Specialists in Agricultural Water Management
Serving Stewards of Western Water since 1993

Technical Memorandum (TM)

To: Larry Walker Associates

From: Davids Engineering, Inc.

Date: November 11, 2020

Subject: **DRAFT Monitoring Results of Shallow Piezometer Transect Study from May 2020 through October 2020 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) lay within the alluvial portion of the Little Shasta Valley. These piezometers, along with the rivers, were instrumented to continuously monitor water surface elevations and temperatures in and adjacent to surface water features. 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. The monitoring results from May through October 2020 indicated that the Shasta River was 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 until 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 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.

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

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

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 valleywide groundwater system 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 river bank, 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 six-month period from May through October 2020[2] along with a discussion of results and recommendations.

Methodology

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 or not 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.

[2] The last site visit to obtain data was completed on October 12, 2020. The October data only represents the first 12 days of the month.

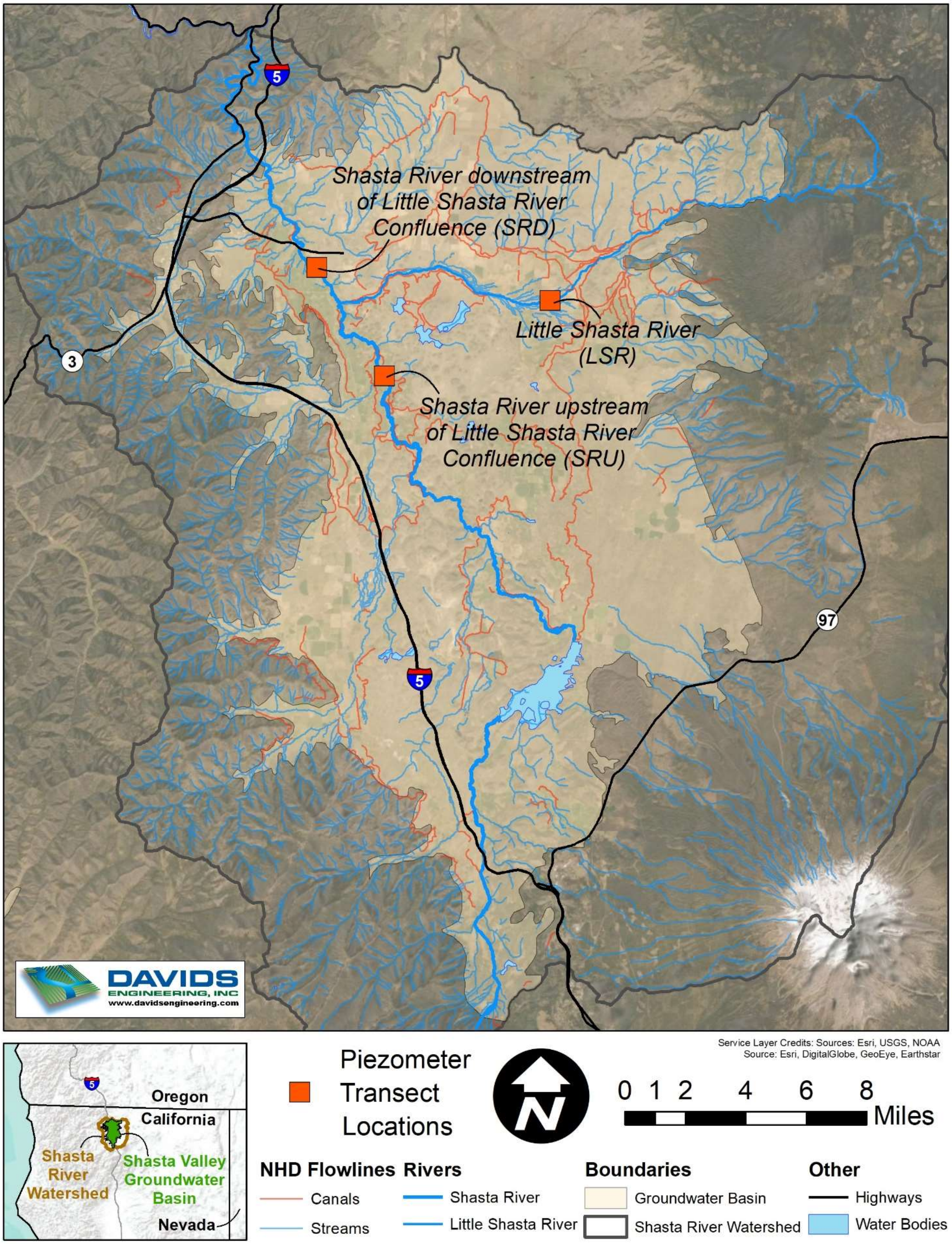

Figure 1. Approximate Location of Piezometer Transects within Shasta Valley.

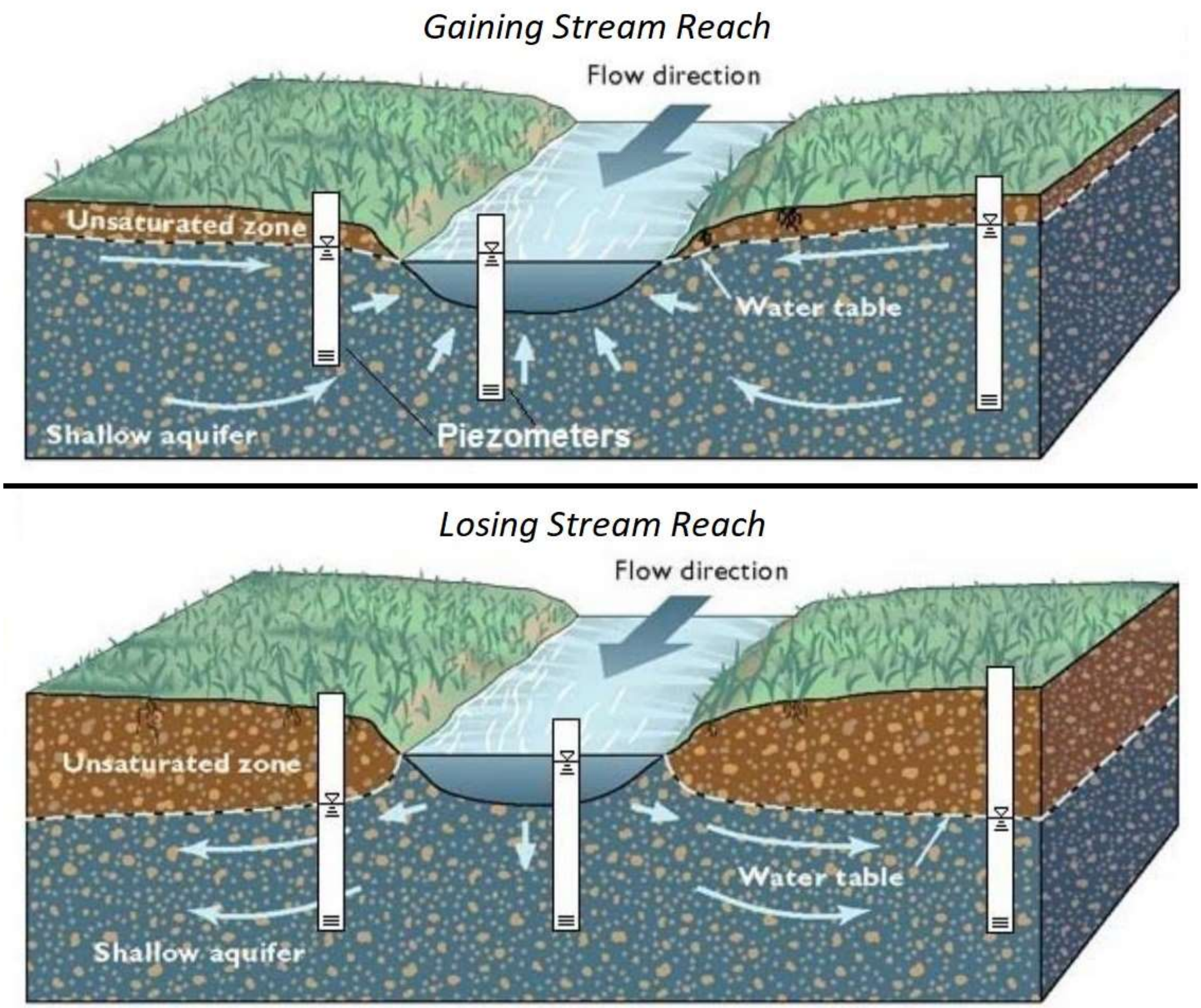

Figure 2. Conceptual Diagram of Piezometers in Gaining and Losing Stream Reaches (Modified from Winter et al., 1999).

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.

Study Design, Initiation, and Implementation

Piezometer Construction, Equipment Installation, Site Commissioning and Maintenance

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, stand pipes, filter pack, surface seals, and well caps, by Lawrence & Associates[3] 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[4]. 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 from the start of the study through October 12, 2020 presented in this TM also underwent additional review and QA/QC measures.

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.

[3] www.lwrnc.com

[4] 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 stand pipe 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[5], 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

[5] 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

Results and Discussion

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 values of water surface elevation and temperature for all 15 measurement sites.

Shasta River Upstream of Little Shasta River Confluence (SRU)

Figures 3 and 4 on the following page show the daily average values of water surface elevation and temperature for the five monitoring sites at the SRU transect. 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 October 2020.

The river stage remained steady during this period, with fluctuations in stage of less than one foot. There was an increase in stage in late September and early October, potentially coinciding with the end of the irrigation season and cessation of upstream diversions. Groundwater elevations in the piezometers on both sides of the river tended to be higher than the surface water elevation 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 throughout the study period. 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. 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 irrigation events.

As expected, the surface water temperature in the Shasta River showed the greatest fluctuations and tended to be highest compared to other locations within the transect. Although fluctuating with weather conditions, sun exposure, and ambient air temperature, it generally increased to a seasonal peak around 70˚F in July, and then decreased to a temperature lower than the initial temperature at the beginning of the study in early May. Groundwater temperatures at the start of the study period were lower than the surface water temperature, although the RBN temperature was higher than at other sites and closely matches minimum surface water temperatures in early May. 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. Groundwater temperatures tended to increase several degrees Fahrenheit over the course of the study period. The piezometers along the left bank of the river showed more minimal increases than those along the right bank of the river. At the end of the study period on October 12th, the surface water temperature was lower than all of the groundwater temperatures, the opposite of conditions at the start of the study period on May 1st.

With the exception of the RBN piezometer in late July and early August, all piezometers showed higher water surface elevations during the study period. Groundwater temperatures also tended to be lower than surface water temperatures for a majority of the study period, and did not show strong responses to surface water temperature fluctuations. These results indicate that the Shasta River was gaining in the transect location over the study period.

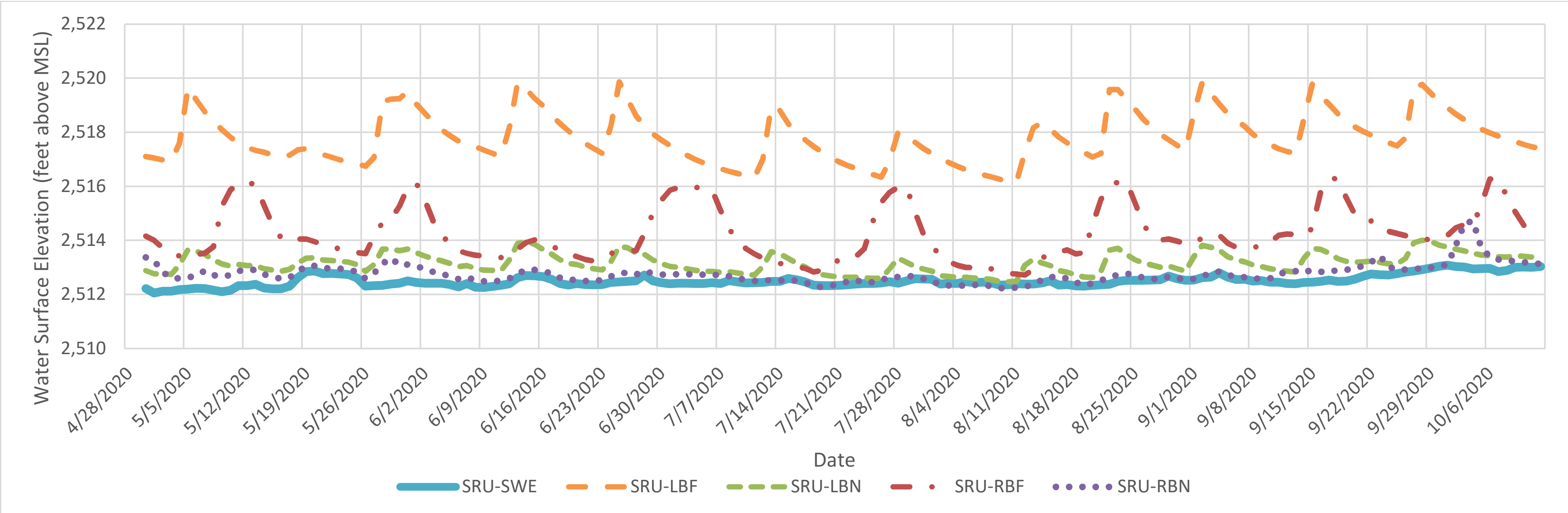

Figure 3. Daily Average Water Surface Elevations at Shasta River Upstream of Little Shasta River Confluence (SRU) Transect.

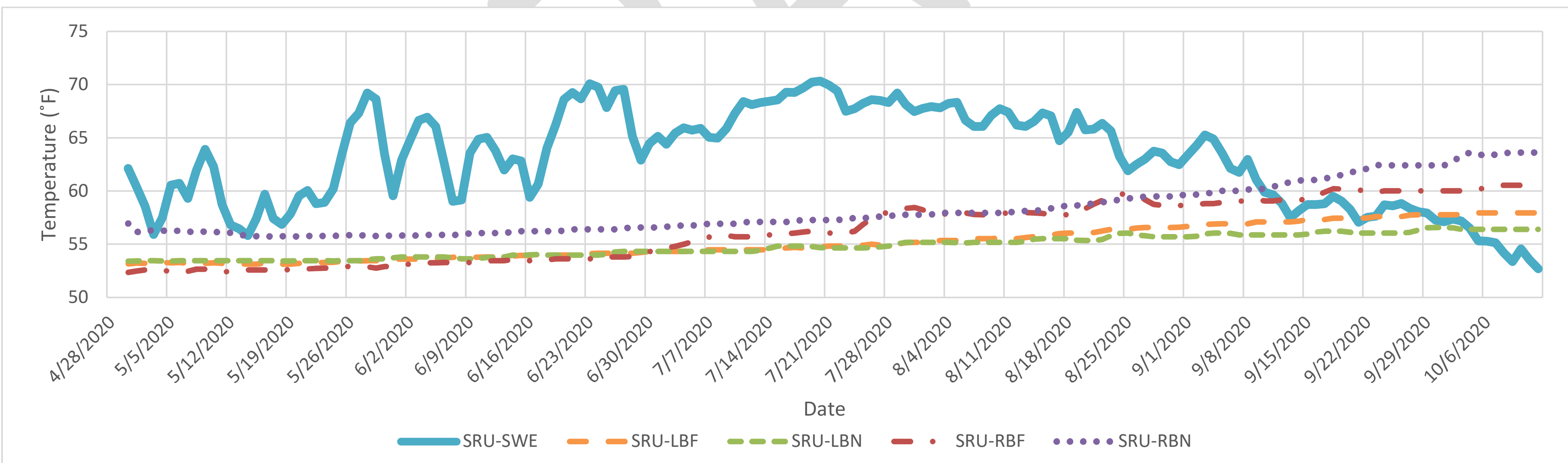

Figure 4. Daily Average Temperatures at Shasta River Upstream of Little Shasta River Confluence (SRU) Transect.

Shasta River Downstream of Little Shasta River Confluence (SRD)

Figures 5 and 6 on the following page show the daily average values of water surface elevation and temperature for the five monitoring sites at the SRD transect. 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 October 2020.

The river stage remained steady during the study period, excluding fluctuations in May. There was also an increase in stage in late September and early October, potentially coinciding with the end of the irrigation season and cessation of upstream diversions. Groundwater elevations in the piezometers on both sides of the river tended to be higher than the surface water elevation through most of the study period, with elevations increasing with distance from the river. At the LBF location, there were sharp increases in water surface elevation periodically throughout the study period followed by a more gradual decrease after the increase peaked. In mid-June, groundwater levels began decreasing on both sides of the river. On the right bank, they decreased roughly 0.5 to 1.0 feet until mid-July when they stabilized. On the left bank, they decreased roughly 1.5 to 2.0 feet until late September. Groundwater levels on both sides of the river increased in late September and early October, similar to surface water elevation. Additionally, the LBN groundwater elevation was lower than the surface water elevation from mid-August through late September and the LBF groundwater elevation decreased below the surface water elevation twice. At the nearer piezometers on both sides of the river, the fluctuations seen appeared to align with fluctuations at the further piezometers. The lands on either side of the river in this transect location were irrigated; increases in groundwater levels observed in piezometers were likely reflective of irrigation events.

As expected, the surface water temperature in the Shasta River showed the greatest fluctuations and tended to be highest compared to other locations within the transect. Although fluctuating with weather conditions, sun exposure, and ambient air temperature, it generally increased to a seasonal peak around 74˚F in July, and then decreased to a temperature lower than the initial temperature at the beginning of the study in early May. Groundwater temperatures at the start of the study period were lower than the surface water temperature, and temperatures along the right bank were higher than those along the left bank. Groundwater temperatures tended to increase by roughly 5-10 ˚F over the course of the study period. The LBF piezometer showed a different seasonal trend than the other three piezometers; its temperature increased more rapidly, peaked around 61 ˚F in mid-September, and was decreasing by October. At the end of the study period on October 12th, the surface water temperature was lower than all of the groundwater temperatures, the opposite of conditions at the start of the study period on May 1st.

With the exception of the LBN piezometer from mid-August to mid-September, piezometers tended to show higher water surface elevations during the study period. Groundwater temperatures also tended to be lower than surface water temperatures for a majority of the study period, and did not show strong responses to surface water temperature fluctuations, although the LBF temperature appeared to be influenced by something distinct from the other sites. These results indicate that the Shasta River was generally gaining in the transect location over the study period, with some potential losses to the aquifer adjacent to the left bank in the late summer.

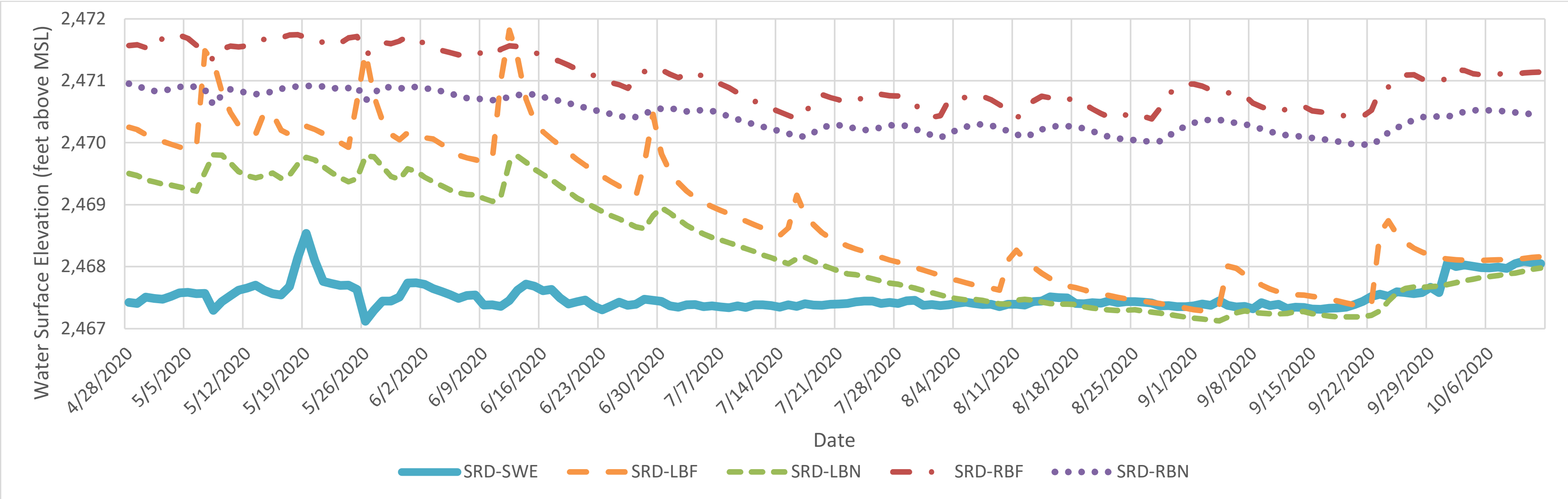

Figure 5. Daily Average Water Surface Elevations at Shasta River Downstream of Little Shasta River Confluence (SRD) Transect.

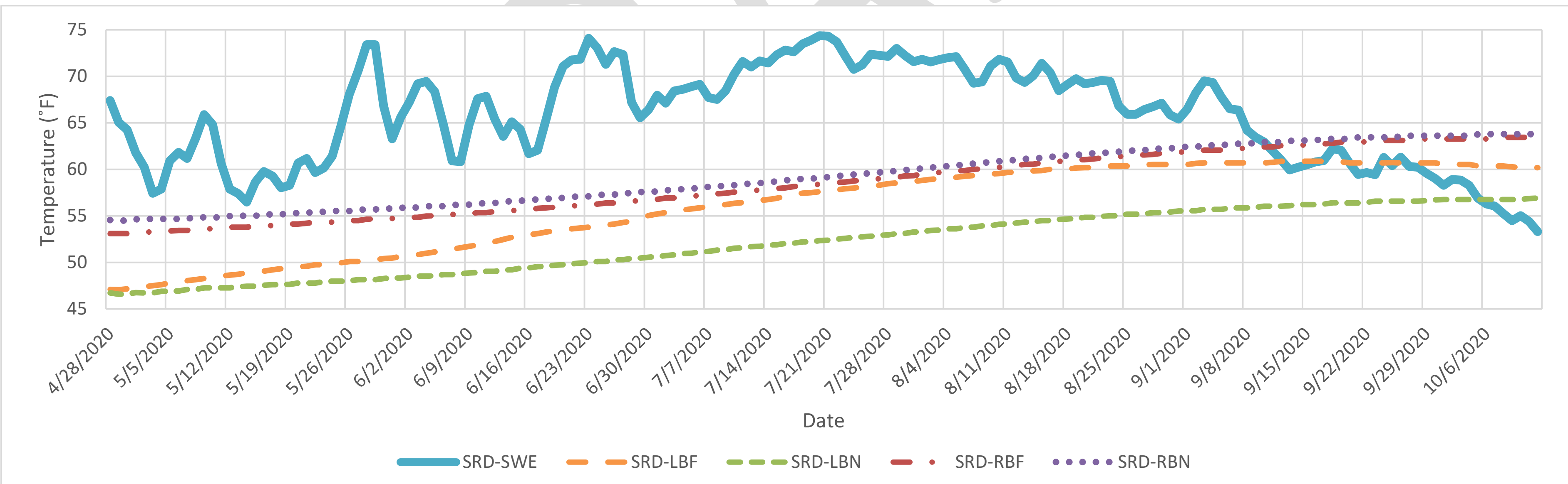

Figure 6. Daily Average Temperatures at Shasta River Downstream of Little Shasta River Confluence (SRD) Transect.

Little Shasta River in the Little Shasta Valley (LSR)

Figures 7 and 8 on the following page show the daily average values of water surface elevation and temperature for the five monitoring sites at the LSR transect. 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. 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 through the study period.

The river stage remained relatively steady until beginning to decline in late June and early July. During a monthly site visit on June 16th the river was noted to have continuous flow, but during the next site visit on July 17th it was noted that surface water was only present in isolated pools. On August 22nd 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. Groundwater elevations in the piezometers on both sides of the river tended to be lower than the surface water elevation throughout the study period.

During May and early June, 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 speaking, groundwater levels were declining during the study period. 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 stand pipe during the study period: at LBF (the most shallow piezometer borehole) this occurred on 6/19/20, at RBN on 9/12/20, and at LBN on 10/10/20. Data collection at these sites will not be possible until groundwater levels rise higher than the pressure transducer elevations again. In contrast to the other two transects, both groundwater levels and surface water stage showed declining trends during the study period. Also in contrast to the other two transects, the lands on either side of the river in this transect location were not irrigated. Finally, the RBF location showed the least decline of all measurement sites in the transect. For the eight days in mid-August 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 and tended to be highest compared to other locations within the transect. Although fluctuating with weather conditions, sun exposure, and ambient air temperature, it generally increased to a seasonal peak above 70˚F in mid-July and fluctuated around 70˚F until the data record stopped in mid-August. Groundwater temperatures at the start of the study period were lower than the surface water temperature, although short decreases in surface water temperature in May decrease to or below some groundwater temperatures and seasonal differences tend to be less than 10˚F. Groundwater temperatures tenedd to increase by roughly 10˚F over the course of the study period and appeared to be plateauing by October. The RBF piezometer was consistently 1-2˚F warmer than the other three piezometers through the study period, providing more evidence that it may have a distinct groundwater source as compared to the other piezometer locations.

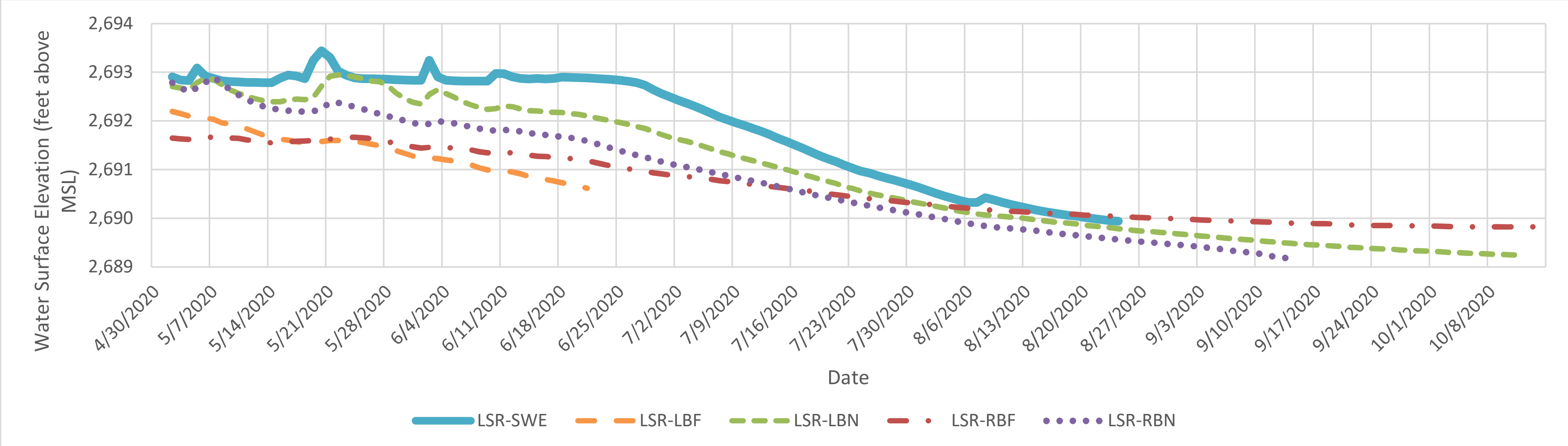

Figure 7. Daily Average Water Surface Elevations at Little Shasta River (LSR) Transect.

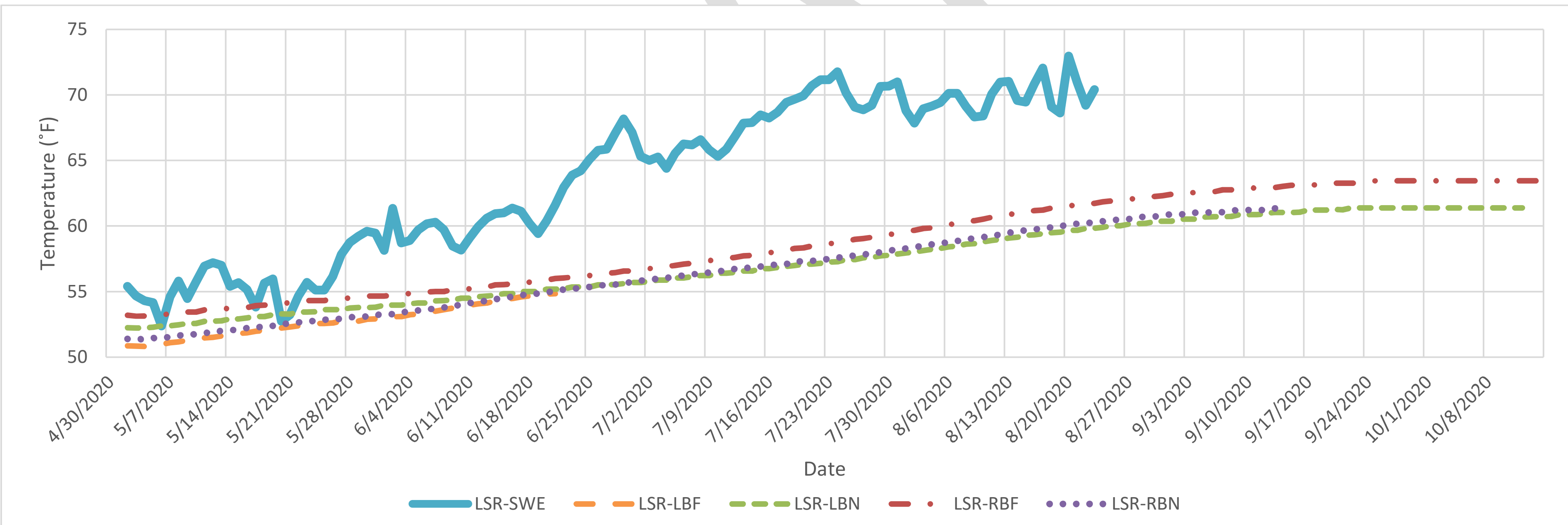

Figure 8. Daily Average Temperatures at Little Shasta River (LSR) Transect.

Piezometers tended to have lower water surface elevations than the surface water site during the study period, and temperatures were typically within 10˚F between groundwater and surface water. These results indicate that the Little Shasta River was losing in the transect location over the study period.

Average Monthly Water Elevations During May, July, and September 2020

As an alternative way of displaying trends during the study period, Figures 9, 10, and 11 below depict a cross-sectional view of water elevations at each piezometer transect. The transect is presented from the perspective of looking downstream at the transect, with the piezometers along the left bank shown on the left side of the figure, and vice versa. The piezometer locations are shown equally spaced in the figures, which is not representative of actual distances between locations in the field. The data depicted are average monthly water surface elevations for May, July, and September. This is every other month during the study period, only including months with a full dataset. It provides an alternative look at seasonal trends during the study period.

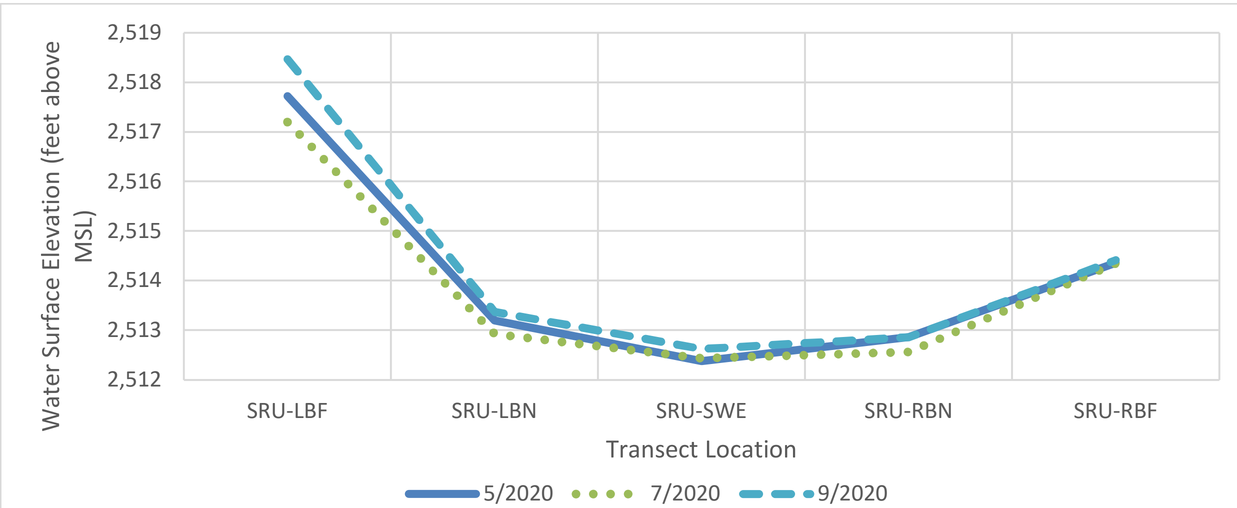

Figure 9. Monthly Average Water Surface Elevations at Shasta River Upstream of Little Shasta River Confluence (SRU) Transect (Perspective Looking Downstream).

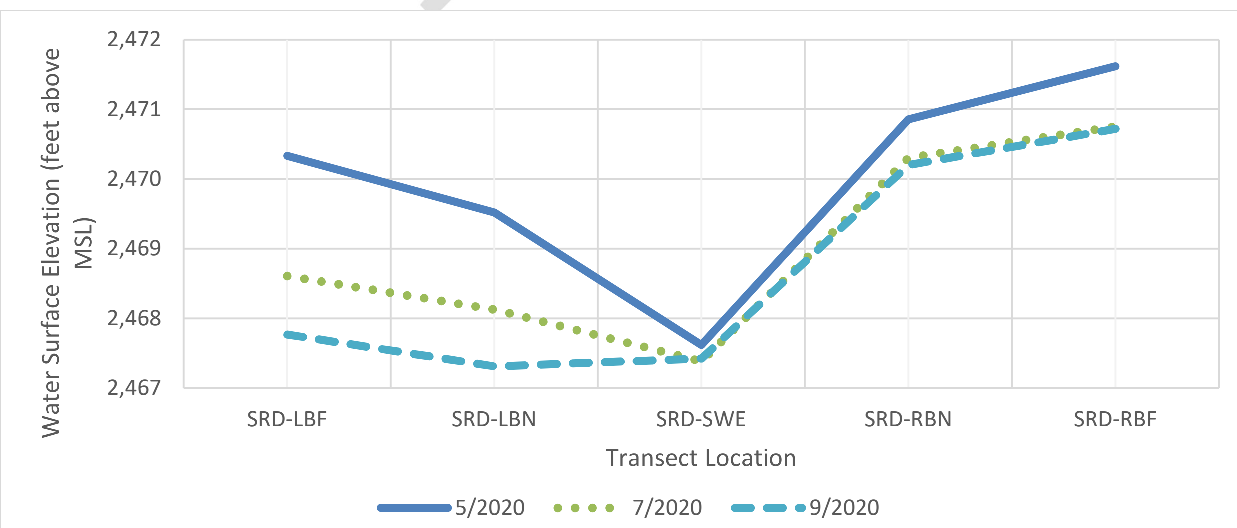

Figure 10. Monthly Average Water Surface Elevations at Shasta River Downstream of Little Shasta River Confluence (SRD) Transect (Perspective Looking Downstream).

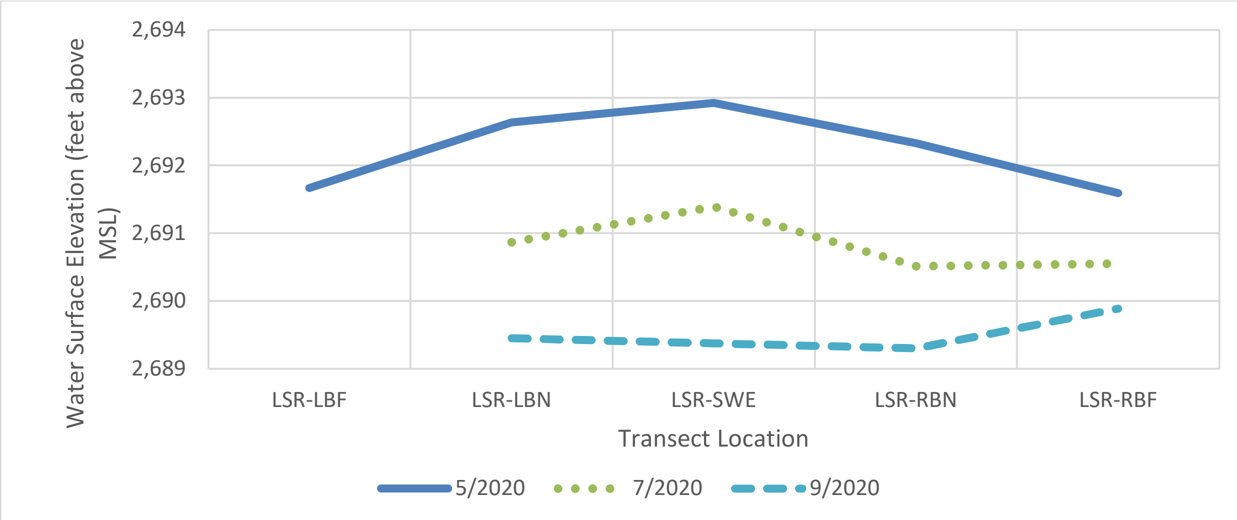

Figure 11. Monthly Average Water Surface Elevations at Little Shasta River (LSR) Transect (Perspective Looking Downstream)[6].

These results show differing trends at each transect. For the SRU transect, conditions remained relatively stable over the study period, and the hydraulic gradient towards the river from the left bank was substantially greater than from the right bank. For the SRD transect, decreasing water surface elevations were seen at all sites over the study period, but to varying degrees. The highest hydraulic gradient towards the river occurred from the right bank; water elevations in the RBN and RBF piezometers declined from May to July but remain steady from July to September. In contrast, along the left bank, the water surface elevations continually decreased from May through September. For the LSR transect, decreasing water surface elevations were seen at all sites over the study period. The smallest decrease was observed in the RBF piezometer in this transect.

Summary of Average Stream-Aquifer Differences and Comparison of Transects

Figures 12 and 13 on the following page show 30-day and daily average results for all three transects. Figure 12 depicts the average water surface elevation difference between piezometers and the surface water elevation in the river. Figure 13 depicts the temperature difference in the same way. These were calculated by averaging the values for all piezometers and subtracting the value from the surface water site; this means 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.

This comparison of water surface elevations illustrates differences between transects. Both transects along the Shasta River (SRU and SRD) had higher shallower groundwater water surface elevations in the piezometers than surface water elevations throughout the study period (e.g. positive values); however, for SRU the average monthly values remained steady around 2 feet, whereas for SRD the value began around 3 feet but steadily decreased to about 1 foot during the study period.

---

[6] Note that no data were available in September for LSR-SWE; water surface elevation dropped below the 2,689.9 feet above MSL elevation of the pressure transducer on 8/22/20. The line shown connects the monthly average water surface elevations of LSR-RBN and LSR-LBN.

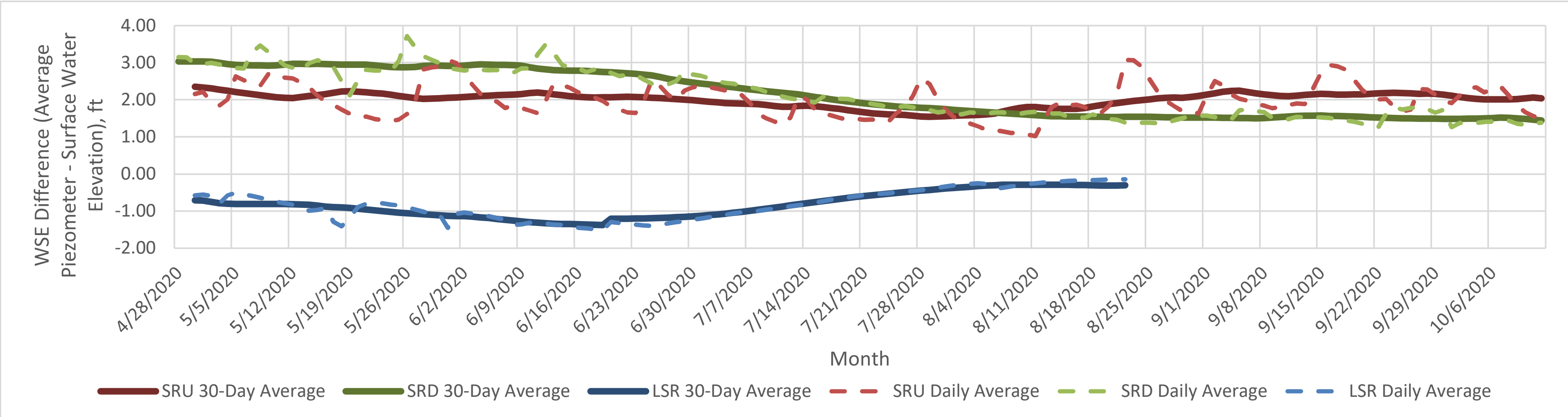

Figure 12. 30-Day and Daily Average Water Surface Elevation Differences at Shasta River Upstream of Little Shasta River Confluence (SRU), Shasta River Downstream of Little Shasta River Confluence (SRD), and Little Shasta River (LSR) Transects. A positive number represents a gaining reach, while a negative number represents a losing reach.

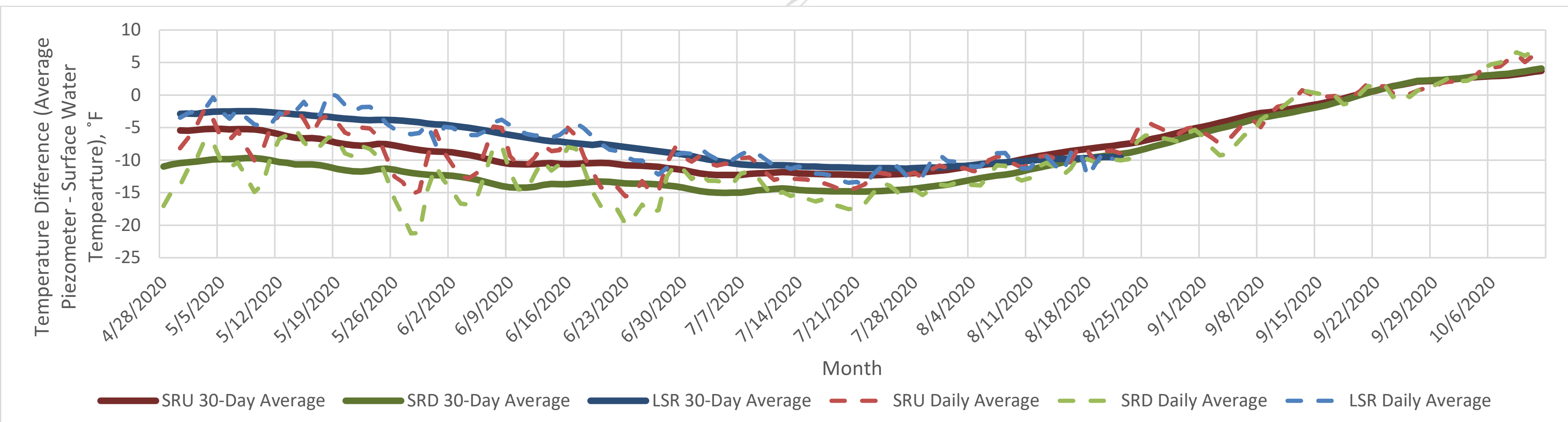

Figure 13. Daily and Monthly Average Temperature Differences at Shasta River Upstream of Little Shasta River Confluence (SRU), Shasta River Downstream of Little Shasta River Confluence (SRD), and Little Shasta River (LSR) Transects.

For the LSR transect, the surface water elevation was higher than the shallow groundwater levels throughout the study period (e.g. negative values). The initial seasonal difference was less than one foot, but continued to grow until late June. After this point, it was influenced by the end of the data record for the LBF transect site (at which groundwater levels dropped below the level of the pressure transducer on 6/19/20 and which had the largest difference from surface water elevation at this date) and by a trend where surface water levels declined more rapidly than shallow groundwater levels. When the surface water level dropped below the level of the pressure transducer on 8/22/20, the daily average shallow groundwater levels in the other three piezometers was only one-tenth of a foot lower than the surface water elevation.

Overall, shallow groundwater levels relative to surface water showed relatively consistent trends during the study period. 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 the transect were irrigated while lands along the Little Shasta River were unirrigated.

Temperature differences varied between 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), and the differences increased into the summer 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, reflective of surface water temperatures decreasing below shallow groundwater temperatures. The temperature difference was the smallest for the LSR transect and greatest for the SRD transect. The temperature difference may have been greater at the SRD transect than the SRU transect because of surface warming in the Shasta River as it flowed downstream. The temperature difference comparison at all transects reflected the slower changes in shallow groundwater temperatures relative to surface water temperatures.

Recommendations

The study provides valuable information about stream-aquifer interactions in the Shasta Valley along the Shasta River and Little Shasta River. Current funding will allow the study to continue through December 2021, and it is anticipated that the additional data collection will provide valuable information about seasonal trends and stream-aquifer interactions over the winter period and that continuing monitoring during the summer and fall of 2021 will provide a comparison to the conditions observed in the summer and fall of 2020. Included below are recommendations based on the data collected thus far:

- It is recommended that the study and data collection 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 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 analysis and evaluation of the piezometer transects could be completed. This includes, but is not limited to, water quality sampling, quantification of accretions or depletions, 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.

Attachments

- Shasta_Valley_Shallow_Piezometer_Transect_Study_Daily_Avg_May-October_2020.xlsx
  - Spreadsheet with daily and monthly averages for water surface elevation and temperature at all sites.

References

California Department of Water Resources (DWR). 2015. California's Groundwater Update 2013: A Compilation of Enhanced Content for California Water Plan Update 2013. p. 12.

Constantz, J. 2008. Heat as a tracer to determine streambed water exchanges. Water Resources Research Vol. 44, p. 1-20.

Mack, S. 1960. Geology and Ground Water of Shasta Valley, Siskiyou County, California. United States Geological Survey (USGS). Water Supply Paper 1484.

Onset Computer Corporation (Onset). 2020. HOBO® U20-001-04 Datasheet.

Shasta Valley Resource Conservation District. 2013. Stream-Aquifer Data Collection Program to Support Preparation of a Groundwater Management Plan for the Shasta Valley, Siskiyou County, California. Prepared by Davids Engineering.

Winter, T., Harvey, J., Franke, O., Alley, W. 1999. Ground Water and Surface Water: A Single Resource. United States Geological Survey (USGS) Survey Circular 1139.

Acknowledgements

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.