TECHNICAL MEMORANDUM

Date:	January 8, 2021
To:	Ad Hoc Sustainable Groundwater Planning Advisory Committee (GSU22 Committee)
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From:	Greg Kamman, P.G., C.Hg.
Reviewed by:	Cameron Tana, Montgomery & Associates
Project:	20-1030/M&A 9090.0401
Subject:	Quantify Depletions of Interconnected Surface Waters Basin Management Plan: Groundwater Sustainability Update 2022 (GSU22)

1.0 Introduction

The Pajaro Valley Water Management Agency (PV Water) submitted a Groundwater Sustainability Plan (GSP) Alternative for the Pajaro Valley Subbasin (Basin) on December 31, 2016 per the Sustainable Groundwater Management Act (SGMA). The California Department of Water Resources (DWR) assessed the Alternative and approved PV Water's GSP Alternative (DWR, 2019). DWR's assessment listed recommendations for PV Water to address in its first five-year update of the Alternative, including Recommended Action 2: "Staff recommend that the Agency quantify depletions of interconnected surface waters occurring as of January 1, 2015, which the Agency intends to use the threshold beyond which undesirable results occur, or other thresholds as defined and justified by the Agency." Recommended Action 5 also recommends that the "Agency define specific, quantitative criteria for depletion of interconnected surface water that can be used to objectively determine compliance of the Plan with the objectives of SGMA on an ongoing basis", consistent with Recommended Action 2. This memo addresses these recommended actions as part of the Basin Management Plan: Groundwater Sustainability Update 2022 (GSU22) to be submitted to DWR as the first five-year update of the Alternative.

2.0 Background and Study Approach

Recommended Actions 2 and 5 are recommendations for PV Water to define sustainable management criteria for depletion of interconnected surface waters as required for GSPs. The recommendation includes quantifying historical and current depletion of interconnected surface waters, which is also required for GSPs. Section 351 (o) of the GSP Regulations define interconnected surface water (ISW) as, "surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted." Depletions of ISW refers to reduction in surface water flow caused by groundwater pumping. As PV Water's accepted GSP

Alternative provides a plan for sustainably managing groundwater in the principal aquifer consisting of the Aromas Red Sands (or Aromas), the GSU22 will address depletions of ISW from the Aromas Red Sands.

Our study approach in quantifying depletions of ISW is to first review available streamflow and groundwater monitoring data representative of the principal aquifer and identify the spatial and temporal extent of hydraulically connected surface water reaches, if present. Upon identifying hydraulically connected reaches, this study would then focus on efforts to quantify depletions of ISW from pumping in the Aromas Red Sands with available empirical data.

3.0 Basin Hydrogeology

The hydrogeologic conditions of the Basin are described in the Basin Management Plan (PV Water, 2014) and the Pajaro Valley Hydrologic Model (PVHM) Report (Hanson et al., 2014). These reports indicate that aquifers in the Basin include the uppermost alluvium/terrace/dune deposits, intermediate Upper Aromas Red Sands, and deeper Lower Aromas Red Sands and Purisma Formations. In developing the latest groundwater model for the Basin, Hanson et al. (2014) describe the hydrogeologic framework that was used to represent the six discrete hydrologic model layers as well as the aquifers and confining units. These layers include: two layers of the alluvial deposits representing the uppermost alluvial deposit layer and basal fine-grained confining unit; three layers of the Aromas Red Sands representing the upper Aromas, an upper Aromas basal fine-grained confining unit, and a lower Aromas unit; and the deepest layer representing a combination of the Purisima Formation and other minor bedrock units. The Aromas Red Sands aquifer provides most of the groundwater pumped by wells in Pajaro Valley (Hanson et al. (2014; PV Water, 2014) and constitutes the principal aquifer being managed under the GSP Alternative.

Perched groundwater systems found above the alluvial basal confining unit are not being managed under the GSP Alternative as there is not a continuous saturated zone between perched systems and the principal aquifer. Thus, an important component of this study is to distinguish where and when ISW conditions exist between surface waters and the principal aquifer as compared to other overlying perched alluvial aquifer systems. This is complicated by the spatial variability in hydrogeologic units, especially the occurrence and thickness of the overlying alluvial aquifer and alluvial basal confining unit[1].

4.0 Identification of Interconnected Surface Water Systems

The depth to groundwater in relationship to overlying surface waters provides an initial evaluation of where groundwater has the highest potential to be in hydraulic connection with surface waters. Figure 1 illustrates the depth to the potentiometric surface of the Aromas aquifer developed using water levels collected from the PV Water groundwater monitoring network in spring of 2015. The areas shaded in color on Figure 1 represent where the spring 2015 depth to the potentiometric surface is less than 100-feet below ground surface (bgs), while unshaded areas indicate where the potentiometric surface is greater than 100 feet bgs. It illustrates where groundwater levels are closest to the ground surface and possibly in hydraulic connection to surface waters. For example, groundwater levels are relatively shallow

[1] The location and thickness of hydrogeologic units in the Basin are provided in Figure 3 of the PVHM report (Hanson et al., 2014).

(e.g., less than 10 feet bgs) in the western Basin beneath the Pajaro River and Elkhorn Slough corridors. In contrast Aromas groundwater levels are relatively deep beneath Corralitos Creek, ranging from approximately 60-feet downstream of Freedom to around 200-feet at the town of Corralitos. The depth to water in unshaded areas is greater than 100 feet bgs indicating a low probability of hydraulic connection of the Aromas aquifer with overlying surface waters.

In order to better evaluate potential ISW, cbec obtained and evaluated selected groundwater level monitoring data from wells located along the Pajaro River and main tributaries. The PV Water groundwater monitoring network is composed of over 170 public monitoring and private production wells that PV Water staff routinely visit to obtain groundwater level and water quality information. At a minimum, PV Water staff measure groundwater levels in these wells in the spring and fall of each year, with a subset of wells monitored more frequently. The locations of monitoring network wells and select surface water flow monitoring gages are provided on Figure 2.

The evaluation of ISW in the Watsonville Slough System was not completed at this stage of the study due to the lack of shallow monitoring well data near these surface waters. Available well data in the vicinity of College, Pinto and Kelly Lakes indicate they are associated with a shallow groundwater system hydraulically segregated from the deeper Aromas aquifer and not considered ISW associated with the principal aquifer. Further analysis and substantiation of hydrogeologic conditions within these areas will require collection of additional data through shallow groundwater wells as part of an augmented monitoring network.

The following sections present a comparison of historical and recent groundwater levels versus channel bed (thalweg) and floodplain elevations along selected reaches of the Pajaro River and Corralitos Creek. These comparisons more accurately identify the locations and periods of possible hydraulic connection and vadose zone thickness beneath these surface waters where the depth to water in the Aromas is relatively shallow. An analysis of stream flow records for the Pajaro River and Corralitos Creek is also presented in order to identify and quantify losing and gaining reaches potentially driven by groundwater interaction.

4.1 Groundwater Levels proximate to the Pajaro River

Well construction information was reviewed for the PV Water groundwater monitoring well network in order to identify shallow wells along the Pajaro River that could help identify and evaluate a potential hydraulic connection with the river. This subset of wells is labeled as “Wells screened in alluvium” and “Wells screened in Aromas” on Figure 2. Groundwater elevation hydrographs were prepared for each of these wells using available data and compared to the adjacent stream bed elevations represented by the estimated thalweg elevation plotted on each hydrograph. The approximate channel thalweg elevation was determined by evaluating cross-sectional ground surface profiles cut through the river alignment perpendicular to well locations. Cross-sectional ground surface profiles were prepared using a digital elevation model (DEM) based on the 2018 QL2 LiDAR data collection effort led by the United States Geological Survey (USGS). The results of this groundwater surface analysis are presented in a downstream

to upstream direction. Water year type classifications[2] are also indicated on hydrographs. The screened aquifer type for each well are indicated in figure captions and include: alluvium (Qal); Upper Aromas (QaUp), Lower Aromas (QaLo), and Purisima (Tp).

Downstream of Watsonville

Figure 3 plots hydrographs for wells A and PV6SM located along the river south of Harkins Slough for the period 1978 to present. Well A is screened in alluvium while well PV6SM is screened in the Aromas. Hydrographs indicate that wet season groundwater levels are generally less than 10-feet below the riverbed in both wells and occasionally intersect the river thalweg elevation, suggesting a short term seasonal hydraulic connection with the river, especially during wet years. During the dry season (summer and fall), the groundwater table drops to a depth of 10- to 30-feet below the riverbed. Prior to around 2005, summer groundwater levels typically lowered to elevations of 20- to 30-feet below the river. However, after 2005, the dry season elevations appear to gradually rise to 12-feet below the river. Recent monitoring data from 2017 to the present indicate wet season groundwater levels in both wells connect with the river and dry-season levels are consistently approximately 12-feet below the riverbed, even during dry year types. These data indicate a long-term rise in annual average groundwater level in this area likely the result of reduced groundwater extractions due to PV Water's supplemental water deliveries, which commenced in 2002 and significantly increased in 2009 following the completion of the Watsonville Area Water Recycling Facility (Figure 4).

Figures 5 and 6 plot hydrographs for wells B and C, located on the north and south sides of the river downstream of Watsonville, respectively. The hydrograph for well B (Figure 5), which is screened primarily in the alluvium, indicates much shallower groundwater elevations in 1947-1950 versus those post 1969. Since 1969, maximum wet season groundwater elevations remain at least 5-feet below the approximate river thalweg elevation and dry season levels at least 15-feet below this grade. These data indicate, that except for the 1947-1950 period at well B, there is always a vadose zone present between the riverbed and groundwater surface, suggesting no ISW conditions between river and alluvium post-1969. Assuming the 1947-1950 channel thalweg elevation was the same as current conditions at well B, groundwater level monitoring data suggests brief hydraulic connections with the river in water years 1948 and 1949, both dry year types (Figure 5). The annual variability in groundwater levels during the 1947-1950 period appear to be of similar magnitude to annual variability observed during the post-1969 period, suggesting a similar water table level response to seasonal pumping between historic and recent periods.

Well C is screened predominantly in the Aromas and water level elevations are similar to those in the overlying alluvium found at well B (Figure 6). Similarly, levels at well C remain below the channel thalweg elevation.

[2] PV Water divides water year types into five classifications based on average exceedance probability of annual precipitation totals for the Watsonville Water Works rain gage period of record from 1880-2020. The classifications are very dry, dry, average, wet, and very wet.

Watsonville Area

Hydrographs for four wells north of the river in Watsonville (wells D, E, B and PV20S) are plotted against the river thalweg elevation for the period 2007 to present in Figure 7. All wells are screened in alluvium except well D, which is screened in the Upper Aromas. All hydrographs show a steady rise in average annual groundwater elevations with post-2016 wet season levels reaching to within approximately 5-feet of the channel thalweg elevation and dry season levels dropping to approximately 15-feet below the thalweg. Again, these hydrographs suggest no ISW based on groundwater levels in both shallow aquifer and the Aromas. However, if the long-term trend of rising average annual groundwater level continues, wet season ISW conditions could occur in this area. On the opposite (south) side of the river near the town of Pajaro, hydrographs for wells F, G and H (Figure 8) display less seasonal variability (with the exception of the water levels in well H during water years 2004-2007, and wet season groundwater elevations remain 6- to 15-feet below the approximate channel thalweg elevation. This greater 2004-2007 variability in well H water levels may be due to the well being screened in shallow alluvium, while wells F and G are screened in the deeper Aromas. Even with this difference, groundwater levels in both the shallow alluvium and deeper Aromas suggest no ISW on both sides of the river, in this area.

Upstream of Watsonville

Figure 9 plots groundwater elevation hydrographs for Aromas wells I, J and K located on the south side of the river about 1/4-mile upstream of Watsonville. The hydrograph for well K indicates average annual groundwater elevations about 12-feet below channel grade from 1947-1952, which drop to over 40-feet below channel grade in the early 1990's drought. After 1991, average annual water levels in all wells gradually increase in elevation to approximately 15 feet below the channel thalweg elevation by 2019. Recent (2019) wet season groundwater elevations rise to within 3 to 8 feet below channel grade in wells I and J, respectively. If the long-term trend of rising groundwater elevations continues like that seen in the wells at Watsonville (Figure 7), there may be periods that ISW conditions arise at this location in the future, although that would need to be confirmed based on shallow alluvium groundwater levels.

Further upstream, the hydrographs for wells L and M (Figure 10) appear relatively stable for the period 1999 through 2015 with a 20-foot vadose zone during the wet season period. However, after 2015, there is a noticeable rise in the both wet and dry season groundwater levels when compared to the prior 15 years. Regardless, these wells, which are screened in alluvium, do not indicate ISW conditions in this area as water levels remain 15 feet or more below the channel thalweg. These wells are also close enough to wells I, J, and K screened in the Aromas shown in Figure 9 to extrapolate that there have not been ISW with the shallow alluvium throughout this area between Watsonville and Murphy Crossing.

Near Murphy Crossing

Figure 11 plots groundwater elevation hydrographs for wells PV14, N and O at and upstream of Murphy Crossing for the period 1947 to present. Well PV14 is the upstream-most well evaluated for this study and is screened in the shallow alluvium – wells N and O are screened deeper in the Aromas. In water year 1970, there was a brief period where groundwater levels at well O indicate a hydraulic connection with the river assuming similar groundwater levels in the shallow alluvium. Since then, wet season groundwater elevations at wells N and O have been consistently at least 5 feet below the approximate channel thalweg elevation and more recently 8 to 14 feet below the thalweg. In contrast, wet season

groundwater levels at PV14 are higher and occasionally seen intersecting or rising very close to the channel grade but remain below the channel grade at elevations more like groundwater levels in the Aromas most of the time. All the hydrographs display water levels with greater variability between different water year types than wells located downstream.

In addition to the discrete seasonal water level measurements collected as part of the groundwater well network, PV Water has maintained continuous logger measurements of groundwater elevations in well PV14 during water years 2018 (dry), 2019 (wet) and 2020 (dry). These data are plotted on Figure 12 and indicate a multi-week period of ISW conditions only in February of 2019 during a period of high flow events on the river. For comparison, the river stage at PV Water's Murphy Crossing gage is also plotted on Figure 12. The relative elevations of river stage and periods of available groundwater monitoring data, where stage is higher than water table, indicates this reach is losing during the monitoring periods. During the wet season, the high flow events in the river stage hydrograph are synchronous with spikes in the groundwater level hydrograph at PV14. The post-storm and wet season river flow recession rate seen in the river stage (e.g., April through August 2019) is similar to the water table recession rates. When the river goes dry at Murphy Crossing in the late summer and infiltration and recharge to the underlying alluvial aquifer ceases (e.g., mid-September 2019 and mid-August 2020), there is a rapid increase in the water table recession rate (i.e., steepening in the groundwater level rate of decline) until the onset of river flow in the fall and infiltration/recharge to the aquifer resume and groundwater surface elevations rise sharply. These results indicate that surface water provides recharge to groundwater while the general lack of ISW conditions mean surface water depletions from groundwater pumping is unlikely to occur.

Summary of Findings

Within the groundwater Basin, beneath the Pajaro River, there are large areas where intervening confining and semi-confining layers separate the Aromas Red Sands aquifer from the shallow alluvium. Along the river, the groundwater level elevations in wells screened in alluvium and underlying Aromas Red Sands are very similar, suggesting these units may be in partial hydraulic connection, even with the presence of the intervening confining layers. Thus, alluvial groundwater levels that are connected to surface water may serve as an indirect connection between the principal aquifer and surface water.

The analysis of groundwater level hydrographs and adjacent stream bed thalweg elevations has identified brief periods of ISW at the far downstream (Figure 3) and upstream reaches (Figures 11 and 12) of the Pajaro River during the winter/spring wet season. The establishment of a hydraulic connection at Murphy Crossing appears driven by increased surface water infiltration during high river flow events. While this is also a contributing factor in the reach south of Harkins Slough, there also appears to be a long-term trend of rising groundwater levels in the lower river, likely resulting from Basin Management Plan activities including, reduction of coastal water production from delivered water through the Coastal Distribution System and operation of the Harkins Slough Managed Aquifer Recharge and Recovery Facility (Figure 13). The seasonality and short duration of ISW conditions suggest ISW are associated with losing river conditions (i.e., infiltration) during winter high flow periods, esp. during wet year types, and do not indicate the potential for surface water depletion from groundwater pumping. Apart from these locations, monitoring data from the shallow alluvium and the Aromas indicates there is a significant vadose zone present between the Pajaro River and Aromas and lack of hydraulic connection.

The potential for adverse impacts to surface water beneficial uses during these limited periods and areas of ISW are very low because river flows are at maximum and groundwater pumping is at a minimum. Any exchange between groundwater and surface water at these times is driven mostly by natural hydrologic process and any change in river flow volume, either gaining or losing due to management actions, would be small and difficult to identify, let alone quantify during peak river flood flows.

4.2 Streamflow Depletions along the Pajaro River

Within the Basin, the USGS maintains stream flow gaging stations on the Pajaro River at Chittenden (USGS 11159000) and Watsonville (USGS 11159500) (see Figure 2). PV Water and the USGS have established independent river stage recorders at Murphy Crossing. The USGS also collected staff gage and discharge measurements during water year 2020. Using these data, cbec prepared a rating curve for the USGS Murphy Crossing gage to convert the continuous (15-minute interval) water level readings to flow for most of water year 2020.

A comparison of sequential hydrographs along the Pajaro River is limited to water year 2020, the only year flow data is available at all three Pajaro River gages. Although PV Water collected near-continuous water levels at Murphy Crossing during water years 2014-2019, there aren't staff plate and flow discharge measurements to convert these data into a flow record.

Chittenden to Murphy Crossing

Figure 14 plots continuous flow hydrographs for the three USGS Pajaro River flow gages in the Basin. The watershed drainage area upstream of the Chittenden gage is 1,186 square miles. The river flows through a relatively narrow canyon carved through the Santa Cruz Mountains on its way to Murphy Crossing, with minor tributary contributions. The Murphy Crossing gage site is located approximately 6.85 miles downstream of Chittenden where the canyon discharges onto the coastal river plain that hosts the primary aquifer. The hydrographs plotted on Figure 14 indicate a reduction in river flow between Chittenden and Murphy Crossing except during peak high flow events. This is consistent with the infiltration study findings for this reach presented in Hanson et al. (2014), Sigler (2007), Ruehl et al. (2006), and Hatch et al. (2010).

Using the 2020 flow records, cbec completed an analysis to quantify the volume of daily stream flow loss between Chittenden and Murphy Crossing. Figure 15 presents a plot of mean daily flow at each gage and the daily difference, plotted as the dashed line, where negative values indicate periods of stream flow loss and positive values represent gains. During most of the 2020 monitoring period, there was a daily reduction in flow by as much as 30 cfs. There also appears to be short-lived periods of stream flow gain coincident with high flow events. These gains are most likely attributable to storm overland runoff draining to the river from the intervening watershed area. Summing the total stream flow loss yields 9,737 AF of infiltration over the 2020 monitoring period. This value falls within the 4,864 to 10,539 AF/year annual range presented in the Ruehl et al. (2006) infiltration study report.

Although the groundwater level analysis presented above indicates that there are typically not ISW conditions that would result in groundwater pumping depleting streamflow in Pajaro River, cbec also

evaluated whether there is any correlation between river flow loss and local area groundwater pumping. To do this, cbec evaluated recent (water years 2005 through 2019) pumping volumes available for production wells within the vicinity of Murphy Crossing. PV Water maintains records of quarterly pumping volumes for non-domestic production wells in the Basin. The locations of production wells within the vicinity of Murphy Crossing are indicated on Figure 16. The total quarterly and annual pumping volumes from these wells are plotted on Figure 17. The quarterly data do not provide enough resolution to determine if groundwater pumping influences surface water levels or flow rates, and therefore these data do not provide evidence indicating issues with the conclusion that there are not ISW conditions.

Figure 17 reveals interesting differences in production well operations over time. During the dry years of water years 2006 through 2009, annual production volumes were between 2,000 to 2,100 AF/y and seasonal quarterly totals ranged from 100 to 1,000 AF. Water years 2010 through 2015 experienced less total annual pumping (maximum of approximately 1,900 AF/y) and seasonal dry year volumes ranged from 200 to 800 AF. After water year 2015, annual total production volumes show a bigger decrease to about 1,400 AF/y, with quarterly pumping volumes ranging from 50 to 700 AF. Whether the post-2015 decrease in production is associated with wet year type operations or changes in groundwater management practices needs to be investigated with PV Water. However, the changes between the 2006-2009 and 2010-2015 suggests a change in groundwater management and/or operations as they are both drought periods.

Murphy Crossing to Watsonville

The 2020 river flows are higher at the USGS Watsonville gage than at Murphy Crossing, primarily due to the intervening contribution of the Salsipuedes Creek watershed inflow to the Pajaro River (Figure 14)[3]. As presented above, analysis of groundwater level data indicates a complete lack of hydraulic connection and ISW conditions between Murphy Crossing and Watsonville, thus it is not feasible for contributions (gains) from the primary aquifer to be a source of flow increase seen at the Watsonville gage.

Summary of Findings

Analysis of Pajaro River stream flow records identify significant and continual river flow losses to infiltration between Chittenden and Murphy Crossing consistent with finding of groundwater levels below river thalweg elevations. Although there is an increase in river flow between Murphy Crossing and Watsonville, the lack of ISW conditions along this reach indicates the increase is attributable to surface water inflow from intervening tributary watersheds.

4.3 Groundwater Levels proximate to Corralitos Creek

Analysis of the potential for interconnected surface water and groundwater conditions along Corralitos Creek included preparing groundwater level hydrographs for comparison to adjacent creek bed elevations. The groundwater level hydrographs for wells analyzed along Corralitos Creek are presented

[3] The Murphy Crossing stream flow data collected by the USGS is preliminary. The one period when Murphy Crossing flows appear greater than Watsonville flows in June 2020 is likely attributable to stream flow gaging and/or data processing error for the Murphy Crossing data. Further evaluation of data from this period is warranted to verify this conclusion.

in a downstream to upstream direction. The locations of wells are indicated on Figure 2. Approximate creek channel thalweg elevations and water year type classifications are provided on hydrographs.

Downstream and Upstream of Freedom

Figure 18 presents historic through recent groundwater level hydrographs for monitoring wells P and Q, located along Corralitos Creek downstream of Freedom (see Figure 2). Both wells are screened in the Aromas and representative of the primary aquifer. Consistent with the depth to water map (Figure 1), the primary aquifer water table in this vicinity is between 40- to 60-feet below channel bed grade during the wet season, with the exception of 1997 (above average wet year) and 2004 (average water year type), when spring levels were much higher coming within approximately 20-feet of the channel thalweg. During the summer, the water table declines to between 60- to 70-feet below the estimated thalweg elevation. Like groundwater level trends along the Pajaro River at and upstream of Watsonville, groundwater levels in well Q show a steady rise post-2015, likely in response to recovery from drought conditions.

Recent wet season groundwater levels in wells R, S and T, located just upstream of Freedom (Figure 19), display average depth to water levels 80 to 100 feet below the Corralitos Creek channel thalweg elevation. These wells are screened in the primary aquifer. During the dry season, groundwater levels typically drop to 140 feet below thalweg as seen in the 2006 to 2009 monitoring data for well S. After water year 2009, the depth to water in summer water levels is reduced to between 110 to 120 feet below channel grade in well S. In total, groundwater level monitoring data downstream and upstream of Freedom indicate a thick unsaturated zone and lack of hydraulic connection between Corralitos Creek and the primary aquifer.

Near Varni Road

Groundwater level data from PV Water monitoring wells V and U are representative of alluvial and Aromas Red Sands groundwater conditions along Corralitos Creek near Varni Road, which is located midway between Freedom and Corralitos. Groundwater levels measured at monitoring well U (Figure 20) are representative of the Aromas aquifer and display elevations and seasonal variability similar to those observed in wells R through T, just upstream of Freedom (Figure 19). The average depth to water below creek channel grade at monitoring well U is approximately 150 feet.

Groundwater elevations at well V are significantly higher than the water table elevations at nearby monitoring well U, with recent (post-2010) wet season depth to waters ranging from 20 to 25 feet below channel grade and 10-20 feet lower during the summer season (Figure 20). Historically, groundwater levels appear to have been higher, with depth to water below thalweg of 15 feet during the 1946 to 1952 period, even during multi-year dry periods.

The groundwater levels measured in well V are not associated with the primary aquifer as the well is screened in the overlying alluvium. The ground surface elevation at well V is approximately 200 feet and the total depth of the well is 148 feet. The well screened interval of 105-135 feet bgs is in the Upper Alluvium. This puts the bottom elevation of the well at approximately 52 feet in elevation, significantly higher than the groundwater surface of the Aromas aquifer, which is at 10 to 20 feet in elevation at monitoring well U (Figure 20). Based on mapping presented in the PVHM report (PV Water, 2014), the alluvial aquifer screened by well V is also segregated from the Aromas by the alluvial basal confining unit.

Because Well V does not intersect the Aromas aquifer, the groundwater levels captured by this well are likely associated with a perched aquifer system. This is consistent with findings presented in the Basin Management Plan (PV Water, 2014), which references a perched aquifer in the Corralitos area and the presence of an aquitard effectively separating the perched unit from underlying Aromas. Regardless, groundwater level monitoring indicates no hydraulic connection and ISW conditions between the alluvial aquifer and creek at this location. Due to lack of ISW conditions and the disconnection between the perched alluvial aquifer and the Aromas aquifer, streamflow depletion from groundwater pumping in the Aromas aquifer is not expected.

Near the Town of Corralitos

Wells W and X are both screened at depth within the Aromas aquifer. Hydrographs for both wells indicate a significant thickness of vadose between overlying surface waters and the groundwater table with a depth to water below channel thalweg of over 80 feet at well W and around 200 feet at well X (Figure 21). The difference in groundwater level elevations at these wells is likely attributable to semi-confined conditions associated with differing aquifer and confining layers encountered by each well. Per unit thickness maps presented in Hanson et al. (2014), the alluvium and alluvial base confining unit are relatively thin (less than or equal to 5 feet, each) in this area, but there is no well monitoring data available to evaluate ISW conditions in these shallow units.

Summary of Findings

Comparison of ground surface topography and groundwater surface elevations for the Aromas aquifer indicate a significant thickness of vadose zone between surface waters and aquifers in the Corralitos Creek watershed. Review of groundwater level monitoring data for wells located along Corralitos Creek do not indicate any instances of hydraulic connection between surface water and the Aromas. Limited available data also indicate a lack of hydraulic connection between the Aromas and perched shallow alluvial aquifer. Because there is no direct or indirect (i.e., via overlying alluvium) ISW with the Aromas aquifer, there is no potential for adverse impacts from groundwater development operations on the beneficial uses to surface waters within the Corralitos Creek watershed.

4.4 Streamflow Depletions along Corralitos Creek

Within the Corralitos Creek watershed, the City of Watsonville monitored continuous flow at four sites during water years 2017 through 2019. City of Watsonville flow monitoring Sites 1-3 on Corralitos Creek are indicated on Figure 22 and include: in Eureka Canyon (Site 1) immediately downstream of their surface water diversion; at Browns Valley Road (Site 2) downstream of Corralitos; and at Varni Road (Site 3). Site 4 is located on Browns Valley Creek below their surface water diversion. In addition, the USGS maintains a continuous flow gage at Freedom (USGS 11159200).

A comparison of Corralitos Creek flow hydrographs for water years 2017 through 2019 are provided in Figures 23 through 25. To aid discussion of changes in flow between gauging locations, the Corralitos Creek watershed can been broken into the following reaches (see Figure 22): Reach A – Corralitos Creek between the Site 1 (Eureka Canyon) and the Site 2 (Brown's Valley Road) gages, plus a length of lower Brown's Valley Creek between Site 4 and the confluence with Corralitos Creek; Reach B – between the Site 2 and Site 3 (Varni Road) gages; and Reach C – between the Site 3 and USGS Freedom gages.

The hydrographs for all three water years reveal that during periods between peak runoff events, there are reductions in stream flow in Reach A and B and stream flow gains in Reach C. The high variability in daily flow hydrographs occurring in the summer through fall period is associated and synchronous with fluctuations in the daily diversions occurring at the City of Watsonville surface water diversion sites immediately upstream of gage Sites 1 and 2. Figure 26 and 27 provide expanded views of the summer-fall period stream flow hydrographs and total diversions (sum of the City's Corralitos and Browns Creek diversions) for the early and later low flow periods of water year 2019, respectively. During October and November 2018 (Figure 26); increases in City diversion rates translate to decreased flow rates at downstream gauging sites and visa versa. These same synchronous cycles are seen in the diversion and stream flow hydrographs for August through September of 2019 (Figure 27). It is interesting to note that prior to August 2019, when City diversions are held at a constant rate, there are still daily fluctuations in downstream flow hydrographs (see June through July 2019 period on Figure 27). Possible reasons for these fluctuations are daily fluctuations in riparian vegetation transpiration rates and/or other stream flow diversions. The possibility of the latter is confirmed by the existence of several water rights for water diversion along Reaches 1 and 2.

In order to quantify the change in stream flow in each reach, cbec calculated the change in daily creek flow rates between downstream and upstream gages for the 2017 (partial) through 2019 water years. Mean daily hydrographs for upstream and downstream flow gages and daily change in flow rate for Reach A are plotted on Figure 28[4]. Daily flow and stream flow changes for Reaches B and C are plotted on Figures 29 and 30, respectively.

As seen on Figure 28, Reach A experiences stream flow reductions year-round during all three years. Apart from periods of wet-season high flow events where the creek shows gains from additional overland flow, Reach B experiences stream flow loss during non-storm periods (Figure 29). Unlike the perennial flows at Sites 1 and 2, flow at Site 3 (Varni Road) dried out in June or July of all water years. Change in flow through Reach C (Figure 30) behaves differently, in that there appears to be both periods of stream flow gains and losses during wet season storms. Gaining flows dominate in Reach C during the dry season. In contrast to the upstream reaches, infiltration along Reach C, only appears to occur during wet season high flows. A full accounting of sources contributing to the flow gains observed in Reach C was not completed due to the lack of flow monitoring from contributing tributary watersheds, the largest consisting of Pleasant Valley, and a better understanding of potential groundwater inflows from shallow alluvium. Regardless, all reaches appear to experience surface water infiltration and contribute to aquifer recharge, findings consistent with those presented in the PVHM report (Hanson et al., 2014).

Using the stream flow gain/loss estimates for the full water year period for 2018 and 2019, the total annual infiltration volumes along Reach A through C were calculated and are presented in Table 1. The estimated total annual infiltration volume along all three reaches was 3,329 AF in 2018 and 5,735 AF in 2019. The higher reach infiltration volumes experience in 2019 are due to higher creek flows experienced

[4] Flow at gage Site 2 represents flow contributions from both Corralitos and Brown's Creeks, thus the depletions in this reach reflects the sum of flow at Sites 1 and 4 minus the flow at Site 2.

during this wet year, as compared to the lower total creek flows that occurred during 2018, a dry water year.

TABLE 1: Estimated Stream flow infiltration (in AF/yr) in Reaches A through C

	Reach A	Reach B	Reach C
WY2018 by Reach	-1,134	-727	-1512.51
cumulative	*-1,134*	*-1,861*	*-3,374*
WY2019 by Reach	-2,708	-693	-2375.05
cumulative	*-2,708*	*-3,401*	*-5,776*

Similar to the analysis completed at the Murphy Crossing reach on Pajaro River, cbec evaluated quarterly and annual pumping volumes available for wells along Corralitos Creek (see Figure 22) in order to identify any correlation between groundwater production and creek flow rates as a check on the conclusion that surface water depletion from groundwater pumping in the primary aquifer is not occurring based on lack of ISW. The total quarterly and annual pumping volumes from these wells during water years 2017 through 2019 are plotted on Figure 31. The resolution of the quarterly data is not detailed enough to identify pumping influences, if any, on surface water flow rates. However, it does not provide evidence indicating issues with the conclusion that there are not ISW conditions. However, Figure 31 reveals a consistent annual production volume of 900- to 1,100 AF/y and seasonal quarterly totals ranged from 100 to just under 400 AF during water years 2017-2019.

Summary of Findings

Analysis of flow records identify significant flow losses to infiltration along Corralitos and Browns Creeks between the City of Watsonville diversion sites and Varni Road (Site 3 stream gage). Some stream flow gains in these reaches are observed during peak winter flow events, but are short-lived and attributable to contributions from overland storm flow. Although there is an increase in dry-season flow between Varni Road and Freedom, the lack of observed ISW conditions along this reach suggests the increase is attributable to surface water inflow from intervening tributary watersheds.

5.0 Conclusions

There are only a couple of locations along the Pajaro River where monitoring data indicate hydraulic connection and potential ISW with the Aromas under current conditions. These locations occur at an area downstream of Watsonville at well sites A and PV6SM and upstream at Murphy Crossing. ISW conditions only develop at these sites during winter high river flow periods, esp. during wet year types and do not persist beyond the duration of the high flow events. During periods when there is ISW, the surface water bodies are losing reaches. Apart from these locations, monitoring data indicate there is a significant vadose zone (i.e., lack of hydraulic connection) present between surface waters and Aromas. Analysis of

stream flow records indicate notable reaches of stream leakage and flow reductions on the Pajaro River and Corralitos Creek. Analysis of stream flow monitoring data also identify reaches of gaining flow. However, groundwater level monitoring data in these reaches do not indicate ISW with the Aromas and flow gains can be attributed to tributary surface water inflows.

The potential for adverse impacts to surface water beneficial uses during periods of ISW are very low as they occur only during the wet season when surface water flows are not limited. The potential for impacts is further reduced as groundwater pumping are at a minimum during this period. Exchange between the surface water and aquifer is one-directional during these periods where the surface waters are losing systems. Surface water exchange at these times is driven mostly by natural hydrologic process and any change in flow volume, either greater (gaining) or smaller (losing) due to management actions, would be small and difficult to identify, let alone quantify during peak river flood flows. Because of the limited spatial and temporal extent of ISW conditions, there are no depletions of interconnected surface water to quantify.

6.0 Recommendations

Apart from a couple discrete locations along the Pajaro River, this study suggests a lack of ISW conditions through direct hydraulic connection with the principal aquifer (Aromas). However, there may be an indirect connection to ISW via the intervening alluvium. Therefore, we recommend the following actions be integrated into the GSU22 Surface and Groundwater Monitoring Plans as next steps in addressing data gaps necessary to develop sustainable management criteria that are protective of the beneficial uses of surface waters.

- Implement targeted groundwater monitoring along the Pajaro River to better evaluate if and where perched and unconfined alluvial aquifer ISW are interacting with the principal confined to semi-confined aquifer. This will likely require installation of nested well pairs screened independently screened in alluvium and Aromas aquifers.
- Implement targeted groundwater monitoring along Corralitos Creek to validate the conceptual model of segregated alluvial and Aromas aquifers, which is based on sparse existing information.
- Complete paired dry-season shallow groundwater and flow monitoring in Reach 3 of Corralitos Creek to determine if gains in river flow are associated with groundwater contributions.
- Integrate shallow groundwater monitoring wells into the monitoring network around surface water sloughs and lakes to evaluate and substantiate ISW conditions.
- Implement targeted groundwater monitoring and production well monitoring in areas identified as ISW in order to evaluate how depletions are affecting surface water levels and/or flow. This information will help develop and quantify sustainable management criteria for ISW.

7.0 References

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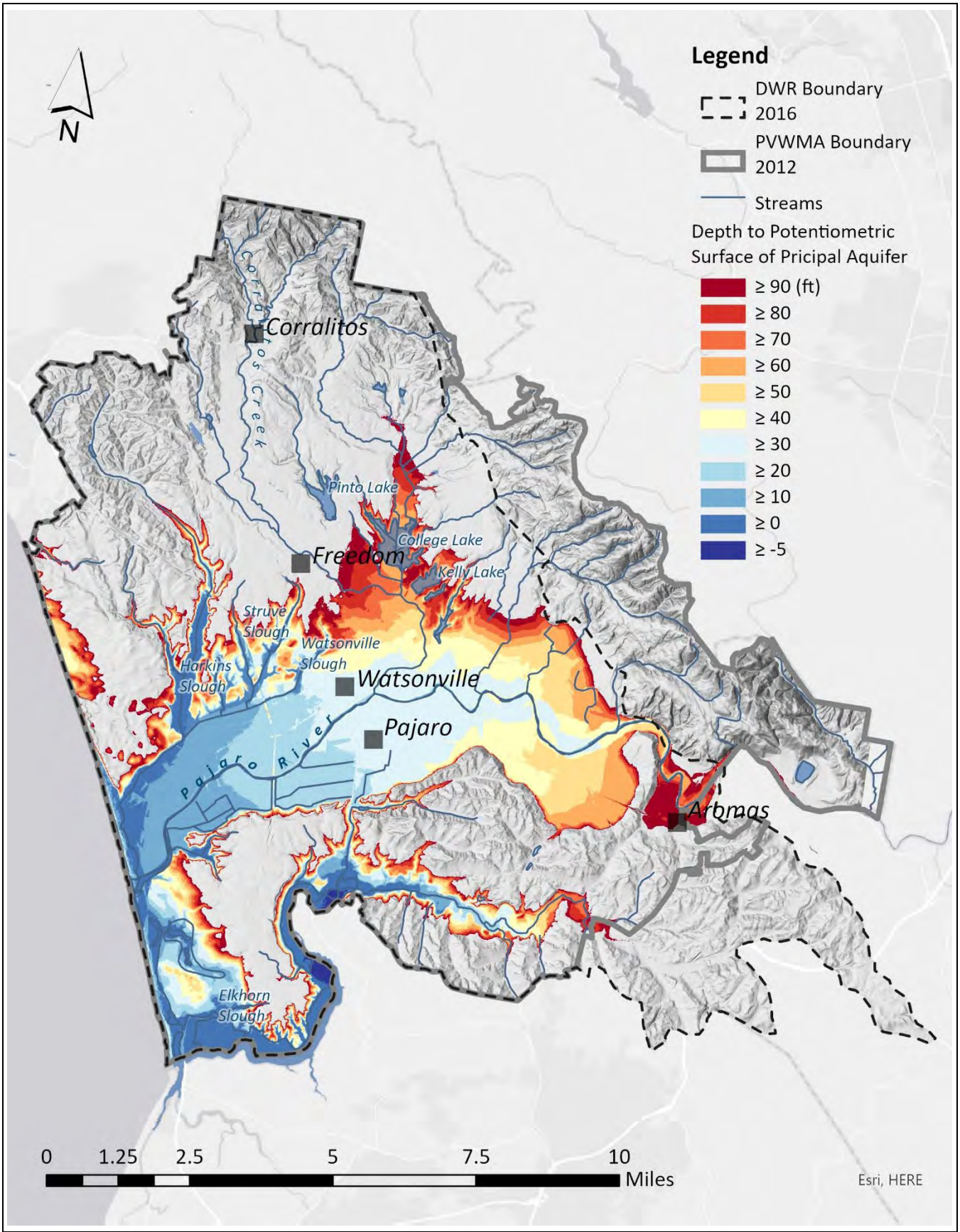
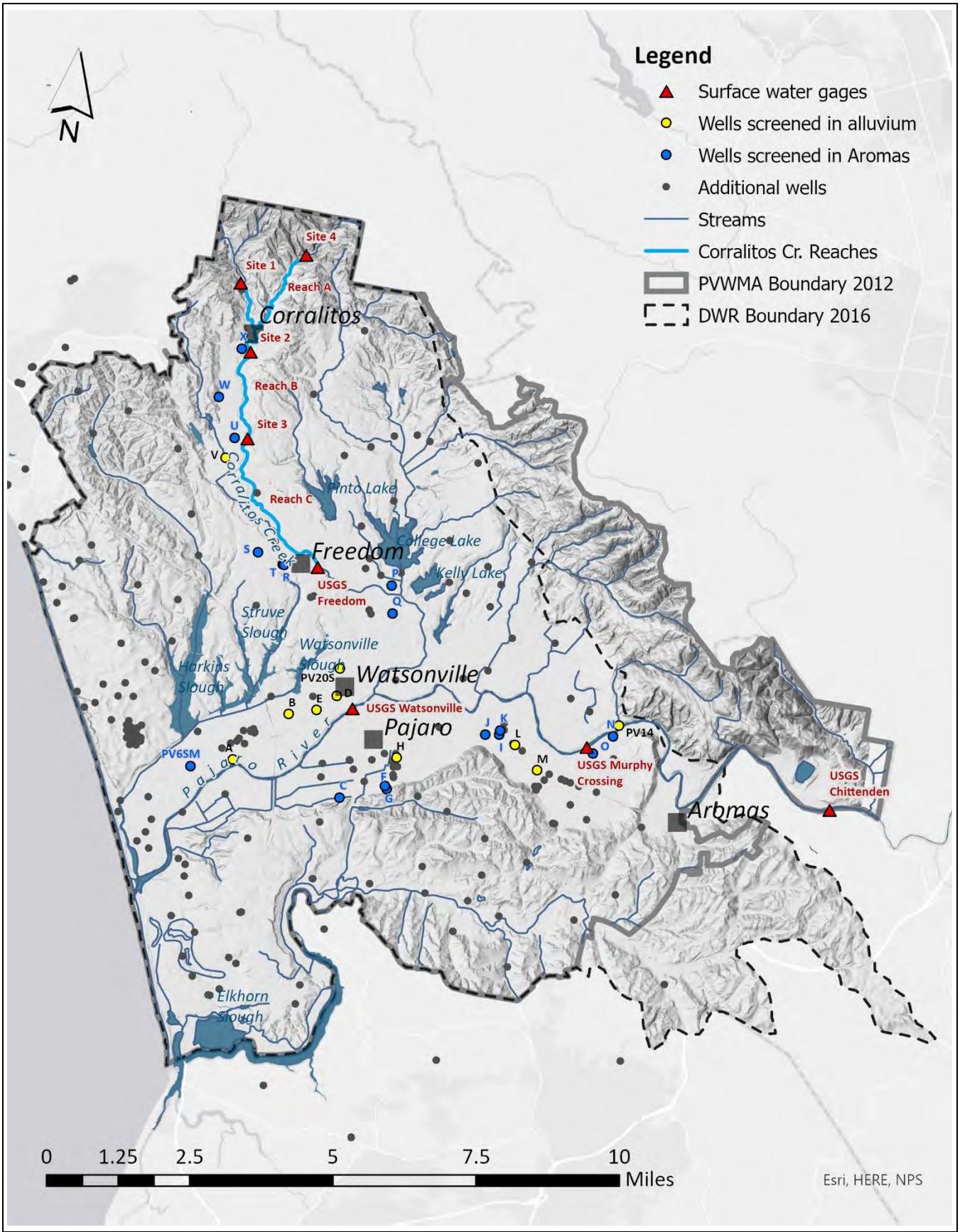
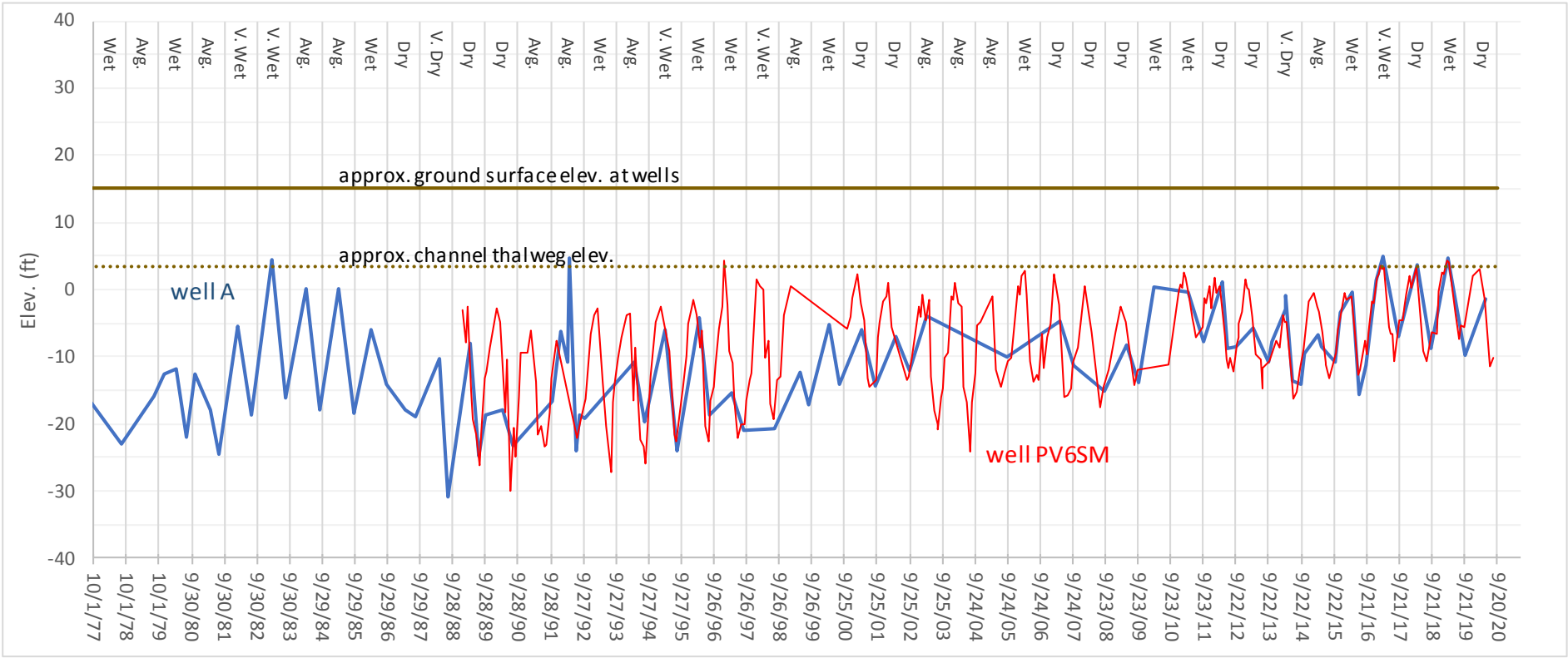


Notes: Areas without color shading indicate groundwater elevations are greater than 100 feet bgs.	cbec eco engineering	**Depth to potentiometric surface of Aromas aquifer less than 100 feet below ground surface during spring 2015**		
		Project No. 20-1030	Created By: GS	**Figure 1**



Notes:		Location of PV Water groundwater monitoring network wells and select surface water flow monitoring gages		
	cbec eco engineering	Project No. 20-1030	Created By: GS	**Figure 2**

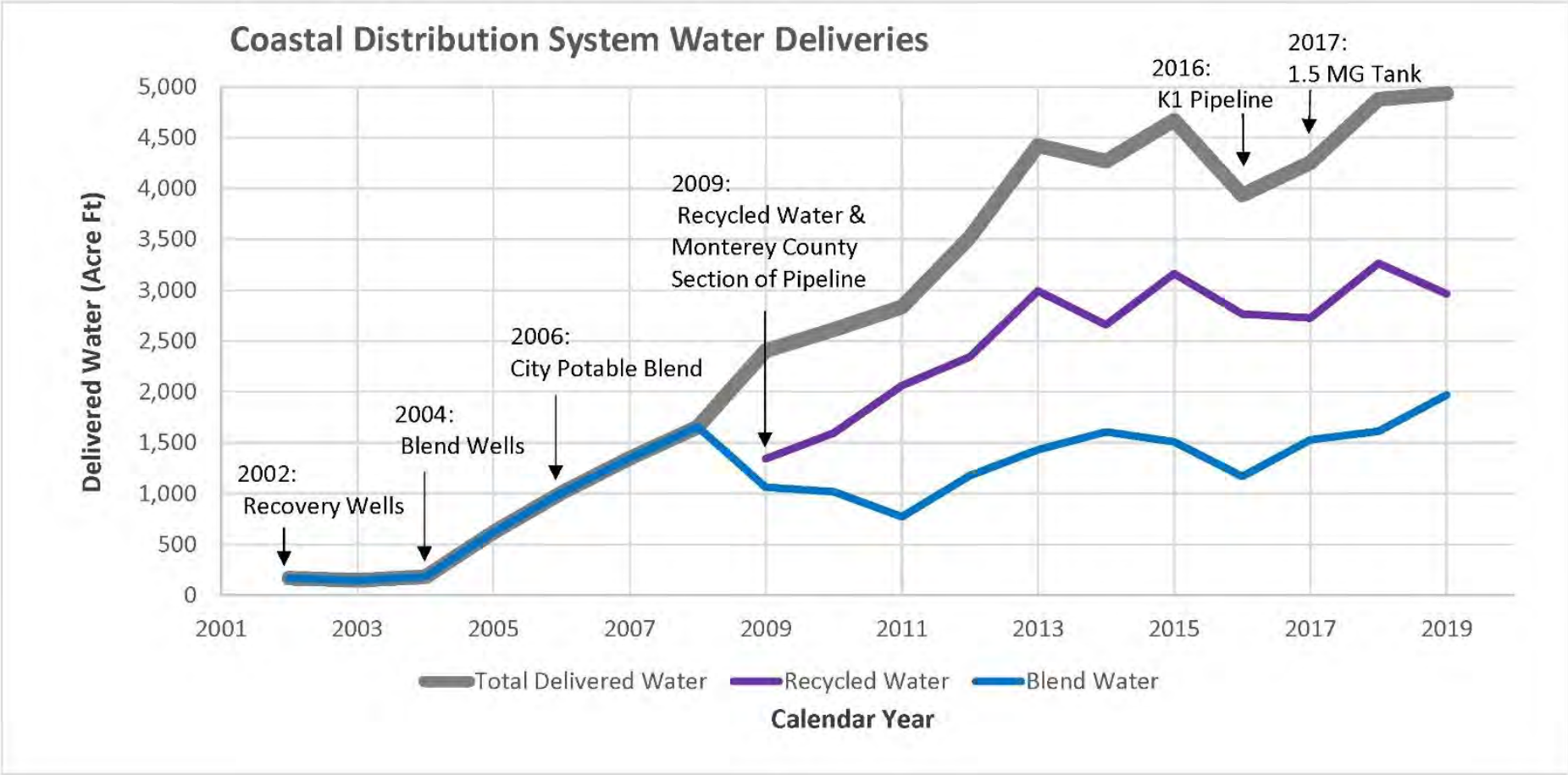


Notes:

Groundwater level hydrographs for wells A (Qal) and PV6SM (QaUp)– Pajaro River area downstream of Watsonville

Project No. 20-1030	Created By: GK	**Figure 3**

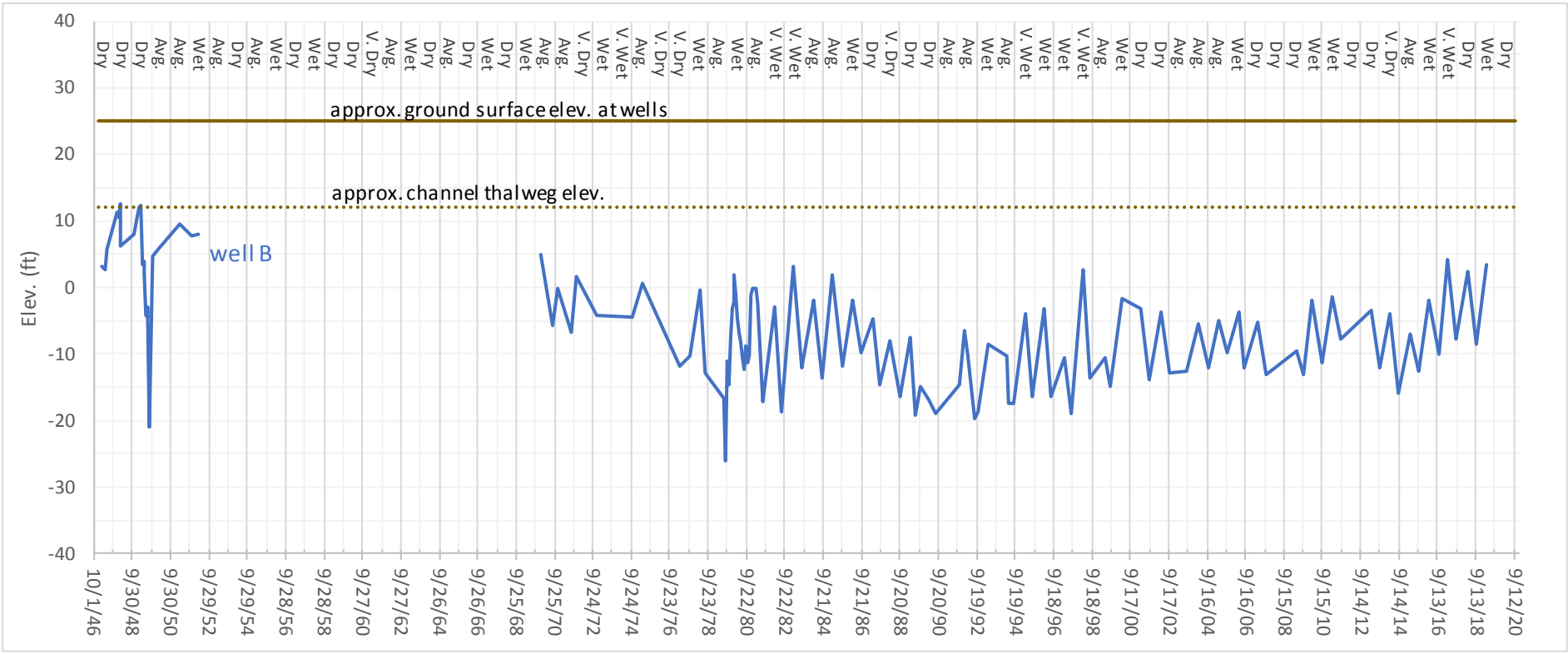
F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
1/8/2021



Notes: Source: PV Water, 2020

Annual supplemental water deliveries in the Pajaro Valley Groundwater Basin

Project No. 20-1030	Created By: GK	**Figure 4**

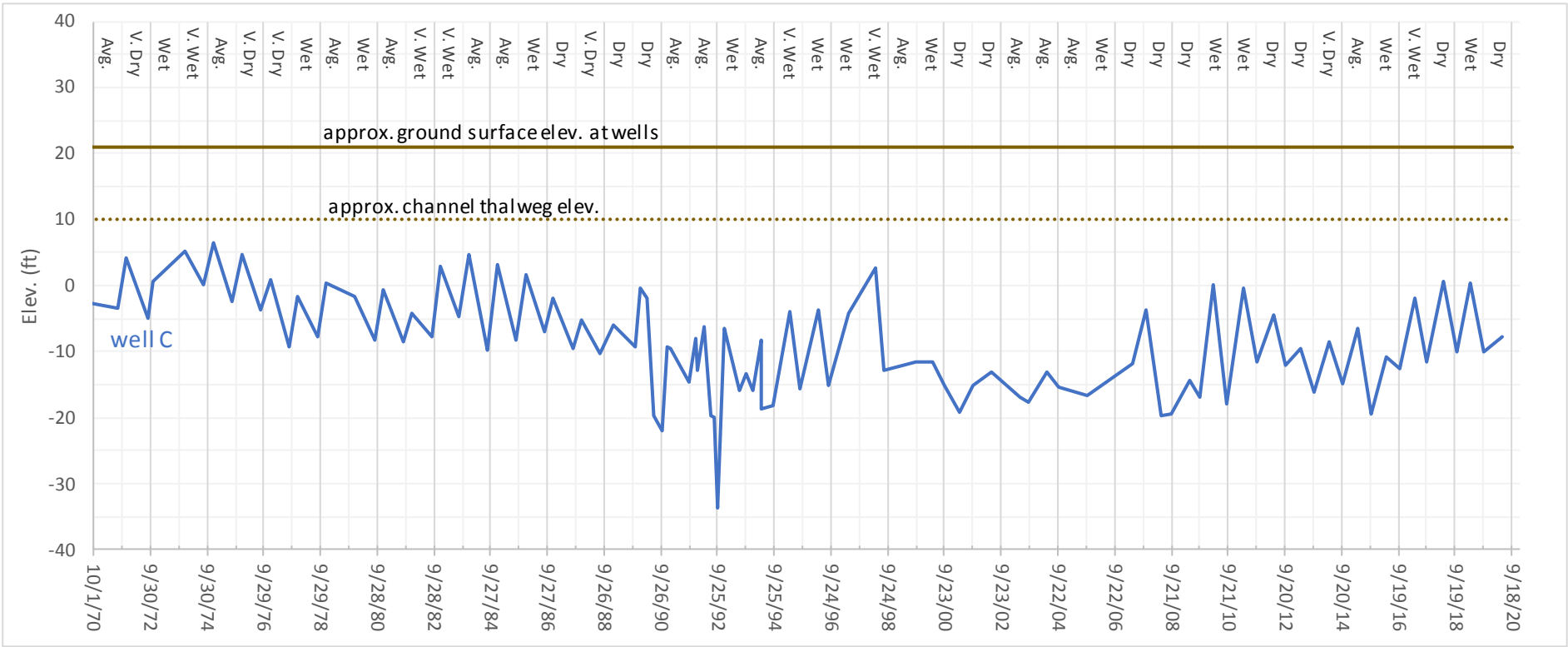


Notes:

Groundwater level hydrograph for well B (Qal) – North Pajaro River area immediately downstream of Watsonville

Project No. 20-1030	Created By: GK	**Figure 5**

F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
1/8/2021



Notes:

Groundwater level hydrograph for well C (QaLo) – South Pajaro River area immediately downstream of Pajaro

Project No. 20-1030	Created By: GK	**Figure 6**

F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
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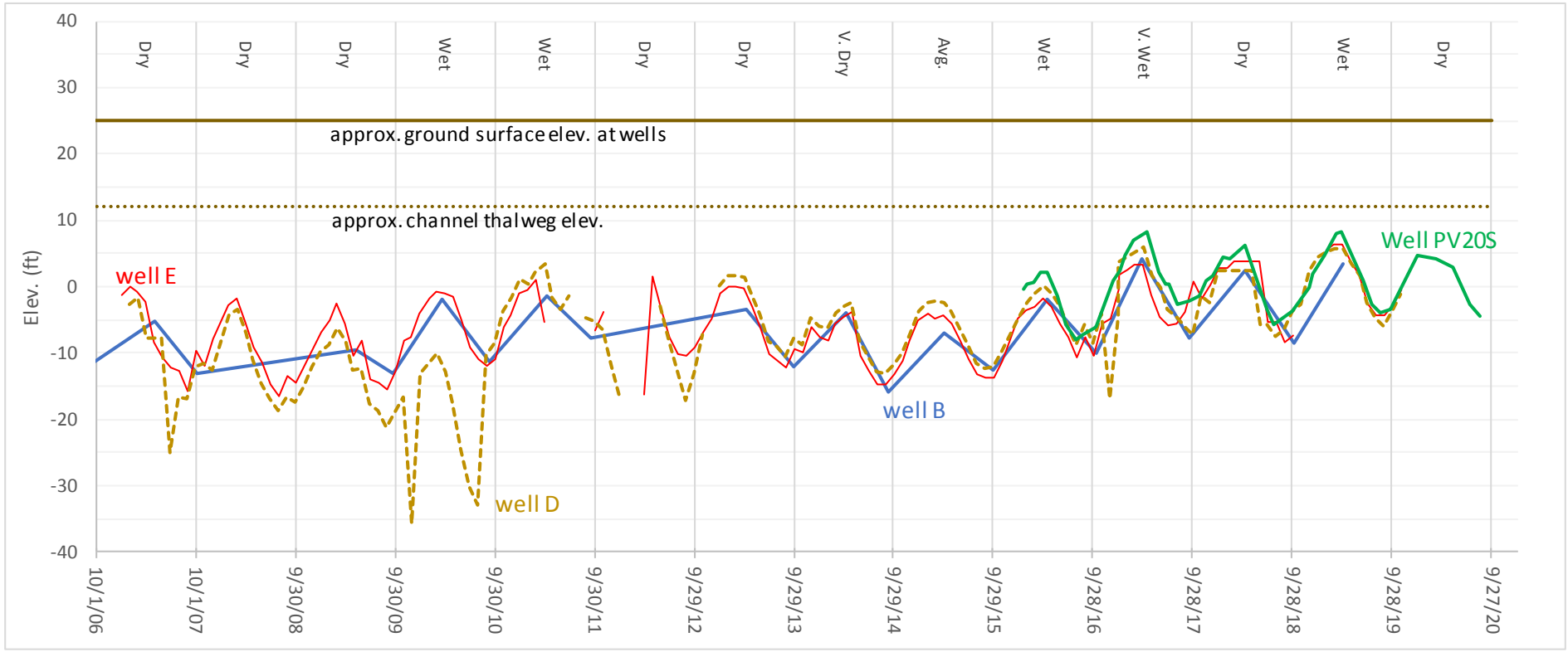

Notes:

Groundwater level hydrographs for wells D (QaUp), E (Qal), B (Qal) and PV20S (Qal) – North Pajaro River area at Watsonville

Project No. 20-1030	Created By: GK	**Figure 7**

F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
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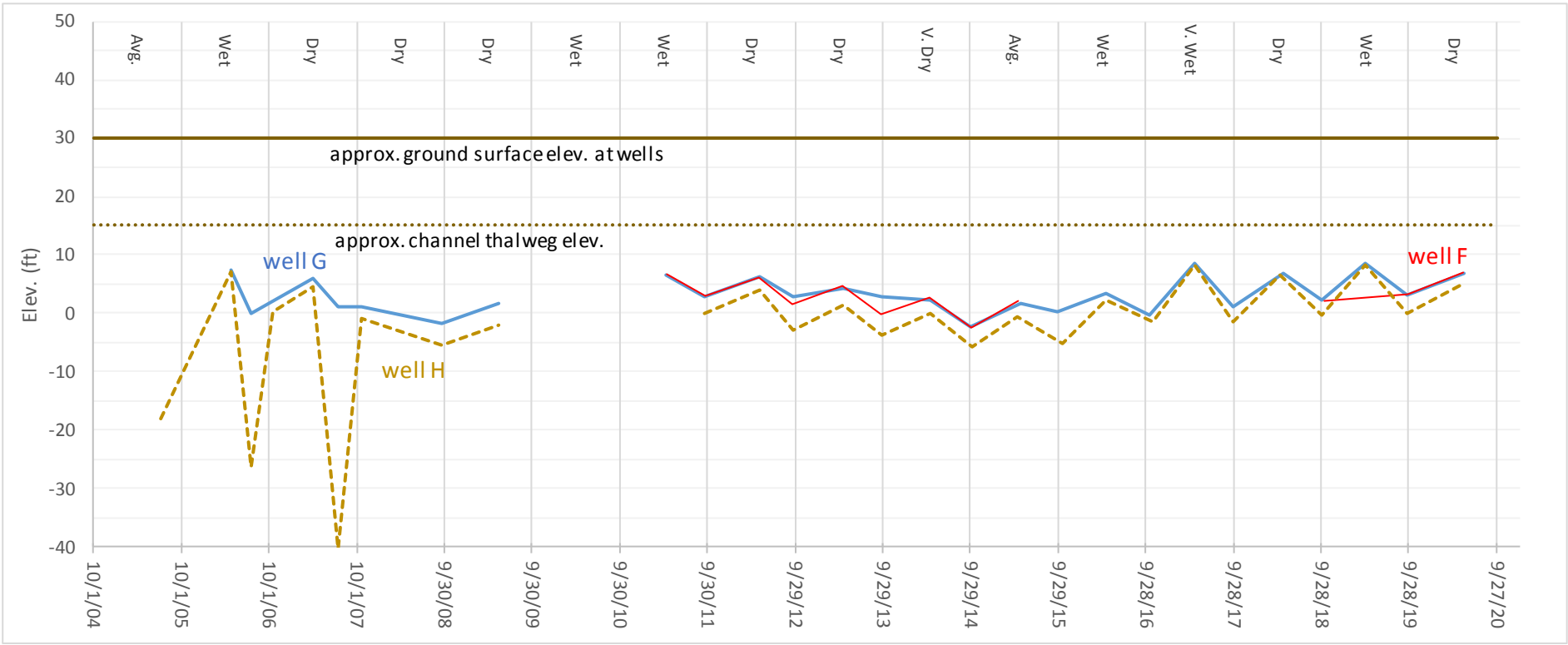

Notes:

Groundwater level hydrographs for wells F (QaUp), G (QaUp) and H (Qal) – South Pajaro River area at Pajaro

Project No. 20-1030	Created By: GK	**Figure 8**

F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
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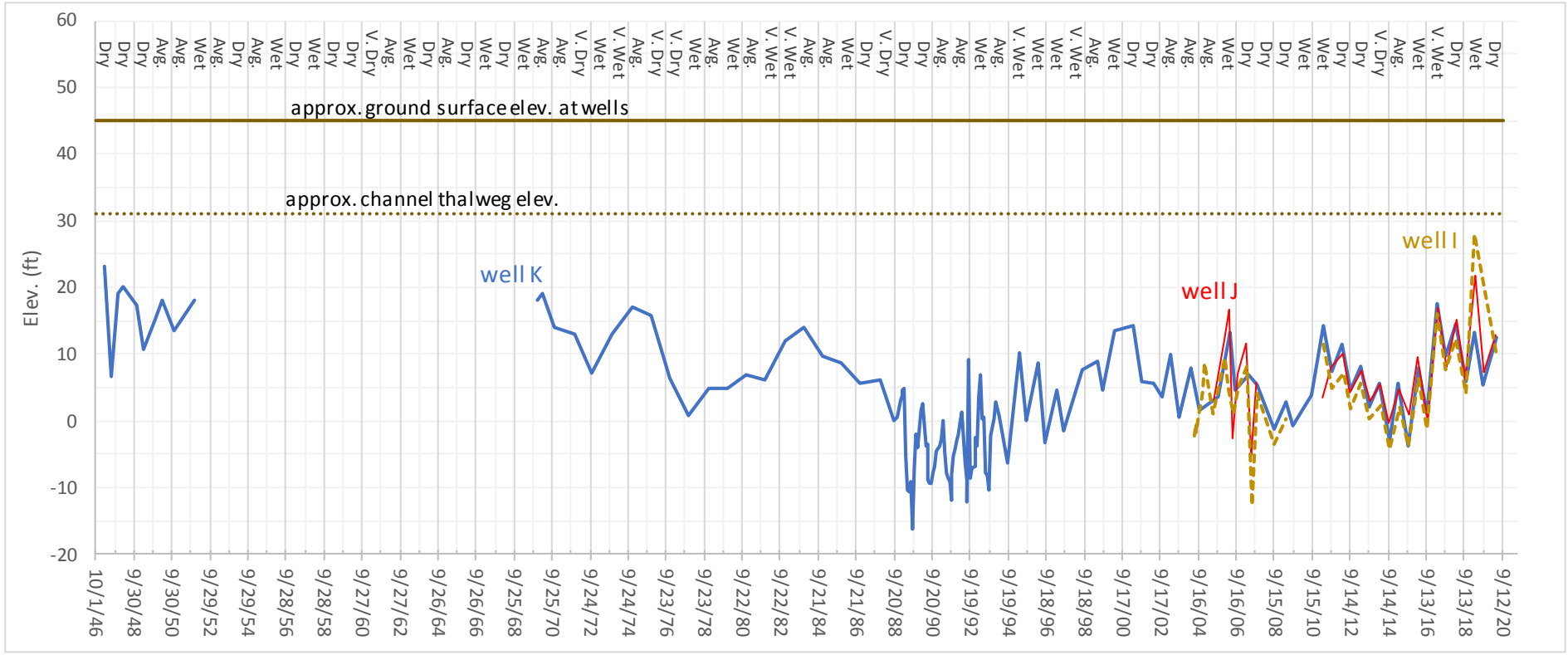

Notes:

Groundwater level hydrographs for wells I (QaLo), J (QaUp) and K (QaUp) – Pajaro River area upstream of Watsonville

Project No. 20-1030	Created By: GK	**Figure 9**

F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
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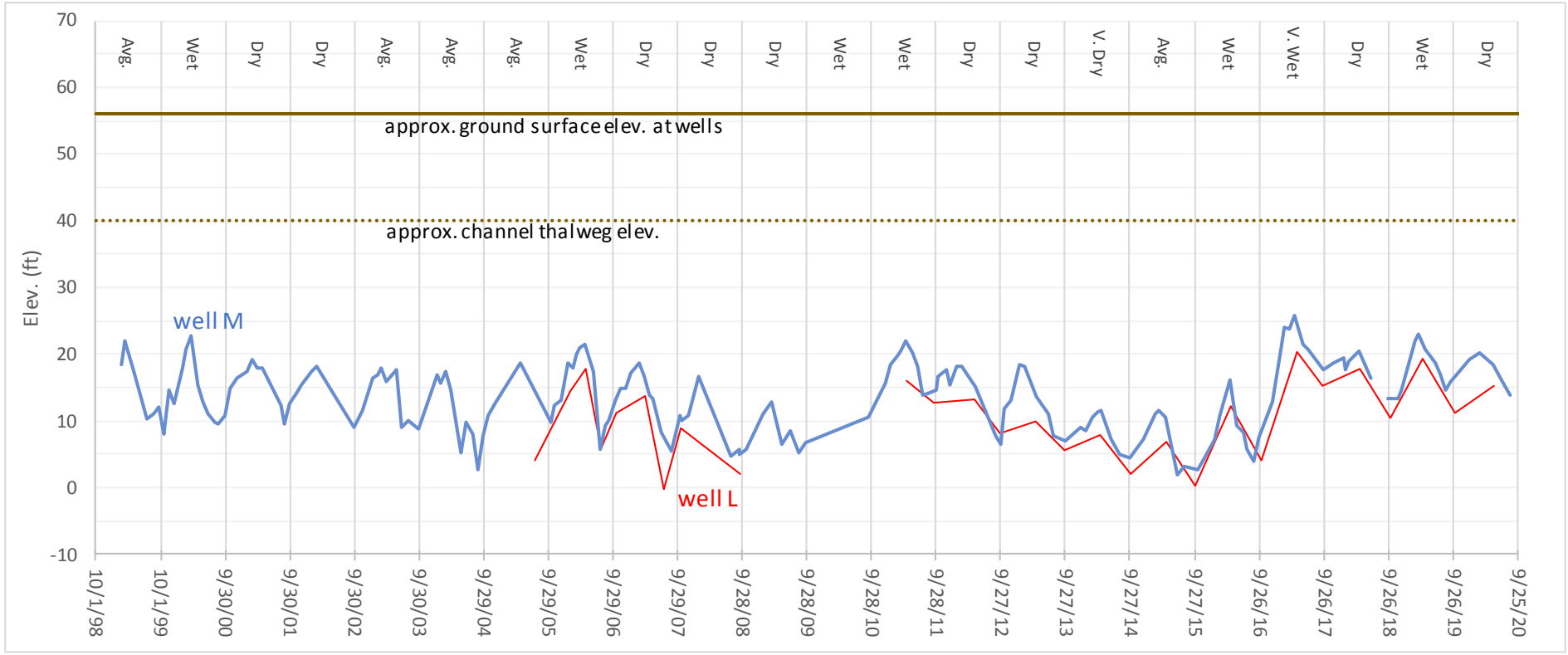

Notes:

Groundwater level hydrographs for wells L (Qal & QaUp) and M (Qal) – Pajaro River area upstream of Watsonville

Project No. 20-1030	Created By: GK	**Figure 10**

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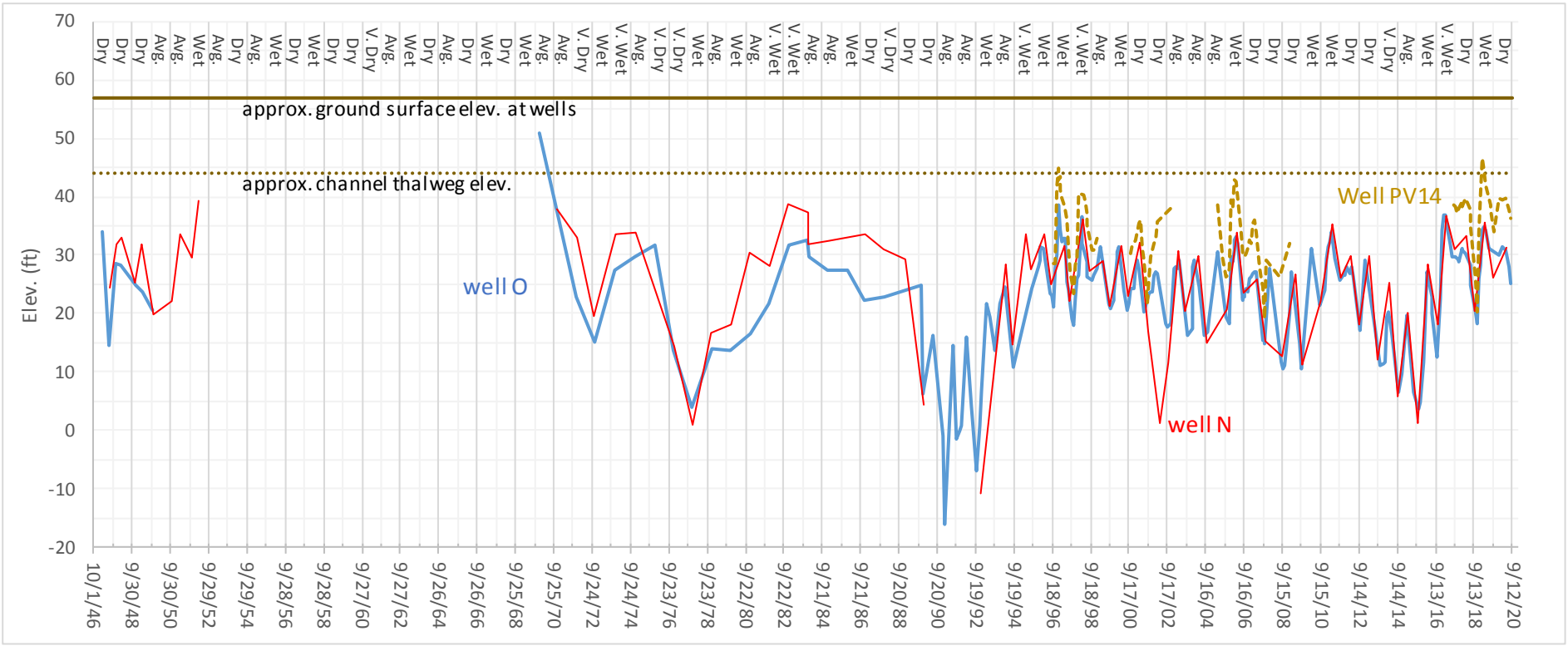

Notes:

Groundwater level hydrographs for wells N (QaUp-Tp), O (QaUp) and PV14 (Qal) – Pajaro River area near Murphy Crossing

Project No. 20-1030	Created By: GK	**Figure 11**

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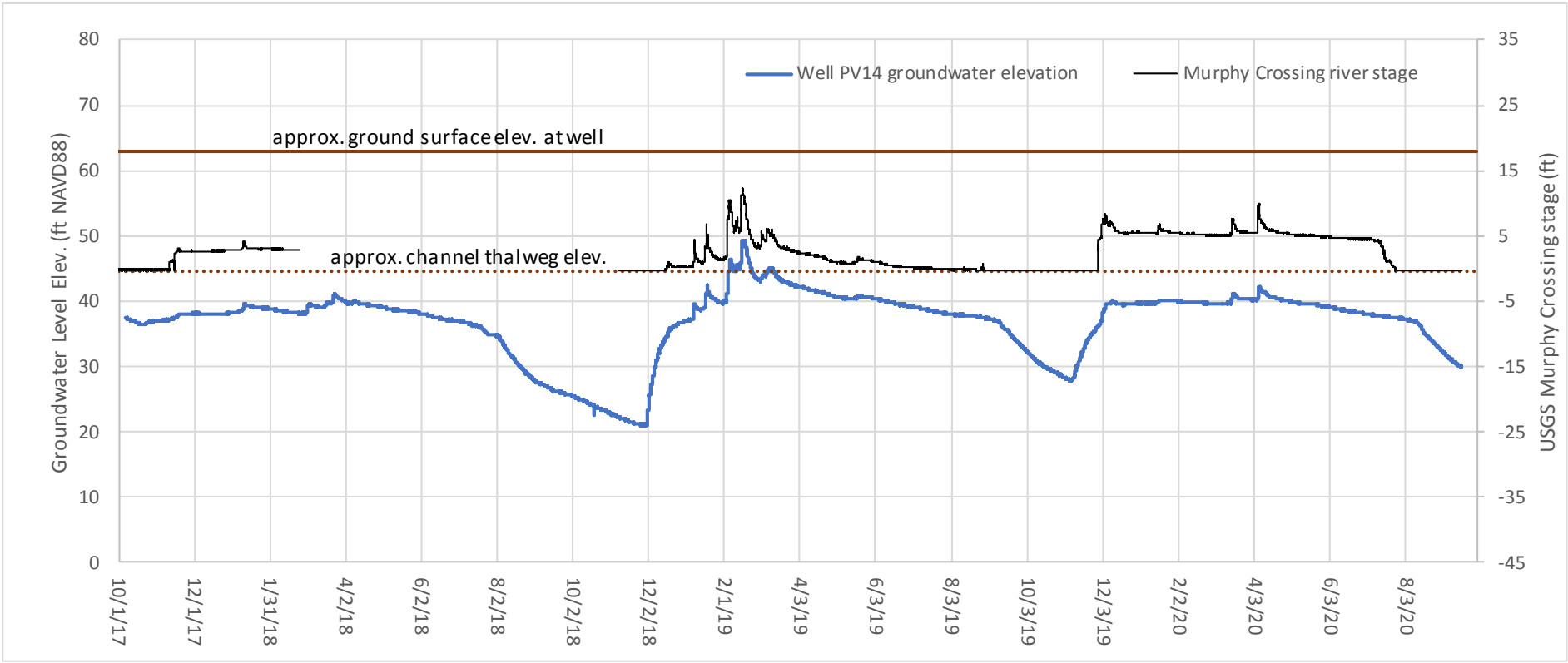

Notes:

Groundwater level hydrograph for well PV14 and Pajaro River stage at USGS Murphy Crossing gage

Project No. 20-1030	Created By: GK	**Figure 12**

F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
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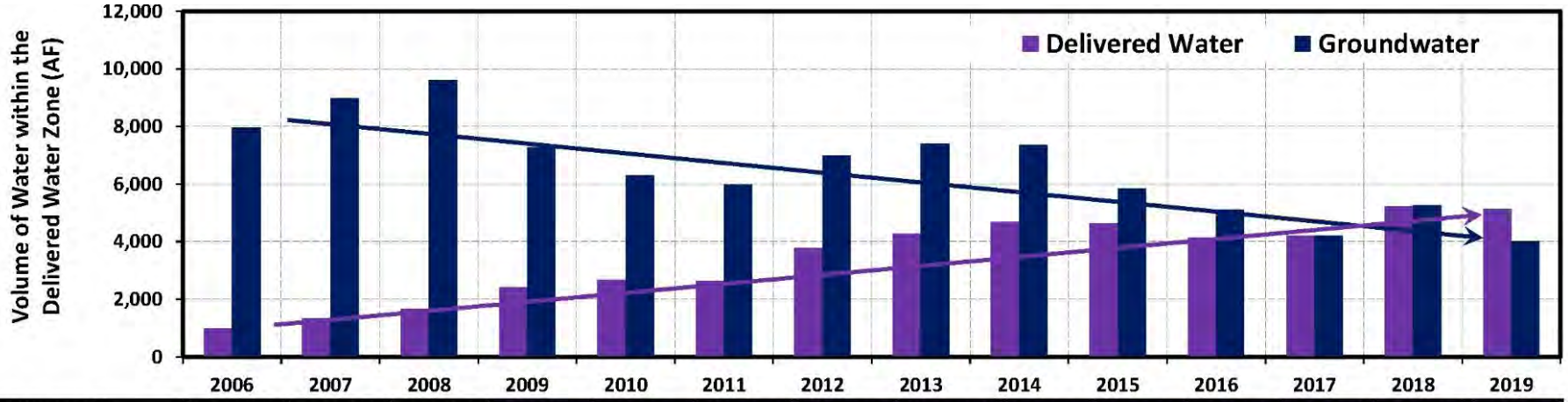


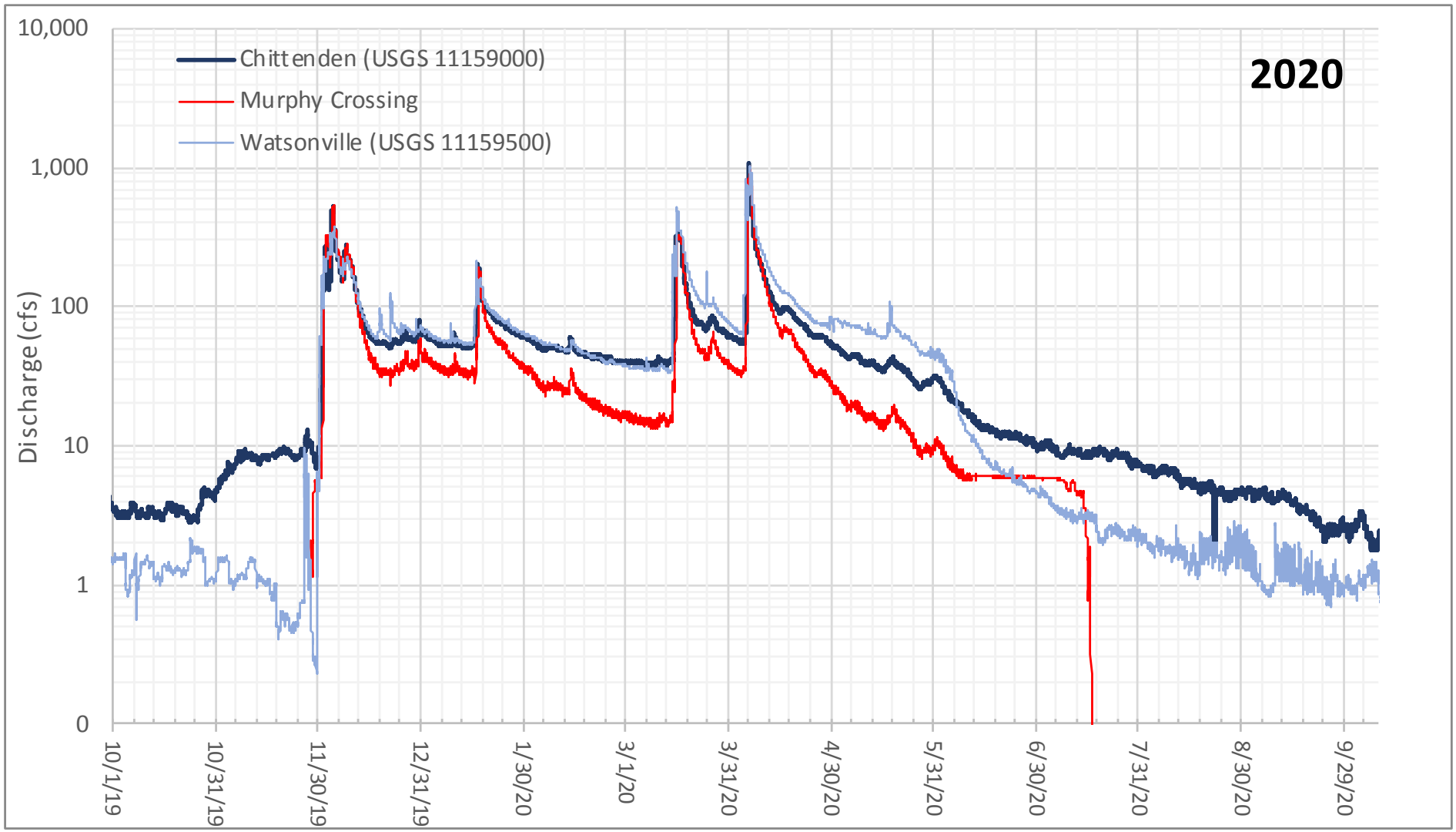
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Delivered Water (AF)	990	1,337	1,665	2,406	2,681	2,630	3,788	4,275	4,685	4,638	4,139	4,203	5,213	5,138
Groundwater (AF)	7,976	8,974	9,614	7,278	6,293	5,971	6,984	7,407	7,360	5,857	5,117	4,210	5,275	4,013
Total DWZ Water Use (AF)	8,966	10,311	11,279	9,684	8,974	8,601	10,772	11,682	12,044	10,495	9,256	8,413	10,488	9,151
Delivered Water % of Total	11%	13%	15%	25%	30%	31%	35%	37%	39%	44%	45%	50%	50%	56%

(Production of Recycled Water Began in 2009)

Notes: Source: PV Water

Annual delivered water and groundwater usage trends within the Pajaro Valley Water Management Agency service area

Project No. 20-1030 | Created By: GK | **Figure 13**



Notes:

Water year 2020 flow hydrographs for Pajaro River - USGS gages at Chittenden (11159000), Murphy Crossing and Watsonville (11159500)

Project No. 20-1030	Created By: GK	**Figure 14**

F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
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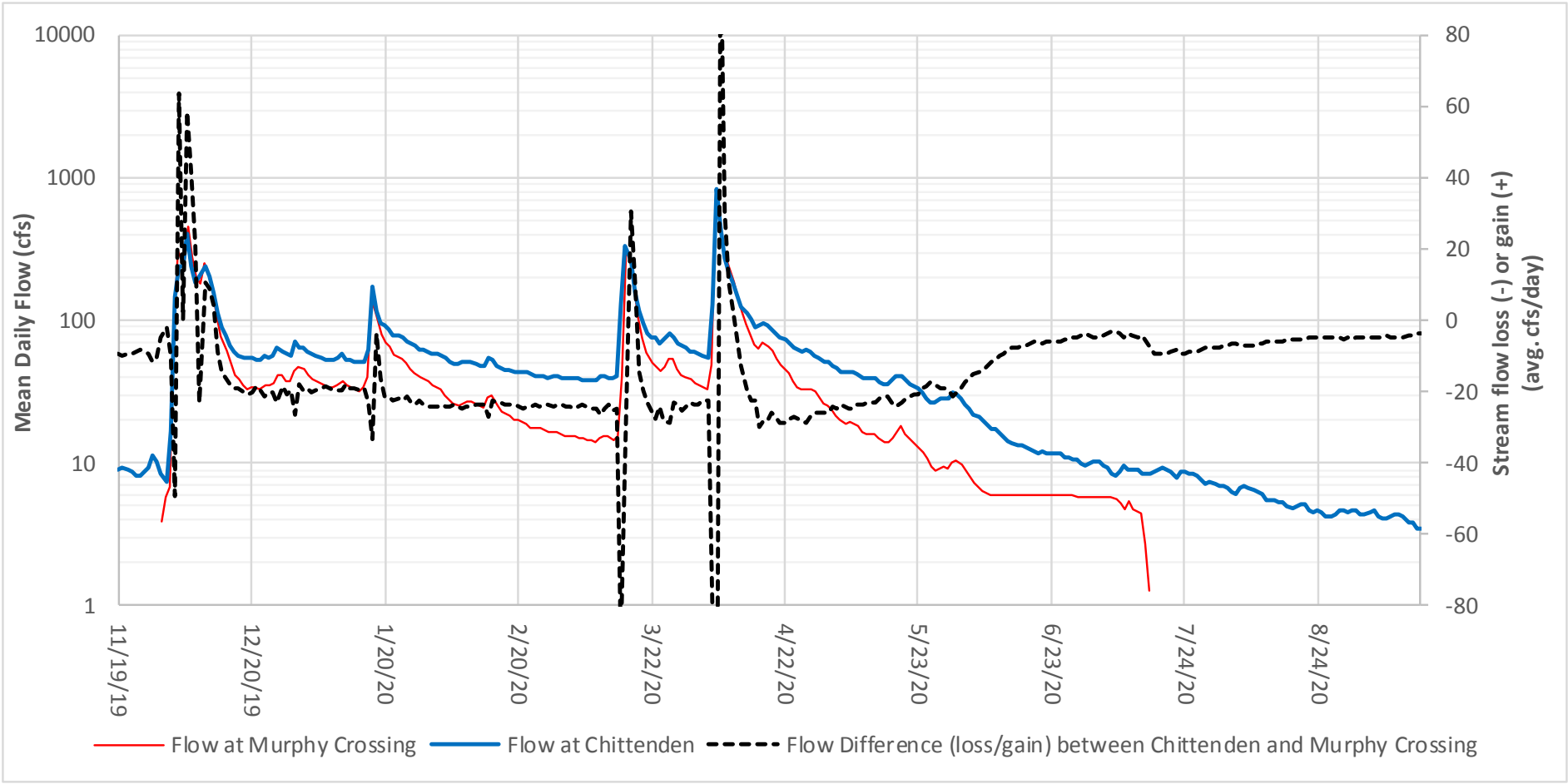

Notes:

Mean daily flow and stream flow loss on Pajaro River between Chittenden and Murphy Crossing

Project No. 20-1030	Created By: GK	**Figure 15**

Notes:

Production (red triangles) and monitoring wells (black circles) in the vicinity of Murphy Crossing stream flow gage (blue square)

Project No. 20-1030	Created By: GK	**Figure 16**

F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
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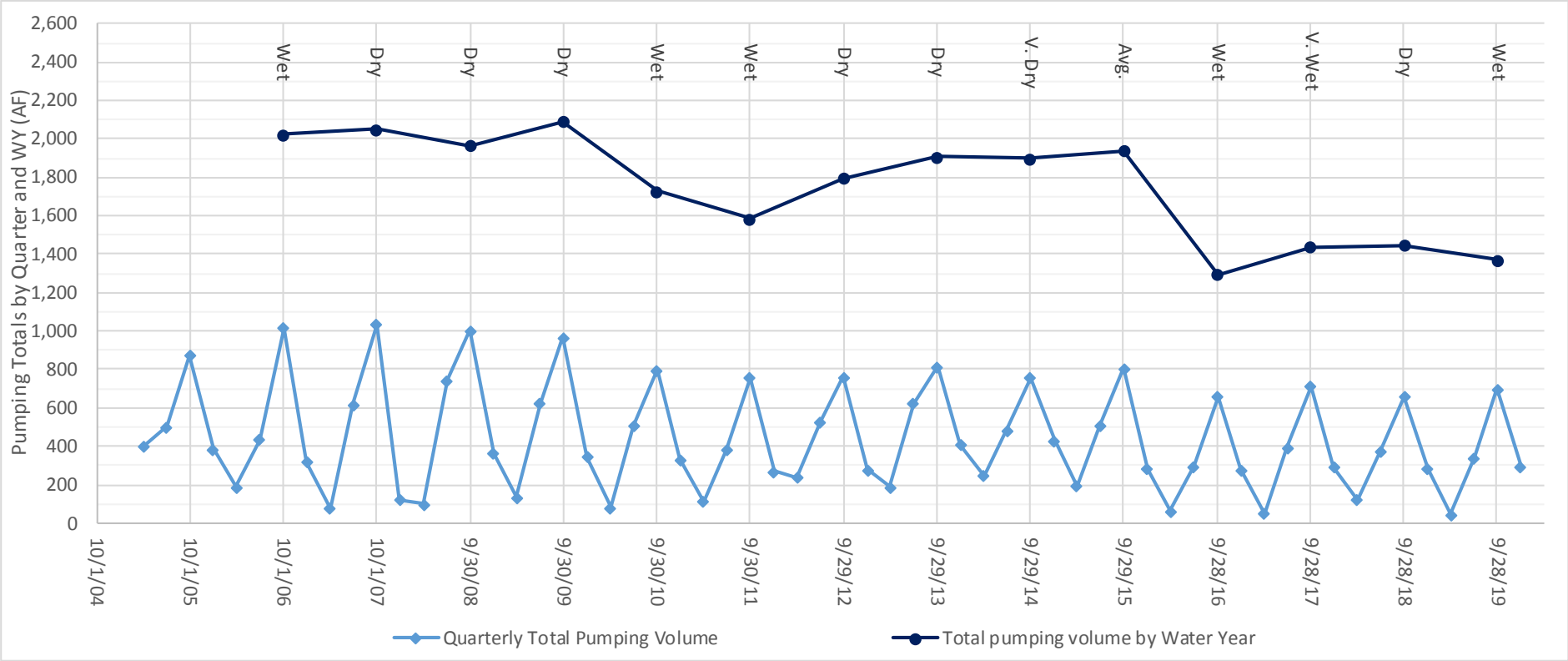

Notes:

Quarterly and total Water Year (WY) pumping volumes from wells in the vicinity of Murphy Crossing stream gage

Project No. 20-1030	Created By: GK	**Figure 17**

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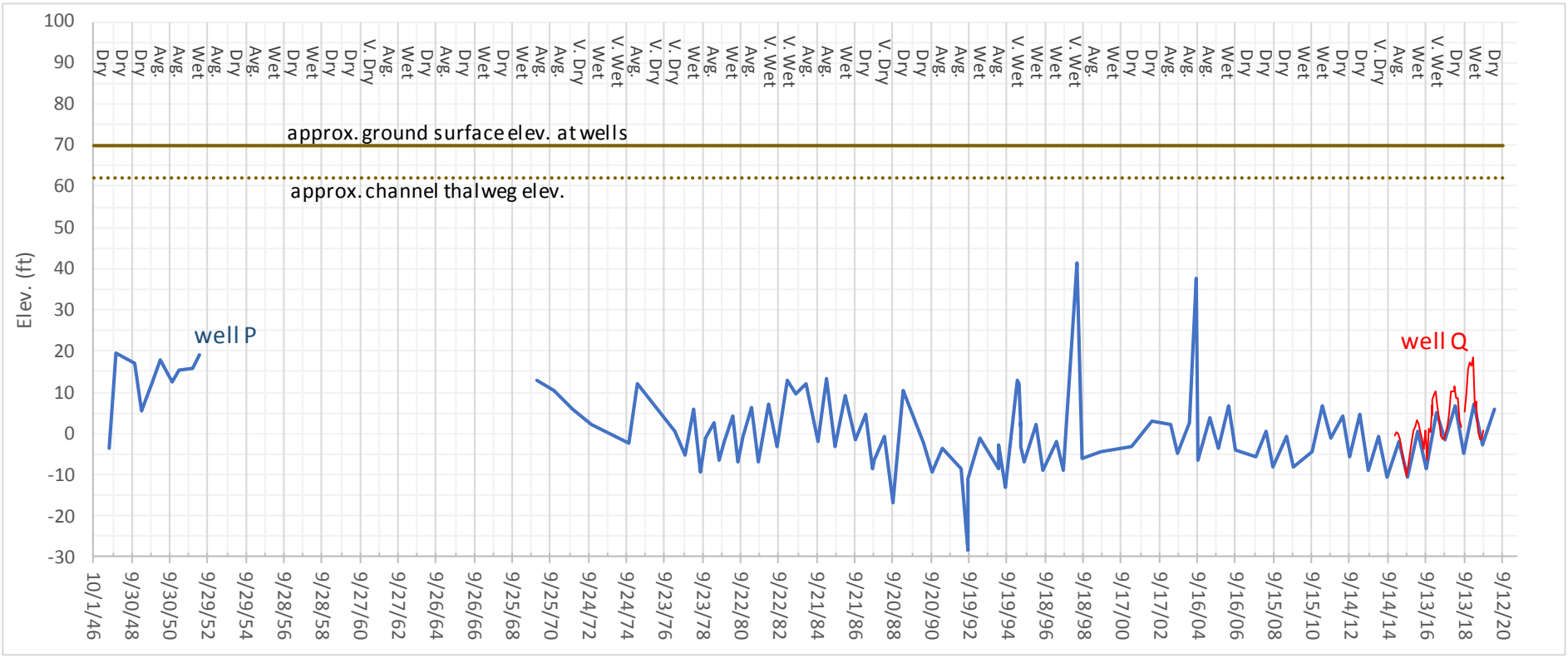
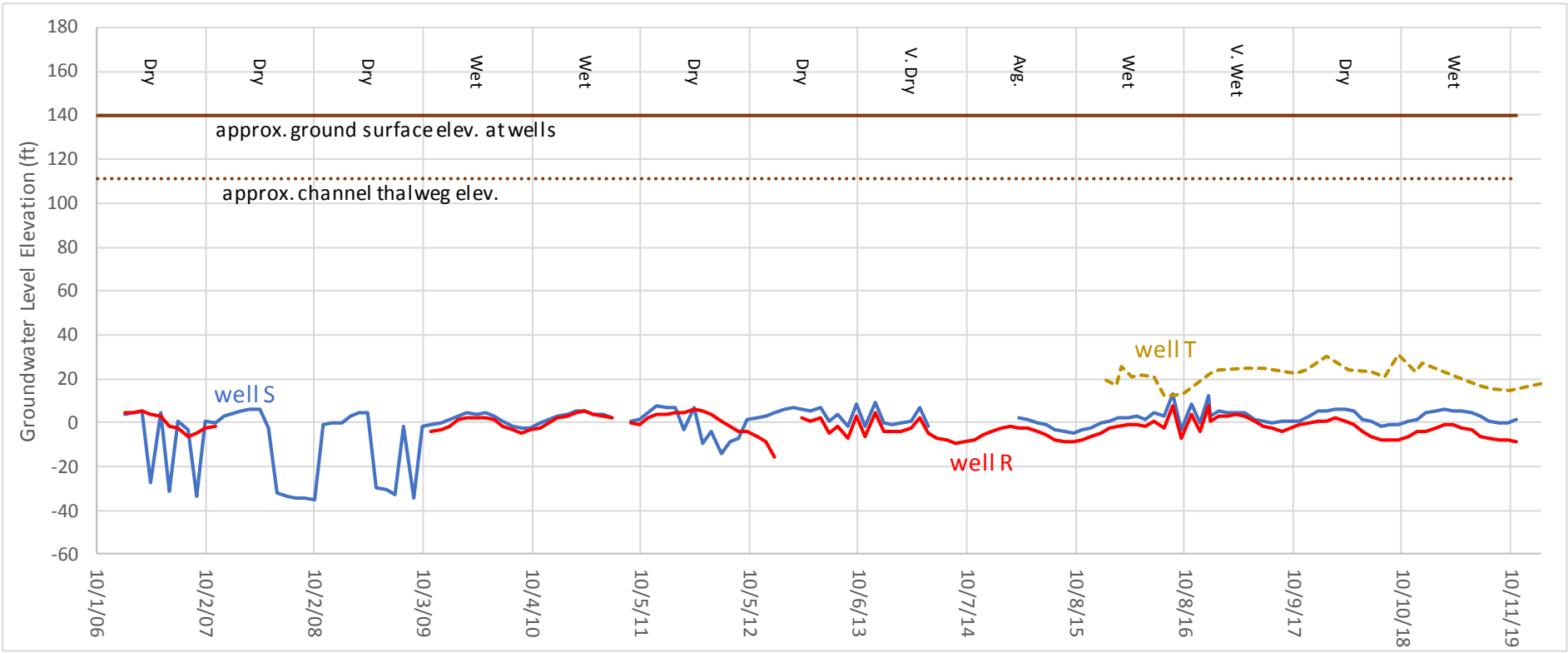


Notes:

Groundwater level hydrographs for wells P (QaUp) and Q (QaUp) – Lower Corralitos Creek downstream of Freedom

Project No. 20-1030	Created By: GK	**Figure 18**



Notes:

Groundwater level hydrographs for wells R (QaUp), S (QaUp) and T (QaUp) upstream of Freedom

Project No. 20-1030	Created By: GK	**Figure 19**

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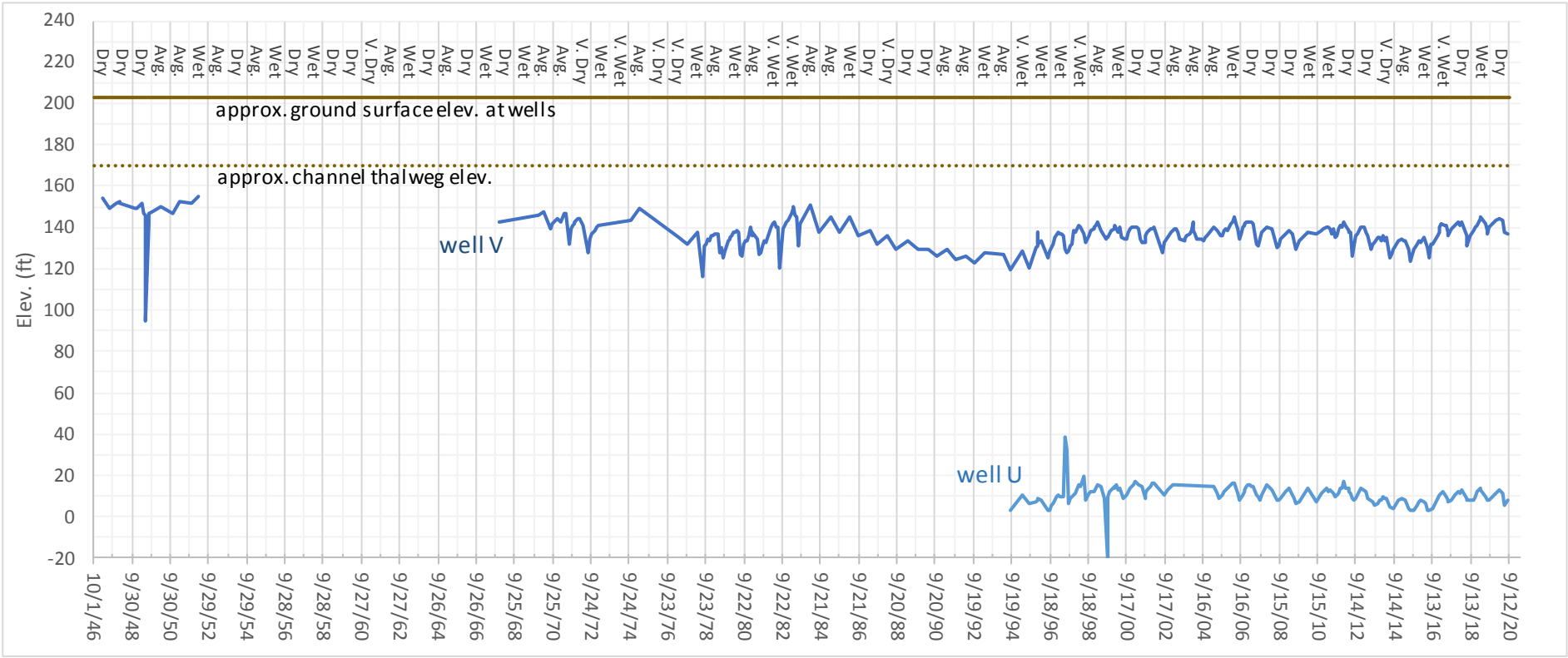
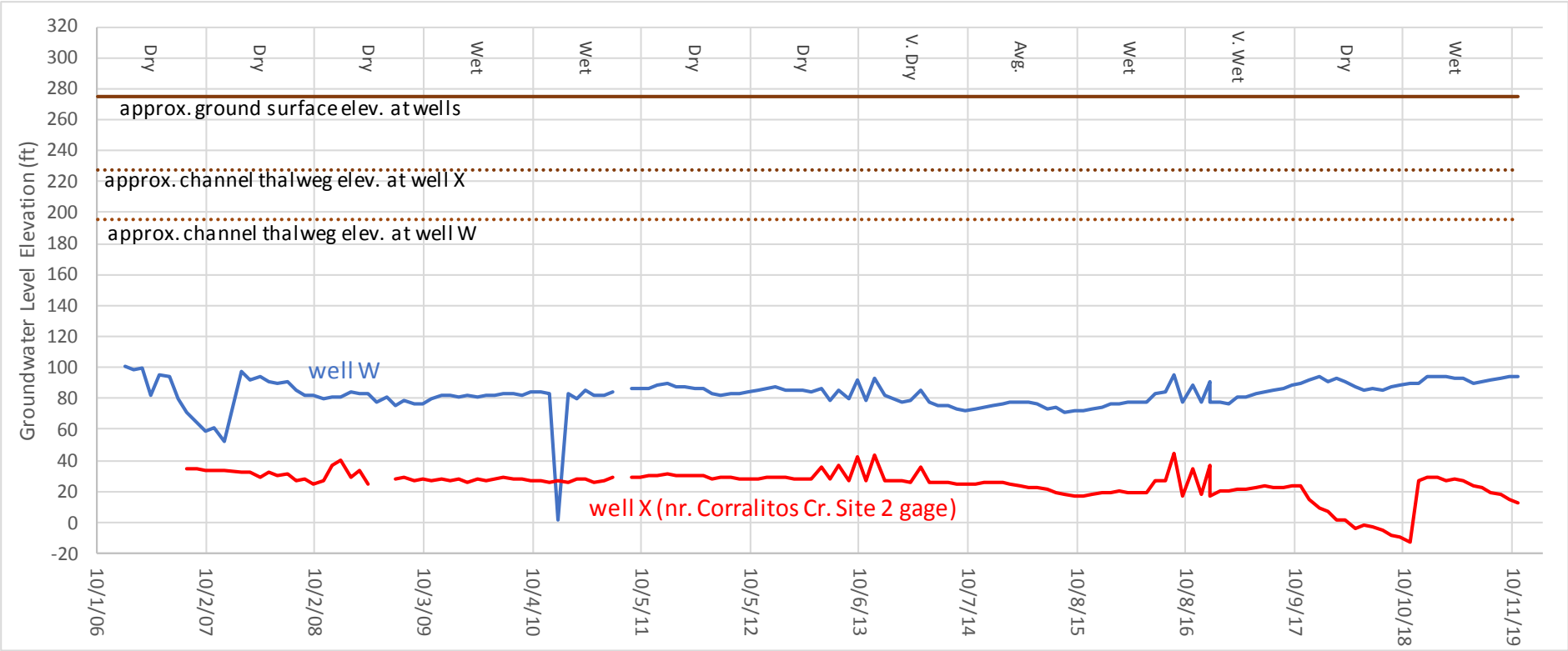
1/8/2021



Notes:

Groundwater level hydrographs for wells U (QaUp) and V (Qal) – Corralitos Creek downstream of Corralitos near Varni Road

Project No. 20-1030	Created By: GK	**Figure 20**



Notes:

Groundwater level hydrographs for wells 8 (QaUp and QaLo) and 19 (QaLo and Tp) – Corralitos Creek near Corralitos

Project No. 20-1030	Created By: GK	**Figure 21**

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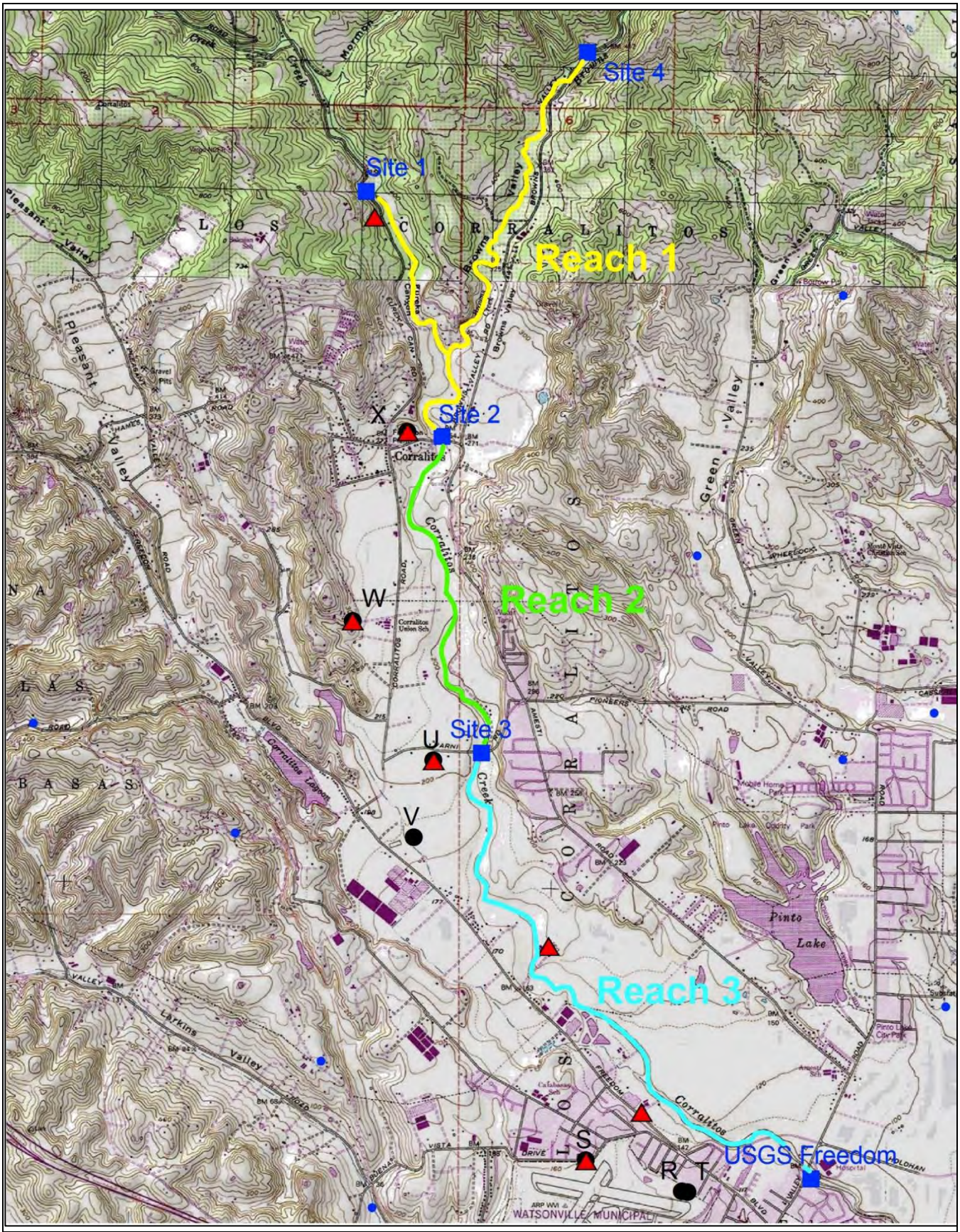
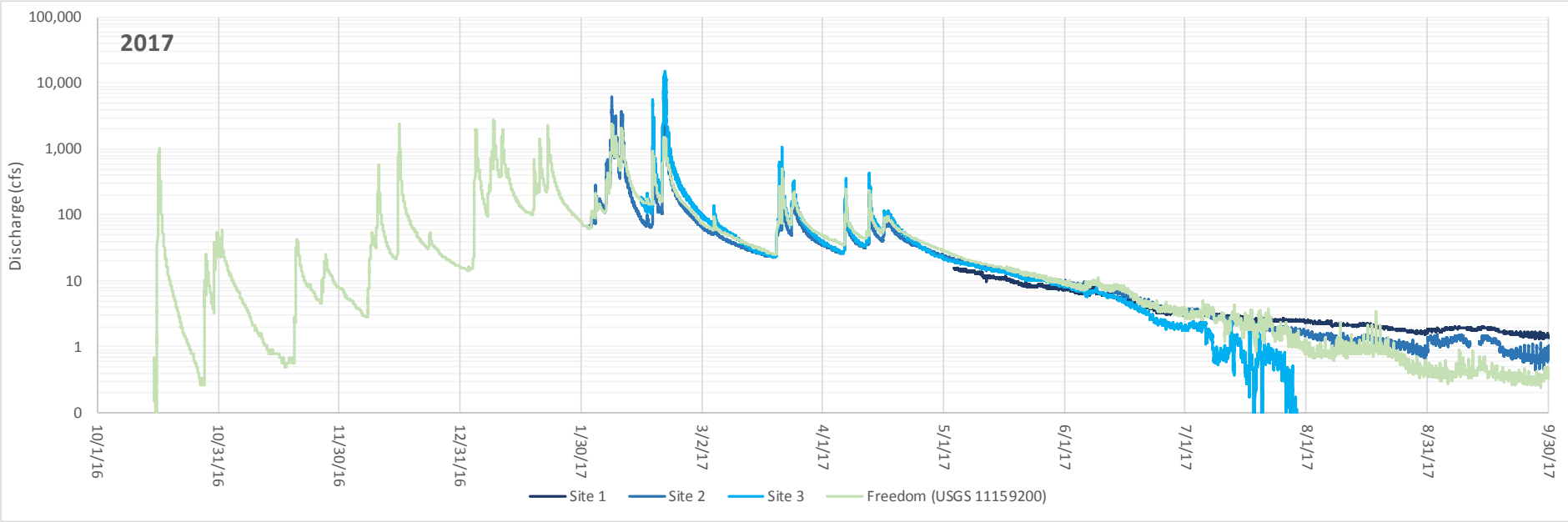


Notes:

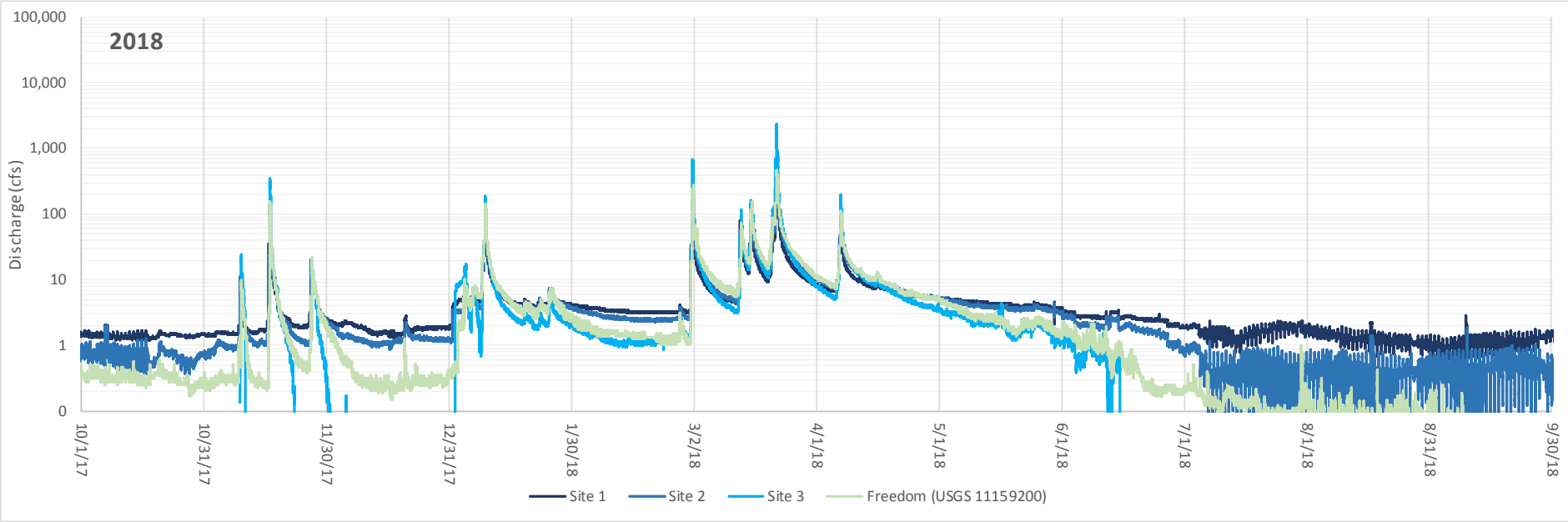
Stream flow gages (blue squares), production wells (red triangles), monitoring wells (black circles), and designated reaches upstream of Freedom on Corralitos Creek

Project No. 20-1030	Created By: GK	**Figure 22**



Notes:		Water Year (WY) 2017 flow on Corralitos Creek at City of Watsonville gage Sites 1-3 and USGS gage at Freedom (11159200)		
		Project No. 20-1030	Created By: GK	**Figure 23**

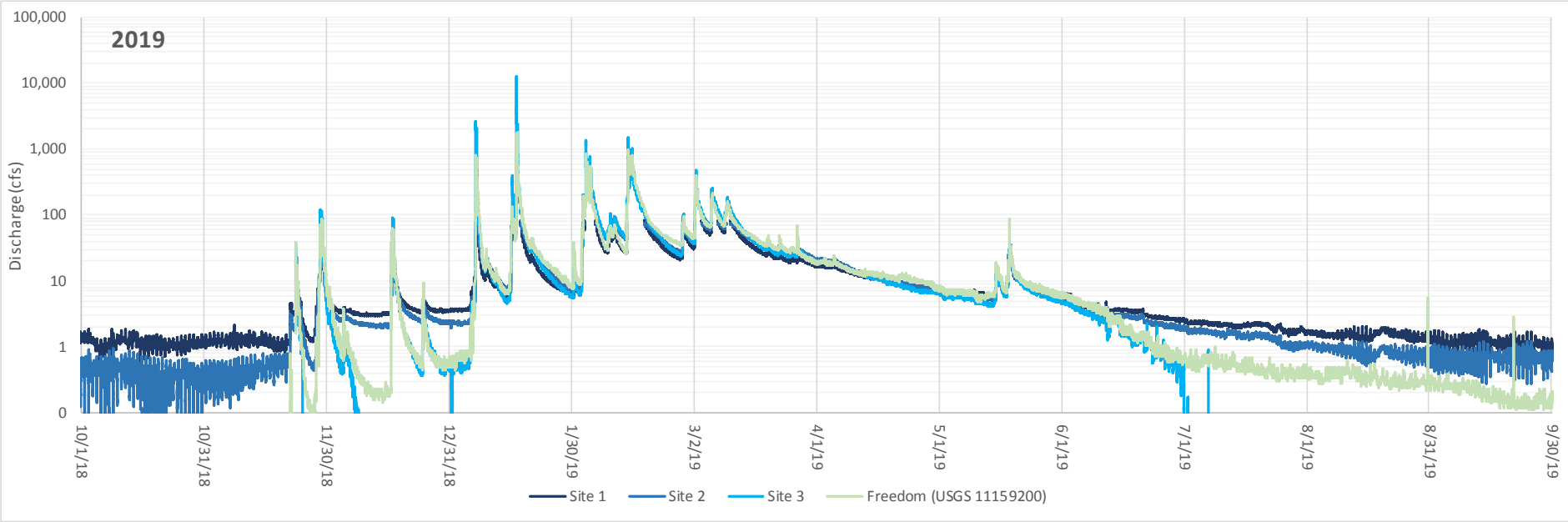
F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
1/8/2021



Notes:

Water Year (WY) 2018 flow on Corralitos Creek at City of Watsonville gage Sites 1-3 and USGS gage at Freedom (11159200)

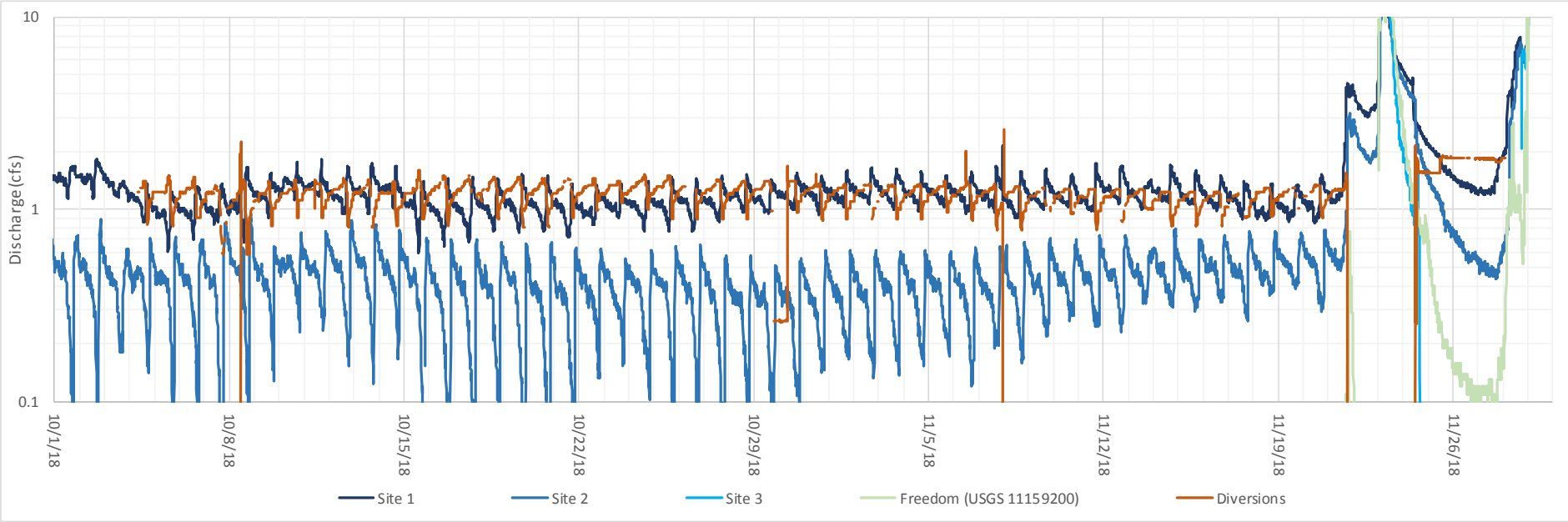
Project No. 20-1030	Created By: GK	**Figure 24**



Notes:

Water Year (WY) 2019 flow on Corralitos Creek at City of Watsonville gage Sites 1-3 and USGS gage at Freedom (11159200)

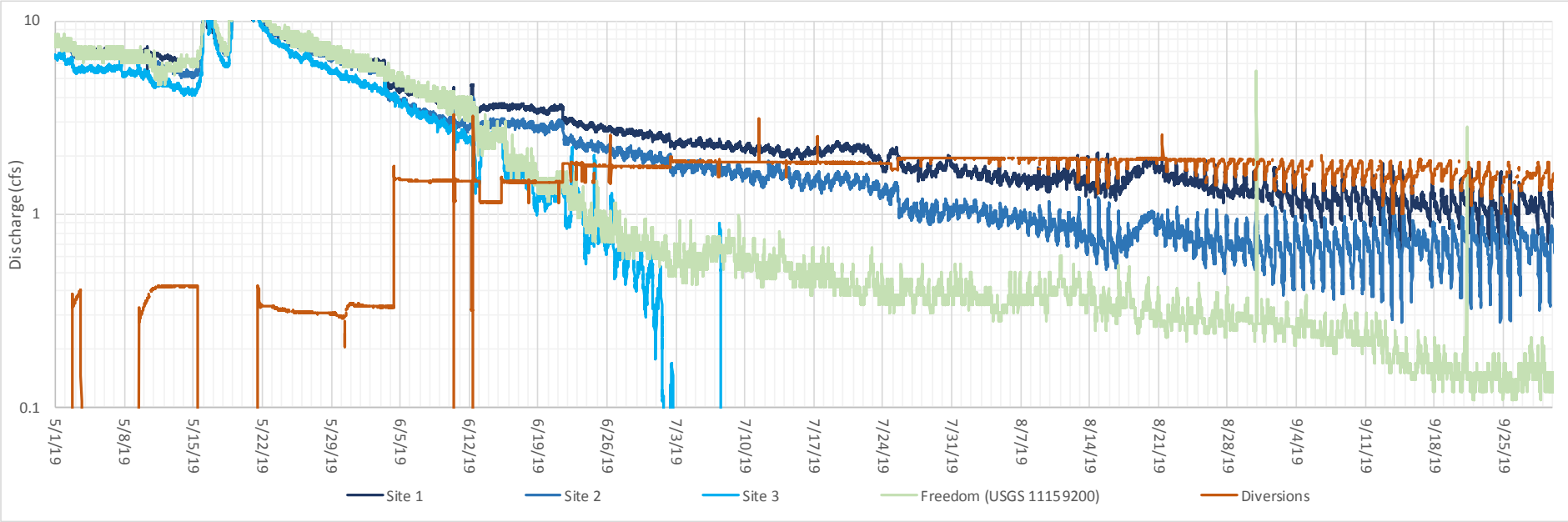
Project No. 20-1030	Created By: GK	**Figure 25**



Notes:

Flow on Corralitos Creek at City of Watsonville gage Sites 1-3 and USGS gage at Freedom (11159200) vs. total diversions for period Oct.–Nov. 2018.

Project No. 20-1030	Created By: GK	**Figure 26**

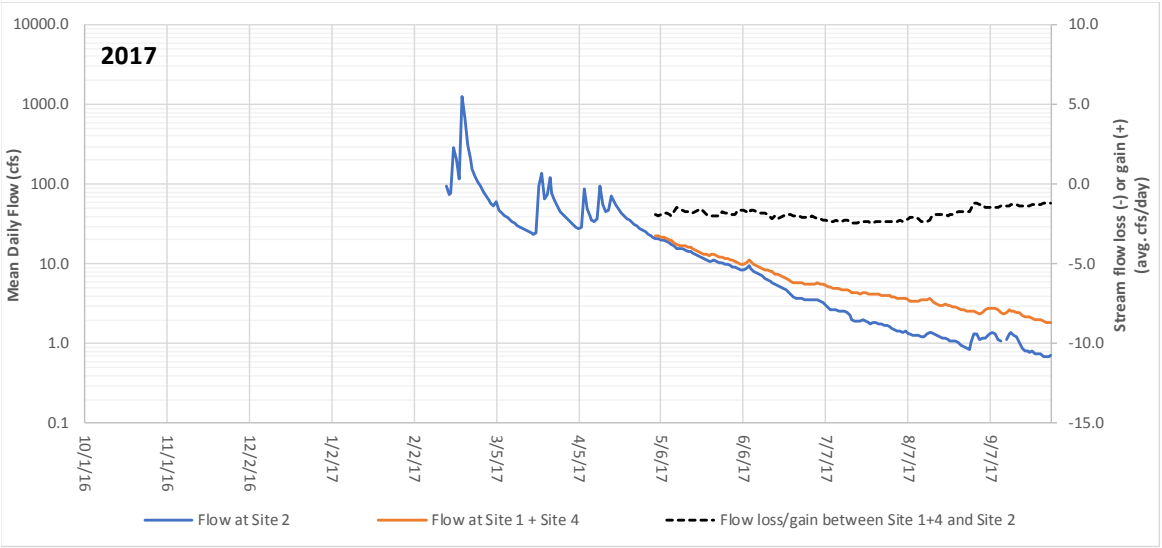


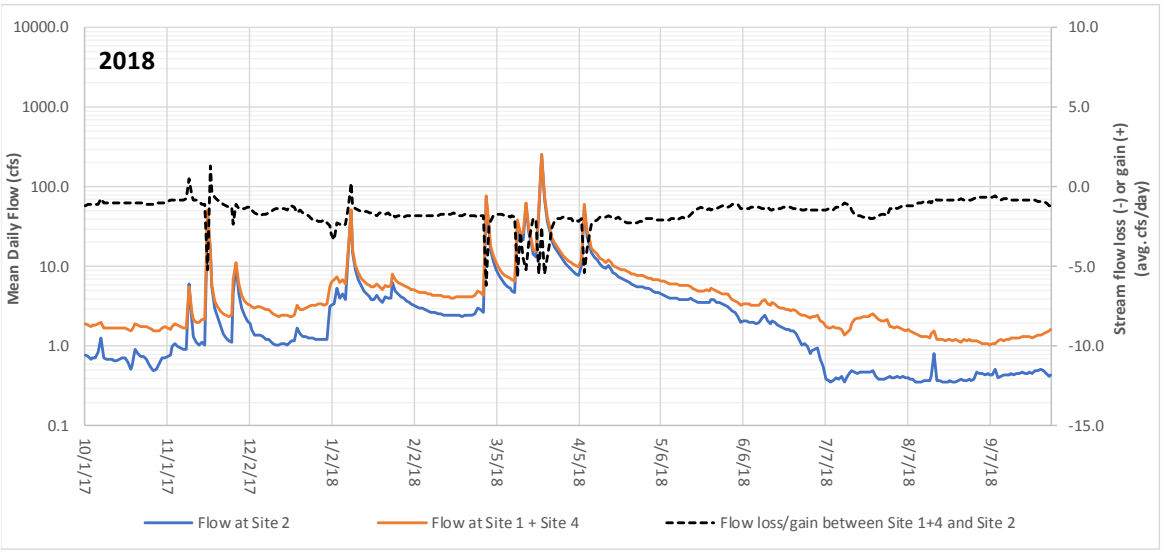
Notes:

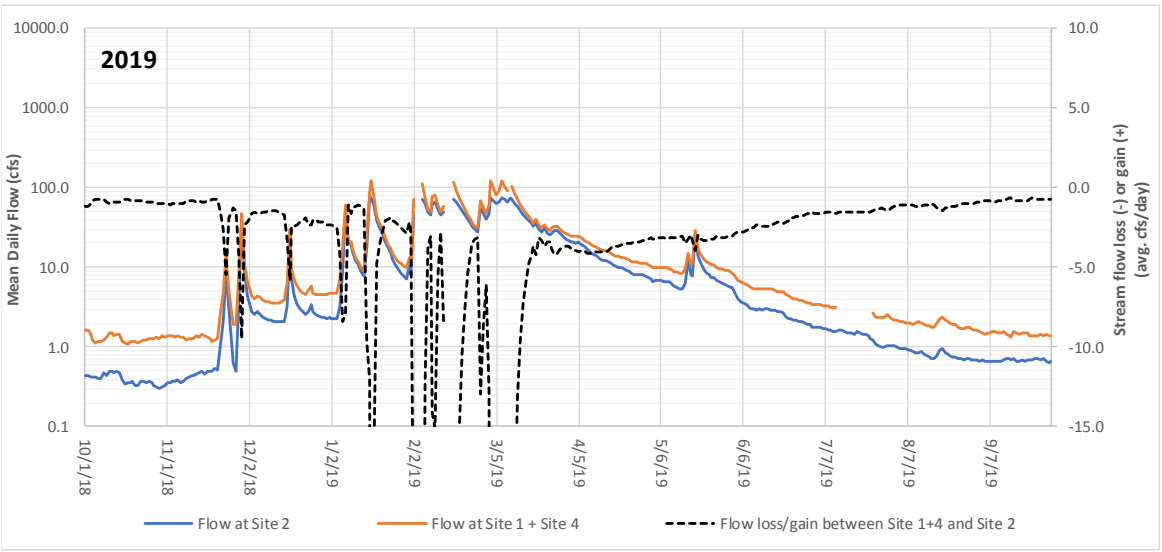
Flow on Corralitos Creek at City of Watsonville gage Sites 1-3 and USGS gage at Freedom (11159200) vs. total diversions for period May-Sept. 2019

Project No. 20-1030	Created By: GK	**Figure 27**

F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
1/8/2021



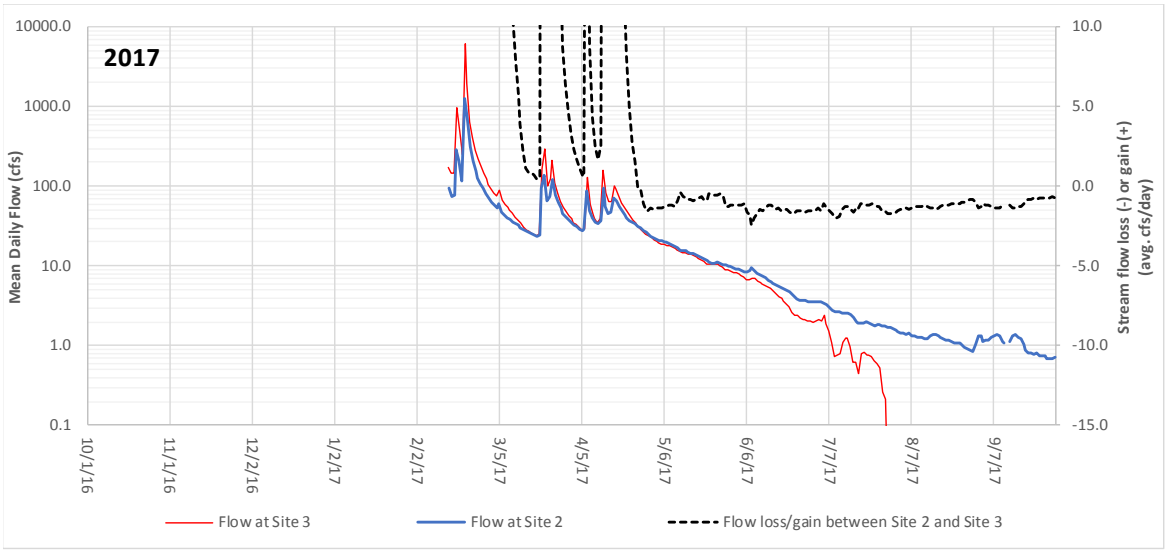


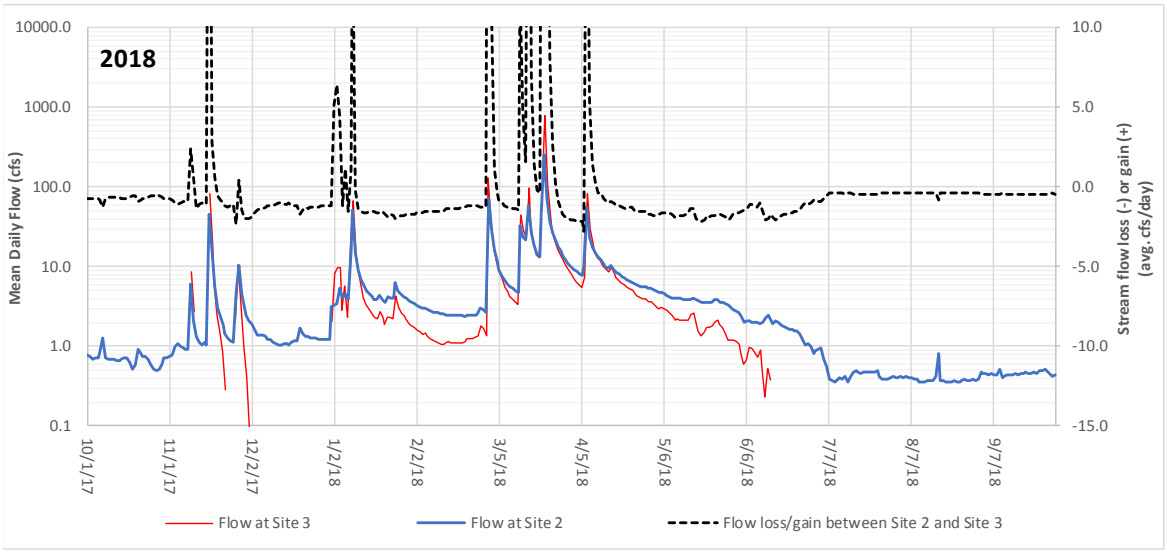


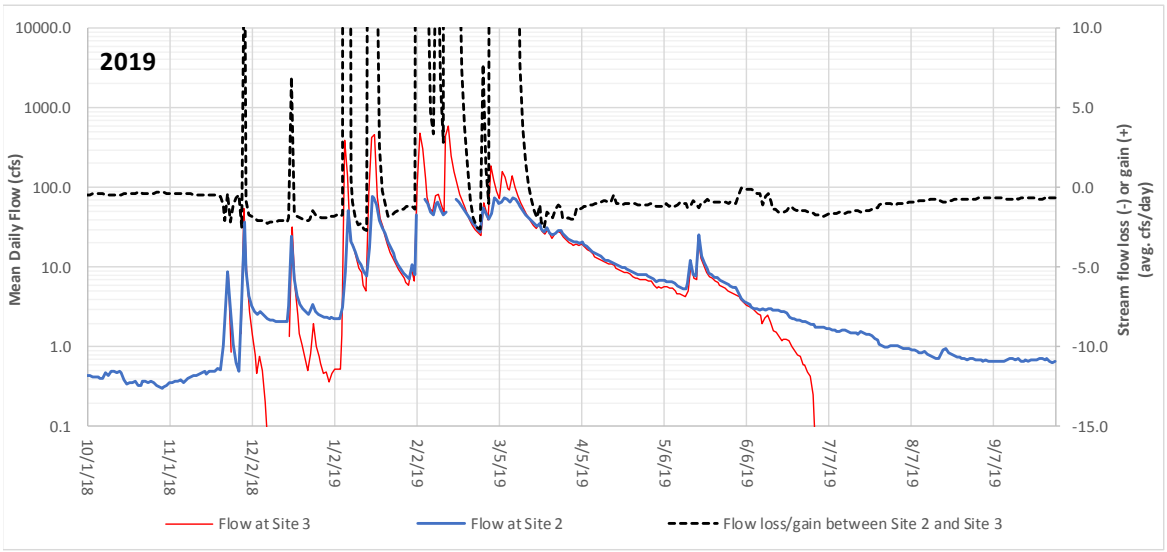
Notes:

Mean daily flow and stream flow change along Reach A upstream of gage Site 2

Project No. 20-1030 | Created By: GK | **Figure 28**



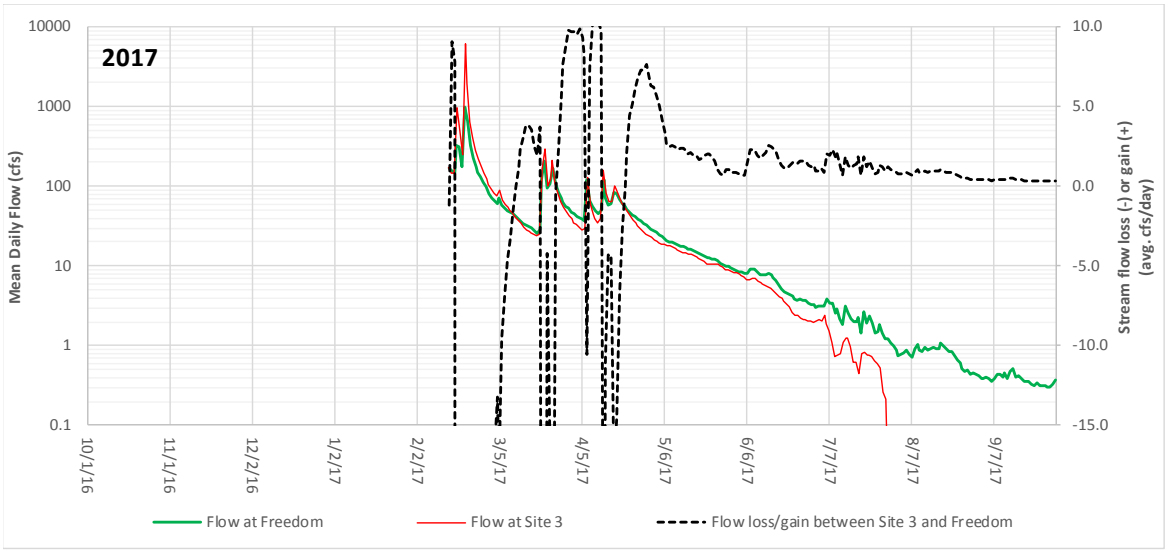


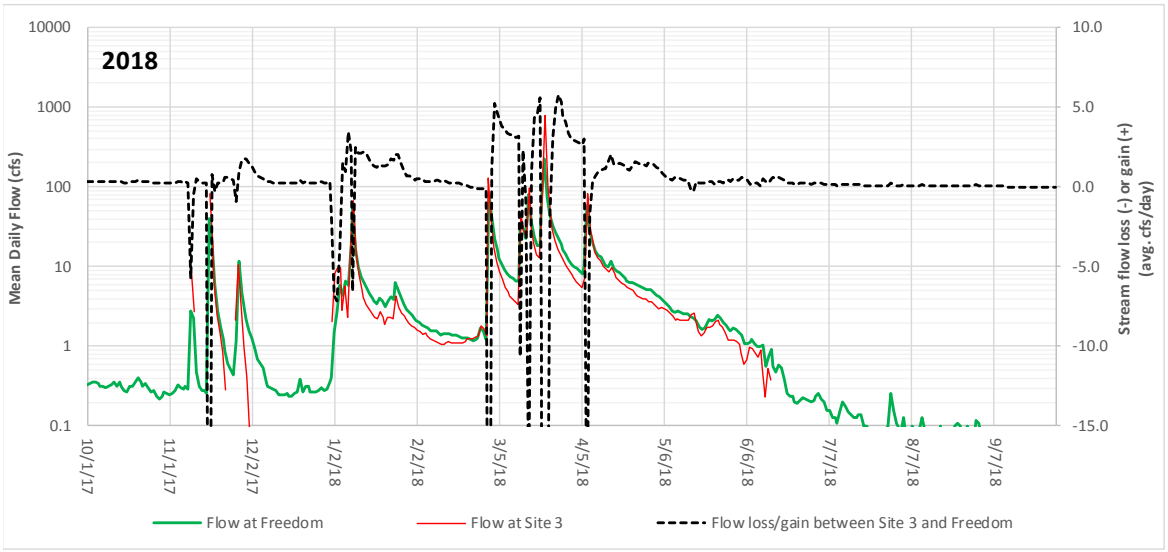


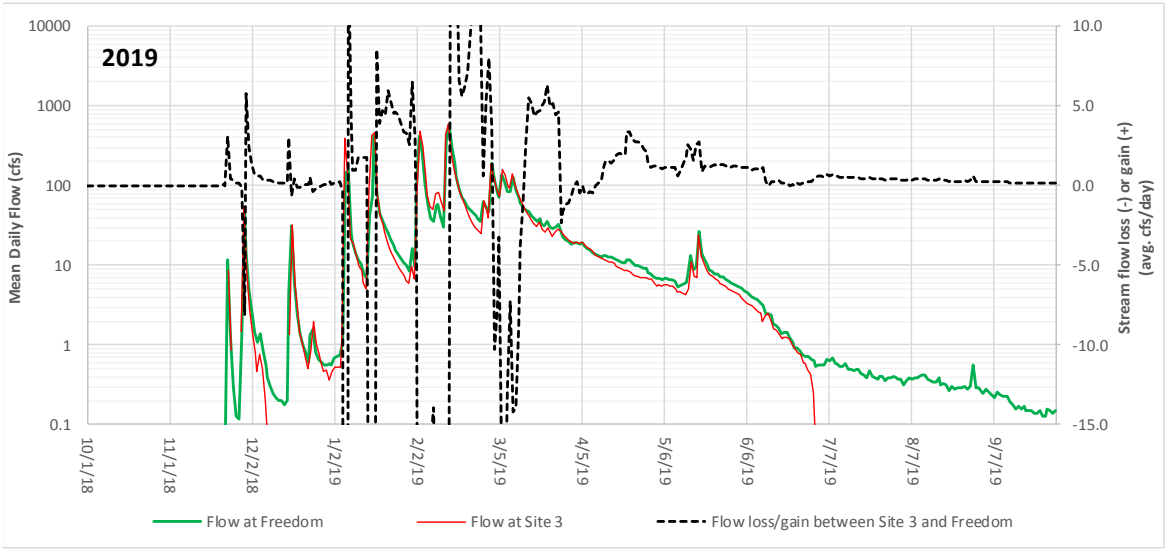
Notes:

Mean daily flow and stream flow change along Reach B upstream of gage Site 3

Project No. 20-1030 | Created By: GK | **Figure 29**





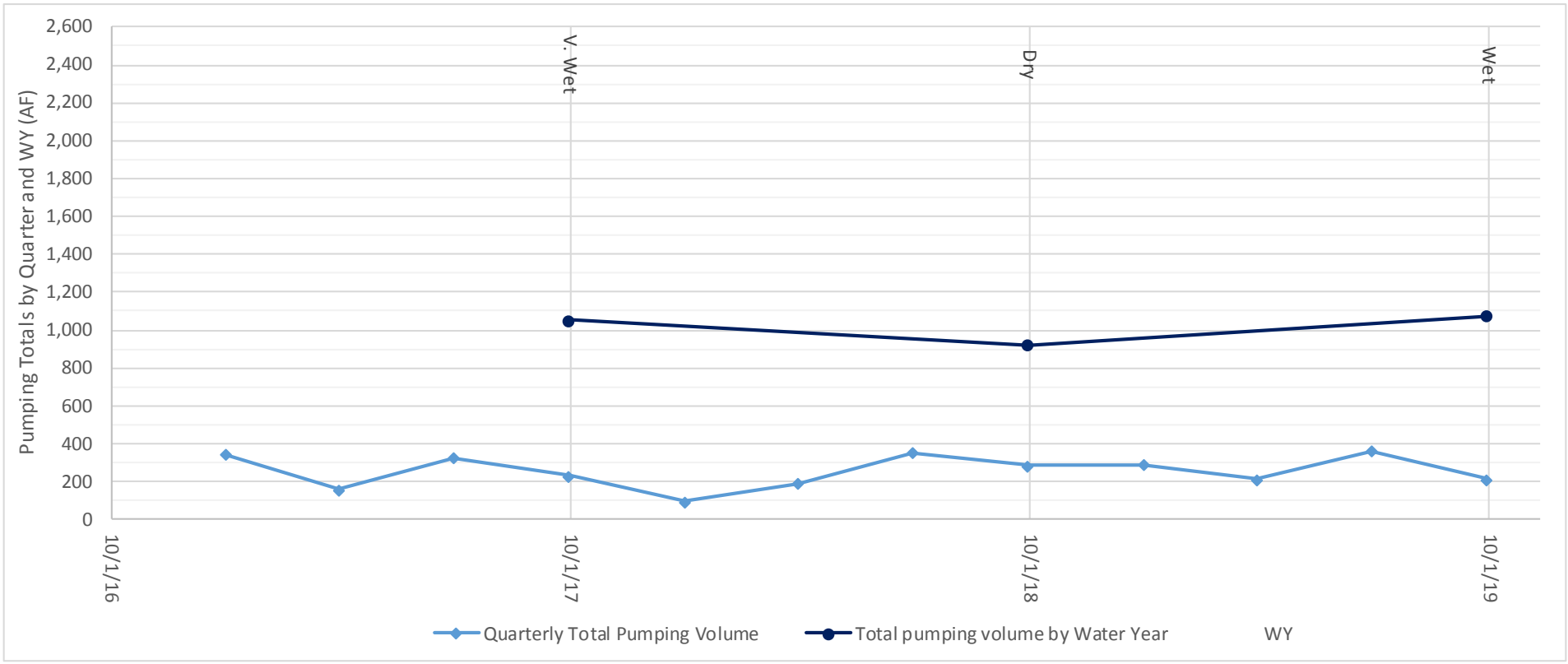


Notes:

cbec eco engineering

Mean daily flow and stream flow change along Reach C upstream of USGS gage at Freedom (11159200)

Project No. 20-1030 | Created By: GK | **Figure 30**



Notes:

Quarterly and total Water Year (WY) pumping volumes from wells along Corralitos Creek upstream of Freedom

Project No. 20-1030	Created By: GK	**Figure 31**

F:\000 cbec\cbec-Projects\20-1030_Pajaro-V-GSP\cbec-work\Task 4 - ISW work\Report\Submittal_ISW_1-8-21\Task4.1_tech-memo_Figures_3-27+31.docx
1/8/2021