Large wood as a restoration tool: I fought the law, and the law won

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Figure 1. Aerial view of Little Topashaw Creek prior to rehabilitation. Flow is toward the top of the photo.

Introduction

Traditional incised stream channel stabilization projects feature combinations of grade control drop structures, riprap streambank protection structures, drop pipes, small reservoirs, and land treatment. These methods are effective, but costs for treating an entire watershed range as high as \$750 ha^{-1}, and costs for channel stabilization are as high as \$399 m^{-1}. Previous work has shown that stabilization of incising channels and their stream corridors can have major, positive ecological effects, particularly when stabilization works are designed to address habitat-limiting factors. The Little Topashaw Creek stream corridor rehabilitation project, a cooperative effort involving landowners, the Corps of Engineers and the U.S. Department of Agriculture, was intended to demonstrate relatively low-cost, environmentally attractive approaches for stabilizing incised channels and rehabilitating associated habitats. Specifically, experiments were designed to test the efficacy of willow planting, placing structures made from large woody debris (LWD), and establishing switchgrass hedges in riparian gullies. This paper focuses on the performance of the large woody debris structures (LWDS).

The study reach was located along 2 km of Little Topashaw Creek, a fourth-order stream in north central Mississippi (Figure 1). The surrounding watershed has been described by Simon and Thomas (2002). Contributing drainage area was about 37 km^2, and floodplain stratigraphy was characterized by dispersive silt and clay soils underlain by sand overlying consolidated cohesive material. Sandy deposits were often found along the bank toe. The channel had an average sinuosity of 2.1, an average width of about 35 m, and an average depth of 3.6 m. Channel bed materials were primarily medium sand (0.2 mm < D_{50} < 0.3 mm). However, cohesive materials occurred as massive outcrops and as gravel-sized particles. Available evidence suggested that mean width had increased by a factor of 4 to 5 between 1955 and 1999. A geomorphic evaluation performed immediately prior to construction indicated that the downstream end of the reach was in the aggradational stage V of the Simon (1989) conceptual model of incised channel evolution, while the middle part of the reach was stage IV, and the upstream fourth of the reach was still degrading (stage III). A knickpoint was located between zones classified as stage IV and stage III, with thalweg slopes ~0.003 upstream of the knickpoint and ~0.002 downstream. In general, concave banks on the outside of meander bends were failing by mass wasting and sand was accreting on large point bars opposite failing banks. Outside of bends, eroding banks were invading adjacent cultivated fields, while inside bends and abandoned sloughs were vegetated with a diverse mixture of hardwood trees and associated species. Surveys of 13 cross sections before and after a flow of 55 m^3s^{-1} that occurred three months prior to construction indicated an average increase in cross-sectional area of 10% with bank retreat as great as 7.6 m. This event, in which peak stages reached mid-bank elevation, triggered 60 m of upstream migration of a 0.6-m high headcut and produced two chute cutoffs across point bars.

Large Woody Debris Structure Construction

Previous work had highlighted the importance of LWD in sand bed stream ecosystems, and the relative scarcity of LWD in channels damaged by incision. Workers in other regions have proposed using woody materials for habitat rehabilitation or channel stabilization (e.g., Edminster *et al.* 1949, Abbe *et al.* 1997). LWDS were designed to withstand the five-year event, address physical habitat impairments, and cost less than traditional stone structures (Shields et al. 2001a, Accepted). Further, LWDS were intended to function in harmony with prevailing geomorphic processes, triggering and facilitating natural habitat recovery in conjunction with incised channel evolution.

Figure 2. Construction of LWDS. Rootwads were retained on 52% of the logs used in the structures.

The finished project consisted of 72 LWDS built with about 1,200 trees. LWD available for construction was limited to material presently in the channel and trees growing in patchy stands on the floodplain. No clearing was permitted within 10 m of top bank. Harvested areas (~3.4 ha) were primarily zones such as fencerows and ditches that landowners wanted cleared for cultivation. Structures were essentially cribs of logs with alternating layers at right angles. When possible, logs placed perpendicular to banks ("key members") were partially buried while those running parallel to banks ("rack members") were angled slightly upstream. Earth anchors were cabled to 58 (80%) of the completed LWDS. Approximately one LWDS was constructed to protect each 25 meters of channel, which represented an order of magnitude increase in LWD loading over preconstruction conditions. As-built dimensions are summarized in Table 1.

Quantity	Mean ± S.D.
Crest elevation above bed, m	2.1 ± 0.5
Length of structure, m	13.9 ± 3.9
Width of structure, m	5.3 ± 1.9
Distance between structures	13.0 ± 10.8
Basal diameter of logs, cm	32 ± 5

Table 1. As-built dimensions for 72 large woody debris structures constructed along Little Topashaw Creek, Mississippi.

Costs for LWDS construction were about \$80 $m^{-1}$of treated bankline, which is only 19% to 49% of recorded costs for recent stone bank stabilization projects in this region. These costs do not include design and contract administration, but construction materials, mobilization, and profit are included.

Large Woody Debris Structure Performance

High flows during the second year following construction produced progressive failure of about a third of the large woody debris structures. Thalweg degradation in the upper one-third of the project reach caused bed lowering of ~0.3 m and dramatic erosion of point bars as the thalweg shifted toward convex banks. Structures apparently failed as velocities within the debris matrix exceeded levels needed to scour sediments deposited there. Buoyant and drag forces acting on partially decomposed LWDS members either triggered failure of earth anchors, or broke LWD into pieces short enough to float out from under the steel cables. Structures located in sharp bends were most prone to fail. Damage rates were slightly higher for anchored LWDS (20/58) than for those without earth anchors (4/14). Forty-seven percent of the anchors were located upon inspection two years after construction, and 61% of those located were not functional. Evidently, the anchors, which were load tested when installed to 4.5 kN, were undersized. Anchor sizing was based on LWDS design dimensions and the assumption that critical conditions would occur shortly after construction. Accordingly, a relatively high value for wood density (0.75 g cm^{-3}) was used in computing buoyant forces. Retrospective computations using as-built dimensions and wood density = 0.45 g cm^{-3} indicate factors of safety well below unity.

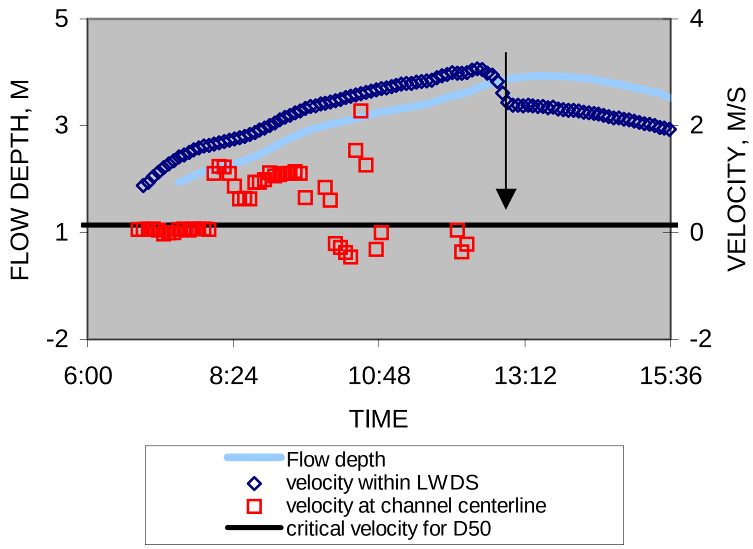

Figure 3. Flow depth and velocity records for an LWDS during high flow event. Vertical arrow shows time at which LWDS failed.

It was assumed that sediments deposited within the LWDS would add ballast to counteract the increased buoyant force associated with drying of the wood as the structure aged. However, in many cases, sediments deposited during the first high flow season were scoured during the second. Acoustic Doppler velocity loggers (Shields et al. 2001b) recorded depth and velocity within and adjacent to an LWDS located at the apex of a bend with a ratio of top width to bend radius ~ 1.0. During the rising limb of a large flow event about 16 months after construction, part of the structure apparently shifted, allowing velocities within the structure to rapidly increase from 0.2 to 1.2 m s^{-1}. Velocities within the LWDS then greatly exceeded the critical level for the sandy bed material and approached the velocity recorded at the adjacent channel centerline (Figure 3). Sediments deposited within the LWDS acting as ballast were scoured away, leading to a rapid decline in the factor of safety (ratio of buoyant forces to the sum of the weight of wood, sediment, and forces due to earth anchors) and failure of the LWDS.

Ecological response

Fish and their habitats were monitored by sampling during base flow in Spring and Fall within the modified reach, and reaches upstream and downstream before and after LWDS construction. Creation of stable pool habitats is a key component in restoration of incised stream corridors and pool habitats are often associated with LWD due to local scour. Approximately 100 water depth measurements (at equidistant points along 20 cross sections) at similar discharges before and during the first three years after construction showed mean water depth increased from 6 to 8 cm while water width remained unchanged. Fish community responses were consistent with previous observations of response to addition of pool habitats in incising warmwater streams—populations featured fewer, larger individuals representing longer-lived pool dwelling species following rehabilitation (Shields et al. In press), while macroinvertebrate community measures (Simpson index, Shannon index and Evenness) showed positive response to LWDS, both within the treatment reach and downstream (Cooper and Testa 2002).

Table 2. Summary of electrofishing catch, Little Topashaw Creek

Quantity	Upstream Reach		Reach modified by debris addition and willow planting		Downstream Reach	
	Before construction	After Construction	Before construction	After Construction	Before construction	After Construction
Mean no. of fish captured per 100 m	74	79	129	124	141	213
Mean biomass, g per 100 m	262	262	152	236	175	358
Mean no. of species captured per 100 m	6.8	10.0	6.8	11.3	6.3	12.0
Mean % biomass comprised of Centrarchids	57	37	11	46	18	27
Largest fish (length, cm)	17	17	12	17	20	13

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