TECHNICAL MEMORANDUM

To: Kristin Williamson
South Puget Sound Salmon Enhancement Group

From: Shawn Higgins, Charissa Young, Mike (Rocky) Hrachovec, and Tim Abbe

Date: July 24, 2015

Re: Water level and temperature monitoring at the Pierce Conservation District property (former Inglin Dairy Farm) on South Prairie Creek

PROJECT BACKGROUND

The South Puget Sound Salmon Enhancement Group (SPSSEG), in partnership with Pierce Conservation District, the Puyallup Tribe, and Pierce County Public Works and Utilities, Surface Water Management (SWM) Division, contracted with Natural Systems Design, Inc. (NSD) to develop design plans for instream habitat enhancement, floodplain reconnection, and restoration of off-channel habitat along South Prairie Creek approximately 2 miles downstream of the community of South Prairie.

The project area is located between River Mile (RM) 4.05 and RM 4.6 and includes 4 adjoining parcels with ownership by Pierce Conservation District and Pierce County SWM (Figure 1). The project site was a former dairy facility (Inglin Dairy Farm) that has been acquired for conservation and restoration of natural processes within the stream corridor. The main channel is approximately 100 feet wide and entrenched 8 to 10 feet below the alluvial surface forming the right bank. A low terrace spans up to 1,200 feet in width between the channel and hillslope to the north. A floodplain swale is cut 3 to 5 feet below the terrace surface marking the path of an abandoned channel. A small channel, 10 to 20 feet in width, parallels the valley wall to the north and is fed by spring flow and seeps emerging from groundwater in the adjacent hillslope.

Project partners requested technical services from NSD to collect hydrologic monitoring data to characterize variability of water level and temperature at the project site. This memorandum summarizes work completed as part of this task and presents results of observed water level and temperature for an array of 8 hydrologic monitoring locations in 2014.

HYDROLOGIC SETTING

South Prairie Creek drains a watershed area encompassing 83 square miles upstream of the project area. The climate is mild; characterized by cool, moist winters and relatively dry summers. Annual precipitation averages 60 inches over the watershed. Elevation ranges from 300 feet near the basin outlet to over 5,900 feet on Carbon Ridge along the northwestern flank of Mount Rainier. A large portion of the watershed is within the elevation range of the transient snow zone characterized by relatively shallow winter snowpack susceptible to rapid melting during rain-on-snow events.

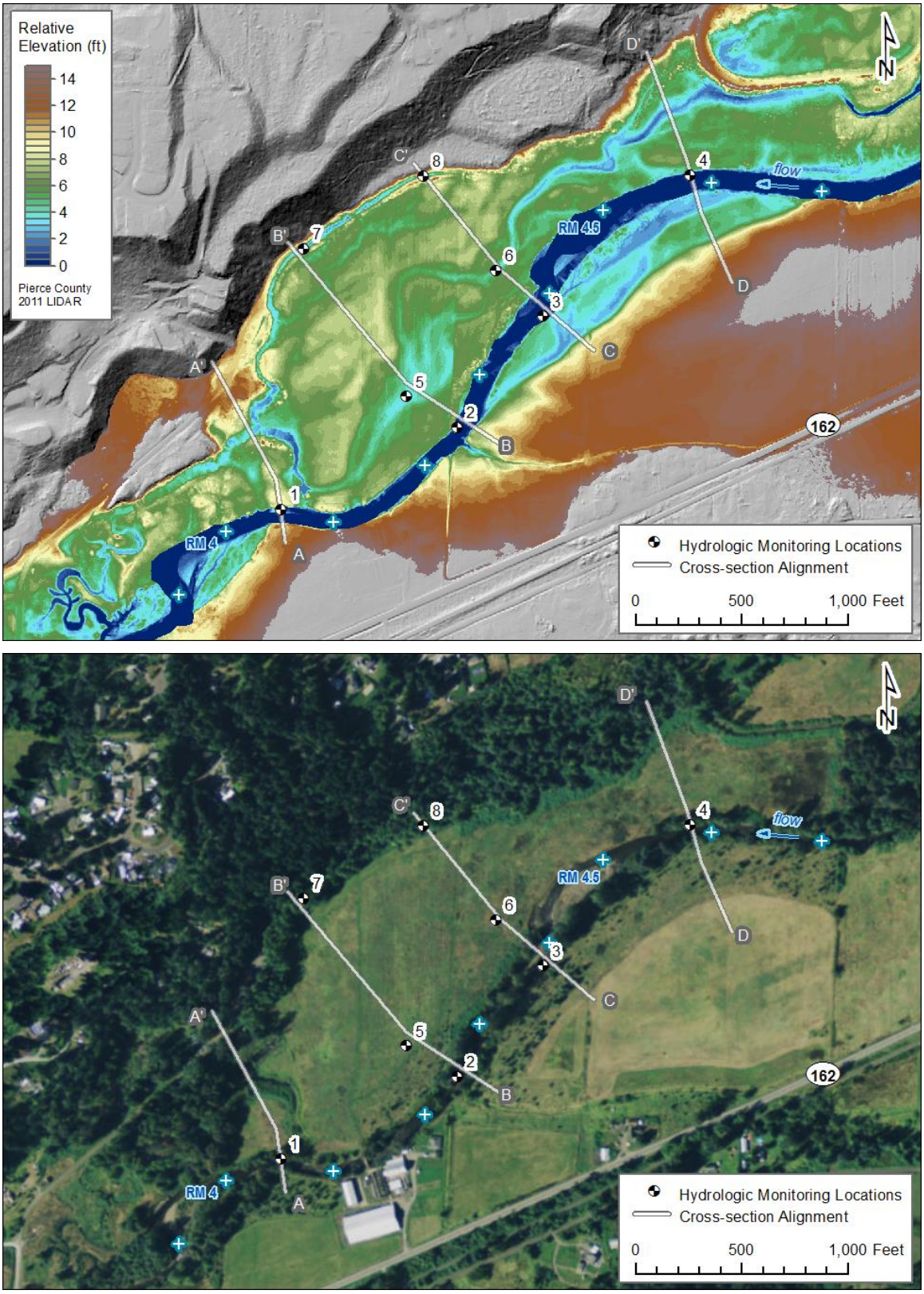


Figure 1. Site maps overlaying hydrologic monitoring locations with relative elevations derived from 2011 LiDAR and a 2013 aerial image.

USGS monitors streamflow characteristics of South Prairie Creek upstream of the project reach on the downstream side of the State Highway 162 bridge (gaging station #12095000). The historical streamflow record includes periods from June 1949 to September 1971 and from October 1987 to present. Drainage area upstream of the USGS gage site is 79.5 square miles. There are no major tributaries joining South Prairie Creek downstream of the gaging station; however, local runoff from hillslope areas and direct precipitation on the valley bottom increase the contributing drainage area at the project site by 6%

Streamflow in South Prairie Creek has a seasonal flow regime that is characterized by relatively high flows in winter and spring, receding flows throughout the summer, and a rise in flow in response to increased precipitation during fall (Figure 2). Flow duration statistics derived from the record of mean daily streamflow are plotted on Figure 4.

Nearly all of the large floods in western Washington are associated with atmospheric river events, commonly known as a Pineapple Express, characterized by a narrow plume (250-350 miles wide) of moisture-rich air that delivers large amounts of water vapor from the subtropical latitudes of the Pacific Ocean. The flood of record (9,480 cfs at the USGS gage) occurred January 2009. Flood frequency statistics for USGS gage #12095000 are summarized below in Table 1.

Reconnaisance imagery taken by Pierce County SWM during the November 7, 2006 flood (6,530 cfs) shows areas of inundation and preferential flowpaths during an event with an expected recurrence interval between 10- and 25-years (Figure 5). Overbank flow upstream of the horse facility on an adjacent parcel collects into a drainage channel that connects with a floodplain swale representing an abandoned channel feature on the low terrace between South Prairie Creek and the north valley wall.

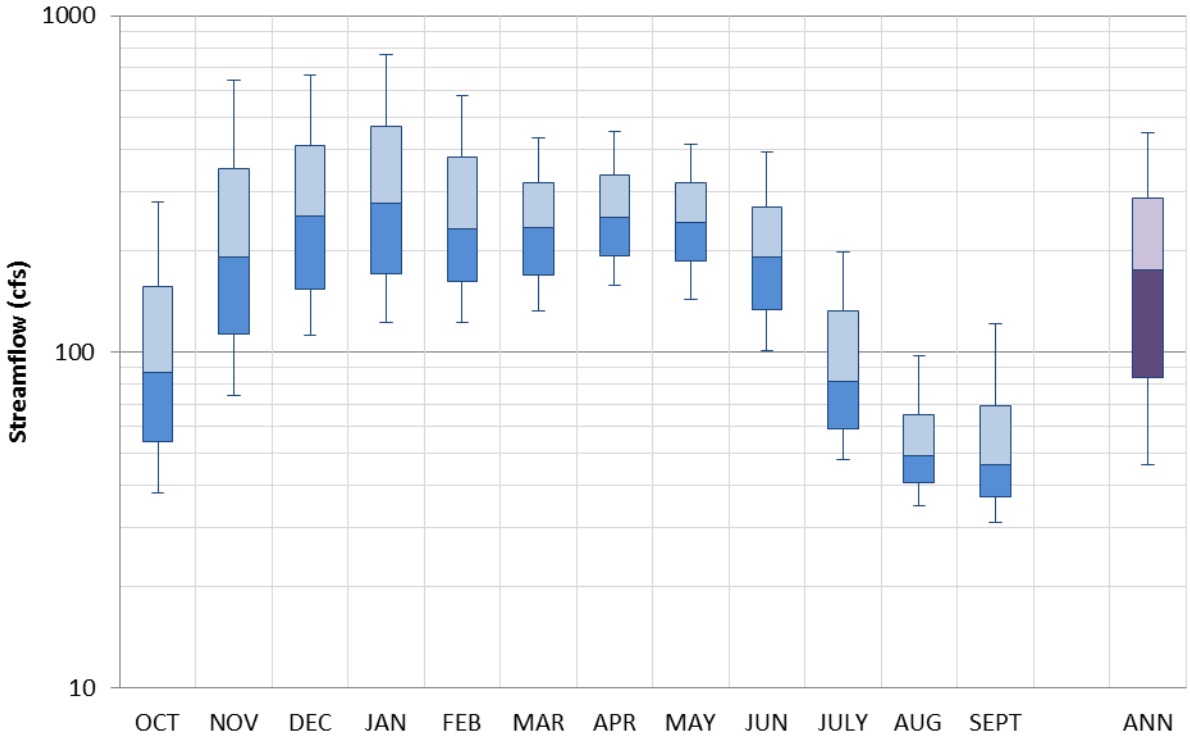


Figure 2. Seasonal variability represented by box and whisker plots of monthly average streamflow at USGS gaging station #12095000 (South Prairie Creek at South Prairie, WA). Boxes show the range between the 25th and 75th percentile values over the historical period and are split at the 50th percentile (median). Whiskers extend vertically to the 10th and 90th percentiles of monthly average streamflow, respectively.

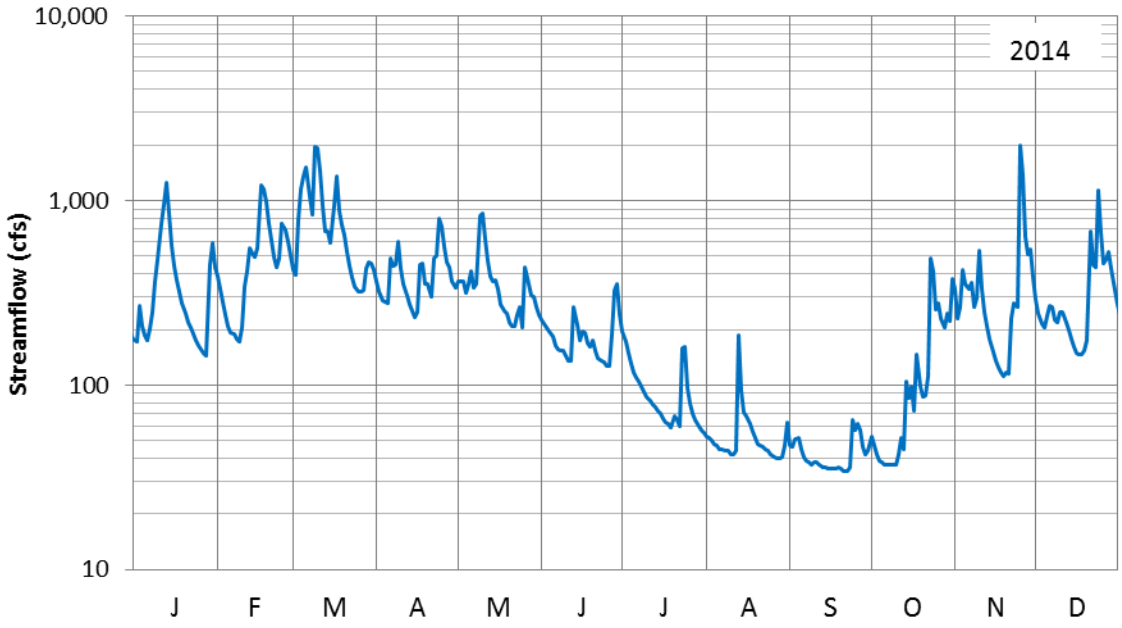


Figure 3. Annual hydrograph of mean daily streamflow for 2014 at USGS gaging station #12095000 (South Prairie Creek at South Prairie, WA).

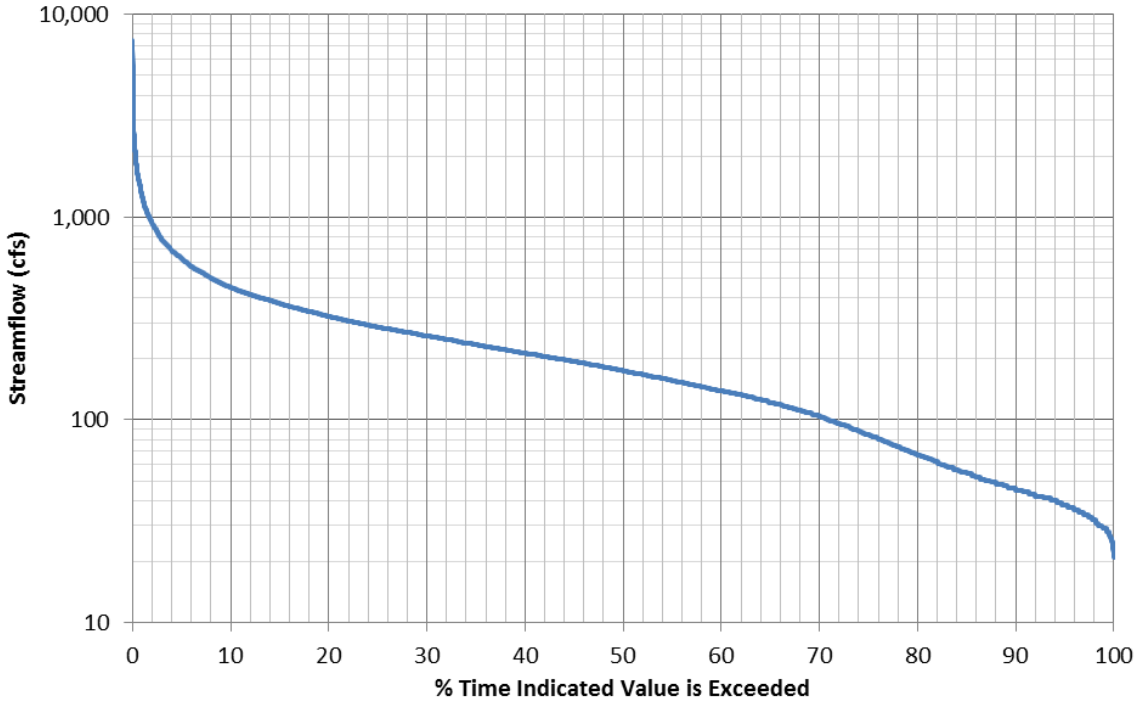


Figure 4. Flow duration statistics derived from the historical record of mean daily streamflow at USGS gaging station #12095000 (South Prairie Creek at South Prairie, WA).

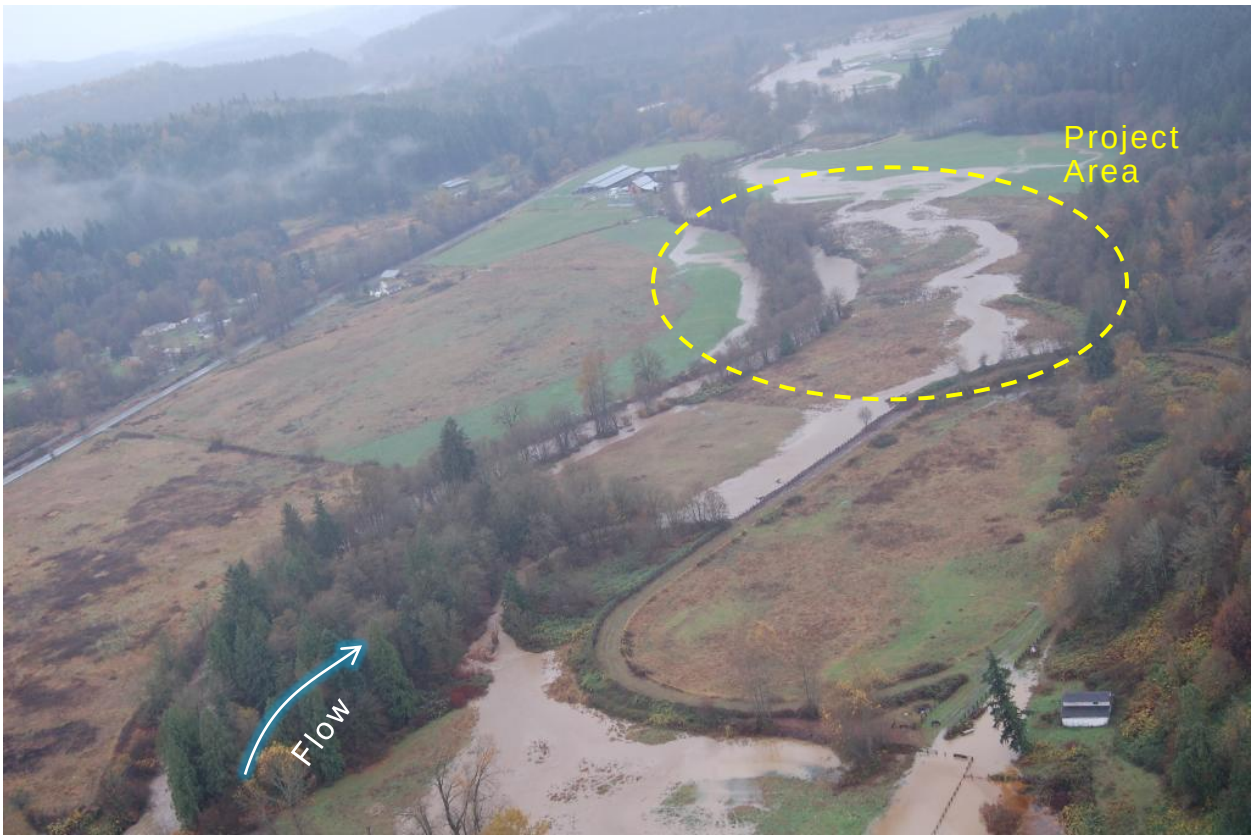


Figure 5. Oblique aerial photo during the November 7, 2006 flood event along South Prairie Creek (6,540 cfs). Image source: Pierce County SWM.

Table 1. Flood frequency statistics at USGS gage #12095000 (South Prairie Creek at South Prairie, WA).

Recurrence Interval (yrs)	Peak Flow (cfs)
1.25	1,880
1.5	2,350
2	2,940
5	4,540
10	5,660
25	7,130
50	8,250
100	9,400

DATA AND METHODS

NSD deployed an array of eight water level and temperature dataloggers at the project site in December 2013. Four dataloggers were deployed in the main channel between RM 4 and 4.6, two dataloggers were placed in groundwater monitoring wells in the adjacent floodplain, and two dataloggers were located in the spring fed, wall-base channel that follows the toe of the hillslope at the north edge of the valley (Figure 1). An additional datalogger was deployed in the dairy facility to record ambient air temperature and fluctuations in barometric pressure. Dataloggers recorded a continuous record of level and temperature at 15 minute intervals between December 2013 and January 2015.

Surface water monitoring sites in the main channel and the wall-base channel utilized PVC stilling wells anchored to t-posts embedded in the bank or bed material. Dataloggers were suspended within stilling wells at a depth just slightly above the bed of the channel. Staff gages were attached to stilling wells in the main channel to facilitate visual observations of water level.

Shallow groundwater monitoring wells were installed at sites SPC-5 and SPC-6 within soil borings that were hand-augured into the floodplain swale paralleling South Prairie Creek. Boring depth was limited by presence of a subsurface cobble layer with median grain size diameter of 200-250 mm (ref geomorphic assessment memo). As a result, monitoring wells had limited depth of 4.8 feet (SPC-5) and 3.3 feet (SPC-6) below ground surface. Dataloggers were suspended just above the bottom of each monitoring well.

Water level data were adjusted to correct for fluctuations in atmospheric pressure (barometric compensation) using the barometer deployed in the dairy facility. Water level data were converted to water surface elevations using a common vertical datum (NAVD 1988) based on survey elevations recorded at monitoring well locations by Larsons and Associates, Inc. in December 2013. Cross-sectional profiles were extracted at monitoring locations from the 2011 LiDAR DEM and adjusted to incorporate survey elevations from 2013 (cross-section alignments are shown in Figure 1). Observed water surface elevations were overlaid with channel geometry and floodplain topography to evaluate floodplain connectivity and surface water-groundwater interactions.

Water temperature data were analyzed to construct a time series of daily maximum temperature for the main channel sites along South Prairie Creek. The 7-day average of the daily maximum temperatures (7-DADMax) was then calculated by averaging the daily maximum temperature on a given day with the daily maximum temperatures of the three days prior and the three days after that date. 7-DADMax values were compared with water quality standards to evaluate water quality impairment. Water quality standards in Chapter 173-201A of the Washington Administrative Code reference the following temperature thresholds for South Prairie Creek:

- 13° C (55° F) between September 15 and July 1 (spawning and incubation criteria) and
- 16° C (61° F) year round (applies July 1 to September 15).

RESULTS AND DISCUSSION

Annual time series of water level and temperature observations for 2014 are illustrated for each site in a series of plots from Figure 6 to Figure 13. Surface water fluctuations in the main channel (sites 1-4) show the response to variations in flow recorded at the USGS gage upstream (Figure 3). Multiple flood pulses occurred between January and March, including a peak of 2,500 cfs (>1.5-year recurrence interval) on March 9, 2014. Flows receded through spring and summer reaching an annual minimum of 31 cfs in mid-September. Flows rose in response to increased rainfall in October and November. The annual maximum

peak flow of 3,330 cfs (between 2- and 5-year recurrence interval flood) occurred on November 25. Overall, mean annual flow for calendar year 2014 (302 cfs) was 28% greater than the historical average at the USGS gage upstream (#12095000).

SPC-1

Site 1 is located along the right bank near RM 4.05 and is 400 feet downstream of the bridge crossing over South Prairie Creek at the former Inglin Dairy (Figure 1). Water level (depth) generally fluctuated between 1 and 4 feet during winter months and receded to a minimum depth of 0.4 feet in September (Figure 6). The November 2014 flood peaked at a maximum depth of 6.9 feet. Water surface elevations are overlaid with cross-sectional profile A-A' in Figure 14. Bank heights on both sides of the channel are high and the maximum water surface elevation in November was contained by the channel with several feet of freeboard along both banks.

Water temperature generally ranged between 35 and 45° F through winter but climbed over summer with a maximum 7-DADMax value of 69° F at the beginning of August (Figure 6). Temperature exceeded the water quality standard for a duration of 131 days in 2014.

SPC-2

Site 2 is located along the right bank near RM 4.25 and is 600 feet upstream of the bridge crossing over South Prairie Creek at the former Inglin Dairy (Figure 1). Water level fluctuations closely followed those described for site SPC-1 (Figure 7). The November 2014 flood peaked at a maximum depth of 6.5 feet. The maximum water surface elevation in November remained 2 to 3 feet below the right bank at cross-section B-B' (Figure 15).

Fluctuation of water temperature was nearly identical to the values observed at SPC-1 with 7-DADMax exceeding the water quality standard for a duration of 126 days in 2014 (Figure 6).

SPC-3

Site 3 is located along the left bank near RM 4.4 and is immediately downstream of a steep bank that eroded laterally on the opposite (north) side of the channel in 2009 (Figure 1). The pool along the left bank maintained a minimum depth of 1.5 feet and reached a maximum depth of 8.1 feet in November (Figure 8). The peak water surface nearly overtopped the left bank at cross-section C-C' but remained approximately 2 feet below the right bank and adjacent ground surface of the low terrace to the north (Figure 16).

Fluctuation of water temperature was nearly identical to the values observed at SPC-1 and 2 with 7-DADMax exceeding the water quality standard for a duration of 126 days in 2014 (Figure 8).

SPC-4

Site 4 is located along the right bank near RM 4.6 at the upstream end of the project area (Figure 1). The channel maintained a minimum depth of 1.5 feet and reached a maximum depth of 6.8 feet in November (Figure 9). The peak water surface nearly overtopped the left bank at cross-section D-D' but remained approximately 4 feet below the right bank and adjacent ground surface of the low terrace to the north (Figure 17).

Water temperature observations at SPC-4 were somewhat anomalous compared to concurrent observations from sites 1-3 downstream. The range of water temperatures at SPC-4 was moderated with a generally higher winter temperature and cooler summer temperatures compared to the downstream sites (Figure 9). The largest differences between temperature at SPC-4 and the downstream sites was observed during July

and August when air temperature exceeded 90° F on multiple days. During the extreme heat, water temperature at SPC-4 was up to 8° F cooler than the concurrent temperature downstream at SPC-3. The 7-DADMax at SPC-4 exceeded the water quality standard for a duration of 29 days in 2014. We hypothesize that the relative difference in temperature between SPC-4 and other main channel locations could be attributed to localized upwelling of hyporheic flows or influx of groundwater from the adjacent floodplain area. A more extensive sampling of water temperature in South Prairie Creek would be required to verify the explanation.

SPC-5

Site 5 is a shallow groundwater monitoring well in the floodplain swale 280 feet northwest of SPC-2 near RM 4.25 (Figure 1).The floodplain swale extends upstream past SPC-6 through cross-section C-C' and continues northeasterly to intersect with a low relief swale draining away from the main channel to north near RM 4. An extension of the floodplain swale connected to SPC-5 and 6 also continues upstream beyond RM 4, abuts the edge of the horse facility on the adjacent property, and connects with a low area in the right bank at RM 5 (Figure 5).

The well was augered in the center of the swale to a depth of 4.8 feet below the ground surface. Water level fluctuated from a minimum depth of 2.1 feet in September to a maximum depth of 5.3 feet in March (Figure 10). The minimum water level in September corresponds to water surface elevation 2.6 feet *below* the ground surface. Maximum water levels in March correspond to a water surface elevation that is 0.6 feet *above* the ground surface (Figure 15).

Comparisons of shallow groundwater elevations at SPC-5 with concurrent water surface elevations in the main channel (SPC-2) and adjacent wall-base channel (SPC-7) are plotted in Figure 18. Shallow groundwater at SPC-5 is consistently perched 2 to 3 feet higher than the concurrent water surface elevation in the main channel. Throughout winter, water level fluctuated from approximately 1 foot below the ground surface to approximately 1 foot above the ground surface with a repeated wetting and drying of the floodplain swale. During flood flows, such as the March 9th or November 25th events, water level at SPC-5 is nearly equivalent to the water surface in the channel, although there is an area of high ground along the right bank that limits floodplain connectivity through this segment (Figure 15). During the summer low flow period, ground water remains close to the ground surface and maintains a positive hydraulic gradient towards the main channel.

Water temperature in the shallow groundwater at SPC-5 is highly moderated relative to observations from main channel locations (Figure 10). Winter minimum temperature was 43° F in February. Temperature slowly increased through the spring, reached a maximum of 54° F in late August and maintained a nearly constant temperature through early November when temperature dropped to the winter average near 46° F.

SPC-6

Site 6 is a shallow groundwater monitoring well in the floodplain swale 310 feet northwest of SPC-3 near RM 4.5 (Figure 1). The well was augered in the center of the swale to a depth of only 3.3 feet below the ground surface due to refusal by a coarse cobble layer that underlies most of the terrace surface. Water level dropped below the base of the well for >150 days in 2014. The maximum water depth occurred in March when water rose to a depth of 3.5 feet (Figure 11). The peak water level corresponds to a surface water elevation that is 0.3 feet above the ground surface resulting in shallow inundation of the floodplain swale (Figure 16). Water level in SPC-6 has a slightly flashier regime compared to SPC-5; however, the shallow groundwater perched beneath the floodplain surface appears to maintain a consistent hydraulic gradient toward the main channel (Figure 19)

Water temperature in the shallow groundwater at SPC-6 was moderated relative to the fluctuations in surface water at the main channel locations (Figure 11). The temperature profile is very similar to observations from SPC-5 with a slightly higher maximum temperature of 56° F in late August.

SPC-7

Site 7 is a surface water monitoring site in the spring-fed, wall-base channel 1,110 feet northwest of South Prairie Creek along cross-section B-B' in a transect with SPC-2 and SPC-5 (Figure 1). The wall-base channel intercepts spring-flow emerging from the northern hillslope and connects with the recently constructed South Silver Springs project site draining into South Prairie Creek downstream near RM 3.8. Active flow in the channel was observed during field reconnaissance in both winter and summer seasons.

Water level at SPC-7 remained nearly constant over 2014 gradually varying within a narrow range of depths between 0.8 and 1.2 feet (Figure 12). The wall-base channel at SPC-7 is 1.5 feet above the streambed in the main channel and about 3 feet below the floodplain swale along cross-section B-B' (Figure 15). The wall-base channel is flanked by a low berm and appears to have been artificially excavated in attempt to increase drainage of the adjacent pasture areas when the project site was managed as a dairy farm. During winter, water level at SPC-7 is generally 1 to 2 feet below the concurrent water surface elevations in the floodplain swale at SPC-5 (Figure 18). During summer, flow in the wall base channel is perched 0.5 to 1 foot above the shallow groundwater at SPC-5.

Water temperature at SPC-7 is a constant 49 to 50° F. The lack of seasonal variation in both water level and temperature indicate the source of water in the wall-base channel as spring-fed origin from the aquifer in the adjacent hillslope.

SPC-8

Site 8 is a surface water monitoring site in the wall-base channel 800 feet northwest of South Prairie Creek along cross-section C-C' in a transect with SPC-3 and SPC-6. The stilling well is embedded within a layer of saturated organic material (muck) that has filled the bed of the channel. The channel is flanked by a large berm on the left bank appears to have been excavated to intercept the groundwater seepage from the adjacent hillslope. Water depth did not vary over the duration of monitoring and maintained a constant depth of 1 foot in the stilling well (Figure 13). This depth corresponds to the top of the muck layer that fills the bed of the channel.

The wall-base channel at SPC-8 has an invert elevation of 382.5 feet indicating a downstream gradient of 0.009 ft/ft (0.9%) between SPC-7 and 8. The wall-base channel is 1.9 feet below the floodplain swale in cross-section C-C' (Figure 16). Plots of concurrent water surface elevations show that the water table at SPC-8 is consistently perched above the fluctuating water table in the floodplain swale at SPC-6 (Figure 19).

Water temperature at SPC-8 is more varied than that observed downstream at site 7 with a range of temperatures between 42 and 56° F. The range and seasonal pattern of water temperatures at SPC-8 and SPC-6 are nearly identical indicating the strong connection of the groundwater in the northeastern part of the project area with shallow groundwater in the floodplain areas between the valley wall and South Prairie Creek.

SUMMARY AND KEY FINDINGS

South Prairie Creek drains a watershed area encompassing 83 square miles upstream of the project area at the Pierce Conservation District property (former Inglin Dairy Farm). An array of 8 water level and

temperature dataloggers were deployed at the site (Figure 1) and collected data at 15-minute intervals between December 2013 and January 2015. Key findings from hydrologic monitoring include:

- Mean annual flow for calendar year 2014 was 302 cfs at USGS gaging station #12095000 (South Prairie Creek at South Prairie, WA).
- Annual maximum peak flow occurred November 25, 2014 and was measured as 3,330 cfs (between 2- and 5-year recurrence interval flood).
- Minimum flows receded to 31 cfs in mid-September.
- Surface water flows in the main channel are flashy and fluctuate over a range of flow depths between 0.5 and 8 feet.
- Flows at each of the main channel sites remained confined by high banks that limit connectivity with the floodplain terrace to the north (i.e., flow did not overtop the right bank in 2014).
- Groundwater inflow from the north valley wall delivered a near-constant flow that drains into the shallow groundwater beneath the terrace surface including the floodplain swale to the north of the channel.
- The water table beneath the terrace surface remained perched approximately 1.5 to 2.5 feet above the water surface elevation in the adjacent channel year round.
- Shallow groundwater elevations in the floodplain swale near the downstream end of the property (SPC-5) was maintained within 1 foot of the ground surface elevation throughout most of the winter and dropped to just over 2 feet below the ground surface elevation in late summer.
- Shallow groundwater elevations in the floodplain swale near the upstream end of the property (SPC-6) fluctuated between 2 to 3 feet below the ground surface elevation during most of the winter and dropped below the bottom of the monitoring well for most of summer (well depth was limited by coarse cobble substrate at depth of 3.3 feet below ground surface).
- Extension of the recession curve at site SPC-6 suggests that shallow groundwater remains perched approximately 2.5 feet above surface water elevations in the adjacent channel and that minimum groundwater elevations in summer are approximately 4 to 4.5 feet below the ground surface elevation.
- 7-day average of the daily maximum temperatures (7-DADMax) ranged between 38 and 69° F (3.3 and 20.5° C) at main channel sites SPC-1, -2, and -3.
- Temperature of shallow groundwater was moderated with a range between 43 and 54° F (6.1 and 12.2° C).
- Water temperatures were slightly moderated at main channel site SPC-4 suggesting a localized influence of groundwater draining into the channel from the floodplain wetland adjacent to the horse track near SPC-4; however, mixing with mainstem flows overwhelm the localized groundwater influence downstream of SPC-4.

Results from the 2014 hydrologic monitoring verify that proposed restoration actions for South Prairie Creek and the adjacent floodplain terrace can anticipate the continued supply of groundwater from the north and shallow groundwater elevations in the floodplain swale that fluctuate just below the ground surface elevation.

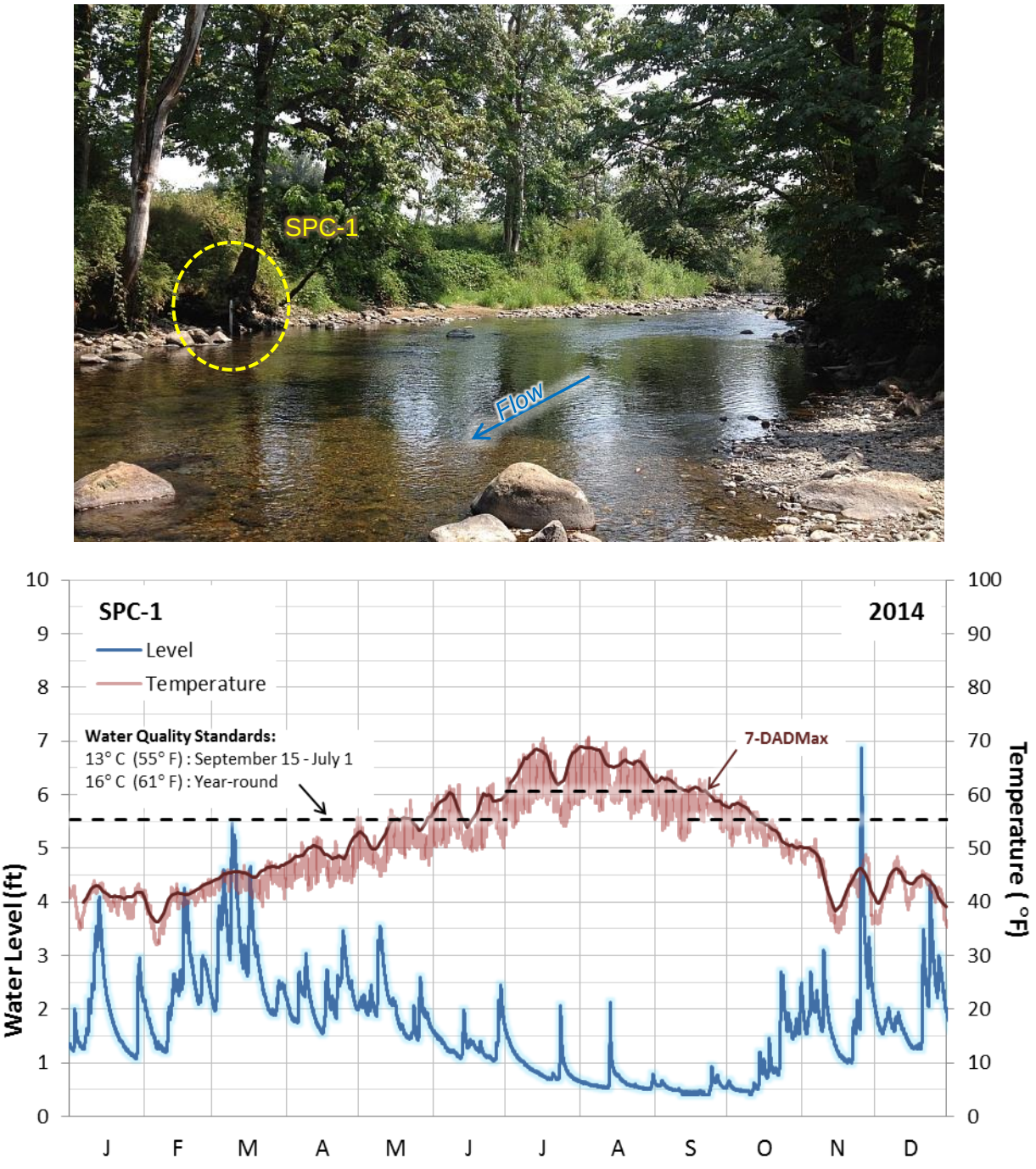


Figure 6. Annual time series (2014) of water level and temperature at SPC-1 on the right bank 400 feet downstream of the bridge.

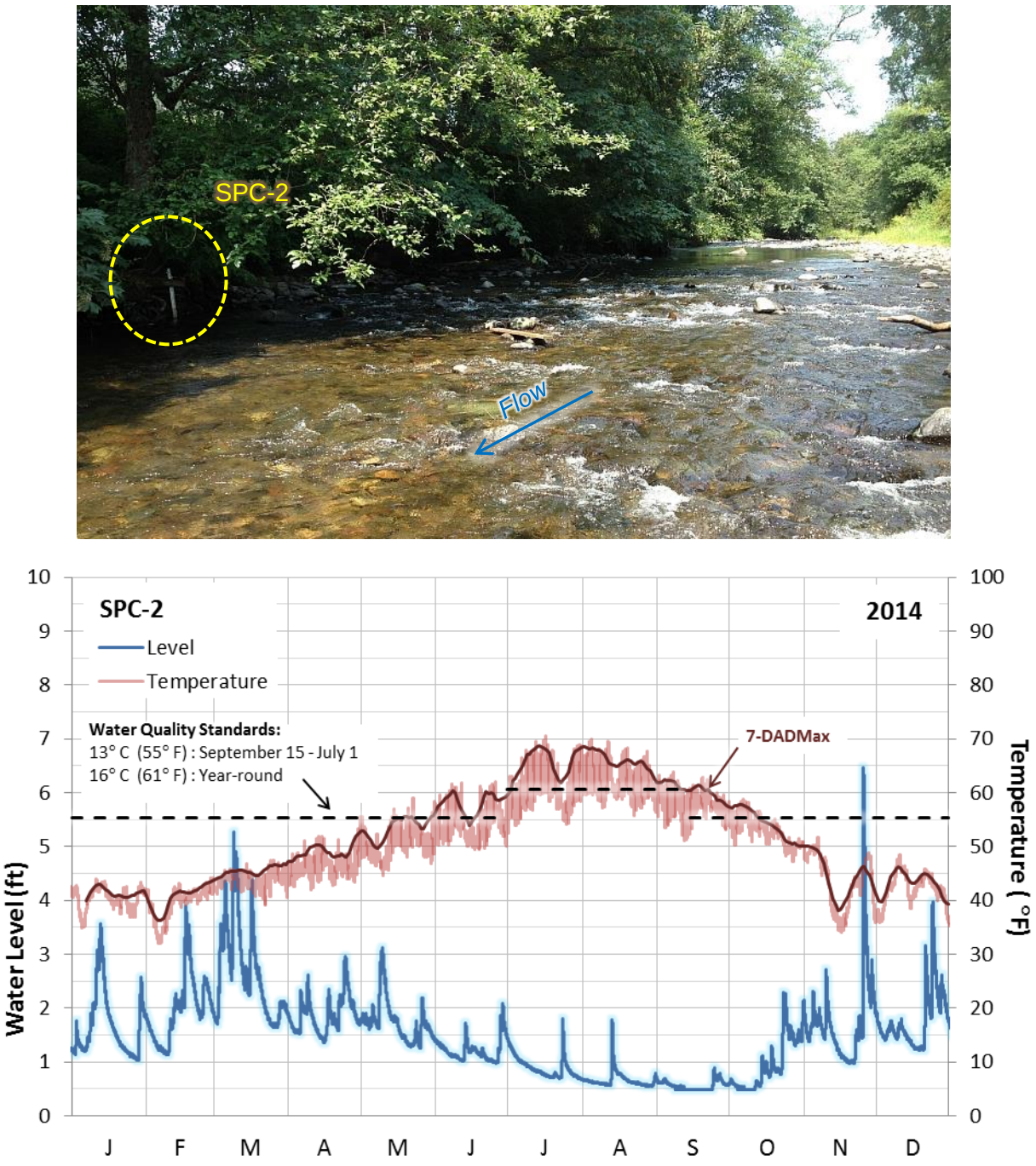


Figure 7. Annual time series (2014) of water level and temperature at SPC-2 on the right bank 600 feet upstream of the bridge.

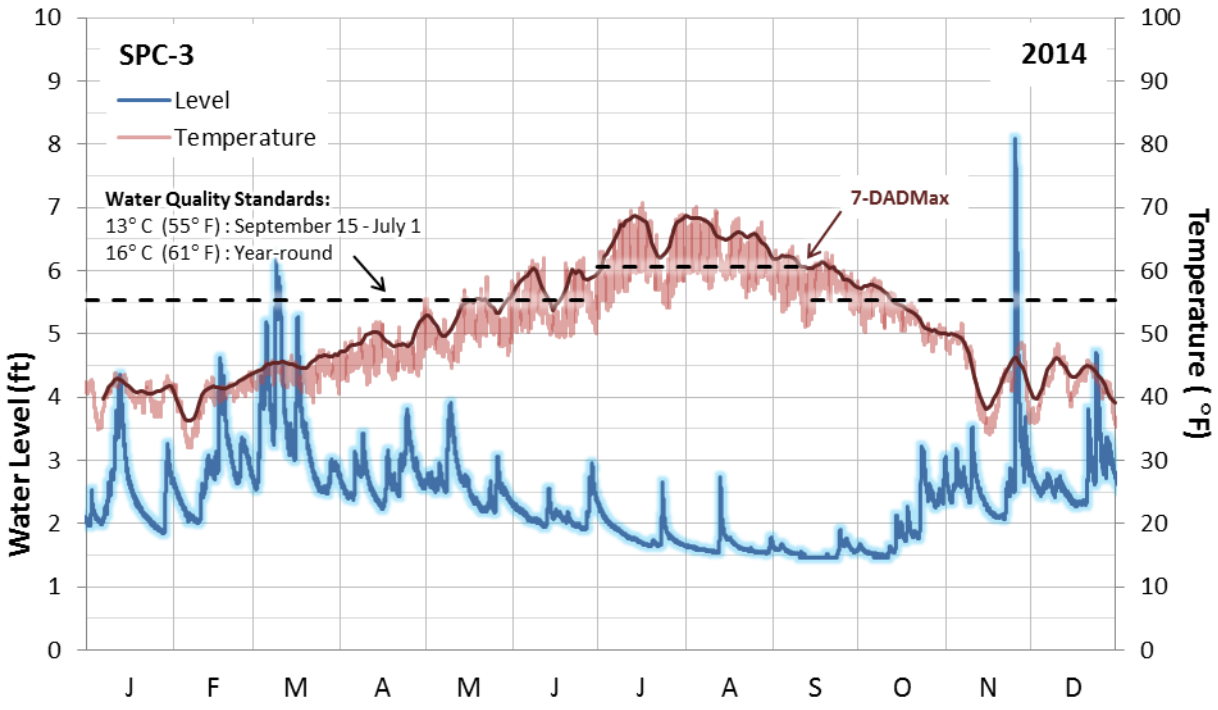
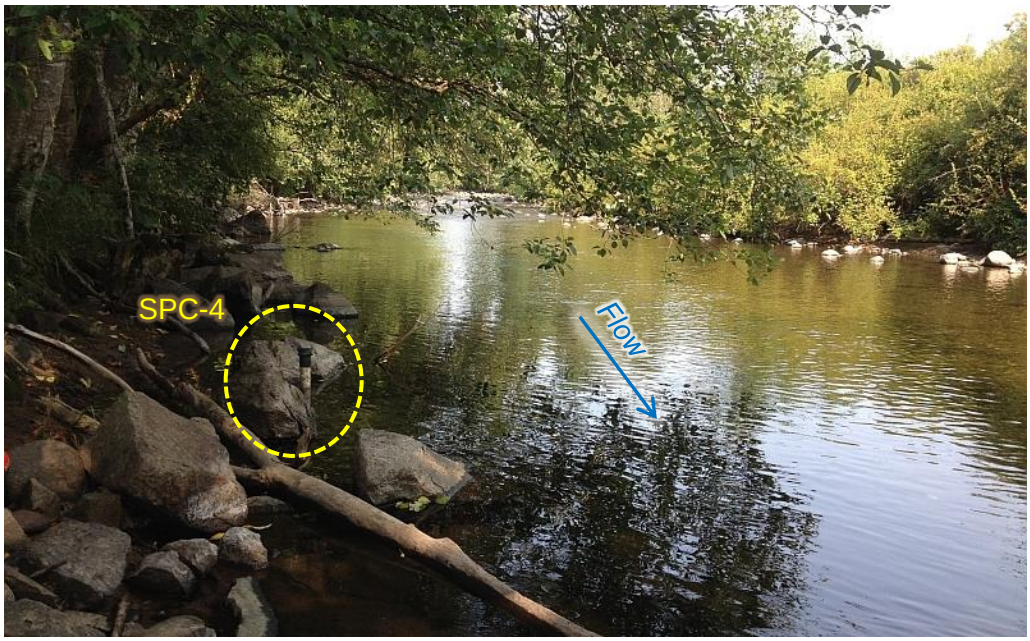


Figure 8. Annual time series (2014) of water level and temperature at SPC-3 on the left bank 1,200 feet upstream of the bridge.



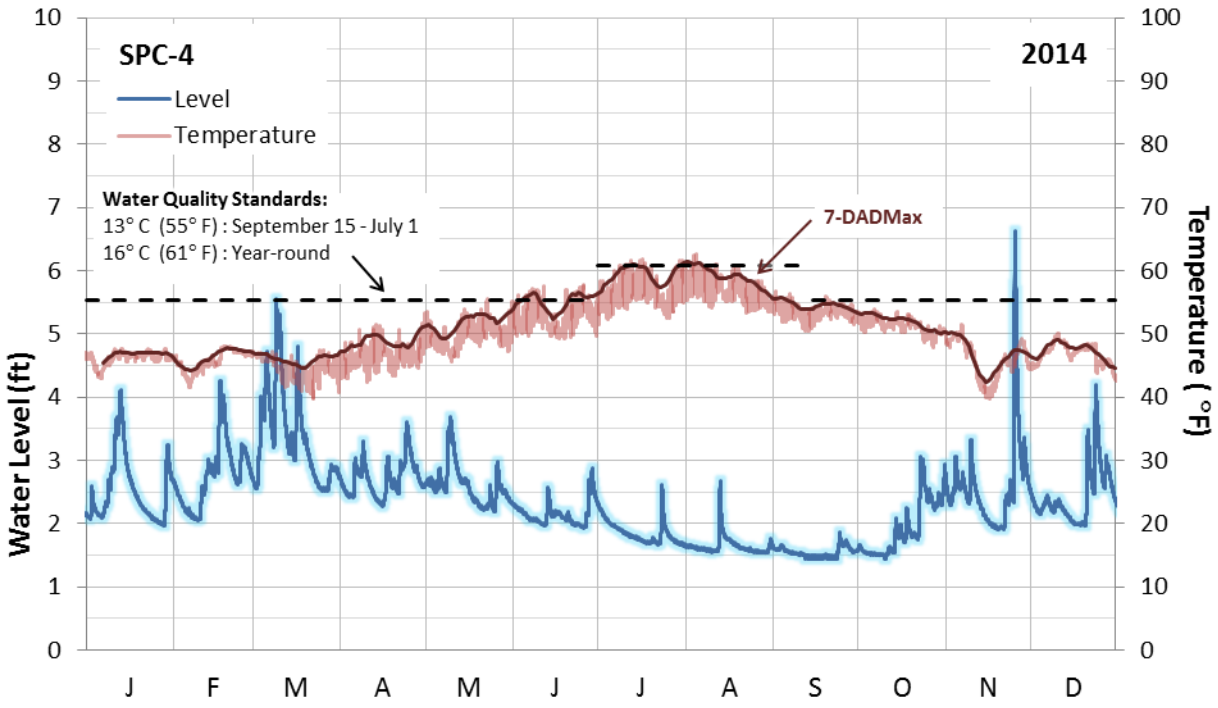


Figure 9. Annual time series (2014) of water level and temperature at SPC-4 on the right bank approximately 2,300 feet upstream of the bridge.

Figure 10. Annual time series (2014) of water level and temperature at SPC-5, a groundwater monitoring well in the floodplain swale 280 feet northwest of SPC-2.

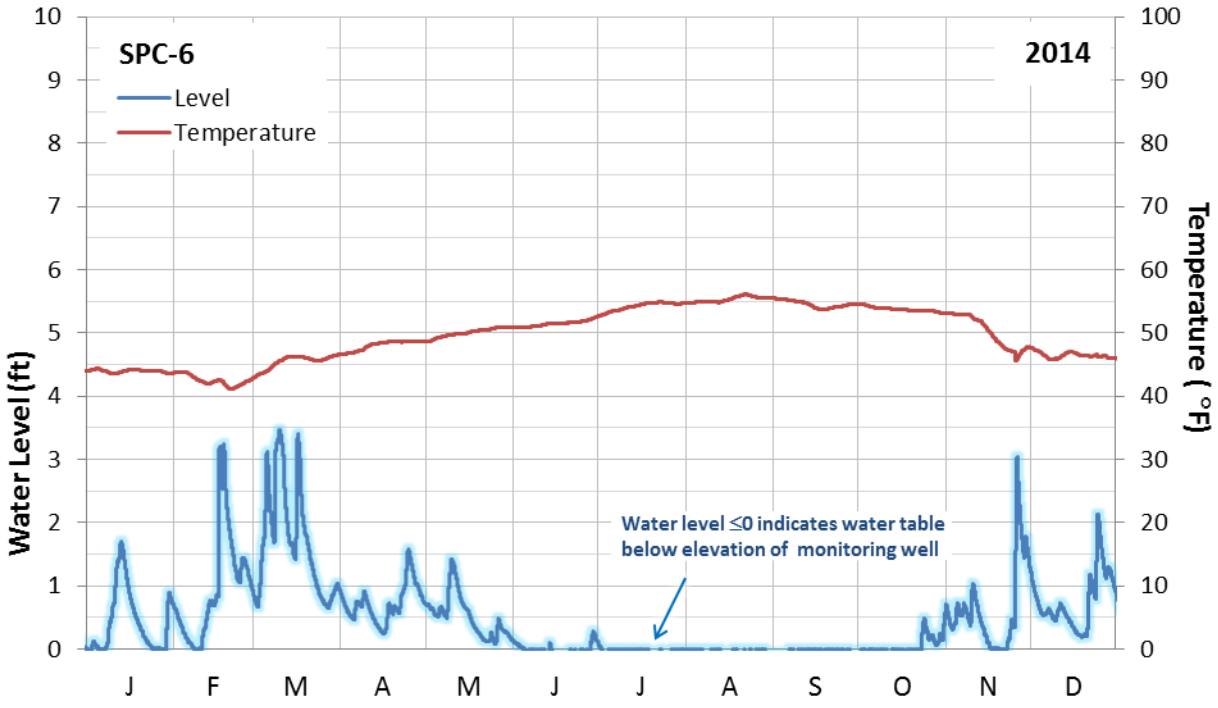


Figure 11. Annual time series (2014) of water level and temperature at SPC-6, a groundwater monitoring well in the floodplain swale 310 feet northwest of SPC-3.

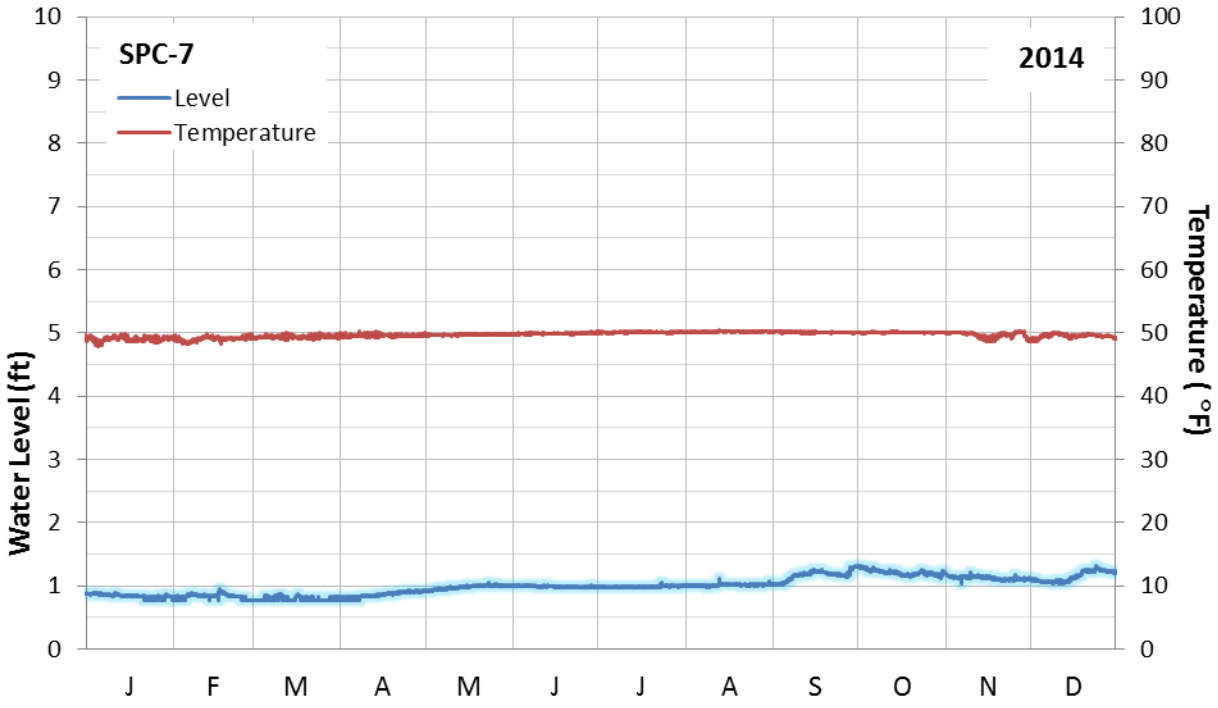


Figure 12. Annual time series (2014) of water level and temperature at SPC-7 in the spring-fed, wall-base channel 1,110 feet northwest of South Prairie Creek in a transect with SPC-2 and SPC-5.

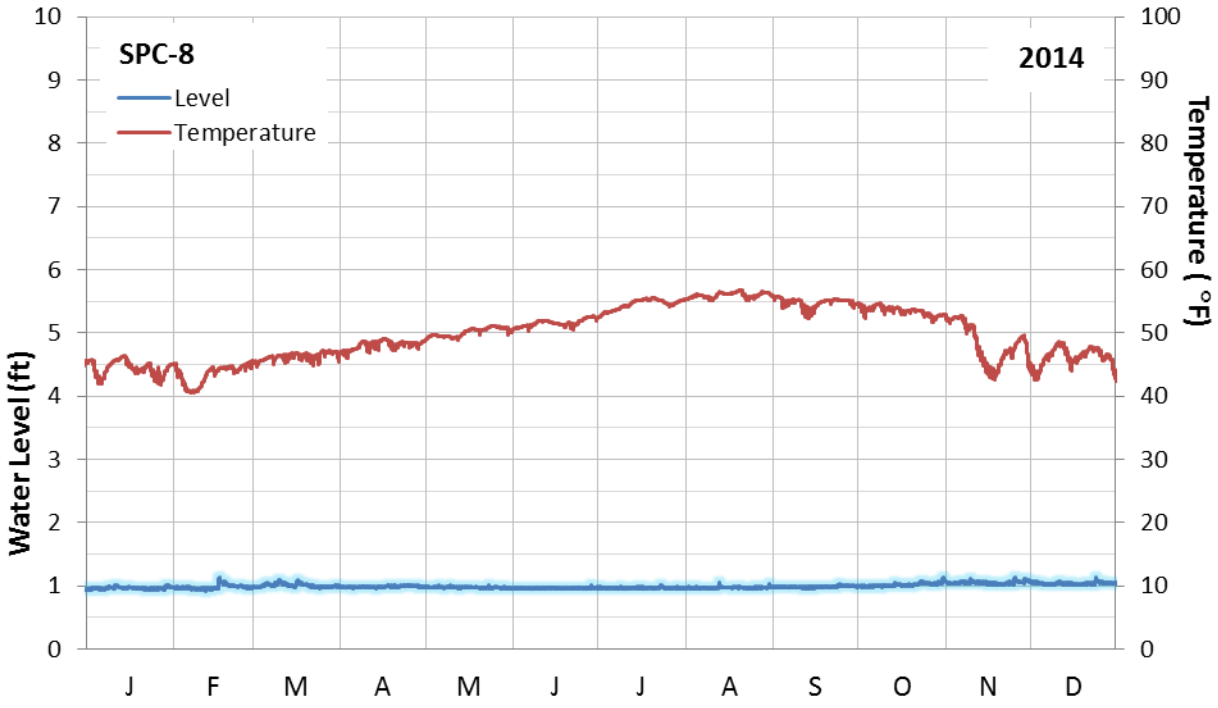


Figure 13. Annual time series (2014) of water level and temperature at SPC-8 in the wall-base channel 800 feet northwest of South Prairie Creek in a transect with SPC-3 and SPC-6.

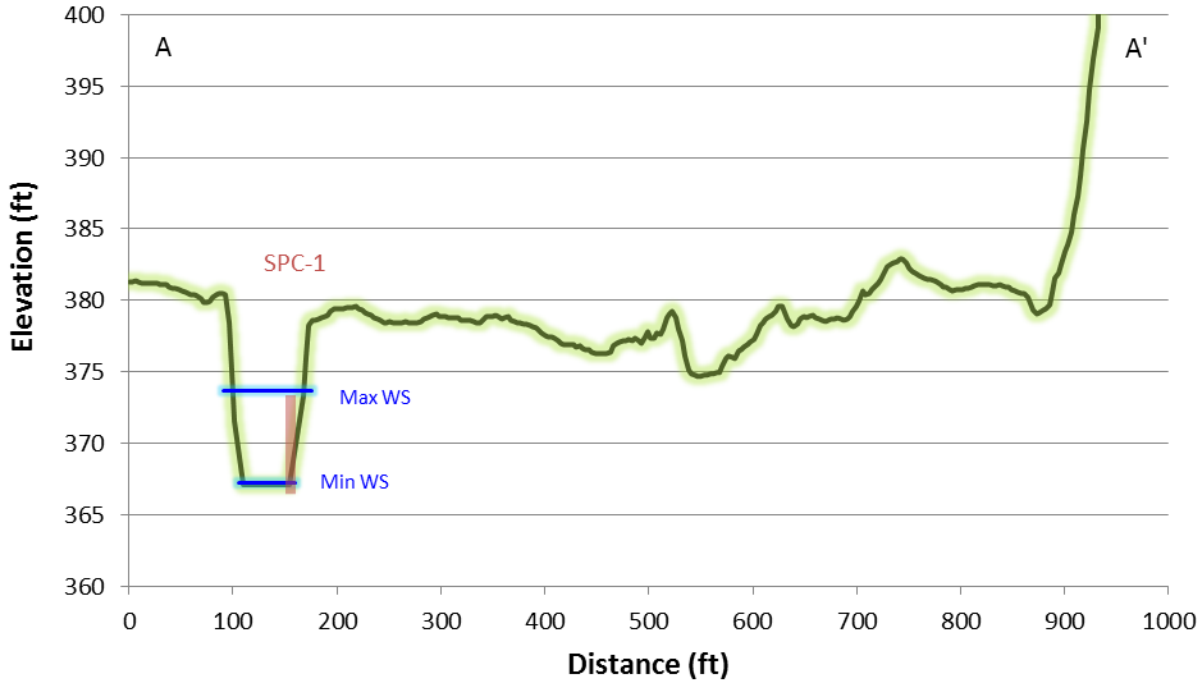


Figure 14. Cross-section A-A' with the range of observed water surface elevations from site SPC-1 in 2014.

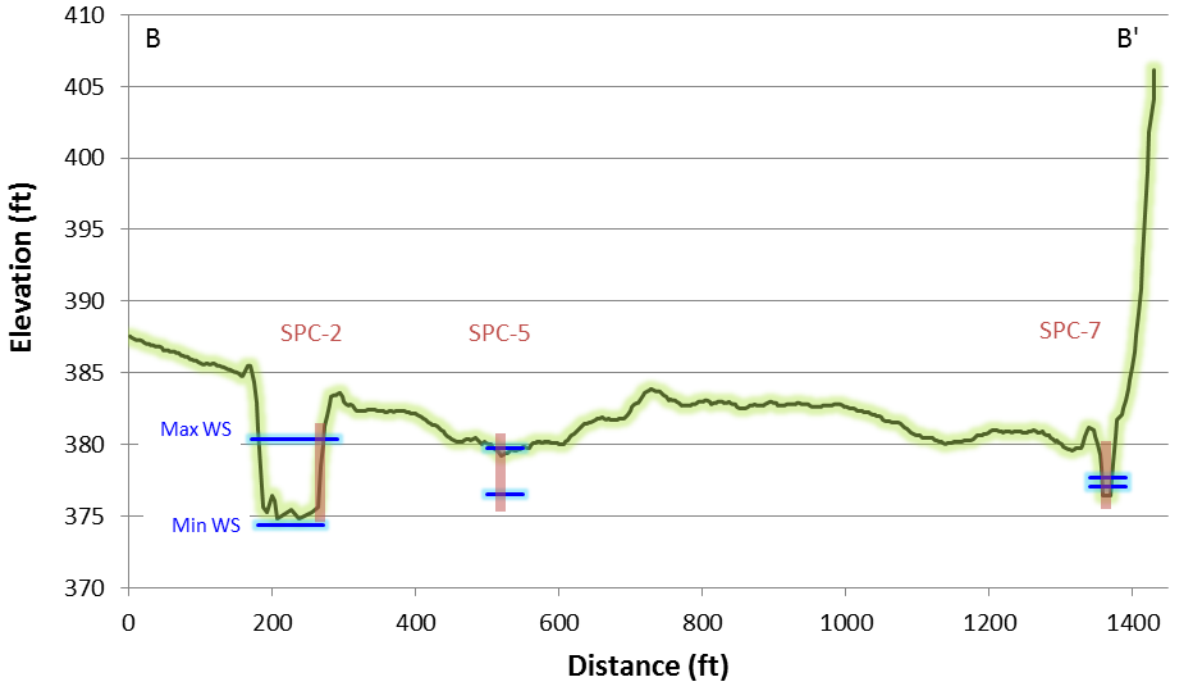


Figure 15. Cross-section B-B' with the range of observed water surface elevations from sites SPC-2, 5, and 7 in 2014.

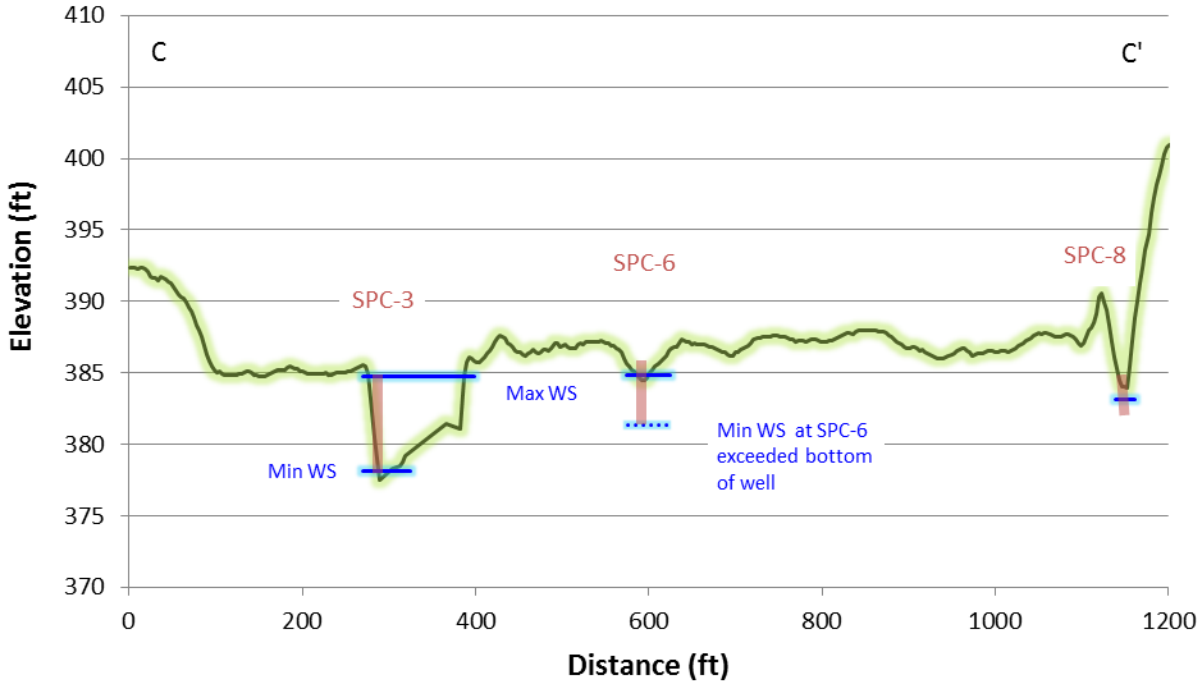


Figure 16. Cross-section C-C' with the range of observed water surface elevations from sites SPC-3, 6, and 8 in 2014.

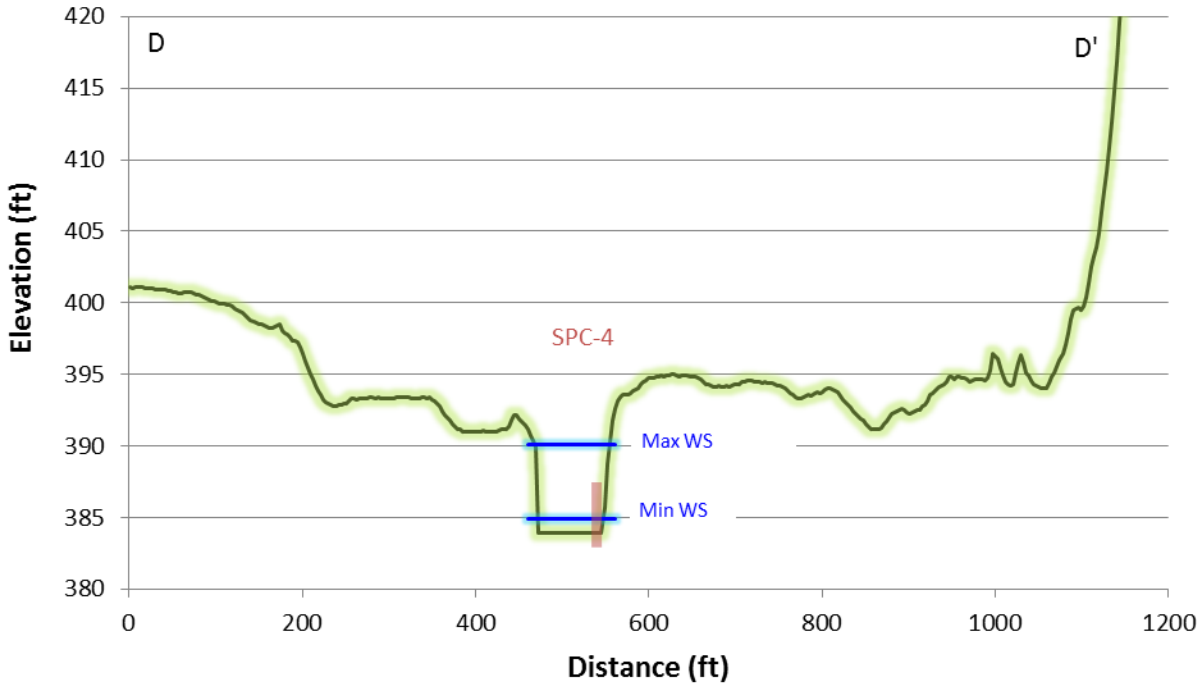


Figure 17. Cross-section D-D' with the range of observed water surface elevations from site SPC-4 in 2014.

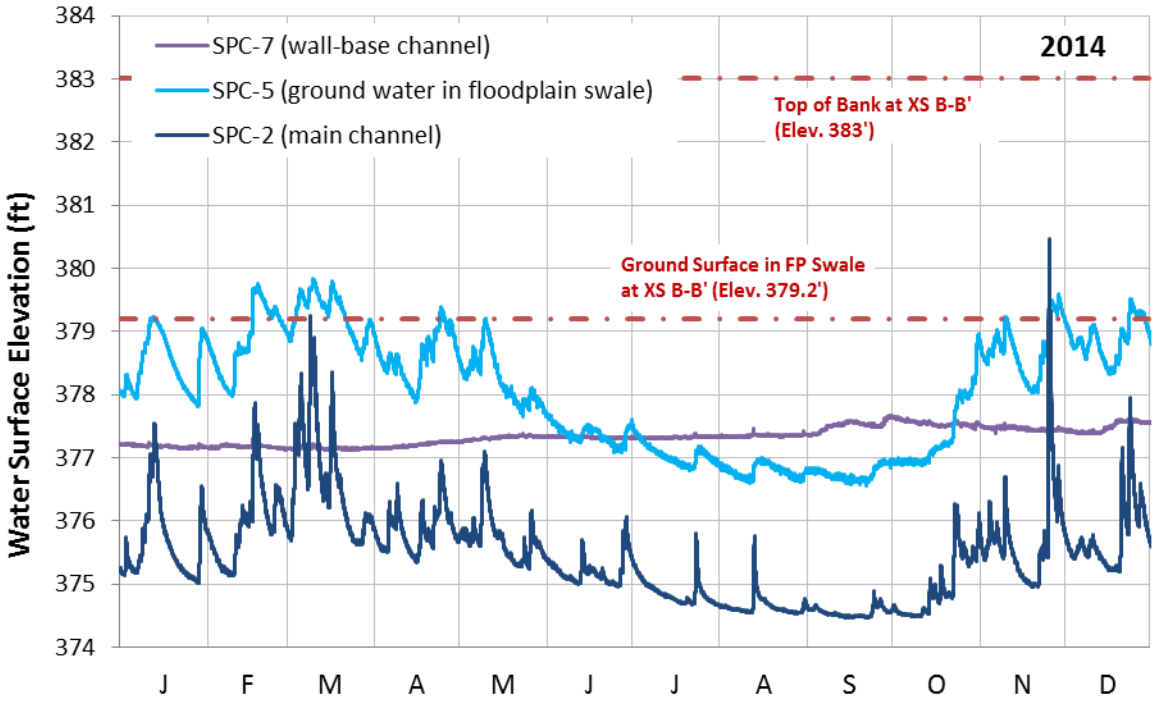


Figure 18. Comparison of water surface elevations for Sites SPC-2, 5, and 7 (cross-section B-B')

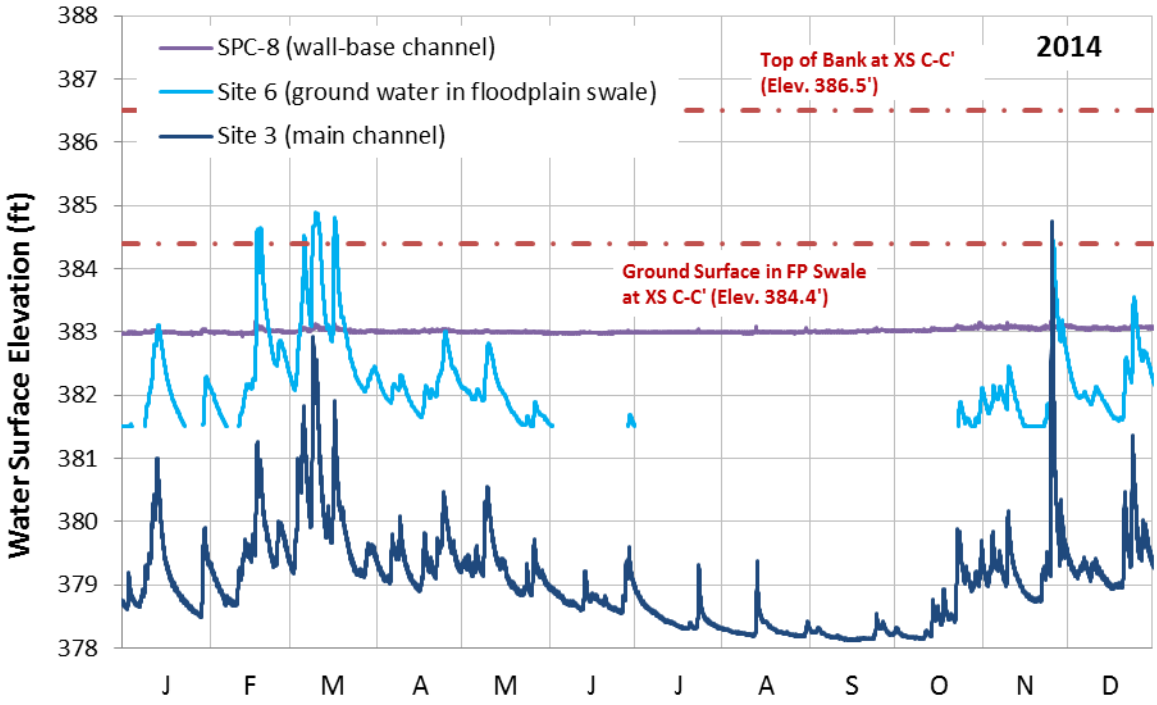


Figure 19. Comparison of water surface elevations for Sites SPC-3, and 6 (cross-section C-C')