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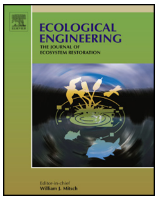

The long-term impact of channel stabilization using gabion structures on Zealand River, New Hampshire

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ABSTRACT

Zealand River, NH contains the second oldest major stream-stabilization project in the U.S. that extensively used gabions, which are stone-filled, wire-mesh baskets used to construct revetment walls, grade-control sills, or groin deflectors. In 2014, a study was conducted on a 4.5-km stretch of river to determine the status of gabion structures installed from 1960 to 1963, and the impact of those gabions on geomorphic channel stability. Longitudinal profiles, cross-sectional surveys and field observations provide evidence of channel incision, narrowing and avulsions at collapsed walls. Gabion sills failed first, which allowed 1–2 m of localized incision that undercut gabion walls, which then toppled into the eroded channel. Corrosion and abrasion by bedload movement, floating large wood and winter ice enhanced failure of gabion structures by breaking wire at the base of walls. Gabions with broken wires often spilled their rock fill and lost their structural integrity. Although gabions were intended to stabilize the river, they enhanced vertical channel incision, failed to prevent bank instability, and created localized channel widening and avulsions associated with depositional reaches.

1. Introduction

Modern approaches to river restoration increasingly focus on reestablishing natural geomorphic processes, including erosion and deposition, to create aquatic and floodplain habitat (Palmer et al., 2005; Kondolf et al., 2006; Beechie et al., 2010). An older, contrasting approach emphasizes channel form and imposes a predetermined channel morphology fixed in place with static instream structures designed to limit bank and bed erosion (Rosgen and Fittante, 1986; Rosgen, 2001; Thompson and Stull, 2002; Roni et al., 2008; Small and Doyle, 2012; Miller and Kochel, 2013). These different approaches reveal opposing views of bedload movement as either an essential habitat-forming processes or simply a flux of material that must be funneled through the design reach. Unfortunately, historical attempts to prevent bank erosion have created long-term problems with ecosystem sustainability (Doyle et al., 1999; Thompson, 2002; Florsheim et al., 2008). Because gabions can survive for decades, they potentially create long-term deleterious impacts. Few restoration projects are ultimately evaluated to determine their success at improving habitat conditions (Bernhardt et al., 2005; Roni et al., 2008), especially at the decadal time scale needed to test geomorphic response to imbalances in sediment continuity with infrequent floods (Wohl et al., 2005). From 1960 to 1963, the U.S. Forest Service (USFS) utilized hundreds of gabions to construct revetment walls, grade-control sills and groin deflectors on the Zealand River, NH to limit channel bed and bank erosion and improve trout habitat (Toblaski and Tripp, 1961; Mulan and Barrett, 1962; Ferrin and Staats, 1989). A study was conducted in 2014 to determine the long-term impact of these gabion structures. It was hypothesized that gabions interfered with natural channel adjustments expected during and after large flood events, which resulted in greater channel instability. Field evidence suggests gabions continued to exert a strong influence on channel adjustments more than 50 years after project completion and created discontinuous patterns of erosion and deposition.

Gabions, wire-mesh baskets filled with cobble-sized rocks, are used to construct instream structures that include revetment walls, grade-control sills and groin deflectors. Gabion use independently dates back centuries to both Egypt and China (Burroughs, 1979; Freeman and Fischenich, 2000). Modern wire-mesh gabions originated in Italy, probably in 1879 (Mulan and Barrett, 1962; Freeman and Fischenich, 2000), and later moved to the U.S. (Maccaferri, 1906; Mulan and Barrett, 1962). Early U.S. stream-improvement manuals included rock-filled, wire crib designs (Davis, 1935; Gee, 1952). The first restoration project in the U.S. to extensively use gabions began on North River, Virginia in 1957 in an effort to

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stop flood erosion and stabilize channel banks (Mulan and Barrett, 1962). It was followed by a second project initiated in 1960 at the study site in New Hampshire (Toblaski and Tripp, 1961). Both projects were collaborations between the USFS and Maccaferri Gabions of America, Inc. (Toblaski and Tripp, 1961). Gabion use for stream stabilization in the U.S. increased in the late 1960s and 1970s (Burroughs, 1979), and their use continued worldwide in later decades (Peyras et al., 1992; Freeman and Fischenich, 2000; Rafter, 2006; Brunet, 2007; Vicari and Crowther, 2013; Issa and Valerio, 2014).

Gabions utilize local materials, are strong, flexible, and can be used on steeper slopes with less thickness for bank protection than riprap (Cline and Koehm, 1974; Lavagnino, 1974; Burroughs, 1979; Williams and Osendorf, 1993; Freeman and Fischenich, 2000; Rafter, 2006). The design life of gabions was estimated at 25 years (Cline and Koehm, 1974), but projects using gabions lasting from 75 to 100 years have been reported (Tobiaski and Tripp, 1961; Burroughs, 1979). One researcher suggested gabions may "remain intact indefinitely" (Jackson, 1974). However, abrasion of wires by debris or bedload can break wires and create failures (Burroughs, 1979; Freeman and Fischenich, 2000), and submerged gabion wire only lasted 10 years in Virginia (Landgraf, 1986a). Unfortunately, there is limited information on the impact of gabions once they degrade or how the growth of woody vegetation within gabion baskets impact structure performance, longevity and long-term channel adjustments.

Thompson (2002) showed that stone revetments completed in the 1930s and 1950s limited riparian-vegetation growth, with potential long-term reductions in beneficial large-wood loading. However, project designers of gabion installations claimed that vegetation growth on gabions was likely, helped to provide a more natural appearance and increased bank protection (Lavagnino, 1974; Burroughs, 1979; Williams and Osendorf, 1993; Rafter, 2006; Brunet, 2007; Vicari and Crowther, 2013; Issa and Valerio, 2014). Conversely, an Army Corps of Engineers study recommended removal of woody vegetation from gabion baskets because this growth could break wires if the plant was uprooted (Freeman and Fischenich, 2000).

Very few long-term studies discuss the impact of gabions on channel evolution. Channel stabilization to prevent lateral migration fails if sediment continuity is not fully considered (Frissell and Nawa, 1992; Sear, 1994; Morris, 1995; Thompson, 2003), and gabions can be overwhelmed or flanked with rapid incision, deposition, or lateral channel migration (Freeman and Fischenich, 2000). Six years after four gabion sills were installed to control knickpoint migration on Enfield Creek, New York, approximately half of two downstream sills washed out completely and the thalweg incised approximately 1.0 m when Hurricane Agnes created a flood with a recurrence interval estimated between 200 and 250 years (Jackson, 1974). Damage to the sills was partially attributed to filling of voids within gabions with smaller rocks, which reduced flexibility and permeability of the structures, increased flow resistance and eventually stressed and broke gabion wires on the top and facing of gabions (Jackson, 1974). Because gabions are permeable, fine sediments can also be extracted through gabions by pressure fluctuation, which necessitates the use of filter material during gabion installation (Lavagnino, 1974; Williams and Osendorf, 1993).

In 1985, and again in 1986 following a major October and November flood associated with Hurricane Juan, the USFS completed studies of seven gabion sills, 69 gabion revetment walls and seventeen gabion groins installed from 1957 to 1965 along 9.3 km of North River within George Washington National Forest (GWNF), Virginia (Landgraf, 1985, 1986a,b). In 1985, 30% of gabion structures were fully intact with no portions slumped, undercut, collapsed, gone or buried (Table 1). However, banks not protected by gabion walls had naturally healed by 1985. After a 215 m^3/s, 150-year recurrence interval flood in 1985, only 9% of structures remained fully intact and 66% were deemed useless (Landgraf, 1986b). From 1965 to 1985, twenty of 31 cross-sections incised an average of 0.2 m, and fourteen widened an average of 1.9 m (Landgraf, 1986b). The following year alone, twenty cross-sections incised an average of 0.3 m, and 22 widened an average of 4.7 m (Landgraf, 1986b). However, erosion was generally balanced by localized deposition with a net loss of only 59 m^3 of sediment. During the 1985 flood, deposition forced several channel avulsions in the project reach.

Zealand River, the second oldest project to extensively utilize gabion structures in the U.S. (Toblaski and Tripp, 1961), provides a unique opportunity to understand long-term impacts of gabions in a watershed with few changes in land-use since project implementation. In particular, the study will investigate: (1) the current status of remaining gabions to evaluate their longevity and continued ability to impact channel conditions; (2) the long-term impact of bed and bank stabilization on channel deposition, incision and migration; (3) the role that woody-vegetation growth on gabion structures plays in structure stability.

2. Study description and earlier evaluations at the project site

Zealand River, a 10.1-km long, north-flowing tributary to the Ammonoosuc River within the Connecticut River watershed, drains a 35.7 km^2 area in White Mountains National Forest (WMNF) with steep slopes and shallow soils (Fig. 1). Elevations range from 445 m to 1333 m and the slope of the completed-project reach is 0.022. Outcrops of Mesozioc age plutonic rocks and exposures of glacial till dominate channel margins, with isolated areas of Devonian metasedimentary bedrock at upper elevations (Hatch and Moench, 1984).

WMNF was extensively logged 90 to 120 years ago (Goodale et al., 2000). Beginning in 1885, the Zealand Valley Railroad extended over nineteen kilometers of track into the watershed in a thirteen year operation, which resulted in extensive deforestation in a selective logging operation of any spruce over ten inches (25 cm) in diameter (Gove, 2012). In July, 1886, 49 km^2 of forest, including the project area, burned and 40 km^2 of the upper basin burned in 1903 in wildfires intense enough to reportedly disrupt soils (Gove, 2012). In 1911, the Weeks Act was created to preserve the remaining forests partly in response to public outcry at the level of devastation in the Zealand Valley, and in 1918 all land in Zealand Valley was purchased for inclusion in WMNF (Gove, 2012). Red maple (*Acer rubrum*), paper birch (*Betula papyrifera*), poplar (*Populus* spp.), and white pine (*Pinus strobus*) often established themselves in WMNF after logging (Leak, 1991; Goodale et al., 2000). The watershed is currently dominated by hardwood vegetation with smaller areas of mixed and coniferous forest cover (Goodale et al., 2000). Selective logging still occurs at a reduced level.

A 2.6-m-high, water-supply dam at the head of the study reach creates a 420-m-long impoundment, Bethlehem Reservoir, which has been in operation since 1928. Discharge from the reservoir is mostly as overflow spillage with limited flood storage in this narrow, shallow reservoir. Ferrin and Staats (1989) estimated a mean annual flow of 0.79 m^3/s on the Zealand River, and 2-year, 10-year and 100-year recurrence-interval flows of 17 m^3/s, 38 m^3/s and 92 m^3/s, respectively. Historic floods of unknown magnitude occurred in January, 1886, September of 1890 (Gove, 2012) and October, 1959. The 1959 event occurred after 20 cm of rain fell in 12 h (Ferrin and Staats, 1989) and was recorded 10.5 km downstream from the Zealand River on October 24, 1959 at a streamflow-gaging station on the Ammonoosuc River (01137500), drainage area of 227 km^2. The 306 m^3/s peak discharge in 1959 is