Installation of the Big Cypress Bayou Monitoring Network: Groundwater, Soil Moisture, and Long-Term Vegetation Plots 2012-2013

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1.0 Introduction

The Caddo Flows Project (hereafter CFP) seeks to qualify the ecological impacts associated with overbanks flow events. Numerous studies have demonstrated that these infrequent high flows provide important ecological benefits including the maintenance of healthy riparian and wetland forests. The linkages between flows and hardwood forests and wetlands are quantified based on inundated area relative to flow rates and species composition, as well as the seasonal timing and duration of these flow events. In 2011, the Sustainable Rivers Program (SRP) funded research estimated flow magnitudes necessary to inundate 75% percent of Swamp and Flooded Forest habitat areas in Big Cypress and literature reviews recommended frequencies and duration of inundation for these two habitat types. With SRP funds for 2012, three tasks were performed to build on the information derived from the 2011 work efforts and help refine the high flow pulse recommendation, evaluate the ability to implement it, and establish a floodplain vegetation monitoring baseline to evaluate the effects of flow implementation.

The CFP project was initiated by the Caddo Lake Institute (CLI) and The Nature Conservancy (TNC) in 2004, in partnership with the U.S. Army Corps of Engineers (USACE) and others, based on the SRP of TNC and USACE. Since 2005, flows research has focused on the quantification and restoration of hydrologic regimes to support riparian forest and wetland habitats and fisheries habitat. The 2011 work used satellite imagery, collected over a full range of flow magnitudes, to produce inundation maps and regression analyses for the 3 major tributaries (Big Cypress, Little Cypress, and Black Cypress bayous) contributing to Caddo Lake and for Caddo Lake itself. The interim results of the analysis suggest that the releases from LOP to Big Cypress Bayou (BCB) could provide the flows needed to meet the natural inundation frequencies for low-lying swamps.

Within this framework, this report describes the planning and subsequent establishment of 3 permanent riparian study sites on BCB above Jefferson, Texas. These new study sites will link inundation patterns and soil moisture, in order to help prescribe minimal environmental-flow releases required to help maintain floodplain habitats and essential ecosystem functions. The location of this monitoring study below LOP also allows input for adaptive management.

The Environmental Conservation Alliance (ECA) has researched the effect of river flows on riparian forests in the Caddo Lake watershed since February 2010. In 2013, the USGS National Wetlands Research Center (NWRC) became a partner in the environmental monitoring and ecosystem modeling for this and future research. The NWRC provides both monitoring technology and expertise, along with supplemental funding sources. ECA and NWRC are now collaborators on the forest plot network, including remote sensing, habitat inundation analyses, vegetation sampling, stem mapping, and detailed elevation survey. The overall purpose of this research is to measure the connectivity of environmental flows with floodplain habitats and processes.

2.0 Approach

On Big Cypress Bayou (BCB), the major tributary to Caddo Lake, the upstream reservoir Lake O' the Pines (LOP) captures high flows and disrupts the natural flood dynamics. Figure 1 summarizes the relationships among forest type, inundation, and elevation. As designed, the maximum release from LOP is about 3000 cfs. The history of long durations of flows at 3000 cfs has resulted in a watermark, which serves as a reference point throughout the BCB floodplain below LOP (Figures 2-3).

Recent research (2010-2011) analyzed satellite imagery, collected over a full range of flow magnitudes, to produce inundation maps and regression analyses for the overall Cypress Basin. Unlike hydrologic modeling, this previous work correlates actual wetted-forest configurations to daily stream discharge. In combination with hydrological modeling and ecological mapping of bottomland habitats, the unsupervised classification of selected Landsat thematic-mapper (TM) data allowed the regression of percent inundation for each habitat type against mean daily river discharge.

The interim results of these prior analyses correlated stream flows to the distribution of BLH habitat types. The results suggested that the releases from LOP to BCB could provide the flows needed to meet the natural inundation frequencies for low-lying swamps, but not BLH forests higher in elevation (CLI 2011).

Overall intent of this phase of the environmental-flow study is to establish a long-term network of monitoring stations and vegetation plots, to assess the impact of the flow regime on the 4 major Bottom Land Hardwood (BLH) forest types within the Cypress-Caddo ecosystem:

LS: Low Swamp - bald cypress dominant, co-dominants: overcup oak, water elm
HS: High Swamp - overcup oak dominant, co-dominants: water hickory, willow oak
SFF: Seasonally Flooded Forest - willow oak dominant, co-dominants: sweetgum, water oak
TFF: Temporarily Flooded Forest - water oak dominant, co-dominants: sweetgum, sugarberry

The network is designed to quantify the relationships among stream flows, floodplain hydroperiods, groundwater levels, soil saturation, and community composition. The monitoring network focuses on lateral and temporal hydrological connections within the floodplain, and the resulting interrelationships of species composition and environmental flows within BLH forests. As described below, the recent establishment of the 3 new study sites on BCB will allow the long-term collection of vegetation, groundwater, and soil moisture data. This continuous database will now provide the foundation for ecological and environmental change detection, in order to inform adaptive management.

3.0 Methods

The first few months of the field effort focused on ground-proofing prior inundation results, which guided the subsequent initiation of soil-moisture, groundwater, and vegetation-plot monitoring in the floodplain. As the various field tasks all measure the impact of environmental releases and other flow events on riparian habitats, the expanded monitoring effort fits within both of the main tasks listed in the Scope of Work for the SRP 2012 funding which states:

1. Since maintaining elevated flow levels for the required durations is not possible, we need to determine how long after an overbank event soil saturation typically persists and thus how

pulses might be implemented within the growing season to maintain soil saturation for the desired duration.

2. Forest composition, particularly understory species and the regeneration dynamics of seedlings and young saplings, is a most sensitive indicator of forest health. In order to determine the efficacy of environmental releases from LOP and establish a baseline for long-term monitoring of forest composition (species and structure), 3 permanent Study Sites will be located on BCB: above Jefferson, below Karnack, and on upper Caddo Lake.

3.1 Habitat Inundation

The current study includes the ground proofing of the habitat-inundation analyses presented in CLI (2011), which described the relationship between percent habitat inundation and the long-term record for daily discharge for USGS gages within the Cypress SRP project area. BCB above its confluence with Black Cypress Bayou is the focus of these field observations.

Inundation measurements were made to monitor the USCE experimental 9-day high-flow release from LOP during May 9-17, 2012. The environmental-flow event resulted in the maintenance of a release of 1930 cfs during May 12-14, preceded by a step-wise increase (May 9-11) and followed by a step-wise decrease (May 15-17). Immediately before and after the release, the mean daily flow (cfs) on May 8 and 18 were 198 and 187, respectively, as measured by USGS stream gage 07346000 below LOP.

Our prior research results (CLI 2011) compare well to actual percent inundation and wetted-surface boundaries measured in the field on May 14 and 15, 2012, during the experimental release from LOP. At 1930 cfs, a significant amount of swamp habitat along BCB flooded. To quantify and track inundation within different habitats, field surveys were conducted along temporary transects perpendicular to the bayou. Along 11 transects, inundation and habitat occurrence were measured with an electronic distance finder and, where necessary, pace counts.

Results of field observations during the May 2012 dam release are presented in tables and figures. Figures 4-9 provide maps of transect locations and predicted inundation areas relative to habitat types, while Table 1 summarizes transect lengths, bearings, and waypoint locations. Table 2 provides more detailed transect results, including lengths (m) for inundated and non-inundated segments, within the 4 main habitat types analyzed in the December 2011 flows report (CLI 2011): LS (Low Swamp), HS (High Swamp), SFF (Seasonally Flooded Forest), and TFF (Temporarily Flooded Forest).

Examining the results above and below Jefferson, the transect data reveal a distinct difference in the connectivity of BCB with its floodplain during the high-flow release. Table 2 reveals more connectivity above Jefferson, relative to the connectivity below the city. Percent inundation along the 7 transects (transects 1, 2, 3, 4, 6, 7, and 8) above Jefferson averages 82.3% per transect, with all low and high swamps and seasonally flooded forests, encountered along the transects inundated by the 1930-cfs release.

In contrast, the 4 transects (transects 18-21) below Jefferson average 28.2% inundation per transect, with only a portion of swamp habitats inundated, and no flooded forest connected by the 1930-cfs event. The few backwater bald cypress swamps crossed by the transects south of Jefferson, which were submerged during the dam release, did not receive surface water from the release. Moreover, the water in these isolated swamps appeared stagnant. The only exception was Moon Lake, a large bald cypress-overcup oak swamp along transect 20, where an active connection to the high-flow release was observed.

As measured where a transect crosses the bayou, the average width of the main channel of BCB also differed above and below Jefferson, being 52.3 m and 38.2 m, respectively (Table 2). A narrower and deeper channel below Jefferson may contribute to the lack of connectivity in this segment. This difference in channel profile may be due to historical dredging operations, which allowed steamboats to travel to Jefferson from the Red River, but no farther upstream. Ongoing removal of obstructions to navigation below Jefferson may also contribute to the difference in channel profiles.

As discussed in Section , all of the present aerial analysis of inundation is for precipitation events, not environmental releases. Analysis of imagery during historical dam releases without precipitation-induced tributary would better describe environmental releases.

3.2 Soil-Moisture and Groundwater Monitoring

A purpose of this monitoring effort is to determine linkages among stream discharge, soil moisture, and groundwater levels. The effort focuses on BCB between Lake ‘O The Pines and Jefferson, the floodplain area that observations indentified as having the most surface connections to the bayou during the May 7-17, 2012, high-flow release.

Selecting Study Areas and individual monitoring locations during and immediately after a high-flow release allowed verification of connectivity. Permanent soil-moisture and groundwater monitoring installations target 3 Study Sites (Figure 10). Within each of the 3 sites, 4 different floodplain forest habitats (Low Swamp-LS, High Swamp-HS, Seasonally Flooded Forest-SFF, Temporarily Flooded Forest-TFF) each receive 2 soil-moisture sensors at depths of 12” and 24” (except LS only receives 1 sensor at 12”) . In addition, at each of the 3 sites a 6-foot deep groundwater monitoring well is installed the LS and TFF habitats (see below).

Soil-Moisture - The Watermark granular-matrix sensor used in this study provides a calibrated, indirect method to measure plant-available soil moisture (soil water tension). With a life of more than 5 years (Irrometer 2012), the sensors are maintenance free, consume very little electricity, and integrate well with electronic data loggers.

The Watermark sensors are inserted 12” and 24” deep into the soil within the 4 habitat types, in order to bracket the horizons containing the densest concentration of fine roots in swamps and flooded forests (see above discussion). The exception is the LS (Low Swamp) habitat, where only 1 Watermark sensor is inserted 12” deep. In order to compensate for temperature when measuring available soil water, 1 temperature sensor is inserted 12” deep with each Study Site. A data logger (Watermark monitor 900M, 4-20 mA, 0-5 V) connects each array of 1 temperature

and 7 Watermark sensors, in order to create a continuous database for comparison to stream flow and precipitation events.
The subsequent soil-moisture database will allow the determination of thresholds, in order to accurately identify boundaries within which soil moisture is sufficient to maintain forest productivity. Initially, the dry and wet (lower and upper) boundaries for soil-water availability are defined as 10% and 50% available water (soil water tension) for the particular soils within the Study Sites (Irrometer 2012). However, adjustments may be necessary as more monitoring data is analyzed over time.

Groundwater - The installation of permanent groundwater-monitoring wells 6 feet into the alluvium allows the analysis of linkages among stream, groundwater, and soil-moisture levels. For example, measuring post-release groundwater responses and soil-moisture dynamics is important to document water availability within species-specific rooting depths for floodplain trees. Relationships between groundwater depth and tree productivity are well documented in the literature, and are key components of floodplain-forest productivity analyses.

Installing 2 long-term groundwater-monitoring wells within each Study Site creates a continuous database for comparison to synchronous data for stream flow and soil moisture. Another important purpose for the wells is to obtain periodic water samples for chemical analysis to identify the sources of groundwater, i.e., BCB versus tributaries versus direct precipitation. The proportional contribution of water sources will likely vary both spatially and temporally. The location of a well in the 2 habitats at opposite ends of the moisture gradient will examine source variability.

Near the Watermark sensors, a 6-foot deep groundwater well is installed in 2 habitats (LS and TFF) within the 3 Study Areas. Each well is located at the same surface elevation as adjacent Watermark sensors, but at a distance of 10’ from the sensors, in order to minimize disturbance. Within the hole outside the well assembly, a sand filter is added which extends 9 inches below bottom of the PVC well assembly and then around the well to a minimum of 1 foot above top of well screen. This results in 3-3.5’ of total height of sand filter surrounding the PVC assembly above the bottom of well. Once the backfilled soil settles, a concrete collar is formed around the top of the wellhead, in order to avoid an artificially increased infiltration of water down the outside of the well. A recording transducer is then installed inside at 4 inches above the bottom of well, so that the transducer is hung above any water held within bottom PVC cap.

Soil-Moisture and Groundwater Database - Soil-moisture and groundwater data files are available for all 3 study sites from 3/8/13 to the present (Table 3). Precipitation data are available beginning 1/1/13.

3.3 Vegetation Plots

Due to the long lifespan of BLH tree species, the appropriate indicators of BLH forest change are understory species (Figure 11) and the regeneration dynamics of seedlings and young saplings (Hughes and Rood 2003). Three riparian study sites (Figure 10) are located on Big Cypress Bayou between Jefferson and LOP. Within these study sites, plant-community composition (species and structure) is measured within permanent vegetation plots during field surveys (Figures 12-14). Ongoing land management, such as cattle grazing (Figure 15), continues within the Study Areas, so as to be representative of local land use.

The purpose of inventorying and monitoring riparian vegetation within the Study Areas is to identify the extent and condition of existing habitats, and determine future deviations from this baseline. The initial baseline inventory has created data sets for comparison to subsequent data collections. In this manner, the quantitative assessment of plant communities establishes a baseline by which the functional status of river-floodplain connectivity may be determined in the future.

The spatial configuration of riparian plant communities is determined by 100% ground surveys, in order to locate vegetation macroplots according to a stratified random design. The layer in this study consist of the 4 BLH forest types: LS: Low Swamp - bald cypress, HS: High Swamp - overcup oak, SFF: Seasonally Flooded Forest - willow oak, and TFF: Temporarily Flooded Forest - water oak. The following is an overview of the vegetation plot methods:

Plot Benchmarks - The precise location of each end of the randomly selected 50-m transects is recorded by GPS coordinates and by triangulation from witness trees or other prominent features. These transects are the centerline for the 10m X 50m macroplots. Five macroplots are randomly located in this manner in each of the 4 layer (forest types) within the 3 BCB study sites. The only exception is Study Area 2, where only 4 of the LS and HS forest types were available.

As appropriate, labeled iron-rebar sections (0.5-in diameter, 18 in long) are driven flush to the ground surface at each end of the central 50-m transect, in order to serve as permanent benchmarks. Benchmarks will increase the precision of relocating sampling locations in the future, as facilitated by metal detectors and/or witness-tree triangulation. The use of the same sampling locations significantly increases the statistical power of change detection, when subsequent samples are compared to baseline conditions.

Tree Layer - Within the 10m X 50m macroplot (Figures 16-17), the diameter at breast height (DBH, 1.37 cm above ground) is recorded by species for all live and dead woody perennial vegetation (trees) with at least 1 stem equal to or greater than 5 cm DBH. In this manner, multi-stemmed trees with at least 1 stem equal to or greater than 5.0 cm DBH are included along with single-stemmed trees. Diameter measurement is to the nearest 0.1 cm, rounded as appropriate. For multi-stemmed trees, DBH and basal area (BA) are calculated based on the respective sum totals for stems having a DBH equal to or greater than 5 cm. All measured trees are tagged.

The data collected for species in the tree layer are sorted and analyzed according to the following size-class categories: 5-15 cm, 16-25 cm, 26-35 cm, 36-45 cm, 46-55 cm, 56-65 cm, 66-75 cm, 76-85 cm, 86-95 cm, and greater than 95 cm. In this way, all trees within 5 m of either side of the center 50-m transect are analyzed according to 10-cm size classes.

Vigor Class – For live and dead trees, a vigor class is recorded representing ranges of % dead canopy volume. The lower the vigor class the fuller and healthier the live tree crown: vigor class 1 represents the healthiest trees, 6 represents the unhealthiest live trees, and 7 represents dead trees. For a small subset of plots, two vigor classes were used for dead trees: vigor class 7 designated trees which were estimated to have died recently during 2013 (dead leaves still present on the dead tree) and class 8 was used for trees dead more than one year.

Location – The location (nearest meter) of stem along the center 50-m transect is recorded, including whether the stem is left or right of the center transect, when facing the 50m end of the transect.

Shrub Layer - Tree saplings and shrub species are quantified within 2 20-m^2 quadrats (10 m X 2 m) centered at 15 and 35 m along the central 50-m transect within the 10m X 50m macroplots. Tree and shrub species (live and dead) greater than 1.37 m in height and with a DBH of less than 5 cm are recorded as described in the Tree Layer method, including species, vigor (only two classes, live or dead), and DBH at a height of 1.37 m. DBHs for multiple stems connected above ground are recorded separately. Measured stems are located in the field as practical, either by tree tags (DBH > 3 cm) or by recorded location (DBH < 3 cm).

Herb Layer - The herb layer (live woody seedlings and herbs) is quantified using a total of 5 1-m^2 quadrats located along the central 50-m transect in each 10m X 50m macroplot. These quadrats are centered at the 5-, 15-, 25-, 35- and 45m positions. Due to time constraints and the lateness of the fall season, the 1-m^2 herb layer quadrats were not measured at this time but were marked on the ground along the 50-m transect to locate them for future measurement.

Calculations - Several variables for both species and layers are calculated from the above data, including basal area (tree layer), density (all layers), and frequency (all layers). Frequency is calculated as the percent of 5m segments along the long axis of the forest-structure plot occupied by a given species or microhabitat. In addition, relative importance is defined as the average of percent relative basal area (tree layer), percent relative density, and percent relative frequency, where the percent relative value equals the value for the species divided by the sum of values for all species times 100.

Plot Inventory Database – Plot data (2013) for all 3 of the study sites (58 macroplots total) are available as digital files (Table 3).

4.0 Research Needs

A significant observation from the habitat inundation observations during the May 2012 release was the sharp contrast in the connectivity of BCB with its floodplain, when floodplain inundation is compared above and below Jefferson. During the 1930-cfs release, connectivity is evident above Jefferson, but not downstream.

The following lists of recommendations are tentative and offered for review and comment. Additional and alternative recommendations are most welcome.

4.1 Current Recommendations

Permanent vegetation plots - In light of the connectivity differences identified above and below Jefferson, permanent vegetation plots were not located on 3 different reaches of BCB: above Jefferson, below Karnack, and upper Caddo Lake, as previously planned. In order to focus on the connectivity of environmental releases, these replicate plots were instead located in the 3 Study Sites below LOP and above Jefferson, where soil-moisture and groundwater monitoring is now also established.

Woody Seedling Inventory – Due to a lack of time, the inventory of woody seedlings has not yet been completed for the 2013 plots. Completing the inventory by mid-March ahead of the next growing season is important, in order to allow the data for all the vegetation layers (trees, saplings/shrubs, and seedlings/herbs) to be synchronous. This facilitates the assessment of successional dynamics, which influence future forest composition in response to environmental changes.

Elevation benchmarks - Detailed topographical surveys of the Study Sites will establish permanent on-site benchmarks, to accurately determine elevations of monitoring equipment (well transducers, sensors, wells), vegetation plots, individual trees, etc. The USGS NWRC plans to complete the elevation surveys in early 2014.

<u>Floodplain transducers</u> – Soil-surface transducers in off-channel and backwater LS habitats will provide site-specific data on the depth, frequency, and duration of overbank events, including LS and adjacent habitats higher in elevation (HS, SFF, TFF). NWRC, as a project collaborator, has secured funding to purchase and install additional transducers in early 2014.

4.2 Future Recommendations

<u>Floodplain water budget</u> - The lack of connectivity during environmental releases below Jefferson may warrant further study. Both above and below Jefferson, additional analyses may discern the relative contributions of BCB flows, tributary flows, alluvial groundwater, and direct precipitation to the floodplain water budget. If possible, additional Study Sites (soil moisture, groundwater, and vegetation) on BCB below Jefferson may be required to complete a water budget for the floodplain downstream of LOP.

<u>Aerial survey of upcoming environmental releases</u> - The difficulty of boat-and-foot observations of inundation along transects during high-flow events may be largely avoided with the use of an infrared camera mounted below a small plane or a drone. Such an aerial survey may take only 60-90 minutes during an event. Subsequent image classification and GIS analysis may then provide more complete and accurate delineations of basin-wide habitat inundation.

A pulse before the growing season may not be as beneficial as a release during the first 2 months of the growing season. Both vegetation and aquatic biota may respond best to releases starting in mid March through May (CLI 2011). However, if an early release could peak near or at 3000 cfs, then there is a good opportunity to extend the 2012 event assessment of environmental-flow connections.

The leafless canopy during winter allows wetted surface classification of the high-flow event for the entire downstream Big Cypress watershed, including above and below Jefferson. Such an inundation analysis would be particularly valuable during a release without co-occurring precipitation, in order to focus on environmental flows. Landsat needs to be turned on or an over-flight (small plane or drone) needs to occur during the event.

Classification of past environmental releases - All of the present aerial analysis of inundation is for precipitation events, not environmental releases. Analysis of Landsat or other imagery during historical dam releases without precipitation-induced tributary flooding is recommended to focus on environmental releases. This would require an examination of historical imagery since the mid 1980s for usable coverage during specific environmental releases. If needed to supplement leaf-off release imagery, wetted-surface classifications during the growing (leaf-on) season, using selected spectral data, may be sufficient to estimate the extent of habitat connectivity during past high-flow and overbank releases.

Monitoring management – Additional funding may be needed for the operation and maintenance of the soil-moisture and groundwater monitoring arrays and permanent vegetation plots.

Regional monitoring network - Expanding the permanent monitoring network to a regional scale would complement the new Study Sites funded by SRP on BCB. Little Cypress and Black Cypress bayous have relatively undeveloped watersheds. Little Cypress Bayou is more similar to BCB in terms of floodplain morphology and habitat types, though it may be threatened by increasing water development. In the near term, 3 more Study Sites on Little Cypress Bayou would provide important baseline data, as a relatively undisturbed control for the BCB monitoring effort.

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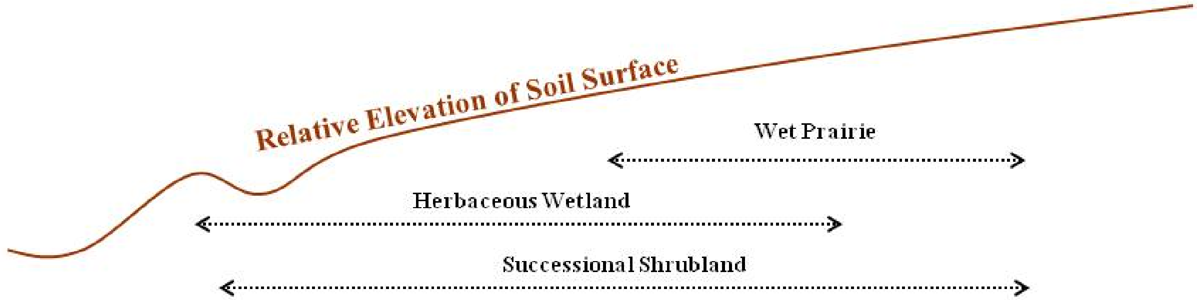
Figure 1. Landscape context of Cypress-Caddo bottomland habitat types: Relative elevation, hydrologic regime, flood frequency, and growing season inundation.



Bottomland Habitat Types:	Stream & Other Open Water	Swamp: Lower Swamp	Swamp: Upper Swamp	Seasonally Flooded Forest	Temporarily Flooded Forest	Transition to Uplands
Dominant Tree Species:	None	Bald cypress	Bald cypress Water elm Overcup oak Sweetgum	Willow oak Water oak Sweetgum Overcup oak	Water oak Sweetgum Loblolly pine Cedar elm	Sugarberry Sweetgum Water oak White oak
Hydrologic Regime[2]:	Permanently Flooded	Intermittently exposed	Semipermanently flooded	Seasonally flooded	Temporarily flooded	Intermittently flooded
Flood Frequency- percent of years[2]:	100%	~ 100%	51-100%	51-100%	11-50%	1-10%
Growing-Season Inundation- total duration[2]:	100% (~8 mos.)	~ 100% (~8 mos.)	>25% (> 2 mos.)	12.5-25% (1-2 mos.)	2-12.5% (5-30 days)	< 2% (< 5 days)

Footnotes: [1] Diamond, D. 2009. FIA Bottomland Summary: East Texas. Unpub. document, Missouri Resource Assessment Partnership, School of Natural Resources, U. Mo. - Columbia.

[2] Huffman, T., and S.W. Forsythe. 1981. Bottomland hardwood forest communities and their relation to anaerobic soil communities. in: Clark, J.R., and J. Benforado. Wetlands of Bottomland Hardwood Forests, Elsevier Scientific Pub. Co., New York, N.Y., pp. 187-196.

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Figure 2. Waterline close-up, Overciup oak swamp, Site 3, Fall 2013.

Figure 3. Waterline close-up, Bald cypress swamp, Site 3, Fall 2013.

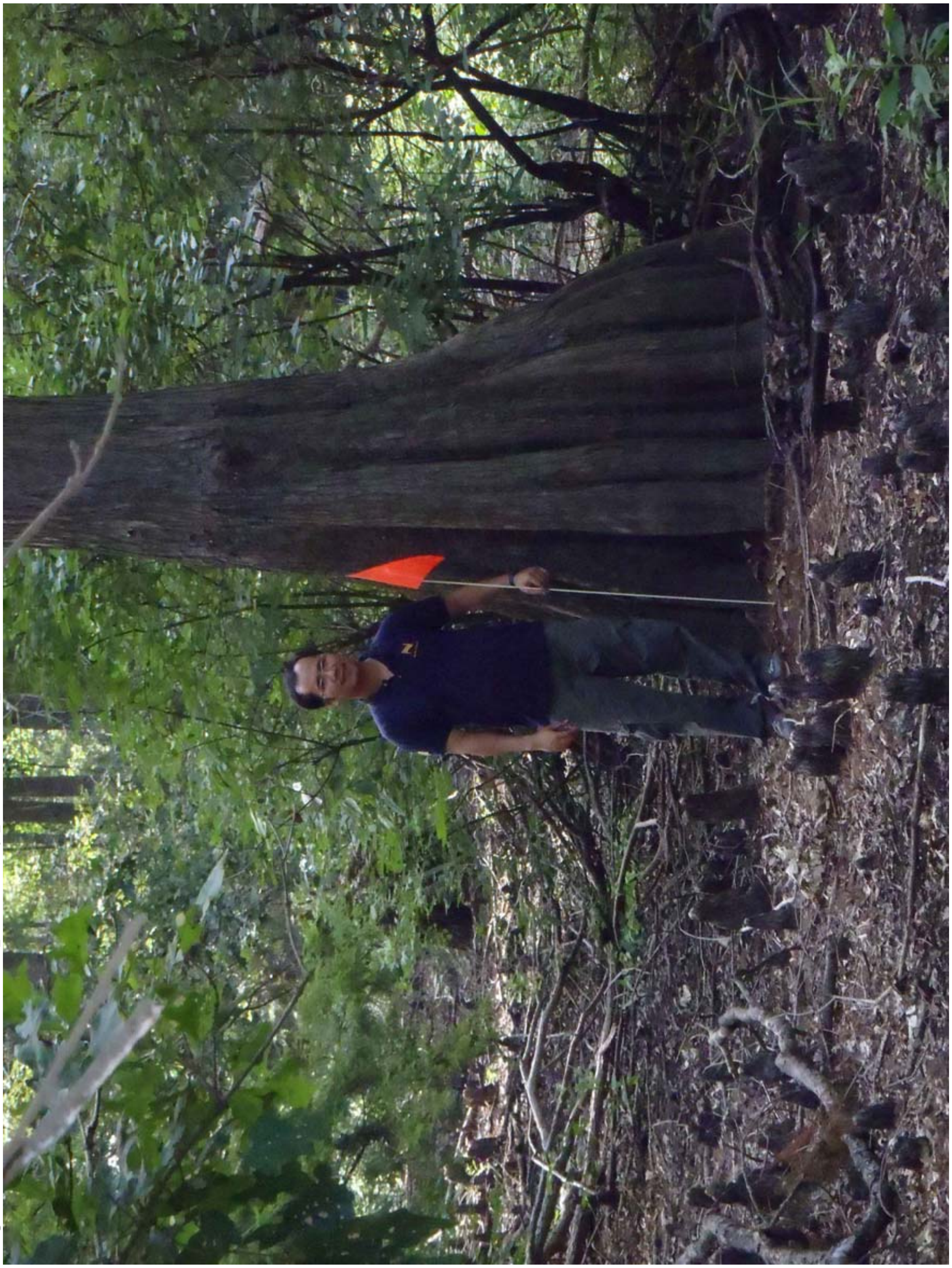

Figure 4. May 2012 High-Flow Event at Big Cypress Bayou: Research Areas 1-4
Predicted Inundation, Habitat Types, Groundproofing Transects, Study Sites

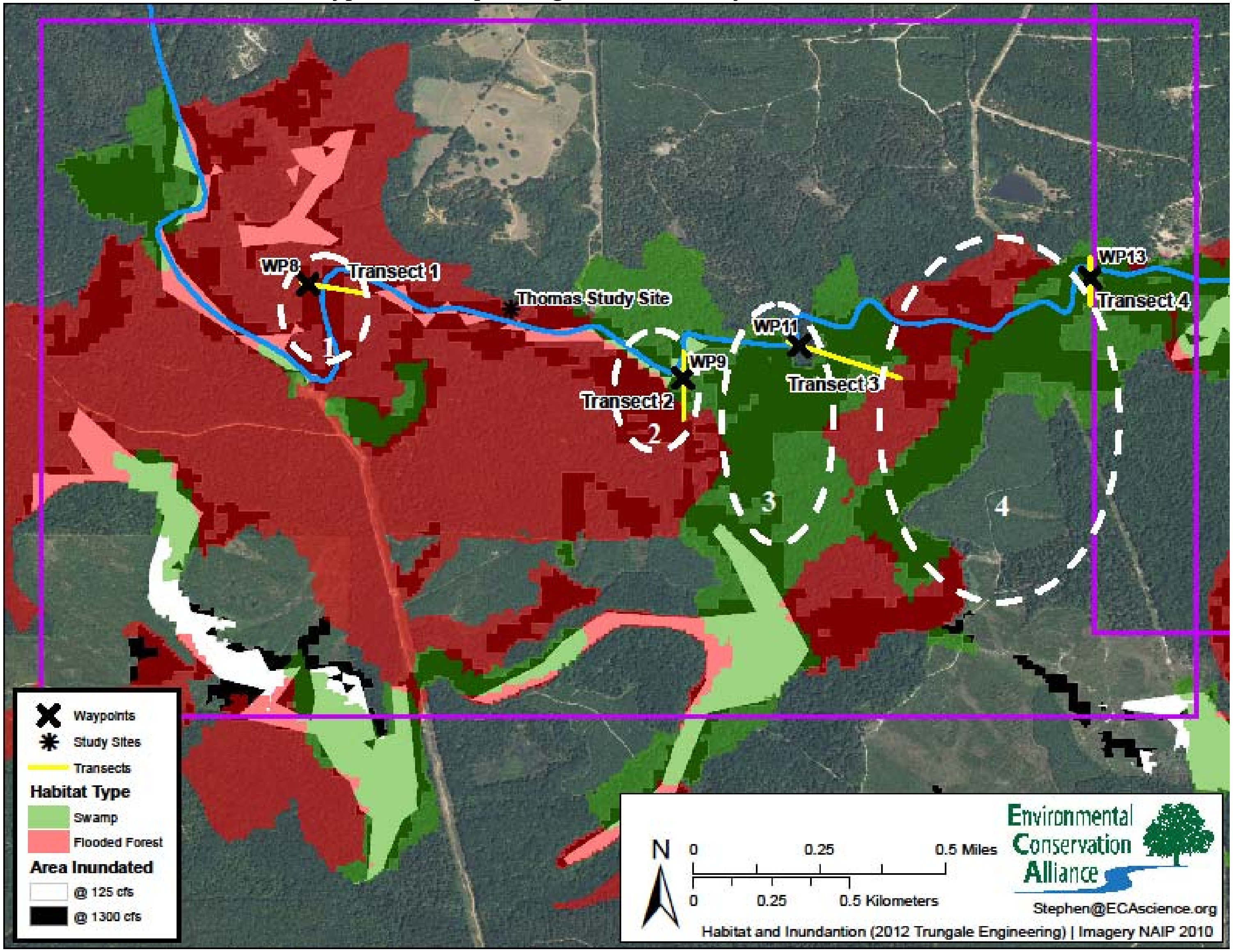

Figure 5. May 2012 High-Flow Event at Big Cypress Bayou: Research Areas 5-7
Predicted Inundation, Habitat Types, Groundproofing Transects, Study Sites

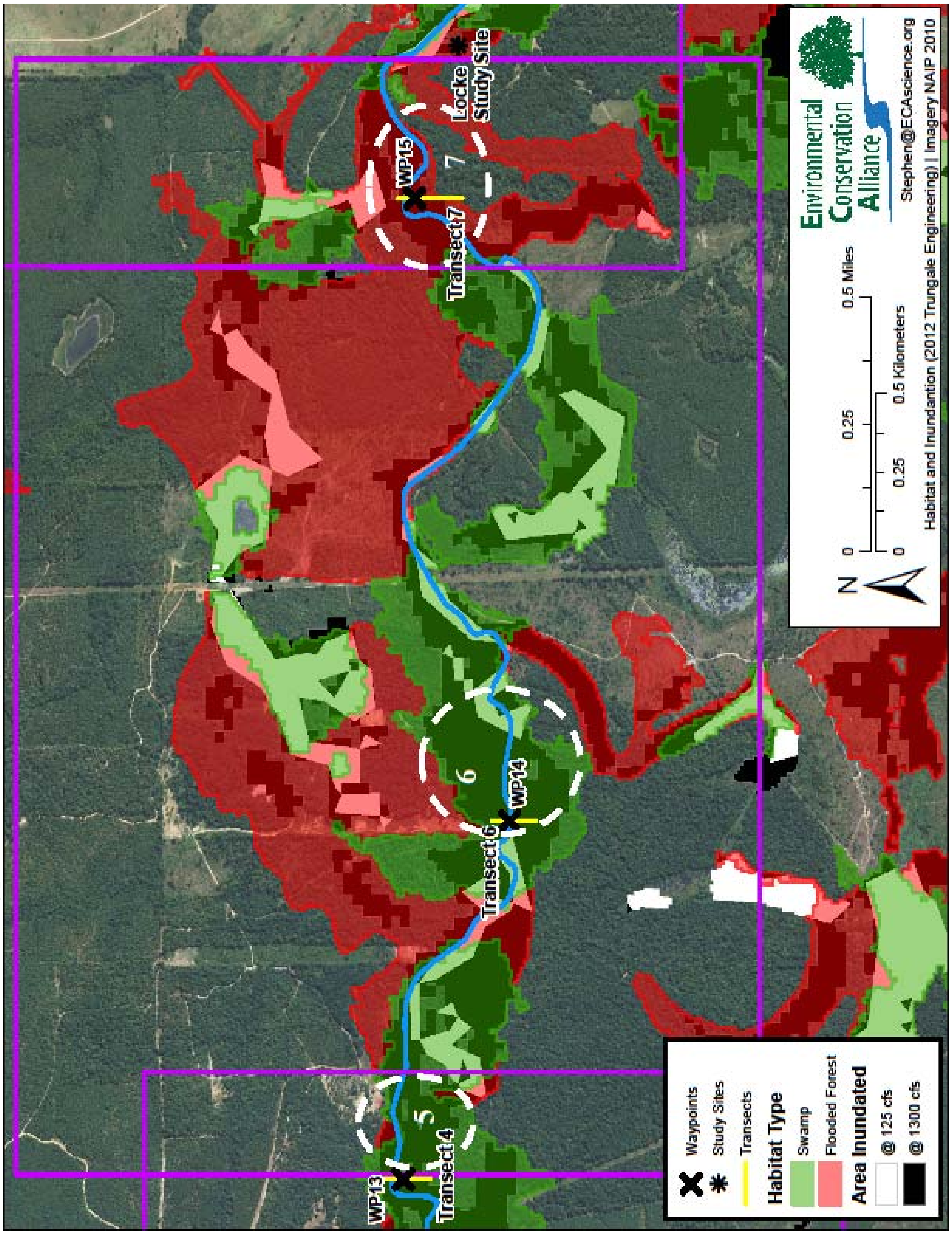

Figure 6. May 2012 High-Flow Event at Big Cypress Bayou: Research Areas 8-10
Predicted Inundation, Habitat Types, Groundproofing Transects, Study Sites

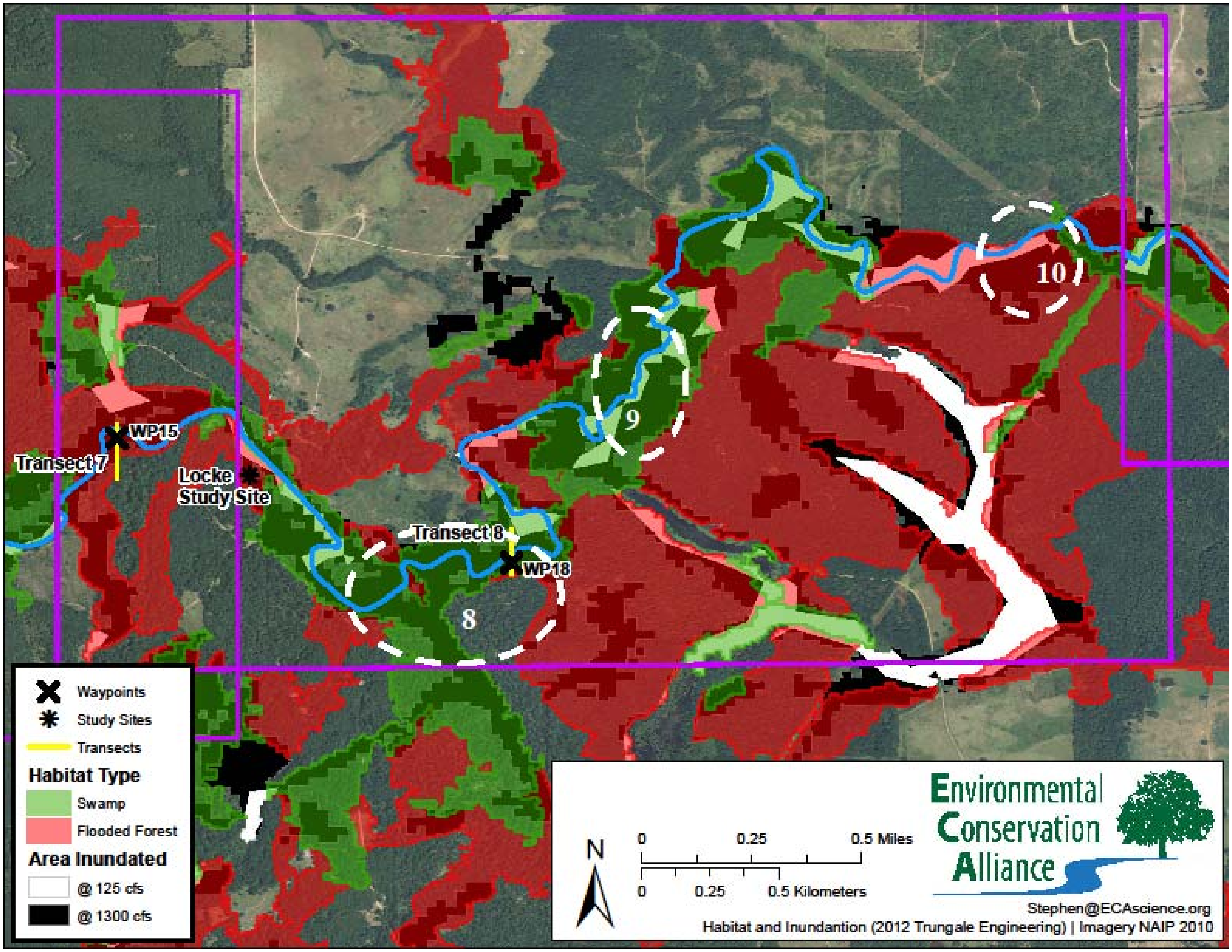

Figure 7. May 2012 High-Flow Event at Big Cypress Bayou: Research Areas 11-13
Predicted Inundation, Habitat Types, Groundproofing Transects, Study Sites

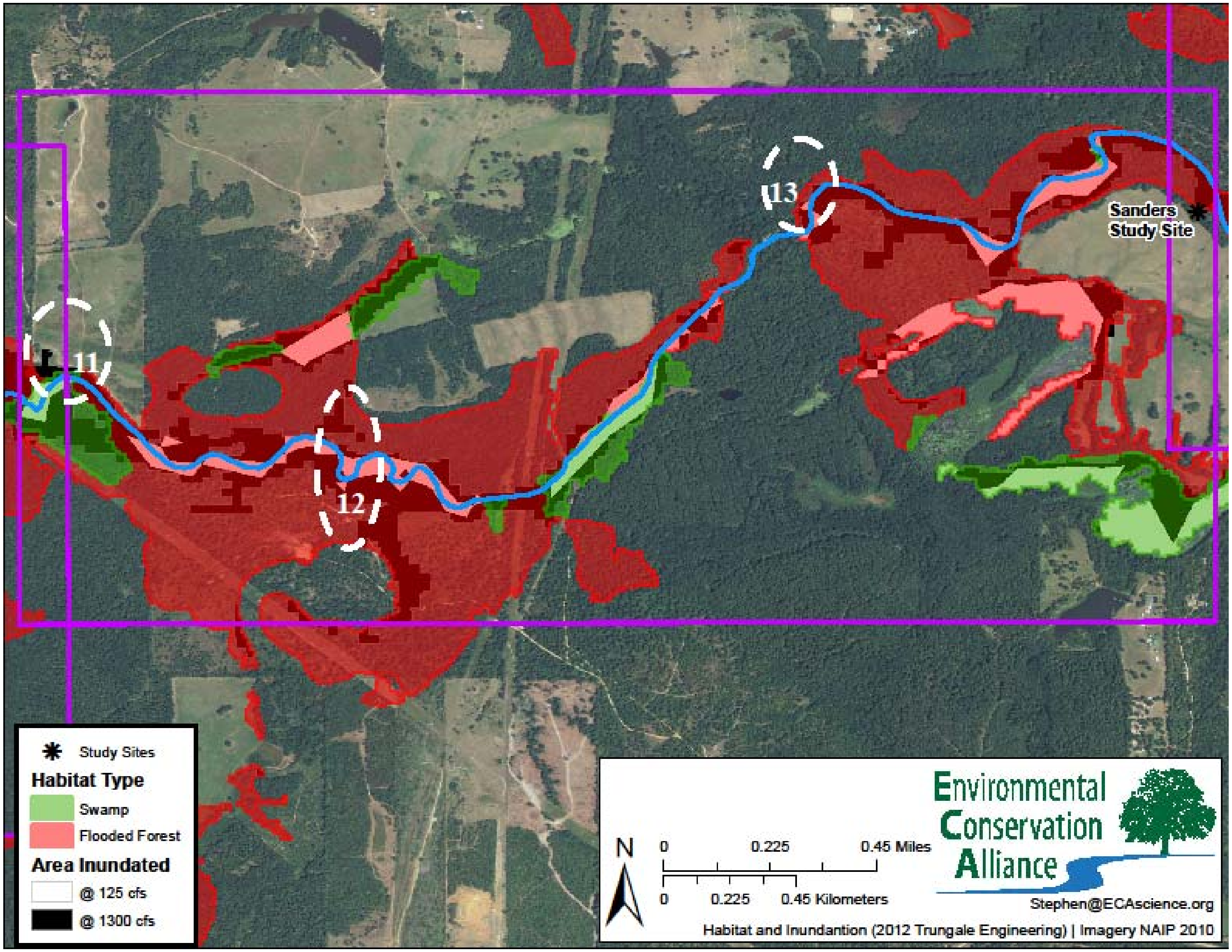

Figure 8. May 2012 High-Flow Event at Big Cypress Bayou: Research Areas 14-17
Predicted Inundation, Habitat Types, Groundproofing Transects, Study Sites

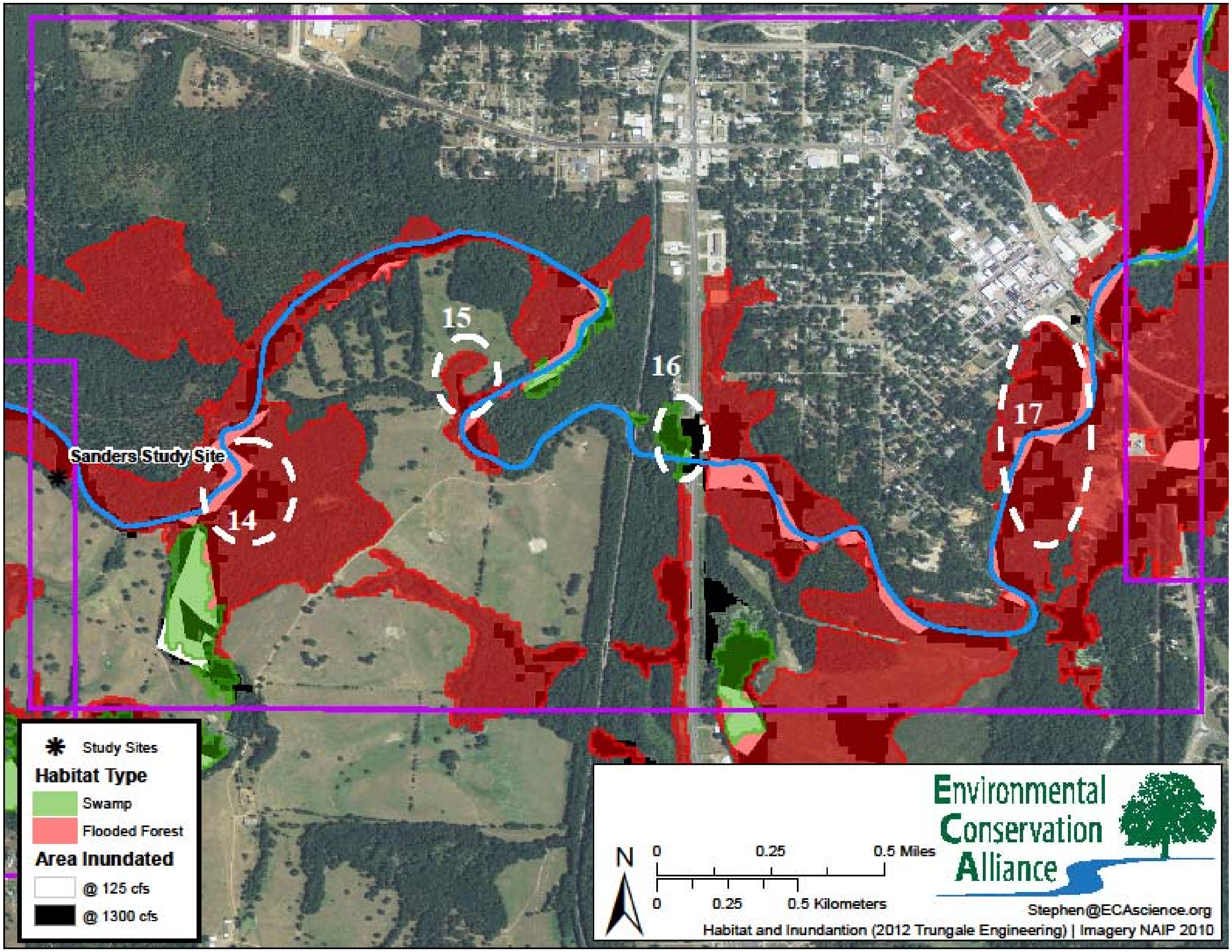

Figure 9. May 2012 High-Flow Event at Big Cypress Bayou: Research Areas 18-22
Predicted Inundation, Habitat Types, Groundproofing Transects, Study Sites

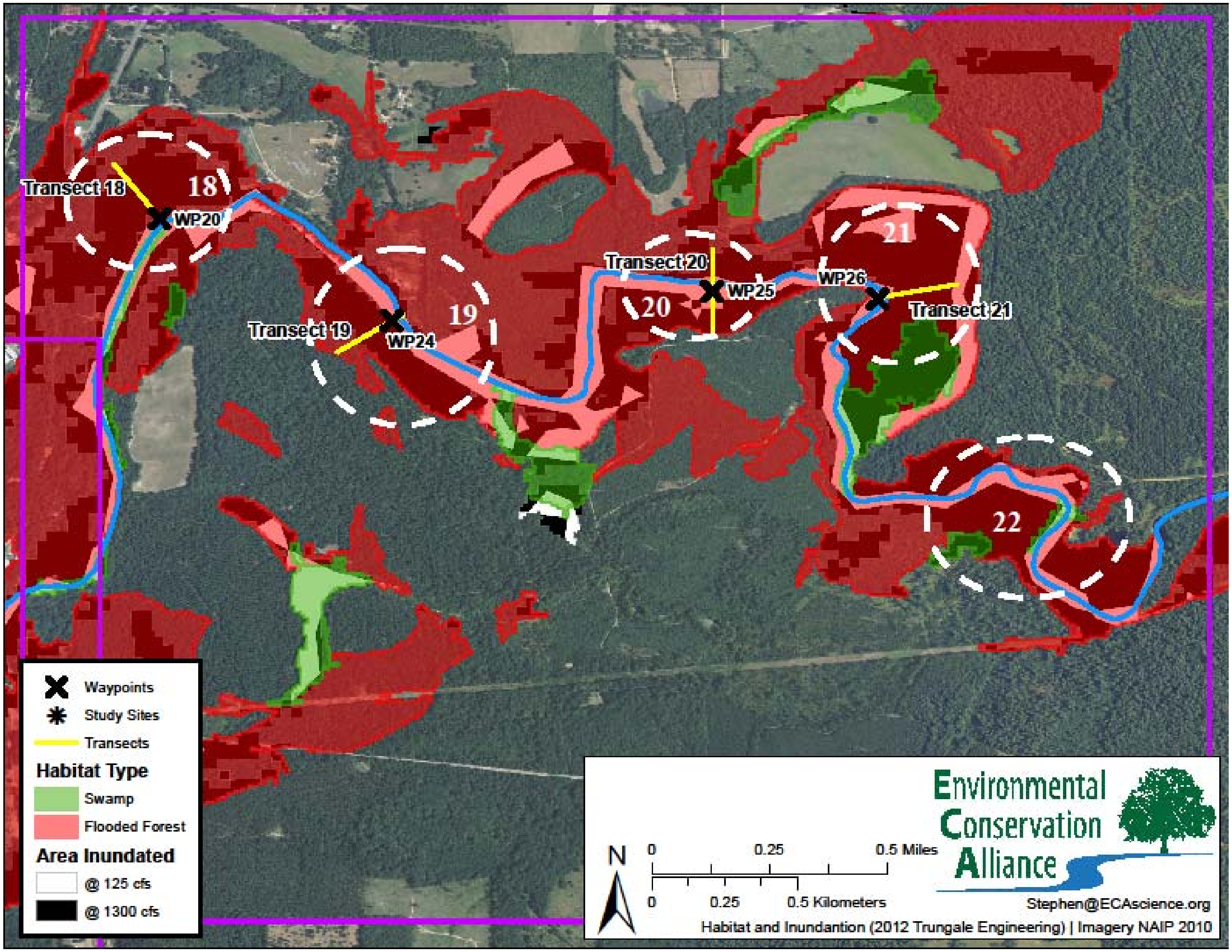

Figure 10. Big Cypress Bayou Monitoring Network:
Locations of Riparian Study Sites on Big Cypress Bayou between Lake O’ the Pines and Jefferson, Texas.

Figure 11. Drought stressed beautyberry, Water oak seasonally flooded forest, Site 1, Fall 2013.

Figure 12. Big Cypress Bayou Monitoring Network:
Riparian Study Site #1 (Sanders and DeWare parcels), including Long-Term Forest Plot Locations.

Figure 13. **Big Cypress Bayou Monitoring Network:**
Riparian Study Site #2 (Locke parcel), including Long-Term Forest Plot Locations.

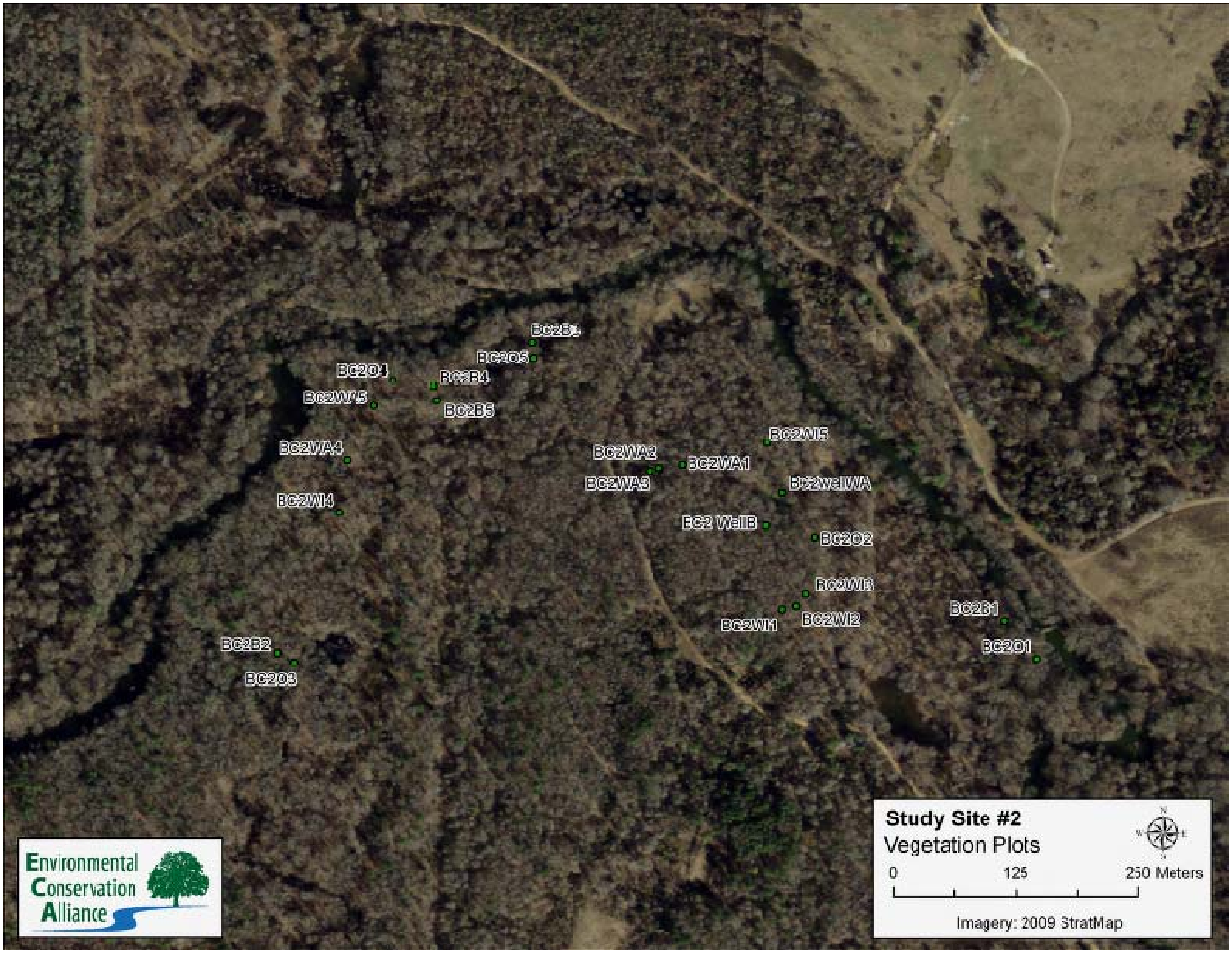

Figure 14. Big Cypress Bayou Monitoring Network:
Riparian Study Site #3 (Thomas parcel), including Long-Term Forest Plot Locations.

Figure 15. Cattle grazing, Overcup oak swamp, Site 3, Fall 2013.

Figure 16. Surveying plot centerline, Bald cypress swamp, Site 3, Fall 2013.

Figure 17. Plot survey, Overcup oak swamp, Site 3, Fall 2013.

Figure 18. Measuring diameter, Bald cypress swamp, Site 2, Fall 2013. © L. Allain

Table 1. **Habitat Inundation - Summary Transect Data**
Transect Lengths, Bearings, and Waypoints
May 2012 High-Flow Event, Big Cypress Bayou above Jefferson

Transect	Transect Distances (m)			Bearing (degrees)	Waypoints		
	North of Mid-Channel	South of Mid-Channel	Total		ID	Y	X
1	60	122	182	281	WP8	32.739207	-94.494826
2	16.5	197.5	214	360	WP9	32.736512	-94.484078
3	30	294	324	291	WP11	32.737431	-94.480731
4	41	109	150	360	WP13	32.739379	-94.472406
6	62	76	138	360	WP14	32.736344	-94.462199
7	31.5	170.5	202	360	WP15	32.739062	-94.444436
8	106.5	58.5	165	360	WP18	32.734957	-94.431471
18	240.5	20.5	261	324	WP20	32.769289	-94.336951
19	16	215	231	236	WP24	32.766142	-94.329813
20	109	180	289	360	WP25	32.767049	-94.319963
21	212	22	234	258	WP26	32.766825	-94.314874

Table 2. Habitat Inundation - Detailed Transect Data

May 2012 High-Flow Event, Big Cypress Bayou above Jefferson

Transect 1: 5/13/12			
WP8: No. bank of BCB			
32.739207	-94.494826		
Section	**Span (m)**	**Wet ?**	**Habitat**
BCB	60	Y	LS
N1	30	Y	HS
S1	92	Y	HS-TFF
Total Transect	**182 m**		**100% Inundated**

Transect 2 - 5/13/12			
WP9: So. bank of BCB			
32.736512	-94.484078		
Section	**Span (m)**	**Wet ?**	**Habitat**
BCB	33	Y	LS
N1	North = NA		
S1	35	N	TFF
S2	32	Y	HS
S3	10	N	TFF
S4	6	Y	HS
S5	35	N	TFF
S6	63	Y	HS
Total Transect	**214 m**		**62.6% Inundated**

Transect 3			
WP11: So. bank of BCB			
32.737431	-94.480731		
Section	**Span (m)**	**Wet ?**	**Habitat**
BCB	60	Y	LS
N1	North = upland		
S1	19	N	TFF
S2	245	Y	SFF
Total Transect	**324 m**		**94.1% Inundated**

Transect 4			
WP13: So. bank of BCB			
32.739379	-94.472406		
Section	**Span (m)**	**Wet ?**	**Habitat**
BCB	82	Y	LS-HS
N1	North = NA		
S1	15	N	TFF
S2	53	Y	SFF
Total Transect	**150 m**		**90% Inundated**

Transect 6			
WP14: Mid-channel BCB			
32.736344	-94.462199		
Section	**Span (m)**	**Wet ?**	**Habitat**
BCB	20	Y	LS
N1	52	Y	HS-SFF
S1	66	Y	HS-SFF
Total Transect	**138 m**		**100% Inundated**

Transect 7			
WP15: So. bank of BCB			
32.739062	-94.444436		
Section	**Span (m)**	**Wet ?**	**Habitat**
BCB	63	Y	LS
N1	North = NA		
S1	38	N	TFF
S2	19	Y	SFF
S3	27	N	TFF
S4	37	Y	SFF
S5	6	N	TFF
S6	12	Y	HS
Total Transect	**202 m**		**64.9% Inundated**

Transect 8			
WP18: So. bank of BCB			
32.734957	-94.431471		
Section	**Span (m)**	**Wet ?**	**Habitat**
BCB	48	Y	LS-HS
N1	8	N	SFF
N2	5	Y	HS
N3	12.5	N	SFF
N4	12	Y	HS-SFF
N5	35	N	TFF
N6	10	Y	HS-SFF
S1	3.5	N	SFF
S2	31	Y	LS-HS
Total Transect	**165 m**		**64.2% Inundated**

Transect 18			
WP20: No. bank of BCB			
32.769289	-94.336951		
Section	**Span (m)**	**Wet ?**	**Habitat**
BCB	41	Y	LS-HS
N1	92	N	SFF
N2	41	Y	HS
N3	42	N	HS-SFF
N4	45	Y	LS-HS
S1	South = NA		
Total Transect	**261 m**		**48.7% Inundated**

Transect 19			
WP24: So. bank of BCB			
32.766142	-94.329813		
Section	**Span (m)**	**Wet ?**	**Habitat**
BCB	32	Y	LS-HS
N1	North = NA		
S1	199	N	HS-SFF
Total Transect	**231 m**		**13.9% Inundated**

Transect 20			
WP25:			
32.767049	-94.319963		
Section	**Span (m)**	**Wet ?**	**Habitat**
BCB	36	Y	LS-HS
N1	35	N	
N2	18	Y	LS-HS
N3	38	N	SFF
S1	162	N	HS-SFF
Total Transect	**289 m**		**18.7% Inundated**

Transect 21			
WP26:			
32.766825	-94.314874		
Section	**Span (m)**	**Wet ?**	**Habitat**
BCB	44	Y	LS-HS
N1	161	N	HS-SFF
N2	29	Y	LS
S1	South = NA		
Total Transect	**234 m**		**31.2% Inundated**

Key

Habitat:
- LS: Low Swamp - bald cypress dominant
- HS: High Swamp - overcup oak dominant
- SFF: Seasonally Flooded Forest - willow oak dominant
- TFF: Temporarily Flooded Forest - water oak dominant

Other:
- WP: Waypoint # (see map) & coordinates
- BCB: Big Cypress Bayou main channel
- NA: Not available
- Section Code: Direction & distance along transect from BCB (i.e., N4 = 4th section north of BCB)

Table 3. Cypress Sustainable Rivers Project, Digital data files, 2013.

Data Type	Start Date		
	Site 1	Site 2	Site 3
Precipitation	01/01/13	01/01/13	01/01/13
Groundwater Depths	03/15/13	03/15/13	03/15/13
Soil Moisture	03/09/13	03/08/13	03/18/12
Vegetation Plots: Tree and Shrub Layers	09/30/13	09/30/13	09/30/13