Assessing the applicability of the Wilcock 2-fraction bedload transport model at the Caspar Creek Experimental Watersheds, CA

Extended Abstract

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Introduction

Predicting bedload transport rates is useful for many reasons, but accurate predictions are difficult to make. At the Caspar Creek Experimental Watersheds, a long-term monitoring site in a coast redwood forest in northern California, we wish to know how bedload transport responds to logging and sediment input such as landslides. To complete such analysis requires being able to accurately measure and predict bedload transport yields. Here, we focus on developing an approach to reconstruct an 18-year record of annual bedload yields for the North Fork of Caspar Creek (Figure 1) and compare the reconstructed yields to predictions from the Wilcock 2-faction bedload transport model (Wilcock, 2001).

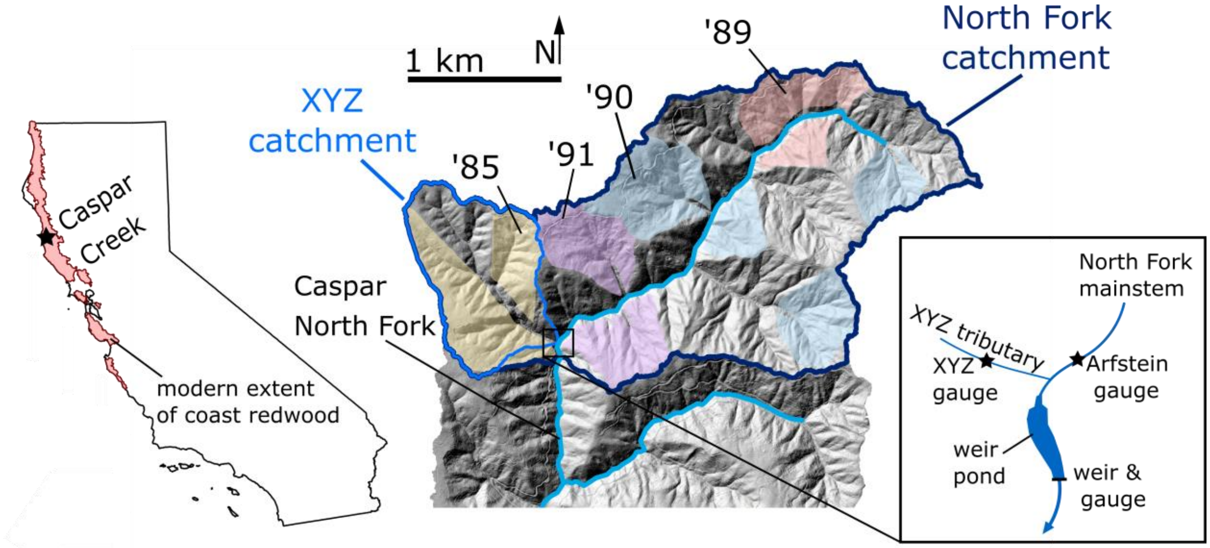

Figure 1. Shaded relief map of the Caspar Creek Experimental Watersheds created from LiDAR data gridded to 1 m. Colored overlay marks boundaries of previously logged catchments and the year the catchment was logged. Inset of California shows location of study site and modern extent of coast redwood (kindly supplied by Save the Redwoods League). Boxed inset shows additional detail near the North Fork weir pond.

Methods

A weir pond is located at the North Fork catchment outlet (Figure 1) and traps bedload, suspended load, and organic material. For hydrologic year (HY) 2000, an automated sampler was installed to monitor suspended sediment yields from the XYZ tributary. This sampler complemented the pre-existing suspended sediment samplers at the pond outlet and on the main stem of the North Fork and made it possible to estimate the mass of suspended sediment that settles in the weir pond.

A delta composed primarily of sand and gravel exists at the upstream end of the weir pond. The remainder of the pond sediment is a mixture of settled suspended sediment and organic matter. The weir pond is cleaned of sediment and organic material every 5-10 years. During the North Fork cleanout in 2018, sediment samples were collected along 10 approximately evenly-spaced transects perpendicular to the long axis of the pond. The samples were collected and analyzed for the fraction of organic matter (f_{o}). In addition, a topographic survey is completed each year, which enables us to estimate the annual captured volume of sediment and organic debris in the pond (V_{p}). The pond volume can be subdivided into individual components according to

$$V_{\mathrm{p}} = V_{\mathrm{b}} + V_{\mathrm{s}} + V_{\mathrm{o}}, \tag{1}$$

where V is annual volume and the subscript denotes the pond (p), bedload (b), settled suspended sediment (s) or organic matter (o). V_{s} and V_{o} can be approximated as

$$V_{\mathrm{s}} + V_{\mathrm{o}} = \frac{M_{\mathrm{s}} + M_{\mathrm{o}}}{\rho_{\mathrm{s,o}}}, \tag{2}$$

where M_{s} is the annual settled suspended sediment mass, M_{o} is the annual organic mass, and $\rho_{\mathrm{s,o}}$ is the density of mixed organic matter and settled suspended sediment. We calculated M_{s} as the difference in measured suspended sediment storm loads calculated upstream and downstream of the weir pond. The mass of each weir pond can also be subdivided into individual components according to

$$M_{\mathrm{p}} = M_{\mathrm{b}} + M_{\mathrm{s}} + M_{\mathrm{o}}, \tag{3}$$

where M_{p} is the pond mass and M_{b} is the bedload mass. We estimated the organic mass (M_{o}) according to

$$M_{\mathrm{o}} = f_{\mathrm{o}} \rho_{\mathrm{p}} V_{\mathrm{p}}, \tag{4}$$

where ρ_{p} is the pond density. The pond and bedload mass are calculated according to

$$M_i = \rho_i V_i, \tag{5}$$

where i is either p (pond) or b (bedload). By combining equation (1)-(5), we can solve for M_{b},

$$M_{\mathrm{b}} = \frac{\rho_{\mathrm{b}} V_{\mathrm{p}} - \frac{\rho_{\mathrm{b}}}{\rho_{\mathrm{s,o}}}\left(1 + \frac{f_{\mathrm{o}}}{1 - f_{\mathrm{o}}}\right) M_{\mathrm{s}}}{1 + \frac{\rho_{\mathrm{b}}}{\rho_{\mathrm{s,o}}}\left(\frac{f_{\mathrm{o}}}{1 - f_{\mathrm{o}}}\right)}. \tag{6}$$

All values in equation (6) were determined from field measurements or samples collected from the North Fork weir pond. We also collected bulk samples from the North Fork delta during summer 2018 to determine the gravel fraction (≥ 2 mm) of the delta.

We compared the reconstructed gravel yields from HY2000-2017 against predicted gravel yields using the 2-fraction bedload transport model described in Wilcock (2001). We focused on modeling bedload transport through the Arfstein reach and used HEC-RAS 5.0.6 to reconstruct flow velocity through a cross-section ~16 m upstream of the Arfstein gauging site from 10-minute discharge measurements made at the Arfstein gauge. We calibrated all model parameters from field measurements along the Arfstein reach of the North Fork except the reference shear stress for gravel (τ_{rg}), which is the shear stress at which a small but observable amount of gravel transport occurs. We calibrated τ_{rg} by minimizing the root mean square error (RMSE) between the predicted and reconstructed annual bedload yields.

Results

Analysis of the pond cores suggests that the organic fraction (f_{o}) is 0.09. Using previously collected data from the North Fork weir pond (Napolitano, 1996), we calculated a bedload density (ρ_{b}) of 1.83 kg/cm3 and a density of mixed organic and settled suspended sediment ($\rho_{\mathrm{s,o}}$) of 1.18 kg/cm3. Analysis of the bulk sediment samples collected from the delta suggests that the gravel fraction of the delta is 0.68. We summarize the remaining pond analysis results in Figure 2.

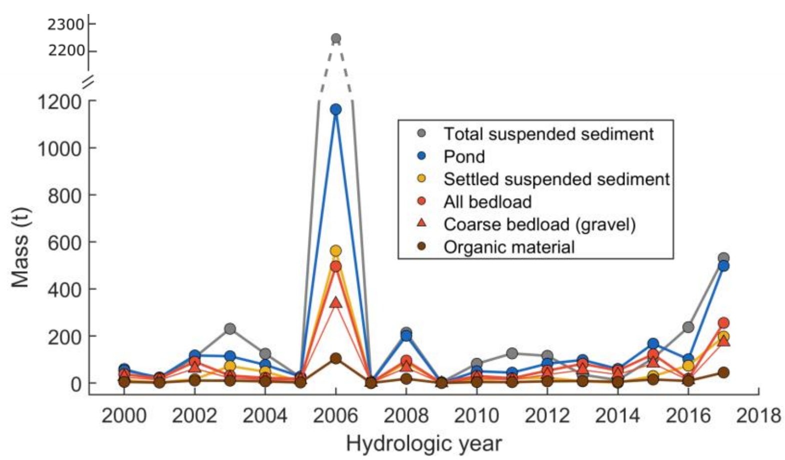

Figure 2. North Fork pond results for HY2000-HY2017. During HY2006, a large landslide contributed to higher than usual suspended sediment yields.

Minimizing the RMSE for the yields required a τ_{rg} of 9.1 Pa. Alternatively, τ_{rg} can be estimated from

$$\tau_{\mathrm{rg}}^{*} = \frac{\tau_{\mathrm{rg}}}{(\rho_{\mathrm{s}} - \rho) g D_{50}}, \qquad (7)$$

where ρ is fluid density, ρ_{s} is sediment density, g is gravitational acceleration, $\tau_{\mathrm{rg}}^{*}$is the dimensionless reference shear stress, and D_{50} is the median grainsize of the gravel fraction. Flume experiments suggest that τ_{rg}^{*}~ 0.04 when the surface sediment is mostly gravel (Wilcock, 2001). Results from previous pebble counts show that D_{50} ~ 1.8 cm for the gravel fraction through the Arfstein reach, which suggests that τ_{rg}~ 11.3 Pa from equation (7). The calibrated τ_{rg} from the RMSE analysis resulted in an estimate of τ_{rg} that is slightly lower. Reconstructed annual bedload yields and predicted yields compare reasonably well (Figure 3). However, the model did not always predict low yields accurately. This analysis will be benefited by consideration of additional annual bedload measurements that include intermediate (100-300 t) and high (>300 t) bedload yields.

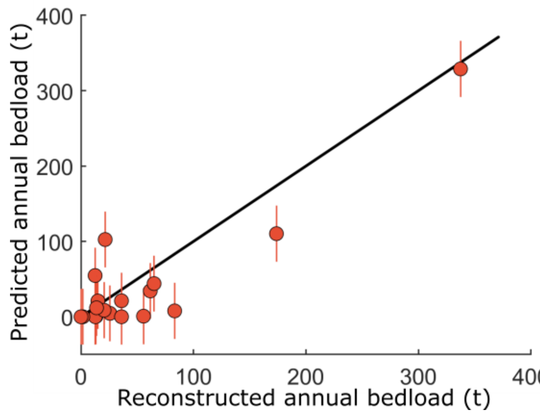

Figure 3. Comparison of reconstructed annual bedload yields and predicted annual bedload yields for the gravel fraction (≥ 2 mm). Uncertainty shown as 1 RMSE between the predicted and reconstructed yields. 1-to-1 reference line shown in black.

Summary

We presented an approach for reconstructing annual bedload yields deposited in the North Fork weir pond at the Caspar Creek Experimental Watersheds. This approach may also be suitable for estimating bedload yields for other weir ponds. We compared reconstructed annual gravel yields from the North Fork of Caspar Creek for HY2000-HY2017 to results of gravel yields predicted by the Wilcock 2-fraction bedload transport model. We calibrated the reference shear stress by minimizing the RMSE between the predicted and reconstructed bedload yields. We find that the calibrated reference shear stress is similar to the value predicted from bedload transport theory and flume experiments. We conclude that the accuracy of the bedload reconstruction approach and the bedload transport model are likely sufficient for addressing questions regarding catchment disturbance when large differences are expected between measured bedload yields and bedload predictions made for an undisturbed condition.

References

Napolitano, M. B. (1996). Sediment transport and storage in North Fork Caspar Creek, Mendocino County, California: water years 1980-1988. MS thesis, Humboldt State University, Arcata, California. 148 p.

Wilcock, P. R. (2001). Toward a practical method for estimating sediment-transport rates in gravel-bed rivers. Earth Surface Processes and Landforms, 26(13), 1395-1408.