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BEAVER OCCUPATION AND SEDIMENT BUDGET: PANTHER BROOK, HUNTINGTON WILDLIFE FOREST, NEWCOMB, NY

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INTRODUCTION

Sediment Budgets

A sediment budget compiles the major sources of input to and output from a fluvial system (Dietrich and Dunne, 1978) and relates the processes that drive the derivation, transport, and deposition of sediment to a sink area. Sediment is sourced from the headwaters and hillslopes of a drainage basin, from the upper layers of soil where soil creep rates are the greatest (Kirkby, 1967), and from incised banks of the channel and the streambed itself as water flows through and erodes the channel. Sediment is moved throughout the system, and undergoes corresponding changes, including diminution during deposition due to fluid transport. Main locations of temporary storage are in soil, on tributary channel floors, in debris fans and gravel bars and in the floodplain (Dietrich and Dunne, 1978 and Ouimet and Dethier, 2002). Estimates of sediment residence time range from decades to ten-thousand years and have been shown to increase down valley and down system (Dietrich and Dunne, 1978). Sediment is ultimately deposited in a sediment sink, or discharged to another body of water such as a river, estuary or lake.

Beaver Occupation

Beaver construct dams in low gradient valleys and on streams that are both narrower and more shallow than navigable rivers. High stream power limits the ability of beaver to construct dams, cut channels that obstruct the natural flow of water, and create backwater areas that store sediment and other organic material (Wohl, 2013 and Ruedemann and Schoonmaker, 1938 and Persico and Meyer, 2009, Johnston and Naiman, 1987, Hjulstrom, 1939, Williams and Wolman, 1984). These dams can persist for varying periods of time, from as short as a single season to as long as multiple decades (Persico and Meyer, 2012). Beaver build successively upstream, beginning in lower reaches and moving toward the source of a watershed as ponds are infilled (Ruedemann and Schoonmaker, 1938). Resulting "beaver meadows" form when beaver abandon these small ponds or water bodies due to sediment infilling past a certain threshold (Ruedemann and Schoonmaker, 1938). This aggradation can occur quickly, as a meter of material can aggrade within a several year period (Persico and Meyer, 2009).

Geologic Background

Our study area, the Panther Brook watershed, empties into Catlin Lake, within the Huntington Wildlife Forest, located in the center of the Adirondack Park of New York State. The Adirondack Mountains were formed during a massive mountain-building episode that produced what is known as the Laurentian or Pre-Cambrian shield (NYSAPA, 2016). The Huntington Wildlife Forest, a 15,000-acre parcel of land, receives a mean annual precipitation of 41 inches of which 12 inches falls as snow (Demers, 2008). Panther Brook has a drainage area of 3,452,700 square meters, determined from a 10-meter digital elevation model (DEM). The surveyed 3-kilometer length streambed comprises six stretches that have been altered from their stable state into beaver meadows due to occupation by *Castor canadensis*. The last recorded presence of beaver in the region dates to 2011.

METHODS

Morphology Characterization

Our study team surveyed the stream at ten meter increments, from the lower reaches of Panther Brook, just above Catlin Lake, to its headwaters located 300 meters from the drainage divide with Wolf and Deer Lake. Channel surveying consisted of a topographic elevation profile using a stadia rod with sighting increments of ten meters and hammer augers of banks to determine soil mantle thickness proximal to each fifty-meter station. Meadow surveying consisted of topographic elevation profiles, using a stadia rod, of beaver meadows along the two major axes and bucket auger surveys and fill thickness measurements across the long and short axes of the meadows at intervals of either fifteen or twenty meter increments.

At each fifty-meter survey mark, three distinct pebble counts, each of 100 pebbles, sampled bedload to determine average grain throughout the stream channel. This allowed us to infer the maximum grain size that can be transported given the observed stream capacity. We employed the technique described by Wolman (1954) for sampling sediment, in which 100 samples were randomly selected and measured, to ensure a more representative sample and improved estimates of channel roughness.

An idealized channel profile was created using a combination of data from a digital elevation model (DEM), and Flint's law reference values (Fig. 1). Flint's power law relates changing channel slope to drainage area, using the equation $S = k_s A^{-\Theta}$, where k_s is a measure of channel steepness, A is drainage area and Θ is a measure of concavity (Flint, 1974). Using a value of 19 for k_s and 0.45 for Θ we connected the steeper headwater reaches to the more gently sloping stream that discharges to Catlin Lake. Comparison of survey data with this idealized channel profile determined the deviation in channel slope due to beaver occupation.

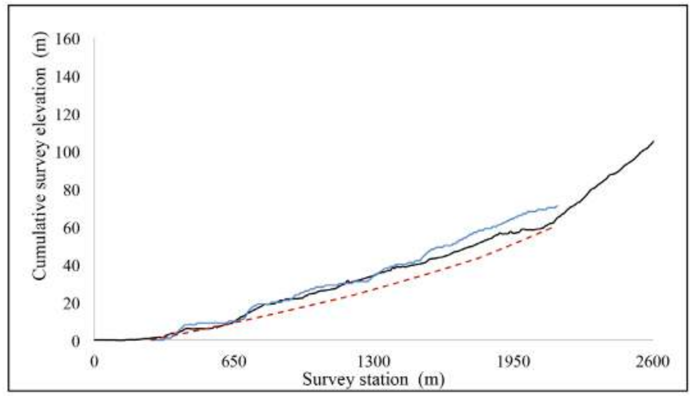

Figure 1. Surveyed longitudinal profile (solid black line), stream profile compiled from a 10m DEM (solid blue line), and slope of stream approximated using Flint's law (dashed red line).

Sediment Storage in Meadows

We measured sediment thickness in the beaver meadows using a bucket auger. Sampling was impossible in the uppermost beaver meadow, inferred to be most recently occupied, as the majority of it was underwater. Using data from a 10-meter resolution DEM and 1-meter resolution LIDAR, I calculated the elevation of the bottom of the beaver meadow at each sample location. These methods estimated subsurface elevation at sample points, limited in precision to the GPS coordinates of the sample area. To extend this to the full areal extent of the meadow I extrapolated these measurements to the surface area of the meadow, as determined by delineation using aerial imagery. I estimated beaver dam induced sediment aggradation by considering the interpolated subsurface layer as the original surface and the current elevations from DEM and LIDAR datasets the surface.

Hillslope Analysis

We took four hammer auger transects in the upper hillslopes of Panther Brook to determine soil mantle fill thickness and measured hillslope angles to infer the dominant sediment transport processes. I used flow accumulation data from a 10-meter DEM to determine the hillslope area that contributes sediment to each beaver meadow. Using these estimates of contributing area and values of sediment generation consistent with those reported by Matmon et al. (2003), I approximated the volume of contributing sediment and soil production rates. Using sediment generation estimates of 15, 20, 25 and 30 meters per million years I determined the corresponding annual input rates for headwater sub-basins that contribute sediment to each meadow. Using these rates, I determined the amount of time required to produce the volume of sediment from our most reliable interpolation, the Kriging method using LIDAR data and meadow specific samples.

RESULTS

Morphology Characterization

Two dominant reach-scale morphologies emerged from our analysis: 1) low-gradient, incised beaver meadows and 2) steeper, boulder filled inter-meadow reaches. These morphologies differed in average grain size, average fill thickness, and total fill thickness.

Statistical analysis of grain size and average fill thickness revealed that differences between morphologies were statistically significant. Average grain size in meadow reach sections (1.32cm) was smaller than average grain size in channel reach sections (4.28cm) and the difference was statistically significant (t.test p-value = 0.013). Average fill thickness was larger in meadow sections (0.91m) than in channel sections (0.13m) and the difference was statistically significant (t.test p-value = 7.299×10^{-5}).

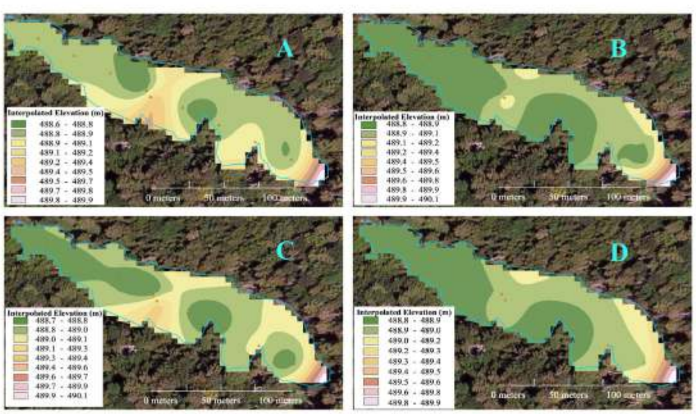

Figure 2. Interpolated subsurface topography of Meadow 1 using elevation extracted from a 10 meter DEM and bucket auger sample points. (A) Spline tension technique using all data points, (B) Kriging using all data points, (C) Spline tension technique using only meadow specific data points, (D) Kriging using only meadow specific data points. Meadow outlines represented by a solid turquoise line; sample points by orange circles.

Figure 3. Interpolated subsurface topography of Meadow 1 using elevations extracted from LIDAR and bucket auger sample points. (A) Spline tension technique using all data points, (B) Kriging using all data points, (C) Spline tension technique using only meadow specific data points, (D) Kriging using only meadow specific data points. Meadow outlines represented by a solid turquoise line; sample points by orange circles.

Sediment Storage in Meadows

I estimated meadow fill using the tension spline method and Kriging interpolation techniques for meadows where bucket auger surveys were possible. Estimates of total sediment fill volume of the first five beaver meadows, once manipulated to cover the entire meadow area, ranged from 17350 cubic meters (spline technique, LIDAR data, in-meadow samples) to 30040 cubic meters (Kriging technique, DEM data, all meadow samples).

Hillslope Analysis

The range of production estimates of between 15 and 30 meters per million years equated to sediment production rates between 1.50×10^{-5} meters per year and 4.5×10^{-4} meters per year for each meadow's contributing hillslope area (Table 12). If we assume that all sediment produced in contributing areas reaches the beaver meadows, rather than being caught up in channel sections, it would take between 174.8 and 743.2 years to fill individual beaver meadows, and 1714.1 years to fill all of the first five meadows at a low-end production rate of 15 meters per million years. At a high-end estimate of 30 meters per million years it would take between 87.4 and 371.6 years to fill individual beaver meadows and 857.0 years to fill all of the first five meadows (Table 1).

	Meadow Volume	15m/m.y.	20m/m.y.	25m/m.y.	30m/m.y.
Meadow 1	5412.5	275.0	206.2	165.0	137.5
Meadow 2	3440.6	174.8	131.1	104.9	87.4
Meadow 3	5331.5	324.8	243.6	194.9	162.4
Meadow 4	2862.8	196.3	147.3	117.8	98.2
Meadow 5	5884.7	743.2	557.4	445.9	371.6

Table 1. Estimates of time required, reported in years, to deliver the volume of sediment located in each beaver meadow, using delivery rates of 15, 20, 25 and 30 meters per million years.

DISCUSSION

Morphology Characterization

We observed nine beaver dams in the 3000 meters surveyed, which equates to one beaver dam every 333 meters. These findings are consistent with those of Ruedemann and Schoonmaker (1938) who observed that it is common to find six dams along a stretch of stream one mile (1609 meters) in length. The total length of beaver meadow occupied stream was 755 meters, representing 25.2 percent of the surveyed profile, which correlates perfectly with the findings of Wohl (2013), who studied twenty streams in Rocky Mountain National Park and found that an average of 32 percent of total stream length was occupied by beaver meadows.

Oakfield augers revealed that the sediment base was slightly below the lower bank, and that channel banks were incised to reach the deposit. The lowest layer was characteristically continuous and distinct; very well drained, organic rich, sandy material, indicative of beaver presence enhanced by transported legacy and hillslope sediment. As auger samples could not penetrate below this layer, we infer that underlying boulders mark the base of beaver-influenced sediment. Beaver derived sediment was highly organic rich and fine grained, distinct from sediment originating in the overlying channel bank sediment, and consistent with Persico and Meyer's (2012) observations of beaver-pond deposits in the Greater Yellowstone Ecosystem that indicated a low energy environment.

As predicted, average grain size within meadow reach sections was smaller than average grain size in channel reach sections, as beaver dams cause sediment backfilling and boulders from glacial deposits are exposed in channel sections. Fill thickness survey transects revealed both increased depth as well as increased lateral extent of sediment fill within beaver meadows. Furthermore, at multiple survey stations within channel sections there was no sediment storage, whereas there was consistent sediment storage throughout the meadow sections. Meadow fill measurements are consistent with the findings of Persico and Meyer (2009) who determined fill thickness in meadows in Yellowstone National Park to be up to 1 meter, and Wohl (2013) who found average thicknesses of 1.3 meters in Rocky Mountain National Park.

Beaver were responsible for changing the slope of Panther Brook, consistent with the findings of Levine and Meyer (2014) who observed a decrease in surface slope due to beaver occupation in Centennial Valley, Montana, due to the buildup of fine sediment behind beaver dams. Were beaver not present in the area we would expect to see a channel gradient similar to the one modeled with Flint's law, using values for concavity channel steepness that fit the profile to our headwater and discharge elevations.

Sediment Storage in Meadows

The resolution of a 10 meter DEM is not precise enough to pick up on differences in elevation in a small area such as a beaver meadow. LIDAR data is a better substitute and thus we expect measurements using LIDAR to be more precise than those constructed from a DEM. However, the precision of both techniques was limited by the number of samples from which I interpolated the subsurface. As such, I conducted interpolation analysis using two sample sizes: (1) meadow specific auger sample depths, and (2) all auger sample depths. There is high predictability of consistency in fill depth near samples sites, and decreasing precision of measurements as the radius around these sample points increases. Estimates of fill confined to samples within each meadow are likely to be more precise than ones which consider all sample points in the interpolation.

Kriging, which uses semivariograms to assess the predictability and uniformity of data and considers nearby data points in projections of z values was more likely to be accurate than was the tension spline technique (Chaplot et al., 2006 and Dubrule, 1984).

The tension spline technique, which mimics passing a rubber sheet through points to minimize curvature, would be less likely to allow for variation along the meadow subsurface. Thus, the most accurate fill volume estimate is compiled from LIDAR data, based on only meadow-specific sample depths, and using the Kriging technique.

Hillslope Analysis

Locally in the upper reaches of the catchment, approaching the drainage divide, bedrock was exposed or covered with a thin layer of soil, and hillslope angles were greater than 30 degrees (Fig. 4). Throughout the remainder of the catchment the hillslope angles were less than 30 degrees, indicating that sediment transport is likely driven by soil creep, bioturbation and tree throw rather than hillslope failure (Reneau and Dietrich, 1991, Heimsath et al., 1997). Accordingly, I infer that the majority of sediment is generated in the headwaters rather than the steeper rock faces, which have minimal soil cover. Average soil mantle fill thickness ranged between 0.09 and 0.40 meters over the four transects, less than observed fill thickness in meadows.

I calculated sediment production and delivery rates from the hillslopes of the watershed to each stem that extends from the main stream of Panther Brook, assuming that soil production was equivalent to erosional delivery rates. As we did not have access to cosmogenic nuclide data for sediment we based

Figure 4. Model of slope throughout the Panther Brook watershed at 10-meter DEM resolution. Areas coded green represent a hillslope angle of less than 30 degrees, areas coded red represent hillslope angles greater than 30 degrees. Dimensions: 1800 m (height) by 3000 m (width).

estimates on delivery rates measured in another mountain range on the east coast of the United States, the southern Appalachian Great Smoky Mountains. It is likely that due to the lower availability of soil in the Adirondack Mountains, true delivery rates are on the lower range of the estimate of 27 +/- 4 meters per million years reported by Matmon et al. (2003). As we cannot assume that sediment delivery correlates perfectly we consider delivery rates between 15 and 30 meters per million years.

If we assume that all sediment produced in contributing areas reaches the beaver meadows, rather than being caught up in channel sections, it would take between 275 and 743 years to fill each of the first five individual beaver meadows using a low-end delivery rate of 15 meters per million years. Using a high-end delivery rate of 30 meters per million years it would take between 137 and 372 years to fill each meadow (Table 1).

Study Limitations

Dietrich and Dunne (1978) and Brown et al. (2009) note limitations in constructing a sediment budget, namely that geomorphological processes are often slow and variable and that it can be difficult to construct a complete picture by averaging localities. Echoing Ellen Wohl's 2013 study, as we do not have a reference state for conditions in Panther Brook, it is difficult to discern the full impact of beaver on the watershed.

Further study should seek to determine fill thickness in beaver meadows using more samples, or samples spread more evenly throughout the meadow to increase the accuracy of interpolation estimates. Dating of sediment and woody debris using cosmogenic nuclide data would better constrain the time of beaver dam construction and provide a timeline for beaver presence in the Panther Brook watershed and Adirondack Park region.

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