INTEGRATED REPORT ON HIGH FLOW PULSES

TRUNGALE ENGINEERING & SCIENCE

TEXAS CONSERVATION SCIENCE

IN PARTNERSHIP WITH

EAST TEXAS BAPTIST UNIVERSITY

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Caddo Watershed Environmental Flows Project

In 2004, the Caddo Lake Institute (CLI) initiated the environmental flows project ("Project") to restore and protect healthy flows in the Caddo Lake watershed and larger Cypress Basin as part of the Sustainable River Project (SRP) (a cooperative program between the U.S. Army Corps of Engineers (USACE) and the Nature Conservancy (TNC)). This Project has developed a set of flow regime recommendations that can be used as guidance to the USACE and the North East Texas Municipal Water District (NETMWD) as they make decisions as to how water will be managed and released from Lake O' the Pines (LOTP) reservoir to restore and maintain the ecological health of Big Cypress Creek and Caddo Lake while also meeting the water needs of people. These recommended flows include low and base flows (discussed in other reports) and high flow pulse and other high flows intended to inundate parts of the watershed and connect it with the river.

At the first flows workshop in 2005, the high flow pulse recommendations were developed based on a review of historical hydrology, including a calculation of the 1.5-year recurrence interval flow, which is equal to about 6,000 cfs base on pre-dam flow records (Winemiller et al 2005). This statistic is often used as a surrogate for bankfull flow when empirical data is not available. Subsequent field studies, conducted by the USGS, documented some riparian and wetland connectivity in Big Cypress above Jefferson at flows between 1,500 – 2,500 cfs, resulting in a modification to the initial recommendations at the third flows workshop in 2008. Prior to the forth flows workshop in 2011, research was conducted to analyze Landsat imagery to determine the spatial extent of inundation of swamp and flooded forest types following high flow pulse events (CLI 2012). This data combined with literature studies, which have documented the soil moisture needs of the species that make up different forest habitat types, resulted in additional recommendations that were considered but not adopted at the 2011 workshop. Some outstanding questions at the time included the desire to verify the inundation areas predicted by the imagery analysis (CLI 2013), develop a better understanding of the relative importance of direct overbank inundation versus groundwater infiltration and to document the duration, after flow events, that the soils remain saturated.

The Project has also developed a holistic monitoring plan (CLI 2014) that includes an approach to monitoring the long-term response to the implementation of the flow regime. This monitoring is being accomplished by establishing approximately 20 forest plots (5 per habitat type) at each of the three study sites on Big Cypress upstream of Jefferson. At each of the three sites two groundwater monitoring wells, one slough elevation monitor and four soil moisture probes has also been installed.

A number of partners have contributed to these studies and data collection and analysis. The aim of this report is to compile and synthesize these collections and analyses into a single report drawing on intermediate technical reports produced by all of the research partners. This report focus specifically on short-term adaptive management findings which are directly related to flows. These include:

1. Report of plot elevations, estimate of flows required to reach those elevations and calculation of frequencies based on historical data.
2. Response of groundwater wells and soil moisture sensors to high flow events.

A much more thorough report documenting the approach to analyze the long-term response of the riparian forest community is contained in a report prepared by the Texas Conservation(TCE) Science entitled "Big Cypress Bayou Monitoring Network Forest Plot Results: 2012-2016".

1 Forest Monitoring Plot Elevations and Relationship to Flows

Three sites along Big Cypress Bayou between Jefferson and Lake O' the Pines were selected to conduct vegetation plot surveys: Thomas (BC03 -upstream site, just below the Lake O' the Pines dam), Locke (BC02 -middle site), and Sanders (BC01 - lowermost site) (Figure 1).

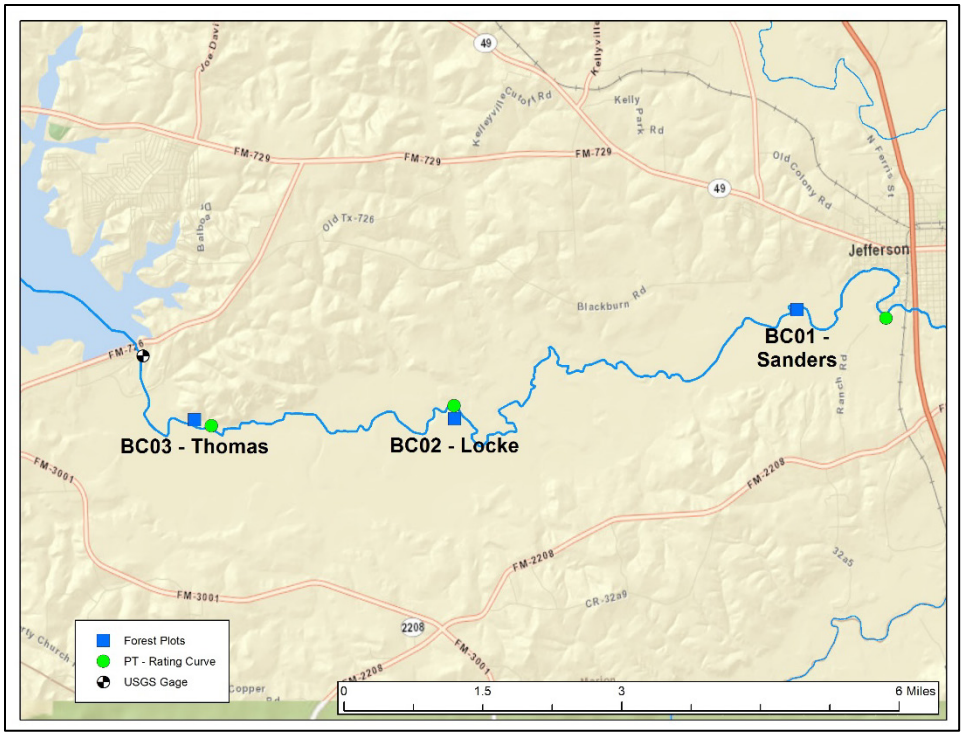

Figure 1 Study areas Located along Big Cypress Bayou between Lake O' the Pines and Jefferson, Texas.

At each study site, four plant communities were identified and delineated:

Table 1 Forest types and dominant species.

Type	Dominate Species	Relative Elevation
Lower Swamp	Bald Cypress	Lowest
Upper Swamp	Overcup Oak	Mid-Low
Seasonaly Flooded Forest	Willow Oak	Mid-High
Temporarily Flooded Forest	Water Oak	Highest

Throughout this report, these plant communities are referenced by their type name and dominant species interchangeably.

Figures 2-4 show the locations of each of the forest plots (5 per type), soil moisture probes and groundwater wells. The green and hatched areas show the areas of inundation based on previous analysis of releases of 3,000 from Lake O' the Pines. The swamp habitat plots at the most upstream site (BC03) are located within a backwater swamp and the flooded forest types along a ridge between this backwater and the main river channel. This level of resolution was not detectable in the earlier Landsat analysis; however; the other two sites do appear to agree with expectations, specifically that the swamp types are well within the foot print of the overbank inundation at 3,000 cfs while the high flooded forest types are located at the edge of just outside that footprint.

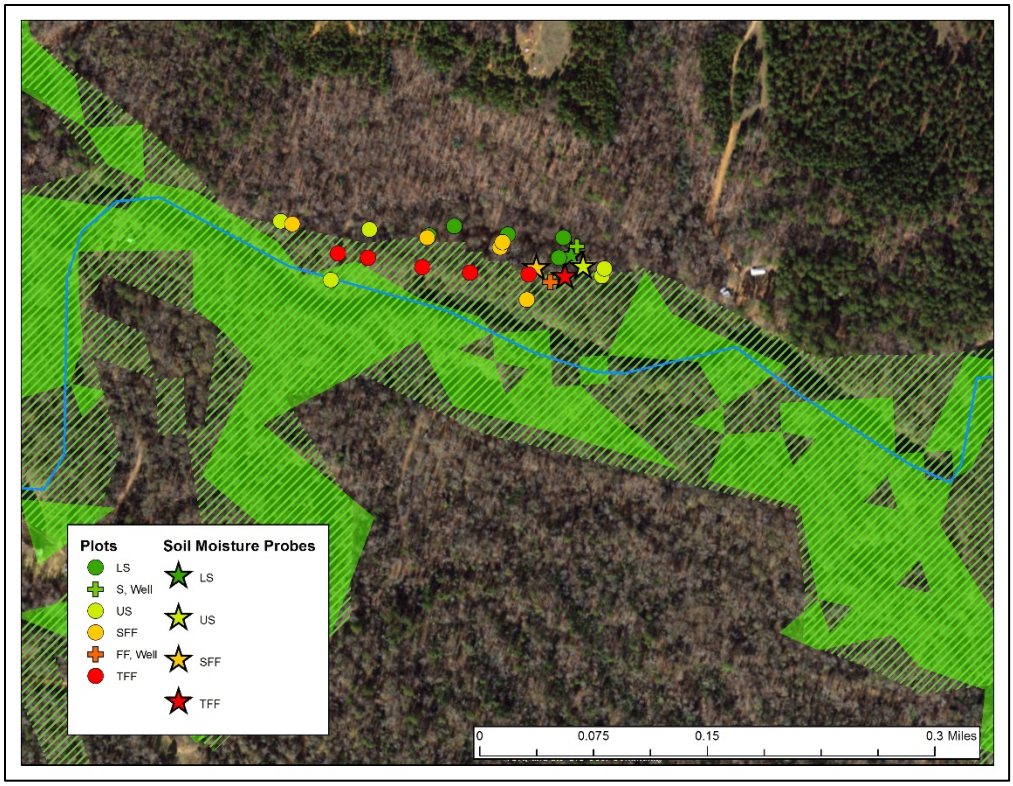

Figure 2 Forest plot, soil moisture probe and groundwater monitoring wells at site BC03 (Thomas).

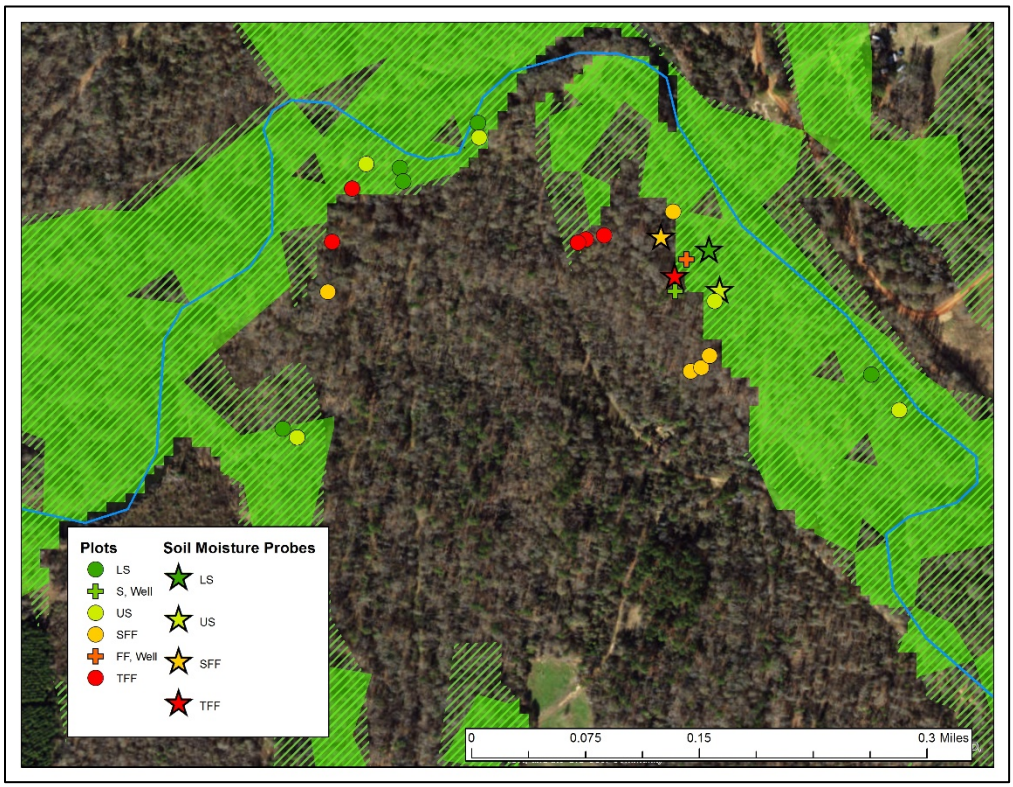

Figure 3 Forest plot, soil moisture probe and groundwater monitoring wells at site BC02 (Locke).

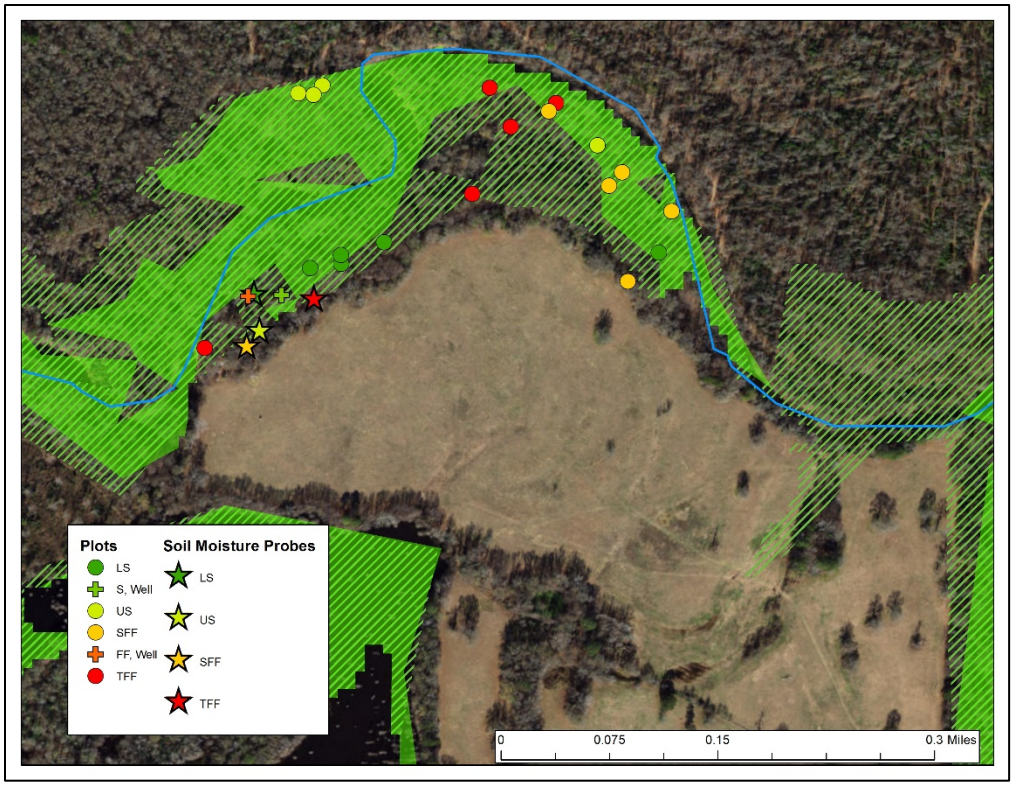

Figure 4 Forest plot, soil moisture probe and groundwater monitoring wells at site BC01 (Sanders).

Elevations were collected at the ends of the 50 meter transect centerlines through each of these plots. Rating curves derived from pressure transducers that had been deployed in the river during 2007 (green dots in Figure 1) were used to estimate of the flow magnitude necessary to reach these elevations. As shown in Figures 2 - 5, the forest plots do not lie in a straight transect perpendicular to the river channel: however, figures 5 - 7 show the relative elevations of the various forest types and bracket the range of flows need to reach those elevations.

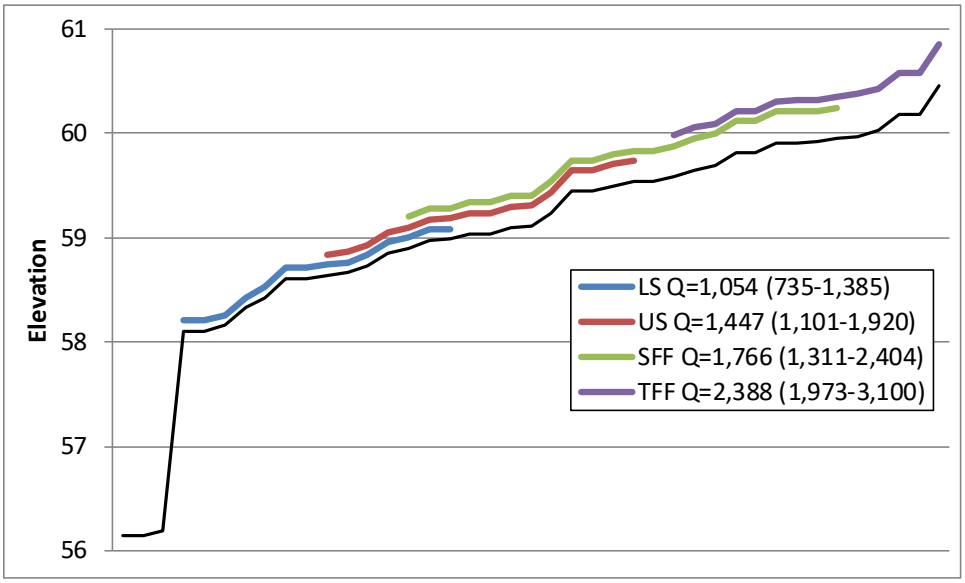

Figure 5 Elevations of forest types and associate flows need to inundate (Average (min-max)) at site BC03 (Thomas).

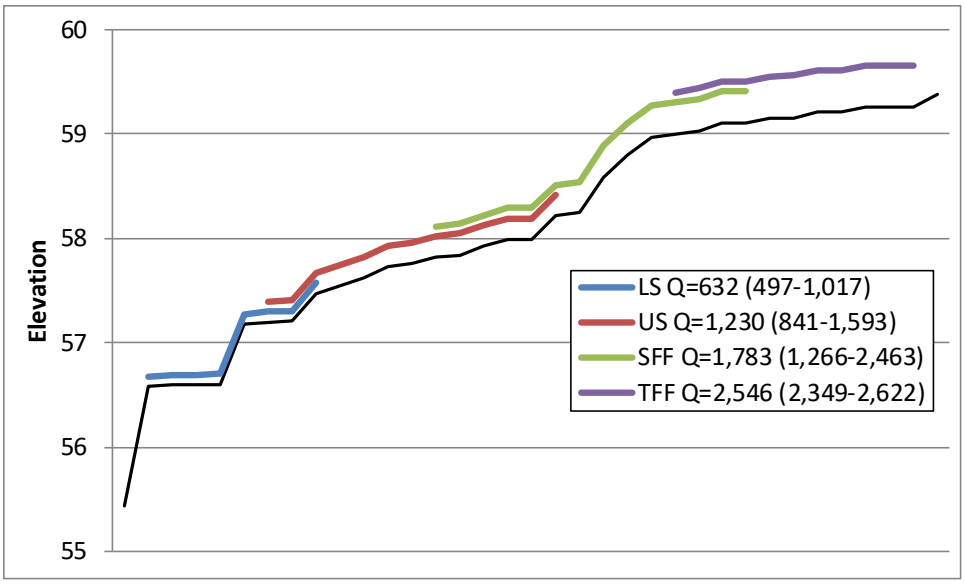

Figure 6 Elevations of forest types and associate flows need to inundate (Average (min-max) at site BC02 (Locke).

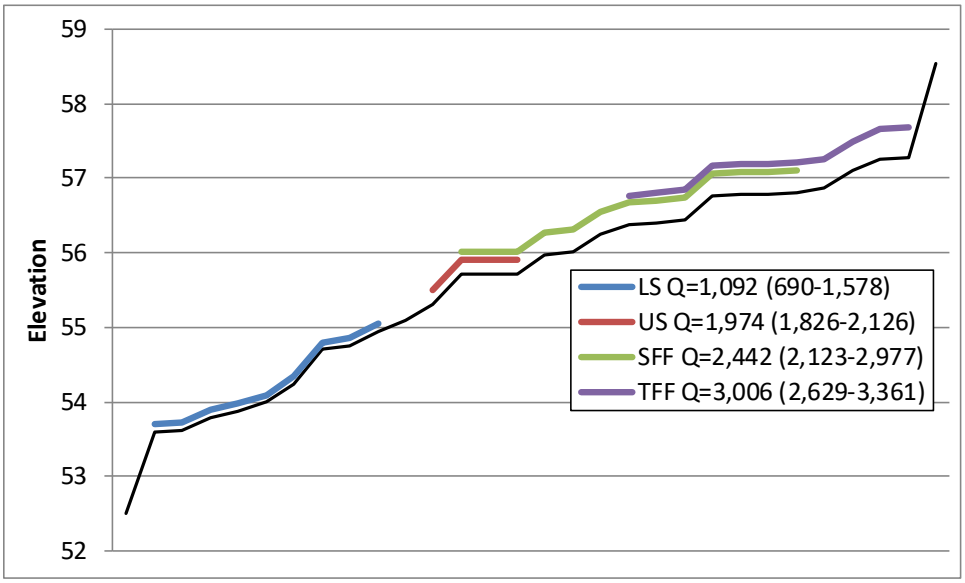

Figure 7 Elevations of forest types and associate flows need to inundate (Average (min-max) at site BC01 (Sanders).

It is important to note that these elevation estimates are incomplete, elevations at some of the plots have not been determined yet and there may be ways to improve or better validate the rating curves at some sites, so the range of flows for some of these forest types may be revised. However, based on the estimates as of December 2016, a frequency analysis of the flow levels corresponding to the mean elevations of each forest type at each site was conducted to determine how often and for how long each of these types would have been inundated in the pre and post dam periods. A subset of this analysis is provide in Table 2.

In general, this preliminary analysis suggests that flows in the range of 1,000 cfs provide water to the lower swamp forest types and flows greater than 2,500 are need to inundate the upper (temporarily) flooded forest type, though some of the upper forest plots are not inundated below 3,000 cfs. From 2008-2014 there was very little if any inundation of the upper forest types (Figure 8).

Table 2 Flow frequency analysis showing the average number of events and their average durations for each forest type at each site and within each season, for the pre and post Lake O' the Pines periods of record.

	Forest Type	LS	US	SFF	TFF	LS	US	SFF	TFF	LS	US	SFF	TFF
	Site	BC3B	BC3O	BC3WI	BC3WA	BC2B	BC2O	BC2WI	BC2WA	BC1B	BC1O	BC1WI	BC1WA
	WSE	58.58	59.06	59.39	59.93	56.84	57.77	58.43	59.19	54.24	55.50	56.13	56.85
	Q	1,054	1,447	1,766	2,388	632	1,230	1,783	2,546	1,092	1,974	2,442	3,006

Period	1925-1959	Thomas				Locke				Sanders			
No. Years	35	BC3B	BC3O	BC3WI	BC3WA	BC2B	BC2O	BC2WI	BC2WA	BC1B	BC1O	BC1WI	BC1WA
Year	Average # Events/yr	4.5	3.7	3.2	2.3	5.0	4.2	3.2	2.3	4.3	2.7	2.3	2.4
	Average Duration	15.5	12.7	10.6	9.7	21.5	13.7	10.6	9.2	15.5	10.8	9.6	6.8
Spring	Average # Events/yr	2.3	2.1	1.7	1.1	2.5	2.2	1.7	1.0	2.2	1.2	1.0	0.9
	Average Duration	17.5	13.1	10.8	9.1	29.3	15.1	10.8	8.9	17.4	11.9	9.0	6.8
Summer	Average # Events/yr	0.7	0.4	0.3	0.3	0.9	0.6	0.3	0.3	0.7	0.3	0.3	0.4
	Average Duration	15.8	17.2	17.6	15.7	22.7	15.5	19.2	16.6	16.0	18.1	15.5	9.2
Winter	Average # Events/yr	2.0	1.5	1.4	1.0	2.2	1.8	1.4	1.0	1.9	1.3	0.9	1.0
	Average Duration	18.3	15.1	11.7	9.5	30.1	15.7	11.6	8.4	18.3	11.2	9.4	6.1
Fall	Average # Events/yr	0.4	0.2	0.2	0.2	0.8	0.3	0.2	0.2	0.3	0.2	0.2	0.2
	Average Duration	23.6	15.9	15.0	11.0	28.2	13.9	15.0	10.1	16.3	13.4	11.0	8.2
Growing	Average # Events/yr	2.9	2.6	2.1	1.4	3.4	2.8	2.1	1.3	2.9	1.6	1.4	1.4
	Average Duration	15.9	12.5	10.7	10.0	25.0	13.8	10.8	9.9	15.8	11.4	9.9	7.3

Period	1980-2015	Thomas				Locke				Sanders			
No. Years	36	BC3B	BC3O	BC3WI	BC3WA	BC2B	BC2O	BC2WI	BC2WA	BC1B	BC1O	BC1WI	BC1WA
Year	Average # Events/yr	3.5	3.4	3.1	2.3	0.5	0.4	0.8	0.4	3.5	2.5	2.1	0.5
	Average Duration	20.7	17.5	15.9	16.1	22.2	19.1	16.5	14.8	20.3	17.0	16.7	8.2
Spring	Average # Events/yr	1.5	1.5	1.4	1.0	0.3	0.2	0.3	0.2	1.5	1.2	0.9	0.3
	Average Duration	26.3	23.3	20.7	16.8	32.3	24.1	21.2	16.1	25.0	22.2	17.3	8.9
Summer	Average # Events/yr	0.7	0.8	0.6	0.5	0.2	0.1	0.3	0.1	0.7	0.5	0.4	0.0
	Average Duration	25.6	21.1	15.7	14.8	25.3	22.2	15.6	12.6	24.3	16.1	14.9	9.0
Winter	Average # Events/yr	1.5	1.4	1.2	0.9	0.2	0.3	0.4	0.2	1.4	1.0	0.8	0.2
	Average Duration	26.6	23.9	22.4	21.3	29.7	26.3	23.1	17.6	27.0	22.2	22.1	8.0
Fall	Average # Events/yr	0.6	0.6	0.4	0.2	0.0	0.0	0.1	0.0	0.6	0.3	0.2	0.1
	Average Duration	21.4	16.9	16.5	24.7	21.4	19.5	18.6	23.0	21.4	18.7	28.5	6.7
Growing	Average # Events/yr	2.1	2.2	2.0	1.4	0.4	0.3	0.5	0.3	2.2	1.6	1.3	0.3
	Average Duration	24.9	21.3	19.9	17.1	28.3	22.4	20.2	16.0	23.6	21.2	18.0	8.2

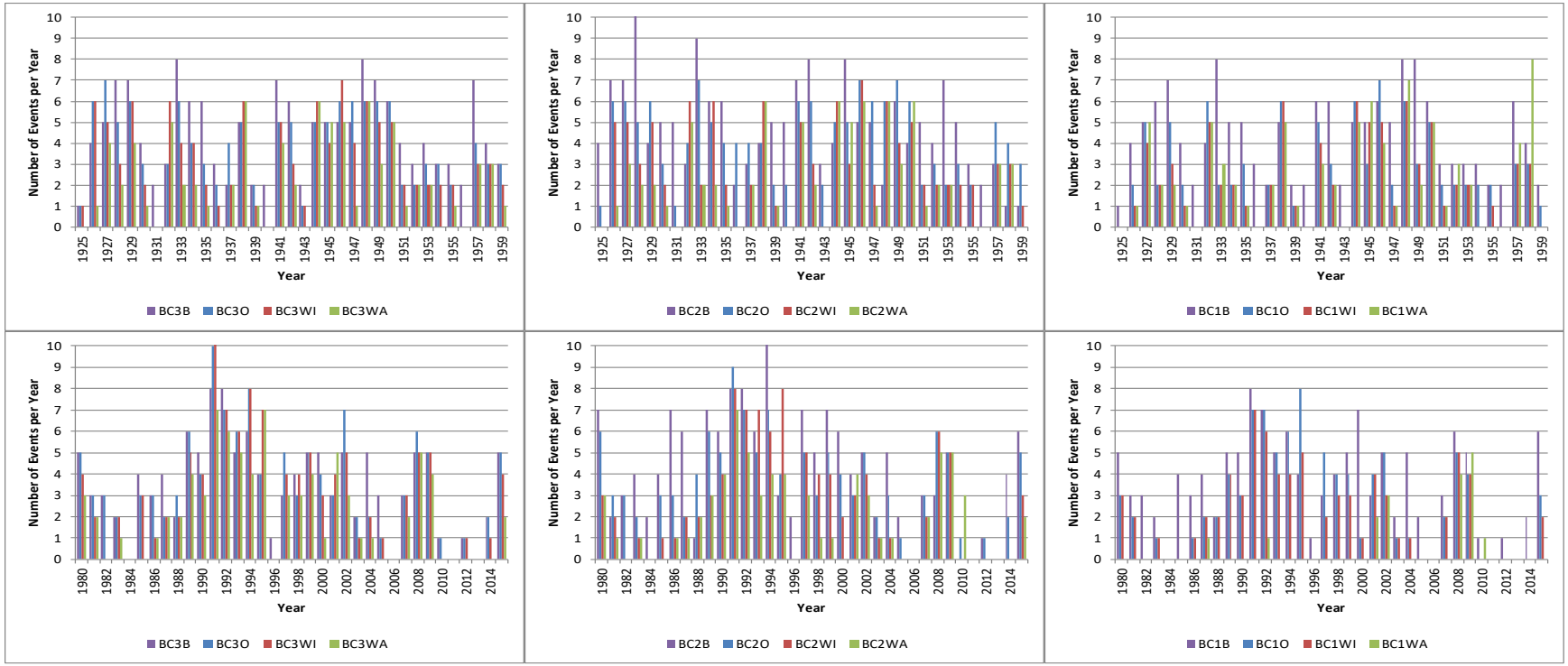

Figure 8 Number of pulse events per year for each forest type at each site and within each season, for the Pre and post Lake O' the Pines periods of record.

2 Groundwater Wells and Soil Moisture Probes

Two groundwater wells, one in the lower swamp type and one in the flooded forest type, and four soil moisture probes, one in each of the forest types were installed at each of the three sites. An additional water level monitor was also installed in sloughs located near the plots.

2.1 Groundwater Wells

Groundwater wells were installed in 2013 and pressure transducer data loggers were activated in 2015 to record the depths in the wells. The wells were surveyed, like the forest plots above, and the depths linked to these elevations to determine the water surface elevation in the wells. Figures 10 -11 show these elevations and the predicted water surface elevation of the river (based on the application of a rating curve described above) on the left axis. The flow level at the site is reported on the right axis.

The groundwater well data shows a very quick response of the increased flow in the river. Preliminary analysis produced results that are consistent with expectations. During high flow events approaching 3,000 cfs (Fall 2015 to Summer 2016) water elevations in Big Cypress Bayou overtop the bank and water in the wells closely tracks the river elevation. At low flows (July -October 2016), the water oak (WA) well goes dry as soon as the river level drops but water remains in the bald cypress (B) well throughout the summer. During an approximately 1,500 cfs release, the bald cypress well begins to fill up at the upstream Thomas site (BC03) but this flow does not recharge the bald cypress well at the downstream Sanders site (BC01). This is consistent with the analysis discussed above which indicated a response to lower flows at the upstream site relative to the downstream site. There appears to be some inconsistency with the slough (Surf) elevation at BC01 (Figure 10), which should closely track the river elevation and the bald cypress well. Further investigation is underway to try to resolve this issue. The data for the mid-stream site (BC02) is still being analyzed.

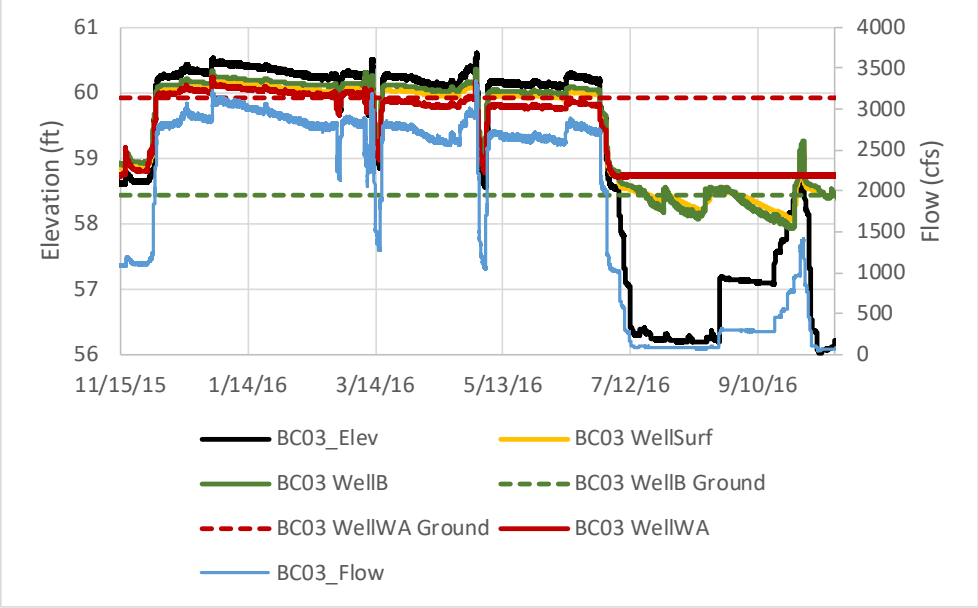

Figure 9 Groundwater well elevations at site BC03 (Thomas).

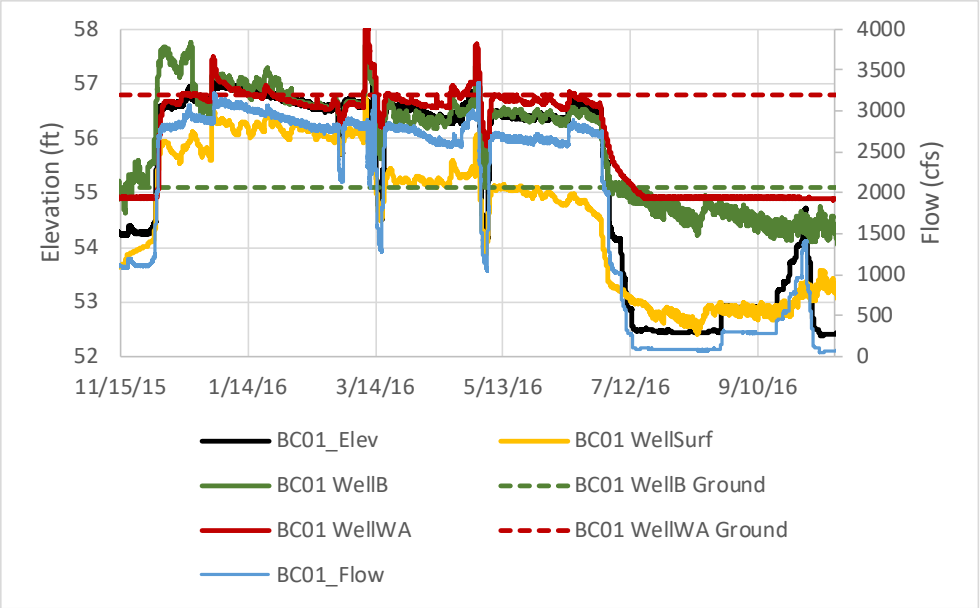

Figure 10 Groundwater well elevations at site BC01 (Sanders).

2.2 Soil Moisture Probes

Soil moisture probes were installed in each forest type at depths of 1 and 2 feet below the ground surface (except for the bald cypress lower swamp which only had one at the 1-foot depth) early in 2013. These monitors report soil moisture in centibars which classify soil moisture content as shown in Table 3.

Table 3 Soil Moisture Ranges.

Centibars	Moisture Content
0 - 10	Saturated.
10 - 30	Moderately Wet
30 -100	Somewhat Wet
> 100	Increasingly Dry

During the study period since 2013 four high flow pulse events have occurred (Table 4).

Table 4 High flow pulse events occurring during study period.

Event	Start	End	Peak Flow
1	1/18/14	1/26/14	1470
2	4/8/14	4/18/14	1790
3	3/21/15	5/4/15	3000
4	9/17/16	10/8/16	1400

The soil moisture response to these events differed from site to site, likely dependent on antecedent conditions and differences in elevations of the different forest types relative to the overbank elevations at each site. A detailed discussion of the these events is provided in a report prepared by researchers at East Texas Baptist University (ETBU) and Stephen F Austin University (SFAU) entitled “Big Cypress Bayou Environmental Flows Project: Effect of Rainfall and High Flow Pulse Release on Soil Moisture”. A summary of the results and brief discussion of these events is provided below. Figures 12 -18 show the soil moisture readings of the 1 and 2 foot probes on the right axis and the corresponding flow on the left axis. Note the right axis is scaled to focus on the observed readings and may vary from figure to figure.

During the first event from January 18, 2014 to January 26, 2014 a short pulse release, peaking at about 1,470 cfs was made from LOTP reservoir. Soil moisture data at the upper site (Figure 9) shows a response to the release with soil moisture increasing during the release. The overcup oak (OA) and willow oak (WI) soils become saturated at flows between 500 and 1,000 and remain saturated for an extended period after the pulse event while the water oak (WA) soils become wetter at about 1,500 cfs but return to their pre pulse state in about a week. The middle (Figure 12) and lower (Figure 13) site do not appear to have been effected. The lower swamp type was completely saturated before the event and remained so at all three sites during and after the pulse event. Rainfall on February 1 resulted in an increase in soil moisture at all three sites, and this may contribute to the persistence of soil moisture at the upper site.

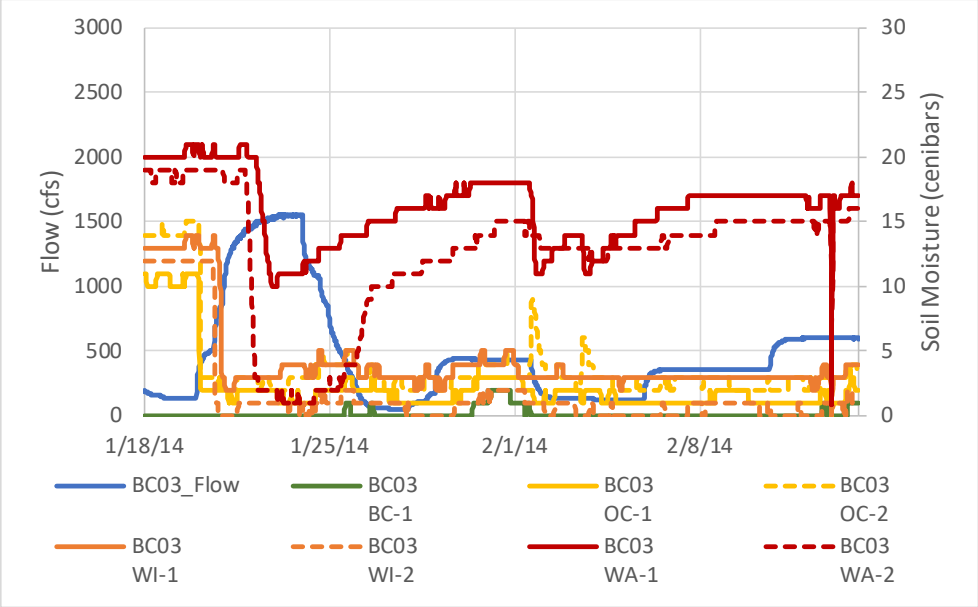

Figure 11 Soil moisture probes at site BC03 (Thomas) - Event #1.

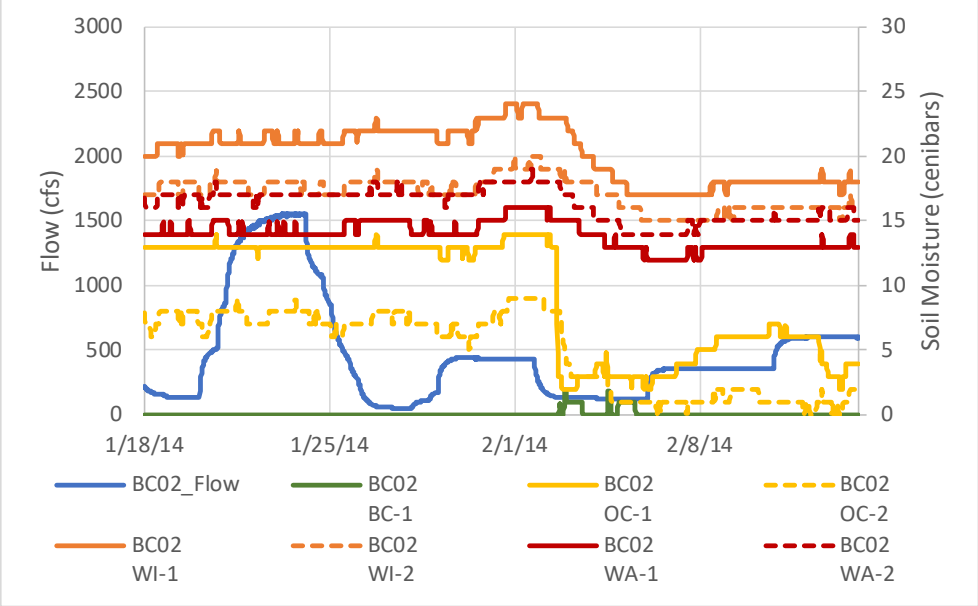

Figure 12 Soil moisture probes at site BC02 (Locke) - Event #1.

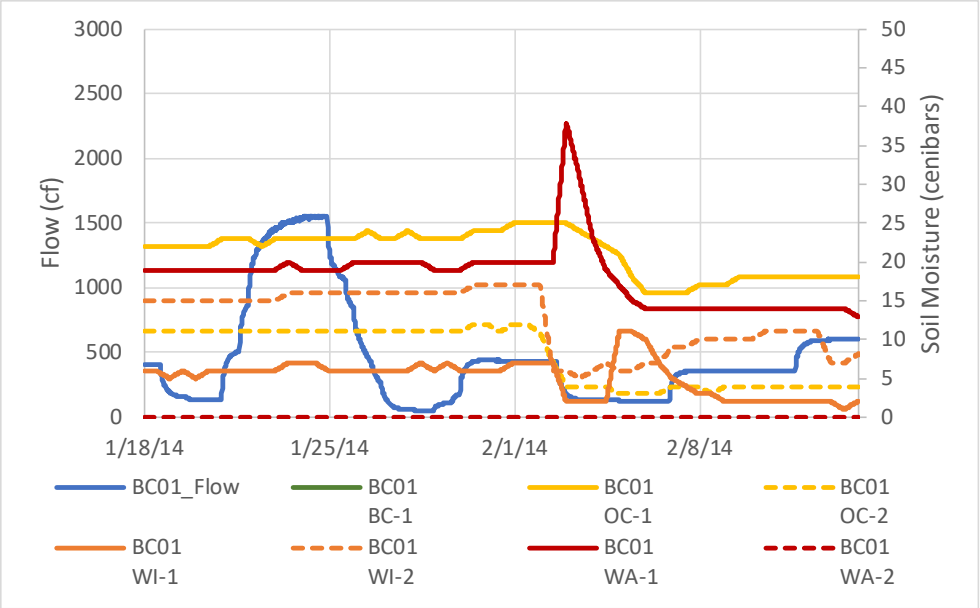

Figure 13 Soil moisture probes at site BC03 (Sanders) - Event #1.

During second event in April 2014 a short duration pulse release from LOTP peaked at about 1,790 cfs. Local rainfall in the week prior on April 4th had already increased soil moisture at these sites. Data shows a slight increase in soil moisture at the mid and downstream sites for most of the forest types, although perplexingly there is no effect at the 1 foot overcup oak probe which is presumably at a lower elevation than the willow and water oak probes which do appear to be wetted (Figure 15). Data is not available for the upper site.

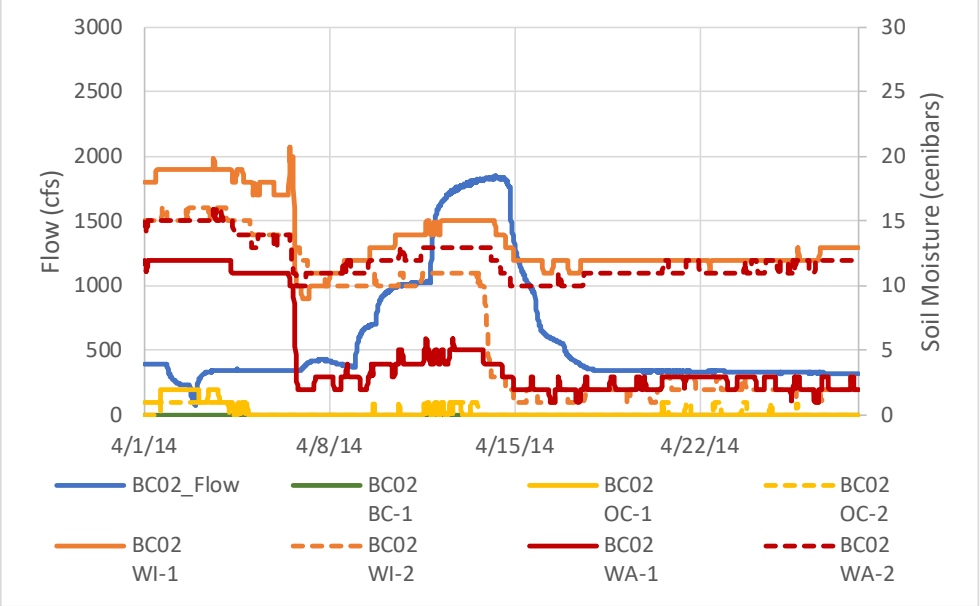

Figure 14 Soil moisture probes at site BC02 (Locke) - Event #2.

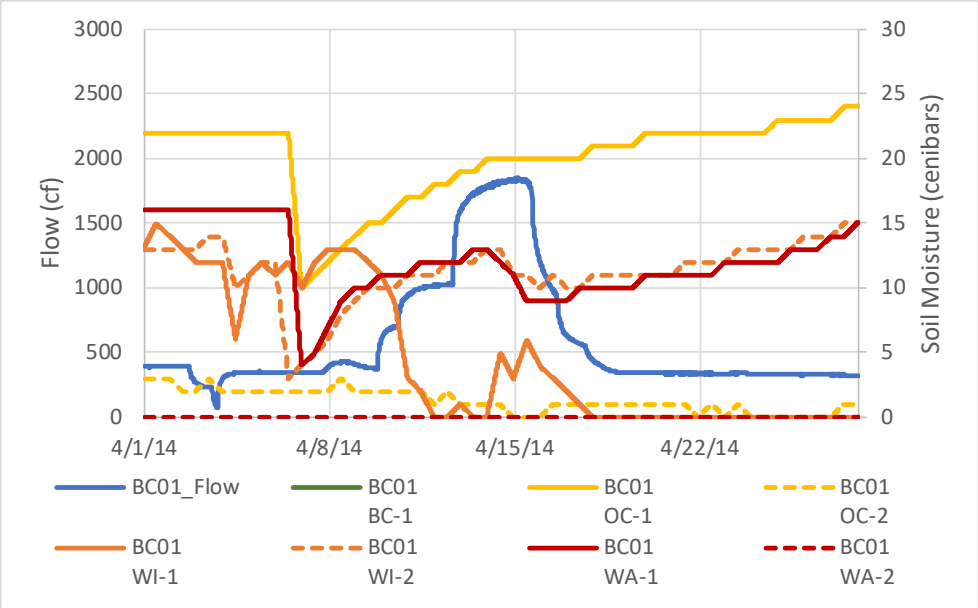

Figure 15 Soil moisture probes at site BC03 (Sanders) - Event #2.

The third high flow event was a multi-month release of 3,000 cfs between March and May of 2015. Most of the sites were completely flooded for extended periods. Presumably all of the probes indicated complete saturation; however, when the data was downloaded in August, it was found that much of the data was corrupted and unusable for analysis.

The forth event, similar to the first, in both flow magnitude and soil moisture response indicates that a pulse of approximately 1,500 cfs increases soil moisture at the most upstream site (Figure 16) but has no impact on soil moisture at the mid-stream (Figure 17) site. Data is not available for the downstream site for this event. Interestingly, soil moisture in the WA forest at the upstream site has a delayed response to the pulse event where increased wetness begins a few days after the pulse. As with the first event, the data suggest a several week persistence of more saturated soils following the pulse event at this site.

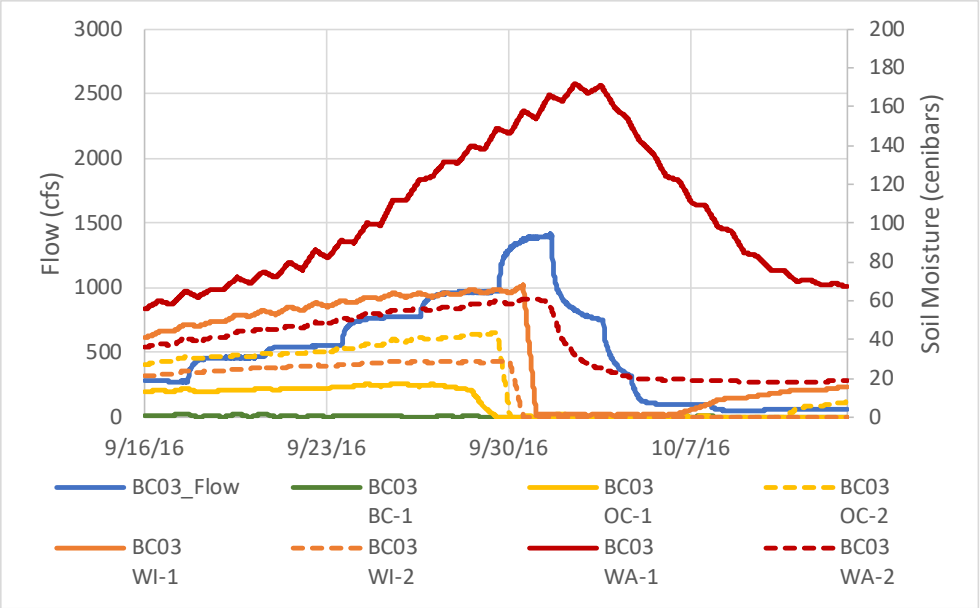

Figure 16 Soil moisture probes at site BC03 (Thomas) - Event #4.

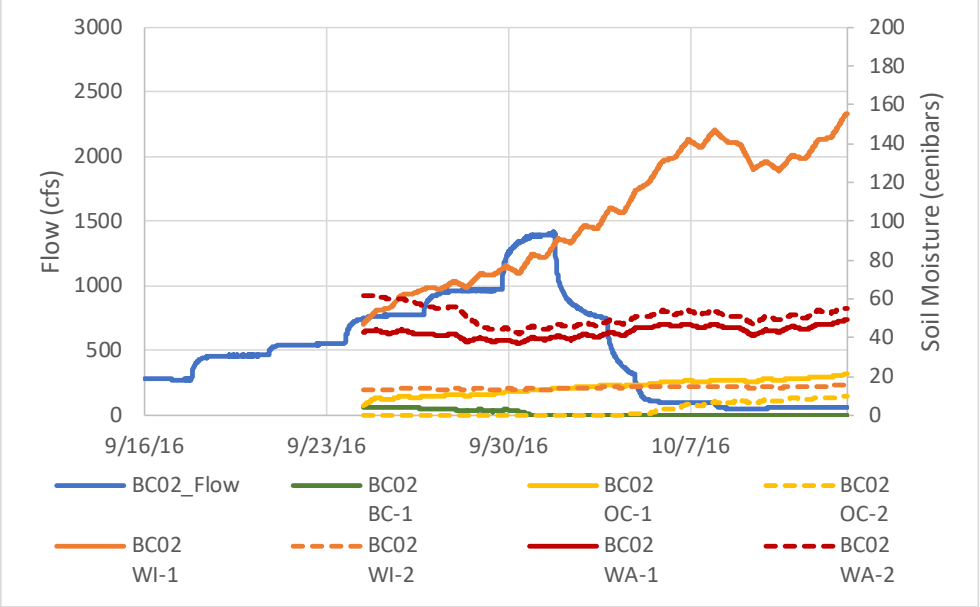

Figure 17 Soil moisture probes at site BC02 (Locke) - Event #4.

3 Findings

Due to the high flow releases and subsequent flooding of the study sites during 2015, much of the data presented in this report was only collected in the last few months. Some of it is incomplete and there are some unexpected results that are continuing to be evaluated. The preliminary results presented in this report have yet to be fully incorporated and considered in terms of the long-term forest plot monitoring analysis (TCE, 2016). That study has documented high mortality water oak in the temporarily flood forest. Continued investigation, including the incorporation of currently missing data and consideration of changes in the flood flow frequency regime will need to be considered.

Preliminary analysis including comparison of estimated of river water surface elevations to measure forest plot elevations, groundwater well and soil moisture data generally confirms previous hypotheses that swamp forest types are inundated at flows in the range of 1,000 – 1,500 cfs and that the flooded forest types are inundated at flows above 2,500 cfs. The soil moisture data and analysis suggests a persistence of wetter conditions following a pulse release for perhaps up to a few weeks; however, this is based on data from just three pulse events which cover a fairly narrow range (1,400-1,790 cfs) and which may be confounded by local rain events.

The reports from on forest plots (TCE 2016) and soil moisture probes (ETBU/SFAU 2016) include more detailed recommendations regarding specific next steps.

4 References

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