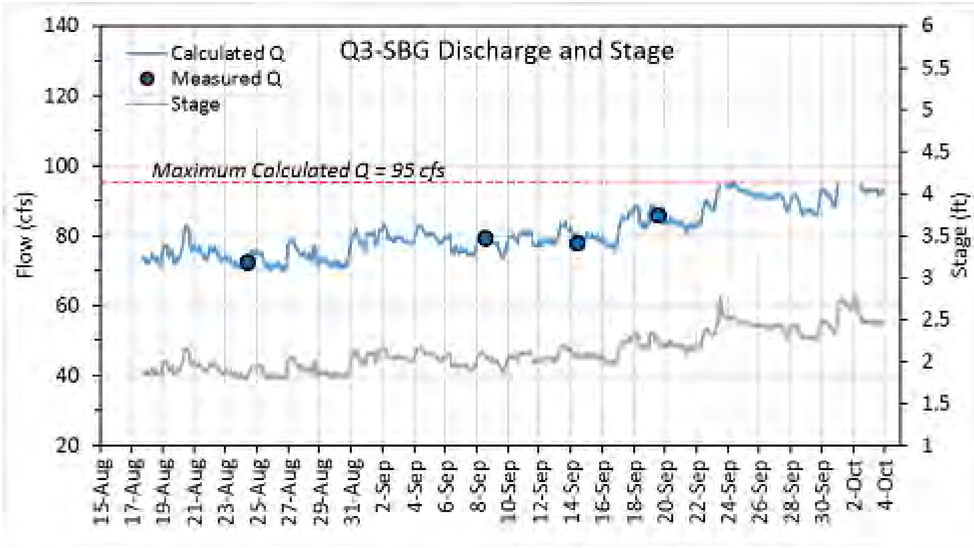

FIGURE 12. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q3-SBG THROUGHOUT THE STUDY PERIOD: AUGUST 17TH THROUGH OCTOBER 4TH, 2016.

REACH 1: ACCRETIONS AND DEPLETIONS

Change in flow, total amount diverted, and the unaccounted accretions and depletions were assessed in each subreach (i.e. from Q1 to Q2-SPU and from Q2-SPU to Q3-SBG). Unaccounted accretions/depletions are the amount of accretion or depletion that occurred which was not attributed to reported diversions or measured inflows. No measured inflows existed in reach 1.

Q1 TO Q2-SPU

Start flow, end flow, change in flow, diversions, measured inflows, and unaccounted accretions and depletions between Q1 and Q2-SPU on assessment days are provided in Table 5.

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Table 5. Start flow, end flow, change in flow, diversions, measured inflows, and unaccounted accretions and depletions between Q1 and Q2-SPU on assessment days.

Q1 to Q2-SPU						
Total Potential Diversions: -2.3 cfs						
Date	Start Q (cfs)	End Q (cfs)	Change in Q (cfs)	Diversions (cfs)	Measured Inflows (cfs)	Unaccounted Accretions/ Depletions (cfs)
24-Aug	84.4	92.9	8.5	-2.3	0.0	10.8
8-Sep	103.1	109.6	6.5	-2.3	0.0	8.8
13-Sep	105.6	112.2	6.6	-2.3	0.0	8.9
14-Sep	92.5	102.2	9.7	-2.3	0.0	12.0
19-Sep	100.7	110.9	10.2	-2.3	0.0	12.5
26-Sep	89.1	104.6	15.5	0.0	0.0	15.5
1-Oct	108.8	121.7	12.9	0.0	0.0	12.9
2-Oct	96.6	112.2	15.6	0.0	0.0	15.6
3-Oct	98.8	112.2	13.4	0.0	0.0	13.4
Average:	97.7	108.7	11.0	-1.3	0.0	12.3

Change in flow averaged +11 cfs in this subreach over the study period. Unaccounted accretions/depletions were calculated via Equation 1, (page 24). An example for August 24th is provided below:

Unaccounted Accretion/Depletion = 92.9 – (84.4 – 2.3 + 0) = 10.8 cfs

After accounting for diversions (-2.3 cfs during the first half of the study period), the average unaccounted accretion in this subreach was +12.3 cfs during the study period. Minimal diversions in this reach reduce potential error in calculations associated with diversion amounts (diversions were not measured but assumed to be equal to their full right if reported as on).

Investigations by TNC have indicated that there are numerous small springs and seeps discharging near the river bank within this subreach and likely many more small sources discharging underwater into the bed of the river.

Q2-SPU to Q3-SBG

Start flow, end flow, change in flow, diversions, measured inflows, and unaccounted accretions and depletions between Q2-SPU and Q3-SBG on assessment days are provided in Table 6.

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TABLE 6. START FLOW, END FLOW, CHANGE IN FLOW, DIVERSIONS, MEASURED INFLOWS, AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q2-SPU AND Q3-SBG ON ASSESSMENT DAYS.

Q2-SPU to Q3-SBG						
Total Potential Diversions: -64.7 cfs						
Date	Start Q (cfs)	End Q (cfs)	Change in Q (cfs)	Diversions (cfs)	Measured Inflows (cfs)	Unaccounted Accretions/ Depletions (cfs)
24-Aug	92.9	75.2	-17.7	-8.1	0.0	-9.7
8-Sep	109.6	80.5	-29.1	-25.6	0.0	-3.5
13-Sep	112.2	82.7	-29.5	-25.9	0.0	-3.6
14-Sep	102.2	79.2	-23.0	-26.0	0.0	3.0
19-Sep	110.9	88.8	-22.1	-23.5	0.0	1.3
26-Sep	104.6	91.4	-13.2	0.0	0.0	-13.2
2-Oct	112.2	94.2	-18.0	-8.8	0.0	-9.2
3-Oct	112.2	93.2	-19.0	-10.5	0.0	-8.5
Average:	107.1	85.6	-21.5	-16.0	0.0	-5.4

Change in flow averaged -21.5 cfs in this subreach over the study period. After accounting for diversions, the average unaccounted depletion in this subreach was -5.4 cfs during the study period but ranged from -13.2 cfs to +3 cfs on any given assessment day.

During irrigation, it appeared that most of what was diverted was returned to the river as irrigation surface return flows or subsurface flow. Interestingly, the most depletion in this subreach (-13.2 cfs) occurred when all diversions were off and had been off for at least 2 consecutive days. It is possible that changes in irrigation practices such as decreased return flows originating outside of this subreach or groundwater pumping nearby led to this anomaly.

It is also possible that the inconsistent unaccounted accretion/depletion values are due to incorrect assumptions of diversion amounts. If diversion amounts were actually lower than amounts reported, unaccounted depletions would match more closely to that calculated on September 26th when diversions were off (see similar discussion in section Reach 2: Accretions and Depletions, Q3-SBG to Q5-SRM (total in Reach 2), page 34).

One additional source of error may include imprecise travel times. Although care was taken to analyze hydrograph shapes and choose travel times and flow values at consecutive measurement sites accordingly, large fluctuations in flow can occur over short periods of time (Figure 11 and Figure 12). This may have led to error in accretion/depletion calculations.

RECOMMENDATIONS

Additional assessments which include increased accuracy in diversion measurements, tracking of groundwater pumping, groundwater level measurements, and more than one day with zero diversions, and an improved analysis of transit times are recommended for this subreach.

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II. REACH 2: HIGHWAY A-12 BRIDGE TO MONTAGUE-GRENADA WEIR (SRM)

Reach 2 includes measurement locations Q3-SBG, Q4, and Q5-SRM. Rating curves for each site are provided in Appendix A and 15-minute discharge hydrographs with associated stage values are displayed below (Q3-SBG provided in previous section).

Q4: BELOW SHASTA WATER USER'S ASSOCIATION AT RM 18.0

Q4 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 13. Discharge measurements are lacking to define the upper end of the rating and therefore, flows greater than 65 cfs could not be calculated. Flow ranged from approximately 20 cfs to >65 cfs during the study period, with large fluctuations in flow (approximately 5 to 10 cfs, at times increasing to 20 cfs) over 1 to 4 day cycles, and a general trend of increasing flows over the study period.

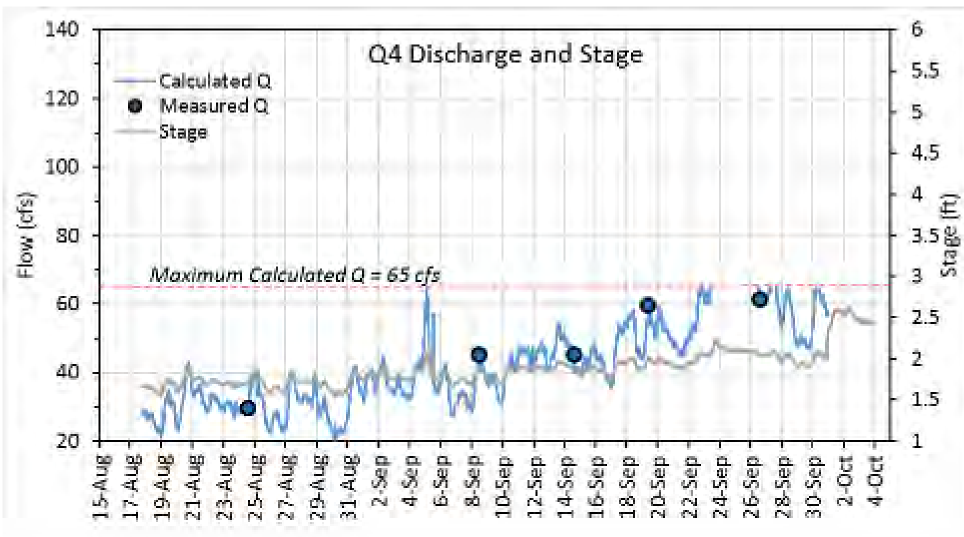

FIGURE 13. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q4 THROUGHOUT THE STUDY PERIOD: AUGUST 17TH THROUGH OCTOBER 4TH, 2016.

Q5-SRM: SHASTA R. NEAR MONTAGUE – USGS AT RM 15.7

Q5-SRM 15-minute discharge hydrograph with associated stage values is displayed in Figure 14. Flow ranged from approximately 30 cfs to 125 cfs during the study period, with large fluctuations in flow (approximately 5 to 10 cfs, at times increasing to 20 cfs) over 1 to 4 day cycles, and a general trend of increasing flows over the study period.

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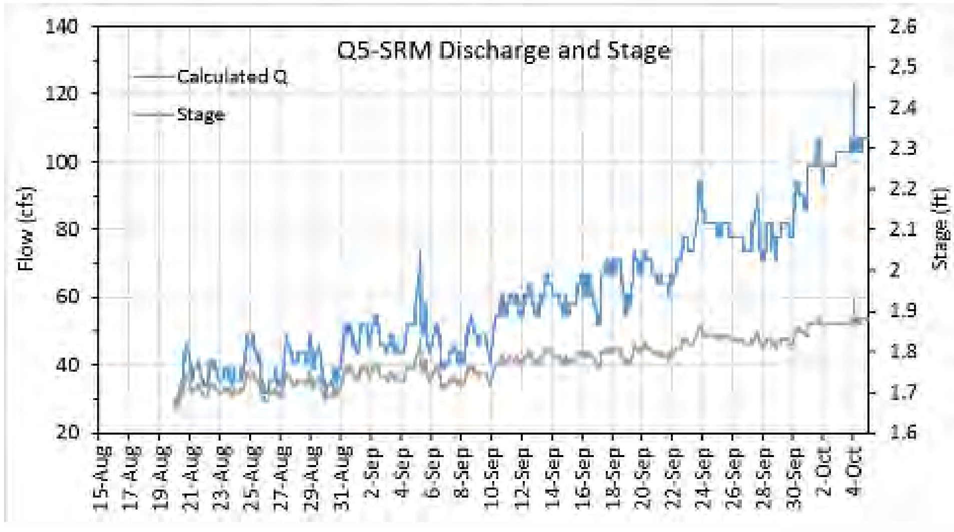

FIGURE 14. STAGE AND CALCULATED FLOW (Q) FOR Q5 THROUGHOUT THE STUDY PERIOD AT USGS SITE 11517000: AUGUST 20TH THROUGH OCTOBER 4TH, 2016. PROVISIONAL USGS DATA ARE PROVIDED BY USGS WATER FOR THE NATION, ACCESSED DECEMBER 2016.

REACH 2: ACCRETIONS AND DEPLETIONS

Change in flow, total amount diverted, and the unaccounted accretions and depletions were assessed in each subreach (i.e. Q3-SBG to Q4 and Q4 to Q5-SRM) and through the entire reach (i.e. Q3-SBG to Q5-SRM). No measured inflows existed in reach 2.

Q3-SBG TO Q4

Start flow, end flow, change in flow, diversions, measured inflows, and unaccounted accretions and depletions between Q3-SBG and Q4 on assessment days are provided in Table 7. Flows on October 1, 2nd, and 3rd could not be assessed; during this time, stage values were greater than those included on the rating curve for Q4. Therefore, flows were also assessed for the entire reach from Q3-SBG to Q5-SRM (Table 9).

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TABLE 7. START FLOW, END FLOW, CHANGE IN FLOW, DIVERSIONS, MEASURED INFLOWS, AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q3-SBG AND Q4 ON ASSESSMENT DAYS. FLOWS ON OCTOBER 1ST, 2ND, AND 3RD COULD NOT BE ASSESSED; DURING THIS TIME, STAGE VALUES WERE GREATER THAN THOSE INCLUDED ON THE RATING CURVE FOR BOTH Q3-SBG AND Q4.

Q3-SBG to Q4						
Total Potential Diversions: -54.2 cfs						
Date	Start Q (cfs)	End Q (cfs)	Change in Q (cfs)	Diversions (cfs)	Measured Inflows (cfs)	Unaccounted Accretions/ Depletions (cfs)
24-Aug	75.2	39.1	-36.1	-52.7	0.0	16.6
8-Sep	80.5	43.1	-37.4	-48.9	0.0	11.5
13-Sep	82.7	54.2	-28.5	-50.7	0.0	22.2
14-Sep	79.2	40.5	-38.7	-50.7	0.0	12.0
19-Sep	88.8	59.9	-28.8	-43.9	0.0	15.1
26-Sep	91.4	63.0	-28.4	-42.3	0.0	13.8
Average:	83.0	50.0	-33.0	-48.2	0.0	15.2

Change in flow averaged -33 cfs in this subreach over the study period. After accounting for diversions, this appeared to be a gaining reach. The average unaccounted accretions in this subreach was +15.2 cfs during the study period but ranged from +11.5 cfs to +22.2 cfs on a given assessment day.

A potential source of error within this reach may have been incorrect assumptions of diversion amounts. It is possible that the consistent unaccounted accretion was due to consistent incorrect assumptions of diversion amounts (see section Q3-SBG to Q5-SRM (total in Reach 2)) below.

Q4 TO Q5-SRM

Start flow, end flow, change in flow, diversions, measured inflows, and accretions and depletions between Q4 and Q5-SRM on assessment days are provided in Table 8. Flows on October 1, 2nd, and 3rd could not be assessed; during this time, stage values were greater than those included on the rating curve for Q4. Therefore, flows were also assessed for the entire reach from Q3-SBG to Q5-SRM (Table 9).

TABLE 8. START FLOW, END FLOW, CHANGE IN FLOW, DIVERSIONS, MEASURED INFLOWS, AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q4 AND Q5-SRM ON ASSESSMENT DAYS. FLOWS ON OCTOBER 1ST, 2ND, AND 3RD COULD NOT BE ASSESSED; DURING THIS TIME, STAGE VALUES WERE GREATER THAN THOSE INCLUDED ON THE RATING CURVE FOR Q4.

Q4 to Q5-SRM						
Total Potential Diversions: 0 cfs (none known)						
Date	Start Q (cfs)	End Q (cfs)	Change in Q (cfs)	Diversions (cfs)	Measured Inflows (cfs)	Unaccounted Accretions/ Depletions (cfs)
24-Aug	39.1	49.0	9.9	0.0	0.0	9.9
8-Sep	43.1	55.0	11.9	0.0	0.0	11.9
13-Sep	54.2	67.0	12.8	0.0	0.0	12.8
14-Sep	40.5	55.0	14.5	0.0	0.0	14.5
19-Sep	59.9	74.0	14.1	0.0	0.0	14.1
26-Sep	63.0	78.0	15.0	0.0	0.0	15.0
Average:	50.0	63.0	13.0	0.0	0.0	13.0

Change in flow averaged +13 cfs in this subreach during the study period. No diversions occurred in this subreach and therefore, the average unaccounted accretion in this subreach was the same (+13.0 cfs) during the study period.

Irrigation return flow is known to occur in this subreach. Irrigation return flow is sporadic in nature and therefore, may not lead to the consistent accretion observed in this subreach. As described in on page 25 in reference to Figure 9, this consistent accretion may originate from Little Shasta River subsurface inflow.

Q3-SBG TO Q5-SRM (TOTAL IN REACH 2)

Flows at Q4 could not be assessed in October, therefore flows for the entire reach were assessed in both September and October. Start flow, end flow, change in flow, diversions, measured inflows, and accretions and depletions between Q3-SBG and Q5-SRM on assessment days are provided in Table 9. It was not possible to assess flows at Q3-SBG on October 1st. On this day stage values were greater than those included on the rating curve.

TABLE 9. START FLOW, END FLOW, CHANGE IN FLOW, DIVERSIONS, MEASURED INFLOWS, AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q3 AND Q5-SRM ON ASSESSMENT DAYS. FLOWS ON OCTOBER 1ST COULD NOT BE ASSESSED; DURING THIS TIME, STAGE VALUES WERE GREATER THAN THOSE INCLUDED ON THE RATING CURVE FOR Q3-SBG.

Q3-SBG to Q5-SRM						
Total Potential Diversions: -54.2 cfs						
Date	Start Q (cfs)	End Q (cfs)	Change in Q (cfs)	Diversions (cfs)	Measured Inflows (cfs)	Unaccounted Accretions/ Depletions (cfs)
24-Aug	75.2	49.0	-26.2	-52.7	0.0	26.6
8-Sep	80.5	55.0	-25.5	-48.9	0.0	23.4
13-Sep	82.7	67.0	-15.7	-50.7	0.0	35.0
14-Sep	79.2	55.0	-24.2	-50.7	0.0	26.5
19-Sep	88.8	74.0	-14.8	-43.9	0.0	29.1
26-Sep	91.4	78.0	-13.4	-42.3	0.0	28.8
2-Oct	94.2	99.0	4.8	0.0	0.0	4.8
3-Oct	93.2	103.0	9.8	0.0	0.0	9.8
Average:	85.6	72.5	-13.1	-36.2	0.0	23.0

Change in flow averaged -13.1 cfs while diversions averaged -36.2 cfs during the study period. A large amount of accretion occurred in reach 2 in September. Accretion occurs in both subreaches Q3-SBG to Q4 and Q4 to Q5-SRM in September (Table 7 and Table 8, combined in Table 9). Accretion in reach 2 is drastically reduced when irrigation ceases in October. This large reduction in accretion when irrigation ceases suggests that one of two scenarios may have occurred.

The first scenario suggests that changes in irrigation practices alter the way water returns to the river. During irrigation, more water returns to the river than the amount diverted from reach 2 (i.e. there is an additional source flow in addition to irrigation return flow diverted from this reach). It is possible that water diverted from a different reach, pumped groundwater, or another source flows to the river in reach 2 and then ceases in October.

The second scenario suggests that diversions in reach 2 were not as large as reported during September. Diversions were only reported as on or off and diversion of the full water right was assumed. If actual diverted amounts were smaller (i.e. closer to change in flow values on September assessment days), this would translate into smaller unaccounted accretions/depletions amounts. An example is provided below which includes a diverted amount of -40 cfs instead of -52.7 cfs on August 24th.

UNACCOUNTED ACCRETION/DEPLETION = 49.0 – (75.2 – 40.0 + 0) = 13.8 CFS

Additionally, on August 24th and September 8th, no diversion information was available for some of the smaller diversions and assumptions were made. On August 24th, three diversions (2 cfs, 2, cfs, and 3.8 cfs) were assumed to be on and two diversions (0.9 cfs and 0.59 cfs) were assumed to be off. On September 8th, two diversions (2 cfs, and 3.8 cfs) were assumed to be on and two diversions (0.9 cfs and 0.59 cfs) were assumed to be off. If unknown diversions instead were assumed to be off, this would

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lower unaccounted accretion values to +18.7 cfs and +17.6 on August 24th and September 8th, respectively.

If accretion amounts were in fact smaller due to incorrect diversion amounts and/or incorrect assumptions, accretion in this reach might instead range from 5 to 10 cfs in September, similar to October assessment days. Thus, accretion in subreach Q3-SBG to Q4 might be closer to zero and most of the +5 to +10 cfs accretion may be interpreted as originating from Little Shasta River subsurface inflow and to a lesser degree, irrigation return flows in subreach Q4 to Q5-SRM.

RECOMMENDATIONS

The uncertainties presented above illustrate the importance of accurate record-keeping of irrigation demands in future studies. This reach is recommended for future studies including accurate tracking of diversion amounts, irrigation return flows, and Little Shasta River surface and subsurface inflows. An improved analysis of transit times is also recommended.

III. REACH 3: MONTAGUE-GRENADA WEIR (SRM) TO ABOVE INTERSTATE 5 CROSSING

Reach 3 includes measurement locations Q5-SRM, Q6, Q7 and Q8 – AV Meters. Rating curves for each site are provided in Appendix A and 15-minute discharge hydrographs with associated stage values are displayed below (Q5-SRM provided in previous section).

Q6 - BELOW HWY 3 AT RM 12.7

Q6 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 15. Discharge measurements are lacking to define the upper end of the rating and therefore, flows greater than 75 cfs could not be calculated. Flow ranged from approximately 20 cfs to > 75 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.

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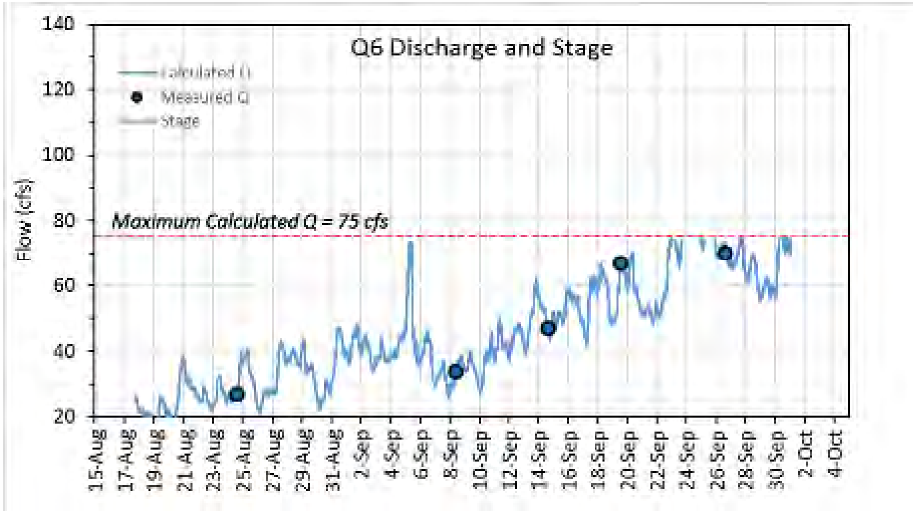

FIGURE 15. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q6 THROUGHOUT THE STUDY PERIOD: AUGUST 17TH THROUGH OCTOBER 4TH, 2016.

Q7: OREGON SLOUGH AT RM 11.8 (INFLOW)

Q7 15-minute stage values are displayed in Figure 13. A rating curve was not created for this small inflow at Oregon Slough because only two discharge measurements were performed. Flow was calculated for assessment days using channel geometry and velocity spot checks. Flow was intermittent and minor (less than 0.2 CFS both times spot flow measurements were taken) throughout the study period.

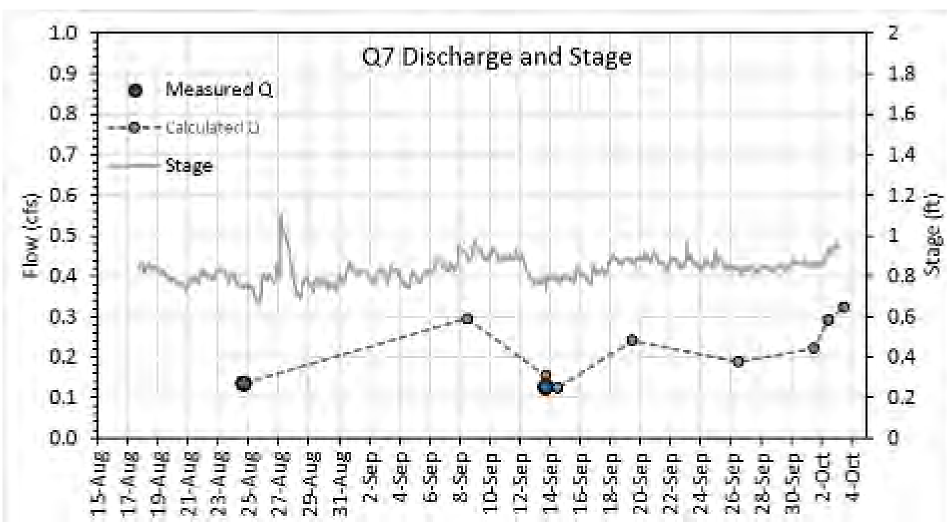

FIGURE 16. STAGE AND MEASURED FLOW (Q) FOR Q7 THROUGHOUT THE STUDY PERIOD: AUGUST 17TH THROUGH OCTOBER 4TH, 2016. A RATING WAS NOT DEVELOPED AT Q7 BECAUSE ONLY TWO MEASUREMENTS WERE PERFORMED. INSTEAD, THE CONFINED CHANNEL GEOMETRY AND VELOCITY MEASUREMENTS WERE USED TO CALCULATE FLOWS ON ASSESSMENT DAYS.

Q8-AV: BUNTON HOLLOW AT RM 11.4 (INFLOW)

Q8-AV 15-minute discharge hydrograph is displayed in Figure 17created with continuous (15-minute) flow data collected by A-V meters installed in 2 culverts. Flow ranged from 0 to 3 cfs during the study period. Flows in this intermittent stream channel during the study period most likely originated from irrigation return flows.

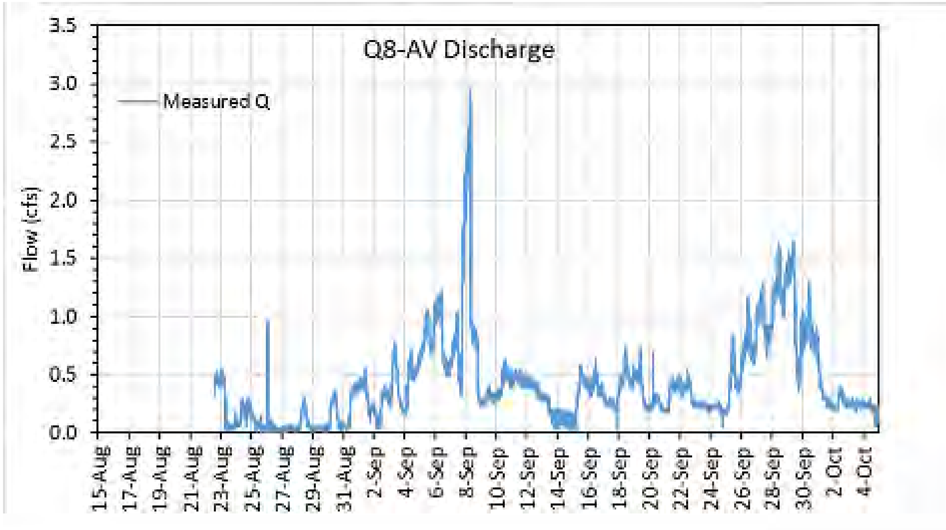

FIGURE 17. CALCULATED FLOW (Q) FOR Q8-AV METERS (TWO CULVERTS COMBINED) THROUGHOUT THE STUDY PERIOD: AUGUST 17TH THROUGH OCTOBER 4TH, 2016.

REACH 3: ACCRETIONS AND DEPLETIONS

Change in flow, total amount diverted, and unaccounted accretions and depletions were assessed in each subreach (i.e. Q5-SRM to Q6 and Q6 to Q9). Measured inflows existed in subreach Q6 to Q9 and included Oregon Slough (Q7) and Bunton Hollow (Q8-AV).

Q5-SRM TO Q6

Start flow, end flow, change in flow, diversions, measured inflows, and unaccounted accretions and depletions between Q5-SRM and Q6 on assessment days are provided in Table 10. Flows on October 1, 2nd, and 3rd could not be assessed; during this time, stage values were greater than those included on the rating curve for Q6.

TABLE 10. START FLOW, END FLOW, CHANGE IN FLOW, DIVERSIONS, MEASURED INFLOWS, AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q5-SRM AND Q-6 ON ASSESSMENT DAYS. FLOWS ON OCTOBER 1ST, 2ND, AND 3RD COULD NOT BE ASSESSED; DURING THIS TIME, STAGE VALUES WERE GREATER THAN THOSE INCLUDED ON THE RATING CURVE FOR Q6.

Q5-SRM to Q6						
Total Potential Diversions: -18.3 cfs						
Date	Start Q (cfs)	End Q (cfs)	Change in Q (cfs)	Diversions (cfs)	Measured Inflows (cfs)	Unaccounted Accretions/ Depletions (cfs)
24-Aug	49.0	39.8	-9.2	-18.3	0.0	9.1
8-Sep	55.0	38.7	-16.3	-18.3	0.0	2.0
13-Sep	67.0	62.2	-4.8	-18.3	0.0	13.4
14-Sep	55.0	48.1	-6.9	-14.0	0.0	7.2
19-Sep	74.0	67.6	-6.4	-7.5	0.0	1.1
26-Sep	78.0	67.3	-10.7	-7.5	0.0	-3.2
Average:	63.0	53.9	-9.1	-14.0	0.0	4.9

Change in flow averaged -9.1 cfs in this subreach over the study period. After accounting for diversions, the average unaccounted accretions/depletions in this subreach was +4.9 cfs during the study period and ranged from -3.2 cfs to +13.4 cfs on a given assessment day.

Records of irrigation demands for three diversions (2 cfs, 1.5 cfs, and 2 cfs) were lacking within this reach on some assessment days. When records were lacking, diversions were assumed to be on. If instead diversions were assumed to be off when no record existed, diverted amounts and unaccounted accretions would also be lower. An example is provided below which includes a diverted amount of -12.9 cfs instead of -18.3 cfs on August 24th.

UNACCOUNTED ACCRETION/DEPLETION = 39.8 – (49.0 – 12.9 + 0) = 3.7 CFS

Q6 TO Q9

Start flow, end flow, change in flow, diversions, measured inflows, and unaccounted accretions and depletions between Q6 and Q9 on assessment days are provided in Table 11. Flows on October 1, 2nd, and 3rd could not be assessed; during this time, stage values were greater than those included on the rating curve for Q6.

TABLE 11. START FLOW, END FLOW, CHANGE IN FLOW, DIVERSIONS, MEASURED INFLOWS, AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q-6 AND Q9 ON ASSESSMENT DAYS. FLOWS ON OCTOBER 1ST, 2ND, AND 3RD COULD NOT BE ASSESSED; DURING THIS TIME, STAGE VALUES WERE GREATER THAN THOSE INCLUDED ON THE RATING CURVE FOR Q6.

Q6 to Q9						
Total Potential Diversions: -3.8 cfs						
Date	Start Q (cfs)	End Q (cfs)	Change in Q (cfs)	Diversions (cfs)	Measured Inflows[1] (cfs)	Unaccounted Accretions/ Depletions (cfs)
24-Aug	39.8	36.5	-3.3	-3.8	0.4	0.1
8-Sep	38.7	40.2	1.5	-3.8	1.2	4.1
13-Sep	62.2	61.8	-0.4	-2.0	0.3	1.3
14-Sep	48.1	50.6	2.5	-2.0	0.2	4.3
19-Sep	67.6	64.1	-3.4	-2.0	0.8	-2.2
26-Sep	67.3	66.2	-1.1	-2.0	1.0	-0.1
Average:	53.9	53.2	-0.7	-2.6	0.7	1.2

[1] Measured inflows between Q6 and Q-9 include Q7 (Oregon Slough) and Q8-AV (Bunton Hollow).

Change in flow averaged -0.7 cfs in this subreach over the study period. After accounting for diversions, the average unaccounted accretions/depletions in this subreach was +1.2 cfs during the study period and ranged from -2.2 cfs to +4.3 cfs on a given assessment day. Diversions were minimal in this reach so any errors in reported versus actual diverted amounts would also be minimal. This subreach is characterized by minimal accretions and/or depletions.

RECOMMENDATIONS

If reach 4 is in included in future assessments, accurate tracking of diversion amounts and irrigation return flows are recommended. An improved analysis of transit times is also recommended.

IV. REACH 4: ABOVE INTERSTATE 5 CROSSING TO CONFLUENCE WITH KLAMATH RIVER

Reach 4 includes measurement locations Q9, Q10 and Q11-SRY. Rating curves for each site are provided in Appendix A and 15-minute discharge hydrographs with associated stage values are displayed below.

Q9: UPPER CANYON AT RM 8.7

Q9 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 18. Discharge measurements are lacking to define the upper end of the rating and therefore, flows greater than 75 cfs could not be calculated. Flow ranged from approximately 20 cfs to > 75 cfs during the study period, with large fluctuations in flow (approximately 5 to 20 cfs) over 1 to 4 day cycles, and a general trend of increasing flows over the study period.

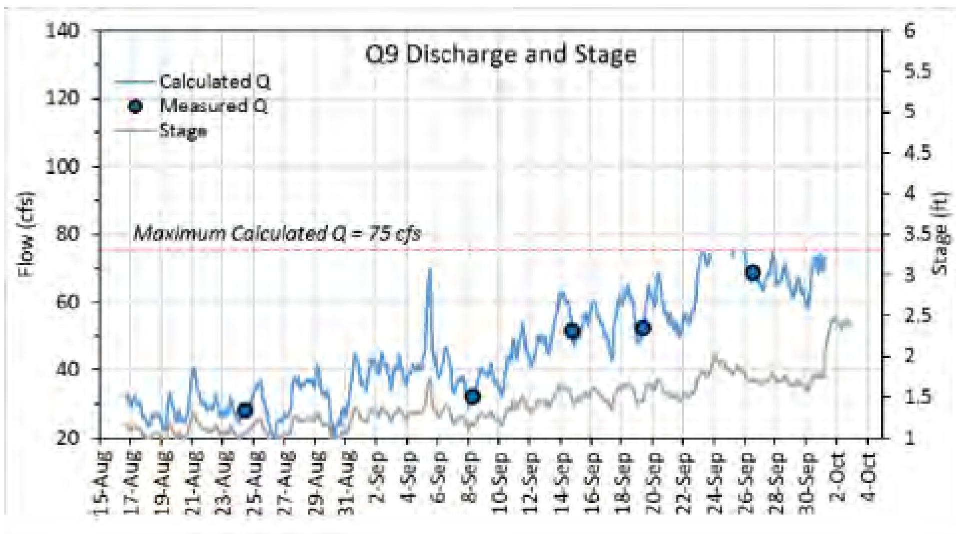

FIGURE 18. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q9 THROUGHOUT THE STUDY PERIOD: AUGUST 17TH THROUGH OCTOBER 3RD, 2016.

Q10-YCK: YREKA CK. AT ANDERSON GRADE AT RM 7.3 (INFLOW)

Q10-YCK 15-minute discharge hydrograph with measured discharge and associated stage values is displayed in Figure 19. Flow ranged from approximately 1.1 cfs to 2.5 cfs during the study period, with small (approximately 0.7 cfs) diurnal fluctuations throughout and a slight increase in flow over the study period.

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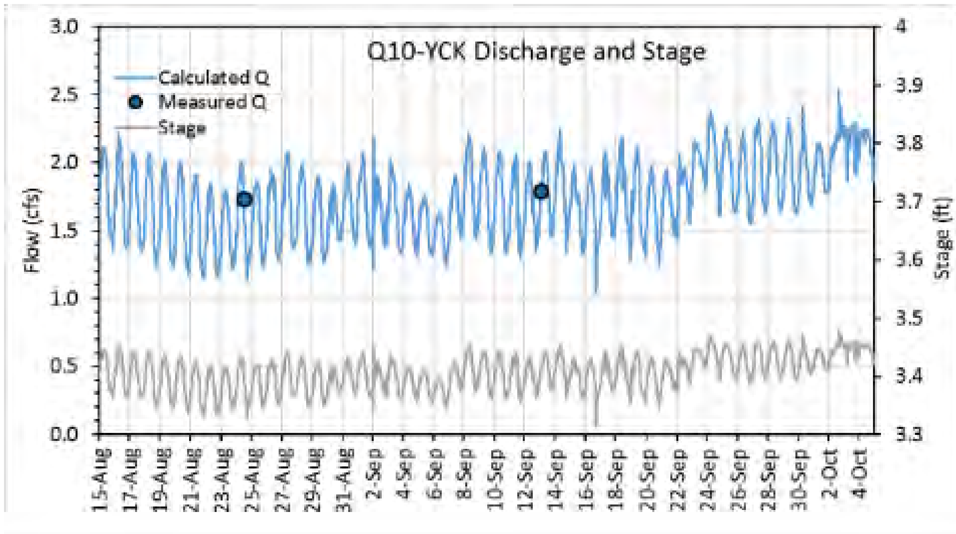

FIGURE 19. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q10-YCK THROUGHOUT THE STUDY PERIOD: AUGUST 17TH THROUGH OCTOBER 3RD, 2016. FLOWS WERE LESS THAN THE MAXIMUM CALCULATED FLOW VALUE OF 70 CFS FOR THE RATING CURVE FOR THE ENTIRE STUDY PERIOD.

Q11-SRY: USGS GAGE IN SHASTA RIVER CANYON AT RM 0.6

Q11-SRY 15-minute discharge hydrograph with associated stage values is displayed in Figure 20. Flow ranged from approximately 20 cfs to 130 cfs during the study period, with large fluctuations in flow (approximately 5 to 15 cfs) over 1 to 4 day cycles, and a general trend of increasing flows over the study period.

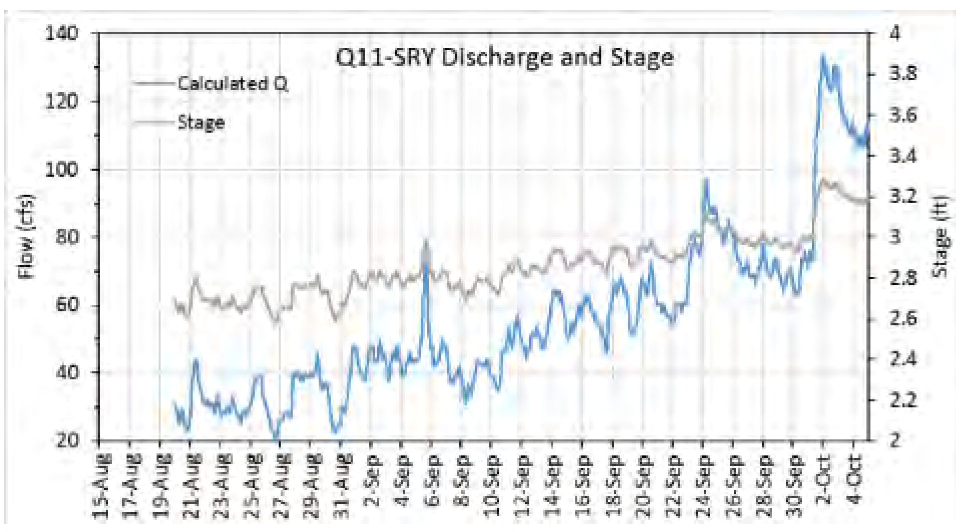

FIGURE 20. STAGE AND CALCULATED FLOW (Q) FOR Q11-SRY THROUGHOUT THE STUDY PERIOD AT USGS SITE 11517500: AUGUST 20TH THROUGH OCTOBER 4TH, 2016. PROVISIONAL USGS DATA ARE PROVIDED BY USGS WATER FOR THE NATION, ACCESSED DECEMBER 2016.

REACH 4: ACCRETIONS AND DEPLETIONS

Change in flow, total amount diverted, and the unaccounted accretions and depletions were assessed in reach 4 (i.e. from Q9 to Q11-SRY). Measured inflows in reach 4 included Yreka Creek (Q10-YCK).

Q9 TO Q11-SRY (TOTAL IN REACH 4)

Start flow, end flow, change in flow, diversions, measured inflows, and unaccounted accretions and depletions between Q6 and Q11-SRY on assessment days are provided in Table 12. Flows on October 1, 2nd, and 3rd could not be assessed; during this time, stage values were greater than those included on the rating curve for Q9.

TABLE 12. START FLOW, END FLOW, CHANGE IN FLOW, DIVERSIONS, MEASURED INFLOWS, AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q9 AND Q11-SRY ON ASSESSMENT DAYS. FLOWS ON OCTOBER 1ST, 2ND, AND 3RD COULD NOT BE ASSESSED; DURING THIS TIME, STAGE VALUES WERE GREATER THAN THOSE INCLUDED ON THE RATING CURVE FOR Q9.

Q9 to Q11-SRY						
Total Potential Diversions: 0 cfs (none known)						
Date	Start Q (cfs)	End Q (cfs)	Change in Q (cfs)	Diversions (cfs)	Measured Inflows[1] (cfs)	Unaccounted Accretions/ Depletions (cfs)
24-Aug	36.5	39.0	2.5	0.0	1.7	0.8
8-Sep	40.2	44.0	3.8	0.0	1.6	2.2
13-Sep	61.8	64.0	2.2	0.0	1.8	0.4
14-Sep	50.6	52.0	1.4	0.0	1.8	-0.4
19-Sep	64.1	68.0	3.9	0.0	1.4	2.4
26-Sep	66.2	69.0	2.8	0.0	1.7	1.1
Average:	53.2	56.0	2.8	0.0	1.7	1.1

[1] Measured inflows between Q9 and Q-11 include Q10-YCK (Yreka Creek).

Change in flow averaged +2.8 cfs in reach 4 over the study period. There were no active diversions in this reach during the study period[2]. Yreka Creek inflow was relatively consistent through the study period and averaged +1.7 cfs. Unaccounted accretions/depletions averaged +1.1 and ranged from -0.4 cfs to +2.4 cfs on a given assessment day. This subreach is characterized by minimal accretions.

RECOMMENDATIONS

Reach 4 is not recommended for future study. If reach 4 is in included in future assessments, accurate tracking of diversion amounts and potentially irrigation return flows are recommended. An improved analysis of transit times is also recommended.

REACH 1 THROUGH REACH 4: ACCRETIONS AND DEPLETIONS

Change in flow, total amount diverted, and the unaccounted accretions and depletions were assessed over the entire study area (i.e. Q1 to Q11-SRY).

Q1 TO Q11-SRY

Start flow, end flow, change in flow, diversions, measured inflows, and unaccounted accretions and depletions between Q6 and Q11-SRY on assessment days are provided in Table 13.

[2] One historical diversion existing downstream of the Anderson Grade Rd. crossing with a right of approximately 3 cfs did not have a record and was thought to not be actively irrigating during the study period.

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TABLE 13. START FLOW, END FLOW, CHANGE IN FLOW, DIVERSIONS, MEASURED INFLOWS, AND UNACCOUNTED ACCRETIONS AND DEPLETIONS BETWEEN Q1 AND Q11-SRY ON ASSESSMENT DAYS.

Q1 to Q11-SRY						
Total Potential Diversions: -143.2 cfs						
Date	Start Q (cfs)	End Q (cfs)	Change in Q (cfs)	Diversions (cfs)	Measured Inflows (cfs)	Unaccounted Accretions/ Depletions (cfs)
24-Aug	84.4	39.0	-45.4	-85.1	2.1	26.8
8-Sep	103.1	44.0	-59.1	-98.8	2.7	37.0
13-Sep	105.6	64.0	-41.6	-99.2	2.1	55.5
14-Sep	92.5	52.0	-40.5	-95.0	2.0	52.5
19-Sep	100.7	68.0	-32.7	-79.2	2.2	44.4
26-Sep	89.1	69.0	-20.1	-51.8	2.7	29.0
1-Oct	108.8	128.0	19.2	-8.0	2.6	24.6
2-Oct	96.6	118.0	21.4	-11.3	2.8	29.9
3-Oct	98.8	110.0	11.2	-13.0	2.8	21.5
Average:	97.7	76.9	-20.8	-60.2	2.5	35.7

From reach 1 through reach 4, change in flow averaged -20.8 cfs, with an average of -60.2 cfs exiting the river via diversions and an average of +2.5 cfs entering the river via measured inflows during the study period. After factoring in diversions and measured inflows, unaccounted accretion averaged of +35.7 cfs during the study period and ranged from +21.5 cfs to +55.5 cfs on a given assessment day. Unaccounted accretion values in September are larger than in October after the majority of diversions had turned off. It is possible that estimated diversion values have been overestimated in some reaches during September, leading to larger unaccounted accretion values.

F. CONCLUSIONS AND RECOMMENDATIONS

I. CONCLUSIONS

In Reach 1, unaccounted accretion occurred in the upper subreach (Q1 to Q2-SPU) and either accretion or depletion occurred in the lower subreach (Q2-SPU to Q3-SBG) depending on the assessment day. Unaccounted accretion in the upper subreach was consistent (ranging from +8.8 cfs to +15.6 cfs with an average of +12.3 cfs). Accretion in this upper subreach was likely due to exposed and underwater springs. Unaccounted accretion or depletion in the lower subreach (Q2-SPU to Q3-SBG) was inconsistent across assessment days ranging from -13.2 cfs to +3.0 cfs with an average of -5.4 cfs. The largest depletion of -13.2 cfs occurred when no irrigation occurred. Inconsistencies in this subreach suggest there may be errors in reported diversion amounts, transit times used in the analysis, or that the hydrology (including subsurface flows) requires further study.

In Reach 2, unaccounted accretion occurred in both the upper and lower subreaches (Q3-SBG to Q4 and Q4 to Q5-SRM). Rating curves at Q3-SBG and Q4 did not cover a sufficient upper range so it was not possible to calculate flows on all assessment days (i.e. those with higher flows). Therefore, flow was assessed over the entire reach (Q3-SBG to Q5-SRM) as well. In the upper subreach (Q3-SBG to Q4), unaccounted accretion was consistent across September assessment days, ranging from +12.0 cfs to +22.2 cfs with an average of +15.2 cfs. In the lower subreach (Q4 to Q5-SRM), unaccounted accretion was also consistent across September assessment days, ranging from +9.9 cfs to +15.0 cfs with an average of +13.0 cfs. No diversions exist in this lower subreach and therefore, unaccounted accretion was not complicated by potential errors in diversion amounts. Irrigation return flow is known to return to the river in this lower subreach but is unlikely to display consistency across assessment days. Little Shasta River enters the Shasta River in this subreach and although dry or near dry during the study period, subsurface flows likely contributed much of the accretion in this subreach. The assessment of both September and October flows over the entire reach (Q3-SBG to Q5-SRM) revealed a large drop in unaccounted accretion when irrigation ceased in October. This inconsistency raises questions about the quality of reported diversion values. If less water was diverted in the upper subreach during September, unaccounted diversions would more closely match with those reported after irrigation ceased in October. Questions remain about the role of changing irrigation practices, inflow sourced from outside of the upper subreach, and potential errors in diversion amounts- one cannot conclude that the average accretion of +12.0 cfs to +22.0 cfs is accurate.

In Reach 3, inconsistent unaccounted accretion occurred in the upper subreach (Q5-SRM to Q6) and minimal to no unaccounted accretion occurred in the lower subreach (Q6 to Q9). Unaccounted accretion in the upper subreach was inconsistent across assessment days and ranged from -3.2 cfs to +13.4 cfs with an average of +4.9 cfs. It is unclear if these inconsistencies originated from changing hydrologic conditions (e.g. changing patterns in irrigation return flows), from errors in diversion amounts, and/or from errors in transit times. Assumptions that were made about diversions when data were missing suggest that errors in diversion amounts may have led to larger than actual unaccounted accretion across assessment days. In the lower subreach, unaccounted accretion was fairly consistent across assessment days ranging from -2.2 cfs to +4.3 cfs with an average of +1.2 cfs. This lower subreach only included two smaller diversions with higher quality records. Bunton Hollow and Oregon Slough contributed minimal flows to this subreach (+0.2 to +1.2 cfs with an average of +0.7 cfs).

In Reach 4 (Q9 to Q11-SRY), unaccounted accretion values were relatively small and consistent ranging from -0.4 cfs to +2.4 cfs with an average of +1.1 cfs. No active diversions occurred in this reach and therefore, there were fewer potential errors in calculated unaccounted accretion values. Yreka Creek flows were consistent throughout the study period, ranging from +1.4 to +1.8 cfs with an average of +1.7 cfs.

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. These impact the overall unaccounted accretion/depletion calculations. During this study, assumptions made about diversion amounts especially in reaches with many diversions and/or large diversion amounts may have contributed significant errors to calculated unaccounted accretion/depletion values. Still, this coarse assessment provides valuable insight into where accretion and depletion generally occur and which subreaches require further investigation.

II. RECOMMENDATIONS

Future flow assessments of the Lower Shasta River (below Big Springs Creek to the mouth) could be improved through various data collection procedures, detailed assessments in specific subreaches, and more detailed data analyses. Recommendations include:

I. Ensure diverted amounts for each diversion are tracked on each measurement day. Measure flow at each diversion using one or more of the following methods to provide the most reliable diversion estimate for each assessment day:
   a. Measure water level at existing measuring weir and calculate flow.
   b. Install area-velocity meters in culverts or other appropriate locations where possible.
   c. Utilize other existing measurement device and check throughout study period (e.g. totalizer).
   d. Install measuring weir prior to experiment if no measurement device exists and no appropriate location exists to install an area-velocity meter.
   e. Measure flow directly with a flow meter (e.g. ADV meter) when no other method of measurement exists.

II. Create system to monitor groundwater pumping in areas adjacent to and above reach 1. If pumping rates are unavailable, on/off cycles for major users would be helpful.

III. Install piezometers in reach 1 to monitor changes in groundwater levels.

IV. Improve transit time calculations so that fluctuations in flow minimally affect accretion/depletion assessments.

V. Improve flow measurement location near Q1 so that the channel cross-sectional area is more uniform.

VI. Improve flow measurement location near Q3-SBG so that high flows are wadable.

VII. Perform additional discharge measurements (>2) to check rating at Q2-SPU, as the rating curve can change annually with flood events and seasonally with vegetation growth.

VIII. Perform additional flow measurements at all locations during high flows where wading is possible to extend rating curve and allow for calculation of flow later in the season when irrigation demands decrease.

IX. Subreaches recommended for further investigations:
   a. Subreach Q2-SPU to Q3-SBG: Additional assessments which include increased accuracy in diversion measurements, tracking of groundwater pumping, groundwater level measurements, at least two assessment days with zero irrigation demand, and an improved analysis of transit times.
   b. Subreach Q3-SBG to Q4: Additional assessments which include increased accuracy in diversion measurements, at least two assessment days with zero irrigation demand, installation of A-V flow meters to measure tailwater, tracking of existing totalizers, and an improved analysis of transit times.
   c. Subreach Q4 to Q5-SRM: Additional assessments which include at least two assessment days with zero irrigation demand, installation of A-V flow meters to measure tailwater, tracking of existing totalizers, tracking of Little Shasta River surface and subsurface inflows (potential installation of piezometers), and an improved analysis of transit times.

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d. Subreach Q5-SRM to Q6: This subreach is secondary to the above three. If this subreach is included in future investigations, recommendations include additional assessment days which include at least two days with zero irrigation demand, adding a measurement location in the middle of this reach, and an improved analysis of transit times.

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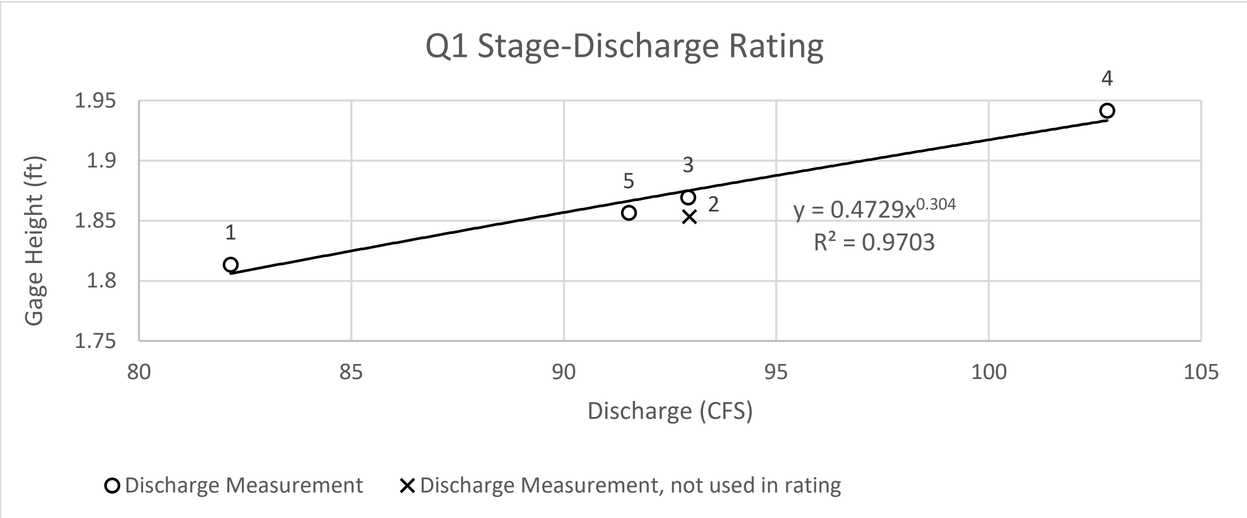
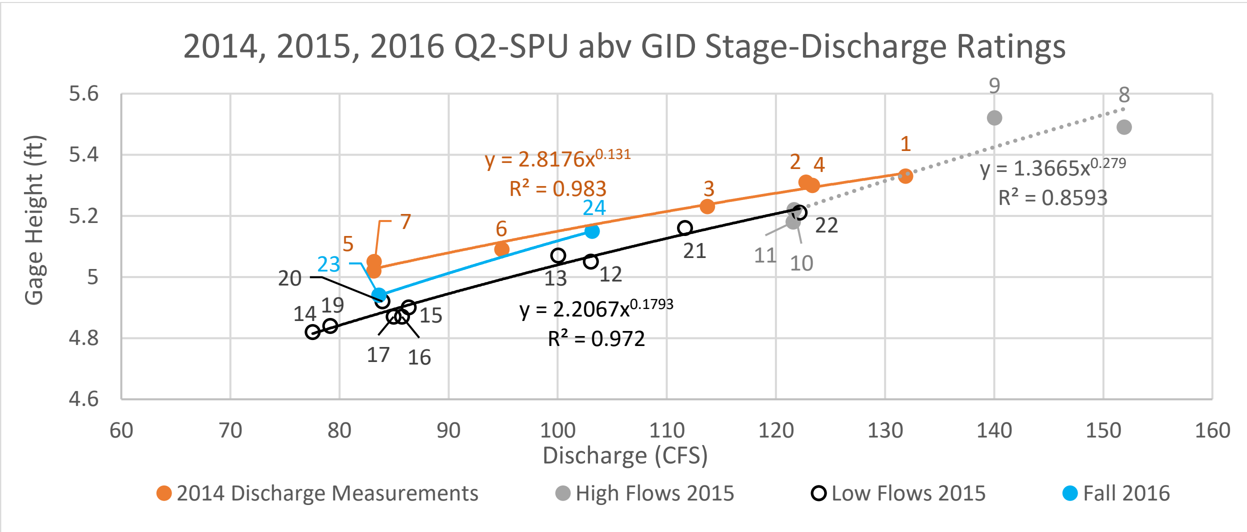
APPENDIX A: RATING CURVES





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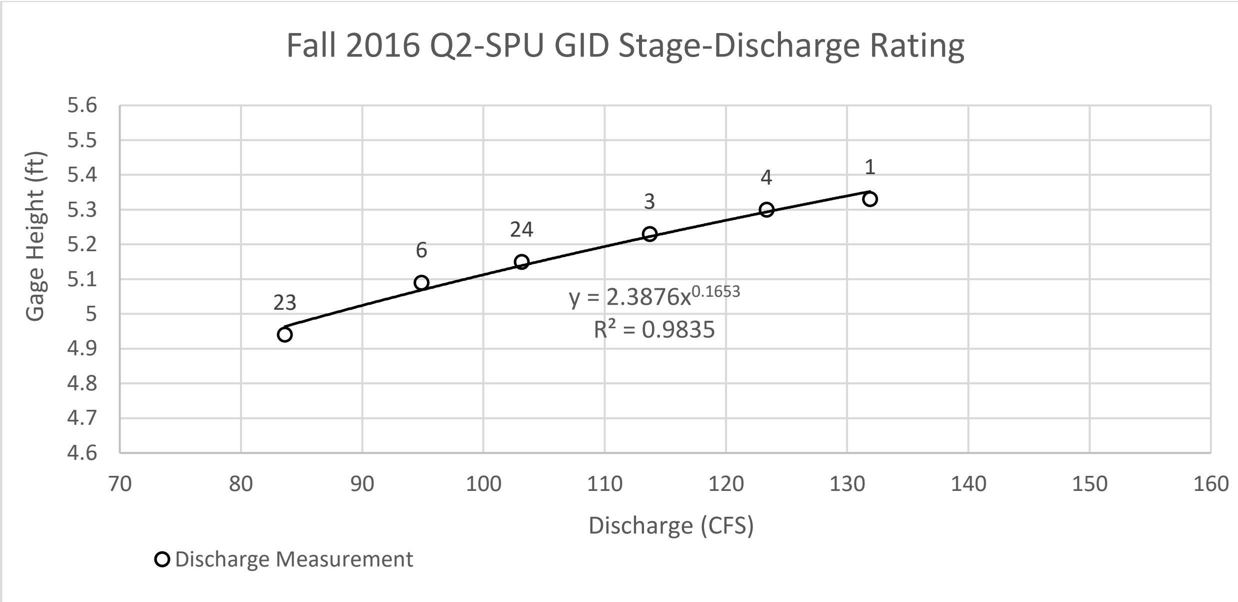
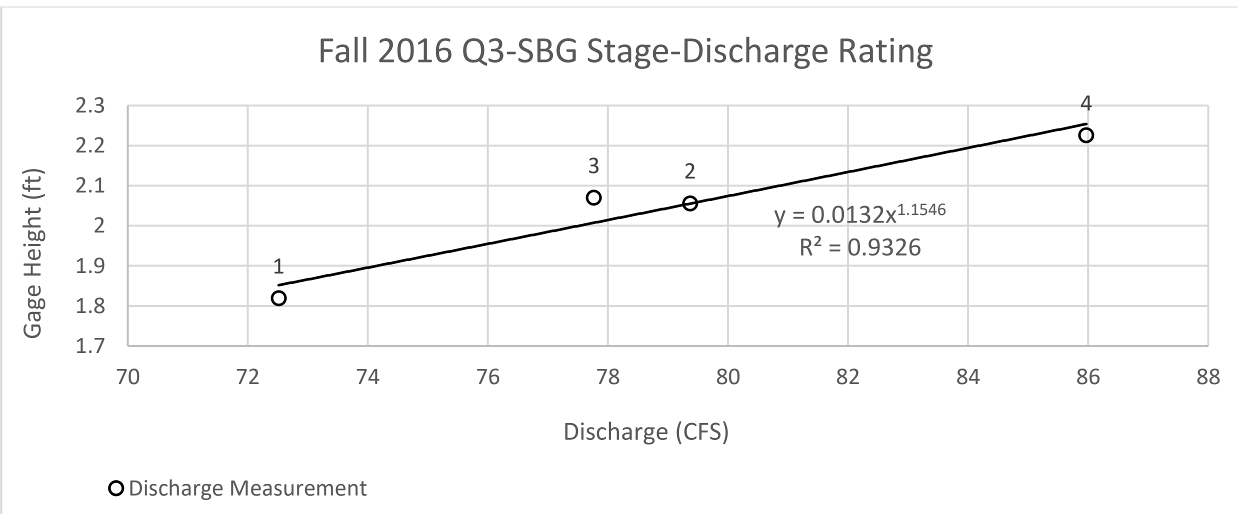
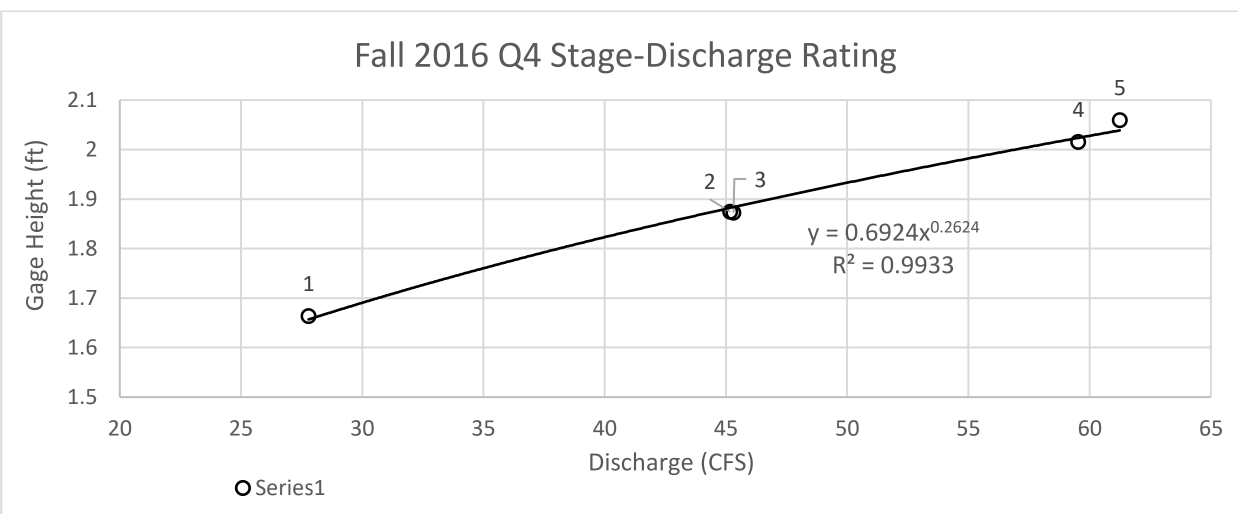
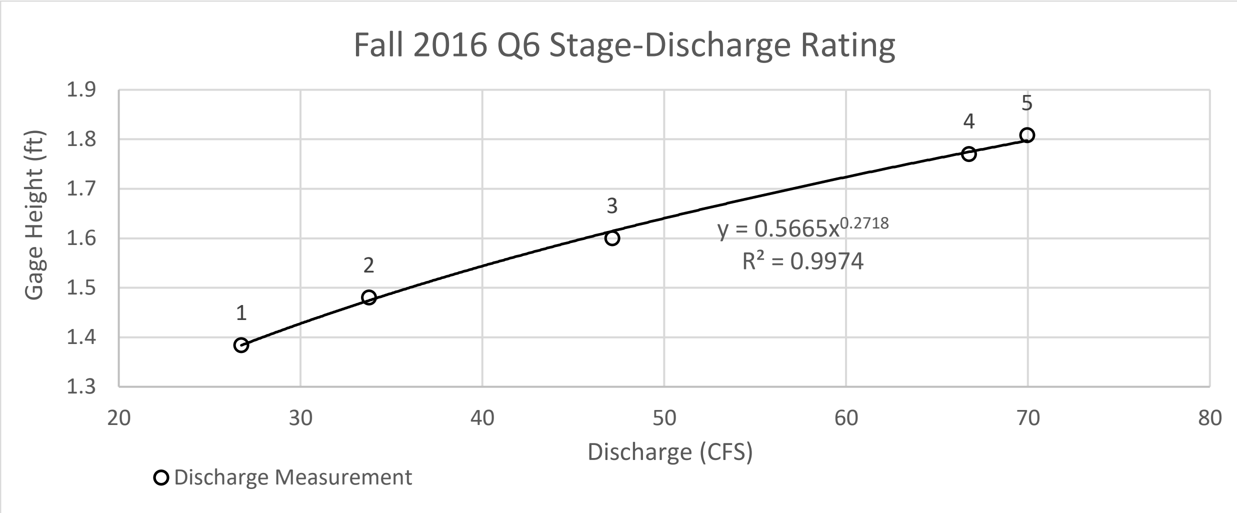
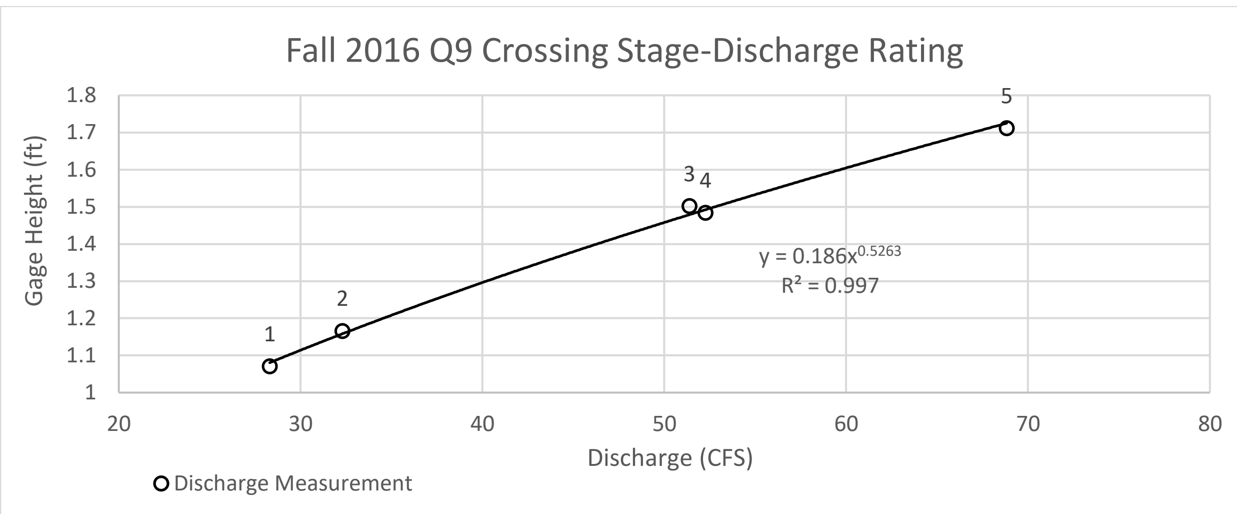
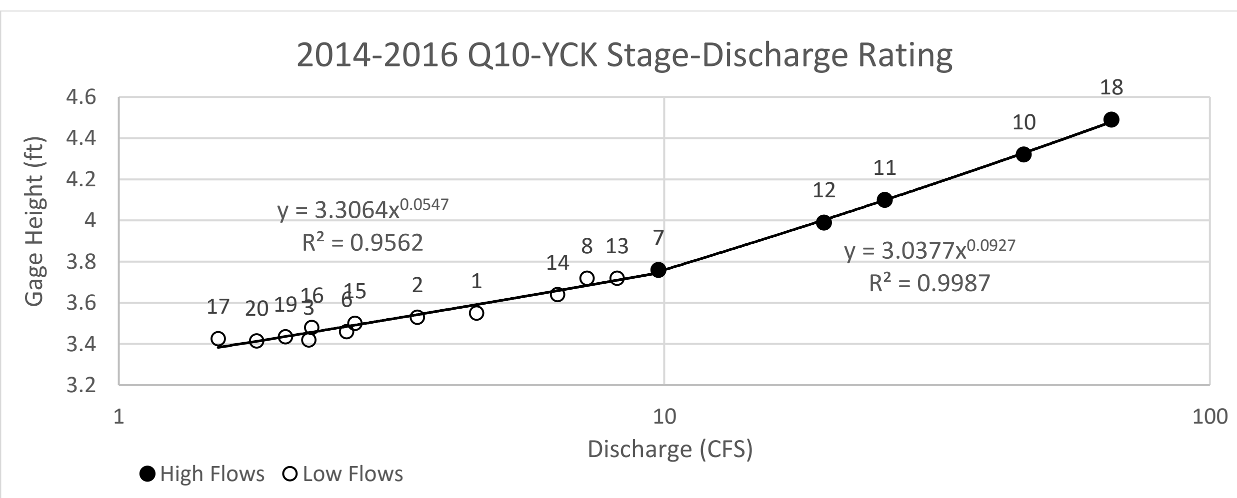

Fall 2016 Q2-SPU GID Stage-Discharge Rating
Gage Height (ft)
Discharge (CFS)
y = 2.3876x^0.1653
R² = 0.9835
23
6
24
3
4
1
Discharge Measurement


Fall 2016 Q3-SBG Stage-Discharge Rating
Gage Height (ft)
Discharge (CFS)
y = 0.0132x^1.1546
R² = 0.9326
1
3
2
4
Discharge Measurement


Fall 2016 Q4 Stage-Discharge Rating
Gage Height (ft)
Discharge (CFS)
y = 0.6924x^0.2624
R² = 0.9933
1
2
3
4
5
Series1


Fall 2016 Q6 Stage-Discharge Rating
Gage Height (ft)
Discharge (CFS)
y = 0.5665x^0.2718
R² = 0.9974
Discharge Measurement


Fall 2016 Q9 Crossing Stage-Discharge Rating
Gage Height (ft)
Discharge (CFS)
y = 0.186x^0.5263
R² = 0.997
Discharge Measurement


2014-2016 Q10-YCK Stage-Discharge Rating
Gage Height (ft)
Discharge (CFS)
y = 3.3064x^0.0547
R² = 0.9562
y = 3.0377x^0.0927
R² = 0.9987
High Flows
Low Flows

MIDDLE SHASTA RIVER WATER BALANCE: SEPTEMBER-OCTOBER 2017

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

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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.

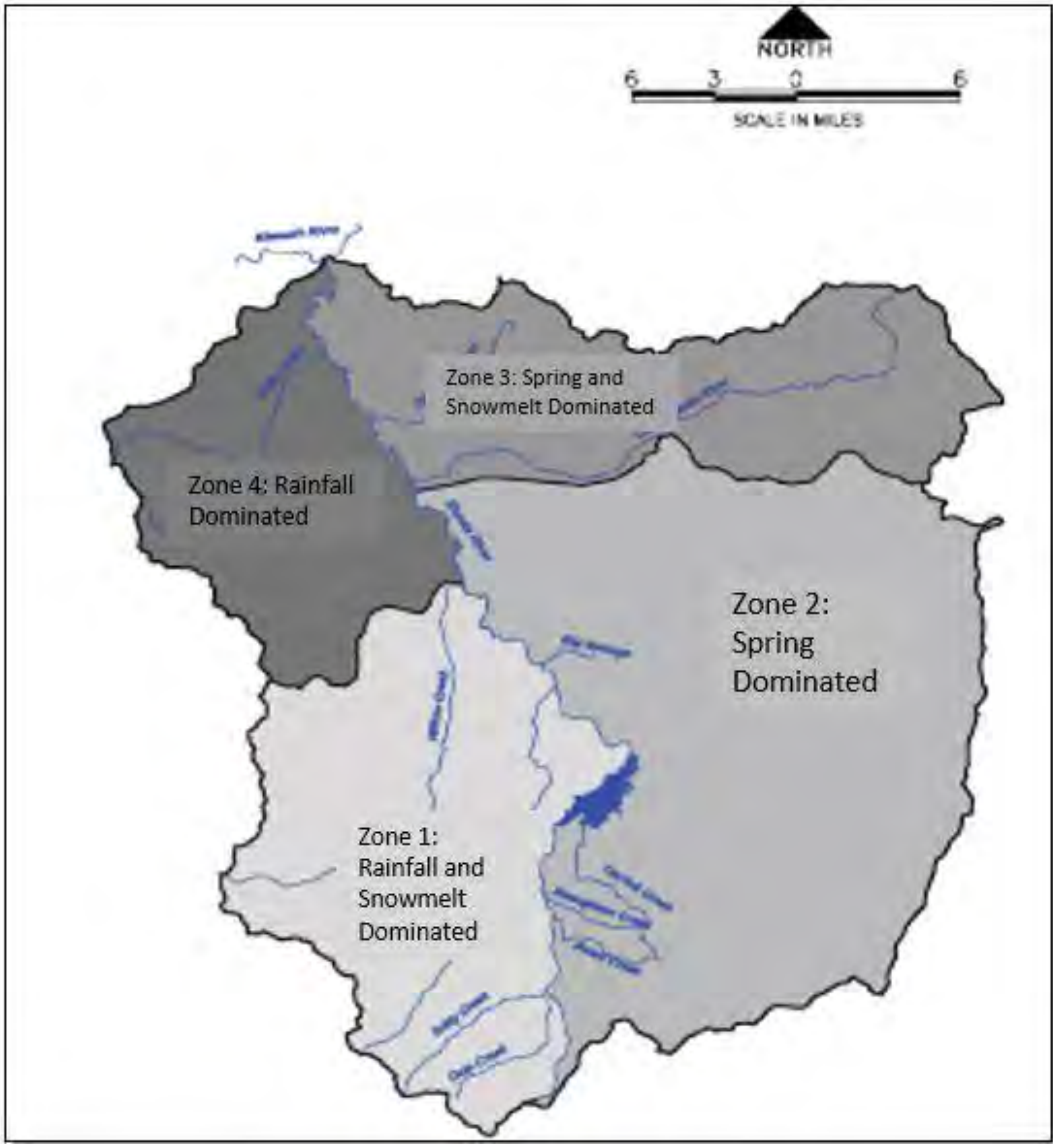

FIGURE 1. HYDROLOGICAL ZONES IN THE SHASTA BASIN BASED ON THE DOMINANT HYDROGRAPH COMPONENTS THAT DETERMINE RUNOFF PATTERNS IN THE MAINSTEM SHASTA RIVER. BOUNDARIES ARE APPROXIMATE. GRAPHIC MODIFIED FROM MCBAIN & TRUSH, INC ET AL. (2010).

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.

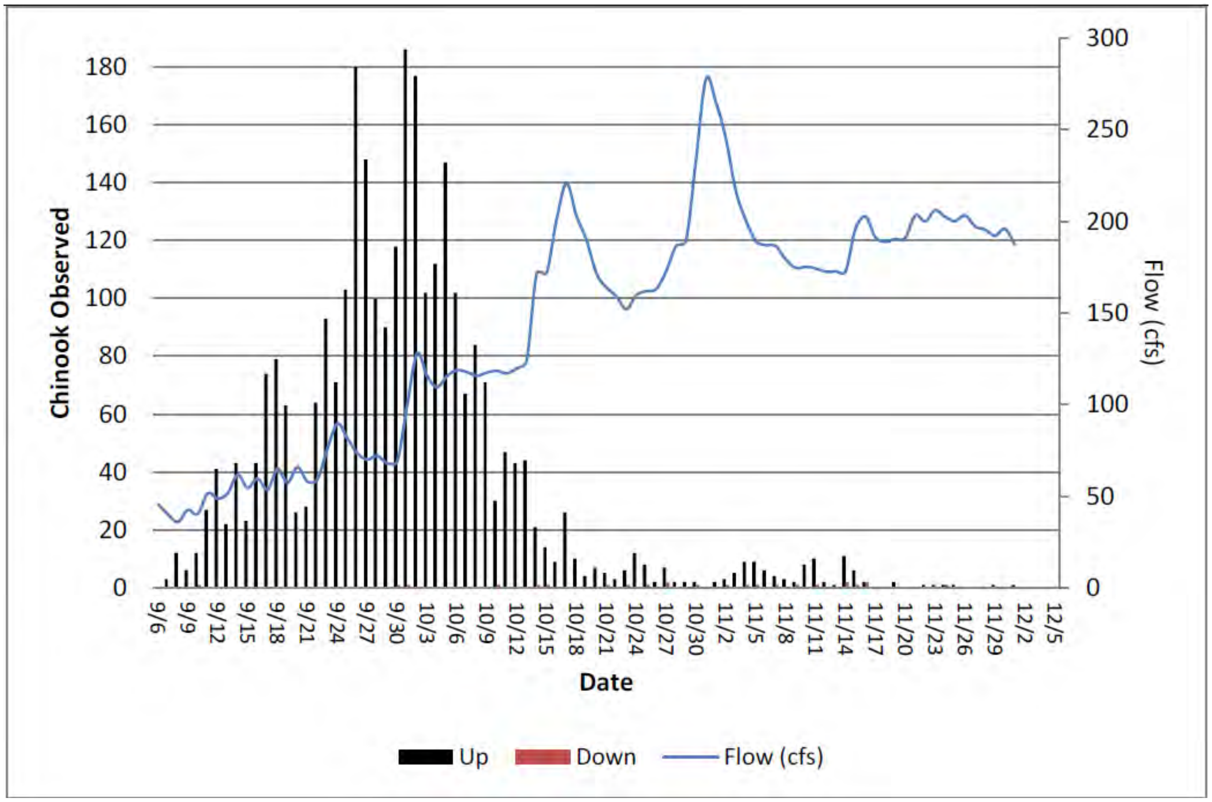

FIGURE 2. CHINOOK SALMON OBSERVED MIGRATING THROUGH SHASTA RIVER FISH COUNTING FACILITY IN 2016, AND FLOW FROM NEARBY USGS GAUGE (GRAPHIC RETRIEVED FROM CHESNEY & KNECHTLE, 2017).

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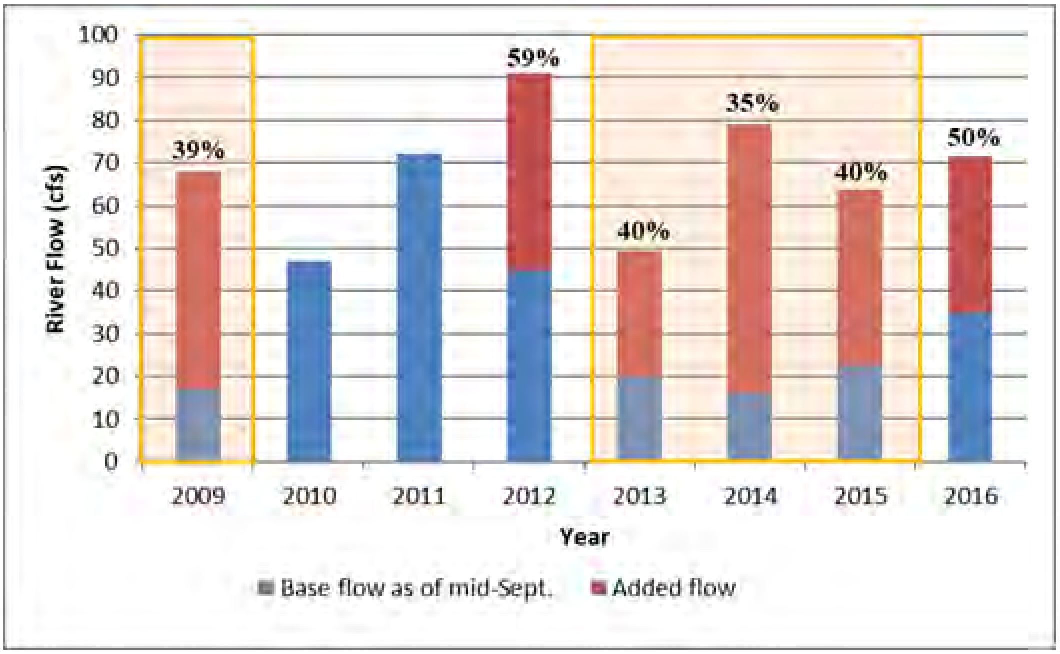

FIGURE 3. BASE FLOW AND FLOW CONTRIBUTIONS (ADDED FLOW) SECURED BY TNC'S FALL FLOW PROGRAM (GRAPHIC COURTESY OF ADA FOWLER, TNC).

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.

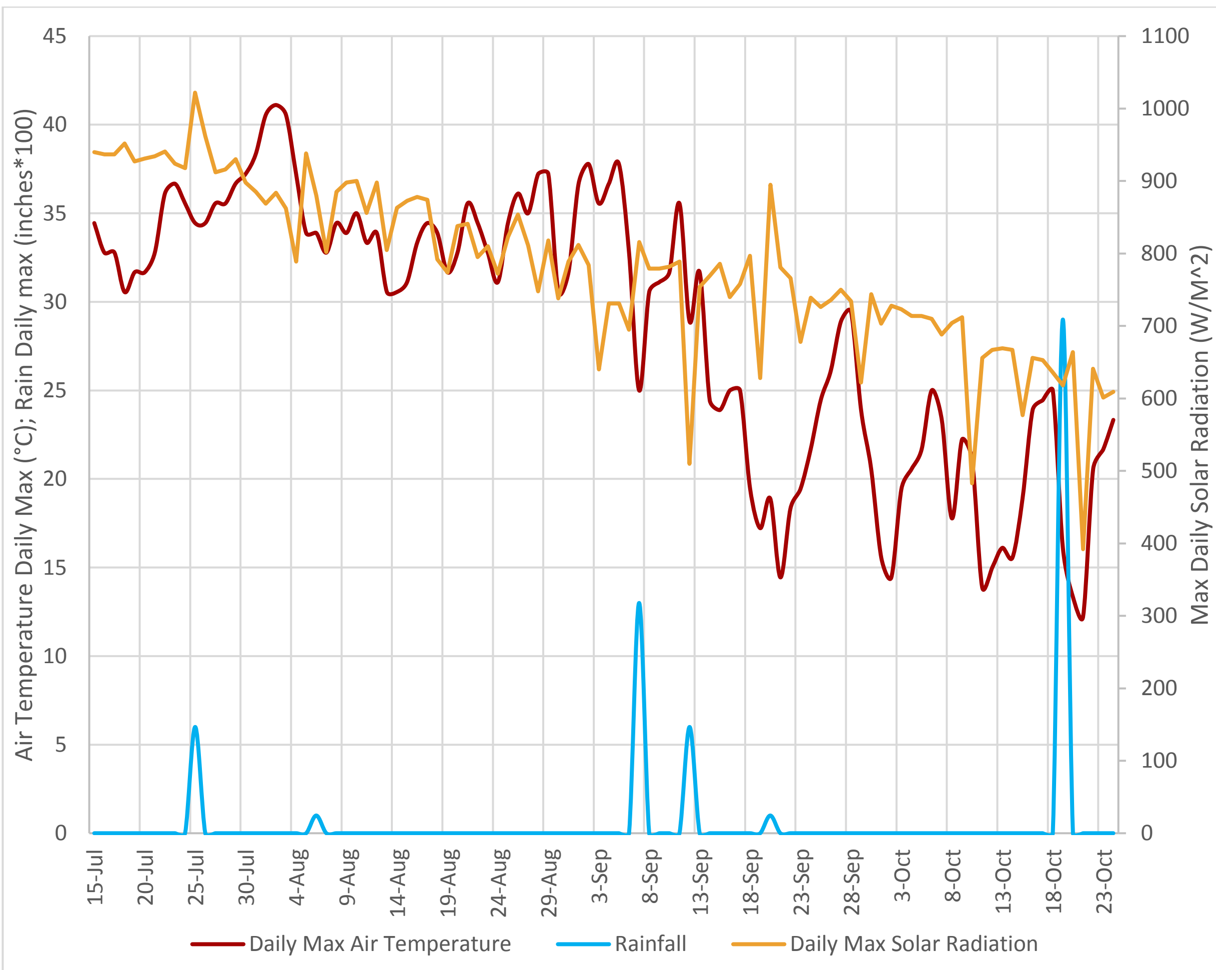

FIGURE 4. METEOROLOGICAL DATA INCLUDING MAXIMUM AIR TEMPERATURE, SOLAR RADIATION, AND PRECIPITATION DURING LATE SUMMER AND FALL 2017 WITH STUDY PERIOD HIGHLIGHTED. DATA SOURCE CDEC STATION WED (WEED AIRPORT): JULY 15, 2017 - OCT. 24, 2017.

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.

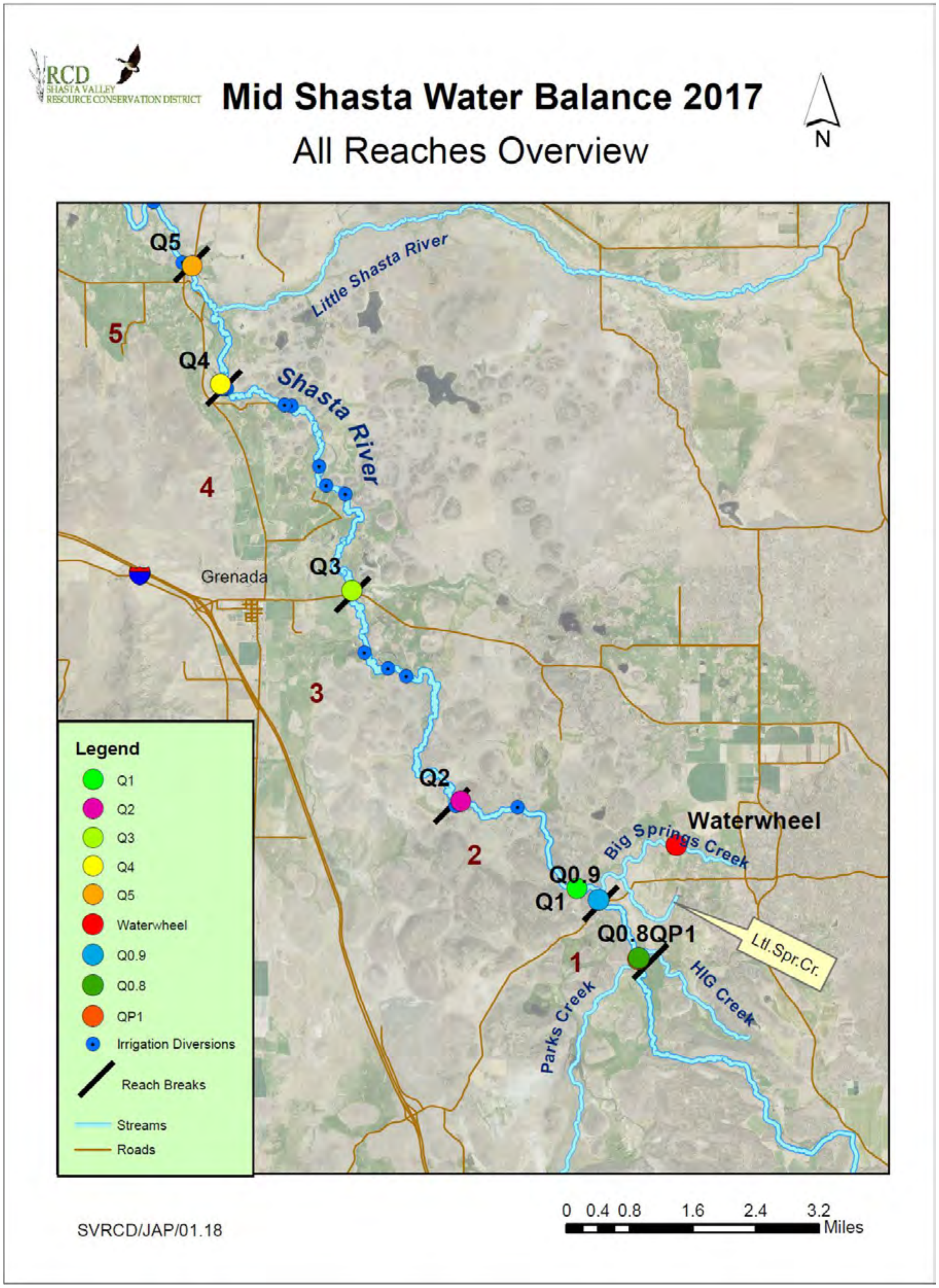

FIGURE 5. MAP OF FLOW STUDY AREA INCLUDING MAJOR TRIBUTARIES WITH ALL MEASUREMENT SITES (NUMBERS PRECEDED BY Q), EXISTING GAGES, AND REACHES (NUMBERS NOT PRECEDED BY Q).

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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

<u>Reach Length:</u> 5.6 miles
<u>Discharge Measurement Locations:</u>

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).

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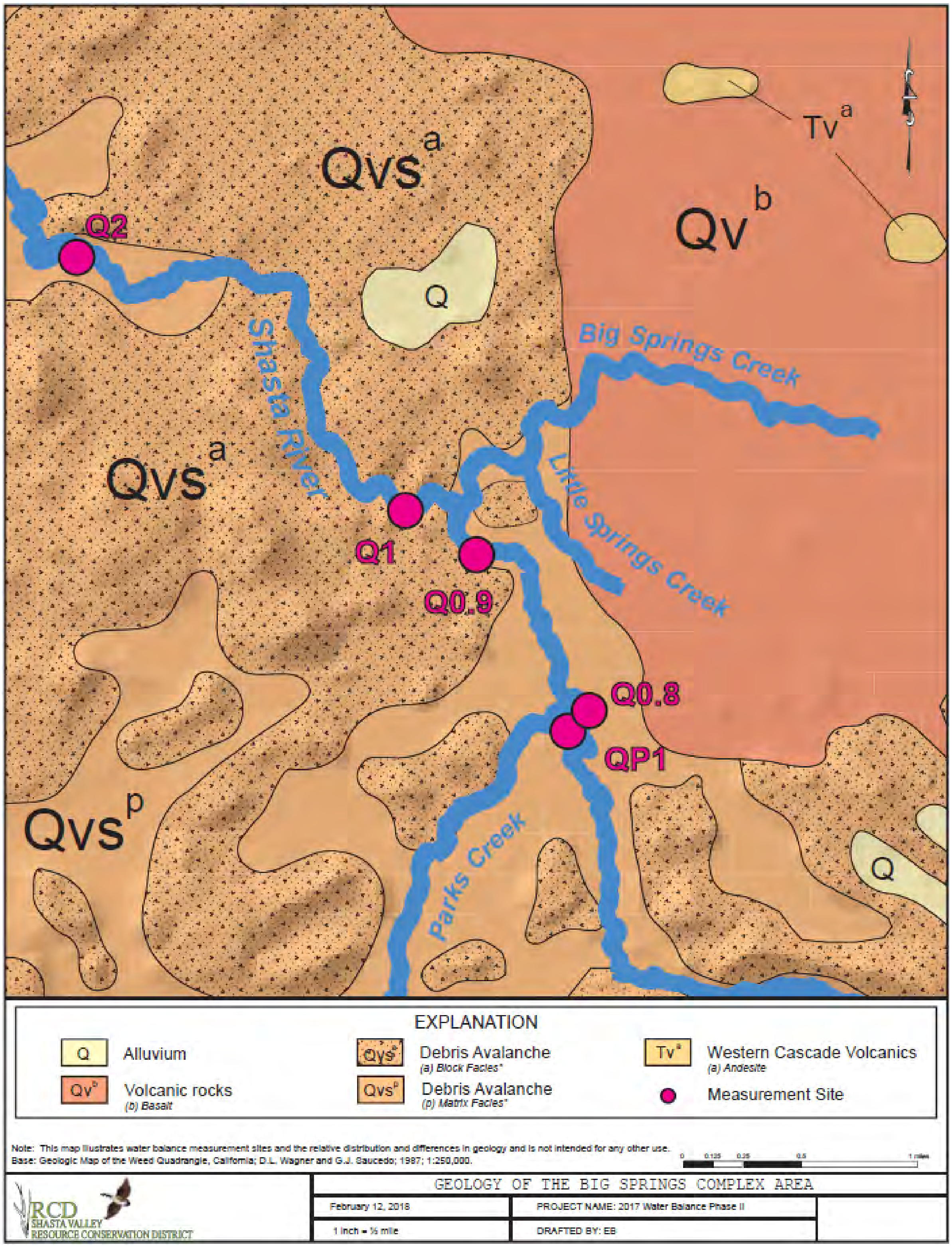

FIGURE 6. GEOLOGIC MAP OF THE BIG SPRINGS COMPLEX AREA.

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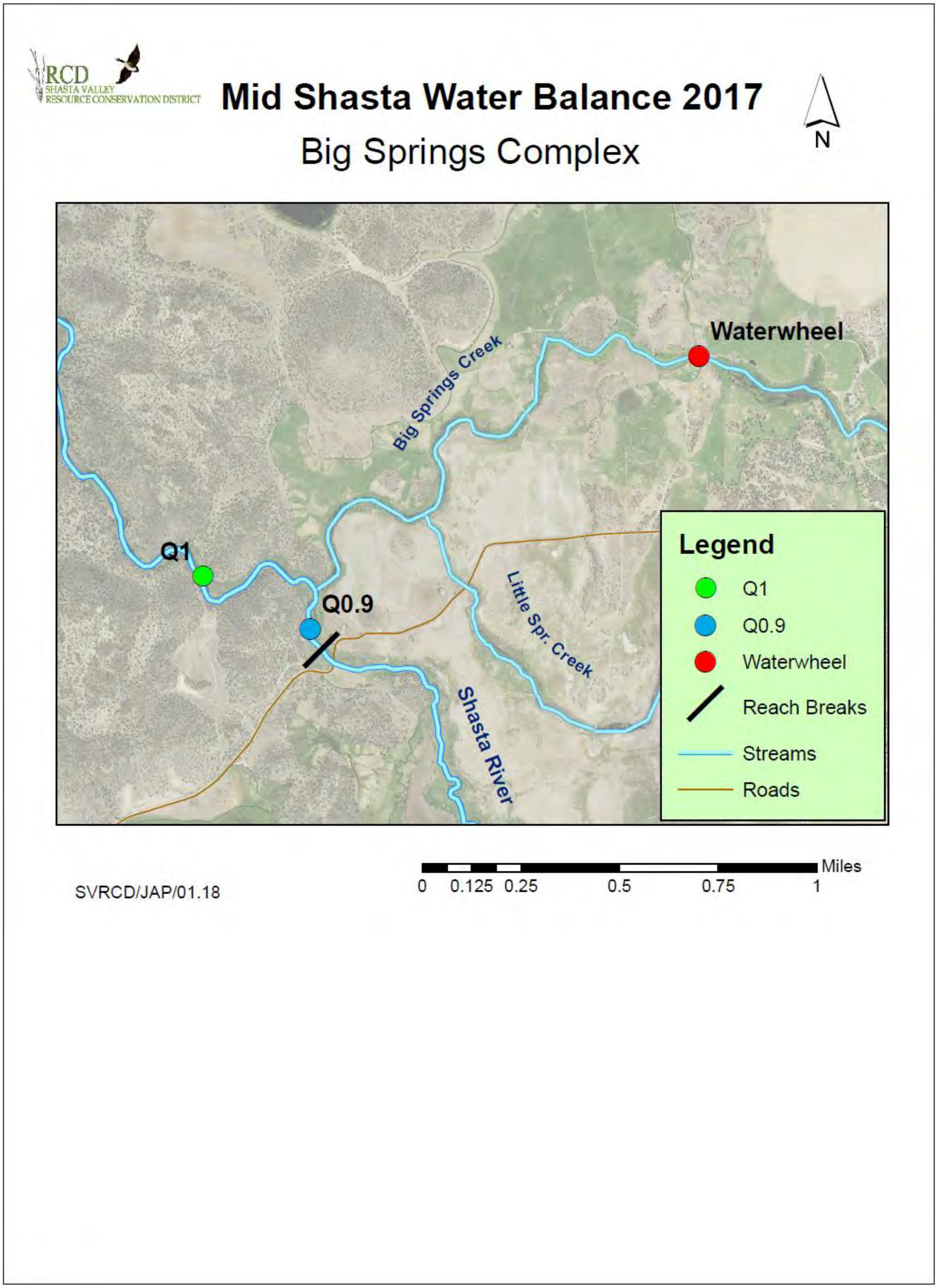

FIGURE 7. MAP OF THE BIG SPRINGS COMPLEX INCLUDING MEASUREMENT SITES AND "WATER WHEEL" EXISTING STAGE/DISCHARGE SITE ON BIG SPRINGS CREEK. ALSO IDENTIFIED IS LITTLE SPRINGS CREEK DOWNSTREAM OF THE WATER WHEEL SITE.

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 ± 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.

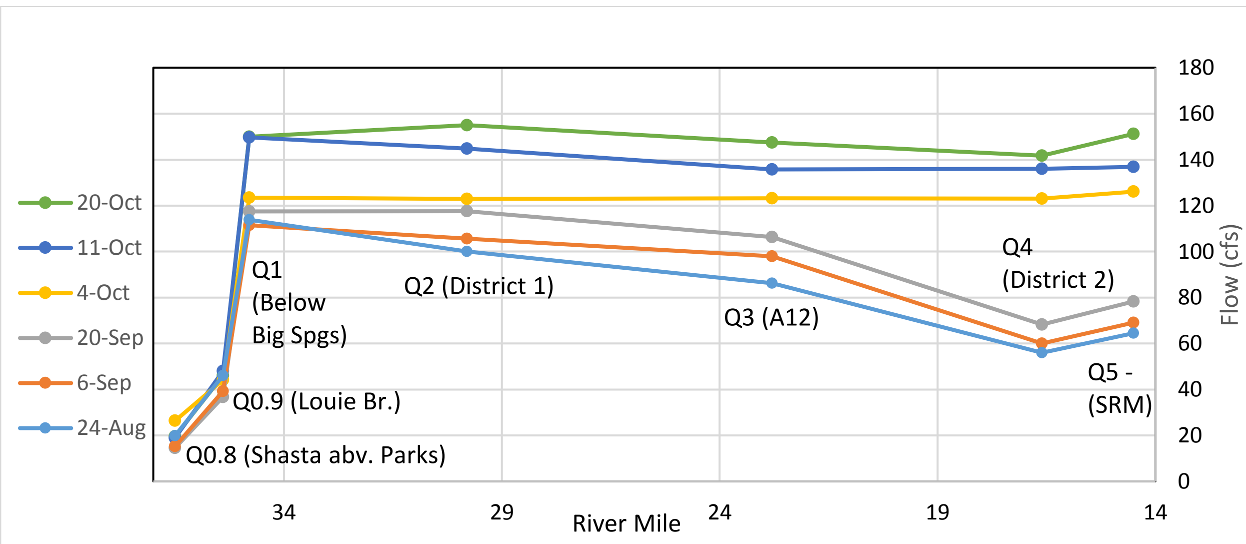

FIGURE 8. SHASTA RIVER CALCULATED FLOWS BY RIVER MILE ON DATE/TIMES ASSOCIATED WITH EACH ASSESSMENT DAY DURING THE STUDY PERIOD, 2017.

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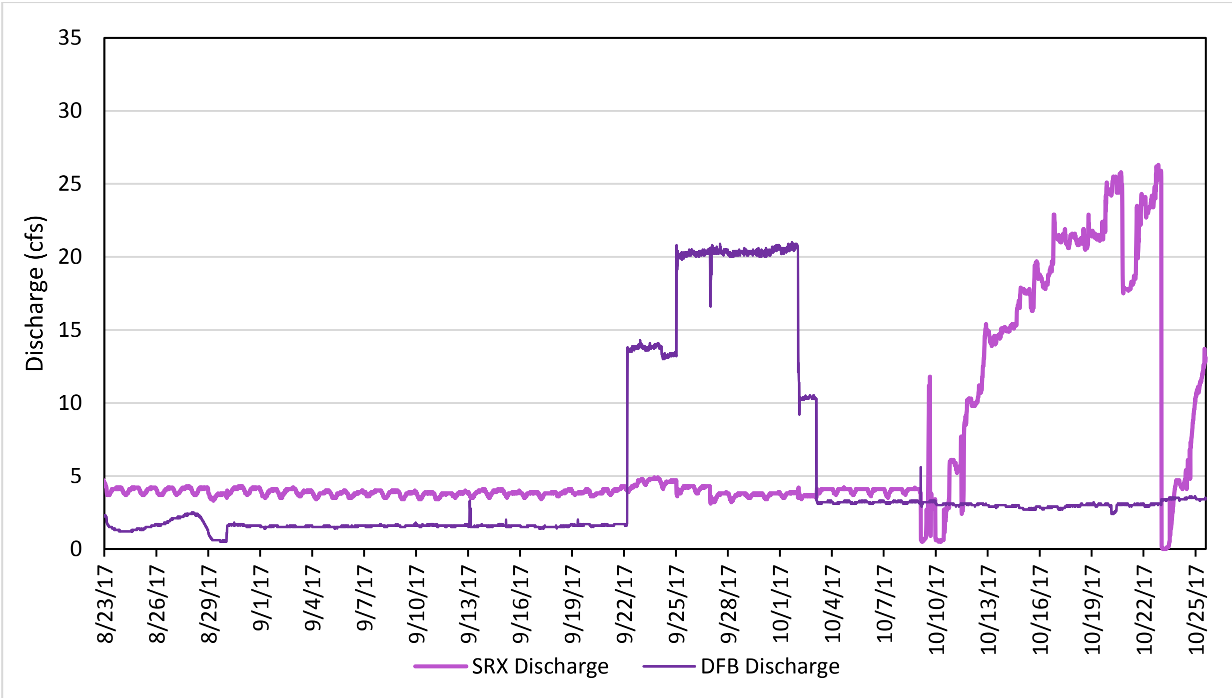

FIGURE 9. DWINNELL RESERVOIR/DAM FLOW RELEASES MEASURED AT CROSS CANAL (SRX) AND DWINNELL FISH BYPASS (DFB) (RETRIEVED FROM CDEC, 2017).

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

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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.

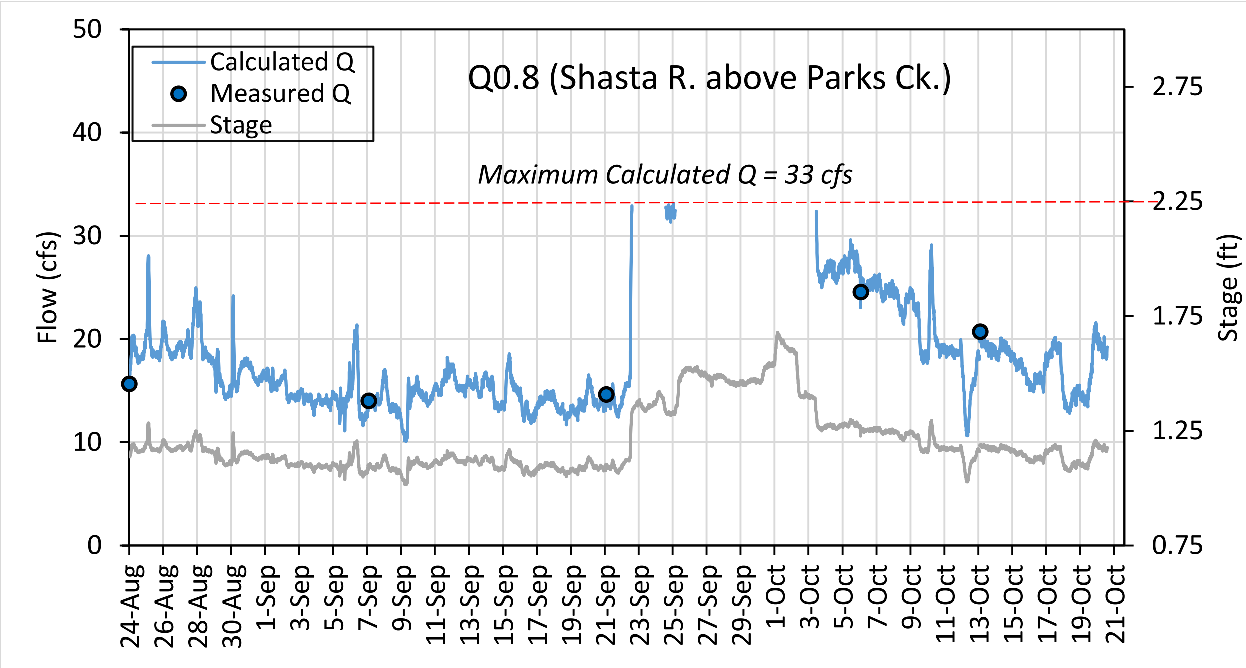

FIGURE 10. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q0.8 DURING THE STUDY PERIOD. MISSING VALUES IN HYDROGRAPH EXCEEDED MEASURED VALUES USED TO CREATE RATING CURVE.

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.

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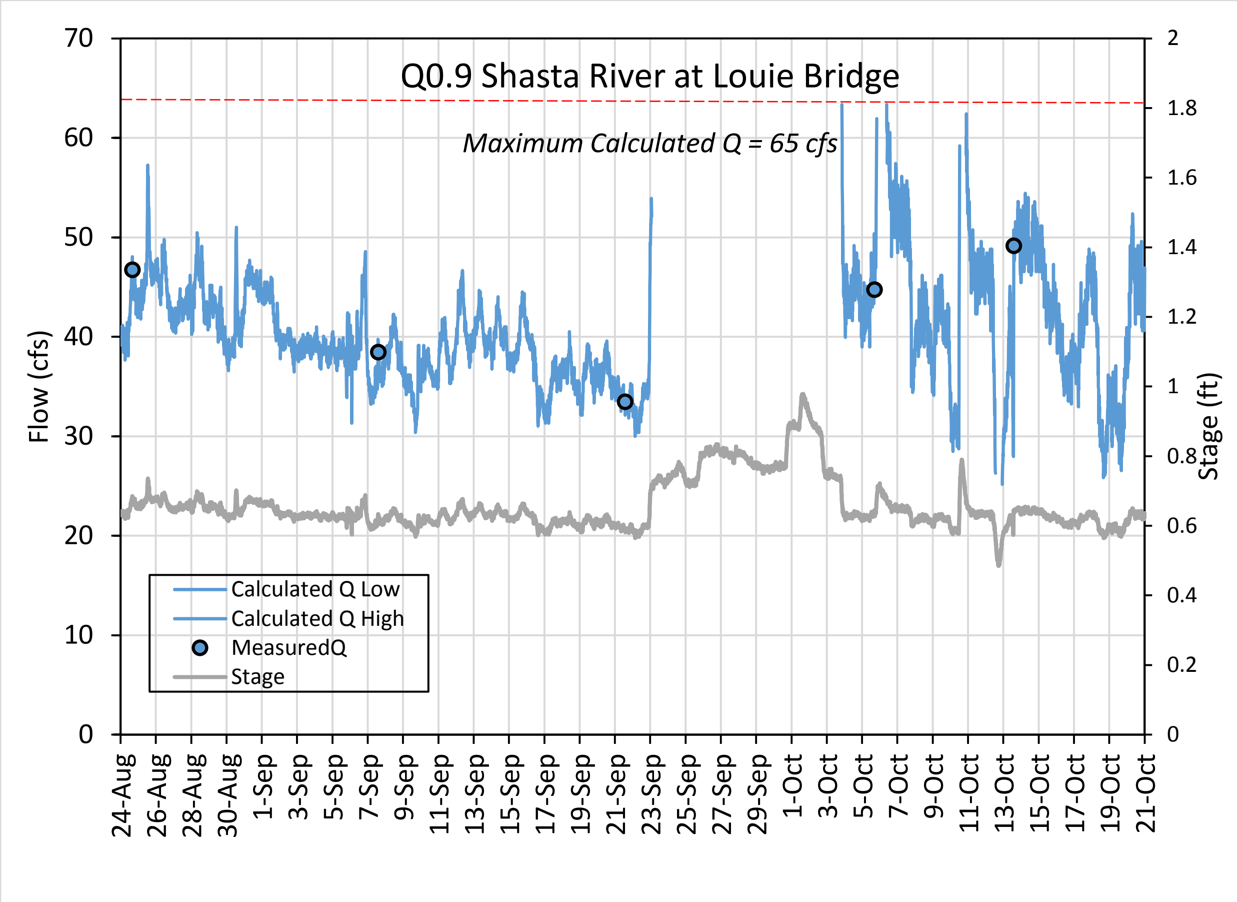

FIGURE 11. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q0.9 (LOUIE BR.) AUGUST 24TH THROUGH OCTOBER 20TH, 2017. RATING CURVE WAS SPLIT INTO SEPARATE "HIGH" AND "LOW" CURVES DUE TO CHANGES IN CHANNEL MORPHOLOGY THAT OCCURRED DURING THE STUDY. THESE CHANGES LED TO A POOR FITTING (LOW R^2 VALUE) 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.

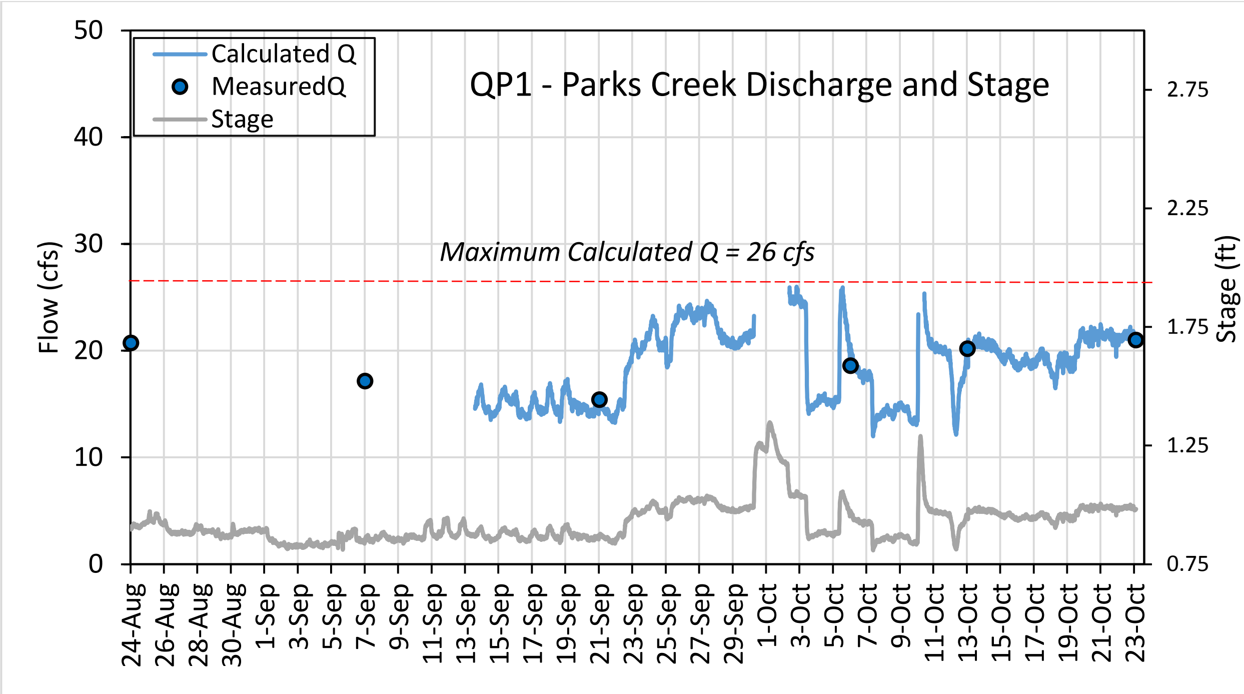

FIGURE 12. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR QP1-PARKS CREEK ABOVE SHASTA RIVER CONFLUENCE, SEPTEMBER 24TH THROUGH OCTOBER 24TH, 2017. RATING PRIOR TO SEPTEMBER 24TH NOT USED DUE TO POOR FITTING RATING CURVE.

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.

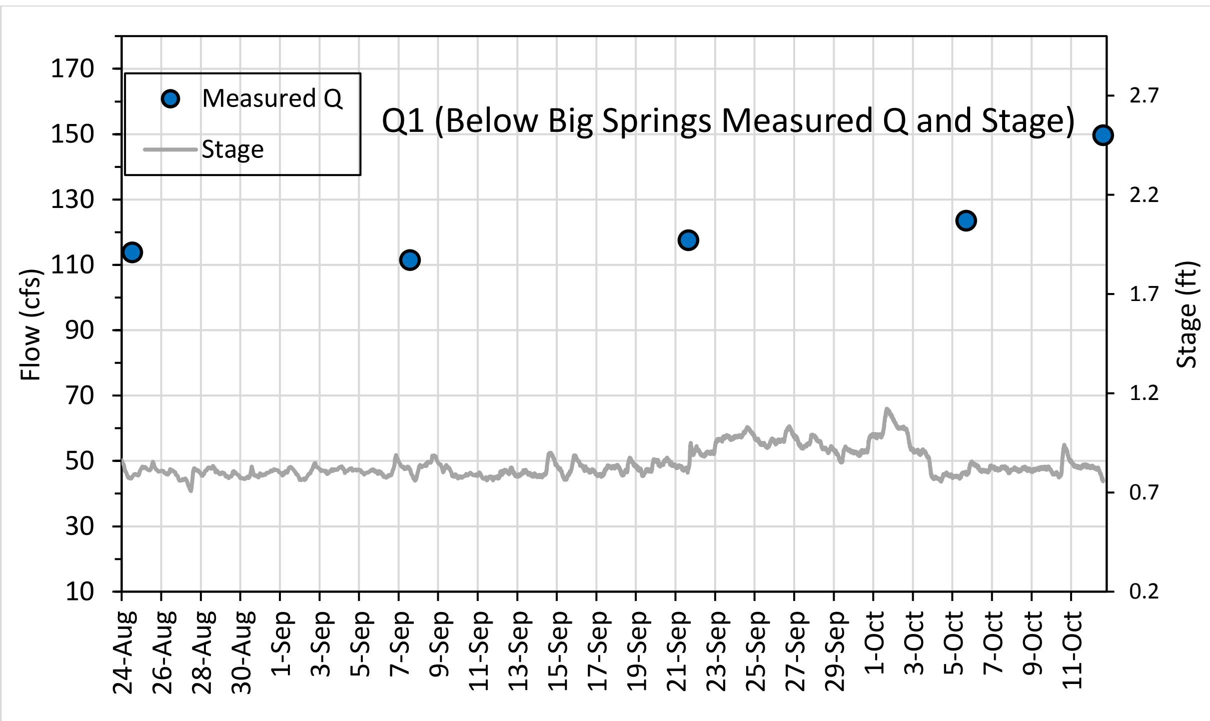

FIGURE 13. STAGE AND SINGLE POINT MEASURED FLOW (Q) FOR Q1 THROUGHOUT THE STUDY PERIOD.

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.

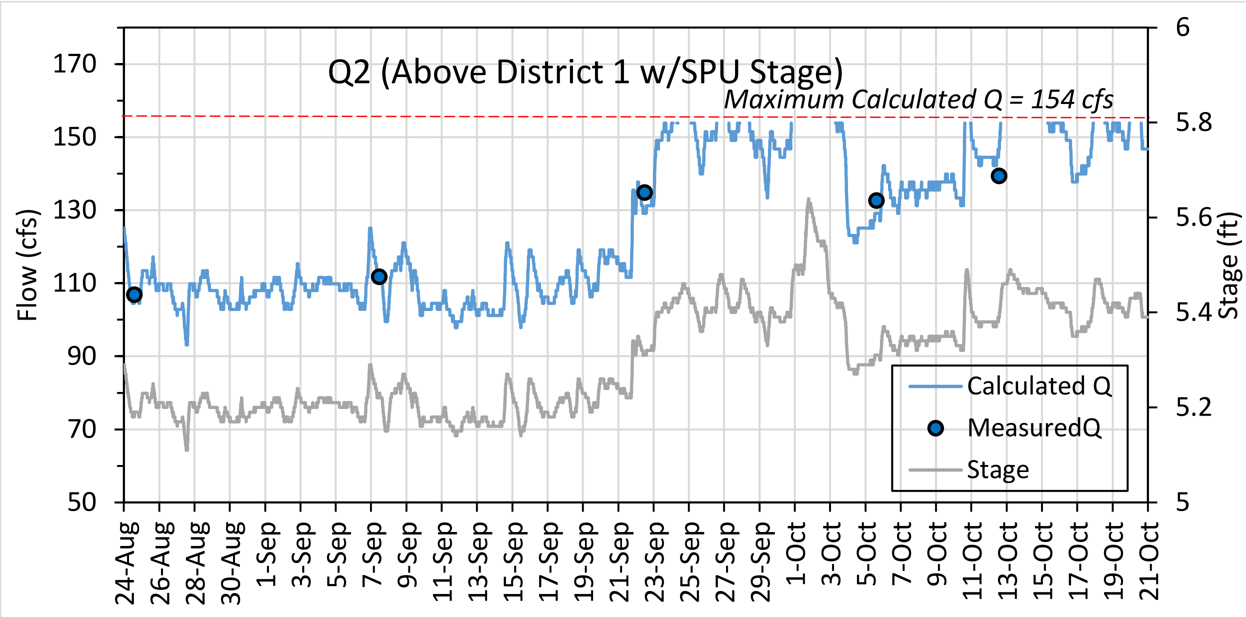

FIGURE 14. STAGE, MEASURED Q, AND CALCULATED FLOW (Q) FOR Q2 THROUGHOUT THE STUDY PERIOD. STAGE DATA RETRIEVED FROM CDEC (DWR STATION SPU).

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)**
Irrigation	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**
	21-Sep	32.6	117.5	84.9	0.0	71.0	**13.9**
Post-Irrigation	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**
	20-Oct	46.0	150.0	104.0	0.0	73.2	**30.8**
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.

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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)**
	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**
Irrigation	21-Sep	32.6	71.0	119.1	86.5	-2.1	**17.6**
	5-Oct	44.8	65.6	129.2	84.4	0.0	**18.8**
Post-	12-Oct	30.0	73.8	161.3	131.3	0.0	**57.5**
Irrigation	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).

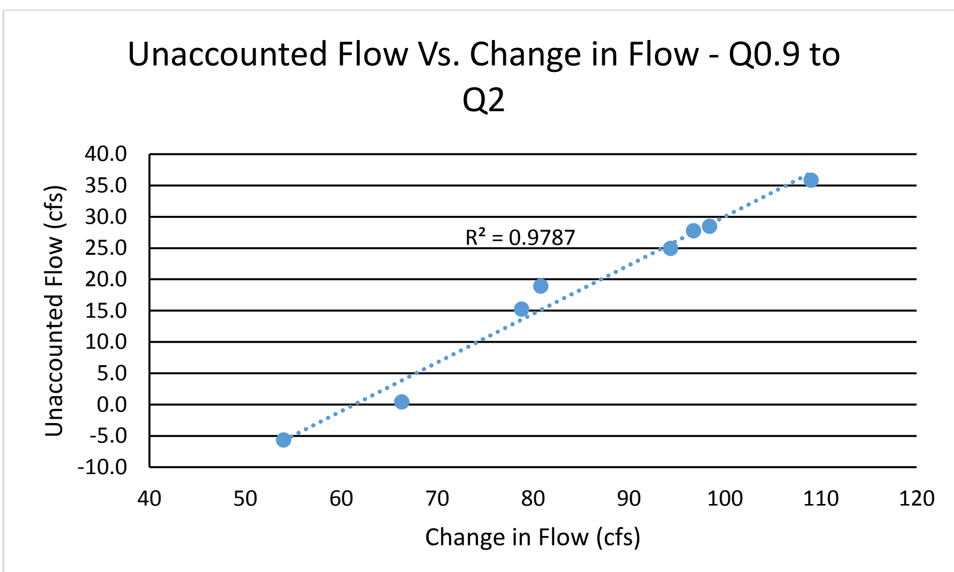

FIGURE 15. UNACCOUNTED FLOW (CFS) VS. CHANGE IN FLOW (CFS) IN REACH 1 BETWEEN Q0.9 AND Q2.

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.

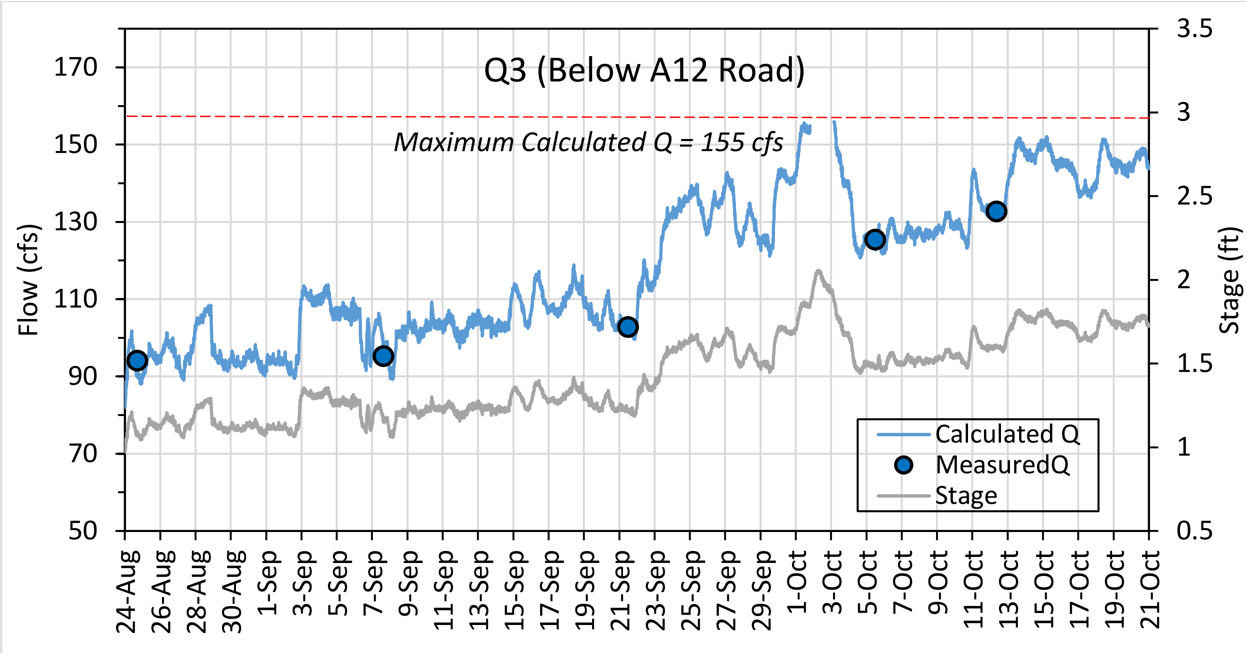

FIGURE 16. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q3 THROUGHOUT THE STUDY PERIOD.

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.

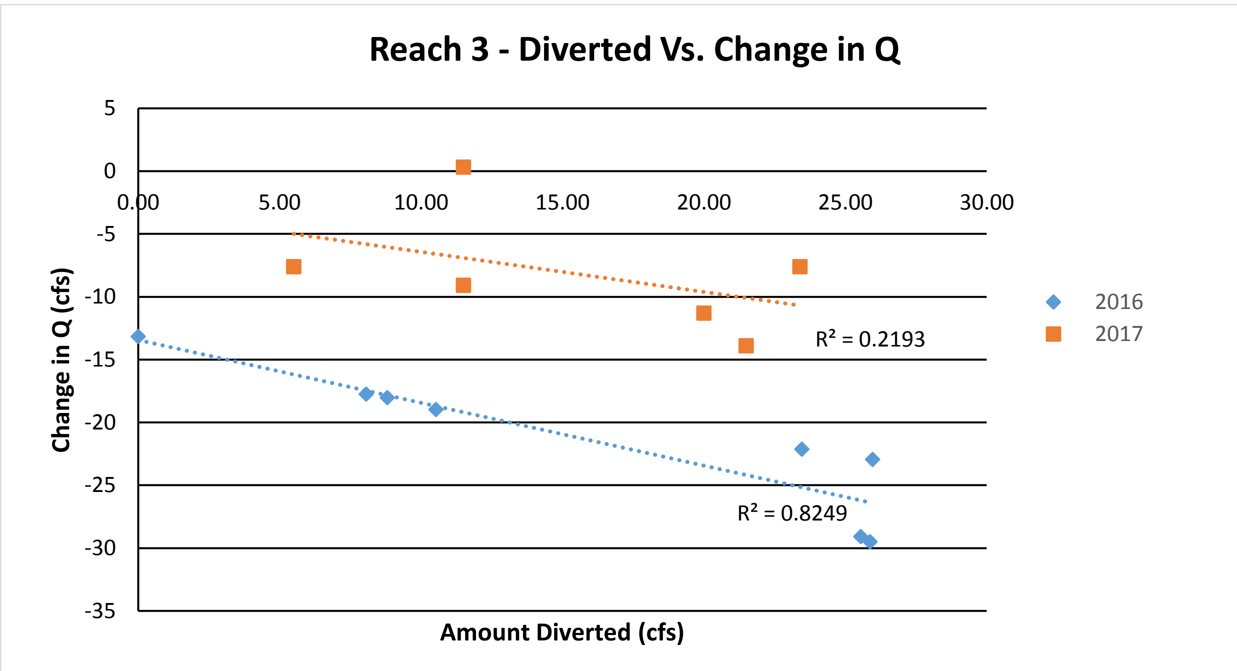

FIGURE 17. DIVERTED FLOW VS. CHANGE IN FLOW IN REACH 3 (Q2 – Q3).

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.

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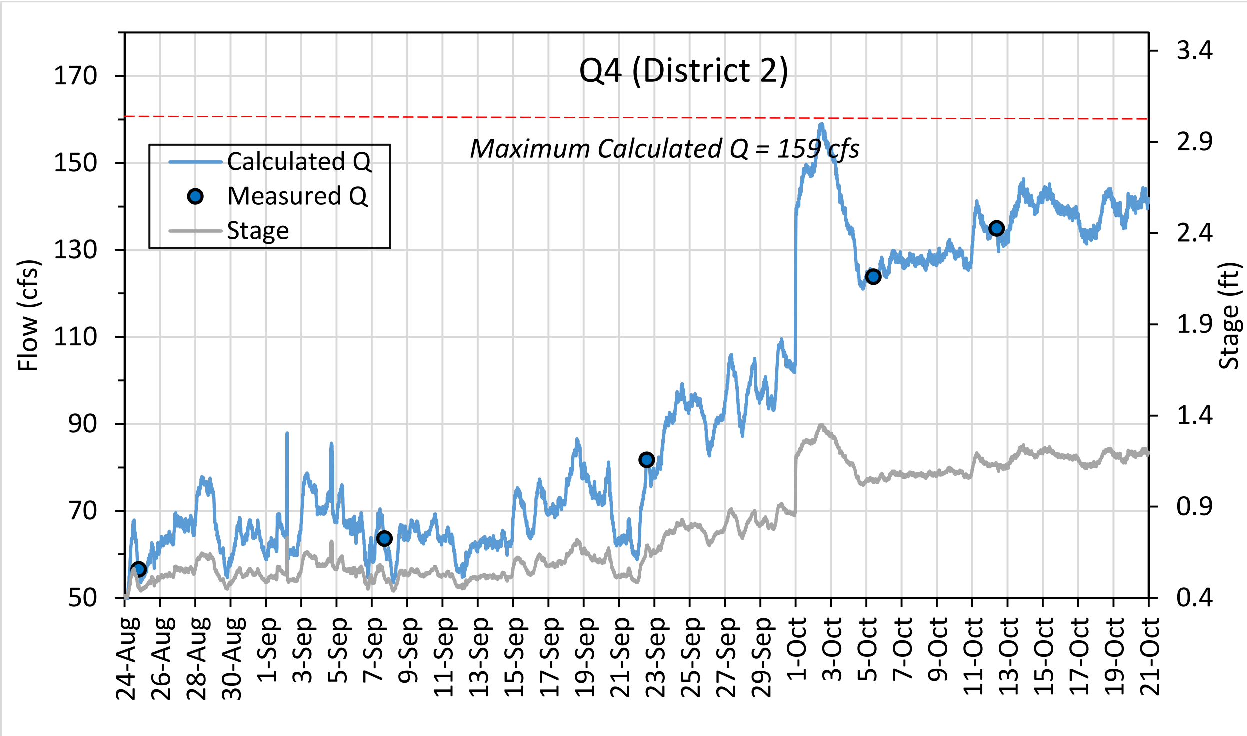

FIGURE 18. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q4 THROUGHOUT THE STUDY PERIOD.

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.

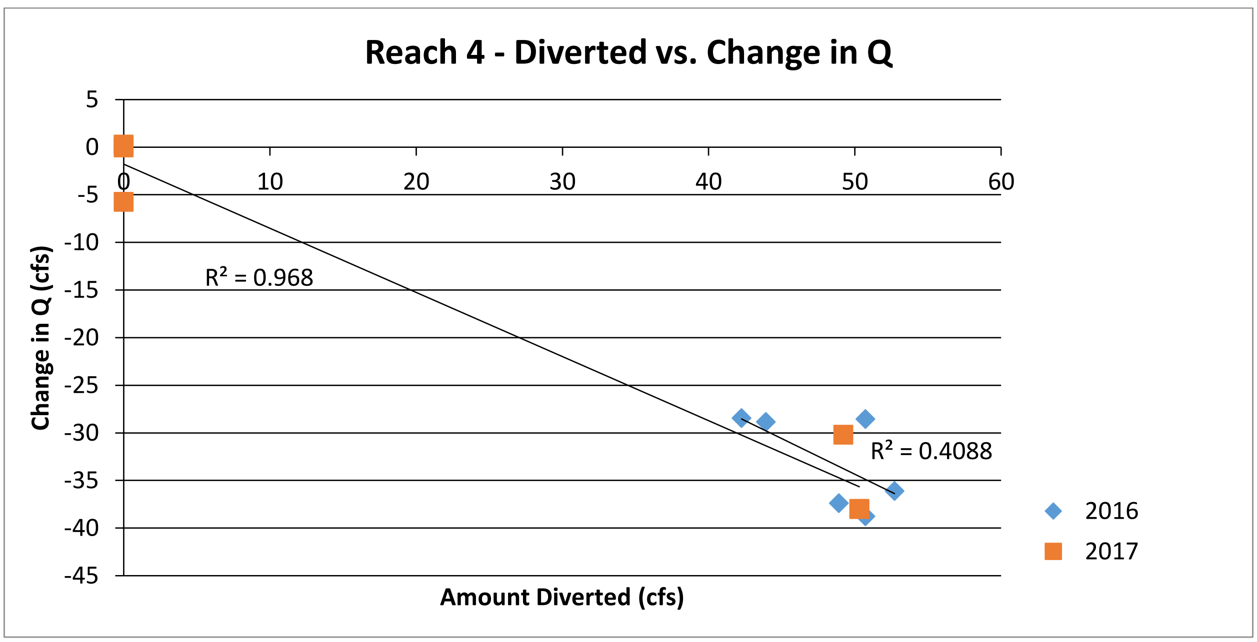

FIGURE 19. DIVERTED FLOW VS. CHANGE IN FLOW IN REACH 4 (Q3 TO Q4).

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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.

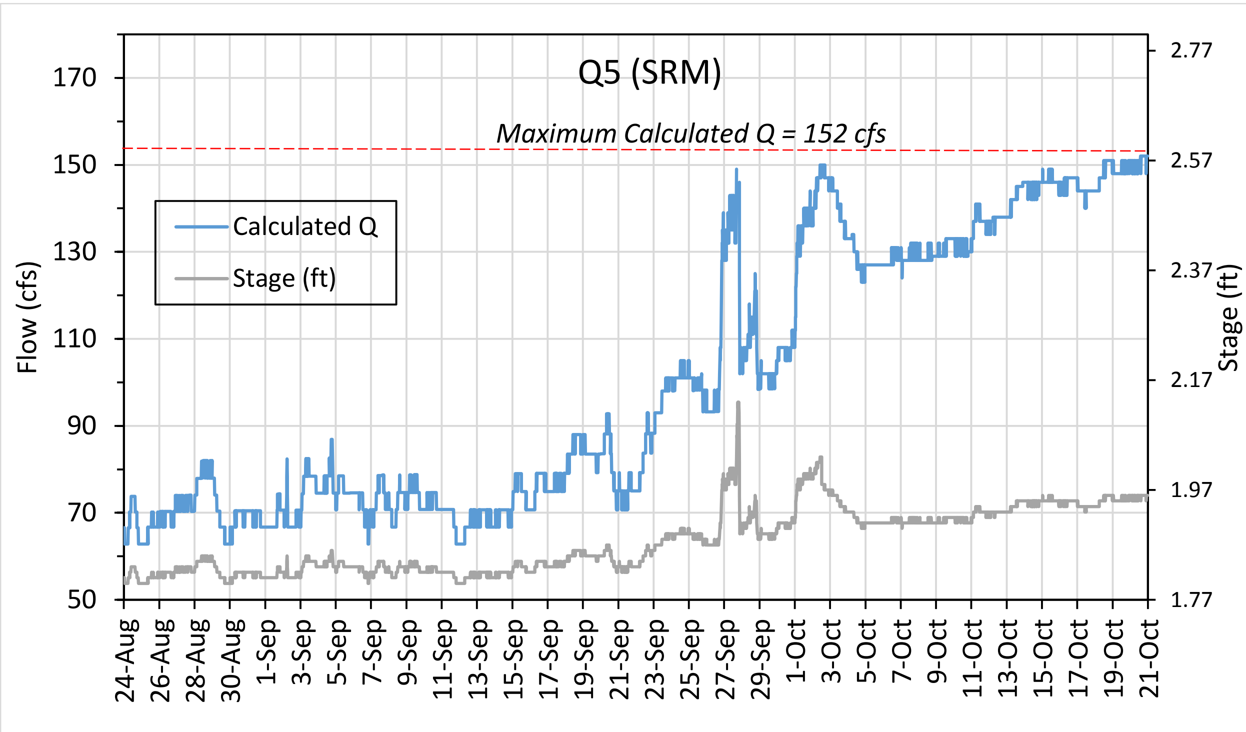

FIGURE 20. STAGE, MEASURED FLOW (Q), AND CALCULATED FLOW (Q) FOR Q5 THROUGHOUT THE STUDY PERIOD. THIS SITE IS MAINTAINED BY USGS. DATA WAS RETRIEVED FROM CDEC, 2017.

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.

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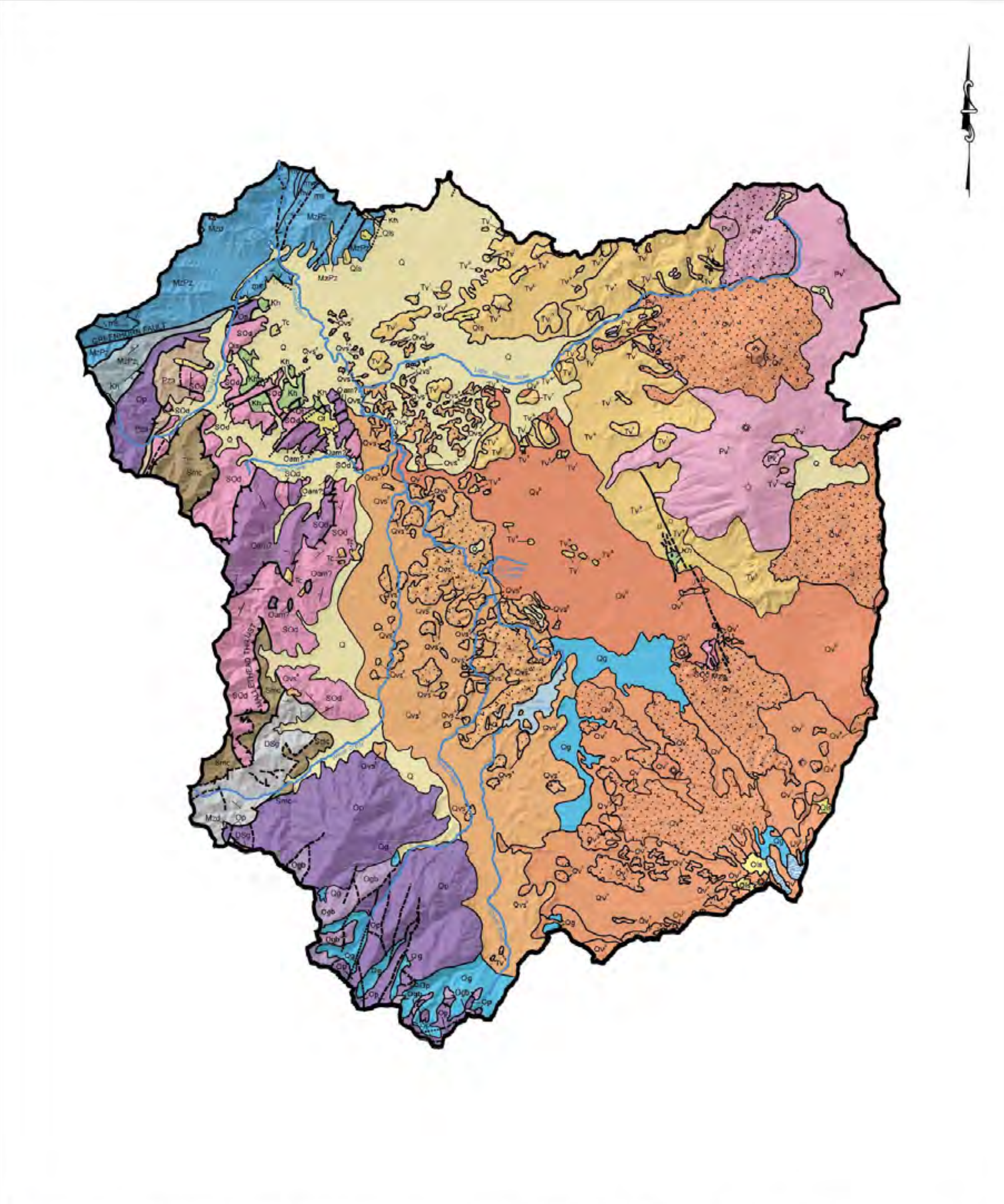
APPENDIX A: SHASTA RIVER WATERSHED GEOLOGIC MAP AND EXPLANATION OF GEOLOGIC ABBREVIATIONS AND SYMBOLS



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

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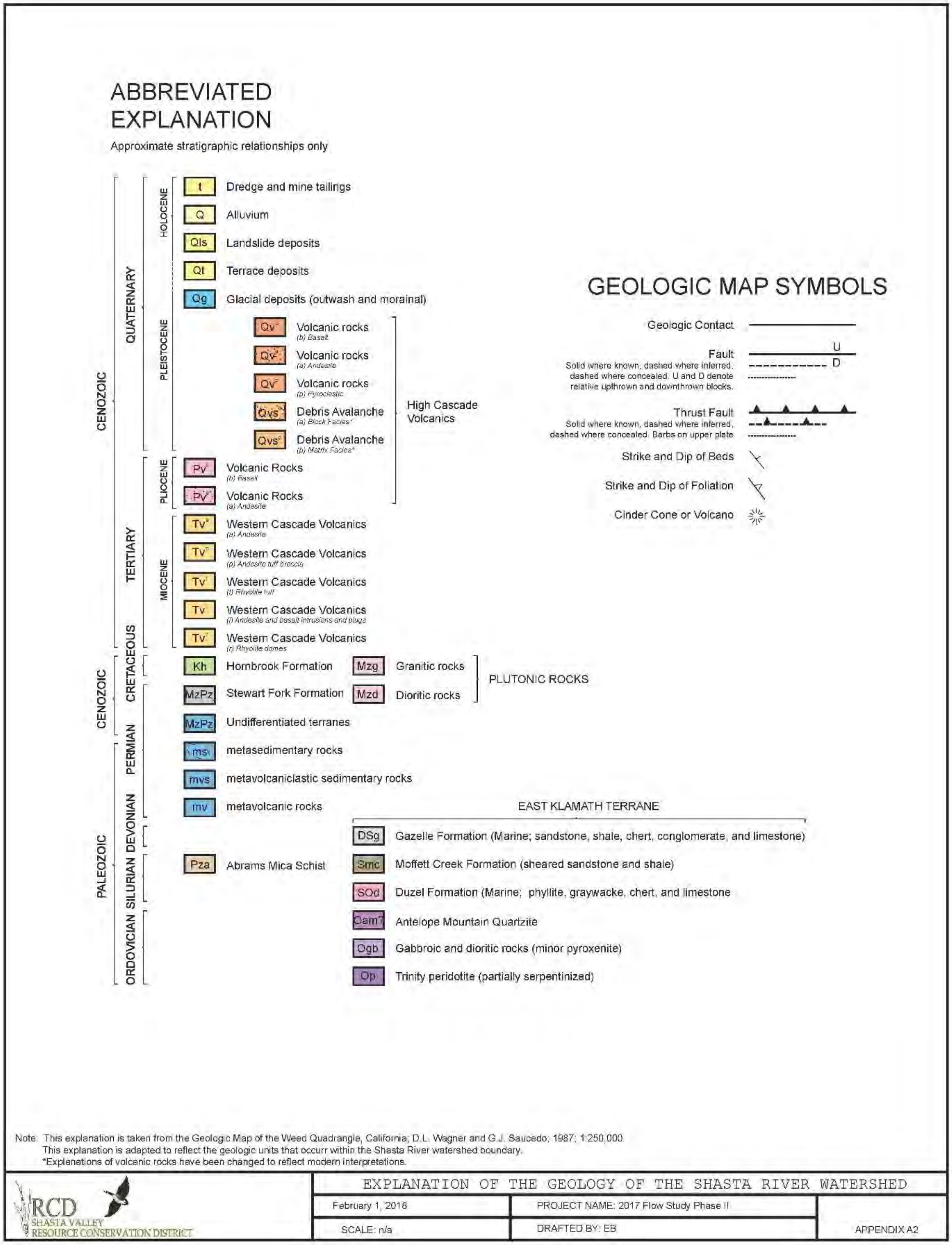
ABBREVIATED EXPLANATION
Approximate stratigraphic relationships only
CENOZOIC
QUATERNARY
HOLOCENE
PLEISTOCENE
PLIOCENE
TERTIARY
MIOCENE
CRETACEOUS
PERMIAN
DEVONIAN
SILURIAN
ORDOVICIAN
PALEOZOIC
t Dredge and mine tailings
Q Alluvium
Qls Landslide deposits
Qt Terrace deposits
Qg Glacial deposits (outwash and morainal)
Qv Volcanic rocks
Qv Volcanic rocks
Qv Volcanic rocks
Qvs Debris Avalanche
Qvs Debris Avalanche
High Cascade Volcanics
Pv Volcanic Rocks
Pv Volcanic Rocks
Tv Western Cascade Volcanics
Tv Western Cascade Volcanics
Tv Western Cascade Volcanics
Tv Western Cascade Volcanics
Tv Western Cascade Volcanics
Kh Hornbrook Formation
MzPz Stewart Fork Formation
Mzg Granitic rocks
Mzd Dioritic rocks
PLUTONIC ROCKS
MzPz Undifferentiated terranes
ms metasedimentary rocks
mvs metavolcaniclastic sedimentary rocks
mv metavolcanic rocks
EAST KLAMATH TERRANE
DSg Gazelle Formation (Marine; sandstone, shale, chert, conglomerate, and limestone)
Pza Abrams Mica Schist
Smc Moffett Creek Formation (sheared sandstone and shale)
SOd Duzel Formation (Marine; phyllite, graywacke, chert, and limestone
Oam? Antelope Mountain Quartzite
Ogb Gabbroic and dioritic rocks (minor pyroxenite)
Op Trinity peridotite (partially serpentinized)
GEOLOGIC MAP SYMBOLS
Geologic Contact
Fault
Solid where known, dashed where inferred, dashed where concealed. U and D denote relative upthrown and downthrown blocks.
U
D
Thrust Fault
Solid where known, dashed where inferred, dashed where concealed. Barbs on upper plate
Strike and Dip of Beds
Strike and Dip of Foliation
Cinder Cone or Volcano
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

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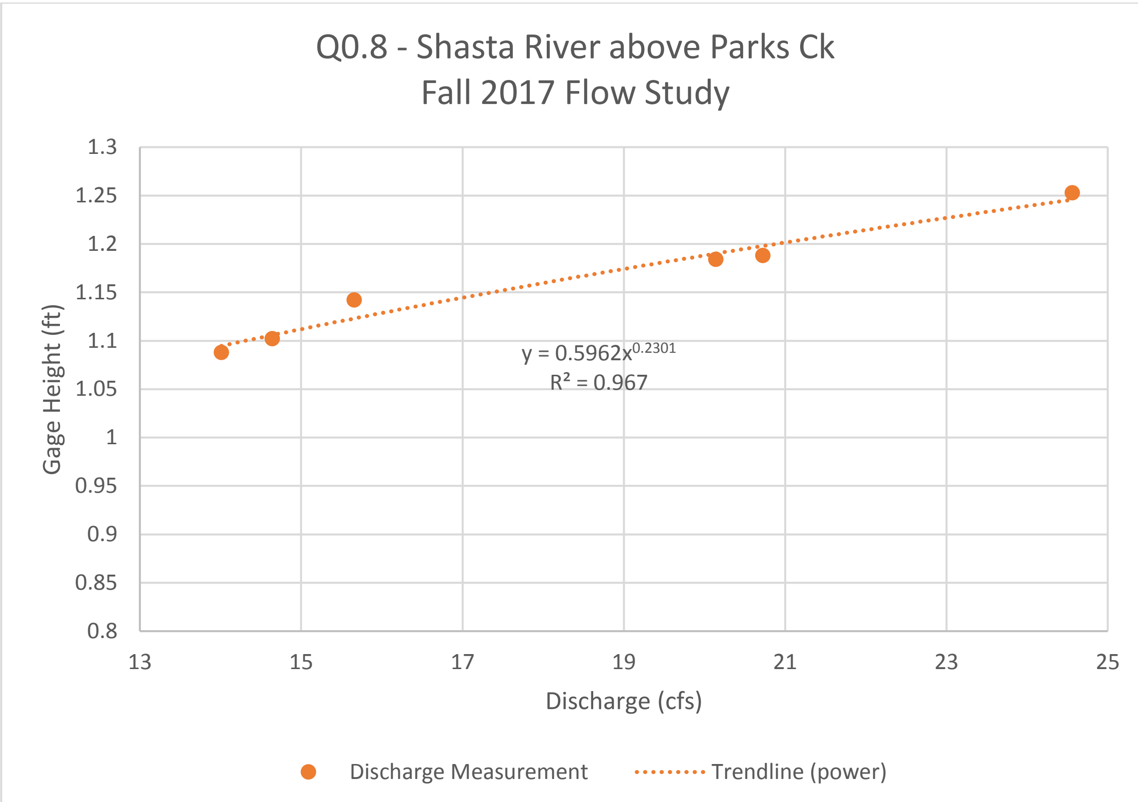
APPENDIX B: RATING CURVES (STAGE-DISCHARGE RELATIONSHIPS)



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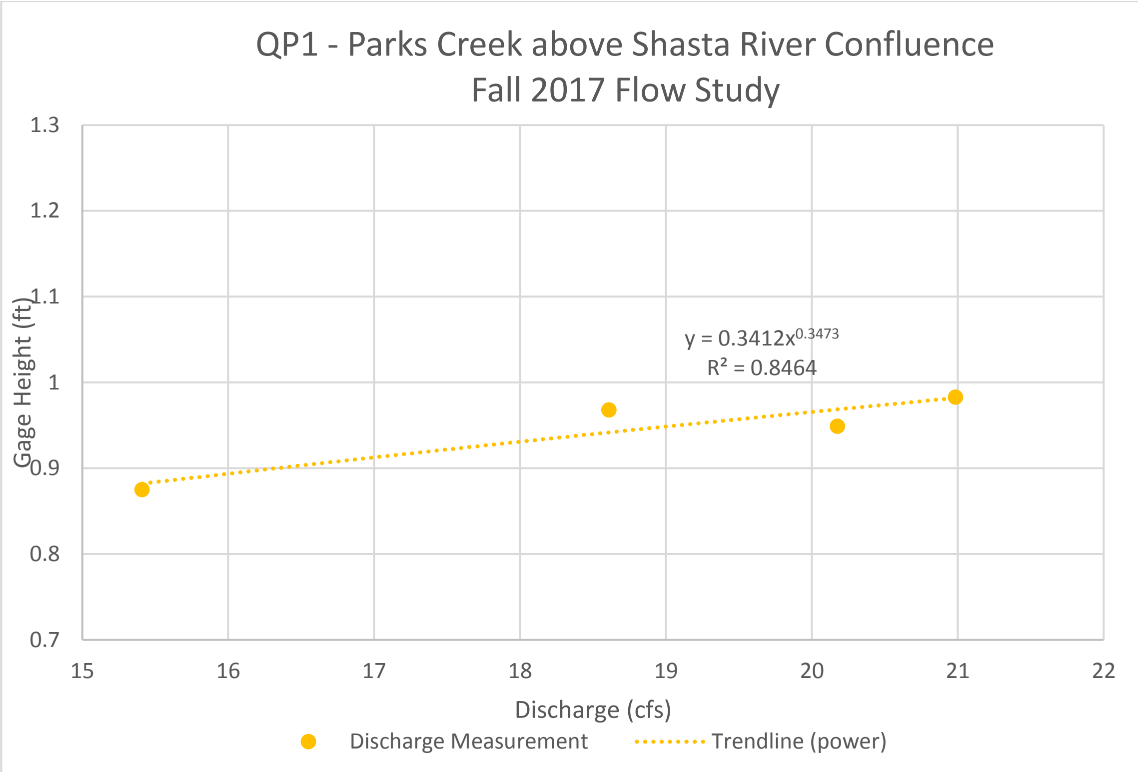
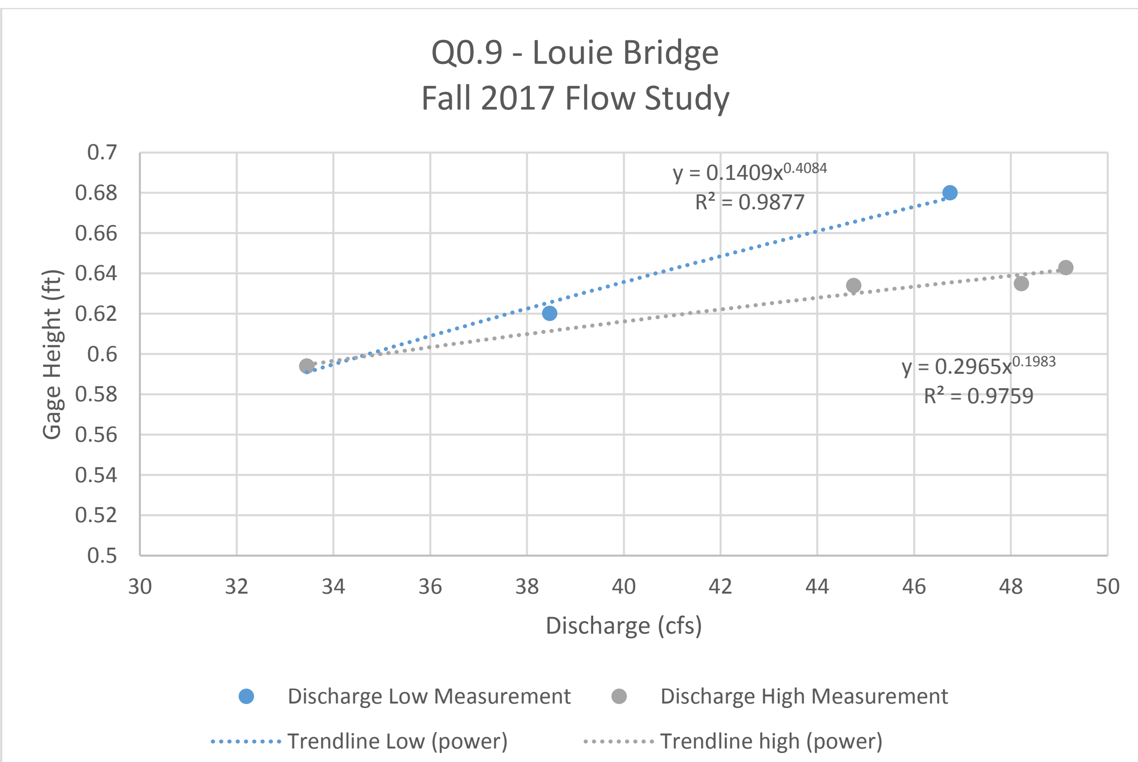
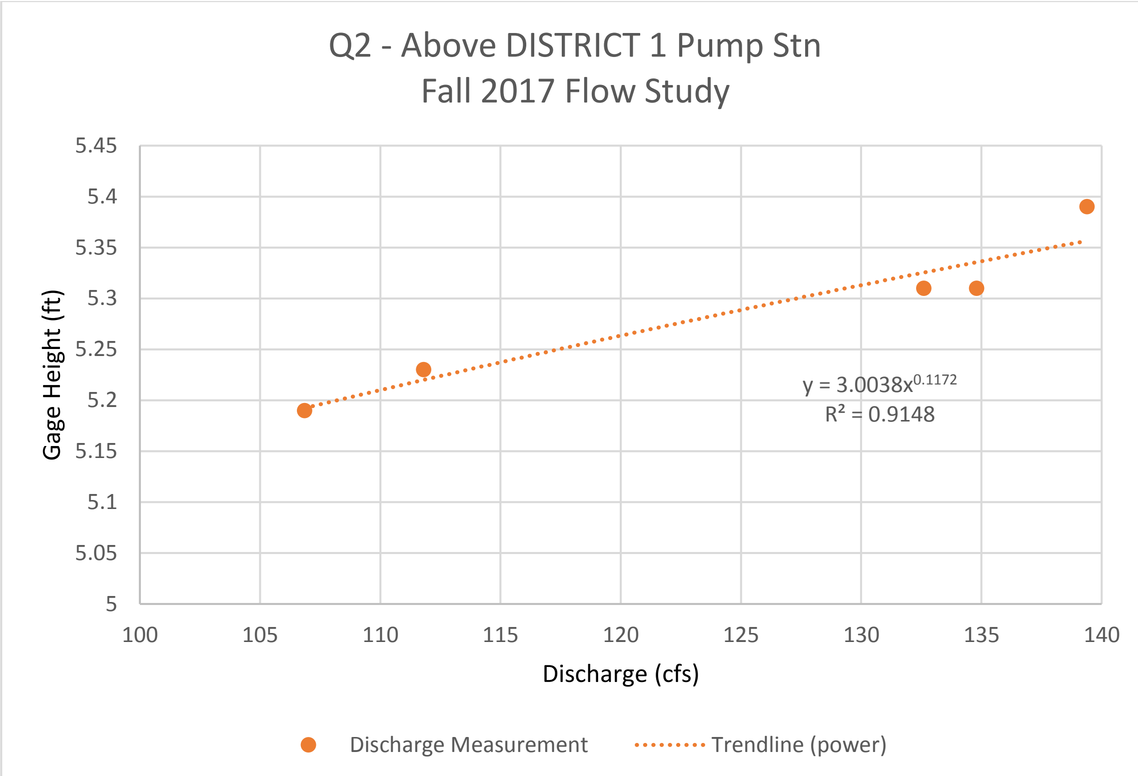
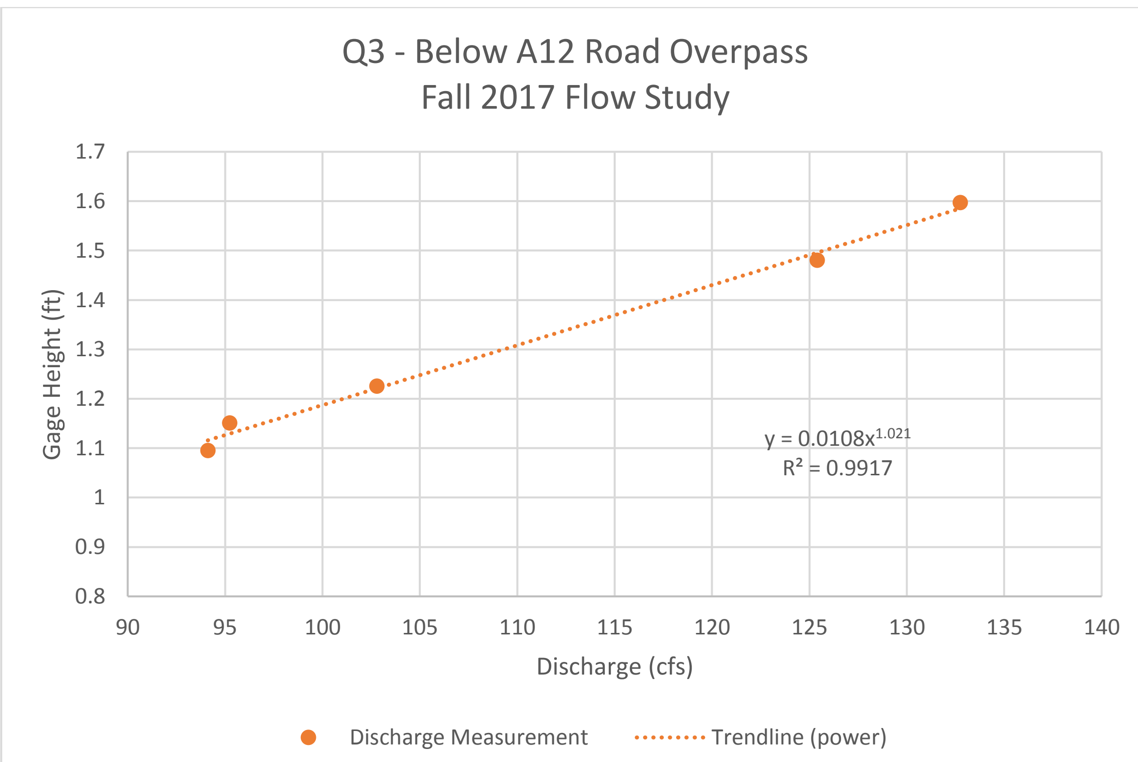

QP1 - Parks Creek above Shasta River Confluence
Fall 2017 Flow Study
Gage Height (ft)
1.3
1.2
1.1
1
0.9
0.8
0.7
y = 0.3412x^0.3473
R² = 0.8464
15
16
17
18
19
20
21
22
Discharge (cfs)
Discharge Measurement
Trendline (power)


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
y = 0.1409x^0.4084
R² = 0.9877
y = 0.2965x^0.1983
R² = 0.9759
30
32
34
36
38
40
42
44
46
48
50
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)

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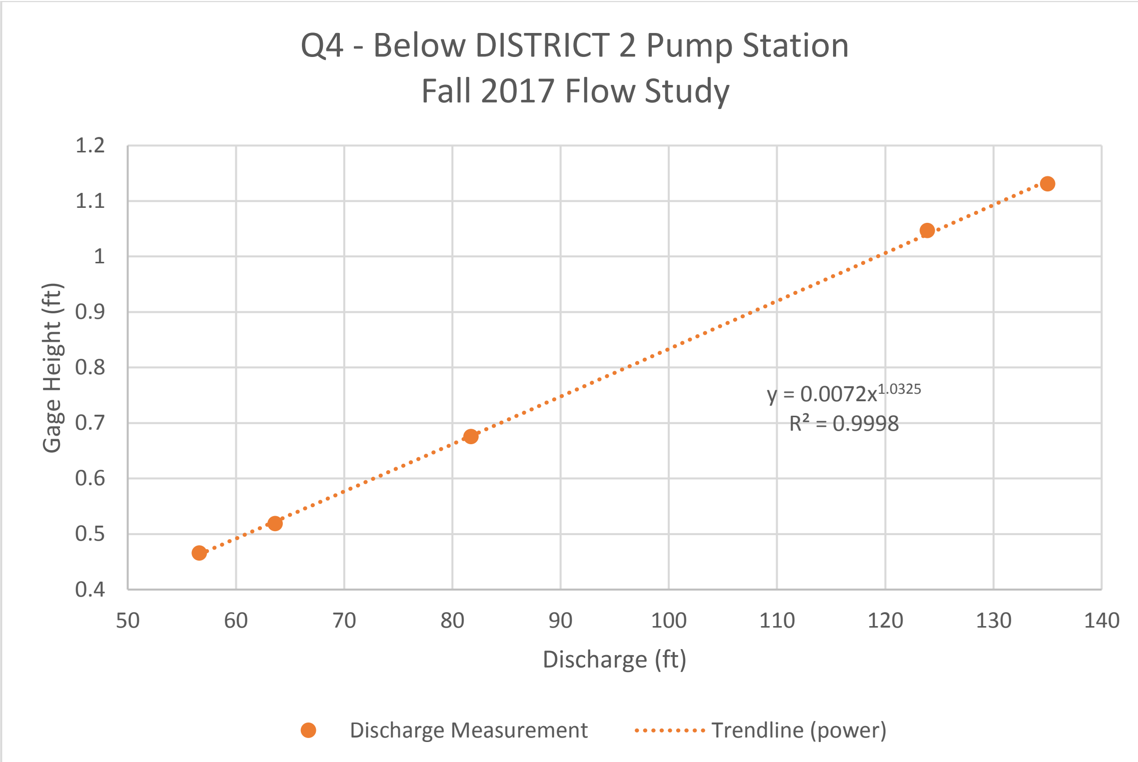

Q4 - Below DISTRICT 2 Pump Station
Fall 2017 Flow Study
Gage Height (ft)
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
50
60
70
80
90
100
110
120
130
140
Discharge (ft)
y = 0.0072x1.0325
R² = 0.9998
Discharge Measurement
Trendline (power)

Appendix 5-A PMA Prioritization and Scoring System

Preliminary criteria, and an associated scoring system, were developed to assist in the evaluation and prioritization of the PMA options identified in Chapter 4. This prioritization system is intended to facilitate strategic implementation of PMAs based on factors including effectiveness, cost, and stakeholder support. The criteria and descriptions for each scoring category are shown in Table 1. A template, with the PMAs identified in Chapter 4 for near-term and for future implementation (Tiers II and III), is included as Table 2. Categories and scoring may be modified throughout GSP implementation to reflect the principal objectives for PMAs.

Table 1: PMA prioritization criteria and score descriptions.

		Score		
Category		**1**	**2**	**3**
Effectiveness	**Anticipated Benefit**	Some physical benefit anticipated	Medium level of benefit anticipated (relative to other PMAs identified).	High level of benefit anticipated (i.e., streamflow depletion reversal is expected to be significant).
	Frequency	One-time benefit expected	PMA expected to provide benefit on more than one occurrence.	Benefits expected to occur repeatedly.
	Duration	Only short-term benefits expected (1-2 years)	Benefits expected over 2 to 5 years.	Benefits expected to occur over the long term (>5 years)
Completeness		No planning or studies have been completed, required permitting and funding sources have not been identified.	Some planning or studies have been completed, required permitting and funding sources may be identified and/ or secured.	Plans or studies have been completed, permitting has been secured, project is funded.
Complexity		Requires little planning and design, labor or materials to implement	Requires some planning, design and/or some labor or materials to implement.	Requires significant planning, design and/or significant labor or material to implement
Cost		Low cost or funding has been secured.	Mid-range cost and/or potential funding sources identified.	High cost and / or funding sources have been identified.

Uncertainty		Unproven technology or mechanism, legal authority unclear or no legal authority, anticipated difficulty obtaining required permits for project implementation.	Proven technology may be unproven in Basin setting or conditions), and/ or modelled results show an expected benefit, legal authority exists, and permits are anticipated to be attainable.	Proven technology and/or modelled results show an expected benefit, clear legal authority and required permitting is attainable.
Acceptability		Low or no support from stakeholders.	Medium support or desirability from stakeholders.	Strong support from stakeholders.

Table 2: Shasta Valley GSP PMA prioritization table template

Shasta Valley GSP Proposed List of Projects and Management Actions																				
											Evaluation Criteria and Score									
			Relevant Sustainability Indicators Affected								Effectiveness									
Tier	**Project Name**	**Lead Agency**	**Groundwater Levels and Storage**	**Groundwater Quality**	**Land Subsidence**	**SW & GW Interconnection**	**Status**	**Timetable / Circumstances for Initiation**	**Physical Benefit (i.e., stream depletion reversal)**	**Anticipated Benefits**	**Frequency**	**Duration**	**Completeness**	**Complexity**	**Cost**	**Uncertainties**	**Acceptability/ Support**	**Total/ Ranking**		
Tier II Projects (PMAs Planned for Near Term Implementation 2022-2027)																				
II	Data Gaps and Data Collection	GSA	•	•		•	Active	Active												
II	Aquifer Characterization Analysis	GSA, TBD	•			•	Conceptual Phase	TBD												
II	Avoiding Significant Increase of Total Net Groundwater Use from the Basin	GSA, County of Siskiyou	•				Conceptual Phase	TBD												

II	Conservation Easements	TBD				•	Planning phase	Expected within 5 years.										
II	Upslope Water Yield Projects	TBD				•	Planning phase	TBD										
II	Habitat Improvement in Shasta Watershed	GSA, TBD				•	Planning phase	TBD										
II	Instream Flow Leases	GSA, TBD				•	Planning phase	TBD										
II	Irrigation Efficiency Improvements	GSA, UCCE	•				Planning phase	TBD										
II	Juniper Removal	GSA, USFS, TBD	•				Conceptual phase	TBD										
II	Public Outreach	GSA					Planning phase	February 2022										
II	Reporting of Pump Volumes	GSA, TBD	•				Conceptual phase	TBD										
II	Voluntary Managed Land Repurposing	GSA, TBD	•				Conceptual phase	TBD										
II	Well Inventory Program	GSA				•	Planning phase	TBD										

Tier III Projects (PMAs with potential implementation in 2027-2042)																		
III	Alternative, Lower ET crops	GSA, UCCE, TBD	•				Conceptual phase	TBD										
III	MAR & ILR	GSA	•			•	Planning phase	TBD										
III	Shasta Recharge Pilot Project	GSA, TBD	•			•	Conceptual phase	TBD										
III	Strategic Groundwater Pumping Restriction	GSA	•			•	Conceptual phase	TBD										
III	Reservoirs	TBD	•			•	Conceptual phase	TBD										
III	Coordinated Shasta Valley Irrigation Mangement	SSWD or RCD				•	Conceptual phase	TBD										

Appendix 5-B Annual Reporting Template

This appendix presents an example template for annual reporting. Use of this appendix is intended as an example only and is not intended to be specific to the Basin. Modification will be required based on specifics outlined in the Basin's Groundwater Sustainability Plan.

SMC Tracker: A web dashboard to support GSP annual reporting with centralized monitoring, modeling, and data access

Contents

Introduction

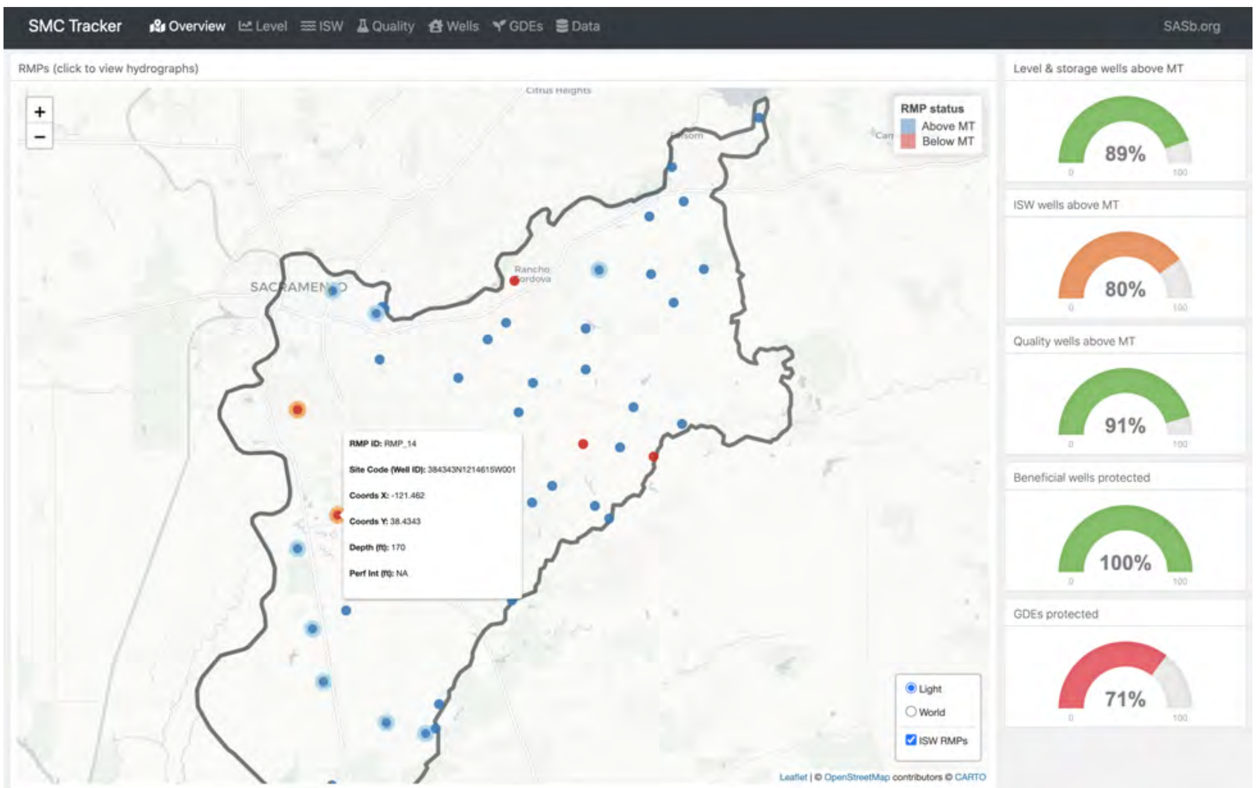
Annual reporting for SGMA requires monitoring at representative monitoring points (RMPs), analysis of potential impacts to beneficial users, evaluation of physical conditions in the basin to sustainable management criteria (SMC), and submission of data to the State. Data is collected different ways and at different sampling frequencies–often by multiple agencies and consulting firms–and the analysis, storage, reporting, and sharing of this information introduces friction into annual reporting, compliance assessment, and decision making. The need for streamlined annual reporting solutions is especially acute during severe drought where rapid access to information to guide critical decision making is paramount.

We propose a solution called **SMC Tracker**: a web-based data reporting and SMC tracking dashboard that integrates RMP monitoring data with assessments to beneficial users in automated interactive visualizations. This dashboard will summarize groundwater conditions in the basin, integrate data and models used in the annual report, and provide a central hub for tracking SMC in near-real time. Users will be able to visualize all RMPs at a glance, drill down into monitoring data collected at each RMP, and use summary panels to rapidly assess "basin vitals" that show if the basin has identified significant and unreasonable results for a given sustainability indicator and/or beneficial users of groundwater. And finally, users will be able to export data for analysis and in forms that directly comply with DWR submission criteria for a painless, drag-and-drop solution.

Overview page

The SMC Tracker main page provides an overview of basin sustainability at a glance. All RMPs for groundwater level and storage are shown. Users can:

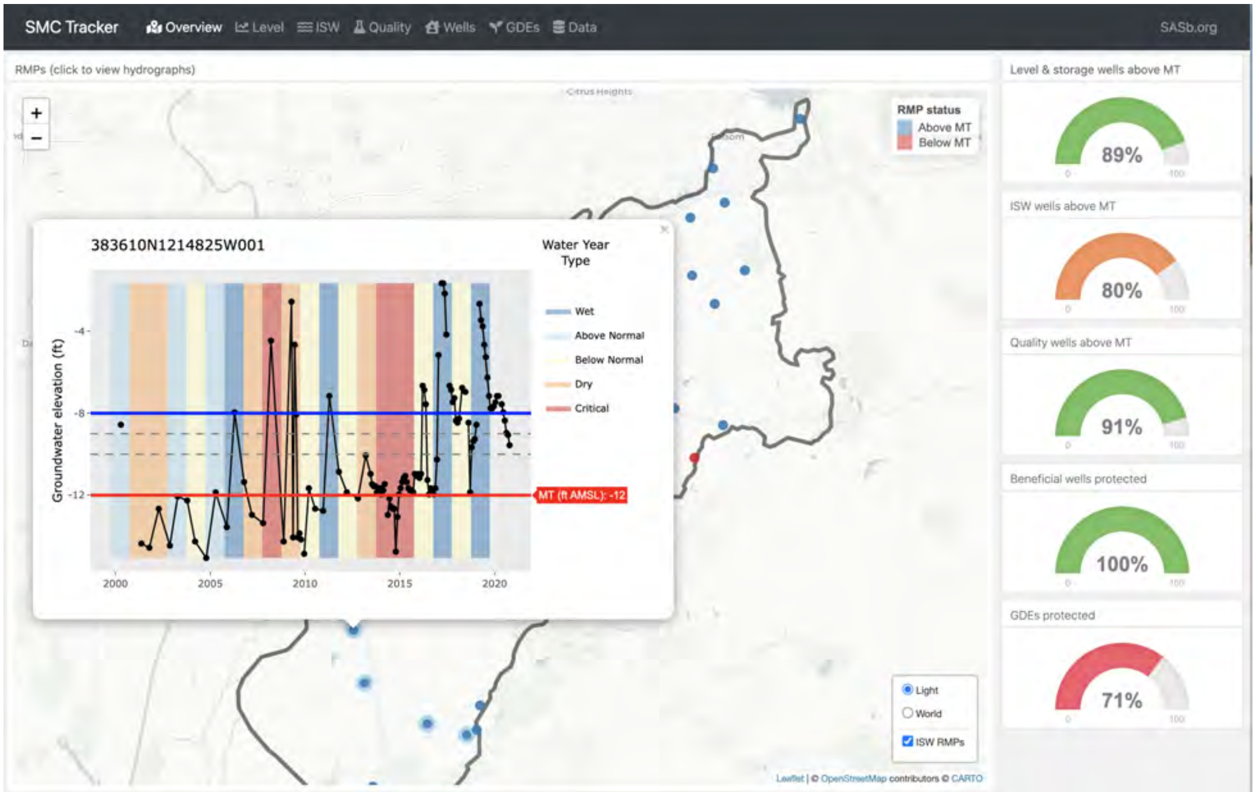
- hover over points to view site metadata
- use the legend to quickly identify RMPs that are above or below their MT
- use the legend to toggle between groundwater level, storage, and ISW monitoring points
- toggle basemaps to view satellite imagery
- click points to expand interactive timeseries plots that allow the user to zoom, pan, and export plots. Plots show:
  - water year type
  - historical data through the present day
  - SMC (minimum thresholds, measurable objectives, and interim milestones)



The lefthand sidebar shows “odometer” gauges which represent critical sustainability criteria, including:

- percentage of groundwater level and storage RMPs above the MT
- percentage of ISW RMPs above the MT
- percentage of water quality wells above the MT
- percentage of shallow wells protected at current groundwater levels
- percentage of GDEs protected

Colors of the gauges can be configured such that when the basin dips into “trigger” or “undesirable result” territory, the gauges show this.



Groundwater level page

The “Groundwater level” pageis one example of many other pages where users can drill down into aggreagted data for a particular sustainability indicator. Whereas in the “Overview” page, users interact with RMPs spatially and click on individual RMPs to view groundwater levels, on the “Groundwater level” page, all groundwater levels are shown in a single interactive visualization.

This page will be configured to automatically incorporate data as is it collected in a standard form by agencies and consultants. In the event that data is collected via telemetry, this page can be configured to auto-update at a regular time interval (e.g., daily) so that users can always view the most up-to-date data. Features include:

- a right hand legend that can be clicked to toggle individual points on and off or highlight one timeseries line
- interactive zoom and pan to inspect small details in the timeseries data
- two tabs that render the data in terms of water surface elevation (ft AMSL) and depth to groundwater (ft below land surface)
- groundwater level data on hover including the site ID, the date, and the groundwater level
- a button to export the current state of the plot to a .png file which can be included in a presentation or a report

Other pages

Just as the "Groundwater level" page allows the user to drill down into groundwater level data, users needs information on other Sustainability indicators that may include interconnected surface water (ISW), groundwater quality, land subsidence, and/or seawater intrusion. Moreover, key beneficial users may include shallow wells and GDEs, and the user may need information on impacts to these users suggested by the latest monitoring data and modeling. "Other" pages accomplish this, and are listed in the header from left to right. Here we include examples for ISW, groundwater quality, wells, and GDEs. Content on these pages will be developed to address basin-specific needs.

Data access

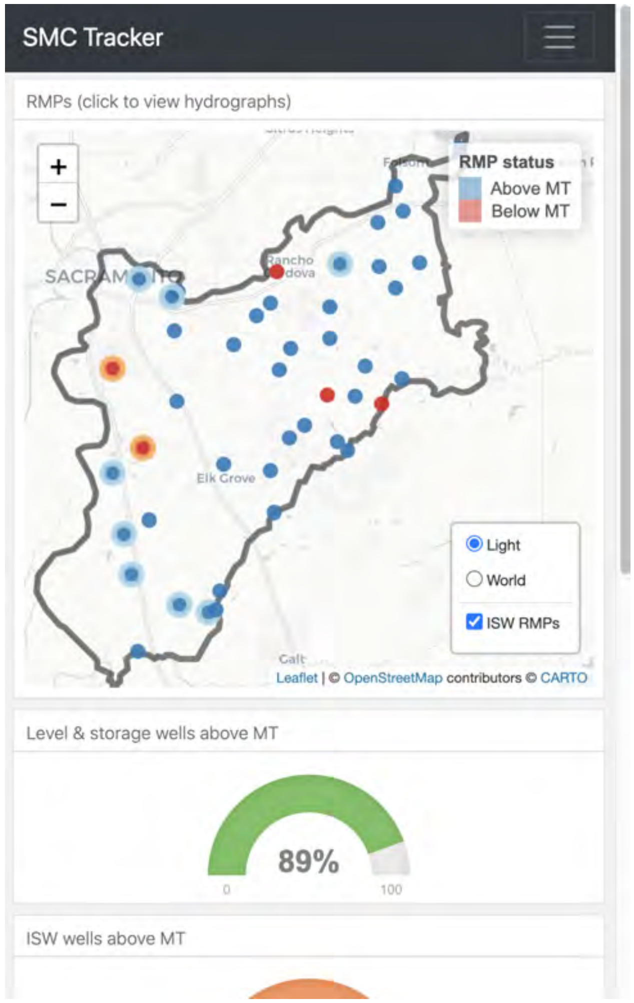
Agencies and consultants may require data from time to time, and as new data is made available, it must be centralized and distributed. SMC Tracker accomplishes this centralization and distribution on a "Data" page with links to the most up-to-date data. Also on this page are download links to data in DWR annual reporting templates for fast, painless, drag-and-drop solutions to annual reporting requirements.

Additional features

Dashboards are highly customizable and additional features may be added on an ad-hoc basis.

Mobile display

SMC Tracker is built with modern software optimized for mobile display. It looks great on smartphones and tablets.



Near-real time monitoring

Custom data extraction for any continuous monitoring sites can be integrated into SMC Tracker so that GSAs can track groundwater levels and other sustainability indicators in near-real-time (e.g., following a recharge project, or during a severe drought). Receiving automated information quickly and in a visual format can help focus priorities for working groups, and allow consultant teams access to standardized data as soon as it is available so data-driven management actions can be rapidly planned and executed.

Password protection and data privacy

Depending on GSA needs, dashboards can be made public or private. If dashboards are made private, they will sit behind password-protected walls for authorized users.

All data will be stored and protected on private servers configured by LWA.

Conclusion

Once developed, SMC defined in GSPs must be monitored for the identification of significant and unreasonable results. Monitoring at RMPs occurs throughout the year and is reported to DWR annually. Data collection, analysis, reporting, and sharing all present friction in the annual reporting and compliance process. These challenges are obviated by centralizing all monitoring data in one place to visualize near-real-time groundwater conditions in the basin and how they measure up to SMC. The SMC Tracker tool will aid agencies and consultants by providing access to monitoring data, SMC tables, and standardized excel data export sheets that can be dragged and dropped into DWR's online reporting system.

Appendix 5-C Financial Analysis for GSP Implementation

SISKIYOU COUNTY FLOOD CONTROL AND WATER CONSERVATION DISTRICT GROUNDWATER SUSTAINABILITY AGENCY

BUTTE VALLEY, SCOTT VALLEY, AND SHASTA VALLEY BASINS

FUNDING OPTIONS TECHNICAL MEMORANDUM

JULY 2021

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Steve Mains, Grenada Irrigation District
Robert Moser, Municipal/City
Lisa Faris, Big Springs Irrigation District
Justin Sandahl, Shasta River Water Users Association

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INTRODUCTION AND EXECUTIVE SUMMARY

INTRODUCTION AND GOALS

The Siskiyou County Flood Control and Water Conservation District (District) was enacted in 1957 to provide for the control and conservation of flood and storm waters and the protection of watercourses, watersheds, public highways, life and property damage or destruction from such waters; to provide for the acquisition, retention, and reclaiming of drainage, storm, flood, and other waters; to save, conserve, and distribute such waters for beneficial use within the District boundaries, and to replenish and augment the supply of water in natural underground reservoirs. The boundaries of the District coincide with the County, and the Siskiyou County Board of Supervisors serve as the Board of Directors (Board) of the Flood and Water Conservation District; however, the District is a separate legal entity from the County, with independent rights and limited powers set forth in its originating act.

The Board passed a resolution on April 4th, 2017 to serve as the Groundwater Sustainability Agency (GSA or Agency) for the Butte Valley, Scott Valley, and Shasta Valley Basins (basins) as required by the Sustainable Groundwater Management (SGMA) Act of 2014.

In the Winter of 2018, the Agency engaged a consultant team led by Larry Walker Associates (LWA Team) to develop the Groundwater Sustainability Plan in compliance with the SGMA for the three basins.

A Groundwater Sustainability Plan (GSP) for each of the three basins includes goals and recommendations, as well as the associated costs required for its implementation. Accordingly, the purpose of this technical memorandum is to describe a path forward to fund the GSP's implementation. It should be noted that SGMA and its associated requirements and goals are quite new, and there is not a clear, well-tested path forward to fund GSP implementations. Rather, the funding efforts for GSP implementation in the three basins need to be carefully crafted for local conditions, preferences, and politics – as well as being flexible, creative, and reactive.

The GSA has been initially funded by existing general funds and grants. The general direction from the GSA Board of Directors in regard to funding the GSP implementation can be summarized as:

- GSA expenses should be well-controlled
- Funding strategy needs to be locally viable and right-sized
- Metering of wells is not desired

EXECUTIVE SUMMARY

Following is a brief summary of the findings and recommendations contained within this Technical Memo, including a summary of the GSP implementation costs, potential funding mechanisms, and recommendations for funding of the implementation.

REVENUE NEEDED FOR GROUNDWATER SUSTAINABILITY PLAN IMPLEMENTATION

The GSP makes numerous implementation recommendations, including annual operations and maintenance as well as capital projects. The associated costs for these tasks, including the low range and high range, are summarized in Tables 1, 2, and 3 below. The total estimated annual costs for all three basins combined ranges from $438,750 to $747,500.

TABLE 1 – SUMMARY OF TOTAL ESTIMATED ANNUAL COSTS FOR BUTTE VALLEY BASIN

Summary	Annual Budget	
	Low Range	**High Range**
Operations and Maintenance	$120,000	$210,000
Grant Writing	$15,000	$20,000
Capital Projects	TBD	TBD
Total	**$135,000**	**$230,000**

TABLE 2 – SUMMARY OF TOTAL ESTIMATED ANNUAL COSTS FOR SCOTT VALLEY BASIN

Summary	Annual Budget	
	Low Range	**High Range**
Operations and Maintenance	$120,000	$210,000
Grant Writing	$15,000	$20,000
Capital Projects	TBD	TBD
Total	**$135,000**	**$230,000**

TABLE 3 – SUMMARY OF TOTAL ESTIMATED ANNUAL COSTS FOR SHASTA VALLEY BASIN

Summary	Annual Budget	
	Low Range	**High Range**
Operations and Maintenance	$150,000	$262,500
Grant Writing	$18,750	$25,000
Capital Projects	TBD	TBD
Total	**$168,750**	**$287,500**

It is anticipated that capital projects will be primarily grant-funded. More detail is provided in Section II., below.

FUNDING APPROACHES AND OPTIONS FOR GSP IMPLEMENTATION

There are a variety of funding approaches, each with pros and cons, and most likely a portfolio of various approaches will prove optimal. The likely most optimal funding mechanisms are listed below:

Best Options

- Existing Revenue Sources
- Grants and Loans
- Regulatory Fees

If additional revenue is needed:

- Property Related Fees – non-Balloted (*allocated to well owners*)
- Special Taxes – Balloted (allocated to all property owners within the basins or County)

Less optimal

- Property Related Fees – Balloted
- Benefit Assessments

Each funding mechanism and approach has key attributes - each of which should be considered to select the optimal funding portfolio, including:

- Flexibility of Methodology (per acre, per acre-feet pumped, per well, etc.)
- Costs of Implementation
- Revenue Potential
- Political Viability / Community Acceptance
- Legal Rigor
- Administration

ALLOCATING IMPLEMENTATION COSTS TO WELL OWNERS VERSUS PROPERTY OWNERS

If funding beyond use of existing sources, grants and regulatory fees is needed, then one of the most important considerations for the GSP's is the allocation of the GSP implementation cost between the well owners and the larger group of all property owners within the three basins, or even County-wide. Conventional wisdom suggests that the costs of the implementation of groundwater mitigation policies should be directly borne by the immediate users of the groundwater – the well owners. However, there are clear benefits to all properties and residents within a well-managed groundwater basin that provides additional, lower cost water resources. It can be argued that a community-wide funding mechanism in which all properties and/or residents pay their fair share is a more optimal approach. Both types of approaches are discussed in Section II of this technical memo.

ROADMAP FORWARD AND RECOMMENDATIONS

A summary of this Technical Memo's major recommendations for implementation includes a step sequential roadmap as summarized below:

1. Conduct community outreach regarding the GSP and its implementation
2. Pursue use of existing revenue sources, grants, and regulatory fees to fund implementation

If additional revenue is needed:

3. Conduct a public opinion survey and focused community outreach
4. Implement a property related fee or special tax

The process of establishing long-term, sustainable, comprehensive funding for GSP implementation will likely take at least 18 months to complete. More detail is provided in Section III., below.

I. DETAILED REVENUE NEEDS

ANNUAL OPERATIONS AND MAINTENANCE COSTS

The GSP includes numerous recommendations for annual operations and maintenance in support of the long-term sustainability of the three basins. The costs of these recommendations have been developed and bracketed with a low range of $120,000 per year and a high range of $210,000 for Butte Valley and Scott Valley Basins, and a low range of $150,000 per year and a high range of $262,500 for Shasta Valley Basin. These figures are detailed in Tables 4, 5, and 6 below:

Table 4 – Detailed Summary of Estimated Maintenance and Operations Costs for Butte Valley Basin

Operations and Maintenance	Annual Budget	
	Low Range	High Range
General GSA Operations	$10,000	$25,000
Annual Reporting	$15,000	$25,000
Model Maintenance	$40,000	$80,000
Monitoring	$45,000	$60,000
Future Stakeholder Engagement	$10,000	$20,000
Mediation Fund	TBD	TBD
Total	**$120,000**	**$210,000**

Table 5 – Detailed Summary of Estimated Maintenance and Operations Costs for Scott Valley Basin

Operations and Maintenance	Annual Budget	
	Low Range	High Range
General GSA Operations	$10,000	$25,000
Annual Reporting	$15,000	$25,000
Model Maintenance	$40,000	$80,000
Monitoring	$45,000	$60,000
Future Stakeholder Engagement	$10,000	$20,000
Mediation Fund	TBD	TBD
Total	**$120,000**	**$210,000**

Table 6 – Detailed Summary of Estimated Maintenance and Operations Costs for Shasta Valley Basin

Operations and Maintenance

	Annual Budget	
	Low Range	**High Range**
General GSA Operations	$12,500	$31,250
Annual Reporting	$18,750	$31,250
Model Maintenance	$50,000	$100,000
Monitoring	$56,250	$75,000
Future Stakeholder Engagement	$12,500	$25,000
Mediation Fund	TBD	TBD
Total	**$150,000**	**$262,500**

Where:

General GSA Operations includes costs to operate the GSA including supporting and facilitating Board and committee meetings, disseminating information, satisfying existing grant administrative requirements, managing contracts for tasks listed below, maintaining the website, etc.

Annual Reporting: includes costs to draft and submit all required annual reports.

Model Maintenance: includes the annual installment costs to use the models every year to test scenarios of Projects and Management Actions and to recalibrate and update the model every 5 years.

Monitoring – Interconnected Surface Water: costs are different in Shasta and Scott Valley, and they do not apply to Butte Valley. In Shasta Valley, cost includes the periodic (likely semi-annual) inspection and maintenance at 3 transects sites already fully installed and equipped - approximately 6 visits per year. For both Shasta and Scott, cost of monitoring of the wells located near the river and already equipped with continuous data is already included in the Water Level Monitoring. Further data collections for SW/GW in both Shasta and Scott will be coordinated with other partners and included in the GSP as management action.

Monitoring - Water Level: includes the periodic (likely semi-annual) inspection of water level monitoring equipment at CASGEM and DWR well sites and 10-15 additional well sites with continuous monitoring – approximately 6 visits per year and, as needed, hardware replacement.

Monitoring - Water Quality: includes the periodic sampling of water quality – approximately 10-15 samples per year.

Mediation Fund: is a placeholder for funds in support of mediation. For example, a grant program could be established for local well-owners to access capital to address compliance issues.

Future Stakeholder Engagement: Costs for future stakeholder engagement have not been included in these budgets but may be incurred.

ANNUAL CAPITAL COSTS

The GSPs include numerous recommendations for capital improvements in support of the long-term sustainability of the Basins. Most likely, these capital improvements will be implemented if and only if significant grant funding is available. However, there are often associated costs with grants including grants writing and grants administration.

The costs of these recommendations have been developed and bracketed with a low range of $10,000 per year and a high range of $40,000, and are detailed in Tables 7, 8, and 9 below:

TABLE 7 – DETAILED SUMMARY OF ESTIMATED MAINTENANCE AND OPERATIONS COSTS FOR BUTTE VALLEY BASIN

Capital Projects	Annual Budget	
	Low Range	High Range
Grant Writing	$15,000	$20,000
Annual Grant Administration	TBD	TBD
Capital Projects Costs	TBD	TBD
Total	**$15,000**	**$20,000**

TABLE 8 – DETAILED SUMMARY OF ESTIMATED MAINTENANCE AND OPERATIONS COSTS FOR SCOTT VALLEY BASIN

Capital Projects	Annual Budget	
	Low Range	High Range
Grant Writing	$15,000	$20,000
Annual Grant Administration	TBD	TBD
Capital Projects Costs	TBD	TBD
Total	**$15,000**	**$20,000**

TABLE 9 – DETAILED SUMMARY OF ESTIMATED MAINTENANCE AND OPERATIONS COSTS FOR SHASTA VALLEY BASIN

Capital Projects

	Annual Budget	
	Low Range	**High Range**
Grant Writing	$18,750	$25,000
Annual Grant Administration	TBD	TBD
Capital Projects Costs	TBD	TBD
Total	**$18,750**	**$25,000**

Where:

Grant Writing: includes periodic grant writing primarily for capital projects.

Annual Grant Administration: includes costs satisfying annual grant administrative requirements including reporting and budget management.

TOTAL ANNUAL IMPLEMENTATION COSTS

The total costs of these recommendations have been developed and bracketed with a low range of $90,000 per year and a high range of $182,500, and are detailed in Tables 10, 11, and 12 below:

TABLE 10 – SUMMARY OF TOTAL ESTIMATED COSTS FOR BUTTE VALLEY BASIN

Summary

	Annual Budget	
	Low Range	**High Range**
Operations and Maintenance	$120,000	$210,000
Grant Writing	$15,000	$20,000
Capital Projects	TBD	TBD
Total	**$135,000**	**$230,000**

TABLE 11 – SUMMARY OF TOTAL ESTIMATED COSTS FOR SCOTT VALLEY BASIN

Summary

	Annual Budget	
	Low Range	**High Range**
Operations and Maintenance	$120,000	$210,000
Grant Writing	$15,000	$20,000
Capital Projects	TBD	TBD
Total	**$135,000**	**$230,000**

TABLE 12 – SUMMARY OF TOTAL ESTIMATED COSTS FOR SHASTA VALLEY BASIN

Summary

	Annual Budget	
	Low Range	**High Range**
Operations and Maintenance	$150,000	$262,500
Grant Writing	$18,750	$25,000
Capital Projects	TBD	TBD
Total	**$168,750**	**$287,500**

Shasta Valley Basin costs: Total estimated costs for the Shasta Valley Basin are generally estimated to be 25% higher than for Butte Valley and Scott Valley.

II. EVALUATION OF POTENTIAL FUNDING MECHANISMS

INTRODUCTION TO AVAILABLE POTENTIAL FUNDING MECHANISMS OPTIONS IN CALIFORNIA

Existing California law provides a relatively finite number of mechanisms for local public agencies to reliably generate revenue to provide services. In many cases, a portfolio approach of several of these mechanisms will be optimal. Also, it is crucial to work closely with legal counsel on the implementation of all funding mechanisms to ensure legal compliance. This section provides a discussion of the mechanisms best suited to provide funding for groundwater management services recommended in the Agency GSP, including, but not limited to, the following:

Best Options

- Existing Revenue Sources
- Grants and Loans
- Regulatory Fees

If Additional Revenue is Needed

- Property Related Fees – non-Balloted (*allocated to well owners*)
- Special Taxes – Balloted (allocated to all property owners within the basin)

Less Optimal

- Property Related Fees – Balloted
- Benefit Assessments

<u>Existing Revenue Sources and Grants Are Likely the Preferred Approach</u>
Of course, it is recommended that the Agency rigorously explore all opportunities to fund the recommended groundwater management services through existing revenue sources and grants, eliminating the need for an additional allocation for well owners or all basin property owners. However, there are likely not sufficient available existing revenue sources to support GSP implementation, especially over the long term. See the discussion "Grants and Loans" below.

<u>Regulatory Fee Should Be Imposed</u>
Regulatory fees are an excellent source of reimbursement of actual costs for inspections, plan checks, etc., and should be imposed.

<u>However, If Additional Revenue is Needed</u>
If additional revenue is need beyond the amount that can be generated by existing revenue sources, there are two primary approaches:

Revenue Generated from	Optimal Revenue Mechanism
Well Owners	Property Related Fee (non-balloted)
All Property Owners	Special Tax (balloting is required)

Additional Funding from Well Owners or Community Property Owners

One unique challenge, and opportunity, associated with implementation of a funding mechanism for groundwater sustainability management is the decision regarding how costs will be allocated between well owners and the overall community of property owners. Generally speaking, the development of the Sustainable Groundwater Management Act was based upon the assumption that the allocation of costs would be primarily, perhaps exclusively, assigned to well owners, with some consideration of *de minimis* ground water users. However, there are clear benefits to all properties and residents within a basin, or even the entire county, with well managed groundwater resources. It can be argued that a community-wide funding mechanism in which all properties and/or residents pay their fair share is a more optimal approach.

Local political forces, often concentrated with well owners, may dictate a preference for allocating the GSP implementation costs more broadly to all property owners within the basins or county, but it should be noted that California law requires that special taxes, which would be the mechanism required for an allocation on all basins or county property owners, requires a balloting. Balloted revenue mechanisms are arguably more legally rigorous, and legal challenges to voter-approved fees have rarely been successful. However, the balloting requirement significantly limits the total revenue that may be generated, as it is limited by the political "willingness to pay" of the local voters or property owners. Ballotings are also expensive and politically risky. For that reason, non-balloted approaches are typically preferable, and do not have the same apparent political limitation on the amount of revenue that can be generated, but political realities and influences are still significant.

As the Agency determines its funding strategy, it should take an in-depth look at many attributes, including flexibility of methodology (per acres, per water quantity, per well, per parcel, etc.), costs of implementation, revenue generation potential, political viability, legal rigor, administrative burden, etc., as described below.

EXISTING REVENUE SOURCES

If the Agency can fund the groundwater management services with existing revenue sources, that is certainly optimal. However, even if this is possible in the short term, it is likely not possible very far into the future.

GRANTS AND LOANS

Grant funding is highly desirable, as it eliminates/lessens the need to generate revenue directly from well owners and/or the broader community of property owners. Grant funding is typically available for capital projects but can be available for other programmatic activities, including maintenance and operations. It is worth noting that grants often come with other funding requirements such as matching funds or requirements for post-project maintenance. For these reasons, an underlying revenue stream is very important to have access to leverage these opportunities.

California has a limited number of State grants and programs which provide funding opportunities for groundwater sustainability. The primary grants in support of SGMA are described below (*from https://water.ca.gov/Work-With-Us/Grants-And-Loans/Sustainable-Groundwater*):

"The SGMA Grant Program is funded by Proposition 68 and Proposition 1. To date, the California Department of Water resources (DWR) has awarded $139.5 million in three rounds of planning grants for development of Groundwater Sustainability Plans (GSPs) and related projects. All Proposition 1 funds have been awarded, with about $103 million now remaining to be awarded using Proposition 68 funds. Additional information can be found below.

PROPOSITION 1, CHAPTER 10: GROUNDWATER SUSTAINABILITY

On November 4, 2014, California voters approved Proposition 1, which authorized $100 million be made available for competitive grants for projects that develop and implement groundwater plans and projects in accordance with groundwater planning requirements established under Division 6, commencing with §10000, Water Code §79775. DWR completed two grant solicitations for planning grants.

PROPOSITION 68, CHAPTER 11.6: REGIONAL SUSTAINABILITY FOR DROUGHT AND GROUNDWATER, AND WATER RECYCLING

On June 5, 2018, California voters approved Proposition 68, which amended the Water Code to add, among other articles, §80146, authorizing the Legislature to appropriate funds for competitive grants for proposals that:

- Develop and implement groundwater plans and projects in accordance with groundwater planning requirements.
- Address drought and groundwater investments to achieve regional sustainability for investments in groundwater recharge with surface water, stormwater, recycled water, and other conjunctive use projects, and projects to prevent or cleanup contamination of groundwater that serves as a source of drinking water."

The Agency should plan to submit an application for the next round of Proposition 68 funding.

FUTURE STATE GRANT OPPORTUNITIES

Since all of Proposition 1 funding has been awarded and the remaining portion of Proposition 68 funding (just over $100 million) will be awarded over the next several years, there will likely be a shortfall of grant funding for GSP implementation in the near future. Unfortunately, there are not any large statewide bond measures (with grant opportunities) on the political horizon, but the Agency should continue to track such efforts. Also, future bond measures will likely emphasize funding for multi-benefit projects and programs that cross traditional organizational structures, and the Agency should also consider coordinating with other affected local agencies to put forth larger and potentially more competitive grant applications.

Proposition 68

The final Proposition 68 Implementation Proposal contains $103 million in available funding. DWR has released Round 1 draft funding recommendations, allocating $26 million to high priority basins.[1] Of the remaining $77 million, $15 million will be reserved for Underrepresented Communities, leaving $62 million available for general awards in Round 2 Implementation.[2]

Round 2 Grant Solicitation will open in spring of 2022, with final awards disbursed in fall of that year. Awards will be allocated to medium and high priority basins that have adopted a GSP that has been deemed complete by DWR. Grant amounts must be between $2 million and $5 million, with a 25% locally matched cost share requirement. A cost share waiver is available for eligible projects proportionate to the degree that they serve Underrepresented Communities. Any local cost share cannot have contributed to other grant awarded projects. Project expenses must be incurred after January 31, 2022, the due date for medium and high priority basin GSPs. The state encourages applicants to work with the stakeholders and other non-member agencies in their basin that have potential activities and tasks that are complimentary to the overall project. Eligible projects are defined by Proposition 68 Chapter 11.6 and include sustainability measures such as groundwater recharge and contamination prevention.

OTHER TYPES OF GRANTS

The Agency should work to identify applicable Federal grants, if any, and compete, in coordination with other affected local agencies for funding. Also, the Agency should consider working with local elected officials to pursue provisions that direct approved funds to be spent on specific projects, often called earmarks.

Grants from non-profits, foundations, high-net-worth individuals, and other stakeholders should be considered, especially with an emphasis on environmental sustainability.

REQUIRED DOCUMENTS FOR GRANTS

- Grant applications meeting specific requirements.

FLEXIBILITY OF METHODOLOGY

Use of grant funding is well-specific in the specific grant.

REVENUE GENERATION POTENTIAL

Amount of grant funding is well-specific in the specific grant.

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1 Proposition 68 SGM Grant Program's Implementation – Round 1 Draft Award List (ca.gov)

2 https://www.grants.ca.gov/grants/sustainable-groundwater-management-sgm-grant-programs-proposition-68-implementation-round-2/

ADVANTAGES

- Does not require cost to be allocated to local well owners or property owners.
- Revenue generation can be sufficient to offset significant costs of certain key activities.
- Legally rigorous as long as grants are expended on eligible activities.

CHALLENGES

- Provides funding for a limited time period only – difficult for long term planning solution.
- Awarded through a highly competitive process.
- Often requires matching local funds, tends to be focused on capital expenses, and are often narrowly focused in terms of scope and services.

REGULATORY FEES

Public agencies throughout California often reimburse themselves for the costs of site inspections, permits, plan checks, plan reviews, and associated administrative and enforcement activities using regulatory fees. These fees are often approved and published as part of a "Master Fee Schedule," and are often collected as part of review for approval process. This approach can assist in significantly reducing the GSA's financial burden.

Proposition 26, approved by California voters in 2010, tightened the definition of regulatory fees. It defined a special tax to be *"any levy, charge, or exaction of any kind imposed by a local government"* with certain exceptions. Pursuant to law, all special taxes must be approved by a two-thirds vote of the electorate.

Regulatory fees are thus defined through the cited exceptions. The pertinent exception is, "a charge imposed for the reasonable regulatory costs to a local government for issuing licenses and permits, performing investigations, inspections, and audits, enforcing agricultural marketing orders, and the administrative enforcement and adjudication thereof." The other pertinent exception is, "assessments and property-related fees imposed in accordance with the provisions of Article XIIID."

The Proposition goes on to state that, "the local government bears the burden of proving by a preponderance of the evidence that a levy, charge, or other exaction is not a tax, that the amount is no more than necessary to cover the reasonable costs of the governmental activity, and that the manner in which those costs are allocated to a payor bear a fair or reasonable relationship to the payor's burdens on, or benefits received from, the governmental activity."

Proposition 26 provides the primary guidance for the funding of the Agency's plan review and inspection fees as regulatory fees. Moreover, Section 10730 of the California Water Code, (which corresponds well with Proposition 26 guidance) stipulates that these fees can be used "to fund the costs of a groundwater sustainability program, including, but not limited to, preparation, adoption, and amendment of a groundwater sustainability plan, and investigations, inspections, compliance assistance, enforcement, and program administration, including a prudent reserve." Hence, it seems that the intent of this section is that the development of the plan can be financed through regulatory fees (and this has been widely agreed upon) as well as some, but not all, GSP implementation activities. In any case, Water Code Section 10730 includes several unique requirements that should be carefully followed when implementing regulatory fees for GSP implementation.

REGULATORY FEE IMPLEMENTATION PROCESS

Regulatory fees are relatively easy and straightforward to implement. Neither a public noticing nor a balloting is required. Typically, a public agency will engage a specialized consultant to conduct a Fee Study. This Study will present findings to meet the procedural requirements of Proposition 26, which require analysis and support that:

1. The levy, charge, or other exaction is not a tax; and
2. The amount is not more than necessary to cover the reasonable cost of the governmental activity; and
3. The way those costs are allocated to a payor bears a fair or reasonable relationship to the payor's burden on, or benefits received from, the governmental activity.

Additionally, case law has provided further clarification of these substantive requirements, that:

1. The costs need not be "finely calibrated to the precise benefit each individual fee payor might derive."
2. The payor's burden or benefit from the program is not measured on an individual basis. Rather, it is measured collectively, considering all fee payors.
3. That the amount collected is no more than is necessary to cover the reasonable costs of the program is satisfied by estimating the approximate cost of the activity and demonstrating that this cost is equal to or greater than the fee revenue to be received. Reasonable costs associated with the creation of the regulatory program may be recovered by the regulatory fee.

REQUIRED DOCUMENTS FOR REGULATORY FEES

- A Fee Study, reviewed by legal counsel and adopted by the governing authority.

FLEXIBILITY OF METHODOLOGY

Legal requirements and industry practice limit these fees to recovery of costs associated with eligible activities (e.g., inspections, permits, etc.) The Agency is advised to work closely with legal counsel and review Proposition 26 and Water Code Section 10730 requirements.

REVENUE GENERATION POTENTIAL

Full recovery of costs associated with eligible activities (e.g., inspections, permits, etc.)

ADVANTAGES

- Quick and inexpensive to implement. No noticing nor balloting is required.

- Revenue generation is sufficient to offset significant costs of certain key activities.
- Legally rigorous as long as fees are for eligible activities.
- Efficient administration.

CHALLENGES

- Very limited revenue generation potential
- Potential for "push back" from affected well owners against fees.
- Potential legal scrutiny if fee covers non-eligible activities.
- Do not typically apply to infrastructure operations and capital costs.

IF ADDITIONAL REVENUE IS NEEDED

To be clear, this technical memorandum is recommending that (if the costs of GSP implementation necessitate it) the Agency consider either a Non-balloted Property Related Fee on Well Owner parcels or a Special Tax on all property owners in the basin, but likely not both, unless the financial need is very significant.

PROPERTY-RELATED FEE – (NON- BALLOTED) ON WELL OWNERS

Property-related fees were first described in 1996's Proposition 218, (which is manifested as Section 6 of Article XIII D of the California Constitution) and are commonly used today to fund water, sewer, solid waste and even storm drainage. They are most commonly referred to as a "water charge or a "sewer charge," etc., but are technically a property-related fee.

Proposition 218 imposes certain procedural requirements for imposing or increasing property related fees. There are two distinct steps: 1.) a mailed noticing of all affected property owners (well owners in this case) and 2.) a mailed balloting on all affected property owners requiring a 50% approval for adoption.

A REALLY IMPORTANT EXEMPTION ELIMINATES THE BALLOTING REQUIREMENT

Proposition 218 goes on to exempt fees for water, sewer and refuse collection from the second step – the balloting. Hence, a property-related fee imposed on well owners' properties would be exempt from the balloting requirement. This is very significant because it reduces costs and political risk and lessens willingness-to-pay limitations.

California Water Code Provides Additional Clarity in 10730.2
California Water Code, Division 6., Part 2.74., Chapter 8. Financial Authority [10730 - 10731] provides considerable direction and authority to local governments tasked with groundwater sustainability regarding property-related fees.

In particular, Section 10730.2 (c) in the water code states:

"Fees imposed pursuant to this section shall be adopted in accordance with subdivisions (a) and (b) of Section 6 of Article XIII D of the California Constitution."

Section 6 of Article XIII of the California Constitution describes the specific requirements of the implementation of a property related fee, and most importantly, refers to subdivision (a) as the noticing requirement, (b) as the limitations on fees and services, and subdivision (c) as the balloting requirement. Hence, by omission of (c) in Section 10730.2, balloting is not required for property related fees for groundwater sustainability.

PROPERTY RELATED FEE IMPLEMENTATION PROCESS

As described above, only the first step of the two-step process applies to property related fees in this context. That step is the noticed public hearing. Once the Agency has determined the fees they wish to impose, they must mail a written notice to each affected property owner at least 45 days prior to the public hearing. During that time, and up until the conclusion of the hearing, any affected property owner may file a written protest opposing the proposed fees. If the owners of a majority of the affected parcels file a written protest, the agency cannot impose the fee (known as a “majority protest”). If a majority protest is not formed, the agency may impose the fees.

Also, Section 10730.2 of the California Water Code includes several unique requirements that should be carefully followed when implementing property related fees for GSP implementation.

REQUIRED DOCUMENTS FOR A PROPERTY RELATED FEE

- Mailed Notices of Rate Proposal/Opportunity to Protest/Public Hearing.
- Fee Report and Presentation for Public Hearing.
- Report to Governing Board (assumes < 50% protest).
- Ordinance or Resolution Adopting Fees (assumes >50% support).

FLEXIBILITY OF METHODOLOGY

Long standing use of property related fees for water charges support relatively flexible use of this approach to fund a wide range of GSP implementation activities.

Section 10730.2 of the California Water Code lists potential uses as:

(1) Administration, operation, and maintenance, including a prudent reserve.
(2) Acquisition of lands or other property, facilities, and services.
(3) Supply, production, treatment, or distribution of water.
(4) Other activities necessary or convenient to implement the plan.

This section also specifies that “fees imposed pursuant to this section may include fixed fees and fees charged on a volumetric basis, including, but not limited to, fees that increase based on the quantity of groundwater produced annually, the year in which the production of groundwater commenced from a groundwater extraction facility, and impacts to the basin.”

Other ideas to consider include:

- Parcel-based Administration Fee,
- Remediation Fee for over-pumping.

- Augmentation Fee on over users to pay to import water.

REVENUE GENERATION POTENTIAL

Two potential revenue methodologies are modelled below based upon the use of a property related fee. Tables 13, 14, and 15 model rates and revenue generated using a hypothetical "flat" annual rate for each type of well. Most notably, this approach relies on "estimated usage" based upon attributes such as land use, affected acreage, etc., and does not rely on use of metered extraction amount. (Number and types of wells is approximate):

TABLE 13 – MODEL OF ESTIMATED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON WELLS IN BUTTE VALLEY BASIN

Basin Wells

	Approx. Number	Low Range		High Range	
		Rate	**Revenue**	**Rate**	**Revenue**
Agricultural	34	$3,000.00	$102,000	$5,300.00	$180,200
Industrial	0	$3,000.00	$0	$5,300.00	$0
Municipal	7	$3,000.00	$21,000	$5,300.00	$37,100
Domestic	73	$125.00	$9,125	$150.00	$10,950
Other (Monitoring, injection, etc.)	24	$125.00	$3,000	$150.00	$3,600
Total	**138**		**$135,125**		**$231,850**
	Revenue Goals:		$135,000		$230,000

TABLE 14 –MODEL OF ESTIMATED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON WELLS IN SCOTT VALLEY BASIN

Basin Wells

	Approx. Number	Low Range		High Range	
		Rate	**Revenue**	**Rate**	**Revenue**
Agricultural	88	$1,100.00	$96,800	$2,000.00	$176,000
Industrial	0	$1,100.00	$0	$2,000.00	$0
Municipal	7	$1,100.00	$7,700	$2,000.00	$14,000
Domestic	336	$75.00	$25,200	$100.00	$33,600
Other (Monitoring, injection,etc.)	86	$75.00	$6,450	$100.00	$8,600
Total	**517**		**$136,150**		**$232,200**
	Revenue Goals:		$135,000		$230,000

TABLE 15 –MODEL OF ESTIMATED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON WELLS IN SHASTA VALLEY BASIN

Basin Wells

	Approx. Number	Low Range		High Range	
		Rate	**Revenue**	**Rate**	**Revenue**
Agricultural	139	$850.00	$118,150	$1,500.00	$208,500
Industrial	8	$850.00	$6,800	$1,500.00	$12,000
Municipal	10	$850.00	$8,500	$1,500.00	$15,000
Domestic	885	$30.00	$26,550	$50.00	$44,250
Other (Monitoring, injection, etc.)	206	$30.00	$6,180	$50.00	$10,300
Total	**1,248**		**$166,180**		**$290,050**
	Revenue Goals:		$168,750		$287,500

Also, a property related fee could be established based upon water drawn out of the basin (which would require of metered measuring of extraction amount), as modelled in Tables 16, 17 and 18, below:

TABLE 16 – MODEL OF METERED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON ACRE-FEET IN BUTTE VALLEY BASIN

Basin Wells

	Approx. Acre Feet	Low Range		High Range	
		Rate	**Revenue**	**Rate**	**Revenue**
All Wells	85,000	$1.60	$136,000	$2.75	$233,750
Total	**85,000**		**$136,000**		**$233,750**
	Revenue Goals:		$135,000		$230,000

TABLE 17 – MODEL OF METERED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON ACRE-FEET IN SCOTT VALLEY BASIN

Basin Wells

	Approx. Acre Feet	Low Range		High Range	
		Rate	**Revenue**	**Rate**	**Revenue**
All Wells	40,000	$3.25	$130,000	$5.75	$230,000
Total	**40,000**		**$130,000**		**$230,000**
	Revenue Goals:		$135,000		$230,000

TABLE 18 – MODEL OF METERED USAGE RATE AND REVENUE FOR PROPERTY RELATED FEE ON ACRE-FEET IN SHASTA VALLEY BASIN

Basin Wells

	Approx. Acre Feet	Low Range		High Range	
		Rate	**Revenue**	**Rate**	**Revenue**
All Wells	44,000	$3.75	$165,000	$6.50	$286,000
Total	**44,000**		**$165,000**		**$286,000**
	Revenue Goals:		$150,000		$262,500

It should be noted that while a "metered usage" rate fee will fluctuate each year with the amount of water drawn, and a fixed "estimated usage" rate fee would be relatively uniform each year. Costs are likely to be relatively uniform and do not fluctuate with amount of water drawn out of the basins.

ADVANTAGES

- Revenue generation is likely sufficient to fund all GSP implementation costs.
- Legally rigorous. Property related fees are the described in the Water Code for funding groundwater sustainability.
- Process is exempt from a balloting, and the likelihood of a 50% protest (out of +-1,900) well owners is unprecedented.
- Cost of implementation is relatively low and includes a fee study, a mailing and additional outreach.
- Efficient administration.

CHALLENGES

- Politically challenging. Many well owners within the basins have made it clear that they prefer the costs be allocated to all properties within the basin and/or county and not just the well owners. Well owners exert significant political influence within the basins. Although a balloting is not required, well owners may be able to stop the process legislatively or possibly could attain a 50% protest, which would force a balloting.

- Unfamiliar Process. One potential criticism of the property-related fee is that property owners are generally unfamiliar with the process, and opponents can exploit this. However, with the recent dramatic increase in voting by mail in California, this is less of a major issue. Nonetheless, political opponents can exploit this unfamiliarity and focus the public's attention on the Proposition 218 process, and away from the proposed groundwater sustainability goals and messaging.

SPECIAL TAX ON ALL PROPERTY OWNERS IN THE BASINS OR COUNTY-WIDE

Special taxes are decided by registered voters and almost always require a two-thirds majority for approval. Traditionally, special taxes have been decided at polling places, or more recently by mail, corresponding with general and special elections. Special taxes are well known to Californians but are not as common as property related fees for funding of water-related services and infrastructure activities.

As a reminder, this technical memorandum is recommending that (only if the costs of GSP implementation requires it) the Agency consider either a Non-balloted Property Related Fee on Well Owner parcels or a Special Tax (described below) on all property owners in the basin, but likely not both, unless the financial need is very significant.

PARCEL BASED TAXES

Many special taxes are conducted on a parcel basis with a uniform "flat" rate across all parcels, or varied rates based upon property attributes such as use and/or size. Parcel taxes based upon the assessed value of a property are not allowed. Parcel based taxes (as opposed to sales taxes, etc.) are the most viable type of special tax for funding water-related activities. As such, most discussion of special taxes in this report will focus on parcel taxes.

LIMITATIONS OF TAXING AUTHORITY – FLOOD CONTROL DISTRICT VERSUS COUNTY

State law requires that only a local government agency, with specific taxing authority, may propose and potentially impose a tax on its underlying parcels. (SGMA does not grant GSAs with specific taxing authority.) The Flood Control District, Siskiyou County and the potentially affected incorporated cities of (Etan, Dorris, Fort Jones, Montague, Yreka and Weed within the basins as well as Dunsmuir, Mount Shasta and Tule Lake if the effort was county-wide) do have taxing authority. Neither the Flood Control District, nor Siskiyou County can tax within the incorporated cities without specific permission.

The Flood Control District is likely the optimal agency to propose the tax, either county-wide or in specific basin areas. The Siskiyou County Flood Control District has the authority, granted by its establishing Act, to establish zones within its boundaries for the purpose of levying taxes. For the GSA to levy a special tax in specific basin areas these areas would need to be established as the zones of benefit for the purposes of the GSA and the implementation of the GSP. The governing board (Siskiyou County Board of Supervisors) is granted the authority to levy taxes upon the taxable property in the benefitting zones to carry out the purposes of its establishing Act, and "to pay the costs and expenses of maintaining, operating, extending and repairing any work or improvement of such zones for the ensuing fiscal year" (Cal Uncod. Water Deer, Act 1240 § 33). The Act stipulates that the Board shall have the power to control and order the expenditures of all tax revenue, with a limitation $0.05 per one hundred dollars of the assessed valuation of property within each zone, and that all taxes levied shall be apportioned in accordance with the established zones.

Other requirements and limitations are included in the Siskiyou County Flood Control District Act that may additionally hamper the District's ability to efficiently and effectively propose a well-designed tax. Modification of the Act, albeit requiring legislative State-level consideration and approval, should be considered.

COUNTY-WIDE VERSUS BASIN SPECIFIC SPECIAL TAX

Both a county-wide and basin area special tax should be considered. A county-wide tax would result in a lower and more voter-palatable proposed tax rate as the needed revenue would be spread over a large number of parcels. However, voters who do not reside within the basin areas may be significantly less likely to vote in favor of a prosed tax as they would be less likely to perceive a direct benefit. Also, special consideration would need to be made for the Tule Lake area which has a different GSA. See Table 26 for a county-wide model of the tax rates that would be need.

Because the tax rates are relatively low for all tax models (<<$15.00 per year) (Tables 23-26), the political advantage of a county-wide tax is muted.

SPECIAL TAX IMPLEMENTATION PROCESS

Public agencies typically work with special consultants familiar with the administrative and political aspects of proposing a special tax to a community. Special tax elections held at polling places are conducted on the statutorily designated dates (typically in November for the general election and either March or June for the primary).

If the Agency ultimately decides to pursue a special tax, it is highly recommended that a special all-mail election be considered. Special all-mail ballot elections are often less expensive and allow for more optimization of the election date, as well as having the advantage of presenting a single issue to the voters.

REQUIRED DOCUMENTS FOR A PARCEL BASED SPECIAL TAX

- Ordinance or Resolution stating: tax type, tax rates, collection method, election date and services provided
- Notice to the Registrar of Voters of measure submitted to voters
- Measure Text including:
    - Ballot question (75 words or less)
    - Full ballot text (300 words or less) including rate structure
    - Arguments in favor or against and independent analysis

- Tax Report

FLEXIBILITY OF METHODOLOGY

There is considerable flexibility in tax methodology. The Agency could propose a flat tax rate in which all parcels are charged the same or a "tiered approach" where, for example larger, and/or commercial parcels may be taxed more than vacant lots. If a tiered approach is considered, the Agency should consider using existing Community Facilities District ("CFD") law and practice which better defends the use of a tiered structure.

REVENUE GENERATION POTENTIAL

A detail breakdown of the parcel attributes including number of parcels, number of residential units (for multi-family parcels) and acres for agricultural parcels in the three basins is shown in Tables 19, 20, and 21 below:

TABLE 19 – PARCEL ATTRIBUTES WITHIN BUTTE VALLEY BASIN

	Parcels	Residential Units	Acres
Single Family	410	434	1,318
Multi: 2 - 4 units	68	136	117
Mobile Home	117	117	4,821
Commercial/Industrial	79	NA	114
Office	12	NA	6
Vacant	540	NA	2,198
Parking & Storage	11	0	16
Agricultural	442	NA	51,904
Timber & Pasture	119	NA	40,372
Not Assessable	55	NA	168
Totals	**1,853**	**687**	**101,035**

TABLE 20 – PARCEL ATTRIBUTES WITHIN SCOTT VALLEY BASIN

	Parcels	Residential Units	Acres
Single Family	1,375	1,401	10,684
Multi: 2 - 4 units	140	280	599
Mobile Home	191	191	3,926
Commercial/Industrial	150	NA	376
Office	16	NA	17
Vacant	659	NA	8,271
Institutional & Gov't	9	0	54
Multi: 5+ units	13	NA	80
Cemetaries	2	NA	34
Agricultural	972	NA	66,763
Timber & Pasture	77		13,981
Not Assessable	167		617
Totals	**3,527**	**1,872**	**90,803**

TABLE 21 – PARCEL ATTRIBUTES WITHIN SHASTA VALLEY BASIN

	Parcels	Residential Units	Acres
Single Family	4,671	4,868	19,828
Multi: 2 - 4 units	441	882	1,526
Condo	21	21	19
Mobile Home	465	465	8,921
Commercial/Industrial	384	NA	1,099
Office	89	NA	32
Vacant	5,303	0	27,291
Parking & Storage	11	NA	19
Multi: 5+ units	28	NA	10
Cemeteries	344	NA	2,405
Agricultural	1,238	NA	167,985
Timber & Pasture	136	NA	31,400
Unassessable	363	NA	1,822
Totals	**13,494**	**6,236**	**262,355**

Next, we have modelled hypothetical rates to generate the revenue goals in the three basins Tables 22, 23, and 24. Table 25 models Shasta Valley is the boundaries are enlarged to include all parcels with the Shasta Valley Watershed. Table 26 models a special tax for all of Siskiyou County (including the Tule Lake GSA area).

TABLE 22 – MODEL OF TAX RATE AND REVENUES FOR SPECIAL TAX IN BUTTE VALLEY BASIN

	Parcels	Residential Units	Acres	Low Range		High Range		Units
Single Family	410	434	1,318	$4.50	$1,953	$10.50	$4,557	*per residential unit*
Multi: 2 - 4 units	68	136	117	$4.50	$612	$10.50	$1,428	*per residential unit*
Mobile Home	117	117	4,821	$4.50	$527	$10.50	$1,229	*per residential unit*
Commercial/Industrial	79	NA	114	$4.50	$356	$10.50	$830	*per parcel*
Office	12	NA	6	$4.50	$54	$10.50	$126	*per parcel*
Vacant	540	NA	2,198	$4.50	$2,430	$10.50	$5,670	*per parcel*
Parking & Storage	11	0	16	$4.50	$0	$10.50	$116	*per parcel*
Agricultural	442	NA	51,904	$1.40	$72,666	$2.35	$121,975	*per acre*
Timber & Pasture	119	NA	40,372	$1.40	$56,521	$2.35	$94,875	*per acre*
Not Assessable	55	NA	168	$0.00	$0	$0.00	$0	*per parcel*
Totals	**1,853**	**687**	**101,035**		**$135,118**		**$230,805**	
				Revenue Goals:	**$135,000**		**$230,000**	

TABLE 23 – MODEL OF TAX RATE AND REVENUES FOR SPECIAL TAX IN SCOTT VALLEY BASIN

	Parcels	Residential Units	Acres	Low Range		High Range		Units
Single Family	1,375	1,401	10,684	$6.50	$9,107	$13.00	$18,213	*per residential unit*
Multi: 2 - 4 units	140	280	599	$6.50	$1,820	$13.00	$3,640	*per residential unit*
Mobile Home	191	191	3,926	$6.50	$1,242	$13.00	$2,483	*per residential unit*
Commercial/Industrial	150	NA	376	$6.50	$975	$13.00	$1,950	*per parcel*
Office	16	NA	17	$6.50	$104	$13.00	$208	*per parcel*
Vacant	659	NA	8,271	$6.50	$4,284	$13.00	$8,567	*per parcel*
Institutional & Gov't	9	0	54	$6.50	$0	$13.00	$117	*per parcel*
Multi: 5+ units	13	NA	80	$1.75	$140	$3.00	$240	*per acre*
Cemetaries	2	NA	34	$1.75	$59	$3.00	$101	*per acre*
Agricultural	972	NA	66,763	$1.75	$116,835	$3.00	$200,289	*per acre*
Timber & Pasture	77		13,981	$1.75	$24,466	$2.75	$38,447	*per acre*
Not Assessable	167		617	$0.00	$0	$0.00	$0	*per parcel*
Totals	**3,527**	**1,872**	**90,803**		**$134,565**		**$235,808**	
				Revenue Goals:	**$135,000**		**$230,000**	

TABLE 24 – MODEL OF TAX RATE AND REVENUES FOR SPECIAL TAX IN SHASTA VALLEY BASIN

	Parcels	Residential Units	Acres	Low Range		High Range		Units
Single Family	4,671	4,868	19,828	$3.00	$14,604	$7.00	$34,076	*per residential unit*
Multi: 2 - 4 units	441	882	1,526	$3.00	$2,646	$7.00	$6,174	*per residential unit*
Condo	21	21	19	$3.00	$63	$7.00	$147	*per residential unit*
Mobile Home	465	465	8,921	$3.00	$1,395	$7.00	$3,255	*per parcel*
Commercial/Industrial	384	NA	1,099	$3.00	$1,152	$7.00	$2,688	*per parcel*
Office	89	NA	32	$3.00	$267	$7.00	$623	*per parcel*
Vacant	5,303	0	27,291	$3.00	$0	$7.00	$37,121	*per parcel*
Parking & Storage	11	NA	19	$0.75	$14	$1.00	$19	*per acre*
Multi: 5+ units	28	NA	10	$0.75	$8	$1.00	$10	*per acre*
Cemeteries	344	NA	2,405	$0.75	$1,804	$1.00	$2,405	*per acre*
Agricultural	1,238	NA	167,985	$0.75	$125,989	$1.00	$167,985	*per acre*
Timber & Pasture	136	NA	31,400	$0.75	$23,550	$1.00	$31,400	*per acre*
Unassessable	363	NA	1,822	$0.00	$0	$0.00	$0	*per parcel*
Totals	**13,494**	**6,236**	**262,355**		**$171,491**		**$285,903**	
				Revenue Goals:	**$168,750**		**$287,500**	

Alternatively, a model of tax rate and revenues might be considered for the Shasta watershed as a whole, given the amount of interconnected surface water above the Basin. This model is shown in table 25 below:

TABLE 25 – MODEL OF TAX RATE AND REVENUES FOR SPECIAL TAX IN THE ENTIRE SHASTA VALLEY WATERSHED

	Parcels	Residential Units	Acres	Low Range		High Range		Units
Single Family	6,556	5,033	25,487	$2.50	$12,583	$4.50	$22,649	*per residential unit*
Multi: 2 - 4 units	552	882	552	$2.50	$2,205	$4.50	$3,969	*per residential unit*
Mobile Home	671	483	9,880	$2.50	$1,208	$4.50	$2,174	*per residential unit*
Commercial/Industrial	563	N/A	1,856	$2.50	$1,408	$4.50	$2,534	*per parcel*
Office	105	N/A	38	$2.50	$263	$4.50	$473	*per parcel*
Vacant	6,653	N/A	49,196	$2.50	$16,633	$4.50	$29,939	*per parcel*
Parking & Storage	11	N/A	19	$2.50	$28	$4.50	$50	*per parcel*
Agricultural	1,397	N/A	196,618	$0.50	$98,309	$0.85	$167,125	*per acre*
Timber & Pasture	266	N/A	76,341	$0.50	$38,170	$0.85	$64,890	*per acre*
Not Assessable	393	N/A	1,872	$0.00	$0	$0.00	$0	*per parcel*
Totals	**17,167**	**6,398**	**361,857**		**$170,804**		**$293,800**	
				Revenue Goals:	**$168,750**		**$287,500**	

Another consideration for a special tax is implementing a county-wide model. This would help to spread costs out among all landowners in the county, lessening the financial burden for well owners. This may be perceived as unfair to those who do not reside above the basins, but it can be asserted that the GSP implementation is beneficial to all county residents. A county-wide special tax is modelled below in Table 26:

TABLE 26 – MODEL OF TAX RATE AND REVENUES FOR SPECIAL TAX IN ENTIRE SISKIYOU COUNTY

	Parcels	Residential Units	Acres	Low Range		High Range		Units
Single Family	14,863	7,725	69,376	$2.75	$21,244	$5.25	$40,556	*per residential unit*
Multi: 2 - 4 units	2,185	1,323	5,993	$2.75	$3,638	$5.25	$6,946	*per residential unit*
Mobile Home	2,914	921	32,626	$2.75	$2,533	$5.25	$4,835	*per residential unit*
Commercial/Industrial	1,415	N/A	6,067	$2.75	$3,891	$5.25	$7,429	*per parcel*
Office	186	N/A	66	$2.75	$512	$5.25	$977	*per parcel*
Vacant	16,833	N/A	169,920	$2.75	$46,291	$5.25	$88,373	*per parcel*
Parking & Storage	46	N/A	135	$2.75	$127	$5.25	$242	*per parcel*
Agricultural	4,078	N/A	548,372	$0.30	$164,512	$0.50	$274,186	*per acre*
Timber & Pasture	2,078	N/A	660,295	$0.30	$198,088	$0.50	$330,147	*per acre*
Not Assessable	988	N/A	21,473	$0.00	$0	$0.00	$0	*per parcel*
Totals	**45,586**	**9,969**	**1,514,323**		**$440,835**		**$753,691**	
			Revenue Goals:		$438,750		$747,500	

ADVANTAGES

- Revenue generation is likely sufficient to fund all GSP implementation costs if voter approved.
- Legally rigorous. Special taxes, if approved by two-thirds of the registered voters within a community, are very reliable and very rarely legally challenged successfully. Special tax revenue has not been subject to state level "take-aways" like ERAF.
- Well known. Most property owners are aware and comfortable with (but not necessarily supportive of) the special taxes and the special tax process.
- Very low tax rates (<<$15.00) per year are often reasonably well-supported by voters
- Efficient administration

CHALLENGES

- Political support at required rate and revenue may be difficult. Generally speaking, the two-thirds majority threshold for approval is very politically challenging. Special taxes are subject to significant outside influence from media and opposition groups during voting and are more vulnerable to other measures and candidates that share the ballot. (However, a recent California Supreme Court decision called the “Upland Case” allows for voter initiatives to be approved with a more easily achievable 50% threshed. The Agency should evaluate the pros and cons of the effectiveness of an voter initiative.)

GENERAL OBLIGATION BONDS SUPPORTED BY A SPECIAL TAX

In California, special taxes can be linked directly to the sale of general obligation bonds to finance the construction of infrastructure. In 2004, the City of Los Angeles successfully passed "Measure O" which provided funding for a variety of capital improvements related to water quality. Arguably, voters are more likely to support general obligation bond special taxes than parcel-based taxes at equivalent rates.

However, since special taxes for general obligations bonds can only be used for the financing of capital improvements, this mechanism could only be used to fund the CIP portion of the needs – not the operating costs of the groundwater management infrastructure.

In other words, the passage of a G.O. Bond would not satisfy the Agency's overall groundwater management funding goals, because this source could not fund ongoing operations and maintenance. However, it is possible that community priorities and a revised funding strategy could dictate that pursuit of a G.O. bond measure is optimal to fund any significant groundwater management capital projects. Results of the public opinion survey should help guide this decision.

OTHER APPROACHES – LESS OPTIMAL

BALLOTED PROPERTY-RELATED FEE OR BENEFIT ASSESSMENTS ON ALL PROPERTY OWNERS IN THE BASIN

If the Agency decides to pursue a revenue mechanism applied to well owners, a non-balloted property related fee is optimal, and if the Agency decides to pursue a revenue mechanism applied to all property owners in the basin, a special tax is most likely the best choice. However, there are two other approaches described in Proposition 218 worthy of discussion, especially if voter support is marginal: 1.) a balloted property related fee or 2.) a benefit assessment. Both of these are more expensive to implement and administer and are considerably less legally rigorous (especially with no current precedent) than a special tax. Nonetheless, both require only a 50% approval for implementation. Further research and evaluation would need to be pursued.

OTHER CONSIDERATIONS

CONDUCT A SURVEY IF CONSIDERING A PROPERTY-RELATED FEE OR SPECIAL TAX

See a full discussion in the next section.

IMPLEMENT RIGOROUS COMMUNITY OUTREACH IF CONSIDERING A PROPERTY-RELATED FEE OR SPECIAL TAX

See a full discussion in the next section.

TIMING AND SCHEDULE

The selection of the balloting date is one of the most important factors affecting the success of any measure. Potential competition with other measures, income and property tax due dates, seasons, and holidays, etc. should all be evaluated when choosing a balloting date.

A COST ESCALATOR IS RECOMMENDED FOR BALLOTED MECHANISMS

Non-balloted funding mechanisms can be updated periodically using the noticed public hearing procedure described above. This is the typical method of keeping revenues aligned with costs through the years as in the case for retail water and sewer fees. Accordingly, the rates can be kept updated for inflationary forces and other cost increases on a five-year recurrence cycle.

However, for balloted mechanisms, any increase or change in rate structures requires a re-balloting unless the original balloting included a pre-determined formula for escalation – such as the Consumer Price Index (CPI). Infrastructure-intensive utilities are driven by many different forces than those that drive the CPI, including the need for capital investment programs, regulatory programs, and the economics of sustainability, conservation, and commodity constraints. Due, in part, to these other drivers, rates for utilities have not traditionally been tied to a straightforward CPI, but rather have been expressed as a specific rate amount for a given year based on actual projected costs. Nonetheless, costs do increase over time and a cost escalator is recommended to reimburse the Agency for this increase. The simplest to explain to property owners and to administer annually is a CPI, based upon a readily available index such as the U.S. Department of Labor, which would allow for annual rate increases without annual balloting. A CPI escalator is legally defensible with property related fees, regulatory fees, and special taxes.

However, a CPI approach may make it difficult to accommodate infrastructure-driven cost increases in coming years. An alternative approach would be to include a rate adjustment schedule that would include specific increases in future years that meet the UVBGAS's needs. (This approach, commonly used by water and sewer providers, often communicates to the property owner in table form with the proposed rate corresponding to each year for the next four or five years.)

At this point in the process, it is difficult to make a concise recommendation for the escalator mechanism. It would depend on the escalating costs and how they affect the proposed rates in the foreseeable future. It would also depend in part on the proposed rate structure itself, as some structures may be based on variables that intrinsically accommodate increasing groundwater management needs. Finally, it would depend on the political considerations that come with any ballot measure. Historically, the majority of survey data supports the fact that a CPI escalator introduces minimal decay in overall support.

A SUNSET PROVISION IS NOT RECOMMENDED, BUT SHOULD BE CONSIDERED

A "Sunset Provision" is a mechanism used to increase political support by setting an expiration date for a measure, and can be used with a property related fee, regulatory fee, or tax. Sunset provisions typically range from five years to as much as 20 years in some rare cases. However, the political advantage may be slight and does not outweigh the negative aspect of the increased costs and political risk of having to re-ballot at the termination of the sunset period.

One variation is the "sundown" clause. This is the name given to a tax or fee that would reduce after a specific date – leaving a portion of the tax or fee to continue indefinitely. This tactic is useful for programs that have a one-time capital need and then would reduce to fund only operations and maintenance beyond that. If the one-time capital need is debt financed, the "sundown" period would need to be at least as long as the debt repayment period.

A "DISCOUNT MECHANISM" SHOULD BE CONSIDERED, BUT MAY NOT BE COST-EFFECTIVE

Consistent with the efforts of obtaining higher quality groundwater, a discount or "rate reduction" program should be considered which rewards well owners implementing groundwater sustainability management measures on their properties with a lower fee, based on the reduced cost of providing groundwater service. Any such program would need to be coordinated with whatever rate structure the Agency decides on to ensure that it fits with the rationale and is compliant with Proposition 218.

The advantages of such a program include improved water quality, improved engagement by the community, as well as a rate more tailored to individual usage. Also, discount programs tend to be well received by the electorate, although most people do not participate. The downside of such a program is that the benefit may not justify the cost of administering this program, because the inspection of property-specific improvements is expensive and time consuming. Nonetheless, a couple of public agencies including the cities of Portland, Oregon, South Lake Tahoe, and Palo Alto have successfully implemented discount programs on their storm drainage fees. The community's interest level for a discount mechanism will be evaluated as part of the mail survey opinion research.

III. RECOMMENDATIONS FOR IMPLEMENTATION OF FUNDING MECHANISMS

Following is a "Game Plan" outline of the recommended steps for implementation of funding for the GSA's GSP implementation. Most of the steps have been discussed above – a discussion of community public opinion surveying and community outreach is included below.

GAME PLAN

1. Conduct community outreach regarding the Plan and its implementation.
2. Pursue use of existing revenue sources to fund implementation.
3. Pursue Grants and Loan Opportunities to fund implementation.
4. Implement Regulatory Fees to offset eligible implementation costs.

If additional revenue is needed:

5. Conduct a survey and stakeholder outreach to better evaluate:
    a. Community priorities and associated messaging.
    b. Optimal rate.
    c. Preference of non-balloted property related fee versus special tax.
6. Use results of surveys, stakeholder input and other analyses to develop a community outreach plan.
7. Implement the community outreach.
8. Implement a property related fee or special tax balloting:
    a. Include a cost escalator schedule or mechanism.
    b. Include the use of rate zones or other distinguishing factors.
    c. Do not include a rate expiration date (also known as a "Sunset Clause").
    d. Include a Discount Program to encourage better groundwater management by well owners.

CONSIDER A PUBLIC OPINION SURVEY

The primary purpose of the public opinion survey is to produce an unbiased, statistically reliable evaluation of voters' and property owners' interest in supporting a local revenue measure. Should the Agency decide to move forward with a revenue measure (property-related fee or special tax), the survey data provides guidance as to how to structure the measure so that it is consistent with the community's priorities and expressed needs. Agencies typically engage specialized survey firms to conduct surveys.

Specifically, the survey should:

- Gauge current, baseline support for a local revenue measure associated with specific dollar amounts. (How much are well owners/property owners willing to pay?)
- Identify the types of services and projects that voters and property owners are most interested in funding.
- Identify the issues voters and property owners are most responsive to (e.g., preventing subsidence, maintaining water availability, reducing pumping costs, protecting water quality, etc.).

- Expose respondents to arguments in favor of—and against—the proposed revenue measure to gauge how information affects support for the measure.
- Identify whether local residents prefer the measure as a property related fee or a special tax.

As the nation struggles with the COVID-19 pandemic, it is more important than ever to measure a community's position on all of these elements. What community leaders thought they knew about public opinion may no longer be accurate in a post-COVID world. And while a survey can provide the Agency with valuable information, it will also be an opportunity to begin getting the groundwater "brand" out into the community – a valuable early step in this process.

COMMUNITY SUPPORT AND ENGAGEMENT

Clear, concise, and appropriate community outreach is one of the most important elements for successful implementation of a funding mechanism. The basic message components need to be simple, clear, and transparent, and need to be well supported with detailed and substantive information. Credibility is the most important factor in this outreach.

Agencies often, but not always, will engage specialized consultants to assist with community outreach in support of implementation of funding mechanisms. A community outreach plan should be developed and implemented. Three major steps are described blow.

Develop Communication Infrastructure

The GSA should carefully evaluate and develop potential communication infrastructure, ultimately coordinating with existing communication infrastructure, including stakeholder contacts, print media, website, social media, print publications, neighborhood groups, and newsletters, etc. Use of e-mail contacts (with HOA, neighborhood and stakeholder groups and leaders, and web-based platforms like nextdoor.com is encouraged). Develop a schedule of community stakeholder meetings, due dates for local group newsletters, etc.

In most cases, the most effective communication mechanisms for this type of infrastructure are small, local, and neighborhood-based, with personal communication or face-to-face (as appropriate in COVID-19 environment). This approach is not expensive, but it is a significant amount of work and is very effective when well-executed.

Develop Communication Messaging

The development of the messaging and supporting information is an iterative process with staff, consultant, and community members. (If a community survey is conducted, it can be extremely helpful in developing the most effective messaging.) Throughout this process, the Agency and consultant will analyze and refine messaging associated with groundwater sustainability management benefits. In this task, the Agency should develop draft communications of various types, including Frequently Asked Questions documents, social media content, mailers and brochures, PowerPoint presentations, and e-mails, scripts, and other adaptable messages.

Communications Rollout and Implementation
Once the outreach plan is well-vetted, reviewed, and refined, the Agency should coordinate the plan's rollout and implementation.

Appendix 5-D Siskiyou County Agricultural Economics Analysis Considering Groundwater Regulation

University of California, Merced

Siskiyou County Agricultural Economics Analysis Considering Groundwater Regulation

Supplementary Information for the Groundwater Sustainability Plan

Spencer A. Cole & Josué MedellÍn-Azuara
9-2-2021

1. Introduction

1.1. Background

This economic analysis estimates potential impacts in gross revenues from changing cropping patterns in Siskiyou County's three agricultural valleys namely Butte Valley (Butte), Scott River Valley (Scott), and Shasta Valley (Shasta). This analysis provides insight on economic costs of benefits of land and water use decisions, while identifying areas that may benefit from intervention and stakeholder processes.

Below, we outline the structure and basis for an agricultural production and water use economic model whose purpose is to estimate impacts of land and water use policies on agricultural value in Siskiyou County. Model coverage includes most of the agriculture by irrigated area within the county, with the notable exception of the greater Tulelake area located in the northeast corner of the county (Figure 1) which contains some valuable commodities such potatoes. The Butte, Scott River, and Shasta Valleys were the most distinct agricultural regions within the county and showing significant differences in production factors such as access to groundwater and crop mix. The agricultural model is calibrated using 2018 as a baseline water year because it represents a relatively recent water year with most crop demands fulfilled in comparison to the drier 2014 and 2016 water years (Department of Water Resources, 2021), which are also available at the Department of Water Resources streamflow indices (Department of Water Resources, 2020).

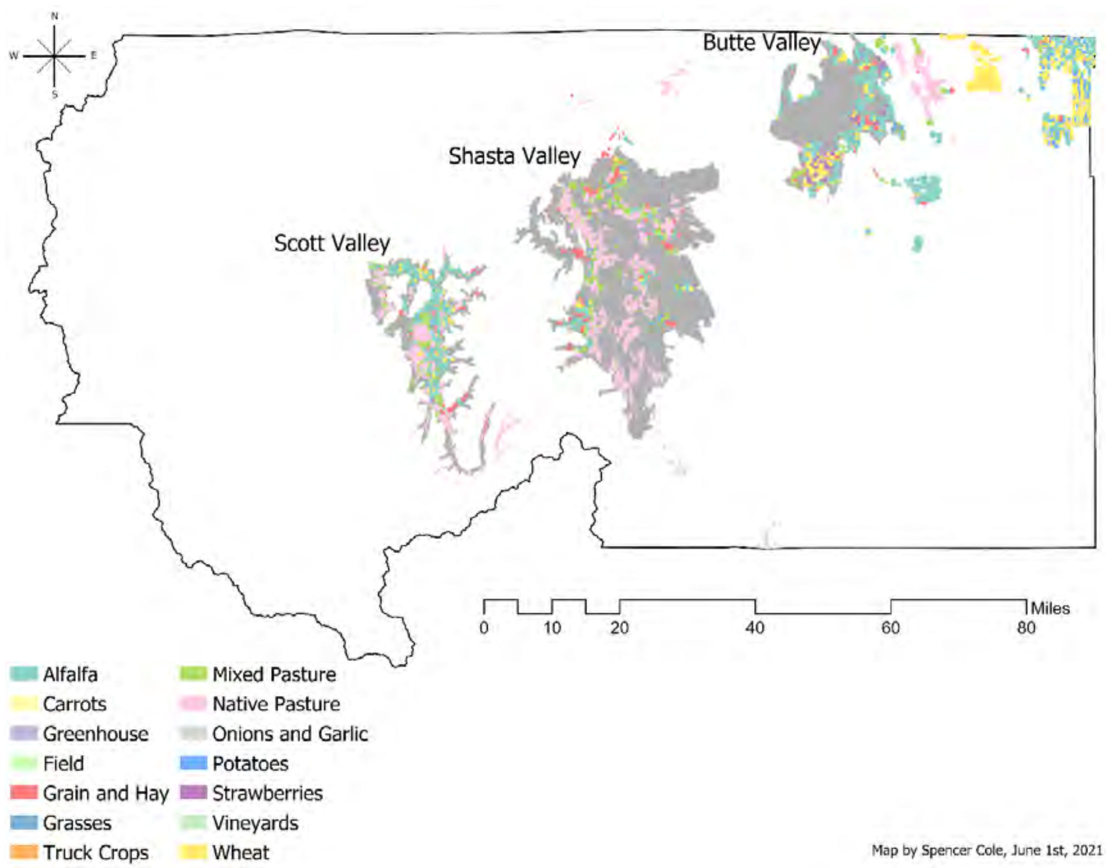

Figure 1: Region delineations and crop coverage represented in the agricultural model. Parcels located outside grey valley boundaries are not included in the model. *Source: 2018 LandIQ land use survey (Department of Water Resources, 2021)*.

1.2. Data sources

Information employed for defining the base case for production in the three valleys is summarized in Table 1. Land use calibration is based on 2018 data for land use and crop production economics where available. Recent cost information for crop commodities is prioritized when available and relevant to the production in Siskiyou County. Applied water requirements for crops are based on specific estimates at the valley scale for use in the integrated valley models. Whereas the model is calibrated using land use information from the LandIQ 2018 land use survey deployed through the California Land Use Viewer (Department of Water Resources, 2021), crop mix across the county and in individual valleys were cross-checked with parcel scale Department of Water Resources surveys for 2000 and 2010, the LandIQ 2016 survey, and the total agricultural footprint represented in the Siskiyou County Agricultural Commissioner's Report to ensure capture of key crops in the region.

Table 1: Summary of data sources for modeling of Siskiyou agricultural production.

Data type	Source	Spatial resolution	Temporal resolution
Valley boundaries	Department of Water Resources[1]	Polygon layer	N/A
Agricultural land use	LandIQ[2]	Parcel	Annual
Crop prices	Siskiyou County Agricultural Commissioner Reports[3]	County	Annual
Crop yields	Siskiyou County Agricultural Commissioner Reports[3]	County	Annual
Crop production costs	UC Davis Cost and Return Studies[4]	Regional	Varies
Applied water	Scott Valley Integrated Hydrologic Model[5], Butte Valley Integrated Hydrologic Model[1], Shasta Valley Integrated Hydrologic Model[6]	Valley	Annual

[1] Provided by Bill Rice.
[2] https://gis.water.ca.gov/app/CADWRLandUseViewer/.
[3] https://www.co.siskiyou.ca.us/agriculture/page/crop-report.
[4] https://coststudies.ucdavis.edu/en/.
[5] Provided by Claire Kouba.
[6] Provided by Cab Esposita.

1.3. Baseline conditions

Tables 2 to 4, below summarize the 2018 base conditions across each of the valleys in the model in terms of land and water use as well as crop revenues. Data is taken directly from the data sources described in section 1.2. above, apart from minor additions and adjustments when necessary to support the model function or to reflect farmer feedback during the workshop stakeholder meetings in June 2021. For example, in Butte Valley, 400 acres of onions and garlic were added to the model because the 2018 land use dataset did not identify any of these crops within the valley boundaries; farmers provided feedback noting that there was cultivation in areas within the valley. Currently, production cost information and crop water demand for nursery berries (raspberries and strawberries) is unavailable and is estimated based on the assumption that returns yield a 15% profit margin over total costs. Cost information available for carrot production is outdated and represents only fresh market cultivation, which does not represent the seed production in Siskiyou County; thus, costs for carrots are scaled to account for these differences. It is assumed that average profit margins for most crops range between zero and five percent of the crop gross revenues, thus some minor adjustments in selected crop prices were implemented in case negative profits from using the cost and return studies data were identified.

Table 2: Butte Valley base conditions. ***Source:*** **Author calculations using data listed in Table 1.**

Crop	Land (ac)	Applied water (AF/ac)	Price ($/ton)	Yield (ton/ac)	Labor cost ($/ac)	Supply cost ($/ac)	Land cost ($/ac)	Gross revenue ($ million)
Alfalfa	14,015	2.22	193	6.4	187	437	482	17.42 (10.6%)
Barley	1,460	1.51	286	2.3	122	285	204	0.97 (0.6%)
Carrots	313	2.09	56	66.7	976	2,278	248	1.16 (0.7%)
Onions and garlic	400	2.09	166	25.0	792	1,849	1,193	1.66 (1.0%)
Other hay	529	2.22	260	4.5	187	437	482	0.62 (0.4%)
Pasture	1,215	2.70	200	3.5	109	254	255	0.85 (0.5%)
Raspberries†	140	3.32	14	4,286	31,945	15,734	1,500	8.10 (4.9%)
Strawberries†	2,537	3.32	0.14	37,0000	28,495	14,035	1,500	131.39 (79.6%)
Wheat	4,502	1.51	203	3.2	122	285	204	2.90 (1.8%)
Total	**25,112**	-	-	-	-	-	-	**165.06 (100%)**

† Units in terms of plants rather than tons.

Table 3: Scott River Valley base conditions. ***Source:*** **Author calculations using data listed in Table 1.**

Crop	Land (ac)	Applied water (AF/ac)	Price ($/ton)	Yield (ton/ac)	Labor cost ($/ac)	Supply cost ($/ac)	Land cost ($/ac)	Gross revenue ($ million)
Alfalfa	12,267	1.97	193	6.4	187	437	482	15.25 (54.9%)
Barley	1,415	1.08	284	2.3	122	285	204	0.92 (3.3%)
Other hay	546	1.97	260	4.5	187	437	482	0.64 (2.3%)
Pasture	13,948	2.30	200	3.5	109	254	255	9.76 (35.1%)
Wheat	1,883	1.08	203	3.2	122	285	204	1.21 (4.4%)
Total	**30,060**	-	-	-	-	-	-	**27.79 (100%)**

Table 4: Shasta Valley base conditions. ***Source:*** **Author calculations using data listed in Table 1.**

Crop	Land (ac)	Applied water (AF/ac)	Price ($/ton)	Yield (ton/ac)	Labor cost ($/ac)	Supply cost ($/ac)	Land cost ($/ac)	Gross revenue ($ million)
Alfalfa	4,584	2.22	193	6.4	187	437	482	5.70 (14.7%)
Barley	3,780	1.51	286	2.3	122	285	204	2.49 (6.4%)
Other hay	1,660	2.22	260	4.5	187	437	482	1.95 (5.0%)
Pasture	30,642	2.70	200	3.5	109	254	255	21.45 (55.2%)
Strawberries†	125	3.32	0.14	370,000	28,495	14,035	1,500	6.49 (16.7%)
Wheat	1,273	1.51	203	3.2	122	285	204	0.83 (2.1%)
Total	**42,063**	-	-	-	-	-	-	**38.89 (100%)**

† Units in terms of plants rather than tons.

Table 5 summarizes overall land use, gross revenue, and water use summed across the three valleys. Following the modifications outlined above. The baseline dataset suggests the gross economic value within the three valleys totals $231.8 million, with $164.8 million, $27.6 million, and $38.4 million allocated to Butte, Scott River, and Shasta Valleys, respectively. Total agricultural land use in the study area is estimated to be about 97,000 acres, with 25,000 acres, 30,000 acres, and 42,000 acres in Butte, Scott River, and Shasta Valleys, respectively. Water use from irrigation is estimated at 220,000 acre-feet per year, of which 55,000 acre-feet, 61,000 acre-feet, and 104,000 acre-feet are used in Butte, Scott River, and Shasta Valleys, respectively on an annual basis. Agricultural value in Butte Valley is dominated by the small but extremely valuable berry plant transplant industry, which contributes $139.5 million of the region's $164.8 million gross revenue on only 11% of land (Siskiyou County Agricultural Commissioner, 2018). Both agricultural land and value in Scott River Valley consist of roughly 85% alfalfa and pasture in combination, with nearly equal area of each crop and small acres of other miscellaneous crops. About 75% of agricultural land and 50% of value in Shasta Valley is composed of pasture, with only about 125 acres of nursery strawberries making up a significant portion of remaining value.

Table 5: Baseline conditions across all three valleys. ***Source:*** **Author calculations using data listed in Table 1.**

Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Alfalfa	30,866 (31.7%)	65,511 (29.7%)	38.4 (16.6%)
Barley	6,655 (6.8%)	9,424 (4.3%)	4.4 (1.9%)
Carrots	313 (0.3%)	653 (0.3%)	1.2 (0.5%)
Onions and garlic	400 (0.4%)	834 (0.4%)	1.7 (0.7%)
Other hay	2,734 (2.8%)	5,942 (2.7%)	3.2 (1.4%)
Pasture	45,805 (47.1%)	118,017 (53.5%)	32.0 (13.8%)
Raspberries	139 (0.1%)	465 (0.2%)	8.1 (3.5%)
Strawberries	2,661 (2.7%)	8,837 (4.0%)	137.9 (59.5%)
Wheat	7,657 (7.9%)	10,735 (4.9%)	4.9 (2.1%)
Total	**97,236 (100%)**	**217,121 (100%)**	**231.8 (100%)**

2. Model calibration and assumptions

Calibration of the model is based on the concept of Positive Mathematical Programming (PMP; Howitt, 1995), a self-calibrating technique to economically represent agricultural production and water use based on profit maximization theory and capturing non-linearities in production. PMP modeling avoids overspecialization in land allocation decisions which is common in linear programming. Thus, highly profitable crops which are produced in limited amounts do not expand at the expense of low-value crops in a way that is inconsistent with observations. The PMP calibration method consists of three steps as described in Howitt et al. (2012): (1) constrained linear optimization to derive shadow values of crop land; (2) parametrization of a constant elasticity of substitution (CES) production function and non-linear cost function; and (3) specification of the model objective function and check for calibration quality. Once the model is fully calibrated, constraint and objective function modifications can be used to examine scenarios of interest. Each of the three regions in the model (Butte, Scott River, Shasta) are calibrated and run independently from one another with an annual decision period. The calibrated model employs the equations listed below which include a CES production function and a non-linear exponential cost function (Howitt et al. 2012).

Box 1: Specification of calibrated model.

$$max \ \{x_{i,land}\} \prod = \sum_i \left(p_i \tau_i \left(\sum_j \beta_{i,j} \, x_{i,j}^{\rho_i} \right)^{\frac{1}{\rho_i}} - \delta_i e^{\gamma_i x_{i,land}} - \sum_{labor,supplies,water} \alpha_{i,j} \omega_{i,j} x_{i,land} \right)$$

$$s.t.$$

$$\sum_i x_{i,land} \leq \sum_i \tilde{x}_{i,land}$$

$$\sum_i x_{i,land} \tilde{x}_{i,water} \leq \sum_i \tilde{x}_{i,land} \tilde{x}_{i,water}$$

$$\frac{x_{i,water}}{x_{i,land}} \leq 0.99\tilde{x}_{i,water}$$

$$\forall\ i\ \in \begin{bmatrix} alfalfa, barley, carrots, onions\ and\ garlic, other\ hay, pasture, raspebrries, \\ strawberries, wheat \end{bmatrix}$$

$$\forall\ j\ \in [land, labor, supplies, water]$$

The first equation is the profit maximization objective function, which is followed by the land and water availability constraint sets, and an irrigation stress constraint to avoid deficit irrigation of crops. Parameters in the three constraint sets above can be modified, including the limit of land and/or water available for crops and use of deficit irrigation as a potential adaptation to drought or water rationing policies.

2.4. Model assumptions

Interpretation of model function and output is contingent on several assumptions employed in the model framework. Agriculture is represented in the model as a "snapshot" of cropping patterns and economics observed across one or more years and pertains only to annual decision-making processes. In many cases, agriculture follows rotation cycles which are not captured explicitly in the model; land use data employed in model calibration is assumed to represent an pseudo-equilibrium state for rotating crops which is representative of a typical annual crop mix, with some portion of cropland in each cycle of their rotation. Farm-scale decisions for plantings oftentimes depend on multi-year investments and production conditions which are not captured in the annual structure of the model. As such, the model's purpose is not to suggest planting decisions for individual parcels, but rather to present possible impacts on agriculture at the aggregate scale. To predict annual cropping patterns at the regional scale, the model assumes that some degree of water trading occurs within each region to retain more profitable crops when resource shortages are in place.

3. Scenarios Overview

The calibrated model was applied in seven scenarios which are designed to establish preliminary measure for the effects of land management policies on agricultural value across the three valleys. Table 6 below, summarizes the context and implementation of the scenarios in the model.

Table 6: Summary of model scenarios.

Scenario number / name	**Description**
Scenario 1a: 15% fallowing of pasture and alfalfa	All alfalfa and pasture are fallowed by 15%, with no ability to re-operationalize land and water use reductions with other crops.
Scenario 1b: 30% fallowing of pasture and alfalfa	All alfalfa and pasture are fallowed by 30%, with no ability to re-operationalize land and water use reductions with other crops.
Scenario 1c: 60% fallowing of pasture and alfalfa	All alfalfa and pasture are fallowed by 60%, with no ability to re-operationalize land and water use reductions with other crops.
Scenario 2: forego third alfalfa cutting	Simulate ceasing half of irrigation for alfalfa by July 1st, represented in the model as 33% deficit irrigation for alfalfa and a corresponding reduction

	in yield of 33%. Water use reductions from deficit irrigating alfalfa are retained.
Scenario 3: 15% fallowing (adaptive)	Total agricultural land undergoes 15% fallowing, and model given flexibility to optimize distribution of cutbacks across individual crops.
Scenario 4: 15% fallowing ("worst case")	Total agricultural land undergoes 15% fallowing, distributed evenly across all crops (area of all crop reduced by 15%).
Scenario 5: 15% water shortage (adaptive)	Total agricultural water use cutback by 15%, and model given flexibility to optimize distribution of cutbacks across individual crops.
Scenario 6: exploring economic tradeoffs between alfalfa and strawberries in Butte Valley	Comparison of marginal value and unit water use for alfalfa and berry plant transplant strawberries conducted to assess viability of converting between the two crops.
Scenario 7: exploring lower water use alternatives to alfalfa and pasture	Crop portfolio is assessed to locate water saving opportunities through crop conversion, with high retention or expansion of crop value.

4. Scenario Model Outcomes

4.1. Direct agricultural impacts (model results)

4.1.1. Scenario 1a: 15% fallowing of pasture and alfalfa

In this scenario, we simulate prescribed fallowing of pasture and alfalfa by 15% of baseline conditions within each region. Land and water previously devoted to these crops are treated as savings and thus are not allowed to be utilized in the model for the expansion of other crops. Under this land management policy, a total of 11,502 acres are fallowed (11.8%), of which 4,630 acres are alfalfa and 6,871 acres are pasture. Greatest cutbacks in land use occur in Shasta due to the exceptionally high baseline acreage of pasture, resulting in fallowing of 4,596 acres of pasture, nearly half of the total fallowed land. Slack water in lieu of irrigating the fallowed land total 27,530 acre-feet per year across the three valleys (12.5%). Gross revenue losses across all valleys together total $10.56 million (4.6%), concentrated in Scott ($3.75 million; 13.5%) and Shasta ($4.07 million; 10.5%). Economic losses in Butte – 1.7% as a percentage of baseline revenues – are weathered because of the high contribution of other crops such as nursery strawberries to overall agricultural value in the valley. Figure 2 and Table 7 below provide more detailed model outcomes of the cropping patterns, water use reductions, and value associated with this scenario.

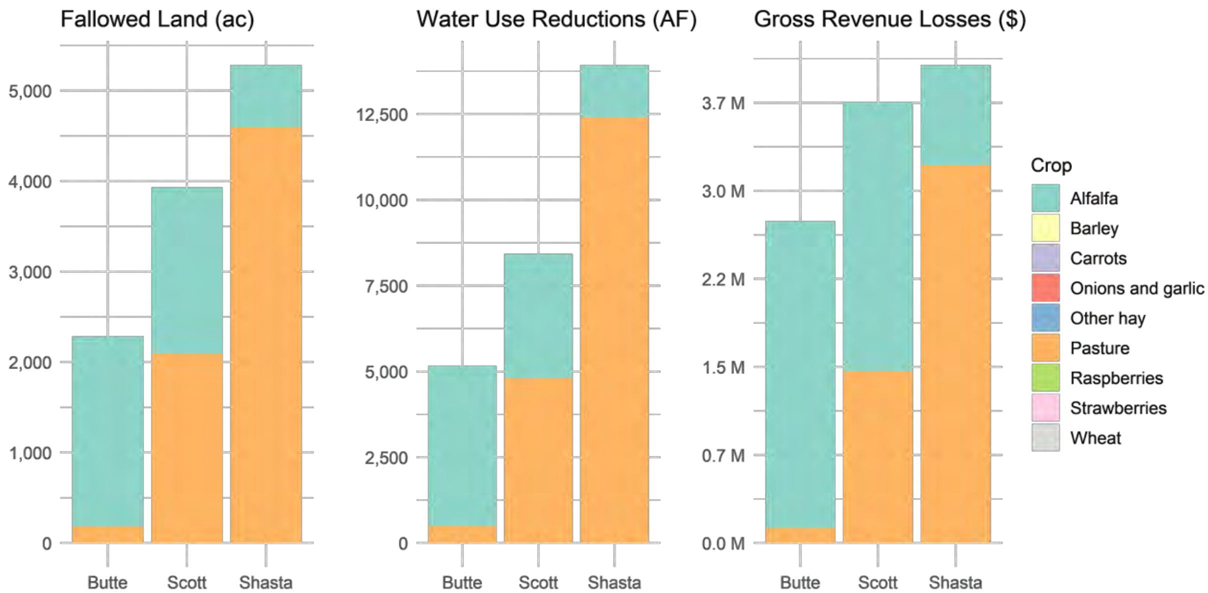

Figure 2: Results of land allocations, water use, and gross revenue differences from base for scenario 1a, 15% fallowing of pasture and alfalfa.

Table 7: Tabulated results of land allocations, water use, and gross revenues for scenario 1a, 15% fallowing of pasture and alfalfa.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	11,913	26,495	14.81
	Barley	1,460	2,199	0.96
	Carrots	313	654	1.16
	Onions and garlic	400	834	1.66
	Other hay	529	1,177	0.62
	Pasture	1,033	2,789	0.72
	Raspberries	140	465	8.10
	Strawberries	2,537	8,421	131.39
	Wheat	4,502	6,780	2.90
	Subtotal	**22,828 (-9.1%)**	**49,813 (-9.4%)**	**162.32 (-1.7%)**
Scott	Alfalfa	10,427	20,525	12.96
	Barley	1,415	1,532	0.92
	Other hay	546	1,076	0.64
	Pasture	11,856	27,229	8.30
	Wheat	1,883	2,039	1.21
	Subtotal	**26,128 (-13.1%)**	**52,400 (-13.9%)**	**24.04 (-13.5%)**
Shasta	Alfalfa	3,896	8,665	4.84
	Barley	3,780	5,693	2.49
	Other hay	1,660	3,691	1.95
	Pasture	26,046	70,298	18.23
	Strawberries	125	416	6.49
	Wheat	1,273	1,917	0.82
	Subtotal	**36,780 (-12.6%)**	**90,679 (-13.3%)**	**34.82 (-10.5%)**
Three valleys	**Total**	**85,735 (-11.8%)**	**192,892 (-12.5%)**	**221.18 (-4.6%)**

4.1.2. Scenario 1b: 30% fallowing of pasture and alfalfa

Scenario 1b is an upscaled version of scenario 1a, wherein the model prescribes a more severe fallowing of 30% of all pasture and alfalfa. As expected, the results follow the same trends as in scenario 1a but with more significant reductions in all categories. A total of 23,002 acres are fallowed (23.7%), of which 4,569 acres are in Butte, 7,865 acres are in Scott, and the remaining 10,568 acres are in Shasta. Cutbacks in land use represent about one-quarter of all land in Scott and Shasta as individual regions, and about one-fifth of total land in Butte. Water use reductions total 55,060 acre-feet across the three valleys (25.0%). Compared with scenario 1a gross revenue losses are doubled, valuing $21.13 million in total (9.1%) and distributed similarly to each valley (3.3%, 27.7%, and 20.9% loss for Butte, Scott, and Shasta, respectively). Figure 3 and Table 8 below provide more detailed predictions of the cropping patterns, water use reductions, and value associated with this scenario.

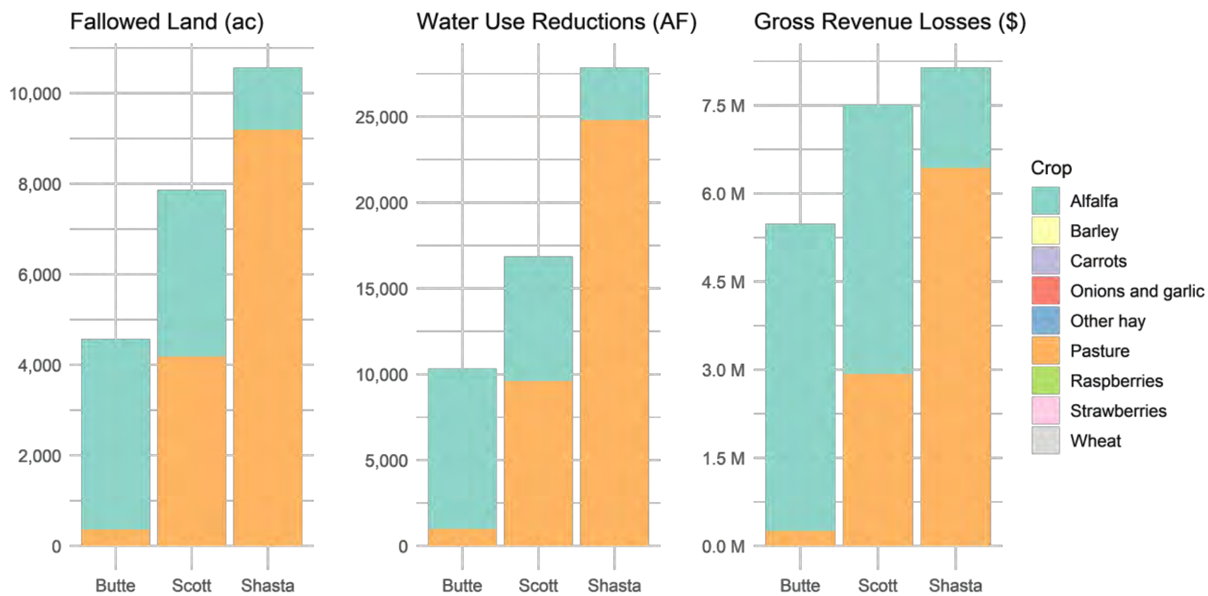

Figure 3: Results of land allocations, water use, and gross revenue differences from base for scenario 1b, 30% fallowing of pasture and alfalfa.

Table 8: Tabulated results of land allocations, water use, and gross revenues for scenario 1b, 30% fallowing of pasture and alfalfa.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	9,811	21,819	12.20
	Barley	1,460	2,199	0.96
	Carrots	313	654	1.16
	Onions and garlic	400	834	1.66
	Other hay	529	1,177	0.62
	Pasture	851	2,296	0.59
	Raspberries	140	465	8.10
	Strawberries	2,537	8,421	131.39
	Wheat	4,502	6,780	2.90
	Subtotal	**20,543** (-18.2%)	**43,973** (-18.8%)	**159.58** (-3.3%)
Scott	Alfalfa	8,587	16,903	10.68
	Barley	1,415	1,532	0.92

	Other hay	546	1,076	0.64
	Pasture	9,764	22,424	6.83
	Wheat	1,883	2,039	1.21
	Subtotal	**22,196** (-26.2%)	**43,973** (-27.7%)	**20.29** (-27.7%)
Shasta	Alfalfa	3,209	7,136	3.99
	Barley	3,780	5,693	2.49
	Other hay	1,660	3,691	1.95
	Pasture	21,449	57,892	15.01
	Strawberries	125	416	6.49
	Wheat	1,273	1,917	0.82
	Subtotal	**31,496** (-25.1%)	**76,745** (-26.6%)	**30.75** (-20.9%)
Three valleys	**Total**	**74,234** (-23.7%)	**165,363** (-25.0%)	**210.63** (-9.1%)

4.1.3. Scenario 1c: 60% fallowing of pasture and alfalfa

Scenario 1c further extends the fallowing cutbacks from the previous two scenarios and simulates a 60% fallowing of pasture and alfalfa. Total fallowing totals 46,003 acres (47.3%) with 9,139 acres, 15,729, and 21,136 acres occurring in Butte, Scott, and Shasta, respectively. Reductions in land represent over half of the agricultural acreage in Scott and Shasta but roughly one-third of Butte land use. Water use reductions in the three valleys total 110,117 acre-feet or about 50% of total estimated baseline irrigation demands. Gross revenue losses total $42.26 million (18.2%); Butte experiences the least value loss at $10.97 million (6.6%), followed by Scott at $15.01 million (54.0%), and lastly Shasta with $16.29 million (41.9%). Figure 4 and Table 9 below provide more detailed predictions of the cropping patterns changes, water use reductions, and value associated with this scenario.

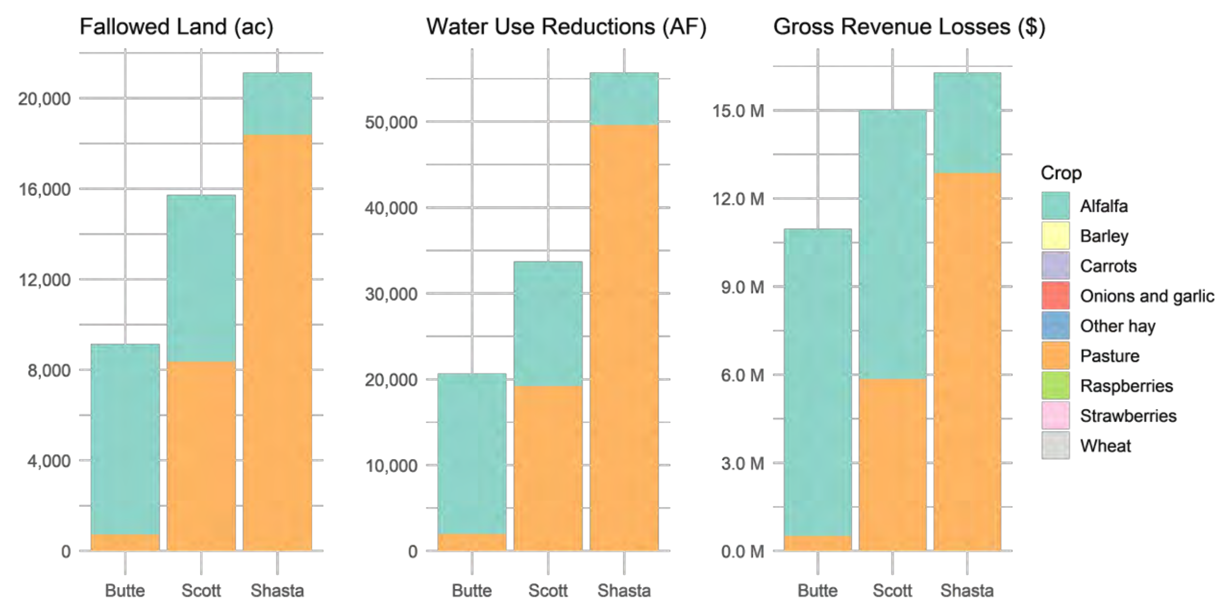

Figure 4: Results of land allocations, water use, and gross revenue differences from base for scenario 1c, 60% fallowing of pasture and alfalfa.

Table 9: Tabulated results of land allocations, water use, and gross revenues for scenario 1c, 60% fallowing of pasture and alfalfa.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	5,006	12,468	6.97
	Barley	1,460	2,199	0.96
	Carrots	313	654	1.16
	Onions and garlic	400	834	1.66
	Other hay	529	1,177	0.62
	Pasture	486	1,177	0.34
	Raspberries	140	465	8.10
	Strawberries	2,537	8,421	131.39
	Wheat	4,502	6,780	2.90
	Subtotal	**15,974 (-36.4%)**	**34,310 (-37.6%)**	**154.10 (-6.6%)**
Scott	Alfalfa	4,907	9,659	6.10
	Barley	1,415	1,532	0.92
	Other hay	546	1,076	0.64
	Pasture	5,579	12,814	3.91
	Wheat	1,883	2,039	1.21
	Subtotal	**14,331 (-52.3%)**	**27,118 (-55.4%)**	**12.78 (-54.0%)**
Shasta	Alfalfa	1,834	4,078	2.28
	Barley	3,780	5,693	2.49
	Other hay	1,660	3,691	1.95
	Pasture	12,257	33,081	8.58
	Strawberries	125	416	6.49
	Wheat	1,273	1,917	0.82
	Subtotal	**20,928 (-50.2%)**	**48,875 (-53.3%)**	**22.60 (-41.9%)**
Three valleys	**Total**	**51,233 (-47.3%)**	**110,304 (-50.0%)**	**189.49 (-18.2%)**

4.1.4. Scenario 2: forego third alfalfa cutting

Scenario 2 presents results of a less constrained case as compared with scenario 1. The model simulates deficit irrigation of alfalfa during the summer and consequentially a reduction in the number of cuttings harvested from the crop. Total annual irrigation for alfalfa is reduced by one-third (33%) to reflect these conditions, and crop yield is assumed to respond linearly to deficit irrigation. Changes in yield are accounted for in the profitability of alfalfa when land allocations are made by the model and are also applied to the final assessment of gross crop revenues. To reflect changes in harvesting and cultural costs, all costs are also scaled linearly with yield reductions. Reductions in water use connected to deficit irrigation are assumed to be retained in the model, meaning that the water cannot be reallocated to the expansion of other crops beyond what is otherwise used.

This scenario results in minor fallowing of alfalfa land (2.9% of baseline alfalfa) due to the steep decrease in marginal value making it less attractive to grow in comparison with other options, a factor that also lowers the returns of the allocated alfalfa land. Some compensation occurs to account for profitability shifts, leading to minor expansions of some select crops (Figure 5). Fallowing totals 117 acres across the three valleys (0.1%) after considering alfalfa losses and expansion in other crops. Water use reductions total 21,620 acre-feet (9.8%) of which most occur in Butte and Scott where alfalfa is plentiful. Total net gross revenue losses after accounting for combined cropping pattern shifts come to $12.8 million (5.5%), distributed as $5.7 million, $5.1 million, and $1.9 million in Butte, Scott, and Shasta, respectively. As compared with scenario 1a, both gross revenue losses and water use reductions are similar, but total changes in agricultural land use are much lower. Figure 5 and Table 10 below provide more detailed results of the cropping patterns, water use reductions, and value associated with this scenario.

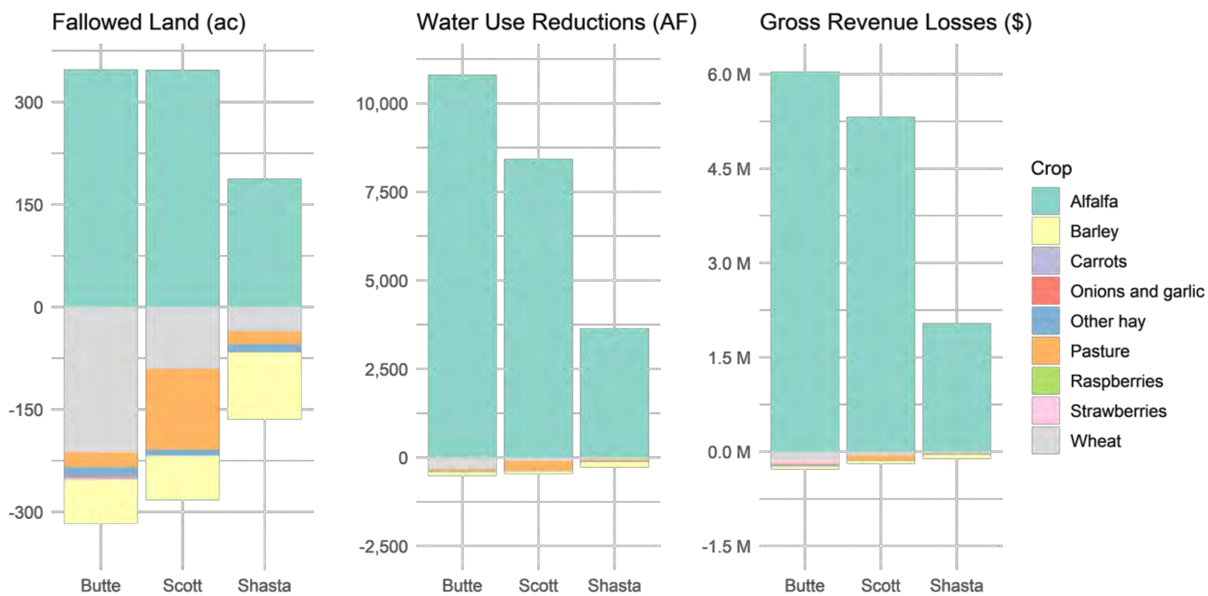

Figure 5: Results of land allocations, water use, and gross revenue differences from base for scenario 2, foregoing third cutting of alfalfa.

Table 10: Tabulated results of land allocations, water use, and gross revenues for scenario 2, foregoing third cutting of alfalfa.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	13,668	20,367	11.39
	Barley	1,525	2,296	1.00
	Carrots	317	662	1.17
	Onions and garlic	401	837	1.67
	Other hay	542	1,206	0.64
	Pasture	1,237	3,339	0.87
	Raspberries	140	465	8.10
	Strawberries	2,537	8,424	131.46
	Wheat	4,714	7,099	3.03
	Subtotal	**25,083 (-0.1%)**	**44,695 (-18.7%)**	**159.32 (-3.5%)**
Scott	Alfalfa	11,921	15,721	9.93
	Barley	1,480	1,602	0.97
	Other hay	555	1,092	0.65
	Pasture	14,067	32,307	9.85
	Wheat	1,974	2,136	1.27
	Subtotal	**29,996 (-0.2%)**	**52,859 (-13.1%)**	**22.66 (-18.5%)**
Shasta	Alfalfa	4,396	6,551	3.66
	Barley	3,879	5,841	2.55
	Other hay	1,671	3,717	1.96
	Pasture	30,661	82,754	21.46
	Strawberries	125	416	6.50

	Wheat	1,308	1,970	0.84
	Subtotal	**42,041** (-0.1%)	**101,250** (-3.2%)	**36.97** (-4.9%)
Three valleys	**Total**	**97,120** (-0.1%)	**198,803** (-9.8%)	**218.94** (-5.5%)

4.1.5. Scenario 3: 15% fallowing (adaptive)

Scenario 3 examines the expected impacts under a 15% land fallowing policy wherein cropping patterns can adapt to reduce the economic impacts. This scenario constrains the total land available to be allocated but does not prescribe fallowing in any given crop, meaning that the model is able to cut back in crops in such a way that minimizes farmer profit losses. Adaptive fallowing in this way assumes that there is some form of water trading which allows valuable crops to resist cutbacks because of some willingness to pay for scarce resources such as water.

Land fallowing totals 14,585 acres (15%) of which a large percentage (6,031 acres, 41.3%) consists of pasture reduction mostly in Shasta or Scott; remaining losses come in the form of alfalfa (4,101 acres, 28.1%), wheat (2,201 acres, 15.1%), barley (1,795 acres, 12.3%), and other crops (457 acres, 3.1%). Reductions in water use are slightly lower than land reductions by percentage, totaling 30,850 acre-feet (14.0%) across the three valleys. Gross revenue losses are in the order of $12.9 million (5.6%), distributed approximately equally across each of the valleys. Alfalfa receives the largest revenue loss of any crop ($5.1 million) followed by pasture ($4.2 million), and other minor crop losses representing the remaining economic impacts. Figure 6 and Table 11 below provide more detailed results of the cropping patterns, water use reductions, and value associated with this scenario.

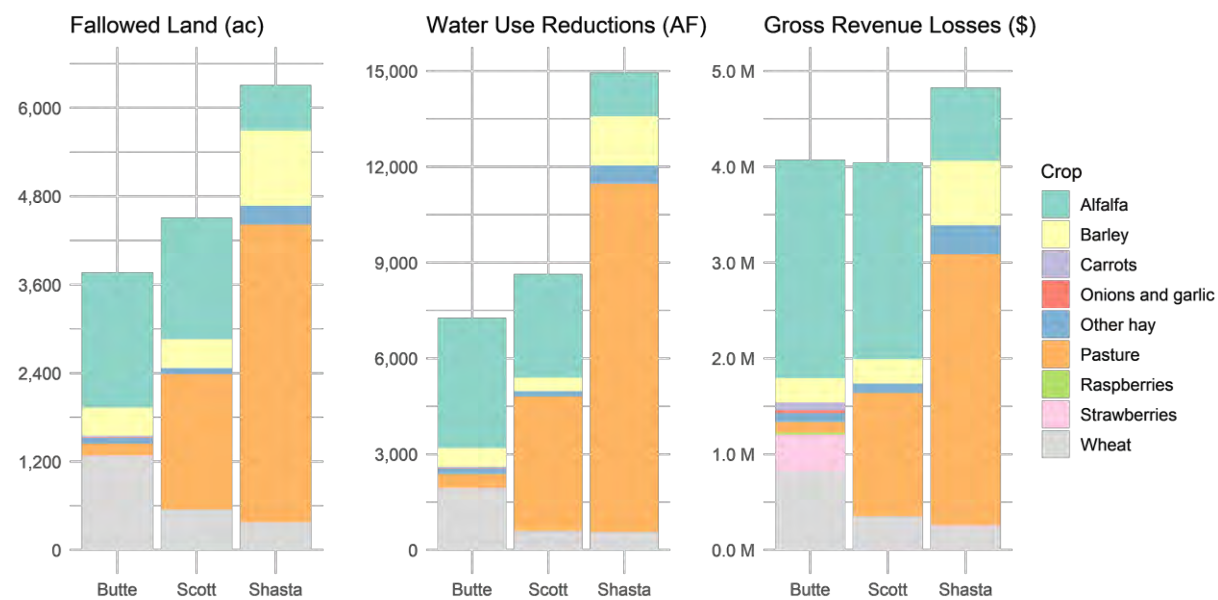

Figure 6: Results of land allocations, water use, and gross revenue differences from base for scenario 3, 15% fallowing of all cropland with adaptive management.

Table 11: Tabulated results of land allocations, water use, and gross revenues for scenario 3, 15% fallowing of all cropland with adaptive management.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	12,181	27,091	15.14

	Barley	1,078	1,623	0.71
	Carrots	291	607	1.08
	Onions and garlic	393	819	1.63
	Other hay	449	1,000	0.53
	Pasture	1,060	2,861	0.74
	Raspberries	140	463	8.08
	Strawberries	2,529	8,421	131.01
	Wheat	3,224	4,856	2.08
	Subtotal	**21,345 (-15.0%)**	**47,717 (-13.2%)**	**160.99 (-2.5%)**
Scott	Alfalfa	10,617	20,899	13.20
	Barley	1,025	1,109	0.67
	Other hay	462	909	0.54
	Pasture	12,114	27,822	8.48
	Wheat	1,333	1,443	0.86
	Subtotal	**25,551 (-15.0%)**	**52,182 (-14.2%)**	**23.75 (-14.5%)**
Shasta	Alfalfa	3,967	8,823	4.93
	Barley	2,758	4,154	1.81
	Other hay	1,403	3,120	1.64
	Pasture	26,601	71,796	18.62
	Strawberries	125	415	6.47
	Wheat	900	1,355	0.58
	Subtotal	**35,754 (-15.0%)**	**89,663 (-14.3%)**	**34.07 (-12.4%)**
Three valleys	**Total**	**82,651 (-15.0%)**	**189,562 (-14.0%)**	**218.81 (-5.6%)**

4.1.6. Scenario 4: 15% fallowing ("worst case")

Scenario 4 examines a similar land policy to that of scenario 3 (15% fallowing of all cropland) but restricts the model's ability to minimize losses. In this case all crop types are equally cut back by 15% without an implicit water trading potential. Removing the potential to shift cutbacks between crops leads to much more drastic economic losses compared to the previous scenario.

As a result of the restrictions imposed on the model, cutbacks across all categories (land, water use, and gross revenues) are all equal to the total fallowing percentage (15%) and do not change based on crop or region. Total fallow land remains at 14,585 acres as in scenario 3, distributed as 3,767 acres, 4,509 acres, and 6,310 acres lost in Butte, Scott, and Shasta, respectively. Water use reductions are slightly higher than the previous scenario, at 33,063 acre-feet. Agricultural revenue losses, however, are nearly three times higher than the adaptive scenario, totaling $34.8 million. Most revenue loss is attributed to reductions in strawberries and raspberries which value $21.9 million (62.9%) in combination; alfalfa and pasture make up most remaining value loss. Figure 7 and Table 12 below provide more detailed results of the cropping patterns, water use reductions, and value associated with this scenario.

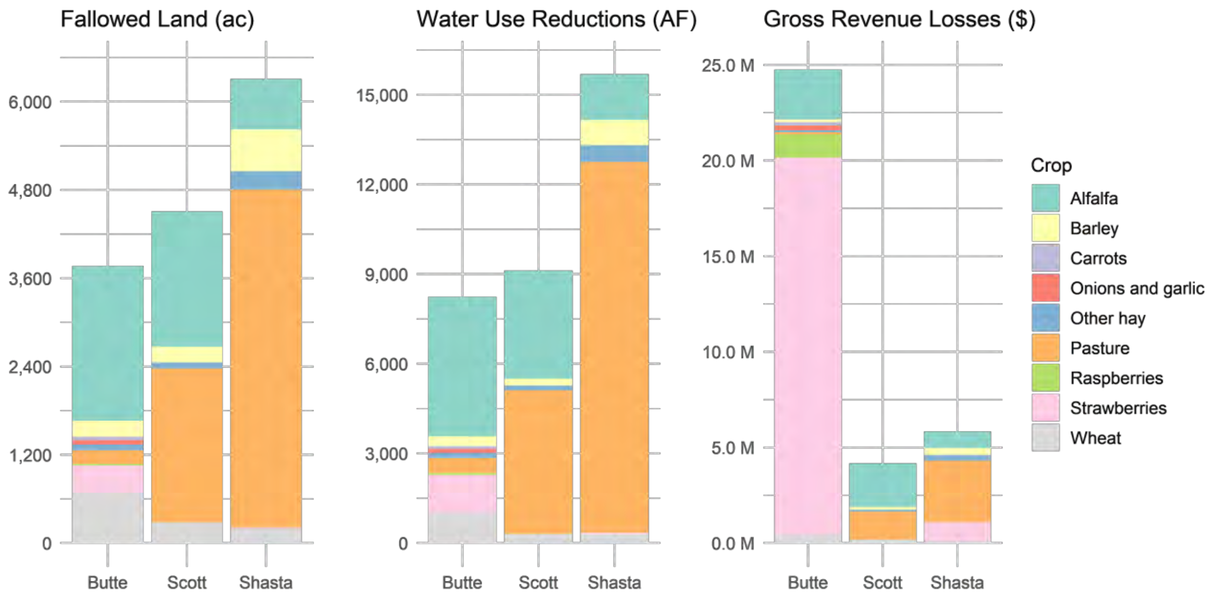

Figure 7: Results of land allocations, water use, and gross revenue differences from base for scenario 4, 15% fallowing of all cropland without adaptive management.

Table 12: Tabulated results of land allocations, water use, and gross revenues for scenario 4, 15% fallowing of all cropland without adaptive management.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	11,913	26,495	14.81
	Barley	1,241	1,869	0.82
	Carrots	266	556	0.99
	Onions and garlic	340	709	1.41
	Other hay	450	1,000	0.53
	Pasture	1,033	2,789	0.72
	Raspberries	119	395	6.88
	Strawberries	2,156	7,158	111.68
	Wheat	3,827	5,763	2.46
	Subtotal	**21,345 (-15.0%)**	**46,734 (-15.0%)**	**140.30 (-15.0%)**
Scott	Alfalfa	10,427	20,525	12.96
	Barley	1,203	1,302	0.79
	Other hay	464	914	0.54
	Pasture	11,856	27,229	8.30
	Wheat	1,601	1,733	1.03
	Subtotal	**25,551 (-15.0%)**	**51,703 (-15.0%)**	**23.62 (-15.0%)**
Shasta	Alfalfa	3,896	8,665	4.84
	Barley	3,213	4,839	2.11
	Other hay	1,411	3,137	1.65
	Pasture	26,046	70,298	18.23
	Strawberries	107	354	5.52
	Wheat	1,082	1,629	0.70
	Subtotal	**35,754 (-15.0%)**	**88,922 (-15.0%)**	**33.06 (-15.0%)**
Three valleys	**Total**	**82,651 (-15.0%)**	**187,358 (-15.0%)**	**196.99 (-15.0%)**

4.1.7. Scenario 5: 15% water shortage (adaptive)

Scenario 5 follows a similar concept and realization to that of scenario 3, however, restrictions are made more broadly to water as opposed to land availability. Under this scenario the model is again allowed flexibility in allocating land to crops and minimizing economic losses. Trends in overall resource use remain roughly the same as they were in the results of scenario 3 with minor differences in land allocation due to variability in unit water demand across crop types.

Fallowed land totals 13,848 acres across the three valleys and is composed primarily of alfalfa and pasture, with less severe cutbacks in barley and wheat owing to the lower unit water demands of these crops. In summary, total land fallowing is reduced compared with scenario 3, but targets towards higher water use crops. Water use reductions total of 32,760 acre-feet (15%). Changes in gross revenue losses are minimal compared with the land-limited scenario, and total $13.0 million. Both scenario 3 and 5 see much more evenly distributed economic impacts as compared to scenario 4, which experiences almost all effects in Butte Valley because of losses in berry plant transplant crops.

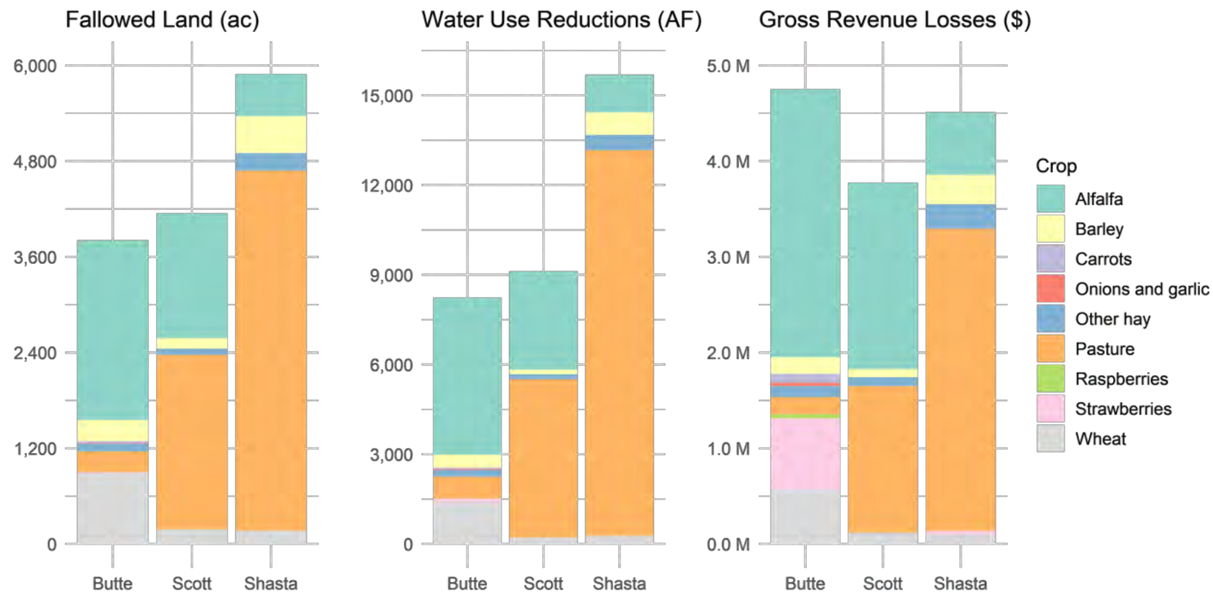

Figure 8: Results of land allocations, water use, and gross revenue differences from base for scenario 5, 15% total water shortage with adaptive management.

Table 13: Tabulated results of land allocations, water use, and gross revenues for scenario 5, 15% total water shortage with adaptive management.

Region	Crop	Land (ac)	Water use (AF)	Gross revenue ($ million)
Butte	Alfalfa	11,765	25,903	14.63
	Barley	1,193	1,779	0.78
	Carrots	288	595	1.07
	Onions and garlic	392	809	1.63
	Other hay	431	949	0.51
	Pasture	959	2,563	0.67
	Raspberries	139	458	8.06
	Strawberries	2,522	8,290	130.65
	Wheat	3,614	5,388	2.33

	Subtotal	**21,303 (-15.2%)**	**46,734 (-15.0%)**	**160.31 (-2.9%)**
Scott	Alfalfa	10,702	20,854	13.31
	Barley	1,284	1,376	0.84
	Other hay	466	909	0.55
	Pasture	11,761	26,742	8.23
	Wheat	1,700	1,822	1.09
	Subtotal	**25,914 (-13.8%)**	**51,703 (-15.0%)**	**24.02 (-13.6%)**
Shasta	Alfalfa	4,057	8,933	5.04
	Barley	3,316	4,943	2.18
	Other hay	1,441	3,172	1.69
	Pasture	26,129	69,817	18.29
	Strawberries	125	410	6.47
	Wheat	1,104	1,647	0.71
	Subtotal	**36,172 (-14.0%)**	**88,922 (-15.0%)**	**34.38 (-11.6%)**
Three valleys	**Total**	**83,389 (-14.2%)**	**187,358 (-15.0%)**	**218.71 (-5.6%)**

4.1.8. Scenario 6: exploring economic tradeoffs between alfalfa and strawberries in Butte Valley

Strawberry plants for transplant are a particularly unique specialty crop grown in Butte Valley due to their high value and importance in supporting downstream berry production on the Central Coast. As such, these crops pose an opportunity for generating great economic value with less land and water resource use – suggesting that conversion of other crops to strawberries may have benefits for managing water use while maintaining agricultural value. Given that alfalfa is the dominant crop by area in the valley (55.8%) and is relatively low value compared to nursery berries, this scenario explores tradeoffs in converting between these two crops.

In this analysis, the marginal revenue of an acre of transplant strawberry plants is estimated to be about $51,800 and the crop is estimated to operate with a 15% profit margin after costs are considered. Irrigation needs for strawberries are estimated at 3.32 AF/ac per year. Alfalfa is estimated to have a marginal revenue of $1,240/ac with a 5% profit margin and irrigation needs of 2.22 AF/ac per year in Butte Valley. Assuming constant returns to scale within both crop groups, about 42 acres of alfalfa produce the same gross revenue as 1 acre of nursery strawberries but use significantly more water in the aggregate.

Tables 14 and 15, below, outline possible options for retiring alfalfa in favor of transplant strawberries. The first strategy focuses on maintaining or expanding value while maximizing resource reductions (1:40 ratio of strawberries to alfalfa). The second strategy replaces alfalfa with strawberries at a higher rate (5:40 ratio of strawberries to alfalfa) in favor of economic expansion. These scenarios recognize the rotations exercised in growing transplant strawberry plants, which are understood to typically operate in 3-year rotations of strawberry-grain-fallow with roughly equivalent acreages of each at any given time. Based on this production model, for each acre of transplant strawberries planted, 1 acre of grain is planted, and 1 acre is set aside as fallow for the rotation with land, water use, and revenue impacts reflecting these conditions.

Table 14: Conservative strategy for converting alfalfa to strawberries (1:40 ratio of strawberries to alfalfa) focused on water use reductions.

Alfalfa fallowed (ac)	Strawberries planted (ac)	Grain planted (ac)	Fallow reserved (ac)	Land reductions (ac)	Water reductions (AF)	Revenue impact ($)
200	5	5	5	185	421	+13,570
400	10	10	10	222	505	+16,284
600	15	15	15	259	589	+18,998
800	20	20	20	296	673	+21,712
1000	25	25	25	333	757	+24,426

Table 15: Progressive strategy for converting alfalfa to strawberries (5:40 ratio of strawberries to alfalfa) focused on economic expansion.

Alfalfa fallowed (ac)	Strawberries planted (ac)	Grain planted (ac)	Fallow reserved (ac)	Land reductions (ac)	Water reductions (AF)	Revenue impact ($)
200	25	25	25	125	324	+1,062,443
400	50	50	50	150	389	+1,274,931
600	75	75	75	175	454	+1,487,420
800	100	100	100	200	519	+1,699,909
1000	125	125	125	225	583	+1,912,397

One consideration to make when examining conversion of alfalfa to higher value crops such as strawberries is the limit on strawberry expansion; consistent with PMP modeling which limits crop specialization, it is typically assumed that valuable crops that are observed to be grown in relatively low amounts are constrained by production conditions and upfront costs aside from profitability. For example, soils used in pasture are often less suitable to grow more sensitive crops such as vegetables because of nutrient deficiencies or soil composition. However, because transplant strawberries in Butte Valley are grown in nursery conditions, this may lend itself to better control of production conditions that might otherwise prevent expansion under natural cultivation practices. Expansion of nursery strawberry production is limited by several additional factors including labor availability and high upfront investment in technical knowledge and infrastructure. Many of the farmers currently involved in this sector have accumulated generational knowledge pertaining to management and business practice which are seen for other crops in the county but require fewer capital investments. These scenarios propose minor expansion of transplant berries by area in recognition of the challenges noted by farmers in this sector that currently prevent significant expansion from occurring.

4.1.9. Scenario 7: exploring lower water use alternatives to alfalfa and pasture

Among the crops cultivated in the three valleys examined for this study of Siskiyou County agriculture, pasture and alfalfa are the largest drivers of water demand, both at the aggregated and unit production scales. There is an interest in exploring the role that these crops play in the context of water use as well as economic value. This scenario examines potential for land use tradeoffs involving these crops with the goal of reducing water use while maintaining gross returns. It is worthwhile noticing alfalfa and pasture support downstream agricultural sectors such as the dairy and beef cattle industry, which may be impacted by higher feed crop costs resulting from a reduction in the local supply of irrigated pasture and alfalfa. Intermountain alfalfa is also known for its higher quality and is used as feed in more specialized animal operations beyond dairies and beef cattle.

Under baseline conditions, alfalfa covers roughly 32% of agricultural land across the three valleys while pasture makes up an additional 47% of crop cover. Alfalfa is mostly concentrated in Butte and Scott and pasture composes a majority of land use in Shasta. Unit water use for alfalfa is estimated at 2.22 acre-feet/acre in Butte and Shasta and 1.97 acre-feet/acre in Scott. Pasture is estimated to require 2.70 acre-feet/acre in Butte and Shasta and 2.30 acre-feet/acre in Scott. In the aggregate, these two crops contribute 83% of total water demand for the three valleys, of which 30% is attributed to alfalfa and 53% to irrigated pasture. Siskiyou does not have as stark of contrasts in unit water use between crops as other regions in California, where it is common to see grains with sub- 2 acre-feet/acre irrigation needs grown alongside alfalfa or almonds requiring over 4.5 acre-feet/acre in annual irrigation. However, there is still significant differences in unit demands which suggest opportunities for improving economic efficiency in applied water.

Table 16 below provides a baseline for comparison between water use and value for crops grown within each of the three valleys. This table serves to highlight opportunities for conversion between crop types in the interest of water management benefits. For example, wheat and barley offer some tradeoff from pasture and alfalfa for lowering total water demand at the expense of reduced agricultural revenue. Alfalfa demands roughly 1.5 times the irrigation of wheat or barley (per acre) but has nearly double the marginal value of these crops. In the Scott River Valley, where irrigation demands tend to be lower, each of these crops has comparable value per unit of applied water ($/acre-feet), however, in Butte and Shasta the economic return of water for grain crops is about 25% lower than that of alfalfa. Pasture, on the other hand, has both the highest unit water demands of any crop in the three valleys as well as the lowest value per unit of applied water. Marginal values for pasture are comparable to grain crops. Crops such as carrots and onions are suitable to be grown in Butte and have higher marginal value both per unit of land and water as compared with alfalfa or pasture. However, these crops are observed to be grown in only small amounts (approximately 400 acres at most), suggesting that other production factors may constrain their expansion despite higher value than alternatives. Likewise, transplant berries have higher water demands than alfalfa, carrots, or onions, but are vastly more valuable than other crops grown within the valley.

Table 16: Unit water use, marginal value, and economic efficiency of applied water for crops in Butte Valley.

Crop	Region	Unit water use (AF/ac)	Marginal value ($/ac)	Marginal value / unit water ($/AF)
Alfalfa	Butte/Shasta	2.22	1,243	559
Alfalfa	Scott	1.97	1,243	632
Barley	Butte/Shasta	1.51	658	437
Barley	Scott	1.08	653	603
Carrots	Butte	2.09	3,699	1,773
Onions and garlic	Butte	2.09	4,150	1,989
Other hay	Butte/Shasta	2.22	1,172	527
Other hay	Scott	1.97	1,172	596
Pasture	Butte/Shasta	2.70	700	259
Pasture	Scott	2.30	700	305
Raspberries	Butte	3.32	57,857	17,427
Strawberries	Butte/Shasta	3.32	51,800	15,602

Wheat	Butte	1.51	644	427
Wheat	Scott	1.08	644	595

4.2. Spillover effects of land and water use decisions

Table 17 lists spillover effects related to changes in the agricultural sector revenues within the County's economy based on the scenarios outlined above. We employed IMPLAN (https://www.implan.com/), an input-output model which allows estimation of broader impacts on employment, gross revenues and after sector-specific economic events, such as land fallowing or crop shifting. IMPLAN estimates direct, indirect, and induced effects. The direct effects correspond to the changes in revenues with respect to baseline (2018) conditions in crop farming. As various crops see reductions or changes in acreage, such changes indirectly affect production inputs including farm labor, agrochemicals, farm services and others. These are known as indirect effects. As agriculture and agriculture-related sectors face some impacts in gross revenues, households and government also face income impacts in what is known as an induced or second round effect. Altogether, direct, indirect, and induced impacts constitute the total or multiplier effect which is reported in this section for gross revenues (or output), value added (close to gross domestic product), and employment (full and part time jobs).

Scenario 1c shows the highest losses in all economic categories, resulting in $56 million in direct, indirect, and induced revenue losses, nearly $43 million in value added losses, and 393 fewer jobs in agriculture and all other sectors. Scenarios such as 3 or 4 are likely more realistic because they do not prescribe responses in specific crop categories, with scenario 3 assuming water trading allows retentions of higher value crops at the cost of deeper cutbacks in low value crops, and scenario 4 assuming all crops receive equal cutbacks. Management practices under water shortages would likely fall somewhere between these cases, representing slightly less aggressive water trading. Scenario 3 suggests total output losses of $17 million, $13 million in value added losses, and 120 fewer jobs. Meanwhile, scenario 4 falls closer to the extreme of scenario 1c with $46 million total revenue losses, $35 million in value added losses, and 323 fewer jobs. Other scenarios tend to fall within a similar range of economic impacts as those suggested by scenario 3.

Table 17: Combined direct and indirect regional economic impacts (IMPLAN results) for all scenarios.

Scenario	**Region**	**Lost output ($ million)**		**Lost value added ($ million)**		**Lost jobs (#)**	
		Direct	**Total**	**Direct**	**Total**	**Direct**	**Total**
Scenario 1a	Three valleys	10.57	14.05	5.82	10.68	71	98
	Butte	2.74	3.65	1.51	2.77	18	25
	Scott	3.75	4.99	2.07	3.79	25	35
	Shasta	4.07	5.42	2.24	4.12	27	38
Scenario 1b	Three valleys	21.13	28.11	11.65	21.36	142	197
	Butte	5.48	7.29	3.02	5.54	37	51
	Scott	7.50	9.98	4.14	7.59	51	70
	Shasta	8.14	10.83	4.49	8.23	55	76
Scenario 1c	Three valleys	42.26	56.21	23.30	42.72	285	393
	Butte	10.97	14.58	6.04	11.08	74	102
	Scott	15.01	19.96	8.27	15.17	101	140
	Shasta	16.29	21.66	8.98	16.46	110	151
Scenario 2	Three valleys	12.79	17.01	7.05	12.93	86	119
	Butte	5.74	7.63	3.16	5.80	39	53

	Scott	5.13	6.82	2.83	5.18	35	48
	Shasta	1.92	2.55	1.06	1.94	13	18
Scenario 3	Three valleys	12.94	17.21	7.13	13.08	87	120
	Butte	4.07	5.42	2.24	4.12	27	38
	Scott	4.04	5.38	2.23	4.09	27	38
	Shasta	4.83	6.42	2.66	4.88	33	45
Scenario 4	Three valleys	34.76	46.23	19.16	35.14	234	323
	Butte	24.76	32.93	13.65	25.03	167	230
	Scott	4.17	5.54	2.30	4.21	28	39
	Shasta	5.83	7.76	3.22	5.90	39	54
Scenario 5	Three valleys	13.04	17.34	7.19	13.18	88	121
	Butte	4.75	6.32	2.62	4.80	32	44
	Scott	3.77	5.02	2.08	3.82	25	35
	Shasta	4.51	6.00	2.49	4.56	30	42

Figure 9 summarizes the economic losses considering spillover effects in the regional economy for each scenario along with the average value lost per unit of water reductions. Scenario 1c, prescribing a large cutback (60%) in alfalfa and pasture cultivation, shows the greatest total economic output reduction at $56 million. Following closely in total output reduction is scenario 4 with $46 million, in which all crops receive an equal cutback of 15%. Scenarios 1a, 2, 3, and 5 are all found to have similar output impacts in the order of about $15-20 million. Average output losses per unit of reduced water is consistent across most scenarios at approximately $500/acre-foot. Scenario 2 has slightly higher value losses per unit of water because of the additional value lost from reduced alfalfa yield. Scenario 4 exhibits almost triple the average value lost per unit of water compared with other scenarios ($1,400/acre-foot) because of the higher marginal value of transplant berries.

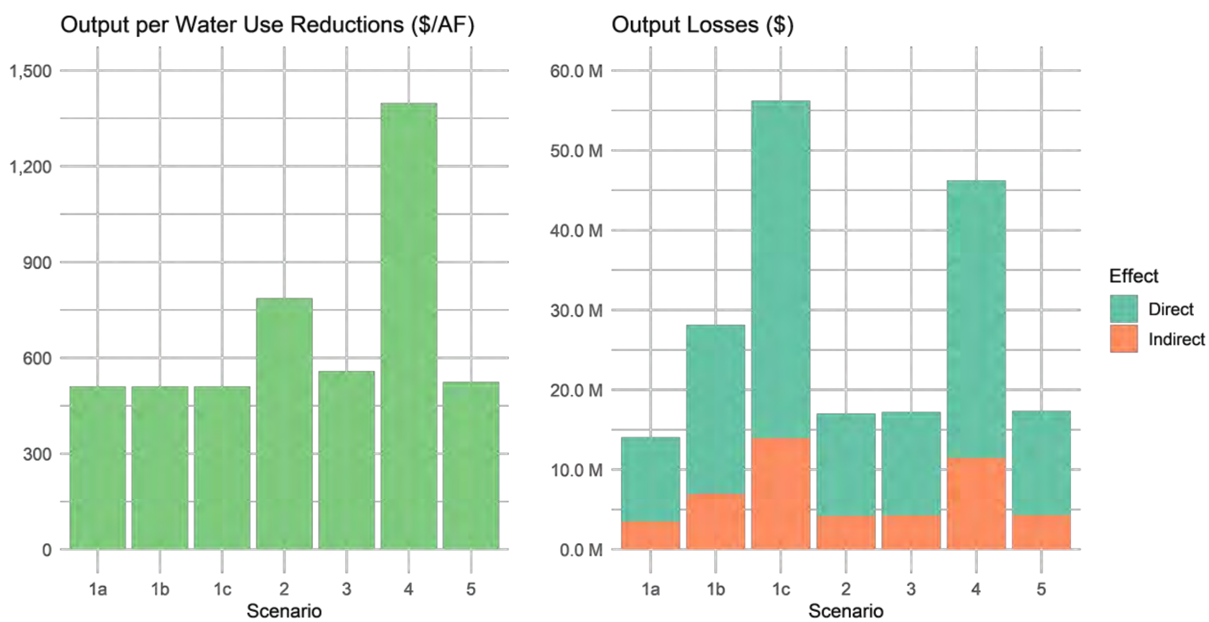

Figure 9: IMPLAN combined spillover effects and average value per unit of water reductions by scenario.

4.3. Economic value of instream flows in the Klamath Basin

Various studies and research reports exist for estimating value of water instream flows in the Klamath River Basin. Kruse and Scholz (2006) estimate a range of net costs for the removal of 4 dams in the Klamath Basin and benefits from temporary employment in the removal and non-use water value with many other costs and benefits unknown. The authors provide an estimate of $172 million in benefits from dam deconstructions, and increased tourism and visitors, and a cost of $2 million for the loss of jobs from the hydropower project. In addition, it is estimated a $104 million benefit from non-use value per year. Considering a flow mean annual flow of 13 million acre-feet in the Klamath River, the estimate in use value is in the order of $8 per acre-foot. This figure does not include the benefits of groundwater dependent ecosystems, fisheries, tourism, tribal, water supply increased reliability and other beneficial uses included in the $172 million above that do not have a direct association to the instream flow gains or change in patterns from dam removal. Yet the study demonstrates values exist for environmental flows and should be weighed against costs of water diversions.

4.4. Limitations of analysis

As with most models, the scenario results shown in this report merit recognition of some limitations. First, data availability on crop production represents average production conditions which rarely occur in specific commodities. Size distribution of farms influences activities and productivity and crop attributes that might also have an influence on crop prices and yields in specific market niches. This also influences the profits from farming. Nevertheless, a representation of the aggregate of production at the county level can still provide useful insights for planning and policy analysis. Second, a profit maximizing behavior and costless water exchanges within each of the valleys are assumed to occur. Thus, results may represent a reasonable lower bound for economic costs of water reductions. Lastly, crops in Siskiyou County have an influence that extends beyond the county boundaries as these are exported or serve as inputs to other sectors including animal operations and food processing. Estimates of these impacts is not estimated in this study yet for most of the scenarios modeled decreases in feed crops will result in higher costs to local ranchers in the dairies and beef cattle sectors which may intermittently or permanently reduce herd sizes to cope with higher production costs and maintain profitability. Animal operations represent roughly 20% of both crops and animal agricultural value in Siskiyou County, thus reductions in their total output due to higher costs should not be ignored. Something similar occurs for transplant berries, which provide inputs to other areas that grow specific commodities into end-products for wholesale or retail. Yet due to their value and profit margins, water shortage price increases from traded water or more expensive water could be absorbed easier than in other sectors. With these limitations in mind, this report may provide insights for discussion of paths forward in water management for Siskiyou County.

5. Conclusions

This report provides costs of agricultural land and water use decisions in selected cropping regions within Siskiyou County and contributes to an improved quantitative understanding of tradeoffs associated with such decisions. Some conclusions arise from this work.

1) Agriculture in Siskiyou County within the Butte, Scott River and Shasta Valleys in our baseline year accounts for 97,000 acres, using roughly 220,000 acre-feet of water per year and generating $231 million in direct gross revenues.

2) The agricultural crop mosaic in these three valleys differ substantially both in the selection of crops and access to water resources. Butte Valley holds the smallest agricultural footprint by area with about 25,000 acres but contributes the greatest value of the three regions owing to the production of berry plants for transplant. Scott River Valley contains about 30,000 acres of cropland consisting primarily of alfalfa and pasture. Shasta Valley has about 42,000 acres of cropland and is mostly pasture. Across the three valleys together, alfalfa and pasture account for 32% and 47%, respectively, of total cropland.
3) A range of scenarios for land and water management was analyzed. Scenarios 1a (15% fallowing alfalfa and pasture), 2 (forego third alfalfa cutting), 3 (15% fallowing, adaptive), and 5 (15% water shortage, adaptive) are expected to result in comparable revenues losses in the order of $10-13 million before considering spillover effects or $15-20 million in related sectors. Scenario 4 (15% fallowing, "worst case") results in the most extreme economic impact with an estimated $35 million in losses stemming in large part from transplant berry reductions. Scenarios 1b and 1c form an intermediate between other scenarios but concentrate impacts on alfalfa and pasture.
4) A 15% reduction in water across the board for all crops can potentially result in direct costs of $35 million for Butte, Scott River, and Shasta Valleys, and 234 jobs lost. When the multiplier effects are accounted for, sector output losses total $46 million and 323 jobs. The cost of applied water reductions in this scenario is about $1,400 per acre-foot when considering direct and indirect sectors.
5) Allowing trading within the valleys for up to 15% applied water reductions substantially decreases economic costs of water use reductions down to $13 million in sector output, and when spillover effects are accounted for such impacts can be as high as $17 million for sector output and 120 jobs. This highlights the potential gains from trading water across commodities to lower economic impacts.
6) Scenarios focusing on resource use reductions in alfalfa and pasture tend to concentrate economic impacts on Shasta Valley, followed by Scott River Valley and finally Butte Valley which generates much of its value from berries for transplant. However, when assessing alfalfa centric scenarios such as foregoing a third cutting (scenario 2), this trend reverses and Butte and Scott River Valleys experience much of the losses. Scenarios which prescribe general reductions in land or water use and allow for adaptive fallowing (scenarios 3 and 5) have nearly equal impacts across each of the regions. When water trading is prohibited and crops experience equal reductions (scenario 4), aggregate impacts become highly concentrated in Butte Valley owing to the exceptional value of berry plants for propagation.
7) Effects from crop production changes into downstream sectors such as dairies and beef cattle and the food processing industry can be sizeable for large enough reductions in crop production and depending on the downstream sector's response to local crop commodity shortages these estimates may merit further investigation.

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