A Tool for beaver dam analogue design

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Introduction

Beaver populations can be powerful tools in restoring stream and riparian habitats since their dams control and influence fluxes of water, sediment and nutrients. Beaver dam analogues (BDAs) are channel-spanning structures built by humans that mimic or reinforce natural beaver dams, and in many cases are intended to be eventually utilized and enhanced by beaver. BDAs are constructed by driving posts in a row perpendicular to the channel, weaving a mat of willow stems to create a weir supported by the posts and placing a berm of sediment, stone and plant material on the upstream face of the weir. A typical cross-sectional view, facing upstream, is provided in Figure 1. Variations on this basic design also occur. Like natural beaver dams, BDAs are temporary features on the landscape with functions that change in response to the effects of flowing water, sediment, and beaver activity (Pollock et al. 2017).

Although early BDA design and construction has relied on professional judgment, quantitative design can reduce the risk of premature failure and suboptimal use of available resources. To support and assist designers, we present a macro-enabled Excel spreadsheet that may be used to perform simple analyses leading to computation of three safety factors. Material quantities and simple cost estimates are also presented as output. Key computational modules include hydrologic flow frequency analyses to support selection of design discharge and uniform flow computations to assess pre-construction hydraulics. Uniform flow hydraulics are performed using an adapted version of the popular cross-section hydraulic analyzer spreadsheet (xsecAnalyzerVer17.xlsm) developed by the USDA-NRCS. The design tool also includes spreadsheets to assist the user in inputting geometry of the channel cross-section and the basic BDA geometry. Post-construction hydraulics are based on critical flow over the BDA crest at design discharge. Using estimates of bed material size input by the user, the design tool computes estimates of scour depth downstream from the BDA and then uses Brom's approach for noncohesive sediments to compute the required minimum embedment for the posts.

The BDA design tool is a macro-enabled Microsoft Excel file with separate sheets for various components of design as shown below. Completion of the analysis produces a set of safety factors and rough estimates of material volumes and construction costs. Support for users is in the form of default input values, tables of wood properties, soil properties and beaver dam dimensions, and a users' manual. The authors aspire to an improved version of the tool upon receipt of suggestions from reviewers.

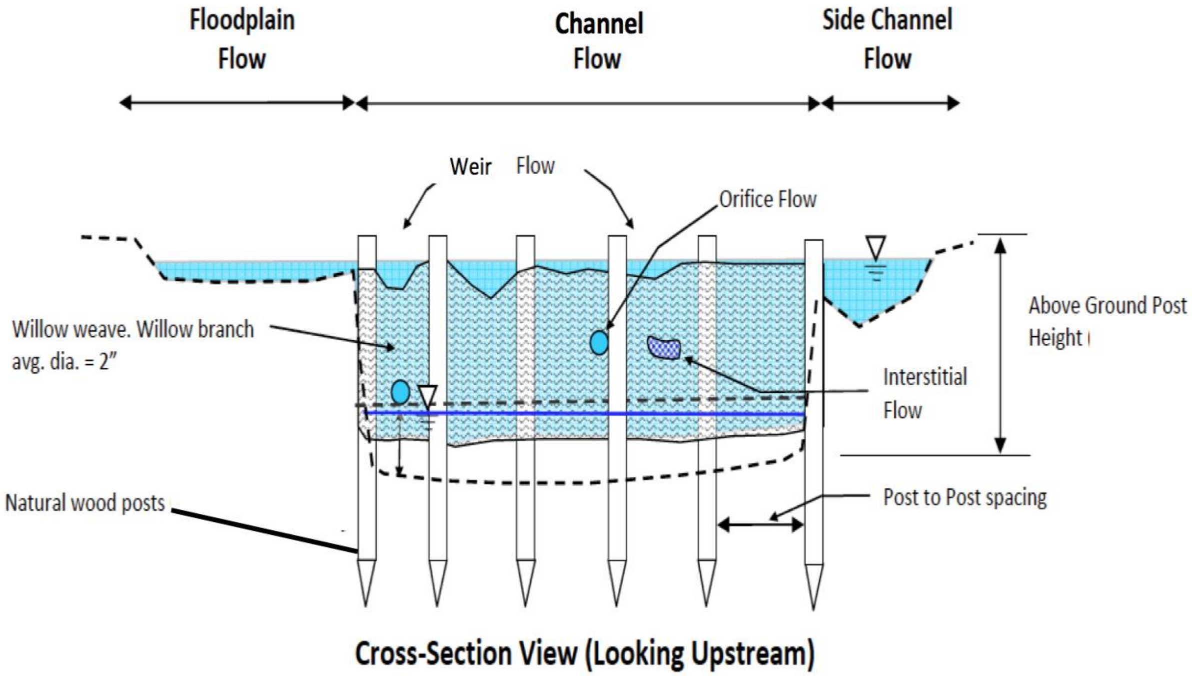


Figure 1. Typical components of beaver dam analogue. Flow passes the structure over its crest as weir flow, through discrete openings as weir flow, through small gaps or openings as interstitial flow and around the structure as floodplain or side channel flow.

Hydrology and hydraulics

Flow frequency distributions are generated within the design tool from annual series supplied by user, Streamstats regression formula, or entered by user based on estimate or other information. The user then selects a design discharge. Pre-BDA hydraulics are computed based on the USDA-NRCS uniform flow spreadsheet, xsecAnalyzerVer17.xlsm (http://go.usa.gov/0Eo), which is embedded in BDA Design Tool. Post-BDA hydraulics assume critical flow over BDA crest. The user must supply estimates of the percent of the design discharge passing the BDA over the crest, or as floodplain, side channel flow, or interstitial flow.

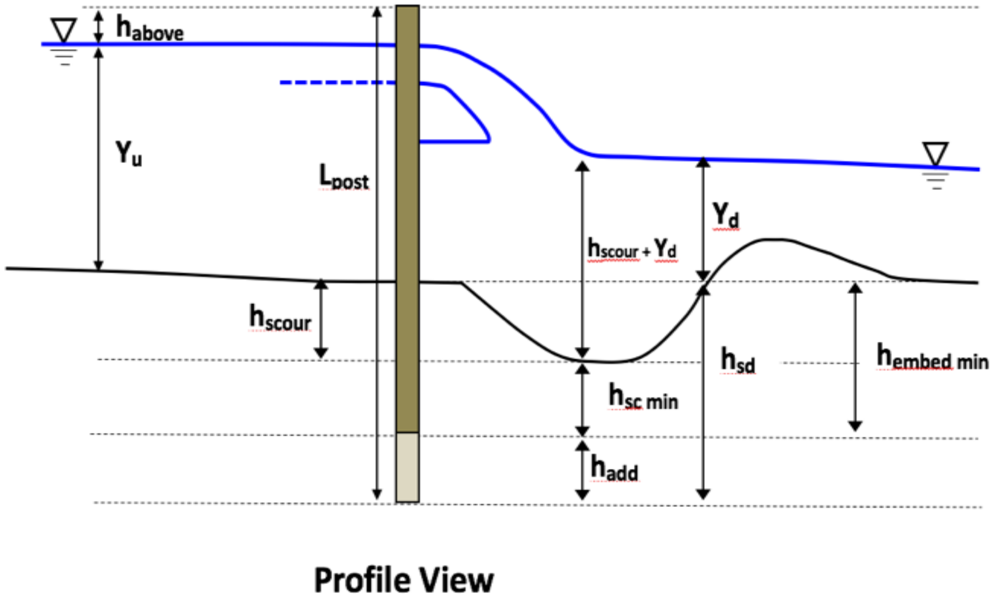
Table 1. Design Tool Contents

Worksheet	Description and function
Design summary	Tabulates metadata and safety factors for vertical movement and post breakage and overturning
Hydrology	Select design discharge and compare return interval to desired design life
Structure dimensions	User specifics structure height, width, slide slopes, etc.
Channel geometry	User provides cross section for BDA site. Sheet provides a cross section plot to visualize and check.
Uniform flow computations	Pre-BDA hydraulics at design discharge from NRCS sheet, Xsecanalyzer
Hydraulics	Post-BDA hydraulics assuming critical flow over weir crest
Scour and downstream rock sizing	Scour depth related to hydraulics and rock sizing using empirical formula (D'Agostino and Ferro 2004)
Upstream rock sizing	Cobble or coarse gravel is normally placed on upstream face. Size needed to remain stable even if underflow occurs is computed using four formulas to rock chutes. User selects desired result.
Impact force	Force BDA due to impact of floating log
Posts-overturning and breakage	Minimum post embedment depth to resist overturning computed using Brom's (1964) method for pilings in noncohesive material.
Posts-vertical forces	Post skin friction compared to buoyant force using method from Knutson and Fealko (2014)
Material volumes	Quantities primarily based on dimensions specified by user in Structure dimensions worksheet
Cost estimate	Based on material volumes and unit costs provided by user
Soil properties	Bulk density, friction angle. Coefficient of lateral earth pressure, etc.
Wood properties	Unit weight, modulus of rupture
Natural beaver dam dimensions	Tabulated from 16 publications

Post embedment depth

The tool computes the post embedment depth needed to resist the horizontal loading forces: fluid drag, hydrostatic force, and impact from floating logs. Dimensions which must be either specified by the user or computed are indicated in Figure 2. An iterative approach is used to compute the post embedment depth because the minimum post embedment depends on the resisting moment, which depends on the embedment depth. Moments due to each type of horizontal loading force are summed about the buried tip of the post. Drag and hydrostatic forces are assumed to act at a point midway between the water surface and the stream bed. Impact forces are assumed to act at the elevation of the crest of the weir. Moments are summed for the entire BDA but divided by the number of posts in order to get the moment acting on each post. The minimum required post embedment depth is computed using the method presented by Broms (1964) for posts in noncohesive soils or sediments.

Experience suggests that BDAs often fail when downstream scour undermines the structure, triggering underflow and enlarging the opening through the structure by progressive erosion. Embedment depth must be great enough to ensure post stability after formation of a downstream scour hole (Figure 2). The tool uses the empirical equation by D'Agostino and Ferro (2004) to relate flow hydraulics, bed sediment size, and equilibrium scour depth. The effect of downstream bed sediment size on required post embedment as calculated by the tool is shown in Figure 3.



Profile View

Figure 2. Definition sketch for post depth calculations. L_{post} = total length of post = h_{add} (additional embedment to increase safety factor) + $h_{sc\ min}$ (minimum embedment given computed downstream scour depth) + h_{scour} (downstream scour depth) + Y_u (upstream flow depth) + h_{above} (height of post above upstream design water surface elevation). The sum of h_{scour} and $h_{sc\ min}$ = $h_{embed\ min}$, and Y_d = downstream flow depth.

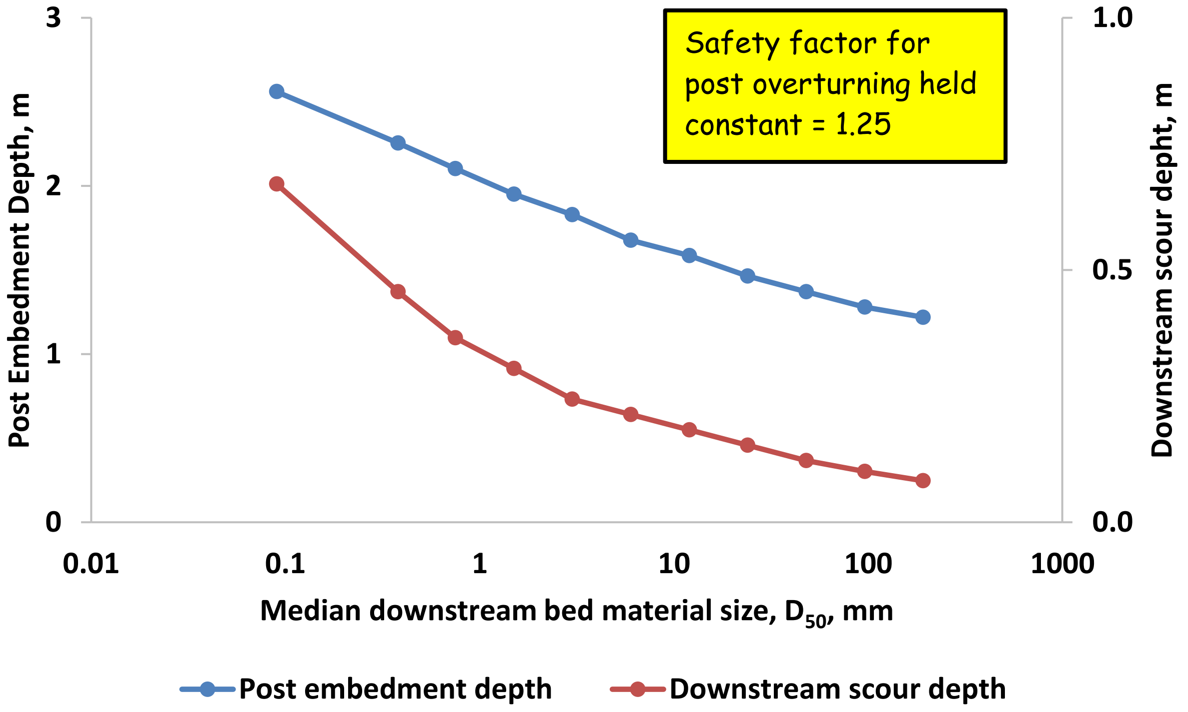


Figure 3. Post embedment and downstream scour depth as a function of bed material size

Conclusion

The BDA design tool may be used by practitioners to facilitate design of resilient, cost-effective structures with appropriate levels of failure risk. The current version is on hold pending obtaining funds to incorporate peer comments and finalize documentation. It should be viewed as model awaiting revision and refinement to reflect ongoing user experience and feedback as it is applied under a variety of hydrogeomorphic and ecological conditions.

References

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