Adaptive management of Catahoula Lake for Sediment Mobility and Control of Woody Encroachment

Basic Information

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Publications

1. Dugué, Lincoln. 2015. Hydrological influence on Catahoula Lake in an Altered Floodplain. MS Thesis, School of Renewable Natural Resources, Louisiana State University, Baton Rouge, LA
2. Edwards, B.L., M. Curcic, and R.F. Keim. 2014. Modeling wave effects on limits of woody vegetation in Catahoula Lake, LA, USA. Abstract presented at 2014 Fall Meeting, American Geophysical Union, San Francisco.
3. Keim, R.F., K. Latuso, R.D. DeLaune, and D.C. Weindorf. 2014. Sediment deposition into a valley-margin lake in a managed floodplain, Catahoula Lake, Louisiana, USA. Abstract presented at 2014 Fall Meeting, American Geophysical Union, San Francisco.

Problem and Research Objectives

Hydrologic management of wetlands and lakes often creates consequences for local ecosystems. Small changes in flooding and drought cycles can create large changes in plant communities and ecosystem structure. Because there are fewer and fewer wetlands remaining with natural hydrologic variability, and because wetland ecosystem services are becoming more valued, it becomes increasingly important to develop hydrologic management strategies to target desired conditions. However, in many cases it is unclear what management strategies are most appropriate and adaptive management of water for ecosystem structure is necessary. One of the most important examples of this problem in Louisiana is at Catahoula Lake (Figure 1), which is a critical, high-value managed wetland currently undergoing undesired ecosystem change.

Catahoula Lake is an important wetland for wildlife habitat in the Lower Mississippi Alluvial Valley (LMAV) characterized by highly variable water levels. Its proximity to the floodplain margin has prevented rapid sedimentation from the Mississippi or Red rivers leading to development of a perirheic wetland lake (Mertes 1997), rather than a forested floodplain. The lake bed consists of a broad, seasonally inundated herbaceous flat bordered by a band of woody shrubs—water-elm (Planera aquatica) and, to a lesser extent, swamp-privet (Forestiera acuminata)—which transitions to baldcypress and bottomland hardwoods with elevation.

Hydrologic variability is driven by both local runoff and the Mississippi River system. The resulting annual summer de-watering of the lake allows the lake bed to support a moist-soil vegetation community of high value for migratory waterfowl (Wills 1965), but encroachment by woody shrubs over the past ~70 years threatens ecosystem conversion to forest. Catahoula Lake has been internationally recognized under the Convention on Wetlands of International Importance (the Ramsar Convention) since 1991, and the control of woody encroachment is a high priority for the Louisiana Department of Wildlife and Fisheries (LDWF) and the U.S. Fish and Wildlife Service (FWS).

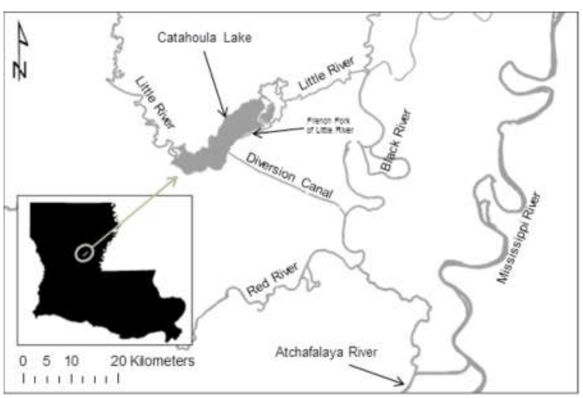


Figure 1. *Location map and hydrologic setting of Catahoula Lake, LA*

Hydrological processes controlling Catahoula Lake water levels and sedimentation have been progressively altered by navigation projects, water control structures, and subsequent geomorphic adjustments in the Mississippi and Red rivers (Latuso 2014, Dugué 2015).

The hydrological conditions in Catahoula Lake are most closely related to the Black River. Construction of locks and dams on the Black River began in 1926. In 1972 a new, higher set of locks and dams were completed on the Black and Little rivers near Catahoula Lake (Saucier 1998). To prevent permanent deep flooding and attempt to preserve the hydrological regime of the lake, the Catahoula Diversion Channel was constructed from the lake to the Black River below the lowest lock, and a control structure installed to partially control drainage from the lake (Figure 1). This channel was intentionally constructed to allow greater flow than the French Fork of the Little River, which was the original outlet of the lake but was closed in 1972 (USACE 1963, as cited by Bruser 1995).

The management plan for the Catahoula Diversion Channel since its completion has been to mimic the hydrological regime prior to the Ouachita-Black Navigation Project. Although there have been some variations through time, the general plan has been to keep the lake flooded from November-January at about 29.5 feet, increase stage to about 34 feet until July, and to de-water the lake to the 27-foot minimum July 1-November. However, targets are not always met because of both local and large-scale climate variations.

In recent decades there has been encroachment of woody shrubs into Catahoula Lake (Figure 2). Woody shrub cover decreases or eliminates production of the herbaceous community (Brown 1943, Wills 1965, Weller 1989), which reduces food value for waterfowl. Therefore, the Louisiana Department of Wildlife and Fisheries has periodically removed woody shrubs in an effort to maintain high quality waterfowl habitat. Encroachment has been occurring since at least the 1950s, but Wills (1965) described the rate of re-colonization as "very slow." The rate of encroachment has apparently increased since then (Bruser 1995), and Wills and Davis (1977) describe aggressive mechanical removals of water-elm and swamp-privet that occupied 10,000 acres by that time. LDWF is now routinely pursuing woody plant control efforts annually.

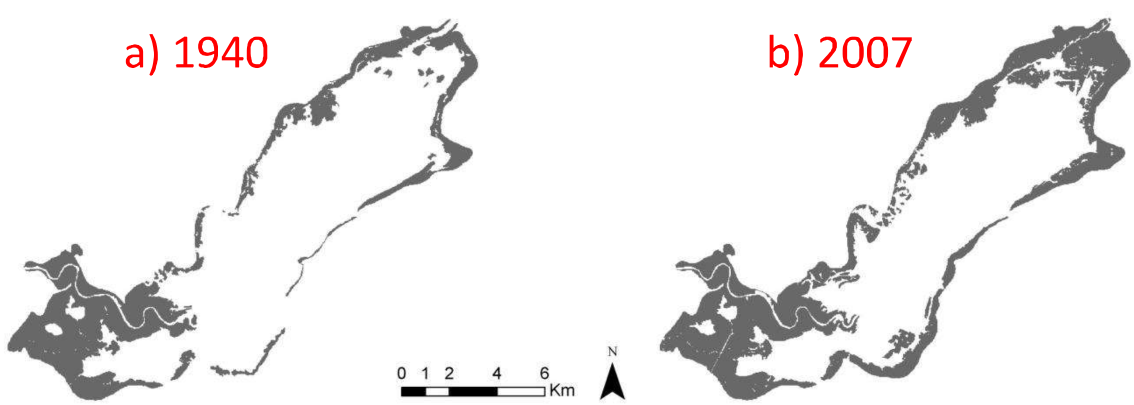


Figure 2. *Woody encroachment at Catahoula Lake. Perimeter of high density woody shrubs for a) 1940 and b) 2007. This encroachment threatens valuable waterfowl habitat and control of continuing encroachment is a management priority. Encroachment is highest on the northeastern end of the lake and relatively low around the rim of the main lake.*

Despite management intentions, there are strong indications that the management of the lake has been responsible for vegetation changes. Premature de-watering relative to the pre-existing natural regime has been linked to observed woody germination events. Bruser (1995) found that operation of the Catahoula Diversion Channel increased drainage rates of lake above those prior to its construction, that they decreased water level variations from August to November, and predicted that these changes would eventually lead to a conversion of the lake to a shrub swamp. Willis (2009) found that baldcypress growing on the western fringe of Catahoula Lake experienced a step increase in growth rates coinciding with the 1972 opening of the Catahoula Diversion Channel, which suggests more hydrologic stable conditions during the growing season. Although the specific details of processes controlling vegetation change are not clear, it is apparent that woody vegetation is now more favored than it was prior to the Diversion Channel, and that the management plan does not mimic the hydrologic regime under which the desired vegetation communities developed.

A new approach is needed for managing water in Catahoula Lake to counteract changes in ecosystem structure. Our goal is to provide decision makers with an adaptive water level management strategy designed to control woody encroachment on the lake bed. Sediment mobility and stresses resulting from wave action prevent establishment of seedlings through disturbance of the soil substrate and uprooting, and we propose that similar processes can be managed adaptively to control encroachment in Catahoula Lake. To accomplish this goal, we developed a stochastic model of hydrodynamic conditions conducive to sediment bed mobility and stress for a range of possible environmental and hydrologic conditions, so that lake water levels can be managed to increase bed disturbance.

Methodology

Historical water level analysis

Historical water levels for Catahoula Lake were analyzed for pre- and post-canal conditions. Lake levels were taken from the center-of-lake gage managed by the USACE for post-canal water level conditions (USACE 2014), and from the Placid Oil gage (private) for pre-canal water conditions.

Wind analysis

Wind data were analyzed using a joint probability distribution calculated using wind speed and direction data from the nearby Esler Regional Airport station for 1/1/1994-12/31/2013 (NCDC 2014).

An angular-linear joint probability function, $f_{V,\Theta}(v,\theta)$, can be defined by (Johnson and Wehrly 1978):

$$f_{V,\Theta}(v,\theta) = 2\pi g(\zeta) f_V(v) f_\Theta(\theta); \;\; 0 \leq \theta < 2\pi, -inf \leq v < inf$$

Where $f_V(v)$ and $f_\Theta(\theta)$ are the probability density functions of wind speed and direction, respectively, and $g(\cdot)$ is the probability density function of ζ, a circular variable defined by:

$$\zeta = 2\pi[F_V(v) - F_\Theta(\theta)]$$

where $F_V(v)$ and $F_\Theta(\theta)$ are the cumulative distribution functions of wind speed and direction, respectively.

Marginal distributions for wind speed and direction can be defined by a mixed singly truncated from below normal Weibull distribution for speed and a mixture of von Mises distributions for direction (Carta et al. 2008). This approach accounts for correlation between speed and direction, includes the frequency of zero-wind events, adequately describes unimodal or bimodal speed regimes, and can represent multiple prevailing wind directions (Carta et al. 2008).

Wave modeling

We used the University of Miami Wave Model (UMWM, Donelan et al., 2012) to estimate hydrodynamic conditions in the lake. The model solves the evolution of wave energy balance equation through time:

$$\frac{\partial E'}{\partial t} = \rho_w g \sum_{i=1}^{N} S_i$$

where *E'* is wave energy spectrum, ρ_w is the water density and g is gravitational acceleration. The source terms, S_i consist of wave growth (S_{in}), wave dissipation (S_{ds}), non-linear wave-wave interactions (S_{nl}), and bottom friction and percolation (S_{bf}) (Donelan et al. 2012).

The UMWM model resolves the following physical processes: (1) wave growth by wind; (2) wave dissipation by (a) spilling (deep water), (b) plunging (shallow water), (c) turbulence in the wave boundary layer, (d) bottom friction, (e) bottom percolation, and (f) viscosity; (3) modulation of short waves by long waves; (4) downshifting of energy due to non-linear dissipation and wave-wave interactions; (5) propagation of waves; (6) advection of wave energy by ocean currents; and (7) bottom and current-induced wave refraction.

The model requires inputs of bathymetry and meteorological forcing. We estimated bathymetry based on available data (Figure 3, Michot et al. 2002, USGS 2014). We truncated the developed elevation estimates by the 1940 tree line to model the effects of water management on woody encroachment in the lake bed.

We used multiple iterations of steady state wind conditions, e.g. a steady velocity from a single direction, to model potential wind scenarios for water level conditions ranging from 34 to 40 ft depth at the center of the lake. Output from model scenarios was used to assess the potential impacts of hydrologic management on bottom shear stress and bed mobility due to wave action in the lake.

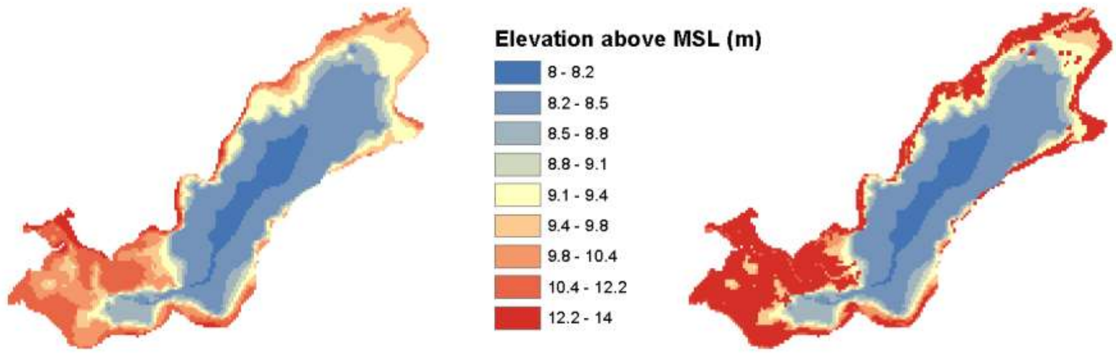


Figure 3. *Model bathymetry for Catahoula Lake. A) Bathymetry for the lake basin estimated from USGS NED DEM data and Michot et al. (2002), and b) bathymetry truncated by 1940 high density shrub perimeter. The high density tree line was treated as the model boundary.*

Principal Findings and Significance

Historic water levels were reconstructed for the center of Catahoula Lake. Overall, hydrologic variability has been moderated and extreme flood events have decreased due to hydrologic management (Figure 4). Notably, much of the natural variability in the timing of late spring and early summer months has been lost due to managed drawdowns via the diversion canal (Figure 4). Prior to hydrologic control via the diversion canal control structure, there was a much greater likelihood of maintaining flooded conditions into the early summer months (Figures 4, 5).

Stochastic analysis of wind data for the region indicates that the strongest winds are predominantly southerly during the late spring and shift toward southwesterly in the early summer, particularly in July (Figure 6). These winds combined with relatively shallow water levels are favorable for causing the maximum wave stress in the northeastern end of the lake, where woody encroachment has been greatest (Figure 2). Results from wave modeling indicate that there are sufficient wind events, in terms of both speed and direction, during this period to cause bottom shear stress to exceed entrainment and bed mobility thresholds for much of the lake (Figure 7). Further, seedling uprooting thresholds (Schutten et al. 2005, Balke et al. 2011, 2013) suggested by the literature are reached under rare conditions, e.g. 8 m/s and higher winds sustained for 1 hour or more).

Even during this period, when winds and historic water levels are best suited for bed disturbance due to waves, the probability of events sufficient to uproot woody seedlings is small. Likely, uprooting events historically occurred on a multi-annual scale. Perhaps more important were annual, moderate events that were more likely to occur during slower, more natural lake ebbs or prolonged floods. Under current hydrological management, however, the likelihood of either is essentially nil.

These results suggest that hydrologic management, particularly managed drawdowns at the end of spring, have removed natural hydrologic variability from the lake. Thus, during the time period that historically has been potentially the most conducive to large bottom shear stresses, bed mobility, and seedling uprooting, water levels in the lake are too low for wave action to play a part in shaping the ecological structure of the lake bed--specifically in the northeastern end of the lake, where elevation is slightly higher and woody encroachment has been the most significant (Figure 8).

There are several water management scenarios that could contribute to controlling woody establishment, but the most effective may be to introduce hydrologic variability into the late spring-early summer hydrograph by managing water levels to fluctuate at low to moderate levels. This could allow for periods of germination and subsequent removal of woody seedlings while mimicking more natural, pre-control variability. Under such a scenario, adverse effects on desired herbaceous communities which grow during the late summer-early fall would be minimized.

Under current management, there is less potential for wave induced stress on the lake bed than prior to hydrologic control, particularly in the early summer. More research is needed to develop specific water level management strategies to maximize the potential for bed mobility and wave stress. Further, species-specific uprooting thresholds need to be measured to better understand ecogeomorphic feedbacks.

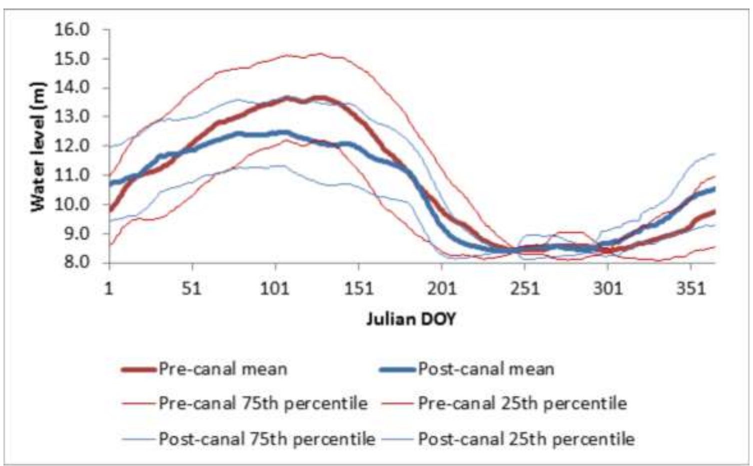


Figure 4. *Pre- and post-canal water levels in Catahoula Lake, LA.*

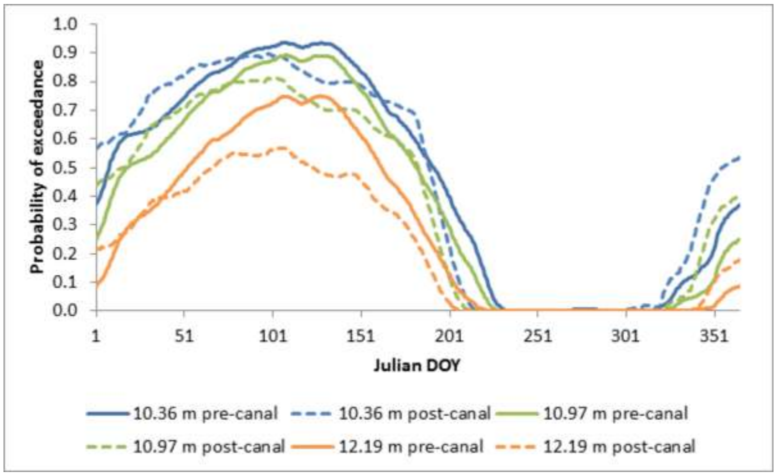
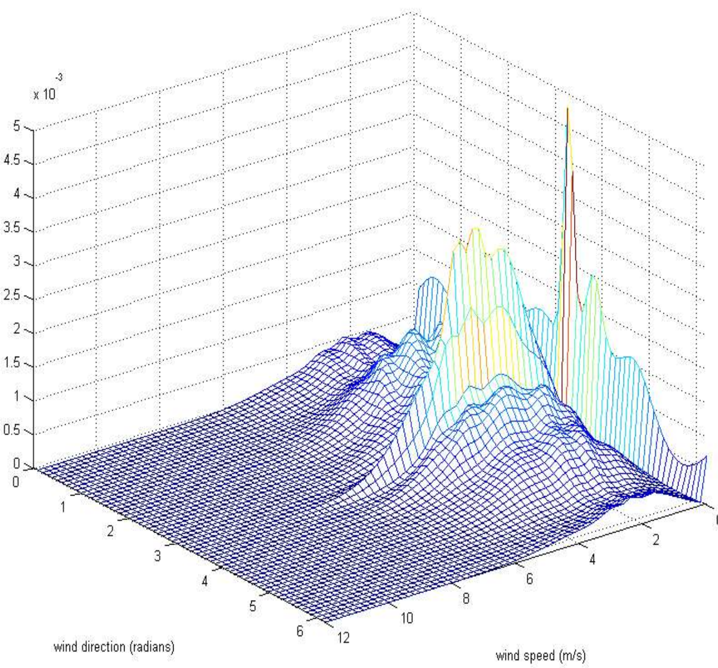


Figure 5. *Probability of exceedance for 34, 36, and 40 ft water levels for pre- and post-canal conditions at Catahoula Lake, LA.*



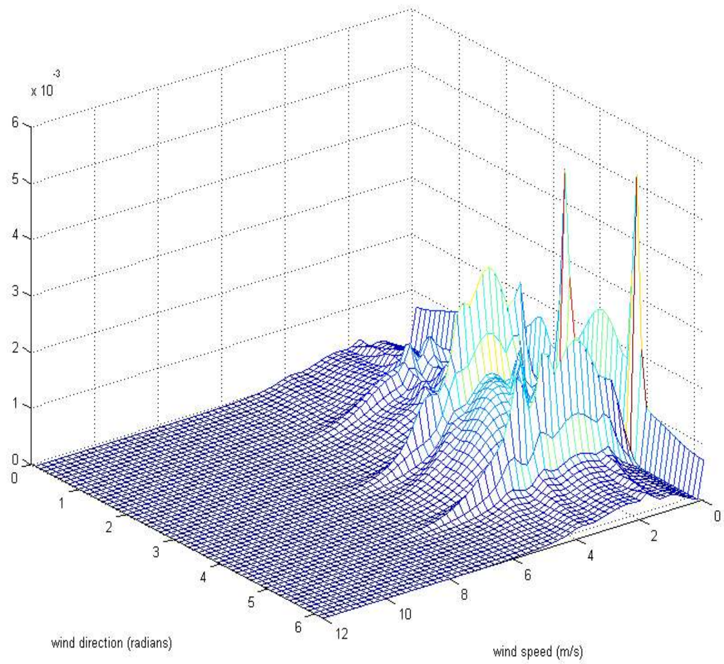


Figure 6. *Joint wind speed-direction probability distribution for June (top) July (bottom)*

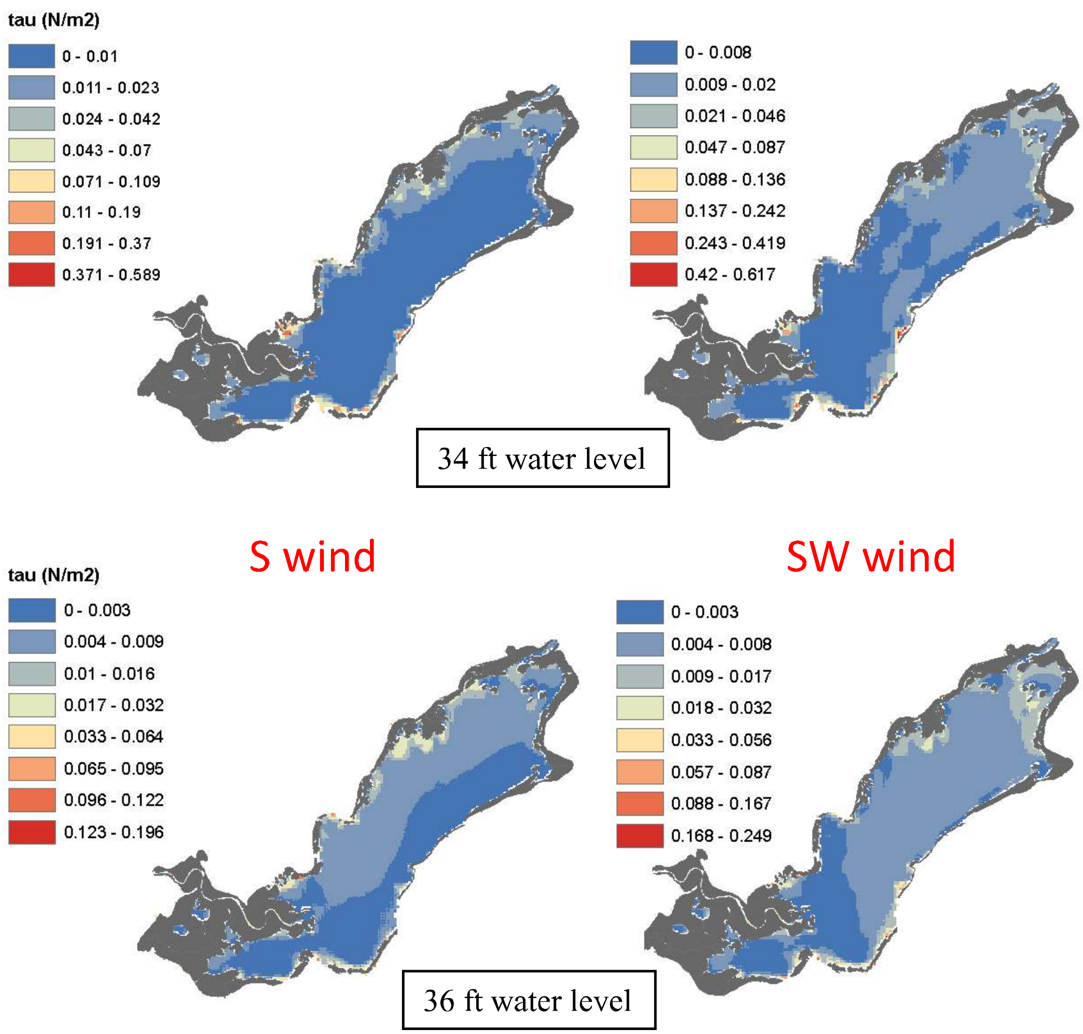


Figure 7. S*hear stress for S and SW winds of 8 m/s for a duration of 1 hour for 36, bottom, and 34, top, ft water levels. Under these scenarios, shear stress is high enough to approach seedling uprooting only in isolated patches on the lake margins. However, bed mobility via resuspension is likely to occur in large areas of the lake, even the northeast end where most encroachment has occurred.*

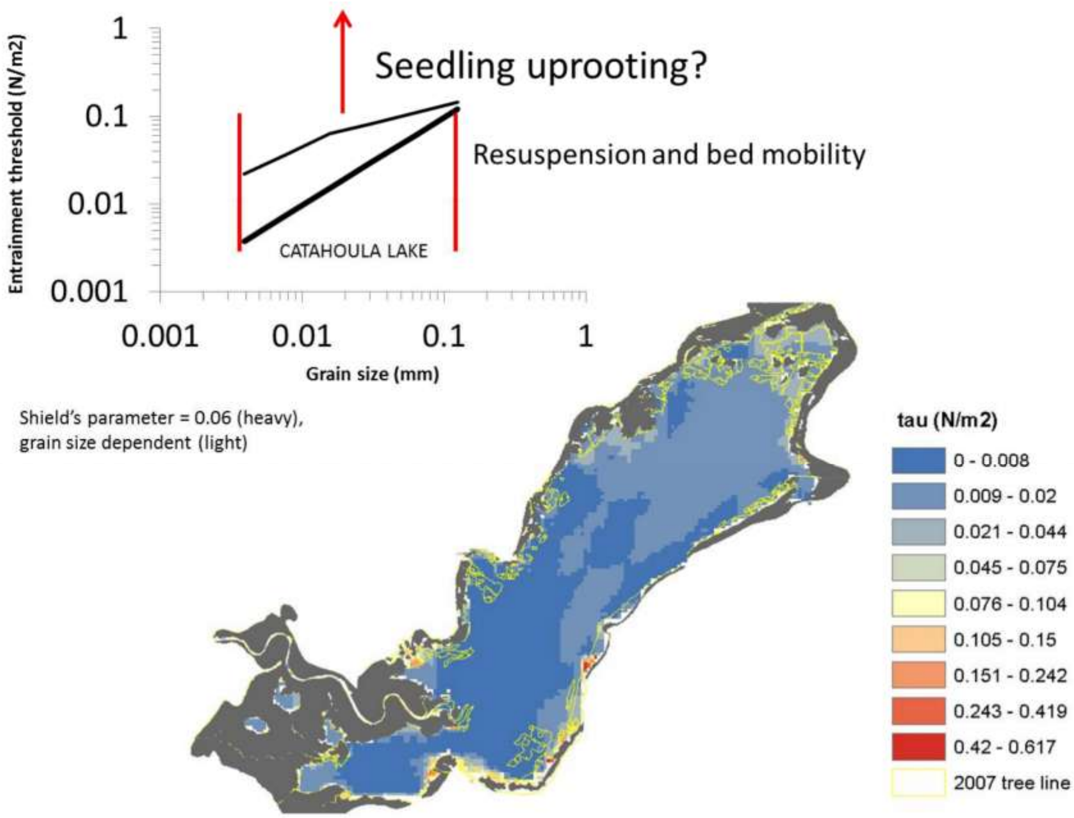


Figure 8. *The 34 ft water level, SW wind scenario overlayed with the 2007 tree line. Areas of higher stress around the lake rim appear to have experienced only gradual encroachment, if any. Also, it is apparent there is a significant increase in potential for wave stress with a relatively small decrease in water level. However, the probability of the lake remaining at or near 34 ft depth for extended periods of time when strong southerly or southwesterly winds are most probable is significantly reduced by current water management. Model runs with higher water levels predicted negligible stress for bed mobility for most of the lake.*

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Information Transfer

We are using results of this work to develop water management protocols for the lake in collaboration with the Louisiana Department of Wildlife and Fisheries.

Student Support

Megan Galbach, B.S., Mechanical & Industrial Engineering; Lincoln Dugué, M.S, Renewable Natural Resources