The nine channel evolution types used in the model represent all scenarios found so far, but there may be more. Each evolution type leads to the anticipated type of channel and recommended types of stability analysis.

5.7 CONCLUSION

Channel evolution models, surrogate dam removal scenarios (glacial lakes, dam failures, reservoir drawdowns), and observations of low dam removals provide empirical information on the behavior of upstream channels and sediment transport. This creates a preliminary screening tool for the initial evaluation of dam removal impacts and for identifying sites that warrant further detailed studies.

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CHAPTER 6

THE GEOMORPHIC EFFECTS OF EXISTING DAMS AND HISTORIC DAM REMOVALS IN THE U.S. MID-ATLANTIC REGION

Katherine Skalak, James Pizzuto, Jennifer Egan, and Nicholas Allmendinger

6.1 INTRODUCTION

Dams have had a substantial impact on the Earth's water resources. Approximately 800,000 dams have been constructed worldwide (Friedl and Wuest 2002; Gleick 1999), and river damming has increased the residence time of river waters from 16 days to 47 days. Human-constructed dams have increased the world's standing water more than 700% (Friedl and Wuest 2002).

There are more than 75,000 major dams in the United States, most of which are relatively old and 90% of which are privately owned. A "major" dam is one taller than 7.6 m or impounding more than 61,650 m^3 (Evans et al. 2002). These dams have a design life expectancy that can be extended by regular maintenance. However, many times this is not done. The Federal Emergency Management Agency (FEMA) found that about 9,200 dams in the United States are classified as "high hazard" due to inadequate maintenance, lack of spillways, and lack of sediment management. About 35% of these dams have not had safety inspections in more than a decade (Doyle et al. 2000; Evans et al. 2002; FEMA 2002). Repairing older dams is often more expensive than removing them, making removal an attractive alternative.

Apart from maintenance problems, many proposed removals are based entirely on the environmental impacts of dams (Shuman 1995). The National Research Council (1992) has deemed research for the rehabilitation and restoration of aquatic ecosystems a priority for rivers in the United States. While dams have provided valuable services such as irrigation, hydroelectric power, navigation, flood protection, and recreational opportunities (Collier et al. 2000; Graf 1999), they have had a dramatic impact on rivers and streams. Flow regimes, channel morphology, sediment transport, and various ecological parameters such as the quality of riparian and aquatic habitats have all been influenced by dams (Heinz Center 2002). Dams have also increased soil salinity and flooding, impeded or eliminated fisheries, and produced unnatural nutrient loading (Shuman 1995).

Although as many as 450 smaller dams have already been removed in the United States, few detailed studies of existing dams or dam removal have been conducted (AR/FE/TU 1999), and therefore a paucity of data exists for predicting the geomorphic effects of dam removal. Due to the complex nature and prolonged duration of many fluvial processes, many predictions regarding the effects of dam removal remain provisional and uncertain (Pizzuto 2002).

The effects of dam removal will vary for each site depending on dam and watershed characteristics (Poff and Hart 2002). The different flow-release policies in a variety of dams and reservoirs introduce changes to the hydrological regime that will vary from dam to dam (Brandt 2000).

Although the effects of a dam and its removal differ with site characteristics, there are common outcomes for all dam removals. The dams in this study varied in height, width, storage capacity, and operation. Moreover, the dams occurred on streams of different sizes, with different topographic and hydrologic characteristics, and a myriad of human impacts and disturbances. These factors have important direct and indirect environmental impacts on a riparian system, which can make it difficult to forecast the effect of dam removal (Poff and Hart 2002). However, we have found that by examining the geomorphic responses to existing dams and dam removals in streams in the U.S. mid-Atlantic region, some general trends regarding the long-term effects of dam removal begin to emerge.

This chapter describes three studies conducted on streams in the mid-Atlantic region of the United States (Fig. 6-1). The first is a dam removal that occurred on the Manatawny Creek in Pottstown, Pennsylvania. The second describes three historic dam removals on Muddy Creek in southeastern Pennsylvania. The final study provides estimates of the long-term effects of dam removal by assessing the effects of existing dams on 13 sites in Pennsylvania and 2 sites in Maryland. By examining data from regional sites at various stages in the dam-removal process, we can create conceptual models and ultimately predictions of channel response to dam removal.

To assess the channel response to dam removal on relatively short time scales, we analyzed data from the Manatawny Creek in Pottstown, Pennsylvania. Manatawny Dam, 2.5 m high, 2 m thick, and 30 m in length, created an impoundment that stretched approximately 800 m upstream from the dam. The impoundment was dredged twice since 1750, with the last dredging occurring around 1970 (Egan 2001). Thus, the impoundment was relatively sediment-starved when the dam was

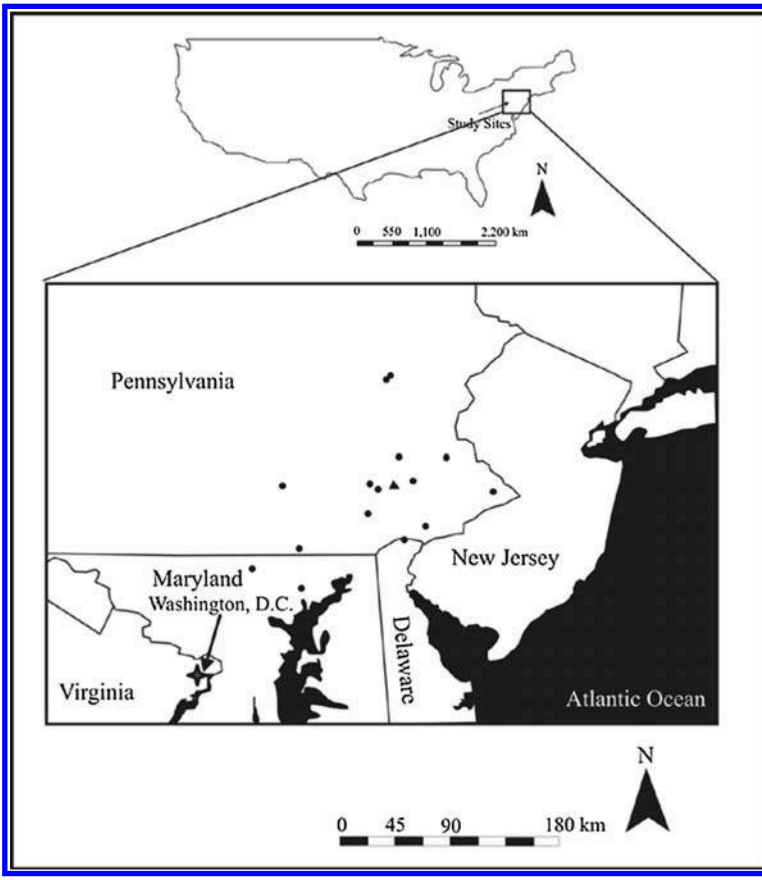

Figure 6-1. Location of study sites. The Manatawny Creek site is shown as a triangle. The 15 sites used in the analysis of the long-term effects of dam removal are shown as circles.

removed. Below the dam, Manatawny Creek joins the Schuylkill River after flowing only about 500 m.

Our measurement program included surveys of the impoundment, and we also surveyed the stream channel below the dam and at a control reach located approximately 2.4 km upstream of the dam.

6.2 THE TRANSIENT EFFECTS OF DAM REMOVAL: MANATAWNY DAM REMOVAL

Manatawny Dam was removed in two phases. In August 2000, a V-notch was cut into the dam and the impoundment was drained. Then

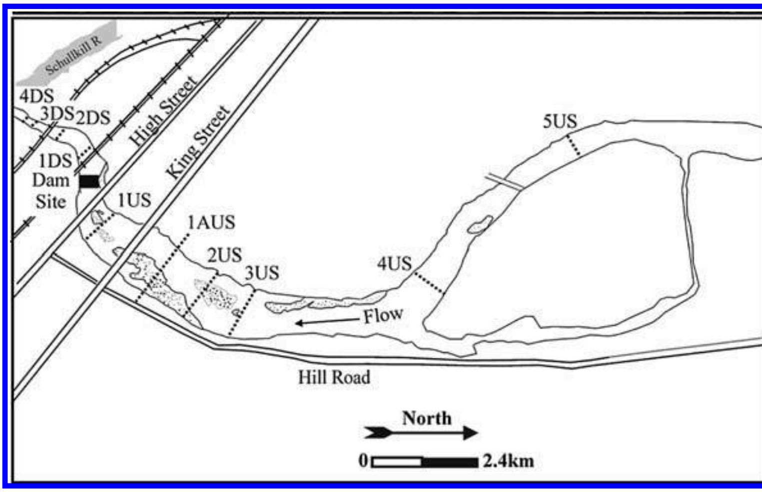

Figure 6-2. Sketch map of Manatawny Creek indicating cross-section locations and former dam site. Cross-sections are numbered consecutively with increasing distances upstream (US) and downstream (DS) of the former dam site. Source: After Egan (2001).

the top portion of the dam was removed. Subsequent surveys indicated that 0.5 m of dam debris remained, so a second removal was completed in November of that year.

Surveys of the channel and pebble counts were conducted both pre- and post-dam removal. Sediment data reflected little change after the August 2000 removal. Grain size data obtained at 0.5-m intervals reflect a coarsening trend at cross sections 1 and 2 (upstream) after the November 2000 dam removal from, initially, sand and mud to coarse sand and gravel (Bushaw-Newton et al. 2002) (Fig. 6-2). Pebble count data obtained at riffles and runs downstream from the dam showed that the sediment at these sites appears to have become significantly finer-grained following dam removal (Fig. 6-3).

The cross-sectional shape of the channel also changed little after the August 2000 removal (Bushaw-Newton et al. 2002). Cross sections taken several months after the second period of removal reflected the formation of large, transient bars in the former impoundment. Lateral bars formed on both sides of the channel, approximately 1 m high and 10 m or more wide. They were comprised primarily of loosely consolidated gravel and coarse sand. Figure 6-4 shows cross-section data taken at 1A US shown in Fig. 6-2. It can be seen in Fig. 6-4 that the initial survey before dam removal shows no evidence of lateral bars. However, the survey conducted several

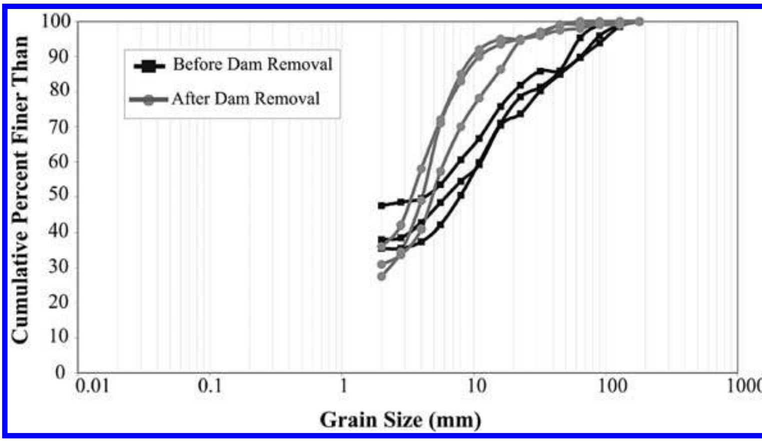

Figure 6-3. Grain size distribution before and after dam removal at cross-section 4 downstream of the former dam site on Manatawny Creek, Pennsylvania. Source: After Egan (2001) and Patrick Center for Environmental Research (2006).

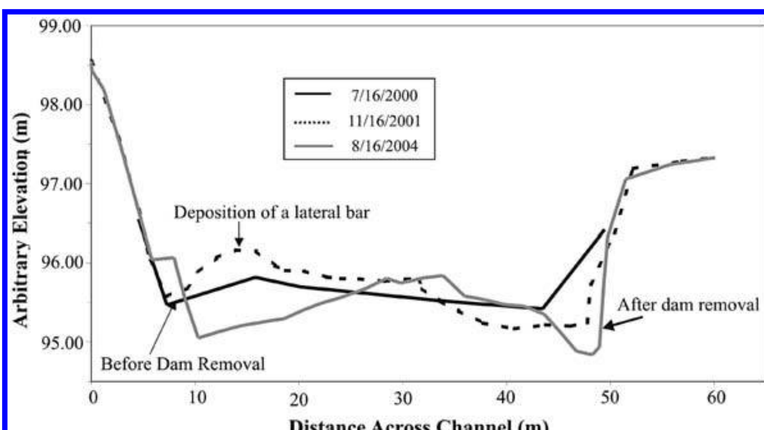

Figure 6-4. Cross sections of the channel upstream of former dam site on Manatawny Creek, Pennsylvania. This cross section corresponds with 1A US in Fig. 6-2.

months after dam removal indicated significant deposition on the left side of the channel. Figure 6-4 shows that 4 years after the dam was removed, there was no evidence of these lateral features remaining, which indicates that the channel upstream has degraded in recent years (Patrick Center for Environmental Research 2006).

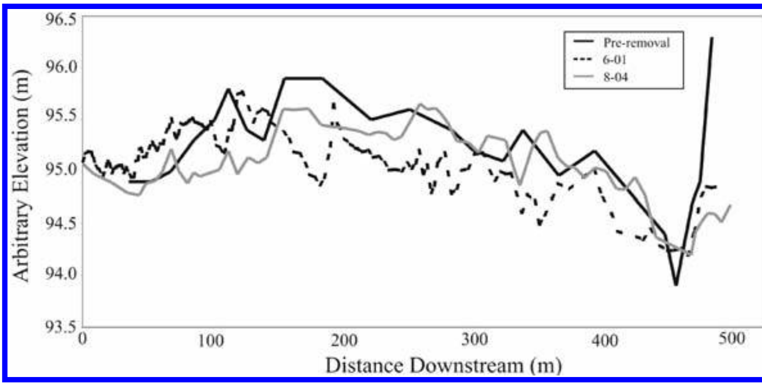

Figure 6-5. Longitudinal profiles of the former impoundment at Manatawny Creek at various stages of dam removal.

Longitudinal profiles upstream and downstream from the dam and in the control reach document changes in slope and pools and riffles. The bed of the impoundment, prior to dam removal, had a positive slope of 0.00015, which indicated an increase in elevation with increasing distance downstream toward the dam. After dam removal, the impoundment had a downstream slope of 0.00147, which indicated a decrease in elevation with increasing distance downstream toward the dam. The longitudinal profile data collected in 2004 in the former impoundment indicate that the channel continues to adjust its slope (Fig. 6-5). The slope of the channel downstream of the dam was 0.0022 before dam removal, close to that of the control reach of 0.0021 (Egan 2001). The slope in the downstream reach of the channel has remained stable.

Pools and riffles developed in the impoundment after removal in August 2000, but were closely spaced and shallow compared to the pools and riffles in the control reach. The downstream reach also exhibits pools and riffles with a spacing of 47 m and an average depth of 0.5 m, which corresponds to a pool riffle spacing of 2 channel widths.

The initial response of Manatawny Creek to the August 2000 removal was greatly subdued due to the 0.5 m of dam debris left in the channel. Additionally, the sand, gravel, and cobble-sized material could have remained in the impoundment because the flows during the months of August to November 2000 were not significant enough to initiate motion. The discharge in December 2000, however, was due to a 2.5-year storm that caused significant changes in the channel. However, this flow occurred after the contractor removed the additional dam debris. Consequently, the observed changes upstream and downstream from the dam resulted from the combined effects of the complete removal of the dam and the 2.5-year storm. In the years since the dam has been removed, there have been several large storm events that continue to stimulate channel adjustment.

Extensive changes continue to occur in the channel, although 4 years have passed since the dam was removed. Surveys of the longitudinal profile demonstrate that the channel is slowly cutting into the remaining rubble left at the dam site (Fig. 6-5). As this baselevel becomes lower, erosion continues at cross sections upstream. In downstream reaches, sand and pebbles have continued to replace the preexisting cobble-sized bed material. Thus, the recovery of Manatawny Creek appears to be an ongoing process 4 years following the removal of the dam.

6.3 ESTIMATING TIME SCALES OF CHANNEL RECOVERY FROM HISTORIC DAM REMOVALS

To determine the time scales of channel recovery time following dam removal, we studied three historic dam removal sites along Muddy Creek in southeastern Pennsylvania. Garthridge Dam, 12.2 m high and located the farthest downstream, was breached and removed in 1933. Highrock Dam, 1.8 m high and located the farthest upstream, was breached and removed in 1972. Castle Finn Dam, 3.1 m high, was removed in 1997. We surveyed the longitudinal profile and channel cross sections upstream of the former dam site. We also sampled the bed material and mapped floodplain and channel deposits. Undammed reaches far upstream were used as controls.

At all sites, laminated muddy reservoir deposits are still preserved as terraces up to 5 m high bordering the channel (Fig. 6-6). These deposits are very cohesive and will likely remain in place for decades. At Castle Finn, laminated muddy reservoir deposits underlie the channel bed, indicating that the channel has not incised to its pre-dam elevation after 6 years. At the other sites, vertical incision has completely removed fine-grained reservoir deposits from beneath the channel, though lateral migration has preserved some dam fill deposits on the left side of the channel at the former site of High Rock Dam. Bed material is finer-grained near the former dam site than at the control reaches at all the sites, and the water surface slope is higher near the former dam site than at the control reaches. These data suggest that, even after many years, channels above locations of removed dams are noticeably different from nearby control reaches, possibly indicating that complete recovery from dam removal may require decades.

Figure 6-7 shows the thickness (or depth) of the remaining dam fill deposits relative to the thickness of the initial reservoir deposits at each of the three sites. To obtain an initial fill thickness, we assumed that the trap efficiency of each dam was 100% and that the reservoir sediments