GEOMORPHIC RESPONSE TO THE REMOVAL OF THE MERRIMACK VILLAGE DAM ON THE SOUHEGAN RIVER, NEW HAMPSHIRE: RESULTS FROM SIX YEARS OF MONITORING

by
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INTRODUCTION

Removing the Merrimack Village Dam (MVD) on the lower Souhegan River in southern New Hampshire in August 2008 provided a field-scale experiment in river response to a major change in sediment flux and base level (Figure 1). We began monitoring the study area in August 2007, surveying a series of eight permanent cross sections within the impoundment and four downstream between the dam and the confluence with the Merrimack River (Figure 2). We also surveyed the longitudinal profile through the 1-km study reach, measured bed grain size, and photographed the site from ground-level stations co-located with the cross sections (Collins et al., 2007). We conducted nine repeat surveys from 2008 to 2014, with the greatest frequency soon after dam removal. The results of the surveys up to 2010 are included in Pearson et al. (2011) and the 2012 surveys are in Conlon (2013). Two Boston College M.S. students have completed theses on the site (Pearson, 2010; Conlon, 2013), as have two B.S. students (Santaniello, 2010; Armistead, 2013). So far, our research there has led to two published articles (Pearson et al., 2011; Santaniello et al., 2013).

Figure 1. Photographs showing the MVD before removal (a, July 16, 2008) and after. Demolition began on August 6, 2008 (b), by breaching to pre-dam bedrock. The channel rapidly changed by August 27, 2008 (c) and incised into impoundment sediment by October 18th, 2008 (d; from Conlon, 2013).
The dam removal caused a near-instantaneous 3.9-m drop in base level in the impoundment (Figure 3). The river incised rapidly through the impounded sand and removed over 50% of it within two months (Figure 4). This added sediment load resulted in up to 3.2 m of deposition in the downstream reach. After the initial, rapid phase of channel adjustment, ongoing erosion of impoundment sediment depended primarily on flood events that could access sediment stored outside of the newly developed, active channel. This process was modulated by the recruitment of large wood from terraces through bank erosion, which subsequently armored banks. By 2012, less than 20% of the impounded sand remained.

After an introduction at the former dam site, the field trip will spend the morning observing important features of the evolving former impoundment and the early afternoon in the downstream reach. We will see evidence for rapid geomorphic adjustment, sedimentary structures in the remaining impounded sediment and active channel, and historical artifacts and structures. We will also discuss the role of vegetation changes and large wood in the impoundment and adjacent wetland in the ongoing geomorphic evolution of the site. The trip will end by 2 pm, allowing time for participants to begin the journey home.
SITE HISTORY

The lowermost falls on the Souhegan River has been a dam site since as early as 1734, when the first bridge, grist mill and saw mill were constructed there (Pearson, 2010). Historical maps from the 19th century show at least one time when an identifiable reservoir existed on the site (1858), and other times when one did not (Figure 5). The modern Merrimack Village Dam, a run-of-the-river hydropower facility, was constructed in 1907 by capping an existing structure with concrete. A spray skirt was added in 1934, and the dam remained unaltered from that time until its removal in 2008 (Figure 1). Remnants of the dam and raceway are still seen adjacent to, and under, the Route 3 bridge.

Pennichuck Water Works (PWW), a public water supplier in Merrimack, NH, purchased the MVD in 1964 to serve as a water storage site. However, the impoundment was never used for this purpose (Gomez and Sullivan Engineers, 2004). In January 2004, PWW was issued a Letter of Deficiency by the NH Department of Environmental Services Dam Bureau because of safety concerns. These factors led PWW to consider removing the dam (Gomez and Sullivan Engineers, 2004). After a four-year public planning process, the dam was removed in August and September 2008 (Figure 1). The removal started with an initial controlled breach (Figure 1b) on August 6, followed by subsequent breaches after the water in the impoundment was allowed sufficient time to drain. The dam was then removed in stages from the left bank to right bank (defined with respect to the downstream direction).
Figure 4. Hydrograph showing Souhegan River discharge from August 2007 through July 2012 (a). Graph of sediment budget calculations upstream and downstream during this period (b). The sediment budget shows rapid erosion of impoundment sediment and rapid downstream deposition by October, 2008. In following surveys impoundment erosion rate slows and downstream erodes toward pre-removal elevation.
Figure 5. (a) 1936 oblique aerial photograph of the Souhegan Falls site and the former location of the MVD (from Merrimack Historic Society). Historical maps of the study area, including (b) 1805 town map, (c) 1858 town map and (d) 1898 town map (from NHDHR, 2006). (e) Plot of dam crest elevation (black outline) on 1968 USGS topographic map. Red extent rectangles on (b) 1805, (c) 1858, and (d) 1898 are the approximate area shown in (e) 1968. From Pearson (2010).
Prior to the dam removal, the impoundment was nearly entirely filled with sediment (Figure 6), almost all of which was sand-sized (Pearson et al., 2011). Using depth-to-refusal measurements, Gomez and Sullivan Engineers (2006) estimated that the main reservoir contained 62,000 m³ of sediment. A ground-penetrating radar survey in June 2008 achieved a similar estimate, 66,900 ± 9,900 m³ (Santaniello et al., 2013). Pearson (2010) cited exposures of historical artifacts in the wetland to the north of the impoundment, along with evidence for active flood deposition, to estimate that the total area of dam-influenced sedimentation was larger than the main reservoir (Figure 7). However, most of the post-removal geomorphic change has been in the former impoundment area identified by Gomez and Sullivan Engineers (2006) and we use their area and volume estimates for subsequent sediment-budget calculations (Figure 4).

Comparison of two pre-removal surveys (August 2007 and June 2008) show a trend of deposition in the thalweg within the former impoundment, which we interpret to be infilling after scour of the stored sediment during a large flood in April 2007 (Figure 6), which had an estimated recurrence interval of approximately 20-25 years based on a nearly 100-year gauge record for the site (USGS 01094000 Souhegan River at Merrimack, NH). Prior to the dam removal, the reservoir contained two islands covered by herbaceous vegetation.

Figure 6. Topographic surveys from August 2007 to July 2014 of cross section MVD06 (located in the middle of the former impoundment; Figure 2). Dashed lines show the water surface during each survey. The first two surveys are from before MVD removal. Note post-removal deposition on the right bank between August and October 2008 and on the left bank since 2010.
Figure 7. Cultural feature near the base of sediment exposed after the removal of the Merrimack Village Dam. (a) Map of proposed reservoir deposit from Gomez and Sullivan Engineers (2006; pink, 32,000 m²) and our estimated area of dam-induced sedimentation in the study area (green, 78,000 m²). (b) Location of cultural feature in cut bank exposure. (c) Detailed image of cultural feature (red brick) within the sediment exposure. From Pearson (2010).
The day of the initial dam breach featured seasonally high discharge and the flow divided between rapidly incised channels on either side of the reservoir islands. In the 24 days until our first post-removal survey, the river eroded 28% of the impounded sediment, incising up to 2.2 m and narrowing (Figure 6). By this time, the channel to the south of the islands (along the right bank) received all of the flow. Following this, the incision slowed and the channel began to widen, and by October 2008, 48% of the sediment had been removed. We refer to this period as the time dominated by “process-based” response (in the sense of Pizzuto, 2002), meaning that the erosion rate was largely independent of hydrology and instead driven by increased energy from the base-level change. By October 2008, channel incision slowed substantially, widening became more important, and lateral migration indicative of floodplain formation was suggested by the deposition of a cobble bar on the right side of the impoundment, downstream of the islands (Figure 6). The widening in this area resulted in recruitment of large trees (up to 20 m tall), which began to armor the banks. At the upstream cross sections (MVD02-MVD03; Figure 2) essentially all of the impounded sediment had been removed by this time, and the river through this section in fall of 2008 looked very much the same as it does now, with a bedrock and boulder bed and steep gradient (slope of 0.9%).

After October 2008, the ongoing response depended largely on floods that could access impounded sediment outside of the active channel. We refer to this as the “event-driven” phase. The survey interval from August 2009 to May 2010 included low-frequency floods in March 2010 (5-10 year recurrence interval), and this period included excavation of another 15% of the impounded sediment. This occurred largely by the active channel switching to the north side of the reservoir islands (by this time only one island remained). Several more trees were recruited from the terrace on the north side of the impoundment and stumps were exhumed along the left bank of the new channel that we interpret to pre-date the earliest dams at the site. After 2010, little change has occurred (<5% of the remaining impounded sediment eroded), probably because of (1) the lack of high-flow events (~2-year recurrence interval floods occurred in 2012 and 2014), and (2) the armoring of the banks by large wood. Indeed, by 2014, measurable deposition had occurred along both sides of the river at cross section MVD06, including burial of several trees, suggesting the initial creation of a floodplain via the process described by Collins et al. (2012). The ongoing evolution of the former reservoir will depend on the sequencing of large floods which may generate further erosion of impounded sediments, deposition of new material, and stabilization by vegetation growth.

CHANNEL RESPONSE DOWNSTREAM OF THE DAM

The August 2008 surveys (Figures 4 and 8) show that erosion of impoundment sediment upon dam removal aggraded the bed downstream of the dam site up to 3.2 m, narrowed the channel by 34 m in places, and steepened the slope (from 0.06% to 0.3%). This deposition was likely enhanced by high-flow conditions at that time on the Merrimack River which caused backwater conditions in the lowermost Souhegan River (Pearson et al., 2011). Erosion of this sediment was evident by the October 2008 surveys, and the May 2010 surveys showed net deposition. By that time, the sand-bedded downstream reach had returned to its pre-removal state of dynamic cutting and filling. In general, the downstream area responded much the same way it did before the dam removal when it would episodically receive sand transported out of the impoundment. The quantity delivered immediately after the dam removal was certainly larger than during pre-removal floods, but the general mechanics of sediment transport in the downstream section, influenced by Merrimack River backwater events, remained the same pre- and post-removal.

ACKNOWLEDGEMENTS

This work was supported by: the NOAA Open Rivers Initiative through a project with Gomez and Sullivan Engineers, P.C. and Pennichuck Water Works; American Chemical Society Petroleum Research Fund grant 47858-GB8 to NPS; and the Department of Earth and Environmental Sciences at Boston College. Boston College students Adam Pearson, David Santaniello, Maricate Conlon and Corrine Armistead all completed theses using data from this field site. We thank the following people for helping in the field: William Armstrong, Dan Hallstrom, Elizabeth Johnson, Grace Lisius, Keila Munz, Austin Nijhuis, Kyra Prats, Peter Snajczuk, and Benjamin Wilkins (Boston College students); Karla Garcia, Eric Hutchins, Sean McDermott, Jim Turek, and Lisa Wade (NOAA); Deb Loiselle, Grace Levergood, and Beth Lambert (NHDES; Lambert now with Massachusetts Riverways Program); Eric Derleth (USFWS); John Kachmar (Gulf of Maine Council, now with The Nature Conservancy); and Brian Graber (American Rivers). Thanks to Mark Wamser (Gomez and Sullivan Engineers, P.C.) for managing the Merrimack Village Dam removal.
Figure 8. Topographic surveys from August 2007 to July 2014 of cross section MVD09 (located downstream of the MVD; Figure 2). Dashed lines show the water surface during each survey. The first two surveys are from before MVD removal. Note the considerable aggradation immediately after the dam removal (August 2008 survey) followed by erosion back to the original base level by May 2010. Subsequent surveys show the ongoing cut-and-fill processes in this dynamic, sand-bedded reach.

ROAD LOG

Assemble at 9 am on Sunday, October 12, at Watson Park on the east side of old Route 3 in Merrimack, NH (across from the fire station; 42°51'44"N, 71°29'34"W). This site has plenty of parking; it is 55 minutes from the Wellesley College campus, and 2 miles from exit 11 on the Everett Turnpike in southern New Hampshire. Once parked, we will conduct the entire fieldtrip on foot, walking a total of perhaps 2 km. The site includes considerable poison ivy and mud; dress accordingly. Some participants may wish to wear waders to better look at bank exposures, but this is not required. We will have a brown-bag lunch in Watson Park, either between stops 4 and 5 or at the end of the trip, depending on timing.

STOP 1: OVERVIEW OF THE FORMER DAM SITE. (20 MINUTES) We will begin by walking the short distance from Watson Park across Rt. 3 (carefully) to the Merrimack fire station parking lot. From there and the adjacent bridge, we will observe the site of the Merrimack Village Dam as well as get a first look at the former impoundment and adjacent wetland.

STOP 2: WETLAND BEHIND THE FIRE STATION PARKING LOT. (20 MINUTES) We will cross the wetland and observe the post-removal incision of the fine-grain deposits (be careful). The wetland is considerably smaller now than it was when the dam was in place and meadow vegetation is now replacing aquatic species.
STOP 3. FORMER IMPOUNDMENT AT MVD04. (40 MINUTES) Here we will have an overview of the channel response in the former impoundment, including observations of the remaining mid-channel island and the development of two channels. At this location, the pre-dam riverbed of boulders and bedrock can be seen upstream. Bank exposures show logs, stumps and a possible beaver lodge, all likely pre-dating dams at this site, although this interpretation has not been tested with ^14C dating.

STOP 4. FORMER IMPOUNDMENT AT MVD06. (40 MINUTES) At this site (Figure 6), we will observe the interaction of large wood and sedimentation in the development of an incipient floodplain. We will also look at the stratigraphy of remaining impoundment deposits and exhumed stumps that we believe may mark an earlier, presettlement location of the left bank. After this stop, we will re-cross the wetland, walk across the Route 3 bridge, and walk downstream on the right side of the river.

STOP 5. DOWNSTREAM REACH AT MVD09. (30 MINUTES) At this site, which is a popular swimming hole, we will discuss deposition and subsequent removal of impounded sand. We will also the influence of backwatering by the Merrimack River on sedimentation in the lowermost Souhegan River.

STOP 6. DOWNSTREAM REACH AT MVD11. (20 MINUTES) Here we will observe the confluence of the Souhegan and Merrimack rivers and further discuss backwater-enhanced depositional processes and remobilization.

REFERENCES CITED

Armistead, C., 2013, Applications of ‘structure from motion’ photogrammetry to river channel change studies: Boston College B.S. thesis.