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Numerical analysis of effects of large wood structures on channel morphology and fish habitat suitability in a Southern US sandy creek

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ABSTRACT

A depth-averaged two-dimensional model was applied to simulate the effect of large wood structures (LWS) on flow, sediment transport, bed change, and fish habitat in a deeply-incised sharp bend in the Little Topashaw Creek, North Central Mississippi. The hydrodynamic simulation showed that the flow was retarded by the large wood matrices along the outer bank and accelerated in the main channel, thus causing deposition along the outer bank and erosion in the main channel, consistent with field observations. Effects on fish habitat were quantified using two approaches. Habitat evaluations using kinetic energy and circulation metrics indicated that LWS only slightly increased the diversity of physical conditions. Weighted usable areas (WUA) for two fish species, blacktail shiner (*Cyprinella venusta*) and largemouth bass (*Micropterus salmoides*), were computed using hydrodynamic simulations of three discharges before and after the LWS construction and habitat preference curves for depth and velocity. The results show that the values of WUA for both fish species were increased after LWS installation at all three discharges. Application of LWS improved the quantity and quality of fish habitats. Habitat evaluations based on computation of WUA were more sensitive to the influence of LWS than metrics based on velocity gradients. Copyright © 2009 John Wiley & Sons, Ltd.

KEY WORDS large wood structures; two-dimensional hydrodynamic model; habitat suitability index; sediment transport; spatial metric; rehabilitation; erosion control; sandy creek

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INTRODUCTION

Large wood (LW), which is often put into channels subsequent to bank failure, is an important component of aquatic habitat in sand-bed streams because it retains particulate organic matter (Bilby and Likens, 1980; Gregory *et al*., 2003), provides substrate for biomass production by benthic macroinvertebrates (Benke *et al*., 1985; Bilby, 2003), and fosters higher levels of invertebrate species richness and abundance (Cooper and Testa, 1999; Dolloff and Warren, 2003). LW also provides cover and pool habitat due to local scour (Abbe and Montgomery, 1996; Rosenfeld and Huato, 2003; Kreutzweiser *et al*., 2005) and creates zones of flow acceleration and deceleration that provide higher levels of physical diversity (Shields and Smith, 1992), which are important for fish (Warren *et al*., 2002; Warren and Kraft, 2003). Therefore, in recent years, engineers have increasingly considered the use of large wood structures (LWS) to stabilize sand-bed streams because it has the potential to be a low-cost and environmentally friendly method of habitat rehabilitation and erosion control. Successful application of LWS can result in decelerated erosion and ecosystem recovery at lower cost than other practices (Shields *et al*., 2004). Stabilization of eroding banks using structures composed entirely or partially of LW has been described for streams in Vermont (Edminster *et al*., 1949),, Arkansas (Mott, 1994),, Washington (Abbe *et al*., 1997), Illinois (Derrick, 1997), Mississippi (Shields *et al*., 2004), and Australia (Brooks *et al*., 2001). Stream aquatic habitat rehabilitation or enhancement using LW addition has been described for a small gravel-bed stream in Virginia (Hilderbrand *et al*., 1998); for a sand-bed stream in Mississippi (Shields *et al*., 2003); for small rivers in British Columbia (D'Aoust and Millar, 2000) and Washington (Larson *et al*., 2001); for a large, regulated river in British Columbia (Goldberg *et al*., 1995); and for a sand-bed river in Australia (Borg *et al*., 2007). Studies in wetlands and lakes with coarse woody debris (CWD) also show that CWD may enhance biodiversity and improve overall wetland health (Roth *et al*., 2007; Alsfeld *et al*., 2009).

LWS change the physical conditions of streams, such as velocity distributions, sediment retention, channel morphology, and vegetation (Nakamura and Swanson, 1993; Manga and Kirchner, 2000; Hygelund and Manga, 2003; Daniels, 2006; Manners *et al*., 2007; Magilligan *et al*., 2008; McBride *et al*., 2008; Oswald and Wohl, 2008). The ecological effects of LWS vary regionally, and therefore designs of LWS should vary regionally

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(e.g. Abbe *et al*., 1997; Drury *et al*., 1999; D'Aoust and Millar, 2000; Shields *et al*., 2004). Simulation of the physical effects of LWS is desirable for developing design criteria. Thus, the impacts of LWS on channel morphology and aquatic habitat need to be quantified to remove uncertainty for rehabilitation projects.

Two approaches: (i) two dimensional (2D) hydraulic metrics based on energy and vorticity concepts, and (ii) the habitat suitability index (HSI) model, have been used to quantify the effects of LWS on fish habitat suitability. Method (i) was suggested by Crowder and Diplas (2000, 2002) and demonstrated by Shields and Rigby (2005), while Method (ii) was developed by the U.S. Fish and Wildlife Service (USFWS) in the 1970s (Bovee *et al*., 1998).

Method (i) calculates two spatial indices of spatial flow complexity in stream habitats: kinetic energy and circulation metrics (Crowder and Diplas, 2000, 2002). The kinetic energy metric indicates the strength of energy gradients and highlights the location of valuable microhabitat features within a stream. The circulation metric is based on vorticity, which measures the rate at which a tiny fluid element rotates around its axes and indicates the presence and strength of eddies and other complex flow phenomena. The circulation metric is a weighted average of the vorticity values of all the fluid elements over a specified region and quantifies flow complexity within an arbitrary area, whether it is mesoscale habitat such as a pool/riffle sequence or the entire stream reach. Since many organisms are known to exploit regions of rotational flow for feeding and resting, these numerical indices are ecologically significant.

Method (ii) applies the HSI to assess the relative habitat availability for a particular life stage of a given species based on physical, chemical, and biological factors in an ecosystem. HSI models are based on the assumption that individuals of a given species will select and use areas that are best suited for a particular activity during a given life stage, resulting in greater use of higher quality habitat (Kliskey *et al*., 1999); thus, they represent the suitability of the habitat. HSI models often apply three types of suitability curves: literature review/expert opinion curves, utilization curves, and preference curves (Jowett and Richardson, 1990; Cheng *et al*., 2006; Gillenwater *et al*., 2006). Mathematical combinations of these curves, such as arithmetic or geometric means, produce an overall suitability index ranging from 0 (unsuitable) to 1 (highly suitable). Geometric mean calculations are preferred over arithmetic means because they allow the HSI to tend to zero if any of the input suitability parameters are zero.

HSI models often use the hydraulic results from one-dimensional (1D) or 2D hydraulic models. PHABSIM (Physical Habitat Simulation System, Milhous *et al*., 1989; Waddle, 2001) is a widely used 1D model (e.g. Carling, 1995; Gore and Hamilton, 1996; Milhous, 1999; Lopes *et al*., 2004; Hayes *et al*., 2007; Nagaya *et al*., 2008; Mwamila *et al*., 2008). Many studies (Ghanem *et al*., 1994; Crowder, 2002; Gard, 2003; Loranger and Kenner, 2004) have demonstrated the utility of horizontal 2D hydrodynamic models to study nature of the flow features (e.g. pool, riffles, and eddies) and associated aquatic habitats. Therefore, 2D hydrodynamic models, such as MASS2, RMA2 and SMS, combined with HSI model were used to evaluate fish habitat within river reaches (see Mussetter *et al*., 2004; Pasternack *et al*., 2004; Perkins *et al*., 2004; Nagaya *et al*., 2008; Pasternack *et al*., 2008), and also some habitat models based on 2D hydraulic simulation have been developed, such as River2D and FISU. The advantage of using 2D models in habitat studies is their capability of reproducing the detailed flow features, such as transverse flows, eddies, velocity gradients, and other complex flow patterns found within streams.

This study implements the computation of two spatial metrics [Method (i)] and HSI model [Method (ii)] based on a 2D hydrodynamic model to quantify effects of LWS on channel morphology and fish habitat suitability in a bend of Little Topashaw Creek in Mississippi. Method (i) can quantify the spatial flows occurring within micro-, meso-, and macro-habitat features to evaluate the flow complexity in stream habitats caused by LWS, while Method (ii) can determine the quality and quantity of habitat based on particular species to assess the effect of LWS on fish habitat.

PROJECT BACKGROUND

To develop and demonstrate a low-cost approach for channel stabilization and habitat rehabilitation, LWS were constructed along a 2-km-long reach of Little Topashaw Creek, which is a fourth-order stream in north central Mississippi. Floodplain stratigraphy was characterized by dispersive silt and clay soils overlying sand overlying consolidated cohesive material, and sandy deposits were often found along the bank toe (Shields *et al*., 2004). Mean channel width was about 30 m, and average thalweg elevation was about 6 m below the floodplain. Channel bed materials were comprised primarily of 0·2–0·3 mm sand. However, cohesive materials occurred as massive outcrops and as gravel-sized aggregates. Streamflow reflected upstream channel straightening, incision, and the absence of floodplain storage. During 1999–2004, only one overbank flow (unmeasured) was observed due to the extreme channel incision. The estimated 2-year discharge (magnitude equaled or exceeded, on average, once every 2 years) is 74 $m^3\ s^{-1}$ with a standard error of 35% (Shields *et al*., 2008). An observed discharge of 55 $m^3\ s^{-1}$ only reached mid-bank levels. High flow events tended to be extremely brief (<30 h) and frequent, with maximum depths of about 3 m and occasional velocities as great as 3 $m\ s^{-1}$ while base flows were generally <0·10 $m^3\ s^{-1}$. Materials available for LWS construction were limited to LW presently in the channel and trees growing in patchy stands on the floodplain. Additional information can be found from the website of the Little Topashaw Creek stream corridor rehabilitation project (USDA, 2008).

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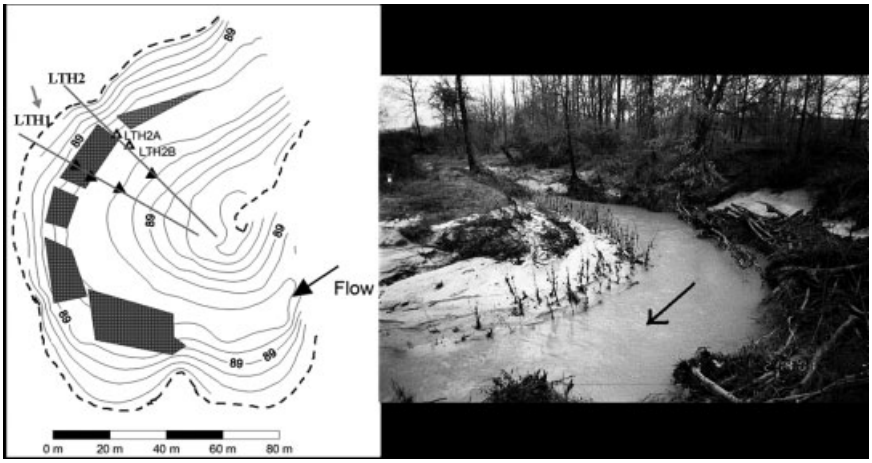

Figure 1. (left) Map of study site, Little Topashaw Creek; (right) Photo facing upstream (Gray arrow at top left of map indicates photo point).

The study site discussed in this paper was a deeply incised sharp bend, as shown in Figure 1 (Wu *et al.*, 2005), in which the shaded polygons are LWS and contours represent bed elevation in meters. Five structures made from felled trees were placed along the outside of the study bend in the summer of 2000 in order to stabilize the channel and create aquatic habitats (Shields *et al.*, 2004). The crests of structures were 1·1–3·2 m higher than the bed, and were emergent at low flows and submerged at high flows. Logs running transverse to the flow direction were about 6 m long and were anchored into the bank toe. Acoustic Doppler velocimeters were used to measure flow depth and vertically averaged velocity during high flows as described by Shields *et al.* (2001, 2004). As shown in Figure 1, these devices were arranged along two cross sections (LTH1 and LTH2). They were secured to either the bed or logs within the structures immediately downstream from the bend apex in order to observe the effects of LWS on flow conditions at the bank toe. Up to 200 velocity measurements were accumulated during each 2-s period, and the median of these values was assumed to be the depth-averaged flow velocity above the instrument. The devices recorded conditions within and adjacent to LWS, showing how the presence of the structure displaced the thread of maximum velocity toward the channel centerline and reduced velocity adjacent to the outer bank below levels required for sediment motion (Shields *et al.*, 2004).

Physical aquatic habitat and fish populations in Little Topashaw Creek were monitored in treated and untreated reaches for 2 years before and 4 years after rehabilitation (Shields *et al.*, 2006). LWS were used for habitat rehabilitation because wood provides important functions such as substrate for macroinvertebrates, pool development through local scour, velocity shelter during high flow, and cover from predators (Crook and Robertson, 1999; Bond and Lake, 2003; Brooks *et al.*, 2004; Shields *et al.*, 2004). The target fish species used for habitat suitability evaluation were blacktail shiner (*Cyprinella venusta*) and largemouth bass (*Micropterus salmoides*). Blacktail shiner is chosen for the habitat analysis because it was frequently present in the electrofishing samples collected from Little Topashaw Creek before and after the LWS construction. Largemouth bass was chosen because it was captured in the treated reach following the LWS addition but not before (Shields *et al.*, 2006). Blacktail shiner is usually most abundant in areas with swift current and riffles and silt, gravel, and bedrock substrates. Largemouth bass are apex predators and prefer clear waters with abundant vegetation. They also inhabit backwaters and pools of creeks and rivers. The construction of LWS may create suitable habitats for both fish species. The habitat suitability curves for blacktail shiner (Killgore and Hathorn, 1987) and largemouth bass (Stuber *et al.*, 1982) are listed in Table I.

ANALYSIS METHODS

FVM-Based CCHE2D hydrodynamic model

The FVM (finite volume method)–based CCHE2D model (National Center for Computational Hydroscience and Engineering's Two-Dimensional (2D) Model) is used in this study to provide hydraulic information in the channel before and after the LWS construction. FVM-based CCHE2D model is a depth-averaged 2D model for flow, sediment transport, water quality, and ecology in aquatic systems, which solves the depth-averaged 2D shallow water equations using the FVM on a non-staggered, curvilinear grid (Wu, 2004; Wu *et al.*, 2005). The sediment transport model simulates the nonequilibrium transport of nonuniform total-load sediment. The model is enhanced to calculate vegetation effects on flow, sediment transport, and channel morphology. The flow and sediment transport are computed in a decoupled way, but a coupling procedure is adopted for the three components of the sediment module: sediment transport, bed change, and bed material sorting.

LWS were placed in the study reach during July and August 2000. Two types of numerical simulations were conducted. First, the flow, sediment transport, and bed change due to the effect of LWS during the period from June 2000 to August 2001 were numerically simulated using the CCHE2D model (Wu *et al.*, 2005). Flow

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Table I. Suitability indices used in habitat model calculations (Stuber *et al.*, 1982; Killgore and Hathorn, 1987).

Blacktail shiner				Largemouth bass			
Velocity range (m s^{-1})	Suitability index	Depth range (m)	Suitability index	Velocity range (m s^{-1})	Suitability index	Depth range (m)	Suitability index
0	0·64	0·0	0·0	0·0	1·0	0	0·0
0.0914	0·72	0·24384	0·05	0·06	1·0	0·305	1·0
0.1524	0·85	0·6096	0·40	0·10	0·71	1·219	1·0
0.1829	1·0	0·97536	0·85	0·15	0·37	1·80	0·6
0.2438	1·0	1·524	1·0	0·2	0·01	2·50	0·3
0.2738	0·6	1·95072	1·0	1·0	0·0	3·00	0·2
0.3048	0·2	2·1336	0·22	5·0	0·0	10·0	0·2
0.4419	0·015	2·56032	0·095				
1.0	0·001	3·048	0·095				

Note: The index values for velocity and depth between two range values are determined by linear interpolation.

Table II. Values of mean absolute vorticity, average energy, and circulation metrics.

Discharge (m^3 s^{-1})		Average energy metric (m^{-1})		Circulation metric (s^{-1})		Mean absolute vorticity (s^{-1})	
		Without LWS	With LWS	Without LWS	With LWS	Without LWS	With LWS
High	15·5	0·677	0·791	0·160	0·163	0·0827	0·0832
Medium	5·0	0·862	1·117	0·214	0·221	0·0778	0·0805
Low	1·5	0·489	0·519	0·184	0·180	0·0552	0·0540

records (15-min interval) from the gage about 1 km upstream from the study reach were used as the inflow condition, and water surface elevations recorded by one of the acoustic Doppler devices in the downstream end of the reach were used as the water level boundary condition. Suspended load and bed load were simulated to obtain the total load. The bed material in the study reach was quite uniform and the median size was about 0·26 mm. The Manning roughness coefficient was estimated as 0·028. In the simulation, the effect of LWS on flow and sediment transport was considered by adding the drag force of the LWS on the fluid into the momentum equations and the turbulence generation into the turbulence kinetic energy equation. The average diameter of the logs was about 0·3 m, and the vegetation density of LWS (submerged volume of logs/submerged volume of entire structure) was estimated as 20%. The effect of helical flow on the main flow and sediment transport in the channel bend was taken into account through the dispersion terms in the momentum equations and in the suspended-load transport equation and by adjusting the movement direction of bed load. The second type of numerical simulation consisted of using the validated 2D model to simulate water depths and velocities for three steady flow conditions: high (15·5 m^3 s^{-1}), medium (5·0 m^3 s^{-1}), and low (1·5 m^3 s^{-1}) flows (see Table II) for conditions before and after LWS construction. These steady flow simulations were then used to evaluate the effect of LWS on fish habitat analysis at the study site.

Spatial metrics of energy and circulation

Computations of two metrics, i.e. kinetic energy and circulation, were implemented in our 2D hydrodynamic model to quantify effects of LWS on the study reach flow complexity. The kinetic energy metric was computed as follows (Crowder and Diplas, 2000):

$$Energy = \frac{\frac{\partial}{\partial s}(V^2/2)}{V^2/2} = \frac{2V_{\text{ave}}\frac{V_2 - V_1}{\Delta s}}{V_{\min}^2} \qquad (1)$$

where V is the magnitude of the depth-averaged velocity; V_1 and V_2 are velocity magnitudes measured a distance Δs apart; V_{ave} is the average of V_1 and V_2; $V_{\min}$ is the minimum value of V_1 and V_2; and s indicates the direction of the line between points 1 and 2 in which the spatial change in kinetic energy ($V^2/2$) is being evaluated.

Vorticity represents the rate at which a tiny fluid element rotates around its axes. For 2D flow fields, ignoring the z-velocity component, vorticity can be calculated by

$$Vorticity = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = \frac{\Delta v}{\Delta x} - \frac{\Delta u}{\Delta y} \qquad (2)$$

where u and v are the x and y velocity components.

Circulation is defined as the sum of the vorticity values of all the fluid elements within an arbitrary area S. Thus, its value could be positive, negative, or zero within a region containing areas of positive and negative vorticity. To reflect the total flow complexity within the region, the area-weighted mean absolute value of circulation is computed as follows (Crowder and Diplas, 2002):

$$Circulation = \frac{\int\int_S |Vorticity| \cdot d\overline{A}}{A_{\text{tot}}}$$

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$$= \frac{\sum_{i}^{M} |Vorticity| \Delta A_i}{\sum_{i}^{M} \Delta A_i} \quad (3)$$

where A_{tot} is the total wetted area over which circulation is being computed, M is the total number of wetted grid cells, and ΔA_i is the area of grid cell i. The magnitudes of metrics based on velocity gradients are inversely related to the grid cell size (Δx and Δy) used in their computation (Shields and Rigby, 2005). Intuitively, one might argue that the most ecologically important vortices are scaled at roughly the same size as the bodies of the organisms of interest. Grid cell sizes in the computation mesh for this model were on the order of 0·5 m on each side, which is larger than the average size of fish collected from the stream (Shields *et al.*, 2006).

Habitat suitability index model

The habitat model computes the weighted usable area (WUA) for a particular species in a life stage of interest. In the determination of usable habitat area, the model weights each cell using habitat suitability curves that assign a relative value between 0 and 1 for the target species. The WUA for all cells in a stream reach is then evaluated as

$$WUA = \sum_{i}^{M} CSI_i \cdot \Delta A_i \quad (4)$$

where CSI_i is the combined suitability index of grid cell i. CSI can be determined using several methods by combining suitability weights for water velocity, depth, channel property (substrate), sediment concentration, etc. The value of combined suitability indices (CSI) may potentially range from 1·0 for a cell with ideal habitat quality to 0·0 for a cell that is entirely unsuitable.

The WUA for blacktail shiner and largemouth bass before, immediately after, and 1 year after the LWS placement was computed. The suitability indices of water depth and velocity (Table I) were combined by computing a geometric mean for each cell for each of the selected discharges:

$$CSI = (C_{vel} \cdot C_{dep})^{1/2} \quad (5)$$

where C_{vel} and C_{dep} are the suitability indices for flow velocity and depth, respectively. Simulation of the effects of LW addition on cover was beyond the scope of this study.

RESULTS

The hydrodynamic model was used to simulate flow, sediment transport, and bed change during the first year after the LWS installation using the recorded stage and discharge hydrographs as model inputs. The mesh, flow and sediment conditions, and model validation were described in detail by Wu *et al.* (2005). Simulated velocities during a flow event with a peak discharge of 15·5 $m^3\ s^{-1}$ were compared with the velocities recorded by Doppler devices. The root-mean-square relative errors for velocities between the simulation and measurement at the LWS zone (LTH2A) and the centerline of the base flow channel (LTH2B) were 40·4 and 26·4%, respectively, for this event (Wu *et al.*, 2005). Considering the noise in the measured velocities due to turbulent fluctuations, acoustic interference from floating and suspended trash and debris, and factors internal to the instrument, the performance of the model is reasonably good.

Since a full description of the hydrodynamic simulation of the study bend before and after LWS placement can be found in Wu *et al.* (2005), only the simulated velocity distributions are shown here (Figure 2). Consistent with field data, flow was retarded by the structures along the outer bank and accelerated in the main channel. Figure 3 shows the distribution of the kinetic energy metric in the study reach for a steady flow of 15·5 $m^3\ s^{-1}$.

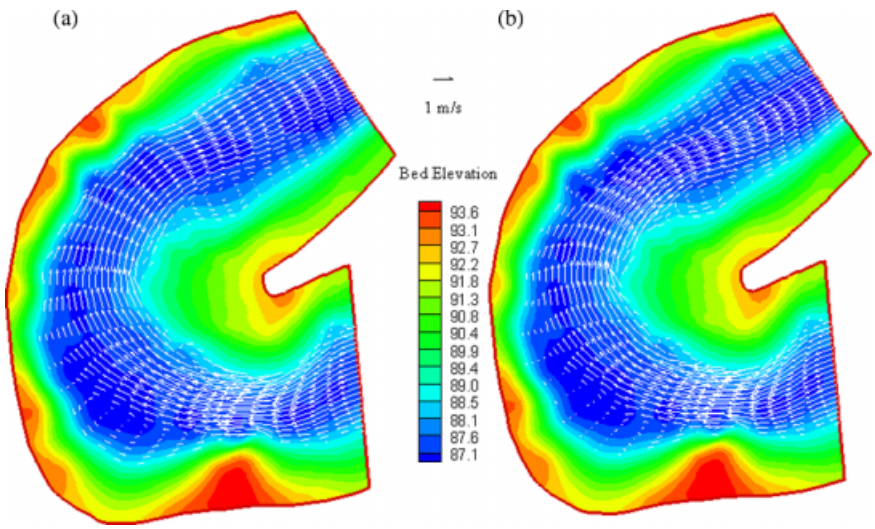

Figure 2. Simulated flow fields at a discharge of 15·5 $m^3\ s^{-1}$: (a) without and (b) with LWS.

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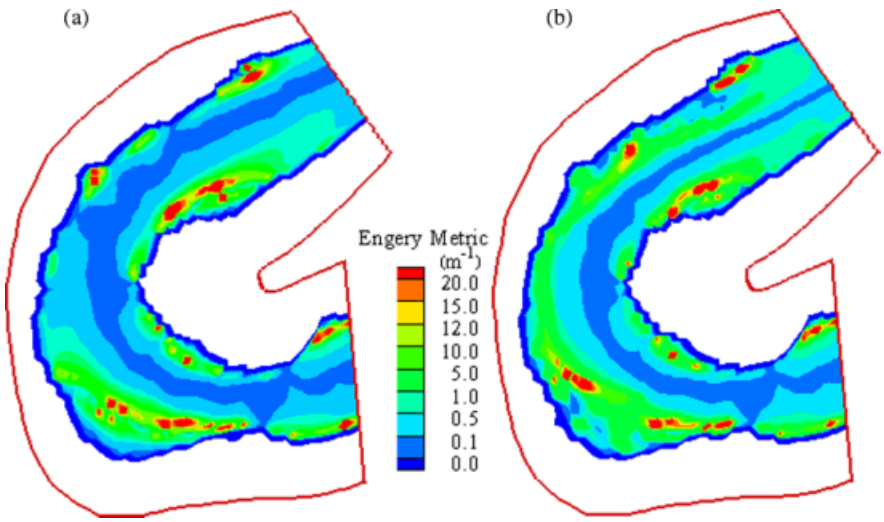

Figure 3. Contour map of kinetic energy metric (m^{-1}) at a discharge of 15·5 m^3 s^{-1}: (a) without and (b) with LWS.

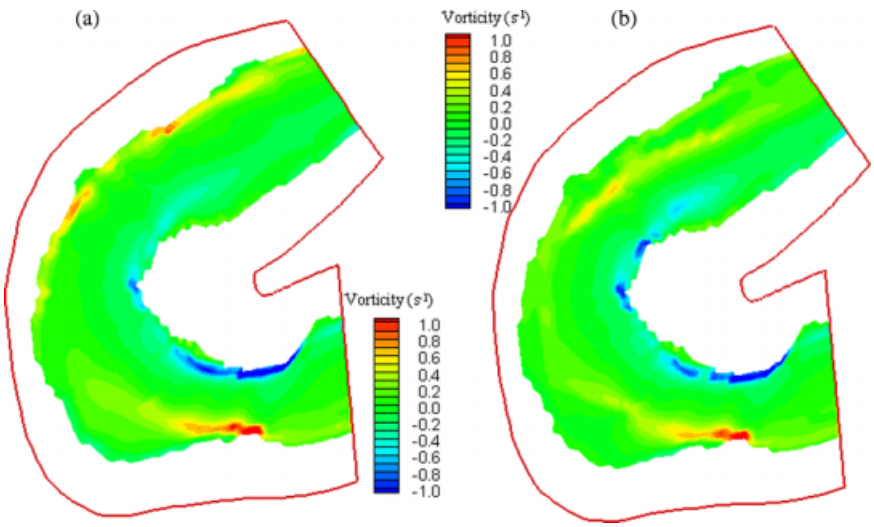

Figure 4. Contour map of vorticity (s^{-1}) at a discharge of 15·5 m^3 s^{-1}: (a) without and (b) with LWS.

After LWS were constructed, the value of the kinetic energy metric along the inner bank did not change much, while its value along the outer bank increased from 0·2 to 3·0 m^{-1}. Kinetic energy gradients were higher near and inside the area covered by LWS, and the area with larger energy metrics greatly increased. LWS also increased the transverse flow, a form of flow complexity, in the study site. The distributions of vorticity and $|\text{vorticity}|/|\text{vorticity}|_{ave}$ (absolute vorticity values scaled by the mean absolute vorticity) in the study reach are illustrated in Figures 4 and 5, respectively. Because of LWS, the regions with the larger positive values of vorticity, which were along the outer bank, were shifted to the main channel (Figure 4), and the magnitude value of vorticity was increased both in the main channel and along the inner bank, although the value was decreased along the outer bank (Figure 5). The reach-mean absolute vorticity with LWS in Figure 5 was 0·0832 s^{-1}, compared with 0·0827 s^{-1} without LWS. The average energy, area-weighted circulation, and mean absolute vorticity metrics for three different discharges before and after the LWS installation for the entire study reach are shown in Table II. The values of the three metrics increased by 0·6 to 29·6% after the LWS installation with the exception of mean absolute vorticity metric at low flow. This was probably due to the fact that most of the LWS were not in the water at very low stages.

Habitat suitability analysis was more sensitive to LWS placement than spatial metrics based on velocity gradients. Figures 6 and 7 compare the CSI for blacktail shiner and largemouth bass, respectively, before and after LWS construction. Following LWS construction, habitat suitability increased along the outer bank, which was covered by LWS, and reach total WUA also increased (Figures 6 and 7). The WUA for blacktail shiner increased 14–23% (Table III and Figure 8), and more than doubled for largemouth bass (Table IV and Figure 8). Figure 9 shows the simulated bed change and the CSI for largemouth bass and blacktail shiner 1 year following rehabilitation at a discharge of 15·5 m^3 s^{-1}. The long-term simulation using the recorded hydrograph showed that deposition occurred in and near the area where LWS were located and the

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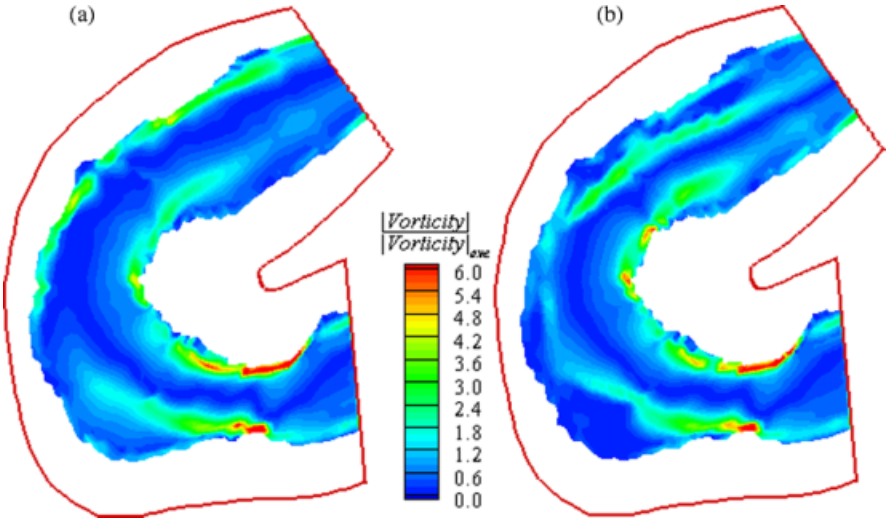

Figure 5. Contour map of |vorticity|/|vorticity|$_{ave}$ at a discharge of 15·5 m^3 s^{-1}: (a) without and (b) with LWS.

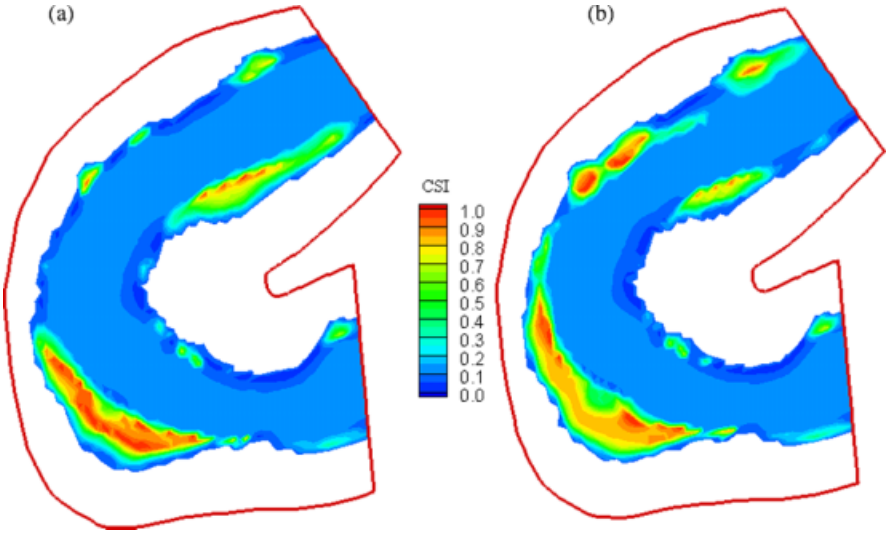

Figure 6. Combined suitability indices (CSI) for blacktail shiner at a discharge of 15·5 m^3 s^{-1}: (a) without and (b) with LWS.

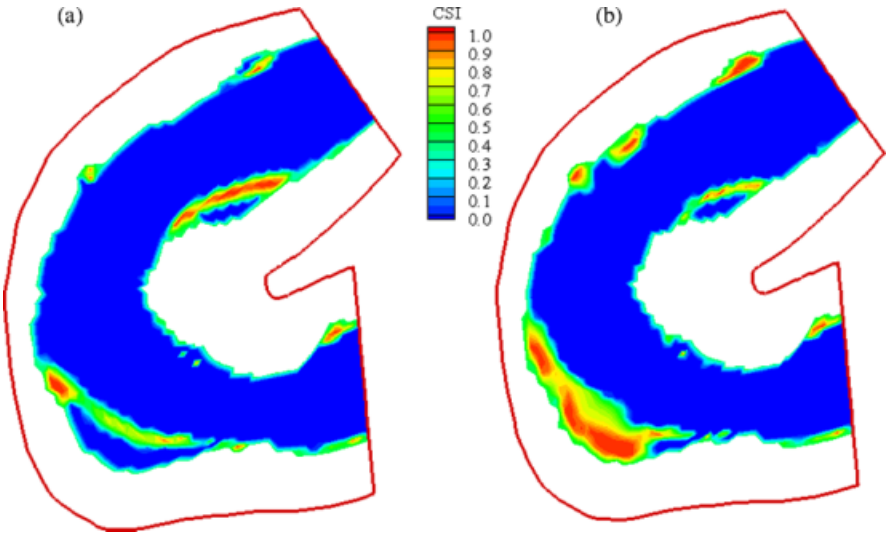

Figure 7. Combined suitability indices (CSI) for largemouth bass at a discharge of 15·5 m^3 s^{-1}: (a) without and (b) with LWS.

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Table III. Weight usable area (WUA) for blacktail shiner at three discharges.

Discharge (m^3 s^{-1})		WUA (m^2)		WUA ratio	
		Without LWS	With LWS	With LWS (initial) / Without LWS	With LWS (after 1 year) / Without LWS
High	15·5	300·42	341·66	1·137	1·140
Medium	5·0	150·71	184·88	1·227	1·233
Low	1·5	112·97	138·35	1·225	1·203

Table IV. Weighted usable area (WUA) for largemouth bass at three discharges.

Discharge (m^3 s^{-1})		WUA (m^2)		WUA ratio	
		Without LWS	With LWS	With LWS (initial) / Without LWS	With LWS (after 1 year) / Without LWS
High	15·5	90·85	164·12	1·806	1·839
Medium	5·0	44·53	113·97	2·559	2·561
Low	1·5	47·26	116·15	2·458	2·226

main channel eroded slightly (Figure 9), consistent with field observations (Shields *et al*., 2004).

DISCUSSION

LW in streams plays an important role in pool formation and in sediment storage (Kreutzweiser *et al*., 2005; Magilligan *et al*., 2008). Fish use pools and cover associated with LW for velocity refuge, overhead over, spawning, rearing, and migration (Crook and Robertson, 1999; Borg *et al*., 2007). Many stream rehabilitation projects involve addition of stone or wooden structural elements to streams to improve physical habitat by replacing lost LW (Borg *et al*., 2007). Design for most of this work is currently based on professional judgment rather than quantitative measures. A better understanding of interactions among flow, channel elements, and organisms may be helpful in producing more effective projects (Crowder and Diplas, 2002).

We selected a small but typical reach of a meandering sand bed creek to study the effects of LWS on fish habitat and channel morphology. Outputs from 2D hydraulic simulations were used to compute habitat quality metrics

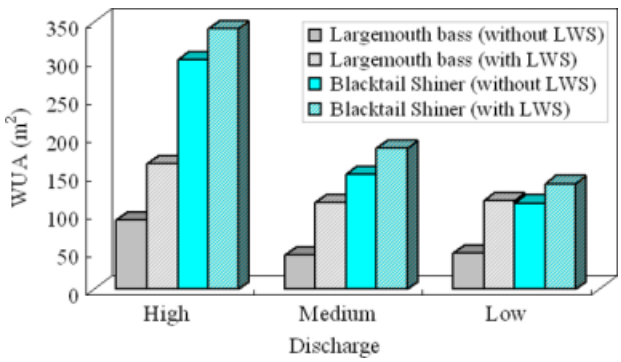

Figure 8. Comparison of weighted usable areas (WUA) for largemouth bass and blacktail shiner.

based on velocity gradients and habitat preference curves. Kinetic energy and circulation metrics within the study reach were only slightly increased by the construction of LWS due to complex flow around the logs and attendant local scour. However, main channel velocities were slightly underpredicted during the higher discharges (14–16 m^3 s^{-1}, Wu *et al*., 2005). Since the main channel velocities were underpredicted, spatial gradients between the main channel and flow regions within the influence of the LWS would also be underpredicted for this range of flows. This would lead to underestimation of the effects of LWS on reach-mean values for the kinetic energy and circulation metrics.

Habitat evaluations based on preference curves and computation of WUA were more sensitive to LWS addition than the kinetic energy and circulation metrics. Overall habitat suitability was increased for both fish species after the construction of LWS (Figures 6 and 7), with greatest changes associated with LWS. For the modeled discharges, WUA for blacktail shiner increased as much as 23%, and the WUA for largemouth bass increased as much as 156%. Use of published habitat preference curves (Table I) implies that biota–habitat relationships are transferable from systems used to develop the curves to our site, Little Topashaw Creek.

The veracity of these habitat simulations should be evaluated in light of fish samples collected from the 2-km-long reach containing the study bend and adjacent untreated reaches upstream and downstream (Table V and Shields *et al*., 2003, 2006). Following LWS construction, fish community composition shifted toward one typical of a lightly degraded reference site, but similar shifts occurred in an untreated reach downstream, which had relatively high levels of naturally occurring LW. The treated reach and adjacent reaches showed recovering fish populations in all areas over the period of observation, but with the most pronounced changes in the treated reach. For example, the number of blacktail shiners doubled

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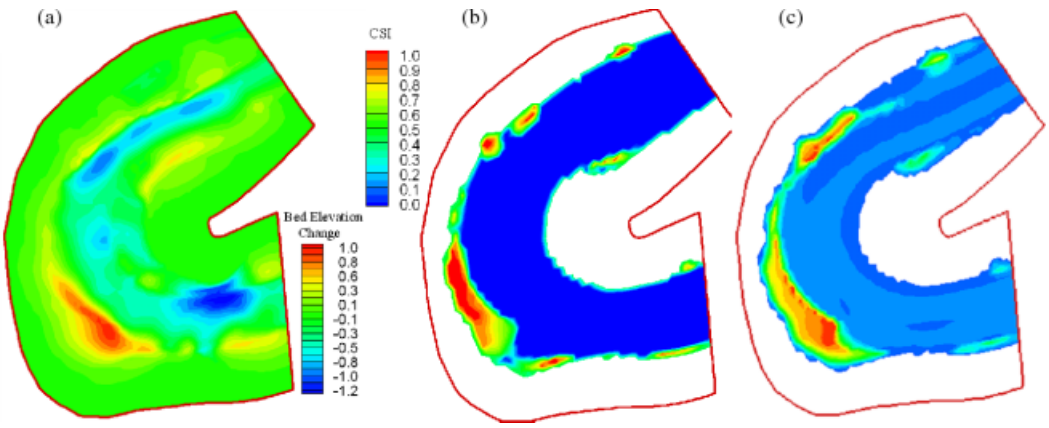

Figure 9. (a) Bed change, (b) combined suitability index (CSI) for largemouth bass after 1 year, and (c) combined suitability index (CSI) for blacktail shiner after 1 year.

Table V. Summary of electrofishing catch (mean values) before and after LWS construction (Shields *et al*., 2006).

Quantity	Upstream Before/after	Treated reach Before/after	Downstream Before/after
Total no. of fish species	13/22	19/25	17/27
Fish catch biomass, g/150 m	262/337	150/407	168/397
Mean no. of fish per sample	74/143	129/177	141/186
Mean no. of species per sample	6·8/11·4	6·8/12·8	6·3/13·1
No. of blacktail shiner (*Cyprinella venusta*)	64/230	368/778	410/753
No. of largemouth bass (*Micropterus salmoides*)	0/7	0/9	3/3
Length of largest individual in each sample, cm	13/16	9/14	10/12

in the treated reach. Three species typically associated with deeper habitats, including largemouth bass, were captured in the treated reach following debris addition but not before (Shields *et al*., 2006). One of these species (spotted bass, *Micropterus punctulatus*) was represented by only one individual that was 4·8 cm long prior to LWS construction, but 11 were captured afterward, with a mean length of 18 cm. Shifts to larger individual sizes are typical of ecological recovery (Shields *et al*., 2006, 2007). However, the construction of LWS in this study reach did not address additional ecological issues associated with flashy hydrology and water quality degradation, and these factors, which were also operative in untreated reaches up- and downstream, may have been even more important determinants of fish community structure than physical characteristics that were modified by LWS addition.

CONCLUSIONS

A 2D hydrodynamic model was used to simulate and evaluate the effect of LWS on flow, sediment transport, bed morphology, and habitat in a sharp, incised bend of Little Topashaw Creek, Mississippi. Habitat evaluations were conducted using two approaches: metrics based on velocity gradients and computation of WUAs based on habitat preference curves, for two fish species. The latter proved to be more sensitive to LWS addition. Spatial velocity gradient metrics indicated that the LWS slightly increased the flow complexity and provided higher levels of physical diversity, which are important to fish. The change of bed topography due to the addition of LWS modified water depth and velocity and significantly increased the WUA for the two species of interest. Field collections of fish before and after LWS installation from treated and adjacent untreated reaches indicated that factors other than steady flow hydraulics such as water quality, riparian conditions, and hydrologic fluctuations may have also influenced fish. Results here show that the 2D model is capable of analyzing the effects of LWS on aquatic habitats when coupled with appropriate habitat evaluation tools. The successful application of LWS may stabilize channel banks and also improve habitat within a stream.

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APPENDIX

$Energy$ = kinetic energy metric
s = direction of the line between points 1 and 2
V = magnitude of the depth-averaged velocity at a point
V_1 and V_2 = velocity magnitudes measured a distance Δs apart
V_{ave} = average of V_1 and V_2
V_{min} = minimum value of V_1 and V_2
Δs = distance between points 1 and 2

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$V^2/2$ = kinetic energy
$Vorticity$ = vorticity metric measures
u, v = x, y velocity components
$Circulation$ = area weighted absolute circulation metric
A_{tot} = total wetted area over which circulation is being computed
M = total number of wetted grid cells
i = index of grid cell
ΔA_i = area of grid cell i
WUA = weighted usable area for all cells in a stream reach
CSI_i = combined suitability index of grid cell i
C_{vel} = suitability indices for velocity
C_{dep} = suitability indices for water depth

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