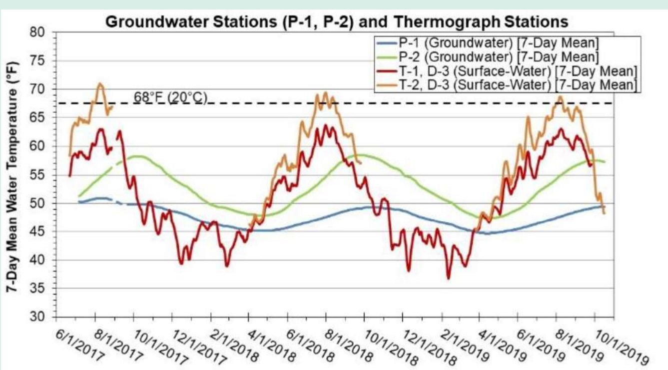
TECHNICAL REPORT ◦ DECEMBER 2019

# Hydrology Monitoring and Analysis for the Gales/Clear Creek Confluence Project:

## Synthesis of Pre-Enhancement and Post-Enhancement Conditions





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**Acknowledgements:**

Our sincere thanks to Executive Director, Scott McEwen, and former Watershed Coordinator, April Olbrich, of the Tualatin River Watershed Council for shepherding the enhancement activities and coordinating landowner engagement, and to Steve Trask of Bio-Surveys for implementing the enhancement activities. We also acknowledge valuable assistance from Rich Van Buskirk of Pacific University.

**Cover graphics:**

*Upper left:* Aerial view of the Gales/Clear Creek Confluence Project site, looking northward in the upstream direction (photo taken December 3, 2018 by Stillwater Sciences).

*Top right:* View of floodplain side-channel and large woody materials near the confluence of Clear and Gales creeks that were constructed in summer 2018 (photo taken December 3, 2018 by Stillwater Sciences).

*Bottom left:* Time-series of water temperatures recorded at two of the groundwater monitoring stations and the two in-stream temperature monitoring stations (analysis by Stillwater Sciences).

*Bottom right:* View of measuring stream discharge along Gales Creek (photo taken October 16, 2019 by Stillwater Sciences).

**Suggested citation:**

Stillwater Sciences. 2019. Hydrology Monitoring and Analysis for the Gales/Clear Creek Confluence Project: Synthesis of Pre-Enhancement and Post-Enhancement Conditions. Prepared by Stillwater Sciences, Portland, Oregon for Clean Water Services, Hillsboro, Oregon.

# Table of Contents

## Tables



## Figures



## Appendices

# 1 INTRODUCTION

This technical report details methods and results of monitoring activities undertaken between June 2017 and October 2019 that document pre-enhancement and post-enhancement hydrologic conditions for the Gales/Clear Creek Confluence Project (hereafter, "the Project"). The Project is led by Clean Water Services (the District) and the Tualatin River Watershed Council (TRWC). This report builds upon the original monitoring plan (Stillwater Sciences 2017) and two interim monitoring reports (Stillwater Sciences 2018, 2019).

## 1.1 Background and Purpose

The overall goal of the Project is to conserve and enhance availability of cold-water habitat and improve access to thermal refugia during warmer months for salmonid fish populations endemic to the upper Tualatin River basin. Thermal refugia for adult salmonids holding in streams like Gales Creek is defined as being less than 68°F (20°C) (Fullerton et al. 2018). The Project was designed by TRWC and Bio-Surveys to improve fish access to cold water refugia and increase habitat complexity at the confluence of Clear and Gales creeks. The primary objective was to reconnect historic side channels on the western floodplain of Gales Creek which is expected to result in greater availability of cold water refugia. Notching of the upstream dike located at the northern (upstream) end of the floodplain would periodically allow high flows in winter to inundate the floodplain. Large wood structures placed along the streambanks of Gales and Clear creeks would create localized pool scour that may be accessed in the summer by temperature-dependent summer migrants. And, planting riparian trees on the floodplain would enhance seedling recruitment opportunities.

Construction of the habitat enhancements occurred between July 20, 2018 and August 5, 2018, which included notching the upstream dike, excavating the side channels, and installing large woody materials in the side channels and along Gales Creek (see photos at right). Planting of native trees throughout the site occurred in January 2019.

The District contracted Stillwater Sciences to develop and execute a monitoring program designed to document the pre-enhancement and post-enhancement conditions at the Project site (Stillwater Sciences 2017). Goals of the pre-enhancement monitoring were to better understand the local creek-floodplain functions and validate assumptions used to develop the proposed Project design. Goals of the post-enhancement are to continue to better understand creek-floodplain connections and document hydrologic and biologic responses to the enhancement features.



Views of the notched dike (top) and excavated side channels with installed large woody materials (bottom) constructed in summer 2018 (photos by Stillwater Sciences)

The monitoring objectives are to achieve the following at the Project site: (1) document streamflow; (2) determine seasonal fluctuations of groundwater; (3) establish the extent, timing, and duration of episodic floodplain-inundation; (4) correlate regional rainfall to the local hydrologic conditions; (5) create a long-term record of water temperatures; (6) document current channel conditions and track their changes over time; and (7) determine trends in salmonid species abundance. The monitoring plan entails collection of information pertaining to hydrological, geomorphic, and biological attributes of the Project vicinity. Stillwater Sciences has been responsible for monitoring of hydro-geomorphic attributes of the Project site (i.e., the first six monitoring objectives listed above), while Bio-Surveys has been responsible for monitoring of biological attributes, specifically aquatic habitat conditions and fish presence via additional snorkel-surveys. Two interim reports that summarized the hydrology monitoring initiation activities, pre-enhancement results, and preliminary post-enhancement results were previously prepared and submitted to the Project team (Stillwater Sciences 2018, 2019).

This report serves as a synthesis summary of methods, results, and discussion of the hydrologic monitoring activities conducted between June 2017 and October 2019 by Stillwater Sciences on behalf of the District and in coordination with TRWC and local landowners.

## 1.2 Project Setting

The Project site is located at the confluence of Clear and Gales creeks in Washington County, Oregon. Clear Creek is a major tributary to Gales Creek, located in the northwestern portion of the Tualatin River basin (Figure 1). The Clear Creek/Gales Creek confluence is near the intersection of Cox Road and Soda Springs Road at Gales Creek river-mile (RM) 10.66 (as reported in Bio-Surveys 2015). Balm Grove Dam is located at Gales Creek RM 12.7 and is a low-flow barrier to upstream migrating fish, especially juvenile salmonids. This makes tributaries downstream of Balm Grove Dam, like Clear Creek, especially important as rearing habitat and cold water refugia.

Situated within the Willamette Valley and Foothills ecoregion, the Project site is approximately 20 acres in size and encompasses approximately 1,900 feet of Gales Creek and its alluvial floodplain (Figure 1). This area includes the westside (river-right) floodplain of Gales Creek and the lower reach of Clear Creek. The site and its immediate vicinity are under private, non-industrial forest ownership, with land use on the higher floodplain-terraces outside of the site boundary consisting primarily of woodlots and agricultural fields. The upper portion of the Clear Creek watershed is owned by the City of Forest Grove, which has sourced the City's water supply since 1917 (Bruener 1998).

Lower Clear Creek emerges from steeper, canyon-confined reaches to join Gales Creek within a low-gradient, broad, alluvial valley. Topography of the site is shown in Figure 2. Within the Project site boundaries, both creeks are composed of coarse gravels and cobbles sourced from Yamhill Formation sandstones and siltstones and more erosion-resistant volcanic basalt and diabase (Walker and MacLeod 1991), exposures of which are visible along lower Clear Creek. Both Gales and Clear creeks host perennial flow with relatively cool temperatures, though elevated temperatures are known to limit salmonid-rearing habitat in summer months (ODEQ 2001, TRWC 2015).

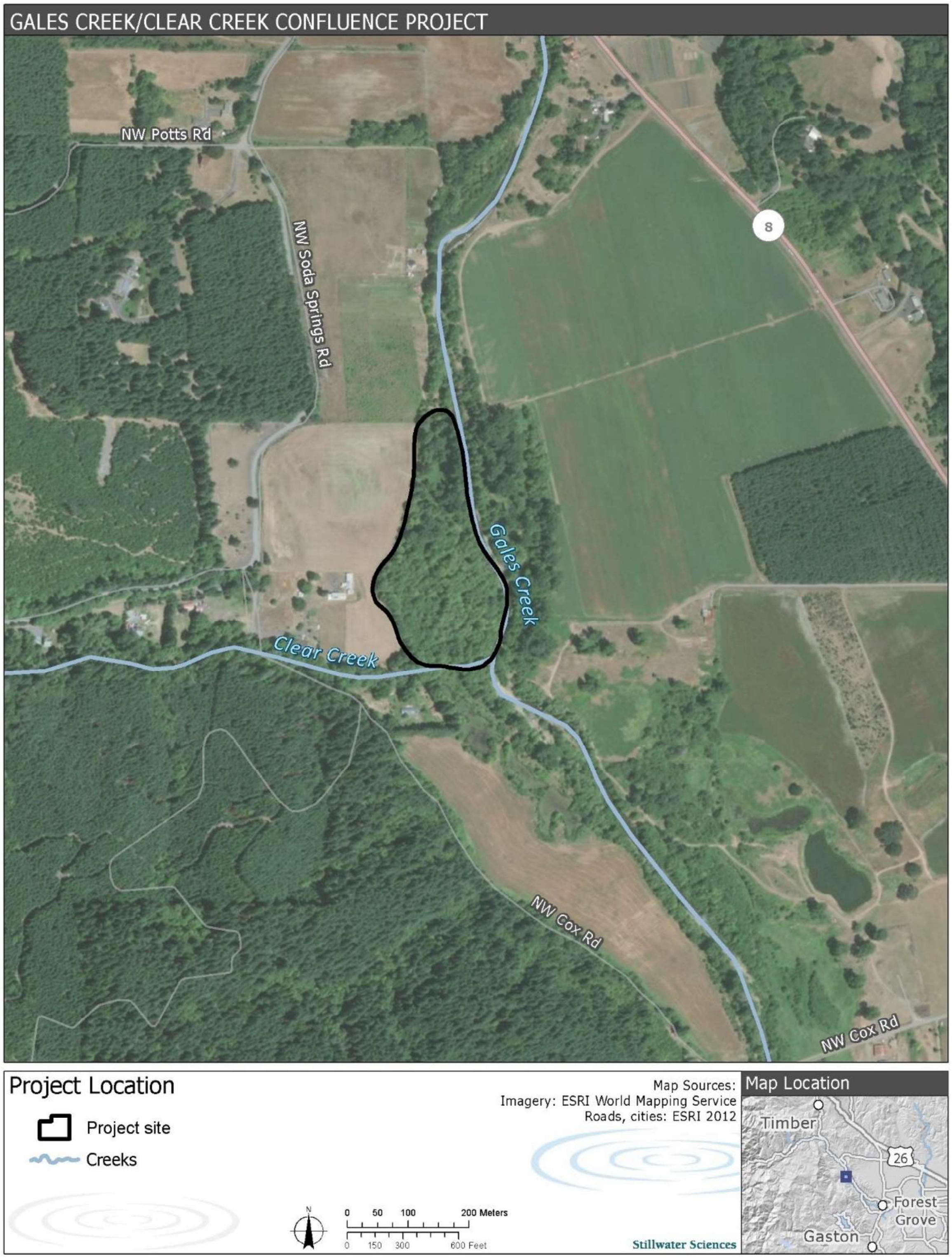



**Figure 1.** Map of the Project location and surroundings.

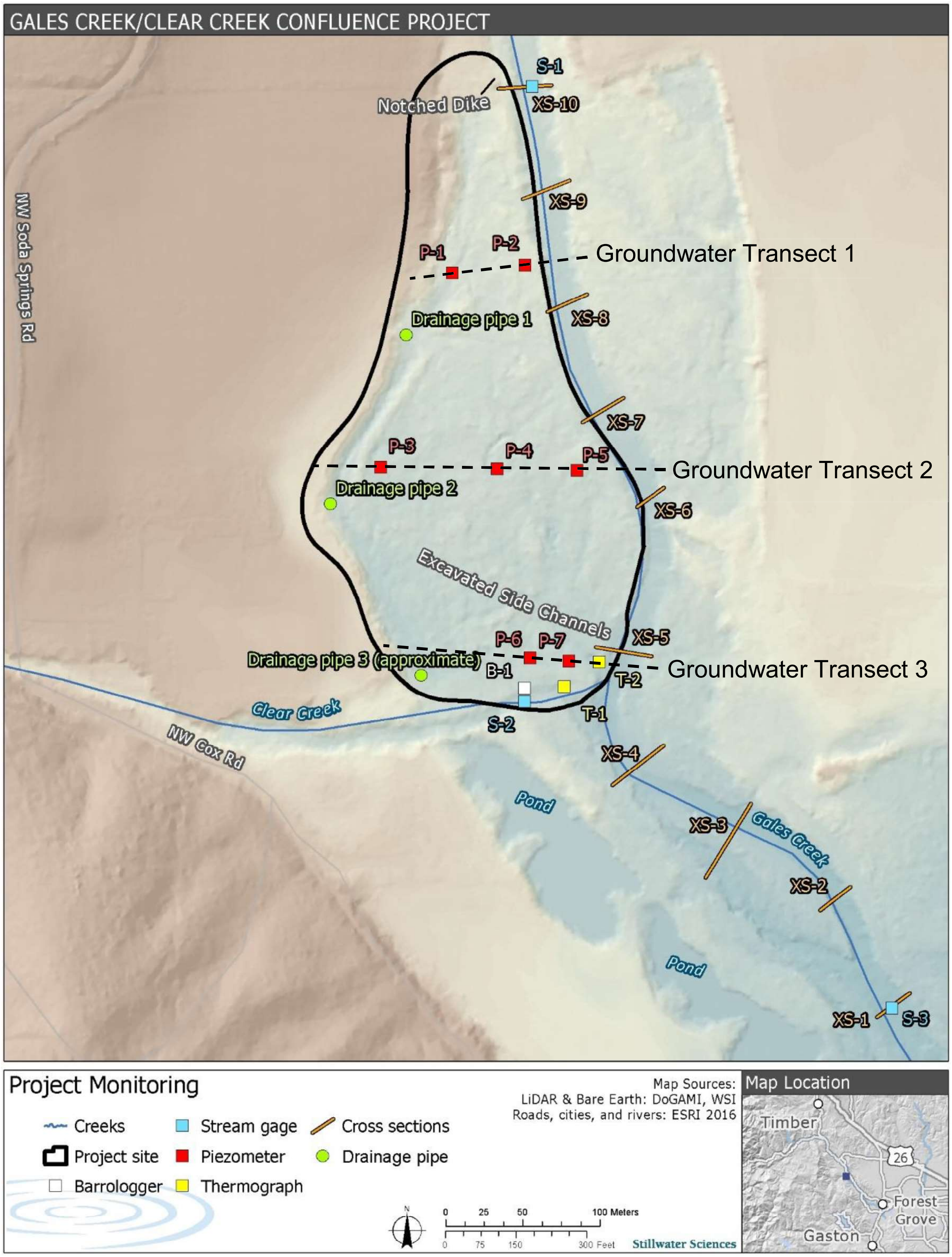



**Figure 2.** Map of the atmospheric pressure, streamflow, groundwater, water temperature, and channel morphology monitoring stations. Groundwater monitoring transects are also shown for reference (see Figure 10).

# 2 HYDROLOGY DATA COLLECTION METHODS

Collection of pre-enhancement data commenced in June 2017 and included continuous and periodic measurement of atmospheric temperature and pressure, streamflow, groundwater levels, water temperatures, floodplain-inundation extent, and channel morphology. Details of the monitoring stations' construction, instrumentation, and data collection methods were provided in the monitoring plan (Stillwater Sciences 2017), pre-enhancement monitoring report (Stillwater Sciences 2018), and preliminary post-enhancement monitoring report (Stillwater Sciences 2019).

The following describes methods of data collection activities conducted during the entire monitoring period, which began during the middle of water year[1] 2017 and concluded soon after the completion of water year 2019. Locations of monitoring stations established for the Project are shown in Figure 2. A tabular summary of all data collection efforts conducted through October 2019 is presented in Appendix A. Field photos of the monitoring stations and other notable site features are included in Appendix B.

## 2.1 Atmospheric Monitoring

Monitoring regional precipitation and air temperature patterns help to understand the site's hydrologic system. Review of publicly available atmospheric data and establishment of site-specific data were initiated to characterize influences of rainfall and air temperatures at the site.

Daily and hourly precipitation recordings made at offsite stations near the Project site, which lies at an elevation of approximately 250 feet, were routinely downloaded from the Global Historical Climatology Network (GHCN) hosted by NOAA's National Climatic Data Center (NCDC 2019a). There are approximately eight active stations located near the site, the most reliable since June 2017 being at Dilley, Forest Grove, Hillsboro, and the Portland-Hillsboro Airport (Table 1). The compiled time-series of daily rainfall was primarily based on the Dilley station given its closer proximity to the site and more complete data coverage. Precipitation records from the Forest Grove, Hillsboro 3.0 WNW, and Portland-Hillsboro Airport stations were also utilized to fill data gaps in the Dilley station record. Use of the secondary stations was appropriate based on a favorable similarity of daily rainfall amounts on days when recordings were made at multiple stations.

Hourly air temperature and pressure records were obtained from the Portland-Hillsboro Airport station, which is the only monitoring station in the Tualatin River basin with hourly data. These data are used as part of the quality assurance and quality control (QA/QC) procedures for the monitoring activities to compare with air temperatures and pressures recorded onsite.

At the Project site, an atmospheric sensor, B-1, was installed in June 2017 to record local air temperature and barometric pressure at one-hour intervals (see Figure 2). The sensor (Solinst Barologger) was installed in the equipment-access box at stream gage S-2 alongside lower Clear Creek. The barometric pressure data recorded with this sensor is necessary to compensate the water-level data recorded by the pressure-transducer sensors at the streamflow and groundwater monitoring stations.

[1] A water year is the 12-month period starting October 1st of the previous calendar year and ending September 30th of the same calendar year (e.g., water year 2019 spans Oct 1, 2018 to Sep 30, 2019).

**Table 1.** Offsite atmospheric monitoring stations utilized in the monitoring program.

| Station Name | Station Elevation (feet) | Station Distance and Heading from Project Site (miles) | Recordings Available during June 1, 2017–October 16, 2019 | | |
|---|---|---|---|---|---|
| | | | Daily Rainfall | Hourly Air Temp | Hourly Air Pressure |
| Dilley 2S, OR US (USC00352325) | 194 | 8.9 SE | 96.5% | 0% | 0% |
| Forest Grove, OR US (USC00352997) | 180 | 6.2 SE | 62.6% | 0% | 0% |
| Hillsboro 3.0 WNW, OR US (US1ORWS0097) | 186 | 10.5 E | 97.4% | 0% | 0% |
| Portland Hillsboro Airport, OR US (USW00094261) | 204 | 12.9 E | 96.9% | 97% | 93% |

Data source: NOAA NCDC; analysis: Stillwater Sciences

## 2.2 Streamflow Monitoring

The timing, duration, and magnitude of streamflow at the Project site are key hydrologic attributes that together directly influence availability of suitable aquatic habitat. Three gaging stations were installed in June 2017 to monitor surface-water flow through the site, with a focus on the summer baseflows when elevated water temperatures may potentially limit fish habitat. The locations of the three gages are shown in Figure 2 and described in Table 2.

View of discharge measurement at S-1 on Gales Creek on December 3, 2018
(photo by Stillwater Sciences)

Gages S-1 and S-2 serve as upstream control points as flows passing by each are not influenced by the constructed enhancement features. Streamflow measured at the downstream gage, S-3, represents the sum of flows passing gages S-1 and S-2, along with any surface runoff delivered to the site's floodplain, such as via the three drainage culverts (see Figure 2). Two irrigation pumps are operated in Gales Creek immediately upstream of S-1. There are no known irrigation water withdrawals in Gales or Clear creeks between the three gages and, therefore, comparison of upstream and downstream flow should not be influenced by irrigation pumping.

Methods of streamflow measurement during the post-enhancement period were unchanged from the pre-enhancement period. All equipment functioned properly and continuously during the monitoring period with three notable exceptions: (1) the downstream gaging station, S-3, was damaged by early-season high flows sometime between September 13, 2017 and December 20, 2017 (presumably during the October 22, 2017 storm), and was subsequently repaired on March 21, 2018; (2) the upstream gaging station, S-1, was temporarily removed between July 30 and August 8, 2018 to accommodate enhancement-construction activities; and (3) the Clear Creek gaging station, S-2, was observed to be dry in summer and fall 2019 due to below-normal flow levels not seen during prior years.

**Table 2.** Summary of streamflow gaging stations operated at the Project site.

| Streamflow gaging station | Description | Location | |
|---|---|---|---|
| | | Coordinates (Lat, Long [WGS84]) | Elevation (feet [NAVD88]) |
| S-1 | Gales Creek along straight, stable reach of creek with minimal floodplain availability, upstream of influence of enhancement features, downstream of two irrigation water withdrawals; installed 6/14/2017 and temporarily removed between 7/30/2018 and 8/8/2018 to accommodate enhancement construction | 45.5776°N, -123.2144°W | 248.4 |
| S-1B | Replacement of S-1; installed 8/8/2018 | 45.5776°N, -123.2144°W | 248.8 |
| S-2 | Lower Clear Creek along straight, mobile reach of creek with floodplain connectivity, upstream of influence of enhancement features, 150-feet upstream from confluence with Gales Creek, downstream of bedrock intrusion (cascade) that acts as a low-flow fish barrier; installed 6/14/2017 | 45.5740°N, -123.2145°W | 248.2 |
| S-3 | Gales Creek along straight, mobile reach of creek with floodplain connectivity, 900-feet downstream of Clear Creek confluence and influence of enhancement features; installed 6/14/2017 and discovered damaged by high flows 12/20/2017 | 45.5722°N, -123.2114°W | 236.7 |
| S-3B | Replacement of S-3; installed 3/21/2018 | 45.5722°N, -123.2113°W | 236.9 |

In addition to the site-specific streamflow data collection, publicly available streamflow data from the state-operated gage #14204530 on lower Gales Creek were routinely downloaded from the Oregon Water Resources Department's online data repository (OWRD 2019). The OWRD gage is located approximately 8 miles downstream of the Project site near Forest Grove and the creek's confluence with the Tualatin River. While there are several documented and undocumented surface-water inputs and outputs located between the Project site and the OWRD gage, these offsite data are used in the present study to provide a comparison of trends with the onsite data. They are also used to provide an upper limit of estimated discharge at gages S-1 and S-3, which have stage-discharge rating curves limited to approximately 300 cfs.

Collected data were used to plot changes in surface-water levels and discharge at each station over time. Results of streamflow monitoring during the entire monitoring period are presented in Section 3.

## 2.3 Groundwater Monitoring

An array of seven shallow groundwater monitoring wells, or piezometers, were installed throughout the floodplain area in June 2017 to help assess current hydrogeologic conditions and enable comparison between pre-enhancement and post-enhancement conditions. The locations of the stations are shown in Figure 2 and described in Table 3. Well construction and soil classification logs are included in Appendix C.

View of groundwater-level measurement and logger download at P-7 near the confluence of Gales and Clear creeks on September 26, 2018 (photo by Stillwater Sciences)

Methods of groundwater-level measurement during the post-enhancement period were unchanged from the pre-enhancement period. All equipment functioned properly and continuously during the monitoring period.

Collected data were used to plot changes in groundwater levels at each station over time. The data were also used to compute groundwater flow directions and gradients across the Project site. Results of groundwater monitoring during the entire monitoring period are presented in Section 3.

**Table 3.** Summary of groundwater-level monitoring stations operated at the Project site.

| Groundwater monitoring station | Description | Location | |
|---|---|---|---|
| | | Coordinates (Lat, Long [WGS84]) | Elevation of sensor (feet [NAVD88]) |
| P-1 | North end of floodplain | 45.5765°N, -123.2151°W | 241.99 |
| P-2 | | 45.5765°N, -123.2145°W | 244.30 |
| P-3 | Middle of floodplain | 45.5754°N, -123.2157°W | 240.30 |
| P-4 | | 45.5754°N, -123.2147°W | 240.76 |
| P-5 | | 45.5753°N, -123.2140°W | 242.08 |
| P-6 | South end of floodplain, near lower Clear Creek | 45.5743°N, -123.2144°W | 240.30 |
| P-7 | | 45.5742°N, -123.2141°W | 240.27 |

## 2.4 Water Temperature Monitoring

View of water-temperature monitoring station T-1 in Clear Creek on September 4, 2019 (photo by Stillwater Sciences)

Water temperature is a key monitoring parameter given the Project's primary goals of conserving the cold-water habitat present in lower Clear Creek and creating new cold-water habitat areas along Gales Creek near the confluence. The pressure-transducer sensors installed at the three streamflow gaging stations and seven piezometers record water temperatures. Further, the atmospheric sensor, B-1, described above is recording air temperature and pressure. Additionally, two dedicated water-temperature recording stations were installed in June 2017 at the lowermost pool of Clear Creek (T-1) and the pool of Gales Creek just upstream of the confluence and near where the constructed side channels join Gales Creek (T-2). Both stations were equipped with three vertically stratified temperature sensors to monitor vertical differences in the water column. Use of these data are to assist with detecting changes between the pre-enhancement and post-enhancement periods. The locations of the stations are shown in Figure 2 and described in Table 4.

**Table 4.** Summary of water-temperature monitoring stations operated at the Project site.

| Water temperature monitoring station | Description | Coordinates (Lat, Long [WGS84]) |
|---|---|---|
| T-1 | Downstream and largest pool along lower Clear Creek between the bedrock intrusion (cascade) that acts as a low-flow fish barrier and the Gales Creek confluence; installed 6/8/2017; permanently removed 10/16/2019 | 45.5741°N, -123.2141°W |
| T-2 | Largest pool along Gales Creek immediately upstream of confluence, along right bank, and near constructed side-channel network; installed 6/8/2017 and discovered damaged by high flows 12/20/2017; replaced 3/21/2018; temporarily removed 9/26/2018–3/18/2019; permanently removed 10/16/2019 | 45.5742°N, -123.2138°W |

Methods of water-temperature measurement at T-1 and T-2 during the post-enhancement period were unchanged from the pre-enhancement period. All equipment functioned properly and continuously during the monitoring period with three notable exceptions: (1) the Gales Creek station, T-2, was damaged by early-season high flows sometime between September 13, 2017 and December 20, 2018 (presumably during the October 22, 2017 storm), and was subsequently repaired on March 21, 2018; (2) the Gales Creek station, T-2, was intentionally removed between September 26, 2018 and March 19, 2019 to avoid potential disturbance from winter high flows;

and (3) the uppermost sensors at the Clear Creek and Gales Creek stations, T-1 and T-2, appear to have been subaerial during extended periods of the summer and early fall months of 2018 and 2019 due to low-flow levels. Both stations were removed during the final field visit on October 16, 2019.

Collected data were used to plot changes in water temperatures at all stations over time. Results of water-temperature monitoring during the entire monitoring period are presented in Section 3.

## 2.5 Floodplain Inundation Mapping

The extent, timing, and duration of seasonal inundation throughout the Project site is another important monitoring parameter because the constructed enhancements are expected to change inundation dynamics. Specifically, notching of the dike is intended to increase floodplain inundation during winter high-flow events and excavating the floodplain side channels is intended to provide year-round instream habitat.

View of floodplain-inundation mapping near the southwest side of the Project site on January 24, 2019 (photo by Stillwater Sciences)

Semi-annual mapping of floodplain inundation was conducted during seasonally dry and wet periods during the pre-enhancement and post-enhancement periods. Field methods during the post-enhancement period were unchanged from the pre-enhancement period. During the pre-enhancement period, the dry season and wet season mapping events were conducted on September 13, 2017 and January 22 and 24, 2018, respectively. The post-enhancement mapping of dry and wet season events occurred on September 26, 2018 and January 24, 2019, respectively. Initiation of these semi-annual events was triggered by indication of below-average and above-average runoff, respectively, as informed by the offsite rainfall and streamflow stations near Forest Grove.

The mapping data were used to locate changes in inundation extent over time. Results of floodplain-inundation monitoring during the entire monitoring period are presented in Section 3.

## 2.6 Channel Morphology Surveying

Another primary influence on flow dynamics and water quality is geomorphic change of the stream channels. Surveying of channel geometry and estimation of sediment character at 10 channel-spanning cross-sections were conducted at the start of Project monitoring in June 2017 to record pre-enhancement conditions. Methods and results from the pre-enhancement surveys were presented in the first interim monitoring report (Stillwater Sciences 2018; see data plots in Appendix E). At the direction of Project partners, post-enhancement monitoring of geomorphic conditions was not conducted due to a lack of visually noticeable changes in channel geometry and sediment texture. When eventually collected after a wetter-than-normal winter season, the future geomorphic survey data may be readily used to compare conditions before and after enhancement construction.

# 3 RESULTS

The following presents results of monitoring of hydrologic conditions at the Project site. Supplemental information is presented in the appendices.

## 3.1 Precipitation and Air Temperature

Rainfall patterns near the Project site have been annually and seasonally variable based on the record of daily rainfall totals reported at the offsite atmospheric monitoring stations (Figure 3). These data are referenced below in the presentation of streamflow and groundwater-level results.

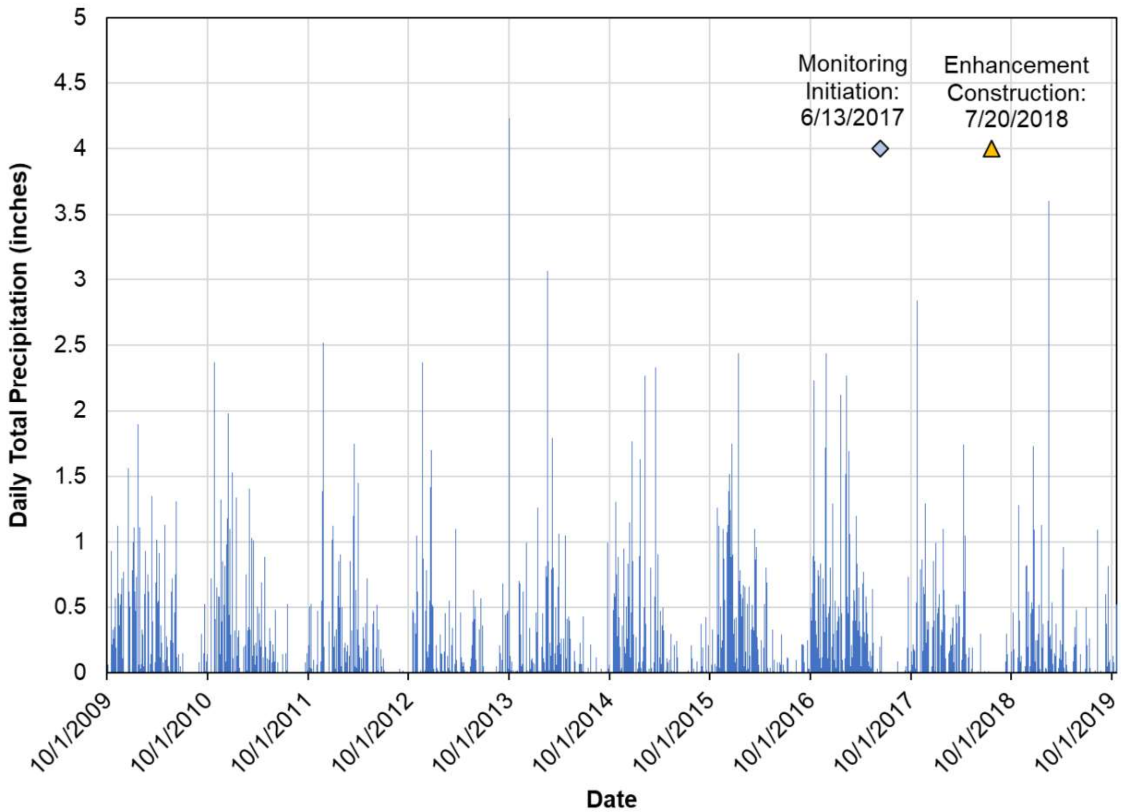



**Figure 3.** Compilation of daily precipitation measured during the past decade using best available data near Forest Grove (source: NOAA NCDC; analysis: Stillwater Sciences).

An evaluation of longer-term precipitation trends since the 1920s reveals substantial annual variability, ranging over a factor of two. Longer-term cyclic patterns of precipitation can be visualized when plotting the cumulative departure, or difference, of each annual total from the long-term average of annual totals from water years 1922–2018 (Figure 4). The time-series of cumulative departures (black line in Figure 4) reveals decadal-scale patterns of generally wetter than average (i.e., gaining trend) and drier than average (i.e., losing trend) in the site vicinity. More recently, local rainfall received during water years 2018 and 2019 has been below the long-term average. These trends agree with regional records published by NOAA (2019b), where precipitation totals for water years 2018–2019 in the Tualatin River basin (and its neighboring

Coast Range and lower Willamette Valley basins) received approximately 70–90% of the long-term average during water years 1981–2010. Since monitoring initiated at the Project site in June 2017, discrete rainfall events recorded near Forest Grove having daily totals greater than 1 inch occurred ten times (Table 5).

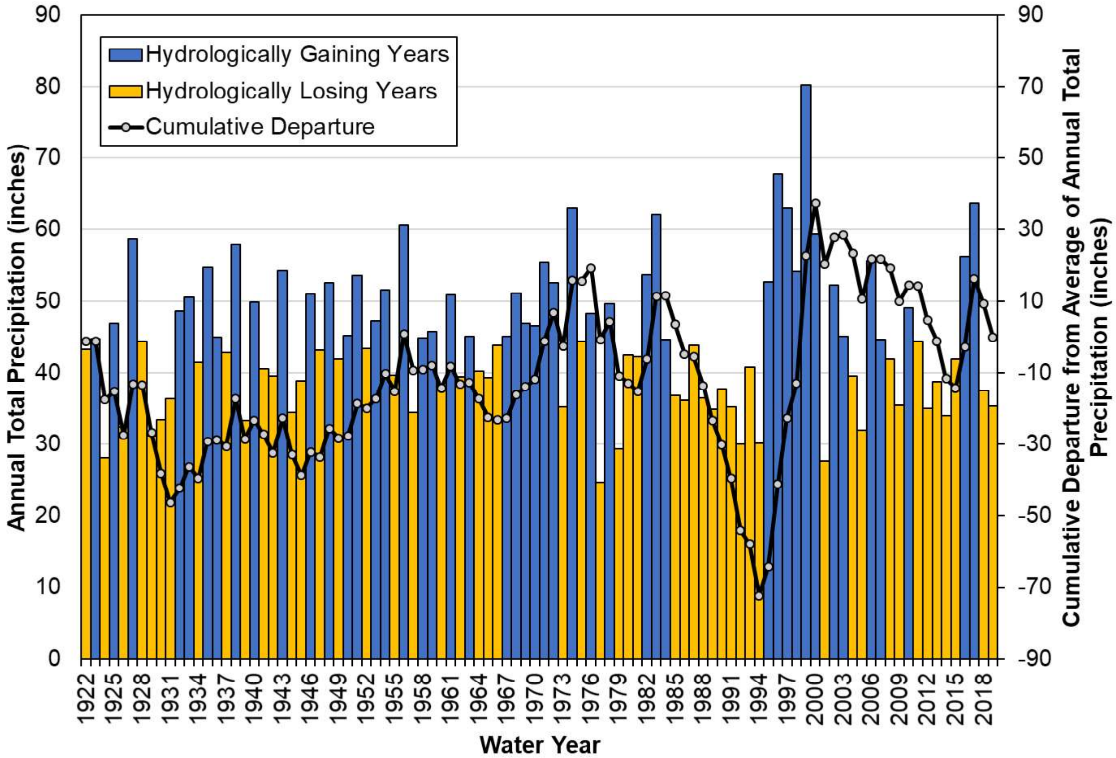



**Figure 4.** Long-term annual precipitation amount and patterns of variation from cumulative departure from average of annual total precipitation amounts near Forest Grove (source: NOAA NCDC; analysis: Stillwater Sciences).

**Table 5.** Rainfall events with precipitation daily totals exceeding one inch during the monitoring period, June 2017 through October 2019.

| Monitoring Period | Date | Daily Total Precipitation (in) |
|---|---|---|
| Pre-enhancement Monitoring | October 22, 2017 | 2.8 |
| | November 20, 2017 | 1.2 |
| | January 24, 2018 | 1.1 |
| | April 8, 2018 | 1.7 |
| | April 16, 2018 | 1.1 |
| Post-enhancement Monitoring | October 28, 2018 | 1.3 |
| | December 18, 2018 | 1.7 |
| | December 23, 2018 | 1.1 |
| | January 19, 2019 | 1.1 |
| | February 12, 2019 | 3.6 |
| | August 11, 2019 | 1.1 |

Source: NOAA NCDC; analysis: Stillwater Sciences

Comparisons of the air temperature and barometric pressure data from B-1 and the Portland-Hillsboro Airport, conducted as part of QA/QC procedures, revealed closely aligned trends through the entire monitoring period (temperature $R^2 \approx 0.95$; pressure $R^2 \approx 0.99$) with consistent differences in absolute values and timing, which are explained by the differences in site elevation (the Project site is higher) and solar insulation (the Project site is densely forested). Overall, station B-1 appears to have accurately measured air temperatures and pressures.

Air temperatures recorded hourly at the atmospheric sensor, B-1, installed at the Project site have tracked the seasonal and diurnal variations (Figure 5), which coincide with temperatures measured hourly at the Portland-Hillsboro Airport monitoring station. In the warmer summer months when elevated water temperatures can potentially limit fish habitat, the warmest daily mean air temperatures in water years 2017 and 2018 occurred on August 2, 2017 (78.1°F at B-1, 83.7°F at Hillsboro Airport) and July 12, 2018 (75.9°F at B-1, 79.4°F at Hillsboro Airport), respectively. For water year 2019, air temperatures were generally cooler; the warmest daily mean air temperature occurred on June 12, 2019 (75.0°F at B-1, 79.0°F at Hillsboro Airport).

The air temperature results are referenced in the presentation of water temperature results (see Section 3.4).

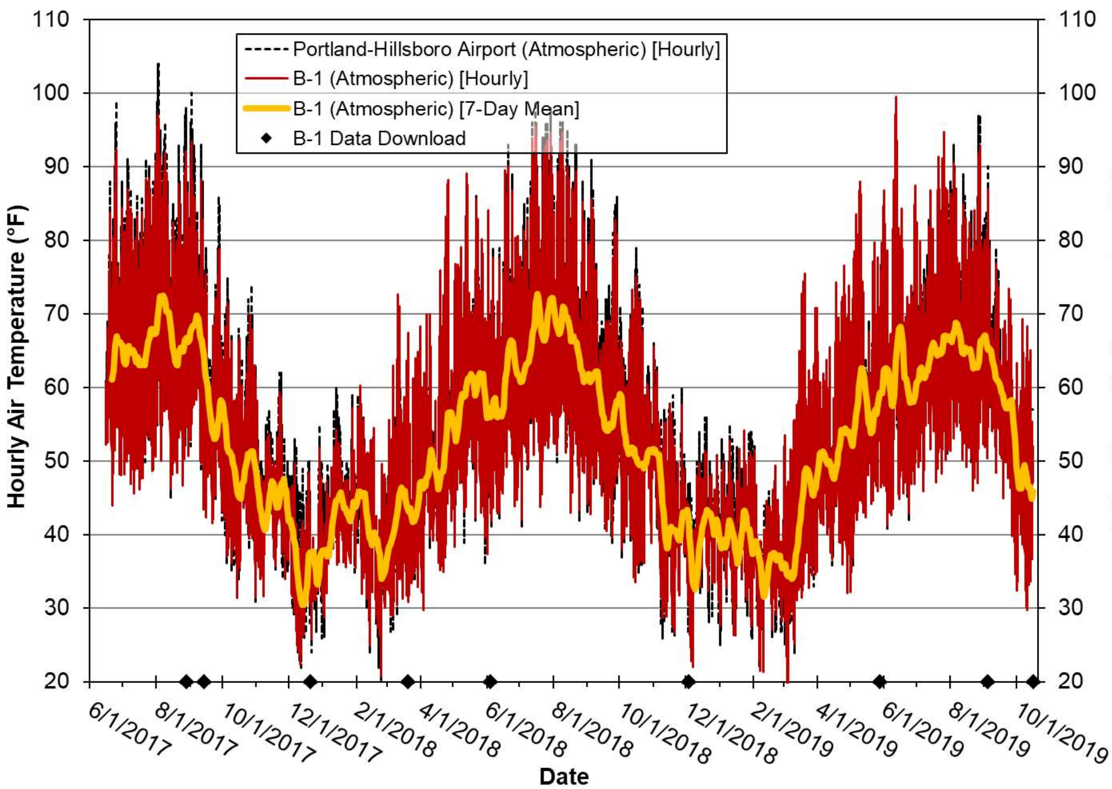



**Figure 5.** Hourly air temperatures measured at the Project site (B-1) and offsite (Portland-Hillsboro Airport), and the 7-day mean air temperatures at the Project site.

## 3.2 Streamflow

Results of the measured stream-channel stage and computed discharge from the entire monitoring period are presented in Figures 6 and 7. The stage-discharge rating curves for the gaging stations are presented in Figure 6b. Streamflow data from the lower Gales Creek gage operated by OWRD, approximately 8 miles downstream from the Project site, are shown in each of the Figure 7 plots for reference.

As acknowledged in the Methods section, all streamflow-gaging equipment functioned properly and continuously during the monitoring period with three notable exceptions (see above). The stage-discharge rating curves constructed for the two Gales Creek gaging stations, (S-1, S-1B, S-3, and S-3B), appear to be well-rated up to approximately 300 cfs ($R^2$>0.94) (see Figure 6b). The rating curve for the Clear Creek gage (S-2), however, appears to less-accurately predict discharge as a function of the logger's measured water depth ($R^2$≈0.54). This condition may be caused by subtle changes in flow dynamics along lower Clear Creek since the gage was installed. During the field visits on September 4, 2019 and October 16, 2019, the water-depth sensor at the Clear Creek gage was observed to be dry due to below-normal water levels in the creek, which had not been observed during the summers of 2017 or 2018. Continuous rainfall on October 16, 2019 eventually caused the Clear Creek flows to increase, which fully submerged the gage sensor later that day. Thus, the computed discharges at the Clear Creek gage contain some degree of uncertainty during periods of very low flow (i.e., <1 cfs).

Comparisons of the stage and discharge recordings from the Project site gages and the OWRD gage near Forest Grove, conducted as part of QA/QC procedures, revealed closely aligned trends through the entire monitoring period (see Figure 7 plots). Differences in absolute values are explained by the differences in drainage area (the OWRD gage integrates a larger area) and seasonality (baseflows and water withdrawals are spatially and temporally variable). Overall, the Project site gages appear to have accurately measured surface-water stage throughout the monitoring period and the computed discharge values are more accurate at flows of 1–300 cfs at the two Gales Creek stations and at flows of 1–50 cfs at the Clear Creek station.

The stream-channel stage and discharge from all three gages exhibited similar fluctuations in direct (and rapid) response to local rainfall and runoff (see Figure 6a). The maximum stages measured in water year 2018 occurred on November 20, 2017 and in water year 2019 occurred during two nearly equal large runoff events on December 18, 2018 and February 12, 2019. Peak discharges observed at the OWRD gage in water years 2018 and 2019 were approximately 2,110 cfs (on November 11, 2017) and 2,620 cfs (on February 12, 2019), respectively. In the drier months, minimum baseflows in Gales Creek have been less than 10 cfs. Minimum baseflows in lower Clear Creek dropped to approximately 7 cfs in water year 2017, 2 cfs in water year 2018, and 1 cfs in water year 2019, which together indicates a declining trend over the past three years, apparently due to the below-normal rainfall totals received in water years 2018–2019 following an above-normal rainfall total received in water year 2017 (see Figure 4).

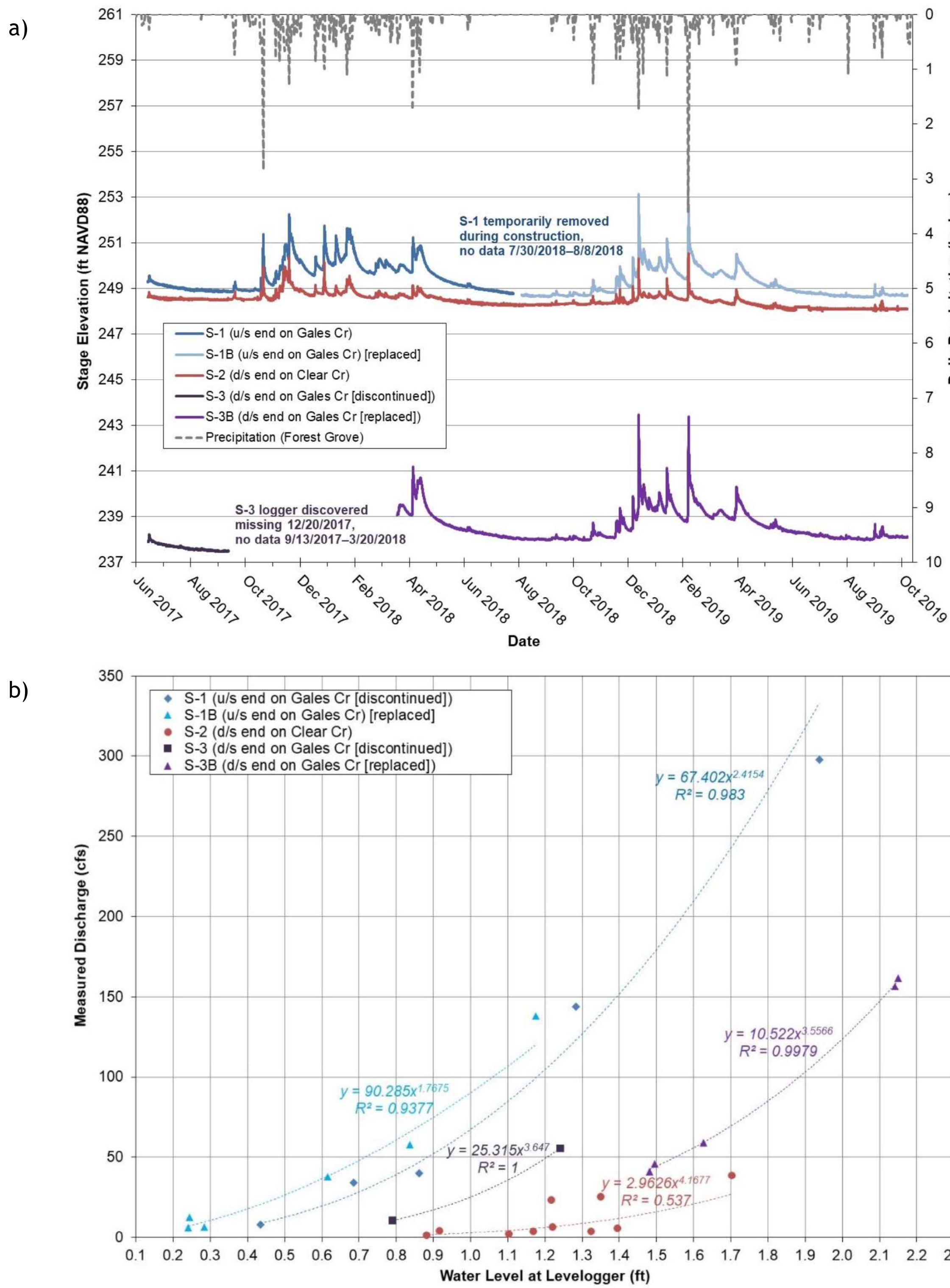
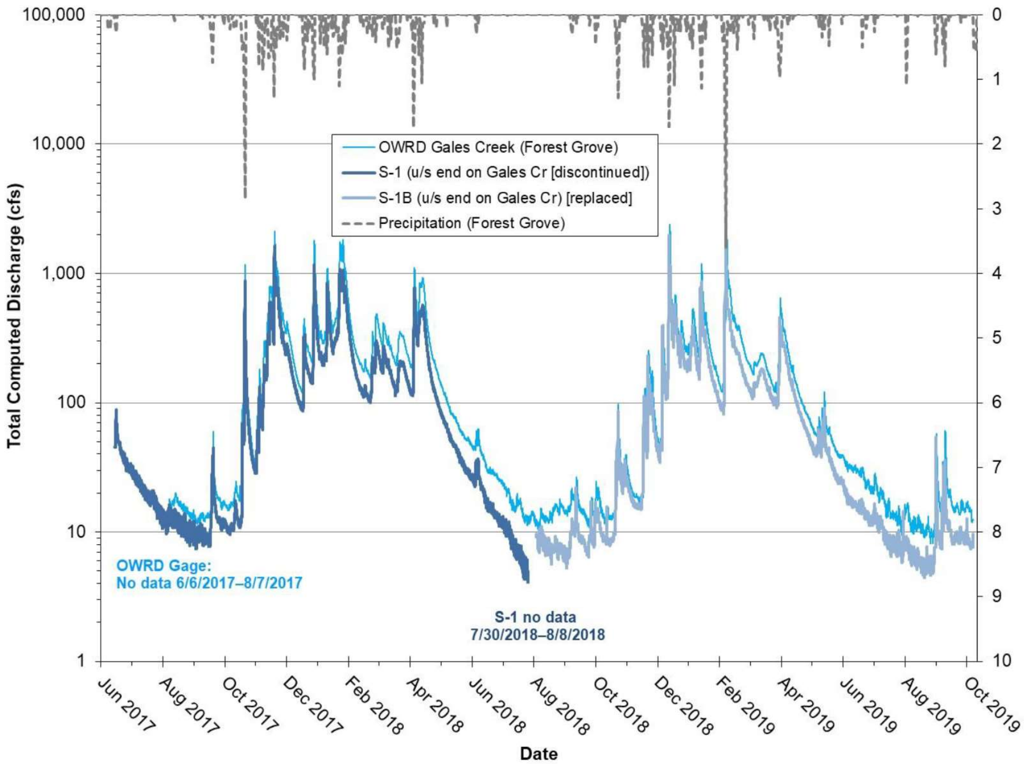



**Figure 6.** Measured surface-water stage elevation (a) and stage-discharge rating curves (b) at streamflow gages installed in Gales and Clear creeks. Offsite precipitation measurements from the Project vicinity are shown for reference (a).

a)




b)

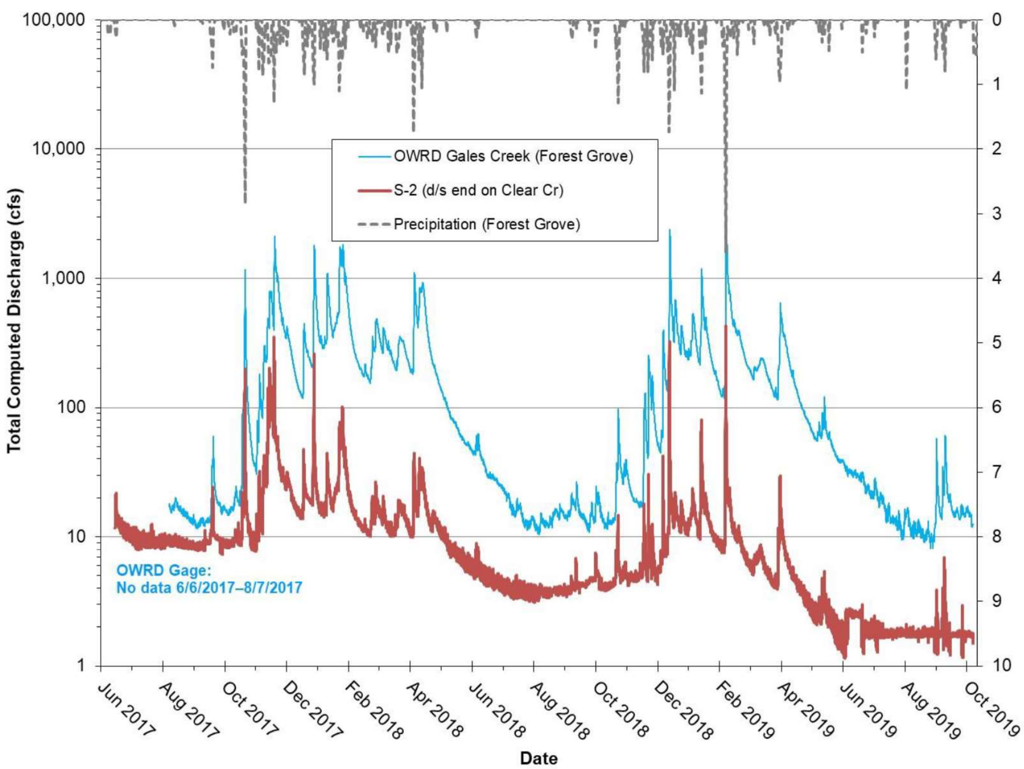



Figure 7 is continued on the next page.

c)

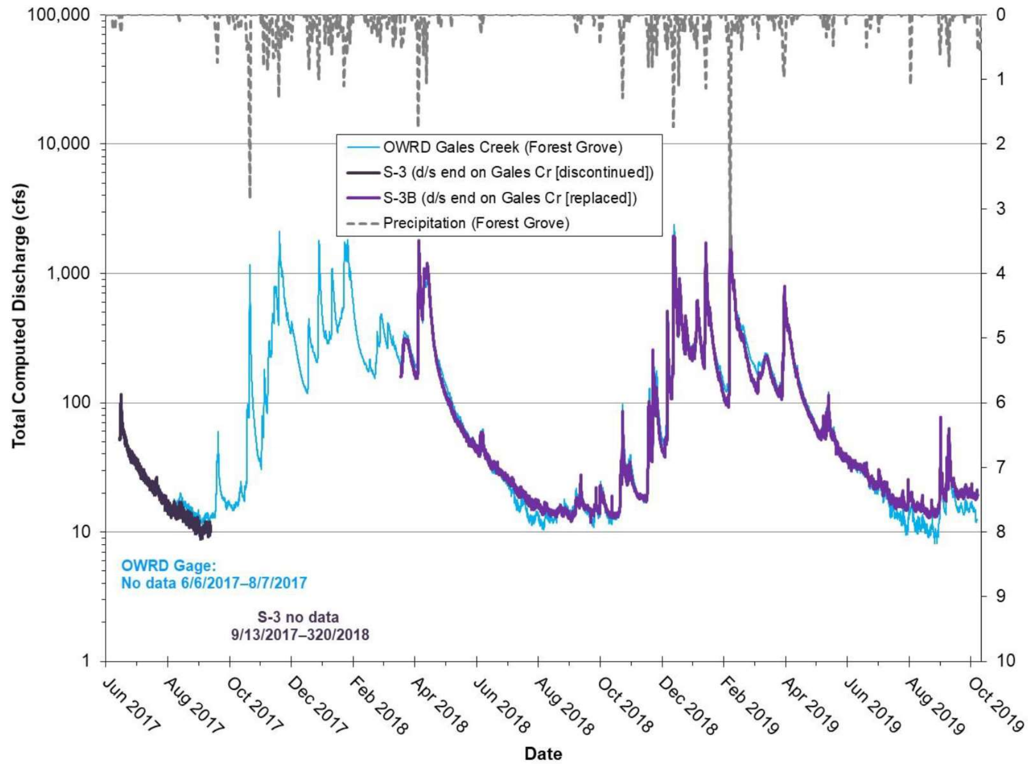



**Figure 7.** Computed discharge at streamflow gages installed in Gales and Clear creeks (a-c). Discharge reported at the OWRD Gales Creek stream gage and offsite precipitation measurements in the Project vicinity are shown for reference.

The magnitudes of discharge at each of the three onsite gages differ, with the smaller discharge contribution from Clear Creek adding to discharge in Gales Creek that generally exhibits increasing amounts with downstream-distance, a process called "accretion." A strong curvilinear correlation ($R^2 \approx 0.99$) exists between the Project site inflows (S-1 plus S-2) and outflows (S-3) under 1,000 cfs (Figure 8). The lower flows of this relationship (i.e., <100 cfs) in drier months have a linear 1:1 correlation indicating a relative balance between inflows and outflows, while the higher flows (i.e., 100–1,000 cfs) in wetter months have a steeper linear correlation indicating an increasing trend of accretion.

Per the monitoring plan, evaluating changes in flow conveyance through the Project area in response to the constructed enhancement features can be achieved through observing any discrete shifts in proportional relationships between the site inflows (gages S-1 and S-2) and outflows (gages S-3 or OWRD at Forest Grove) over time. Figure 8 displays a regression plot of the total inflows (summation of S-1 and S-2 discharges) versus outflows (OWRD-gage discharge) at each hourly time-step of the monitoring period. The OWRD gage data are used here to overcome the data-gap in the S-3 gage records during fall 2017 and winter 2018. The discharge values from the two time periods—pre-enhancement and post-enhancement—are indistinct from one another, thus signifying that the streamflow monitoring activities have not observed any shift between the site inflows and outflows within the flow range of ~1–1,000 cfs since enhancement construction.

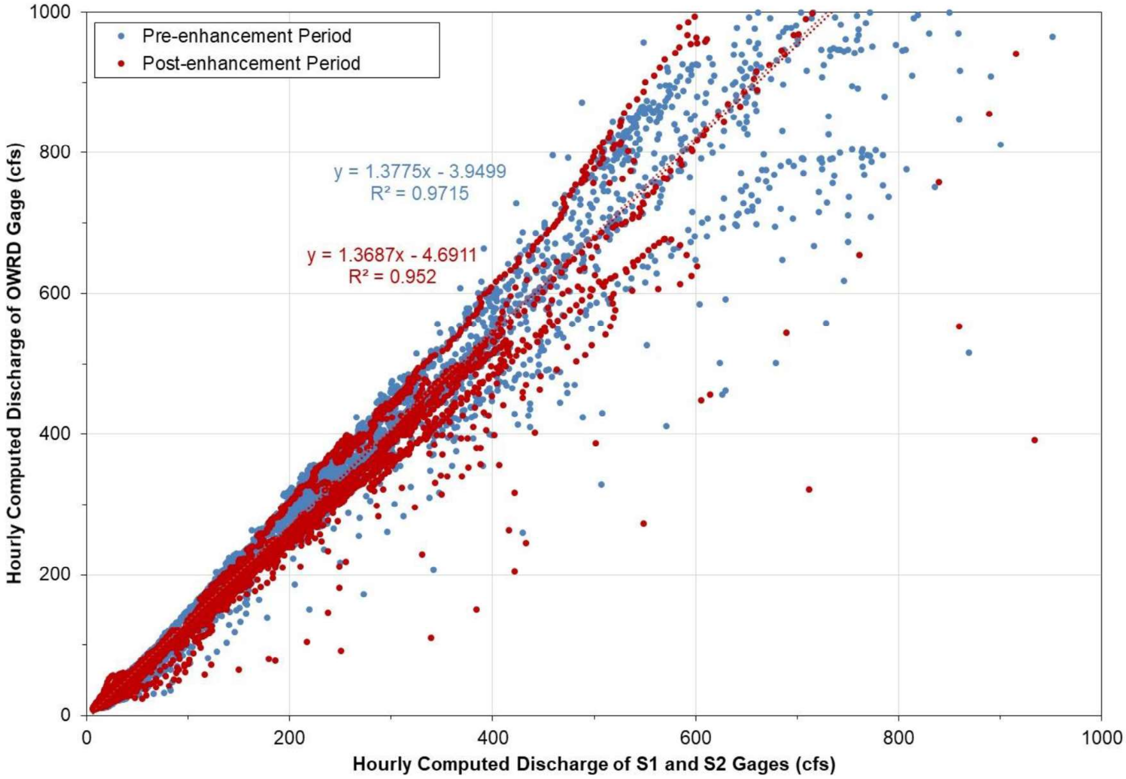



**Figure 8.** Regression of site inflows versus outflows at hourly time-steps during the monitoring period, showing overlap of the pre-enhancement and post-enhancement values.

## 3.3 Groundwater

The results of the groundwater-level monitoring data collected to date are presented graphically in Figure 9. Estimated range of groundwater discharge from Gales and Clear creeks to the site floodplain during summer months is presented in Table 6. Seasonal groundwater elevations projected along three transects that traverse the floodplain from east to west are presented in Figure 10. Individual data plots depicting hourly groundwater elevations at each of the piezometers are presented in Appendix C. Precipitation data are also shown for reference in these figures. Appendix C also presents planform-view data plots depicting groundwater-flow vectors representing flow direction and gradient between well triplets.

The groundwater levels exhibited direct and rapid response to rainfall infiltration and surface-water runoff, marked by longer periods of deeper depths during summer months and shallower depths during winter months. Groundwater levels fluctuated between 3.3 and 6.5 feet, with the greatest range observed in well P-1, which is located near the low-lying meadow in the northwest portion of the site. The water table was observed rising above the ground surface at P-1 during multiple winter storm events in water years 2018–2019 and at P-6 (near Clear Creek) during two storm events in water year 2019: December 18, 2018 and February 12, 2019. Inundation mapping during January 2018 and 2019 confirmed inundation at or very close to these locations (see details below). Higher groundwater levels at P-1 were the steadiest and longest lasting during the wet seasons, as compared to the trends observed in the other wells, which were more closely linked to fluctuations in rainfall and streamflow.

All groundwater-level data exhibited a very slight, albeit statistically weak ($R^2$<10%), declining trend over the course of the monitoring period, which is attributable to the below-normal rainfall totals received in water years 2018–2019 following an above-normal rainfall total received in water year 2017. There are no indications of water-table changes since construction of the enhancement features.

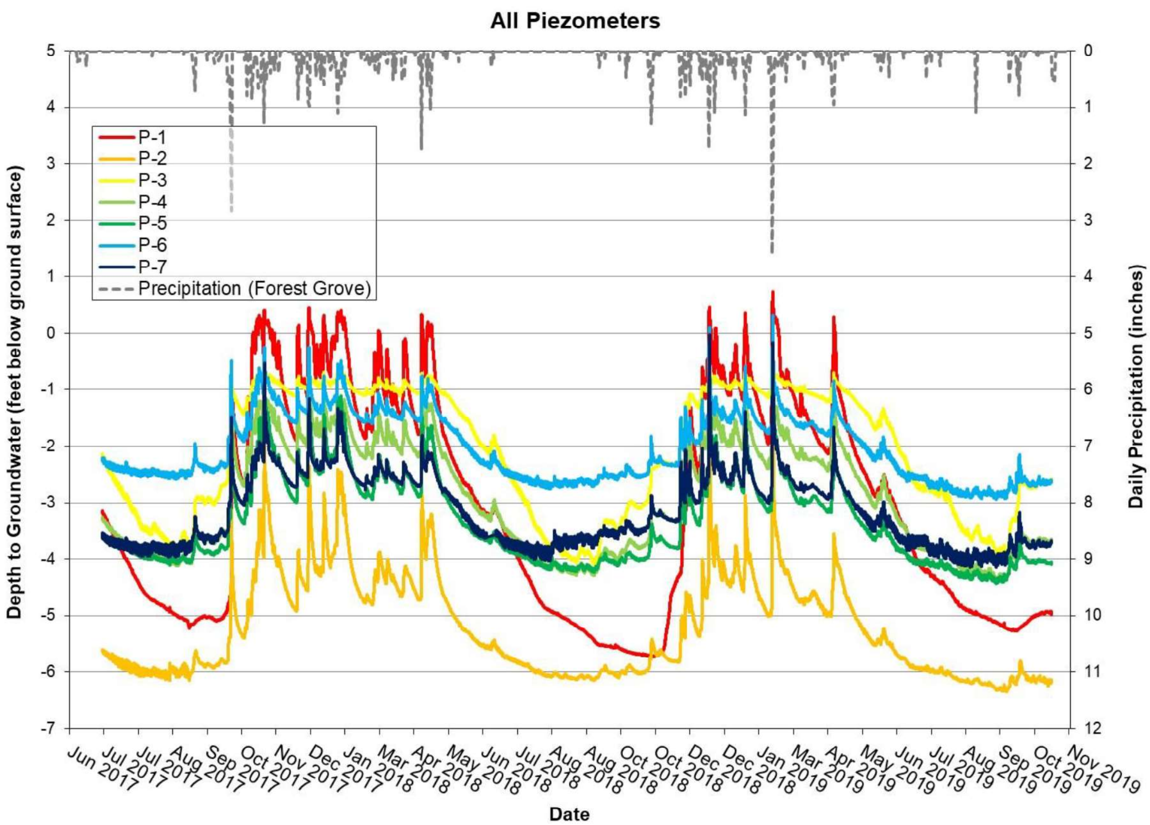



**Figure 9.** Groundwater levels measured in groundwater monitoring wells at the Project site. Offsite precipitation measurements in the Project vicinity are shown for reference.

**Table 6.** Estimated range of groundwater discharge from Gales and Clear creeks to the site floodplain during summer months.

| Groundwater Input Location | Gradient [*h/l*] | Saturated Hydraulic Conductivity [$K_{sat}$] (ft/day) | Porosity, *n* | Groundwater Flow Velocity [*-K/n (h/l)*] (ft/day) | Groundwater Discharge [$Q_{gw}$] (cfs) |
|---|---|---|---|---|---|
| Gales and Clear Creek | 0.001–0.01 | 10–100 | 0.30 | 0.03–3 | 0.001–1 |

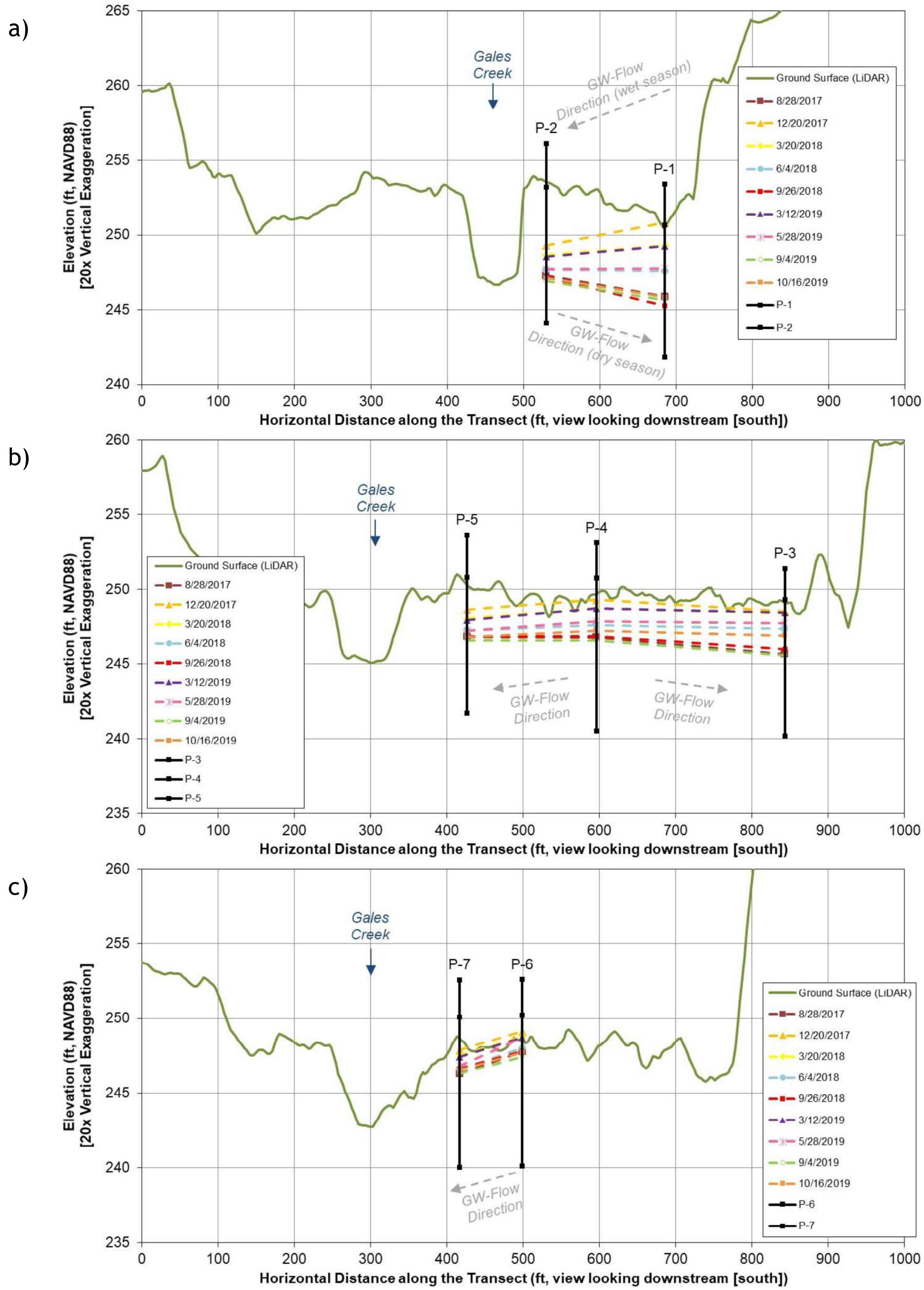



**Figure 10**. Seasonal profiles of the water-table elevations along the three transects: upper-portion of site (a), middle-portion of site (b), and lower-portion of site (c).

The groundwater flow directions and gradients (slopes) also varied seasonally throughout the monitoring period, based on examination of groundwater levels represented in three transects (see Figure 10) and in the planform data plots (see Figures C-22 through C-32 in Appendix C). In the summer months, groundwater flowed primarily away from Gales and Clear creeks and towards the floodplain. This condition is an expected result given that most western alluvial rivers exhibit a hydraulically "losing" characteristic in drier months, often causing perennial streams to eventually become dry during drought periods. Groundwater gradients were steeper nearest to Clear Creek, which is perched higher than Gales Creek in summer and, therefore, is a significant source of groundwater in the southern end of the floodplain, which is near the recently excavated side channels. The estimated groundwater discharge from the creeks into the floodplain was a small fraction of the surface-water discharge during this period (see Table 6). In the winter months, the flow directions reverse course and head toward Gales Creek, which presumably includes eastward-heading subsurface flow from the adjacent agricultural fields and uplands. This condition is also an expected result for streams like Gales Creek that become hydraulically "gaining" when rainfall and runoff in the surrounding landscape have caused the water table to rise higher than surface-water flow in the stream channel.

## 3.4 Water Temperature

Water temperature measurements recorded at the two, vertically stratified monitoring stations in the lower pool of Clear Creek (T-1) and Gales Creek (T-2) are presented in Figure 11 based on the 7-day average of their hourly data. Data plots of their hourly data are presented in Appendix D. Air temperatures recorded at B-1 are shown for reference in these plots. Seven-day average water temperatures recorded at the three streamflow gages and seven groundwater monitoring wells are shown in Figure 12 and 13. The 68°F (20°C) maximum water temperature threshold for salmonid thermal refugia is shown for reference in the plots.

The water temperatures recorded at T-1, T-2, and the three streamflow gages fluctuated rapidly in phase with local air temperatures (Figures 11 and 12), whereas the groundwater temperatures varied minimally over a much longer period (Figure 13). Seasonally, water temperatures were generally cooler than air temperatures in summer months (June–August) and vice-versa in winter months (December–March), with more equal temperatures during the fall and spring months.

The lower Clear Creek pool (T-1) was consistently cooler than the Gales Creek pool above the confluence (T-2). Summer water temperatures measured in the pools and at the streamflow gaging stations were more variable over the course of a given day within Gales Creek than they were in Clear Creek, with daily fluctuations >10°F in Gales Creek and <10°F in Clear Creek. There were minimal (<1°F) differences in temperatures by depth recorded in the pools, indicating there was a lack of thermal stratification[2]. During summer, the maximum hourly temperatures recorded by the deepest sensors in the Clear Creek and Gales Creek pools were 66–68°F and 76–79°F, respectively. The Gales Creek pool temperatures exceeded the cold-water refugia threshold of 68°F on approximately 20 days during July–August of both water years 2017 and 2018 and on only 11 days in water year 2019. This decrease in unsuitably warm-water days in the Gales Creek pool may be explained by the relatively cooler air temperatures during summer 2019 and/or the influence of the newly constructed side-channel feature.

[2] The hourly data for the near-surface sensor (D-1) at both thermograph stations (T-1 and T-2) exhibited a broader amplitude (range) of temperature during summer months due to the sensors being above the water column during lower flow periods (see Figure D-1b in Appendix D).

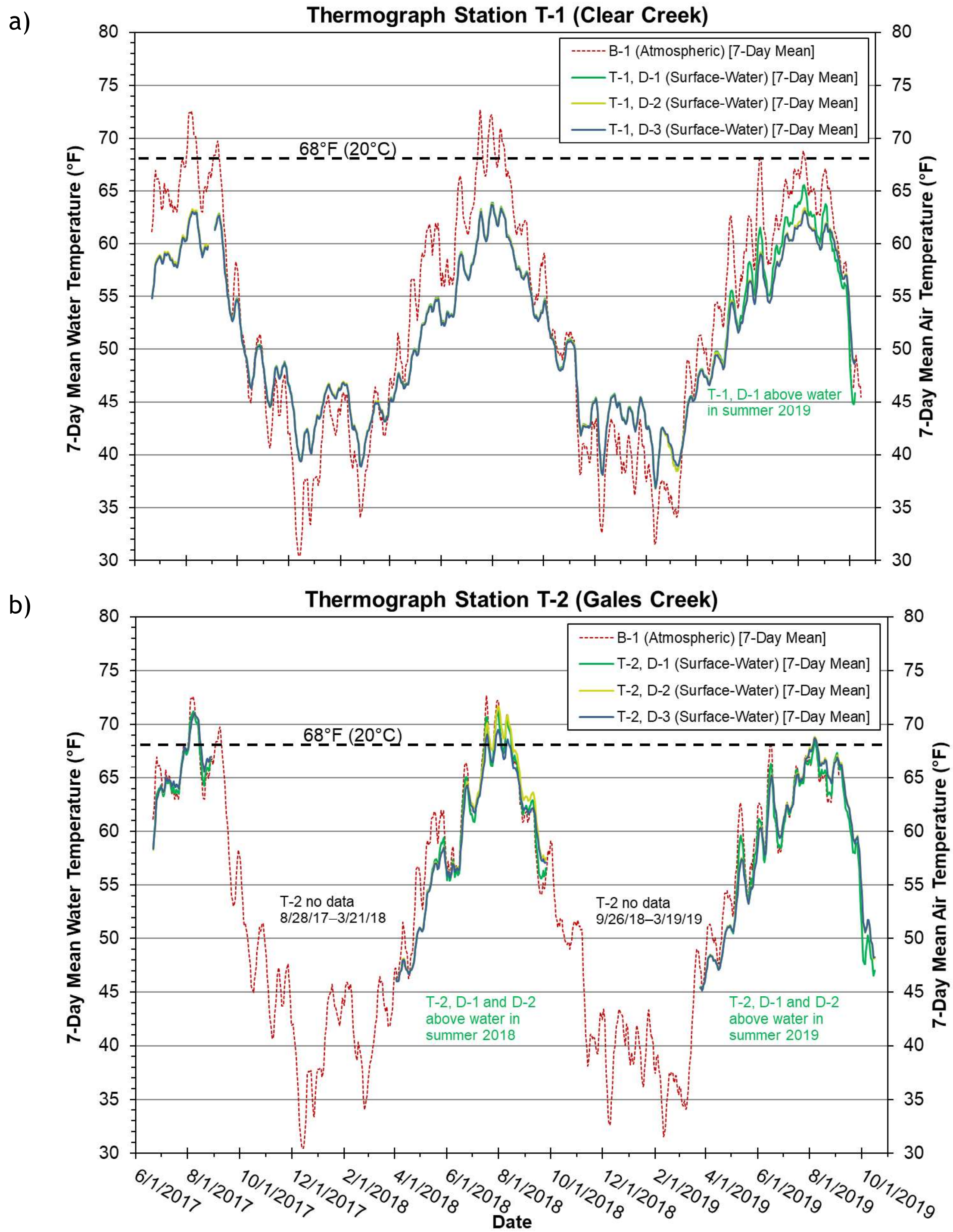



**Figure 11.** Seven-day average water temperature recorded in lower Clear Creek (a) and Gales Creek near the confluence (b). Onsite air-temperatures recorded at B-1 are shown for reference.

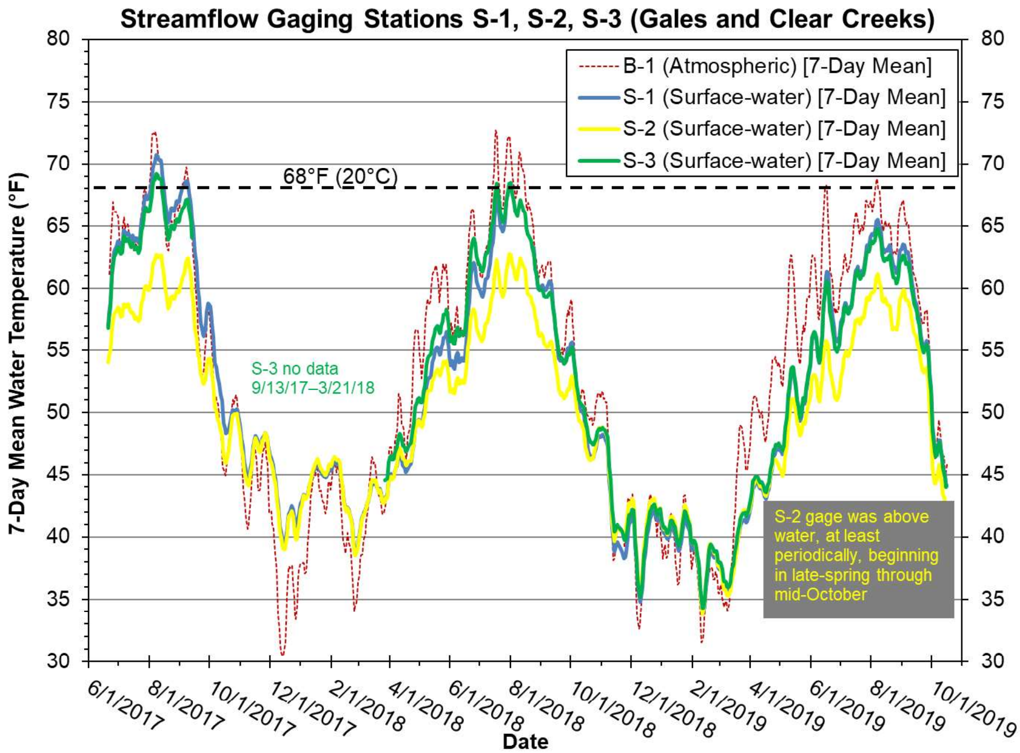



**Figure 12.** Seven-day average water temperatures recorded at the streamflow gages. Onsite air temperatures recorded at B-1 are shown for reference.

Groundwater temperatures at the monitoring wells exhibited a semi-annual periodicity and were generally similar during the pre-enhancement and post-enhancement periods, with the warmest temperatures occurring in late September–early October and the coolest temperatures occurring in late March–early April (see Figure 13). There is a consistent pattern of warmer groundwater temperatures in summer months at the wells located closer to Gales Creek and nearer to the upstream end of the floodplain. Specifically, well P-2 has been warmer than P-1 and well P-5 has been warmer than P-4 and P-3. Additionally, well P-6, which is farther upstream along lower Clear Creek has been warmer than P-7. Compared to surface-water temperatures, the groundwater temperatures were consistently cooler from mid-spring through mid-fall, and vice-versa. The groundwater-temperature pattern exhibits a 2 to 3-month delay behind the air and surface-water temperature patterns. The distribution and timing of cooler groundwater temperatures together suggest that hyporheic flow from the warmer Gales Creek during summer first enters the floodplain at the upstream end near P-2 (and, to a lesser extent, near P-5). If this concept is valid, then the data indicate a general cooling of stream-sourced water as it moves laterally and down-gradient through the floodplain subsurface.

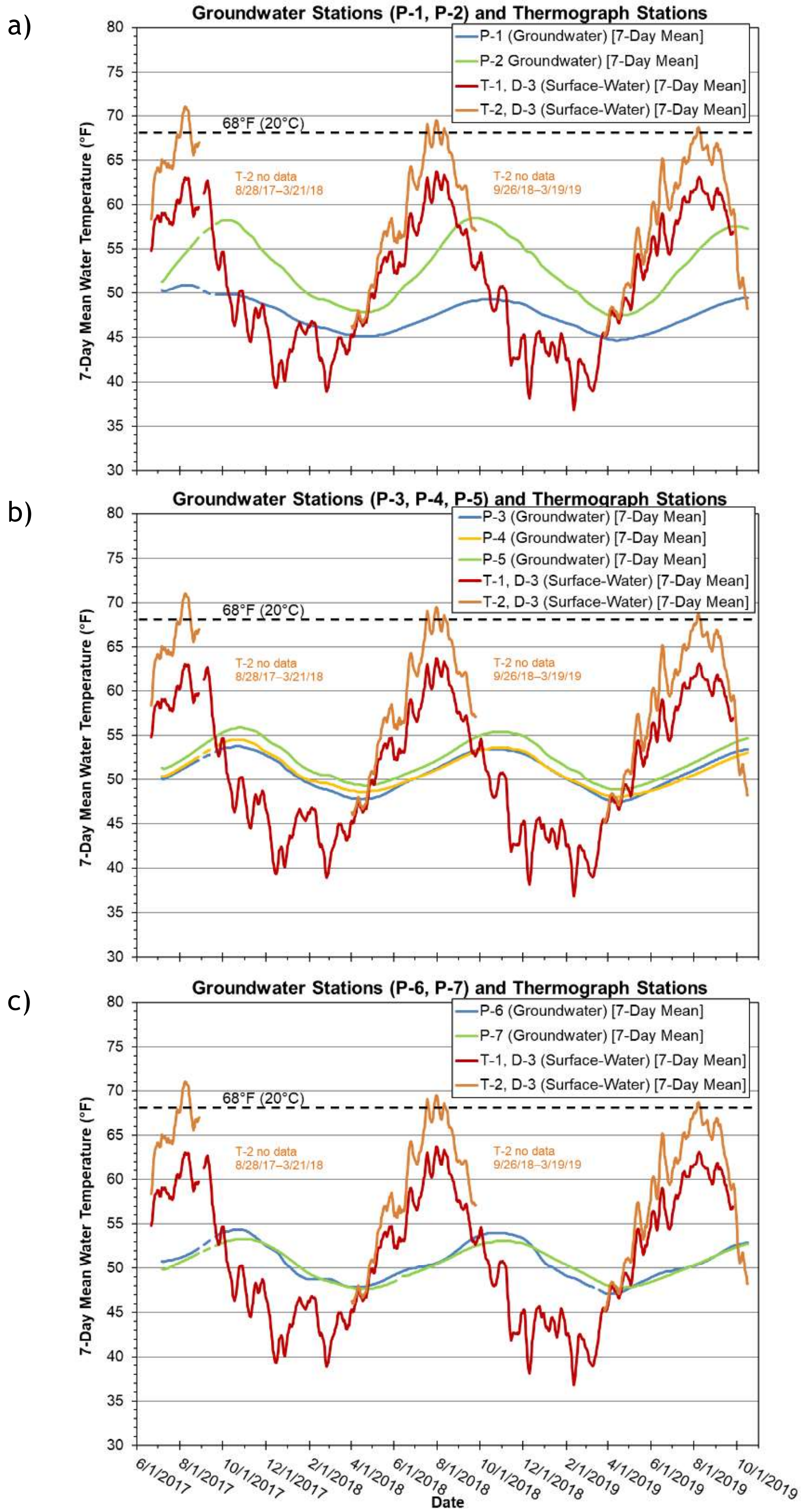



**Figure 13.** Seven-day average groundwater temperatures recorded along the three transects compared to pool temperatures at T-1 and T-2.

## 3.5 Floodplain Inundation

A summary of hydrologic conditions occurring on the days of the dry-season (low-flow) and wet-season (high-flow) mapping events is presented in Table 7. The maps from the four events, which depict inundation boundaries and surface-water depths, are presented in Figures 13 through 16. Ground-based photos taken during the mapping efforts are included in Appendix A.

**Table 7.** Estimated hydrologic conditions near the Project site and areal extent of floodplain inundation during the floodplain-inundation mapping events.

| Event type | Mapping event date | 72-hr total rainfall near Forest Grove (inches) | Daily mean streamflow (cfs) [A] | | | | Average ground-water depth below ground surface at all wells (ft) | Areal size of mapped inundation (acre) |
|---|---|---|---|---|---|---|---|---|
| | | | Up-stream Gales Cr gage, S-1 | Clear Cr gage, S-2 | Down-stream Gales Cr gage, S-3 | OWRD gage near Forest Grove | | |
| Dry | 9/13/2017 | 0 | 8.6 | 3.8 * | 11 | 13 | -4.2 | 0.12 |
| | 9/26/2018 | 0 | 7.5 | 4.3 | 14 | 13 | -4.2 | 0.16 |
| Wet | 1/24/2018 | 1.6 | ~1,000 | 67 | N/A | 1,500 | -1.0 | 2.0 |
| | 1/26/2019 | 0.4 [B] | 220 | 13 | 290 | 310 | -2.1 | 1.7 |

[A] Discharges are based on rating curves, except for S-2 when field-measured values were available (*).
[B] The 7-day total rainfall recorded was 2.43 inches.

The extent of floodplain inundation was related to seasonality and site topography. The inundation extents during the dry-season mapping events in September 2017 and 2018 (Figures 14 and 15) were concentrated along the southwestern corner of the floodplain and accounted for only 1% of the floodplain area. A few additional, albeit small, areas of dry-season ponding were observed in September 2018 where standing water was ponded in the newly excavated pools of the side-channel enhancements.

Inundation extents during the wet-season mapping events in January 2018 and 2019 were much broader in the southwestern corner and extended farther north within two linear topographic depressions that are part of a historic ditch (Figure 16 and 17). The newly constructed side-channels were observed to be fully inundated and well connected with Gales Creek (near station T-2) during January 2019. Floodplain-inundation drainage to Gales Creek via the constructed side-channels was observed during the January 2019 mapping event and other field visits since construction. Evidence of surface-water flow through the notched dike was not observed, which indicates higher flows with a less frequent return period will be necessary to overtop the notched-dike invert and inundate the northern portion of the site floodplain.

The source of floodplain ponding during both wet-season events appeared to originate from direct precipitation and seepage and/or runoff from the agricultural field situated upon the higher terrace immediately to the west of the floodplain. Although little standing water was observed on the gently sloping field, water was discharging into the ditch feature on the floodplain via three drainage pipes extending out from the steep slope at the base of the terrace and edge of the floodplain (see Figure 2). It is assumed the inlets to these pipes are below grade.

Overall, the dry-season and wet-season inundation extents did not appear to significantly change since construction of the enhancement features.

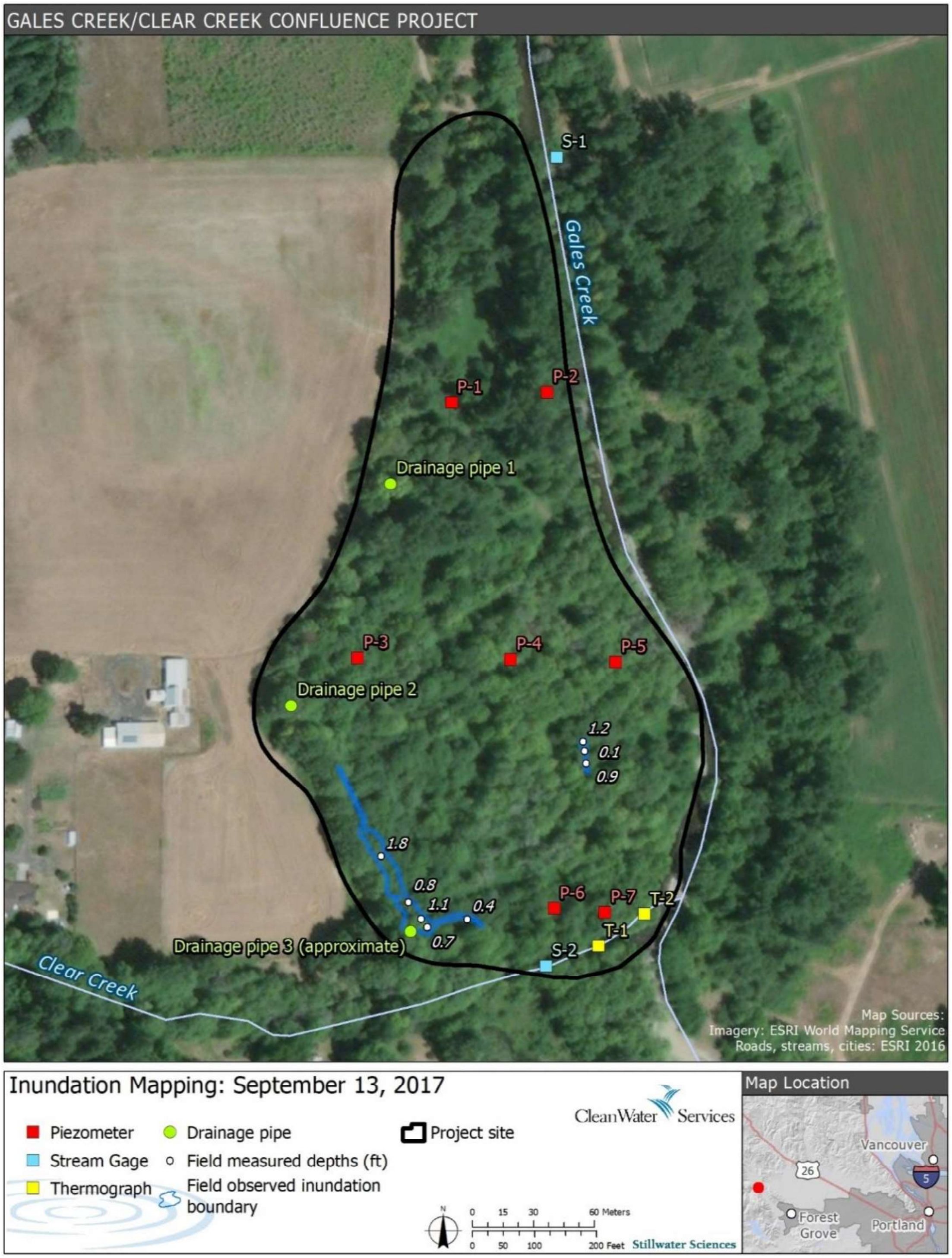



**Figure 14.** Map of field-based delineation of floodplain-inundation extent (polygons) and measurements of inundation depth (points) during dry-season conditions in September 2017 before enhancement construction.

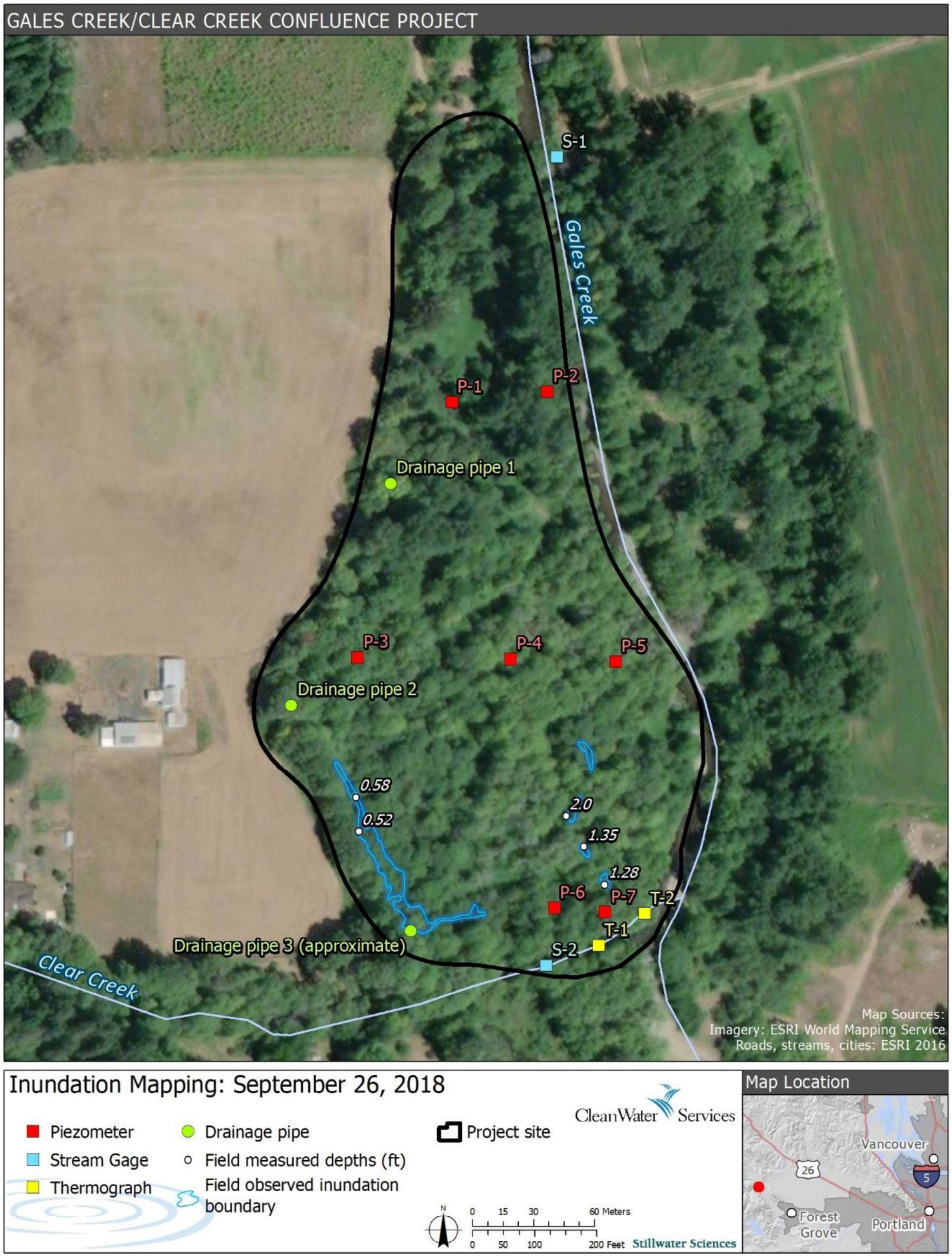



**Figure 15.** Map of field-based delineation of floodplain-inundation extent (polygons) and measurements of inundation depth (points) during dry-season conditions in September 2018 after enhancement construction.

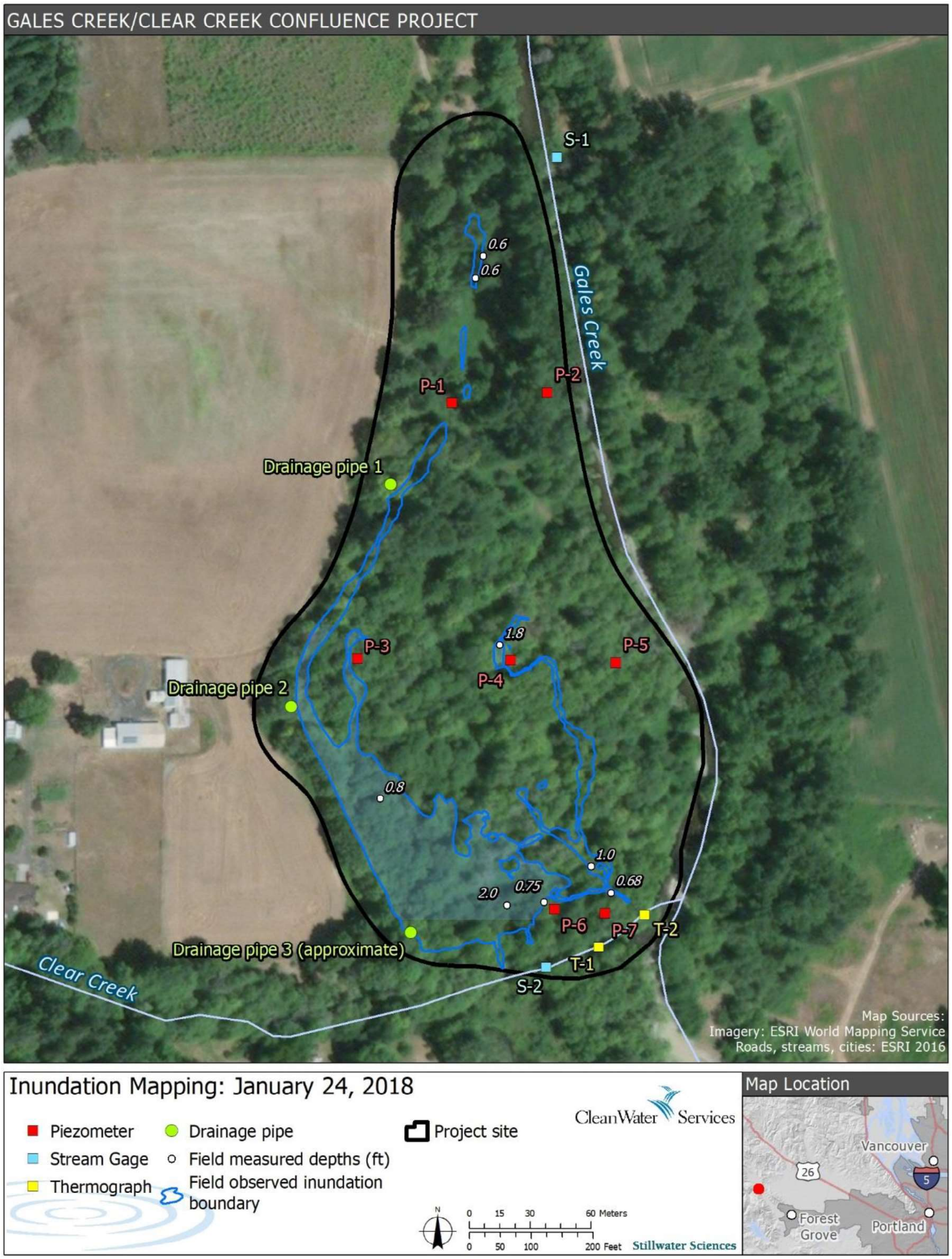



**Figure 16.** Map of field-based delineation of floodplain-inundation extent (polygons) and measurements of inundation depth (points) during wet-season conditions in January 2018 before enhancement construction.

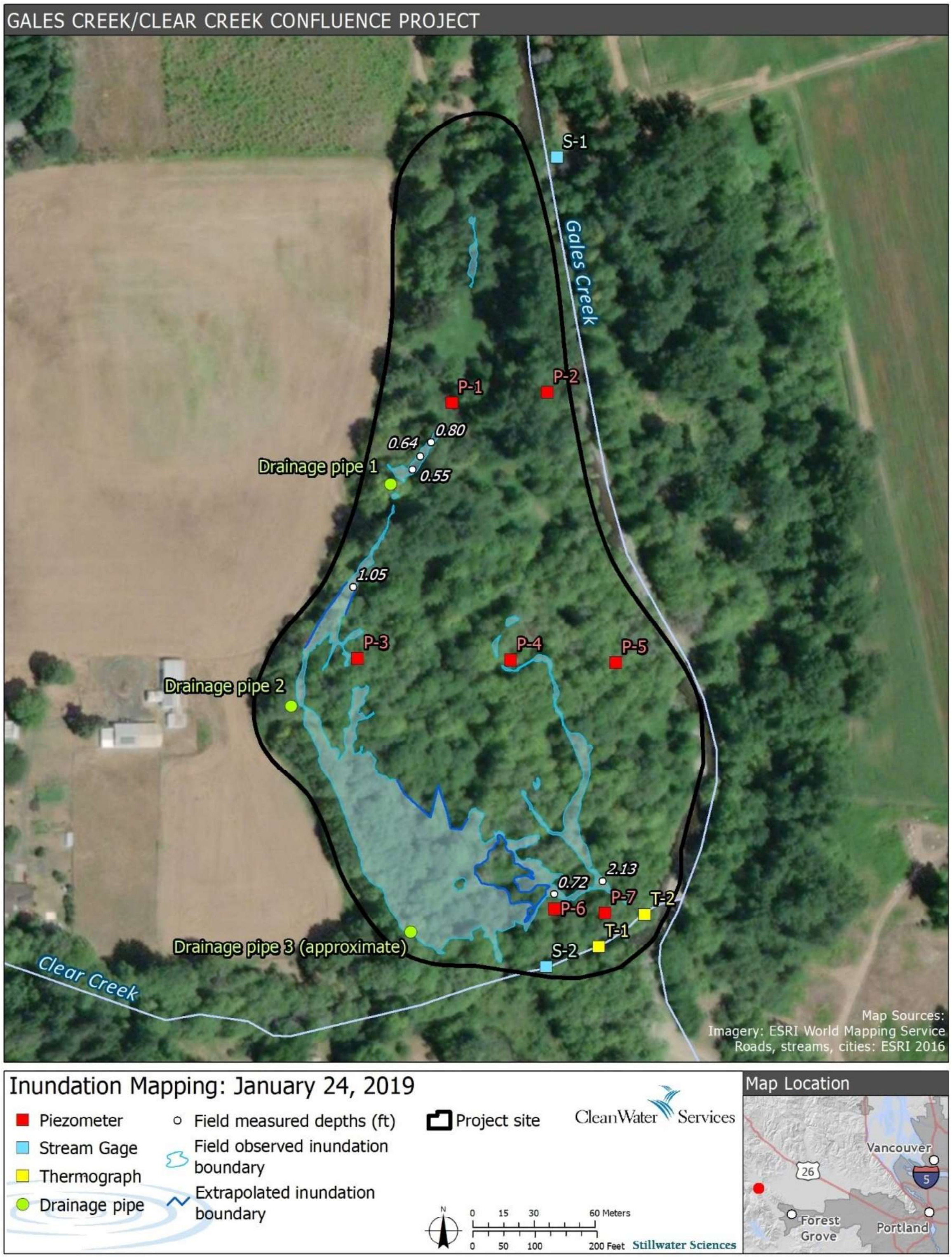



**Figure 17.** Map of field-based delineation of floodplain-inundation extent (polygons) and measurements of inundation depth (points) during wet-season conditions in January 2019 after enhancement construction.

### 3.6 Channel Morphology

Surveying of the morphologic character of Clear and Gales creeks was conducted at Project initiation prior to construction of the enhancement features. Visual observations of the Project site made opportunistically during all subsequent monitoring activities noted no apparent changes to channel geometry or sediment texture, except in the immediate vicinity of the constructed enhancement features. Photos of the Project site showing geomorphic features are presented in Appendix B. Data plots of the initial cross-section surveys are included in Appendix E.

# 4 CONCLUSIONS

The following discusses the primary findings and recommendations based on the results from the entire monitoring period. These conclusions may be refined following future monitoring work.

## 4.1 Major Findings

Monitoring of hydrologic conditions for approximately one year before and after enhancement construction in summer 2018 has observed trends in streamflow, groundwater levels, water temperatures, floodplain inundation, and channel morphology resulting in discovery of several notable processes.

Rainfall has been seasonally variable with larger winter storms causing streamflow to rise, thereby causing groundwater levels within the site floodplain to rise and low-lying areas of the floodplain to inundate. Water years 2018–2019 (representing the bulk of the monitoring period) experienced below-average rainfall. The pre-enhancement period (June 2017–July 2018) and post-enhancement period (August 2018–October 2019) both experienced similar seasonal climatic conditions, with below-normal rainfall in winter months and warm temperatures in summer months. This similarity in climatic conditions therefore enables a fairer comparison of the pre-enhancement and post-enhancement periods.

Streamflow in Clear Creek ranged from approximately 1 cfs to over 100 cfs, while streamflow in Gales Creek ranged from approximately 6 cfs to over 1,000 cfs. The continued below-average rainfall conditions during the entire monitoring period led to a gradual decline in summer baseflows, which was most apparent in lower Clear Creek: minimum summer baseflows dropped to approximately 7 cfs in water year 2017, 2 cfs in water year 2018, and 1 cfs in water year 2019. Because the measurement point on Clear Creek accounts for inflows to the Project site, the decline in summer baseflows appeared to be driven by climatic influences rather than by the constructed enhancement features. During winter months, streamflow accretion was observed indicating additional inputs besides Gales and Clear creeks were contributing to runoff in the site vicinity, which likely include direct precipitation, runoff from adjacent fields and uplands, and groundwater-sourced inflow. The constructed enhancement features did not appear to change flow dynamics through the Project area.

The groundwater levels exhibited direct and rapid response to rainfall infiltration and surface-water runoff, marked by shallow depths during winter months and deeper depths during summer months. The mixed alluvial sediments of the floodplain that overlie an impermeable clay layer at about 10-feet depth were saturated for much of the monitoring period, with groundwater generally flowing away from Gales and Clear creeks and into the floodplain during the summer months and flowing toward the creeks during the winter months. Groundwater discharge from the creeks into the floodplain (occurring primarily during summer months) represented a small fraction of the surface-water discharge of Gales and Clear creeks. Related to the declining trend observed in summer baseflow, the groundwater levels across the site exhibited a very slight declining trend over the course of the monitoring period.

Surface-water temperatures fluctuated rapidly in phase with local air temperatures, whereas groundwater temperatures varied minimally over a much long period. Water temperatures in Clear Creek were found to be cooler than in Gales Creek. There is a greater temperature differential in summer between Gales and Clear Creek, with Gales Creek 7-day mean temperatures peaking at or above 70° F and Clear Creek temperatures peaking at 63° F. The monitored pools exhibited little thermal stratification due to adequate hydraulic mixing by incoming streamflows even during summer months when stratification through stagnation and differential warming of low flows can potentially occur. The number of days water temperatures in the monitored Gales Creek pool exceeded the cold-water refugia threshold of 68°F was reduced by almost half during the post-enhancement period compared to the pre-enhancement period (i.e., 20 days versus 11 days). This decrease in unsuitably warm-water days in the Gales Creek pool, which is situated at the mouth of the newly excavated floodplain side-channel, may be explained by a combination of the slightly cooler air temperatures during summer 2019 and the influence of the side-channel feature.

Groundwater temperatures were nearly static but with the warmest temperatures nearest Gales Creek and the upstream end of the floodplain, which indicates a general cooling of stream-sourced water as it slowly moves laterally and down-gradient through the floodplain subsurface. The groundwater-temperature pattern exhibits a 2 to 3-month delay behind the air and surface-water temperature patterns, which provides further evidence of the slow pace of groundwater movement through the site.

Floodplain inundation was related to seasonality and site topography, with areal extents greatest during wet periods and concentrated in topographic low points, some of which are part of an older ditch-drainage system and some are in the newly constructed side channels. Runoff from the adjacent agricultural field to the west also appeared to contribute to inundation in the winter months. The dry-season and wet-season inundation extents did not appear to significantly change since construction of the enhancement features.

The channel-floodplain morphology has yet to noticeably adjust to the constructed enhancement features (e.g., log jams, excavated side channels and pools, excavated berm, and woody vegetation plantings) due to a relatively quiescent period of below-normal rainfall and runoff during the monitoring period. As a result, the movement of surface-water and shallow groundwater through the site has not been altered to a degree where monitoring has detected any notable difference between pre-enhancement and post-enhancement conditions.

Overall, the light-tough approach to the habitat enhancement work does not appear to have altered the Project site's hydrology or geomorphology in any detectable manner within the resolution of the monitoring methods. The constructed side-channel, however, may be contributing to the slightly cooler summer temperatures observed in the Gales Creek pool. It is expected that hyporheic flow paths elsewhere along Gales Creek and Clear Creek will potentially change and lead to cooler water temperatures once the site experiences higher, channel-forming flows that scour new pools adjacent to the installed log jams.

## 4.2 Recommendations

Based on evaluation of the monitoring methods and results, the following activities are recommended should future monitoring occur. These recommendations are intended to improve the overall monitoring program while still adhering to the original monitoring plan (Stillwater Sciences 2017). The recommendations are listed in order of greatest to least importance.

- **Resume monitoring of biologic conditions** responding to the enhancement features by conducting fish presence and habitat-use surveys at the site. Coho were reportedly observed using the Gales Creek and Clear Creek pools and in the constructed side-channel pools during summer 2019 (S. Trask, personal communication with G. Leverich, 2019). Publishing the results of the completed snorkel surveys and conducting additional surveys would greatly help to assess the success of the Project.
- **Continue monitoring and performing analyses** of surface-water flows, groundwater levels, and water temperatures to more fully assess post-enhancement changes over the next few years. Additionally, the continued monitoring will enable further assessment of uncertainty in the stage-discharge relationships, particularly at the Clear Creek gaging station which may need to be re-positioned upstream. Mapping of floodplain-inundation extent and re-surveying of established geomorphic cross-sections should be included with future monitoring once a relatively large channel-adjusting event has been observed by field crews during other monitoring activities.
- **Improve computation of water quantity and thermal energy budgets** across the Project site through hydrologic/hydraulic modeling and/or thermal tracer tests.
- **Assess function and restoration potential of the abandoned gravel-mining pits** located immediately downstream of the Project site. The pits currently store ponded water year-round that is presumably sourced from local groundwater seepage. The ponded water is exposed to direct solar radiation which may contribute to warming of water in Gales Creek downstream of the Project area. A simple determination of hydrologic connectivity between the ponds and stream channels may help determine an appropriate restoration strategy.
- **Construct additional habitat enhancement features** along Gales Creek and its floodplain to further improve cold-water habitat conditions, should the already-constructed features continue to perform well over the next 3–5 years. The simplified morphologic character of Gales Creek, with its straight channel course and plane-bedded topography, may require a more engineered approach to improve its hyporheic-flow exchanges and provide cooler summer-time water temperatures.

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