Final Report

Non-linear downward flux of water in response to increasing wetland water depth and its influence on groundwater recharge, soil chemistry, and wetland tree growth

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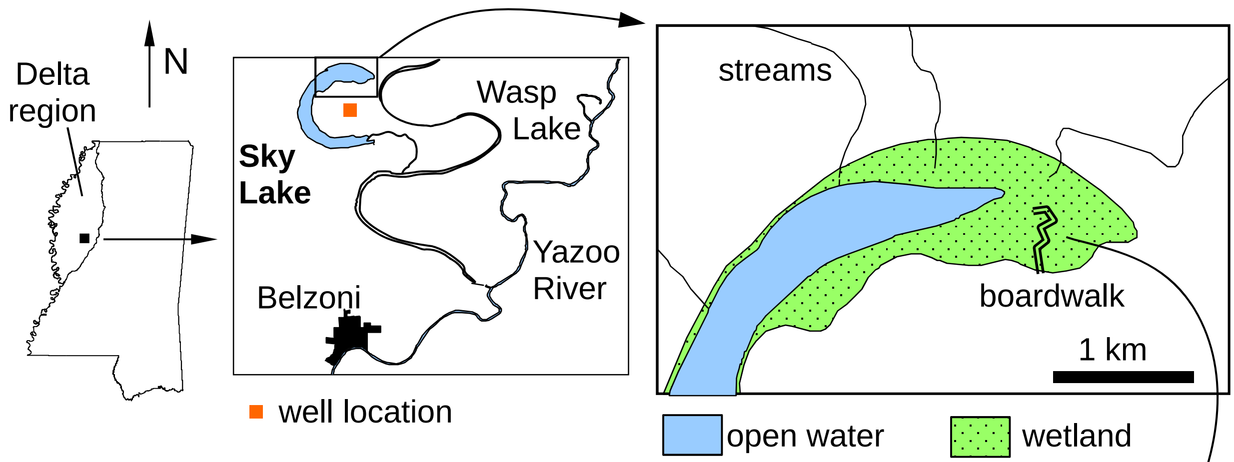
BACKGROUND

Many oxbow lake-wetland systems in the Mississippi River floodplain are perched above the regional water table, resulting in a downward hydraulic gradient. Fine grained sediments that accumulate in these environments limit downward flow, but fallen tree trunks and limbs introduce heterogeneity and isolated pockets of higher hydraulic conductivity. Normally, flux is proportional to the gradient, but previous work by the PI suggested that the relationship between water depth and downward flow in these systems can be non-linear. Studies in Sky Lake, in the Delta region of Mississippi, have documented minimal vertical movement of water until a threshold water depth is reached. Above the threshold, abrupt changes in soil chemistry have been observed as water begins moving downward, which may in turn influence the growth of wetland trees. The role of oxbow lakes as points of groundwater recharge is also largely unknown. Though oxbow-lake bottom-sediments typically serve as barriers to flow, the heterogeneity that exists in the wetland perimeters may provide conduits for vertical flow that bypasses the surficial clay and silt deposits.

The project focused on the influence of changing water depth in Sky Lake, MS, in Humphreys County, where an elevated boardwalk into the heart of an old-growth bald-cypress wetland made it possible to mount equipment for long-term monitoring of a variety of environmental parameters (Fig. 1). The study focused on both the identification of non-linear responses to changing water depth, and its potential impact on tree growth and groundwater recharge. Possible non-linear downward flux in response to increases in wetland water depth was investigated using a series of redox probes at two depths in the sediment to monitor changes in redox potential that might accompany changes in water depth. Significant downward flow of oxygenated surface water should result in a shift to higher redox potentials. The impact on bald-cypress tree growth was assessed using two sets of tree measurements: radial growth and sap flow rates. In order to link any changes in tree growth to water level, a series of additional variables were also measured that could also influence growth and mask a water-depth effect. These included temperature, relative humidity, and precipitation. Groundwater response was monitored by measuring the level of water in an abandoned irrigation well in the center of the oxbow meander loop.



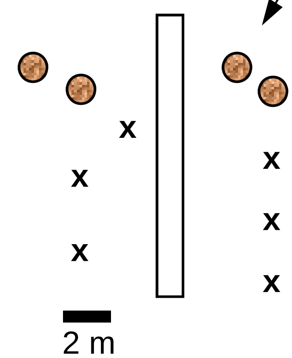


Figure 1. Sky Lake with enlargement of the northern wetland, and layout of the experimental area (to the right). The central rectangle represents the elevated boardwalk. Circles represent cypress trees outfitted with dendrometer bands and sap flow sensors. Locations of the redox measurements are marked with an **x**. Redox probes were placed at 30 and 60 cm at each site.

RESULTS

The project began part way into the 2013 growing season, so the data collection phase was extended to include a second growing season. Data for this report was completed in October, 2014, though investigations at the site will continue into the future.

Wetland water depth

Water depth in the wetland varied considerably over the course of the study (Fig. 2). During the first year (2013), water levels remained high earlier in the growing season, followed by a period of several months with no water above ground surface. Water level in the second year (2014) was much more episodic, with only a few days when the wetland was not flooded.

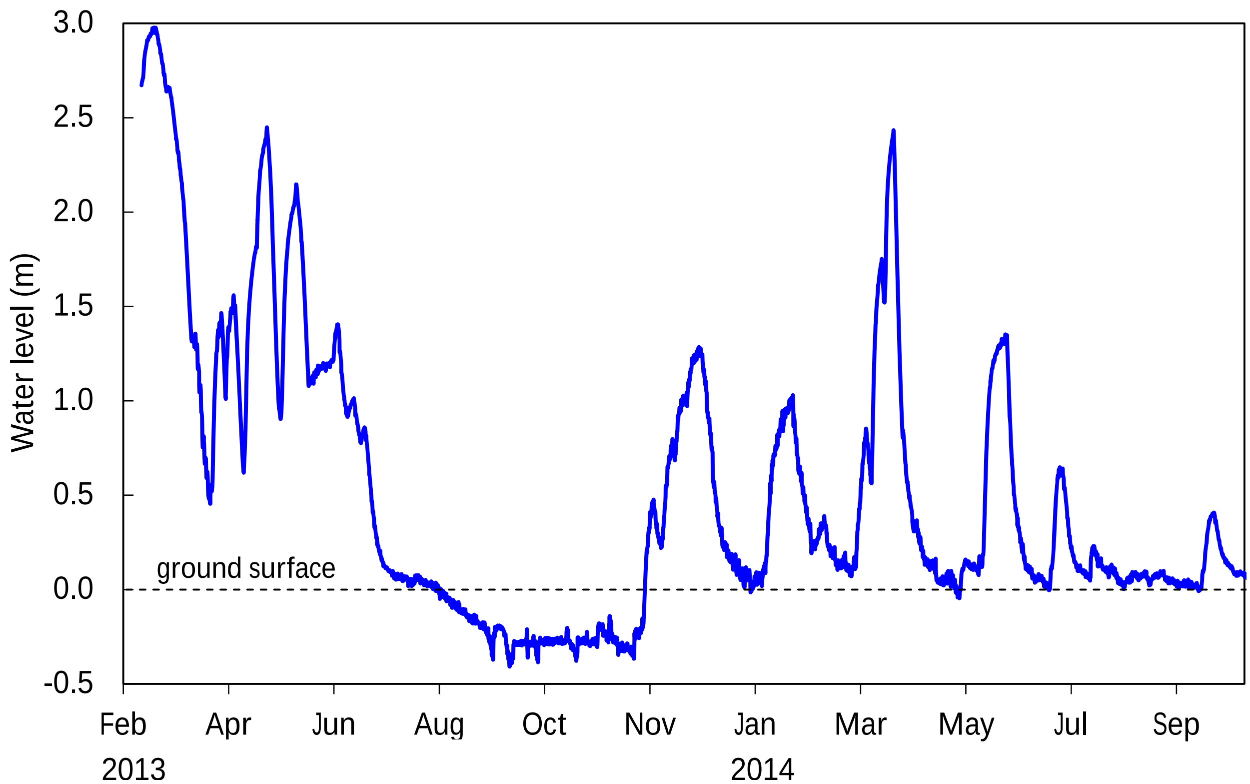


Figure 2. Water depth at the boardwalk in Sky Lake. Values less than zero represent times when the wetland was dry and water levels are the depth to saturated soils.

<u>Redox potential</u>

Redox potential measurements provide strong evidence of preferential flow pathways through the wetland sediments (Fig. 3). Six stations were set up, with separate probes inserted at depths of 30 and 60 cm at each location. In three stations, the redox potential showed no apparent response to changing water level. In two stations, rising water levels resulted in higher redox potential, consistent with the movement of oxygenated surface-water through the root zone at these localized points in the wetland.

Redox potential is not a good proxy for oxygen if trying to *quantify* the concentration of oxygen present. However, the presence or absence of oxygen should be expected to produce generally high or low redox conditions that should also be reflected by high or low Eh, respectively. In a plot of water depth vs Eh, we find a clustering of data in the high-Eh, high-water-level quadrant at two locations (middle row of Fig. 3). Significantly, plots at 30 and 60 cm at these locations show the same general relationship, suggesting downward flow of oxygenated surface water through each depth, but only when surface water levels rise above approximately 1 m. At one additional location, a high Eh response to rising water depth is only seen at 60 cm, not at 30 cm. Because tree limbs often become buried at an angle, the most likely explanation is that an angled preferential flow path was encountered at the 60 cm depth here.

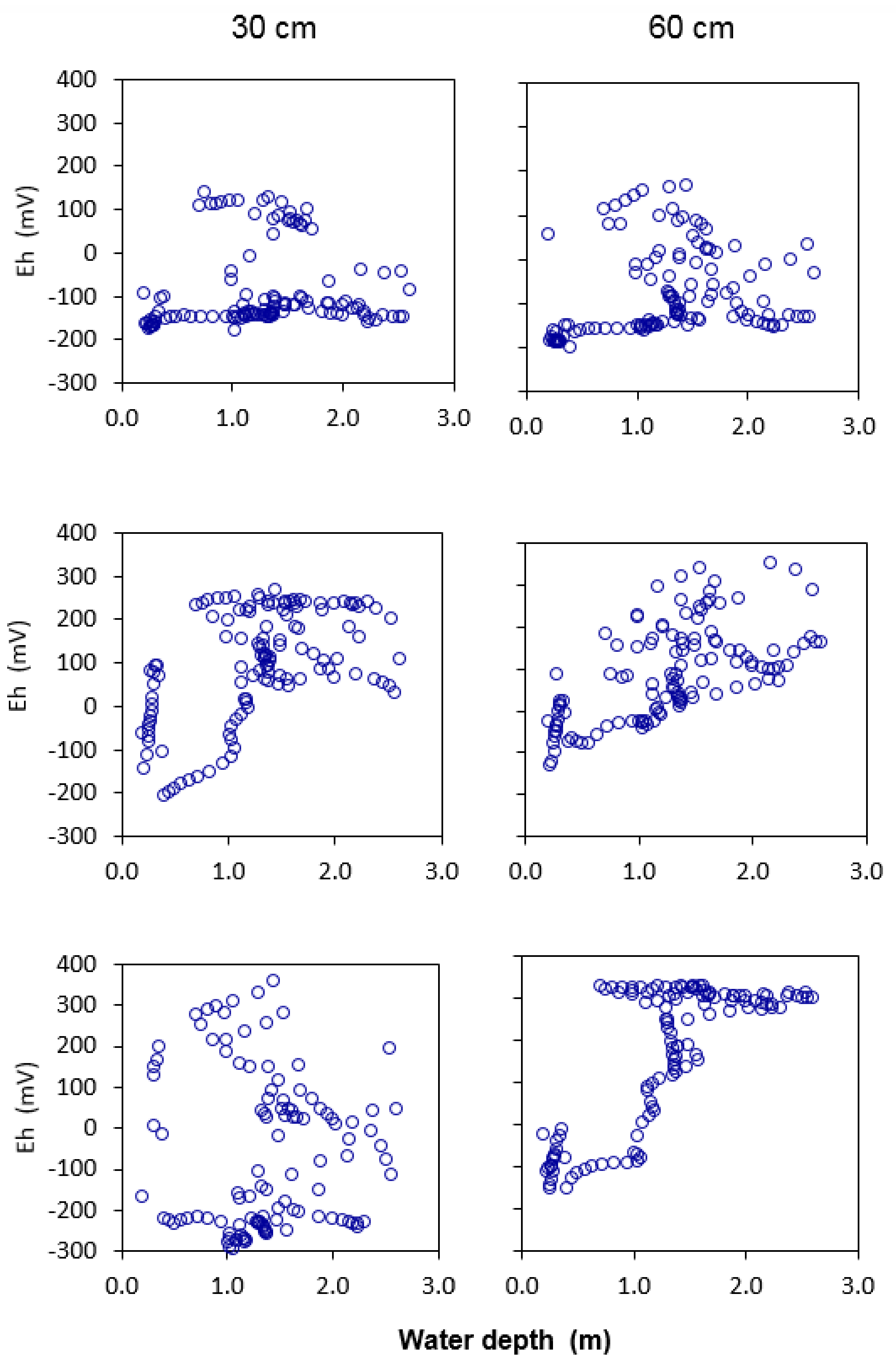


Figure 3. Top row shows no relationship between water depth and Eh (no vertical flow), middle row shows higher Eh with deeper water (flow when water depth exceeds 1 m), and third row shows only a response in the 60 cm probe (possible angled preferential flow path).

The data supports earlier observations of an apparent threshold before significant downward movement begins, though the lack of an Eh response for water levels below 1 m could also be explained by the rapid consumption of oxygen as it enters the system under low hydraulic gradients.

Radial tree growth

An effective, low-tech method for continuous monitoring of radial tree growth was employed by installing dendrometer bands around four bald cypress trees and fixing a time-lapse camera to take daily photographs of the gap in the dendrometer band (Fig. 4). The digital photos were later processed with pixel counts to determine the daily change in growth.

One unexpected result was that the settling of the dendrometer band can take several months. The growth data for the first growing season is much more erratic than the second (Fig. 5). Assessment of any impacts of changing water depth (and associated soil chemistry) during the first year is thus limited. When plotted as cumulative growth, the rate of growth for each tree (all roughly century-old) during the second year was very similar (Fig. 6). No consistent changes in growth rate are found repeated in all four trees except for a modestly slower growth rate at the start of the growing season. The R^2 value for all four trees taken together is very high at more than 0.98 for data up through the end of July, 2014. The highly linear growth rate shows no evidence of being enhanced or diminished by changes in water level over the same time period.

Figure 4. Time lapse camera and dendrometer band.

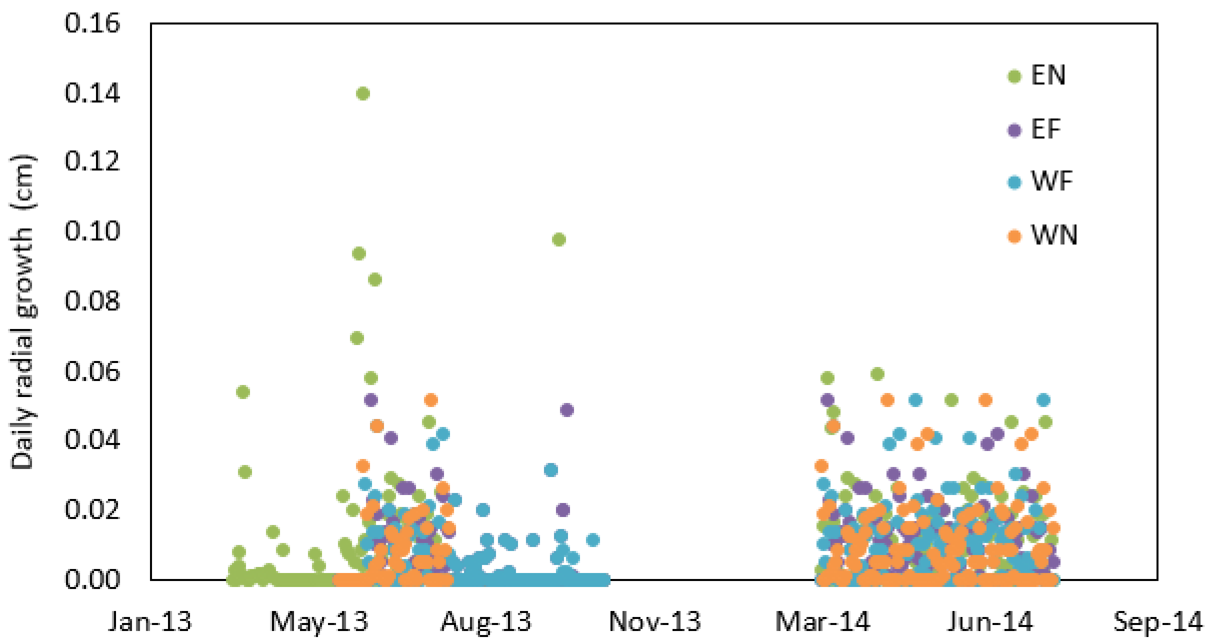


Figure 5. Daily radial growth in four bald cypress trees. Trees were named using their position relative to the boardwalk (east-near: EN, east-far: EF, west-near: WN, west-far: WF).

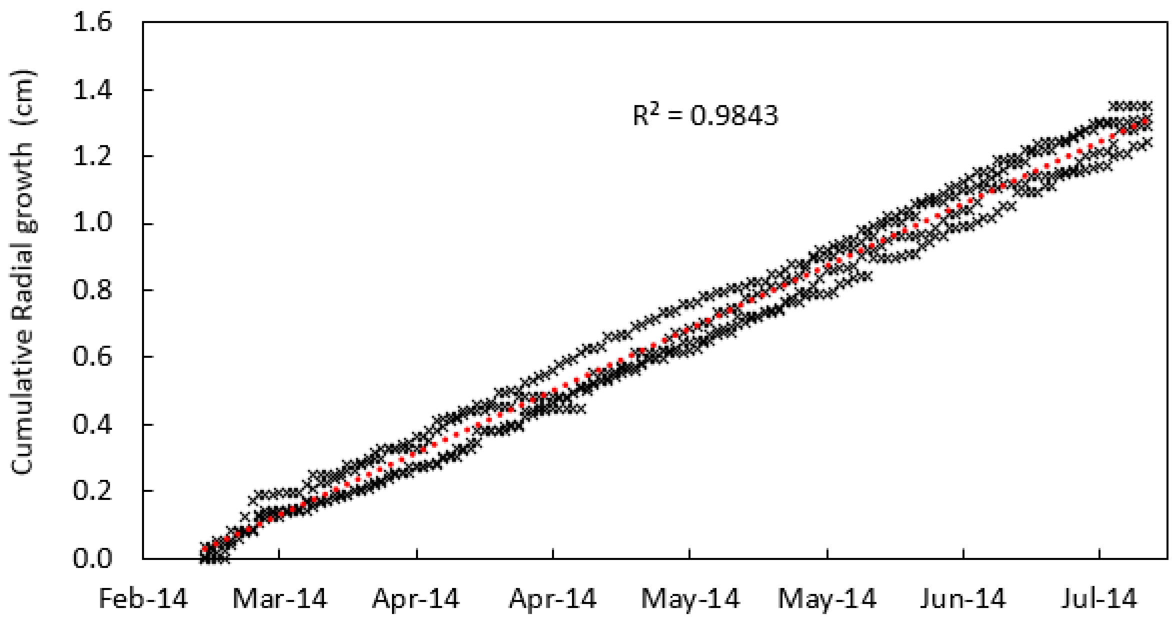


Figure 6. Cumulative growth of all four trees during the second year plotted together and a best fit line.

Sap flow

Sap flow was measured at half-hour intervals during the daytime when active photosynthesis is taking place. The four trees with dendrometer bands were also outfitted with sap flow sensors. For the purpose of this study, the actual velocity of sap flow is less important than relative changes in flow rate over time. Electronic output from the sensors is shown in Fig. 7 as unitless values.

Anomalously high values of sap flow (in excess of 100) were observed in year 1 for one tree over a period of two months during the summer. In the following year, similar anomalous values were observed for a different tree for a one month period, also during the summer. No reason is known for the aberrant results.

In general, one would expect sap flow to increase with increasing average daily temperature and with decreasing relative humidity (easier to move water from leaf stomata into drier air). A plot of the ratio of temperature/relative-humidity vs sap flow shows an overall positive correlation as expected (Fig. 8).

As with the radial growth data, there is no consistent pattern in sap flow over time that suggests enhanced or diminished flow with changes in water depth within a season. Only one abrupt shift in sap-flow rate is observed in mid-August 2013 (Fig. 7). Flow rates in three trees increased significantly over one day. The timing roughly matches when the root zone became desaturated. Subsequent declines in sap flow rate are consistent with daylight hours shortening and average temperatures declining. Sap flow rates were generally higher in year 2, however, indicating a possible effect of water depth over longer time scales. Water depth was low for the second half of the growing season in the first year and sap flow rates were lower. It is conceivable that the greater water depths during the growing season in the second year resulted in more oxygenated water reaching the root zone and enhancing nutrient uptake.

Groundwater response

Water levels in a single well completed near the center of the oxbow meander loop were measured every four hours. Changes in water level are consistent with recharge directly from the overlying oxbow (Fig. 9). Groundwater levels rose during periods of inundation of the wetland and fell when the wetland was dry, with lag times between peak surface-water depth and peak groundwater levels of approximately four weeks. Groundwater levels only rose when water depth in the lake exceeded approximately 1 m. Several periods of flooding of the wetland to depths less than 1 m did not produce increases in groundwater level. However, the rate of groundwater decline during this time was less than when the wetland was dry, which suggests that recharge may be occurring, but at a rate less than groundwater outflow.

While the data is consistent with recharge from the oxbow, there are other possible explanations. It is possible that the lake and groundwater both rise as a result of increases in local precipitation, with recharge to the groundwater via regional infiltration or through the Yazoo River streambed. Regional groundwater flow in the area is reported to be toward the west (Yazoo River is east of Sky Lake). More wells will be needed to characterize whether there is a groundwater mound beneath the lake (consistent with recharge from above), or a general gradient toward the west (consistent with recharge from the Yazoo River). Other wells are present in the area, though heavy pumping during the summer limits their usefulness for continuous monitoring.

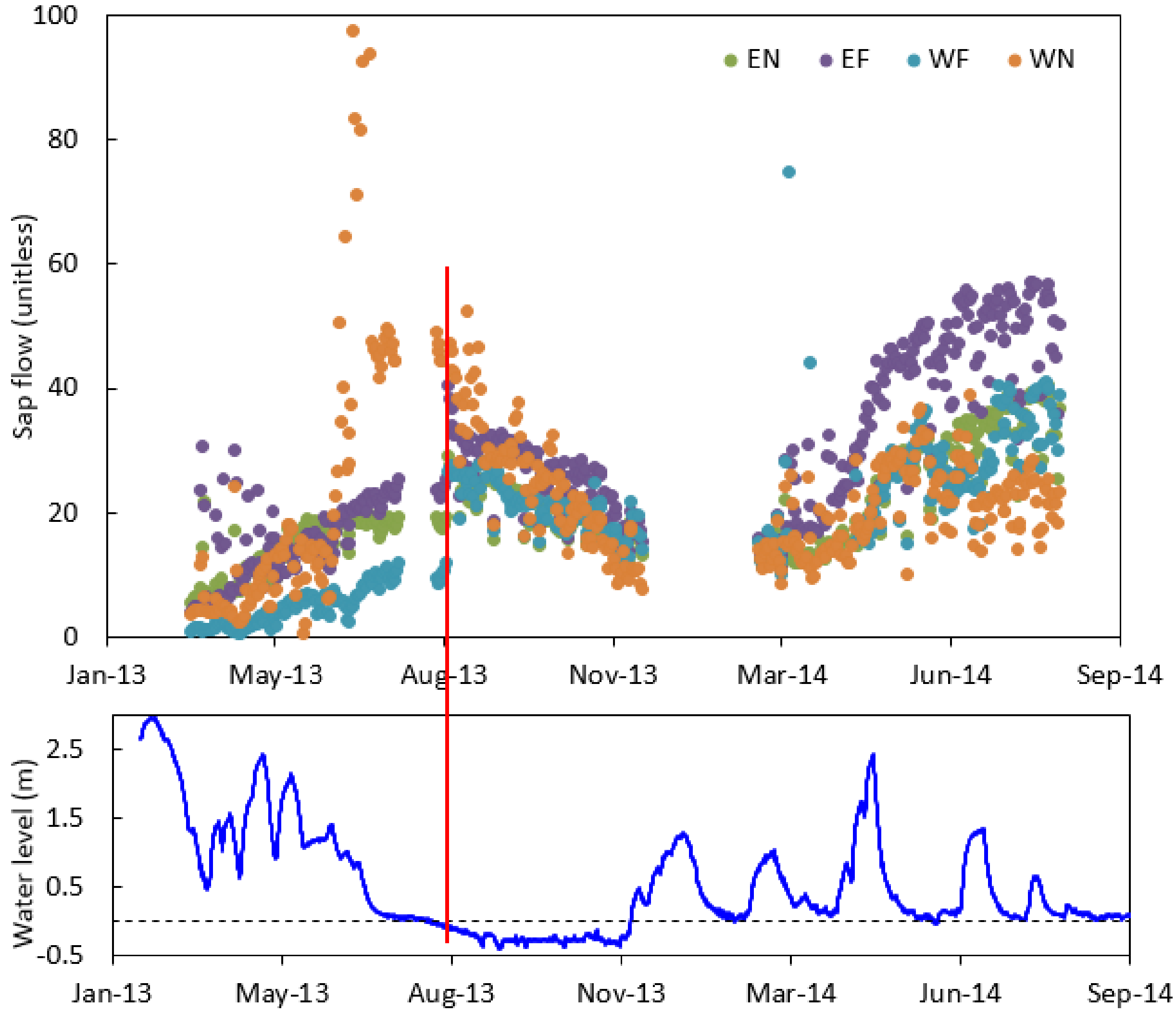


Figure 7. Sap flow (unitless) for four bald cypress trees (see Fig. 6 for key), compared to water depth over the same time period. The red line marks a time when sap flow rates in three trees (all but WN) increased significantly over a one day period. Gaps represent equipment malfunction.

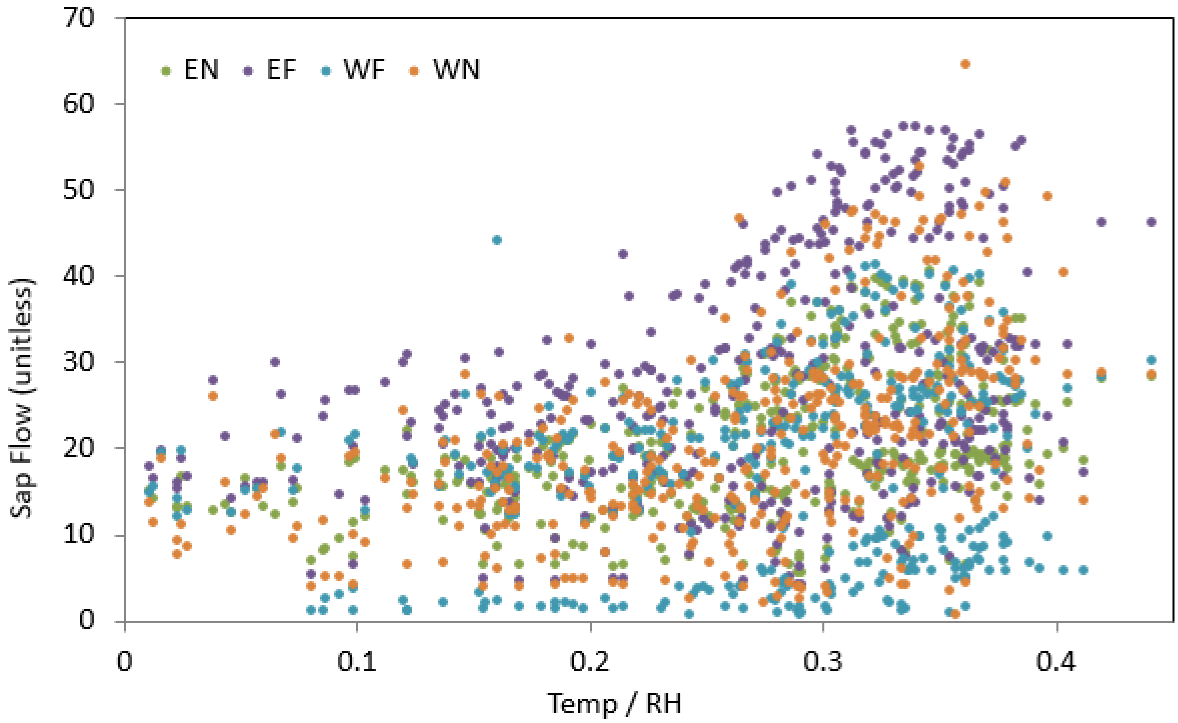


Figure 8. The ratio of temperature and relative humidity vs sap flow rate (anomalously high sap flow data not included).

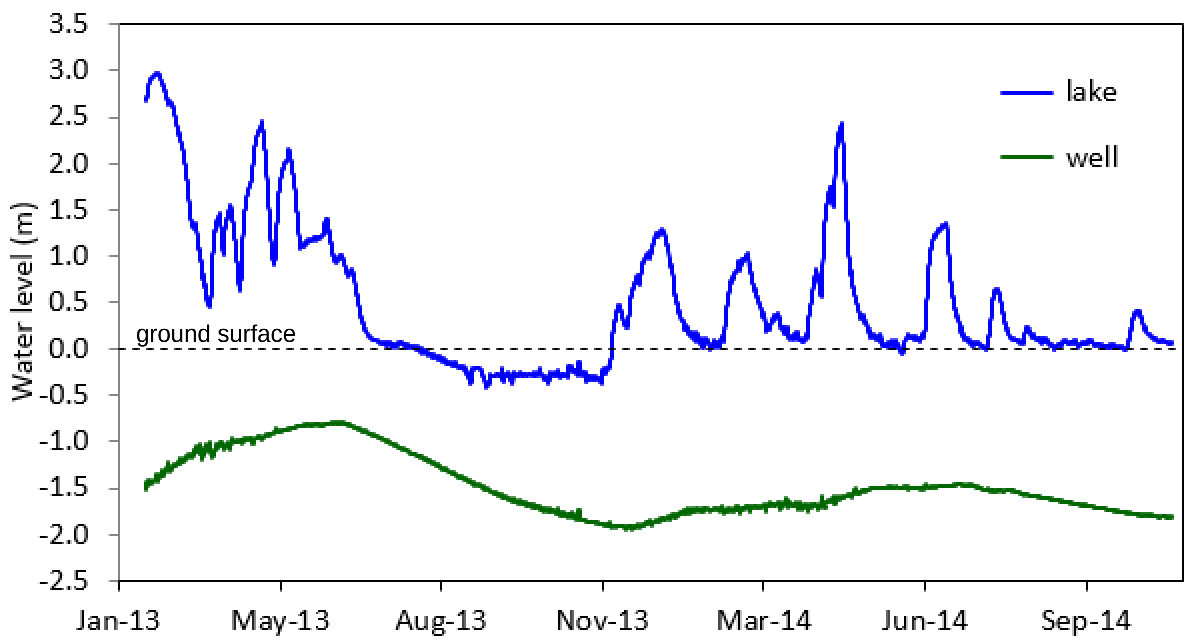


Figure 9. Water depth in the wetland and water level in the well in the center of meander loop (see Fig. 1). Water depth in the wetland and groundwater level are on the same scale, but the actual distance of the water table below ground surface is greater than shown.

Conclusions

Evidence of preferential vertical flow pathways is present in the Eh data where some sites show a clear response to changing water depth and others do not. The data is also consistent with a threshold depth requirement to either initiate flow, or to increase the delivery rate of oxygenated water to the point where it exceeds the oxygen consumption rate caused by respiration and decomposition reactions. The apparent response of groundwater to changes in lake-water depth is consistent with leakage of water from the oxbow along preferential pathways. At present, the sap flow and radial growth data do not appear to indicate short-term growth dependency on water depth. It is possible that long-term flooding of trees might have a measurably impact, but growth over a single season does not appear to be influenced by water depth.

FUTURE WORK

The results of this study point to the need for additional work on at least two fronts. First, a groundwater study with additional wells, as noted above, is needed to determine if there is direct recharge occurring to the groundwater from the overlying oxbow lake. Second, a longer-term study of tree growth is needed to determine the effect of water depth on time scales of three or more years. Plans are underway to further investigate these issues.

STUDENTS MENTORED

Chayan Lahiri, Ph.D. student
Hunter Landry, B.S. student, Geological Engineering

PUBLICATIONS / PRESENTATIONS

Results have been presented at the 2014 and 2105 WRRI annual conferences, the 2014 national meeting of the Geological Society of America (GSA), and the SE GSA regional meeting in Chattanooga, TN, in March. The two GSA citations and published abstracts are printed below.

Davidson, G.R. and C. Lahiri (2014) Preferential flow paths in oxbow wetlands: oxidizing saturated soils and groundwater recharge through clay. Vancouver, British Columbia, October 19-21, 2014, Geological Society of America Abstracts with Programs, vol. 46, no. 6, p. 482. https://gsa.confex.com/gsa/2014AM/webprogram/Paper249085.html

> Recent studies in Sky Lake, an oxbow lake-wetland system in northwest Mississippi, challenge two commonly held assumptions. The first assumption is that the fine-grained sediments that typically infill oxbow lakes create a barrier to vertical flow, effectively eliminating the lakes as a source of groundwater recharge. However, many of the oxbow lakes in the region have perimeter wetlands that host forests of cypress

and tupelo trees with extensive root systems. Decaying roots and fallen limbs have the potential to create preferential pathways to the underlying sands. Preliminary water-level results from a well in the center of the meander loop suggest the local aquifer is receiving recharge directly from the surrounding oxbow. A second assumption is that saturation of wetland sediment leads to reducing redox potential that is independent of subsequent changes in water depth. At Sky Lake, however, long-term measurement of soil redox potential at depths of 0.3 and 0.6 m have found isolated zones where the redox potential consistently rises to oxidizing conditions when wetland water depths exceed approximately 1 m. The response is attributed to the downward movement of oxygenated surface water through preferential flow pathways.

Lahiri, C. and G.R. Davidson (2015) Mississippi oxbow wetlands: Influence of preferential flow paths on soil redox, tree growth, and groundwater recharge. Chattanooga, TN, March 19-20, 2015, SE GSA sectional meeting, Geological Society of America Abstracts with Programs, vol. 47, no. 2, p. 69 https://gsa.confex.com/gsa/2015SE/webprogram/Paper252837.html

The floodplain of the lower Mississippi River is littered with oxbow lake-wetland systems supporting dense forests of bald cypress and tupelo gum. Fine-grained sediments infilling the oxbows form low hydraulic conductivity plugs that should minimize communication between surface water and underlying groundwater, and produce pervasive reducing conditions in the soils during flooding. In forested oxbows, however, extensive root networks and decaying fallen trees have the potential to produce zones of higher conductivity and preferential vertical flow pathways. Evidence of preferential flow paths has been documented in Sky Lake, an abandoned meander loop of the Mississippi River in northeastern Mississippi. Redox potential measured hourly over an 18 month period revealed isolated zones that became oxidizing when surface water levels exceeded one meter. Changes in groundwater levels in a well located inside the meander loop were also consistent with recharge from the overlying oxbow. Advective delivery of oxygen through portions of the root zone has the potential to enhance tree growth during periods of extended inundation. Several cypress trees have been outfitted to continuously monitor sap flow and radial expansion to identify possible links between growth and changes in soil redox potential that accompany changes in water depth.