Paleoflood Hydrology of the Deadwood River, Idaho

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Introduction

Most conventional estimates for the frequency of large floods are based on extrapolations from stream gaging records, commonly with record lengths shorter than 100 years. While flood frequency can be estimated to about two times the record length, estimates greater than 200 years can be vastly improved by including historical flood information and paleoflood data. In the United States, peak discharge estimates of historical (pre-systematic record) floods may extend flood frequency estimates up to several hundred years. In the Deadwood River Basin, Idaho, streamgage records are relatively short, or are relatively long but have been regulated for the majority of the period of record by Deadwood Dam. The addition of paleoflood data provided a long term perspective on extreme floods for a 10-mile valley segment on the Deadwood River and helped direct the flood frequency curve at low annual exceedance probabilities (AEPs), which is critical when assessing hydrologic risk posed by infrastructure to downstream populations.

Setting

The Deadwood River has its headwaters in the Sawtooth and Boise Mountain Ranges in western Idaho and has a basin area of 226 mi^2. From its headwaters at elevations near 9,000 ft, the Deadwood River flows south into Deadwood Reservoir, located upstream from Lowman, Idaho (Figure 1). Downstream of Deadwood Dam in the study reach, several minor tributaries flow into Deadwood River before the river reaches its confluence with the South Fork Payette River west of Lowman, Idaho. The Deadwood River watershed lies within a relatively wet region of the mountains. The range of mean annual precipitation (MAP) within the watershed is 28 to 66 inches. All annual peak floods during the period of measurement record occur during the months of April, May, and June, indicating that this system is driven by snowmelt or rain-on-snow floods.

Granitic bedrock of the Idaho Batholith forms the canyon walls that bound the river. The character of channel alluvium varies within the study reach, ranging from a cobble-boulder channel bed in high-gradient reaches and sand-pebble channel bed in low-gradient reaches. Channel morphology consists of irregular meanders separated by straight reaches of varying lengths. This morphology is likely controlled by a combination of the varying resistance of local bedrock to erosion and tributary alluvial fans that contribute bouldery and cobbly sediment to the channels.

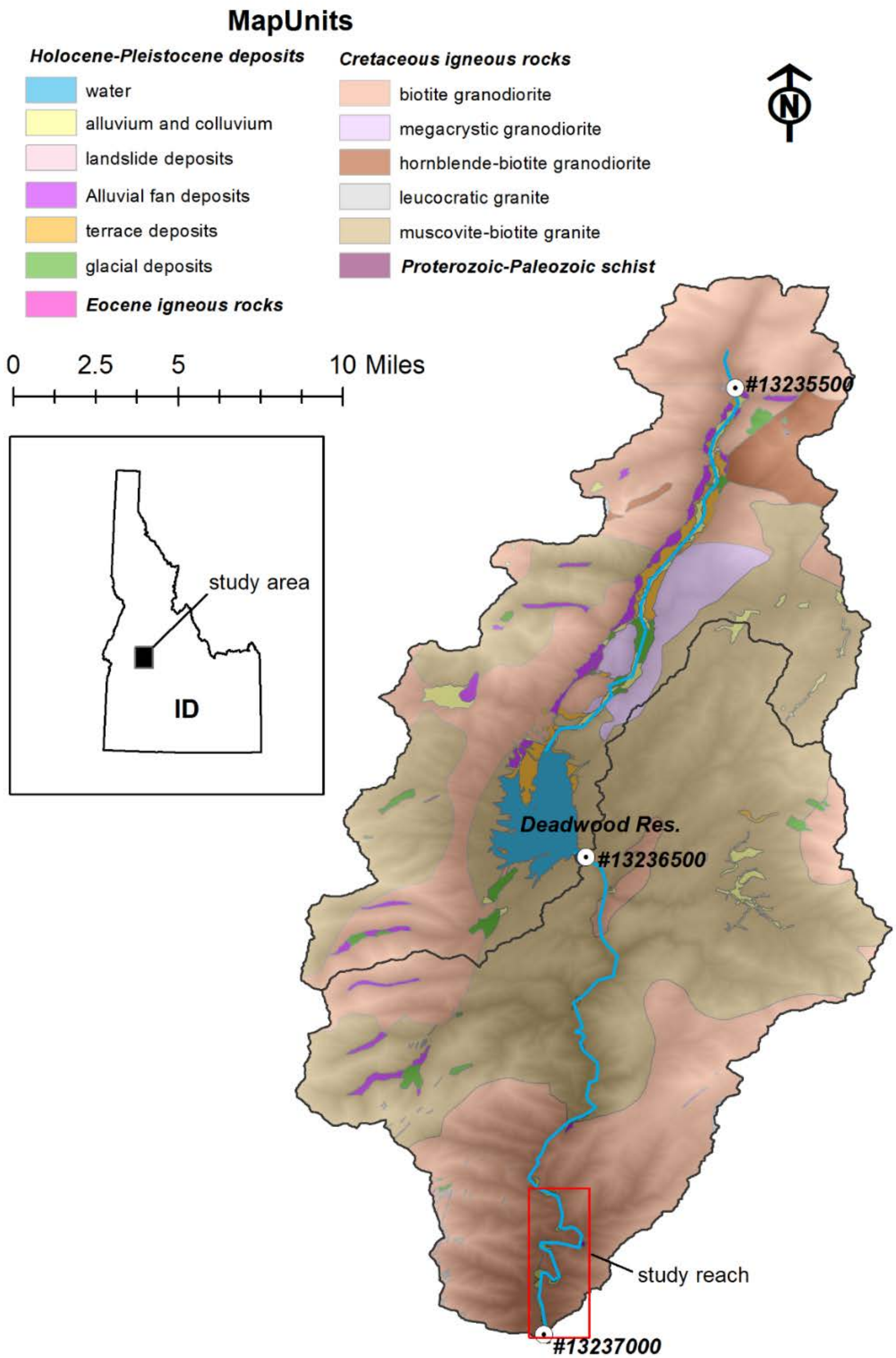

Figure 1 Overview of the upper Deadwood River watershed, showing location of Deadwood River study reach (red box), general geology, and stream gages (white circles). The hydromet gage, DEDI, is located downstream of Deadwood Dam.

Methods

This study utilizes stream terraces formed along the Deadwood River to develop pre-systematic record hydrologic data regarding extreme floods in the Deadwood River basin. Nonexceedance bounds, which provide a credible limit to the magnitude and frequency of extreme floods in the geologic record, can be developed by estimating the stage and corresponding range of discharges that have not been exceeded over the time period of terrace stabilization (Levish, 2002).

Soils were described following USDA standards (Soil Survey Division Staff, 1993) and modified terminology from Birkeland (1999). Charcoal samples were collected from the soil profiles, identified and submitted for radiocarbon analysis to obtain age estimates for the period of surface stabilization. Surface horizons at each pit were sampled to characterize surface sediment grain size for shear stress estimates in the hydraulic modeling that would be required to mobilize the surface sediment. The samples were submitted to the Colorado State University Soil Laboratory for particle size analysis (hydrometer, ASTM, 2014), sand fraction (1mm, 0.5mm, 0.125mm, and 0.0039 mm sieve sizes) and gravel fraction (> 2mm sieve sizes)

The SRH-2D (Lai, 2008) hydraulics model (version 2.2) was used to estimate peak discharges for paleoflood and non-exceedance bounds. This model solves the two-dimensional (2D) depth-averaged dynamic wave equations using a finite volume numerical scheme. SRH-2D utilizes an implicit scheme for time integration to achieve solution robustness and efficiency and makes use of a flexible mesh (Lai, 2010) that can incorporate various mesh resolutions and roughness zones. This zonal modeling concept allows for greater modeling detail in areas of interest that ultimately leads to increased modeling efficiency through a compromise between solution accuracy and computing demand. For the topographic base, Light Detection and Ranging (Lidar) data collected during August 2015 were used to develop a terrain and grid. Although Lidar does not include bathymetric data, the terrain accurately represents the dominant channel and valley topography necessary for floodplain and terrace inundation analysis. While channel erosion and aggradation is likely to occur during floods, the model assumes that the current topography represents an equilibrium condition for the purposes of this analysis due to the armored bed condition and likely presence of shallow bedrock in the channel.

To account for hydraulic model and topographic uncertainty, a range of flows is developed for each site. For paleoflood sites, the range is developed using the wetting flow or the discharge required to just inundate a surface, and the flow that covers the site with up to 2 ft of water. For non-exceedance flows, the range is developed using the wetting flow as a minimum and the flow that exceeds the Shield's critical stress value (τ^*) up to the discharge that covers the site with approximately 2 ft of water.

The Expected Moments Algorithm (EMA; Lane, 1995; Lane and Cohn, 1996) is a moments-based parameter estimation procedure that was designed to incorporate numerous sources of information – including systematic, historical, and paleoflood data – into flood frequency analysis. The core assumption of EMA is that a Log-Pearson type III (LP3) distribution can be used to model peak discharge data. PeakfqSA version 0.998 (England, et al. 2018) was utilized to analyze the data using the EMA method described above. In order to estimate a series of annual peak flows at Deadwood Dam given the low number of observed unregulated peaks, nearby gage data was used in combination with the Hydromet estimated daily unregulated inflows to develop a systematic peak record.

Results

Paleoflood Hydrology

The soil/stratigraphic sites within the study reach were selected based on the presence of stream terrace deposits that appeared to be near or above the highest stage of historical floods as recorded at USGS gaging stations and whose morphological character appeared to have minimal disturbance to their surfaces. Eight soil/stratigraphic sites were analyzed along the 10-mile long model reach. Two main terrace levels are described in the study and are approximately 4-7 ft (T2) and 6-11 ft (T1) above the river. The younger (T2) terrace is prevalent along the study reach and shows evidence for historical inundation with irregular topography and surface channelization. The older (T1) terrace is a broad, planar surface along the study reach and shows evidence for surface stability through development of a surface soil, with no evidence of recent inundation.

One non-exceedance bound for the T1 terrace was developed from data gathered during this study by combining non-exceedance data from five of the eight individual study sites. Although the data from each study site could be used independently, the combination of model output and radiocarbon data from multiple sites provides a more robust estimate by accounting for the uncertainty of age and discharge estimates for alluvial deposits that would be mapped as correlative terraces along the river. Terraces at each of the five sites have similar planar surface morphology and soil development, with all soils exhibiting Bw horizon development, which includes changes in color and structure.

To develop the age estimate for the non-exceedance bound on the T1 terrace, the 2σ distribution of the relevant radiocarbon ages from the soil profiles were plotted in Oxcal v. 4.2 (https://c14.arch.ox.ac.uk/oxcal.html; Bronk Ramsey, 2009). The upper and lower age outliers were discarded to obtain a range of 3,175 to 1,415 Cal BP using a total of 7 radiocarbon ages. Based on the median age of the radiocarbon data, the preferred age estimate is 2,740 Cal BP. The discharge estimate was obtained by combining the discharges from the 5 sites that inundated the terrace surface as a lower bound and that exceeded critical shear stress and/or inundated the surface by an approximate 2-ft depth as an upper bound. Peak discharges using this method ranged from 7,000 to 15,000 ft^3/s for the non-exceedance bound.

Flood Frequency Analysis

In order to utilize the data in flood frequency analysis for estimating the hazard at Deadwood Dam, the age estimate is modified by adding 65 years to account for the 1950 datum in the radiocarbon calibration curve while the discharge estimate is transposed to the drainage area of Deadwood Dam using an exponent of 0.94 in Berenbrock (2002). The modified estimate ranges from 4,000-7,000 ft^3/s with an age estimate of 1,480 to 3,240 years.

The final systematic record consists of 90 years of peak discharge data with temporal range Water Years 1927-2017. The median estimate from EMA adequately represents both the systematic and the paleoflood data. The systematic data is entirely contained within the EMA confidence limits. Using 90 years of systematic data and paleoflood non-exceedance bound, the confidence limits are very reasonable, especially for events as rare as annual exceedance probability (AEP) of 1/10,000 (Figure 2).

The range in discharges for the non-exceedance bound developed along the Deadwood River spans the value of the envelope curve (6,000 ft^3/s) and plots above most of the historical peak data derived from reservoir inflow curves and regional systematic gage records (Figure 3). This implies that the envelope curve and non-exceedance data provide a reasonable limit of flood magnitude for a drainage area of the Deadwood River near Deadwood Dam (110 mi^2) for at least the last ~3,000 years.

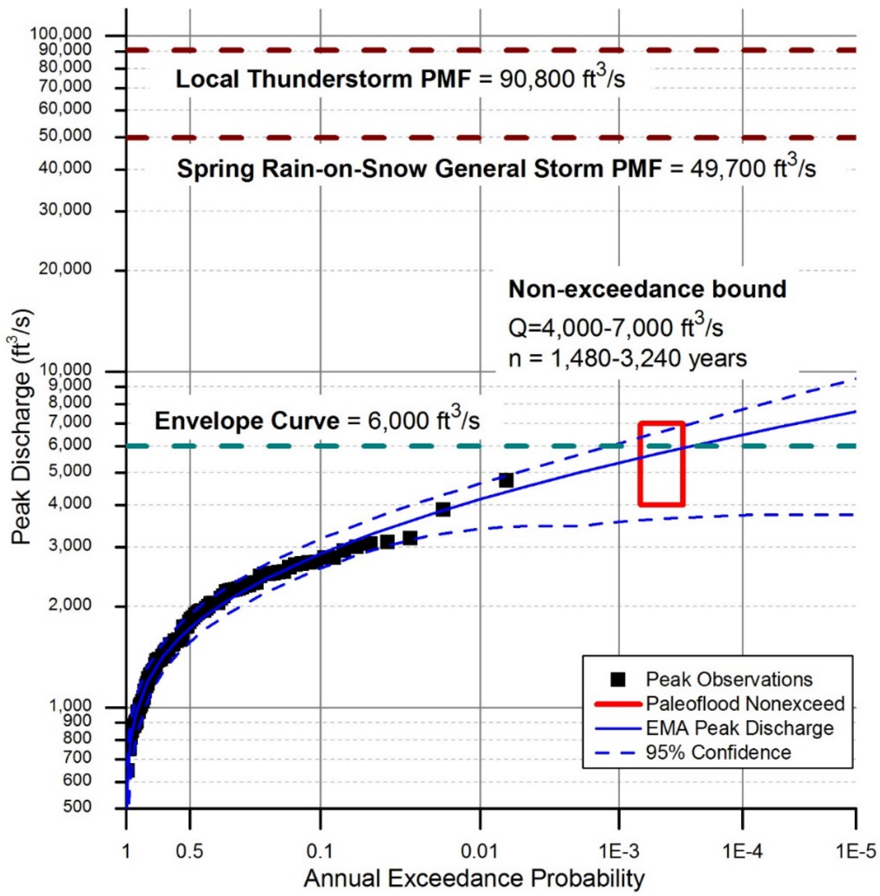

Figure 2. EMA peak discharge frequency curve, Deadwood River at Deadwood Dam, Idaho

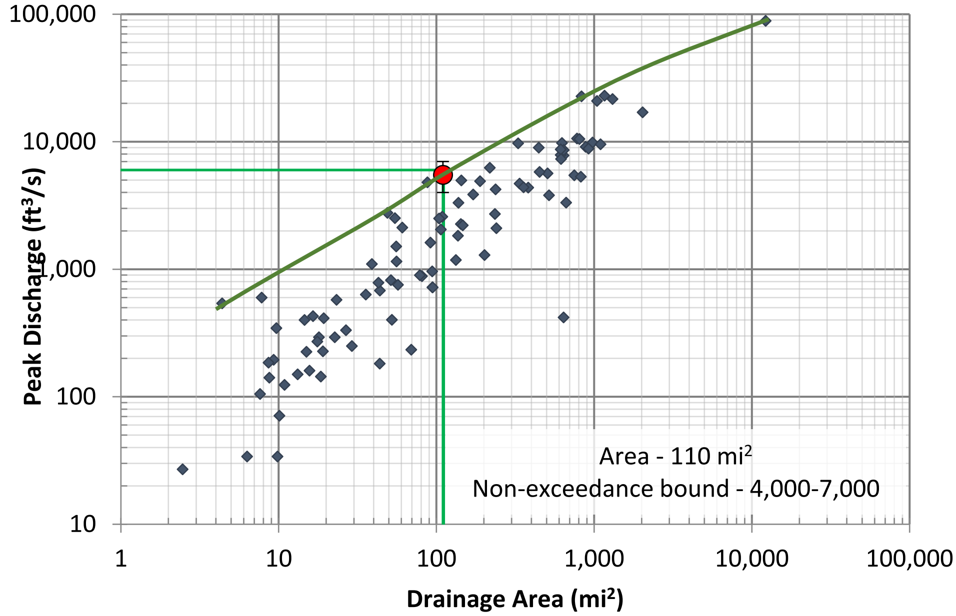

Figure 3. Regional envelope curve in the vicinity of the Deadwood River. Red square shows the non-exceedance bound and uncertainty. Blue symbols represent peak discharges from regional streamgage records.

References

Berenbrock, C., 2002. "Estimating the Magnitude of Peak Flows at Selected Recurrence Intervals for Streams in Idaho," U.S. Geological Survey Water-Resources Investigations Report 02-4170, 59 p.

Birkeland, P.W., 1999. Soils and Geomorphology. Oxford University Press, New York, 448 p.

Bronk Ramsey, C., 2009. "Bayesian analysis of radiocarbon dates," Radiocarbon, v. 51, no.1, p.337-360.

England, J.F., Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas, W.O., Jr., Veilleux, A.G., Kiang, J.E., and Mason, R.R., Jr., 2018, Guidelines for determining flood flow frequency—Bulletin 17C: U.S. Geological Survey Techniques and Methods, book 4, chap. B5, 148 p., https://doi.org/10.3133/tm4B5.

Lai, Y.G., 2008. SRH-2D version 2: Theory and User's Manual. U.S. Department of the Interior, Bureau of Reclamation Technical Service Center, Denver, CO.

Lane, W.L., 1995. "Method of moments approach to historical data, informal handout," Bulletin 17B Working Group, Hydrology Subcommittee, Interagency Advisory Committee on Water Data, 2 p.

Lane, W.L., and T.A. Cohn, 1996. "Expected moments algorithm for flood frequency analysis," North American Water and Environment Congress, edited by C.T. Bathala, American Society of Civil Engineers, Anaheim, California.

Levish, D.R., 2002. "Paleohydrologic bounds--non-exceedance information for flood hazard Assessment," *in* House, P.K., Webb, R.H., Baker, V.R., and Levish, D.R., (eds.), Ancient Floods, Modern Hazards, Principles and Applications of Paleoflood Hydrology: Washington, D.C., American Geophysical Union, Water and Science Application 5, p. 175-190.

Soil Survey Division Staff, 1993. Soil survey manual. Soil Conservation Service, U.S. Department of Agriculture Handbook 18.