Using Reservoir Size, Watershed Characteristics, and Sediment Transport Proxies to Estimate Impounded Sediment Volume and Dominant Grain Size at Dams in New England

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Problem: Dams and Impounded Sediment

Impounded sediment compromises dam functionality by reducing the storage volume of the reservoir [7]. The release of large volumes of sediment can impair downstream ecological health and infrastructure, hence erodible sediment may need to be stabilized or removed prior to dam removal (Figure 1). Fine-grained sediment can be especially challenging because it is easily eroded and is more likely to be contaminated [2]. This project is developing indices of sediment supply, transport, and settling that can be used to estimate the sediment volume and grain-size distribution at a dammed impoundment.

Figure 1. Impounded sediment stored behind the Conway Electric Dam in Conway, MA.

Using High-Resolution Data to Estimate to Estimate Erosion

The Revised Universal Soil Loss Equation [6] states that soil loss (Y) can be calculated as:

$$Y = R \times LS \times K \times P \times C$$

where R is the erodibility due to precipitation, LS is the erodability due to slope and length of hillslopes, K is the erodibility due to intrinsic soil properties, P is the reduction of erosion due to soil conservation practices, and C is the erosivity due to land use type. Here, we assumed that precipitation and the soil conservation are relatively similar across New England, so used a simple index to compare sediment supply among different watersheds:

$$Erosion\ Index = LS \times K \times C$$

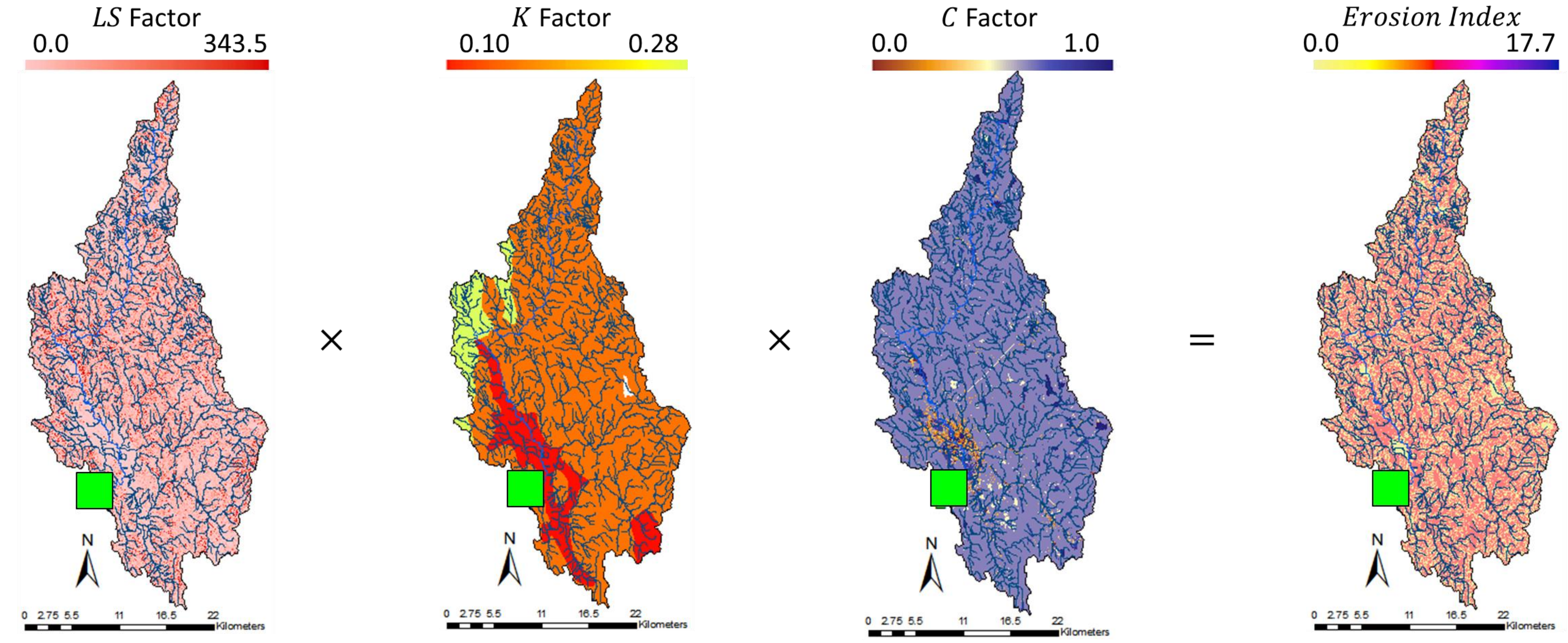

Figure 4: Maps of the Homestead Dam watershed on the Ashuelot River, NH, showing the spatial distribution of the LS, K, and C factors, which have higher magnitudes if the soil is more erodible.. The factors are multiplied to produce a specially variable erosion index

Controls on Impounded Sediment Grain Size and Volume

The volume and grain size of sediment behind a dam depends on sediment supply from watershed erosion, sediment transport in streams and rivers, and sediment settling within the impoundment (Figure 2). In this study a cross-site comparison was conducted at 19 New England dams (Figure 3) using pairwise regression analysis to examine relationships between proxies of sediment supply, transport and settling, and field observations of impounded sediment characteristics.

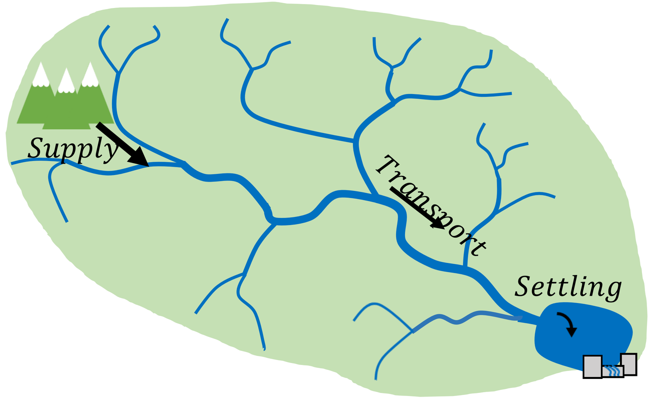

Figure 2: Sediment supply, transport, and settling control impounded sediment volume and grain size behind a dam: .

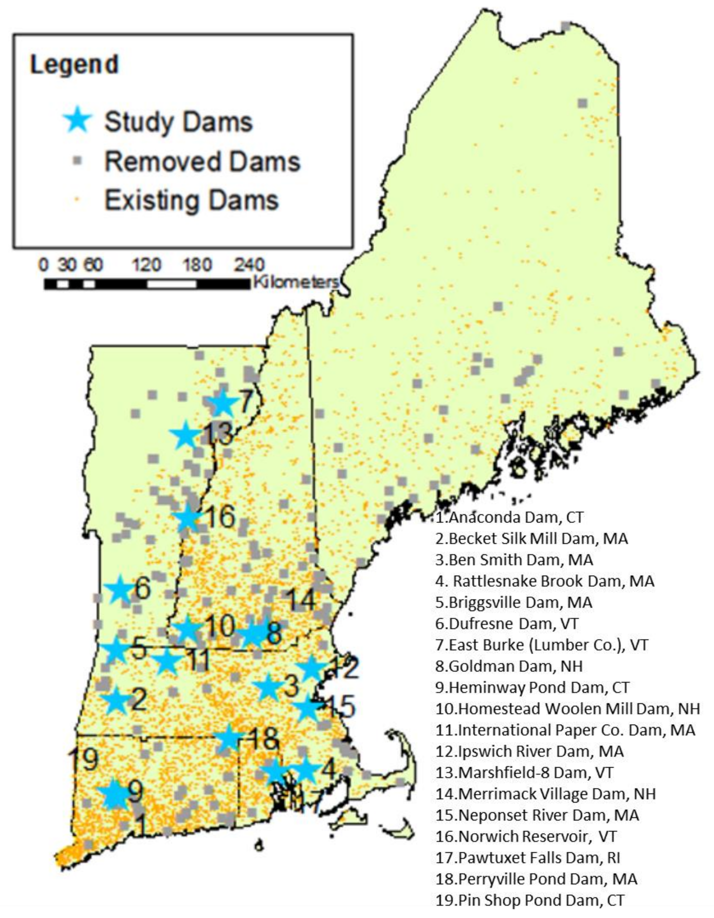

Figure 3: Map showing the 7,000 existing dams in New England, 186 dams that have been removed, and the 19 dams used in this study. (Data from [4].)

Using High-Resolution Data to Estimate Stream Power

Stream power is the energy applied by flowing water to a river's bed and banks and therefore responsible for sediment transport. High-resolution digital elevation models (DEMs) derived from airborne light detection and ranging (LiDAR) were used to remotely sense river banks [1,2] upstream of study dams (Figures 5–7). The resulting spatially varying estimates of longitudinal slope (S) and bankfull width (W_{bnk}) were multiplied by the specific weight of water (γ) and bankfull discharge (Q_{bnk}) to estimate total stream power ($TSP = \gamma Q_{bnk} S$) and specific stream power ($SSP = \frac{\gamma Q_{bnk} S}{W_{bnk}}$).

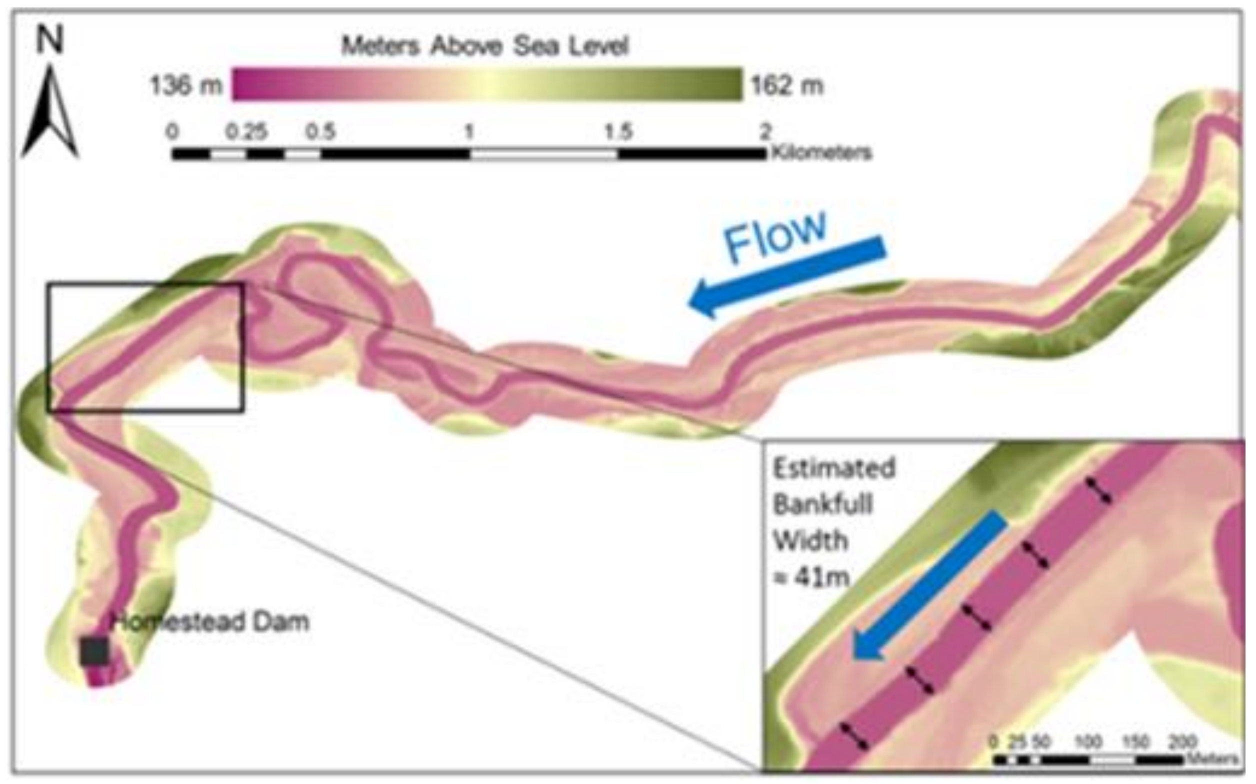

Figure 5: High-resolution LiDAR-derived topography of the Ashuelot River corridor upstream of the Homestead Dam, West Swanzey, NH, showing the calculation of bankfull width.

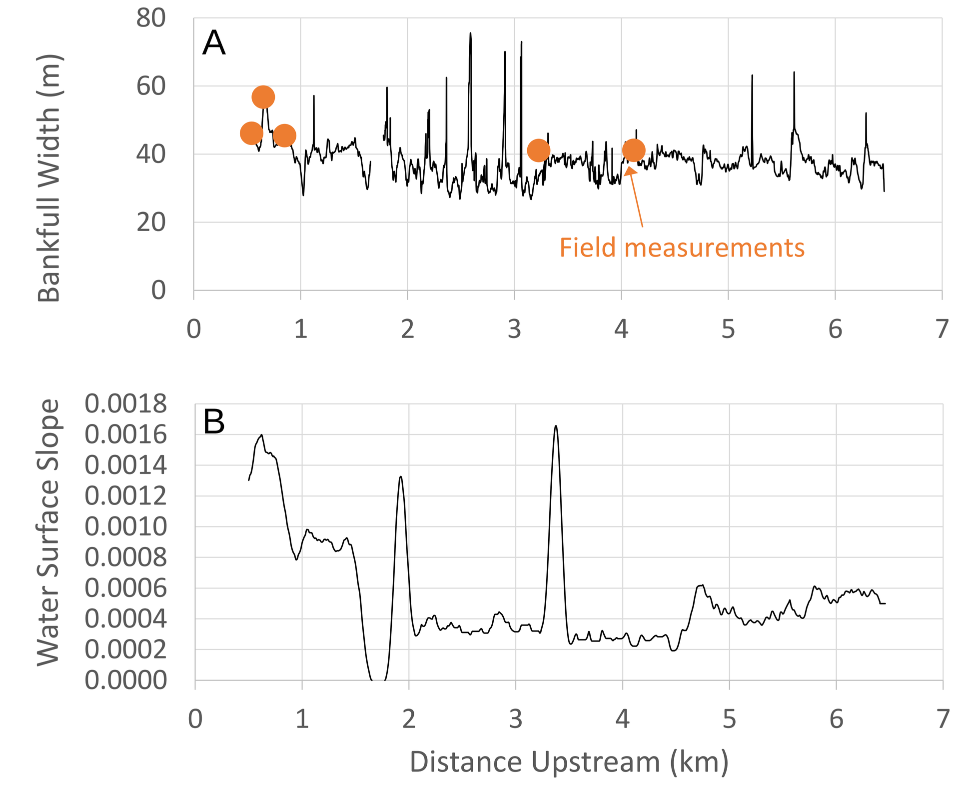

Figure 6. Longitudinal profiles of (A) bankfull river width and (B) water surface slope derived from topographic analysis of river banks.

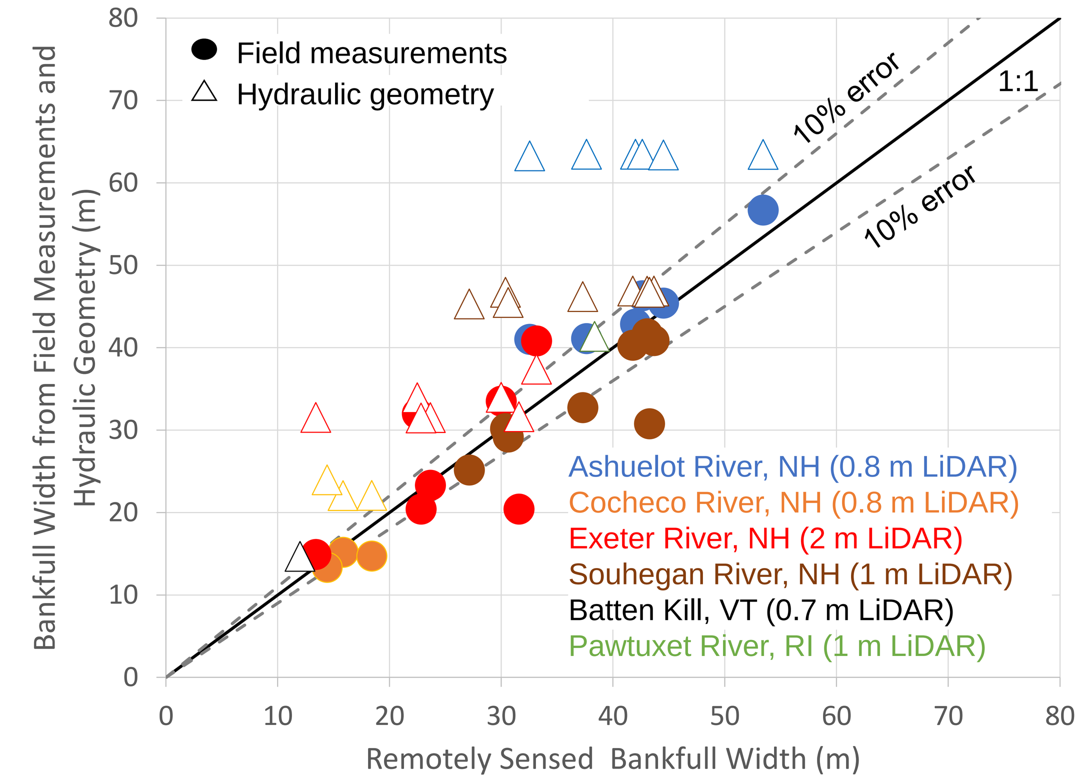

Figure 7: Bankfull widths from remote sensing compared to field measurements (circles) and predictions from hydraulic geometry (triangles).

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Impoundment Geometry and Impounded Sediment Characteristics

Dam trap efficiency [7] was assessed using impoundment geometry attributes including the impoundment surface area (A_{imp}) and aspect ratio which is the ratio of impoundment width to length ($\frac{W_{imp}}{L_{imp}}$; Figure 8). A statistically significant relationship was found between the impoundment surface area and the total volume of impounded sediment (Figure 9).

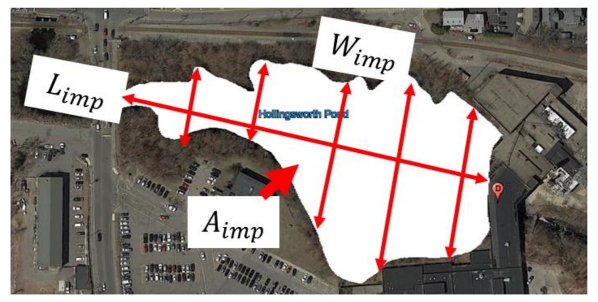

Figure 8: Areal satellite imagery of the Armstrong Dam impoundment, Braintree, MA.

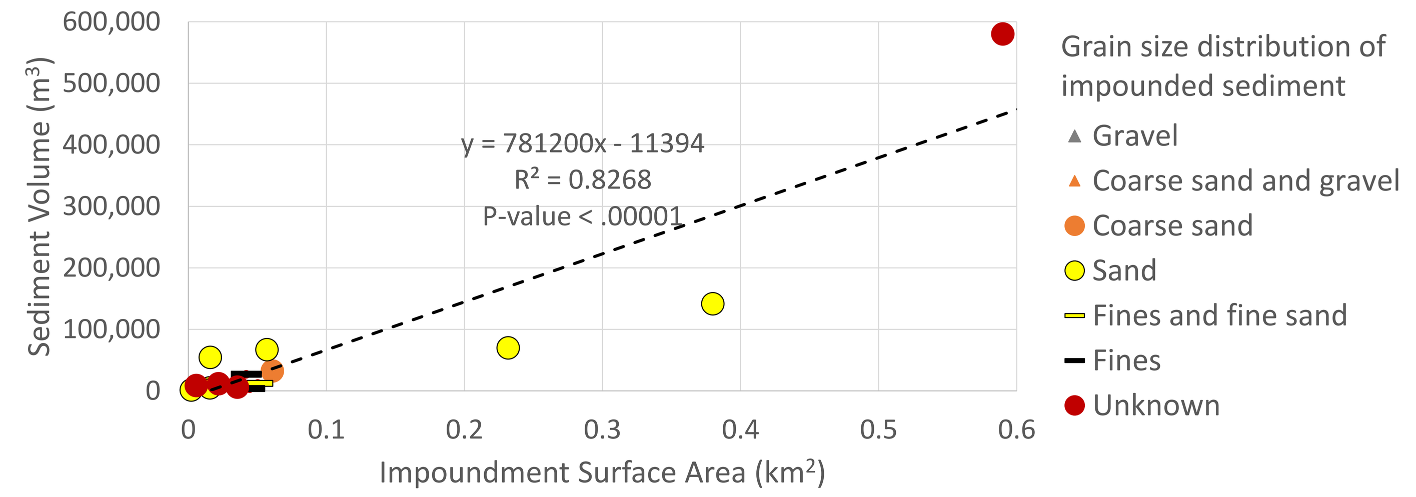

Figure 9: Relationship between impoundment surface area and volume of impounded sediment.

Conclusions

1. Remotely sensed bankfull widths calculated from LiDAR-derived topography agree with field surveys in channelized reaches
2. Proxies of sediment supply, and transport do not appear to be able to individually predict the volume and grain size of impounded sediment at dams in New England.
3. Multivariable regression analysis may be able to provide estimates of impounded sediment volume and grain size. Dam managers could use resulting relationships to estimate impounded sediment characteristics at unsurveyed dams and allocate scarce resources for dam maintenance and monitoring.

Future Research: Dam Removal Tradeoff Analysis

Regression equations will be used to estimate impounded sediment volumes and grain size distributions at additional dams where impounded sediment characteristics have not yet been surveyed. Estimates of the volume and grain size of impounded sediment will be combined with available metrics such as estimates of dam safety [3] and fish passage gains [4]. The resulting dam removal priority index will help assess patterns of historical dam removal in New England as well as assist watershed managers in identifying candidates for future dam removal.

Dam Safety	Fish Passage Gains	Sediment Volume	Grain Size	Dam Removal Priority Index
5: High hazard	5: Greatly inhibits passage	5: Low volume	5: Gravel	20: High priority for removal
3: Significant hazard	3: Moderately inhibits passage	3: Moderate volume	3: Sand	↕
1: Low hazard	1: Mildly inhibits passage	1: High volume	1: Fine-grained sediment	4: Low priority for removal

Table 1: Dam removal priority index example showing characteristics of dams with a high priority for removal and low priority for removal