SUPPLEMENT TO TECHNICAL NOTE 1

EVALUATING SPILLWAY CAPACITY FOR SMALL DAMS

FOR A 500-YEAR STORM

INTRODUCTION

This supplement to the Montana Dam Safety Program's *Technical Note 1, Determination of the Inflow Design Flood for High Hazard Dams in Montana*, provides short, practical guidance for evaluating an existing spillway's capacity to pass a 500-year return period flood. This is intended for dams that are classified as high hazard and are required to meet the minimum spillway capacity requirements for passing a 500-year flood. This method uses available U.S. Geologic Survey (USGS) data and methods for estimating a 500-year peak discharge from a drainage basin upstream of a dam and reservoir, and then evaluating an existing spillway's capacity to pass the peak discharge. The methods presented in this supplement are intended to be relatively easy to conduct, but using data and processes that provide reasonable results in determining a spillway's capacity. These methods are intended to supplant more complex analyses for conducting rainfall-runoff models and computer-based evaluations of spillways.

This supplement assumes the user is familiar with common hydrologic and hydraulic terminology and has some experience in conducting hydrologic analyses for dam safety purposes in Montana, and experience in computing hydraulic parameters for open channel flow. For this type of evaluation, it is expected the engineer has enough dam safety experience to judge adequacy of the analysis and to make modifications appropriate for the public's safety and the dam owner's protection.

DESCRIPTION

The methods suggested in this supplement are readily available to the public. There are two components of the evaluation: 1) estimating the peak discharge for a 500-year return period flood from an ungaged basin using USGS regression equations imbedded in the StreamStats® web model; and 2) evaluating a spillway's capacity using simplified methods such as using a broad crested weir approach. The methods are described below.

Estimating Peak Discharge for a 500-Year Return Period Flood

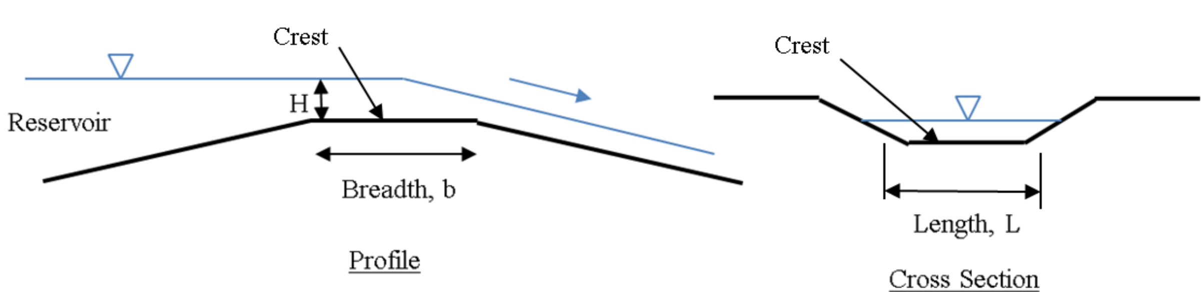
The goal of this method is to obtain a peak discharge for a 500-year return period runoff event for a drainage basin upstream of the dam/spillway being evaluated. This method uses the USGS StreamStats® analysis tool found at https://streamstats.usgs.gov/ss/. The hydrologic information imbedded in StreamStats comes from the data and methods found in *USGS Scientific Investigations Report (SIR) 2015-5019-A through G, Montana StreamStats*. These tools use regression equations developed from stream gage data for different hydrological regions in Montana to estimate peak discharge for various return periods in ungaged basins. StreamStats® automatically delineates the basin in question by having the user click on a point at the mouth of the basin, and then produces the appropriate basin characteristics based on GIS data for estimating peak discharge. The system also computes peak discharges for return periods ranging from 1.5 years to 500 years.

Evaluating Spillway Capacity

Evaluating spillway capacity can be a phased approach, starting with using a broad-crested weir equation to determine capacity, and, if needed to refine the analysis, moving to more complex methods of modeling. This supplement will only cover estimating discharge with a broad-crested weir estimation.

Most spillways for small dams are excavated earthen channels, sometimes vegetated or protected with erosion-control materials. Figure 1 below provides very basic sketches of a cross section and profile of a typical earthen spillway, which can be reasonably represented and modeled as a broad-crested weir. Starting on the reservoir side, the spillway has an approach channel up to the crest, or high point on the spillway, extends some distance horizontally (the broad crested weir breadth) or with a slight downward slope, and then into the exit channel on the downstream side. The cross section at the crest is typically a trapezoidal shape, if excavated in native material, or possibly rectangular-shaped if the sides are made out of concrete or other material to create vertical walls. The crest is usually level or nearly level. The weir length, L, represents the water top width of the weir. If it has vertical side walls, the water top width is the same as the crest length. For trapezoidal sloped sides, the weir length can be estimated by the average water top width from the crest to the water surface, as shown in Figure 1.

FIGURE 1. PROFILE AND CROSS SECTION OF A TYPICAL EARTHEN SPILLWAY.



The broad-crested weir equation in its most basic form is:

$$Q = CLH^{1.5} \quad \text{(Brater and King, 1976)}$$

where: Q = discharge, ft^3/s
C = broad-crested weir coefficient (see Table 1)
L = broad-crested weir length, ft
H = head above weir crest, ft

The weir coefficient C is sometimes difficult to estimate and it has a significant effect on the discharge estimated through the weir. Table 1, while not comprehensive in covering all possibilities, provides guidance for determining C based on water depth above the crest (H) of the weir and the breadth of the crest (b).

TABLE 1. BROAD-CRESTED WEIR COEFFICIENT (C) VALUES.

Table 1.2 Broad-Crested Weir Coefficient (C) Values											
Measured Head (H)*	Weir Crest Breadth (b) in feet										
In feet	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	10.00	15.00
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	2.60	2.60	2.67	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.27	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

* Measured at least 2.5H upstream of the weir.
Source: Brater and King (1976)

EXAMPLE

The following example will demonstrate the methods described above. This example is for a randomly-selected ungaged drainage basin in Central Montana that does not actually have a dam at its mouth. The spillway does not actually exist and its dimensions have been made up for this example. The example will cover two things: 1) determining a peak discharge at the mouth of the basin for a 500-year return period using USGS and StreamStats® methods; and 2) developing a stage-discharge curve for a trapezoidal-shaped spillway using the broad-crested weir equation.

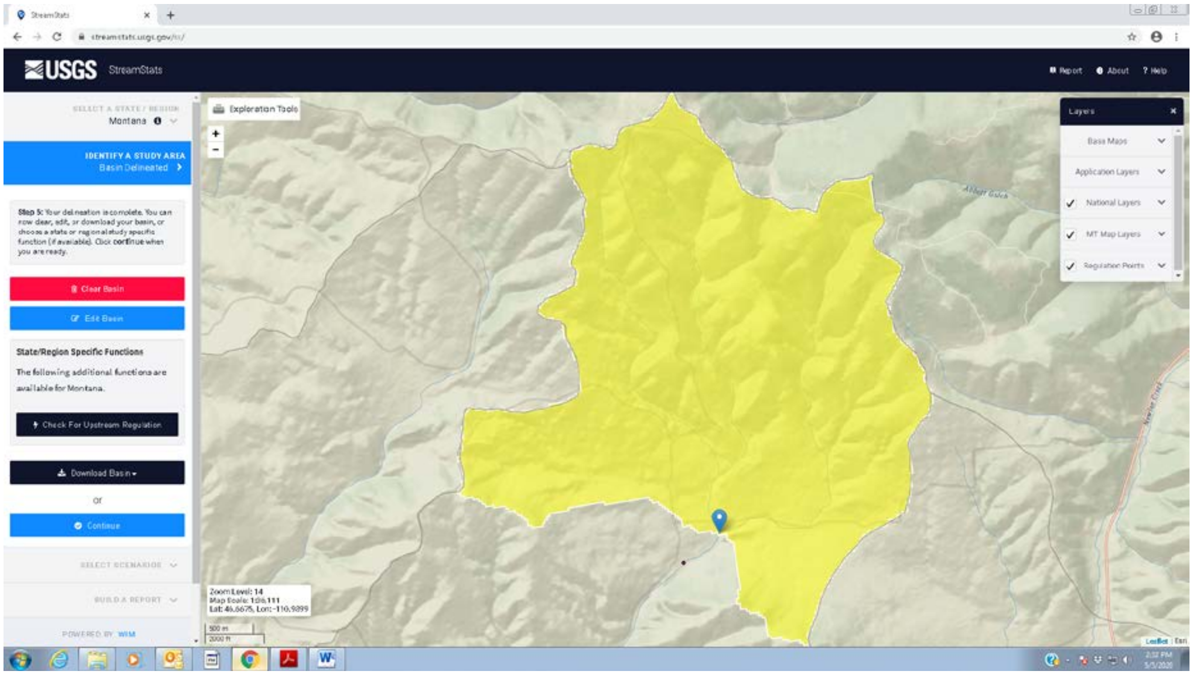
Peak 500-Year Discharge

To utilize the StreamStats® system, go to https://streamstats.usgs.gov/ss/. On the interactive map, zoom to the general area to be delineated. In the upper left corner, it will ask you to identify a state or region. One of the options should be Montana. Once you click on Montana, it will display ‘Step 1: Zoom in to level 15 or greater to enable the delineation tool.’ The zoom level is displayed in the lower left corner of the map. When you reach zoom level 15, stream channels on the map become delineated with large blue pixels, as shown in Figure 2 below. Click on the blue ‘Delineate’ box on the left side. The ‘Delineate’ box will turn orange colored and you will see above it ‘Step 3: Use your mouse or finger to click or tap a blue stream cell on the map.’ Click on the nearest blue stream cell to where you want the delineation. The lower right corner of the map will have a box that indicates the system is working and on the left side it will display ‘Step 4: Wait for delineation process to complete...’

FIGURE 2. SCREEN SHOT OF STREAMSTATS® MAP PRIOR TO BASIN DELINEATION.

When the delineation is complete, the basin will be identified as a yellow area on the map, as shown in Figure 3.

FIGURE 3. SCREEN SHOT OF STREAMSTATS® MAP AFTER BASIN DELINEATION.



Now on the left side it will read ‘Step 5: Your delineation is complete.’ You can now clear, edit, or download your basin, or choose a state or regional study specific function (if available). Click continue when you are ready. For this example, click ‘Continue.’ In the lower right corner it will signify that the system is querying the regression equations appropriate for this region. When this is finished, on the left a blue box will appear that says ‘Select Scenarios’ and below it is a long list of options from which to choose. For this example, select ‘Peak Flow Statistics’ and then ‘Continue.’ It is now ready to prepare a report for peak flow statistics. On the bottom left side, two reports are checked: a Basin Characteristics Report and Scenario Flow Reports. Select ‘Continue.’ A StreamStats report appears that can be customized at the top for the basin. The report is attached as Appendix A to this supplement.

In the report, information is displayed for Peak-Flow Statistics Parameters, which are the parameters used in the regression equations to calculate peak discharge. There is also information in a Peak-Flow Statistics Flow Report. This consists of a table with peak discharge values for selected return periods. The two reports are shown in Figure 4.

FIGURE 4. SCREEN SHOT OF STREAMSTATS PEAK-FLOW STATISTICS REPORT.

Peak-Flow Statistics Parameters [UpYellow CentMount Region BasinC 2015 5019F]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
CONTDA	Contributing Drainage Area	6.1	square miles	0.39	2040
EL6000	Percent above 6000 ft	35.3	percent	0	100

Peak-Flow Statistics Flow Report [UpYellow CentMount Region BasinC 2015 5019F]

PII: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	PII	Plu	SEp
1.5 Year Peak Flood	29.3	ft^3/s	6.14	140	119
2 Year Peak Flood	40.5	ft^3/s	9.15	179	111
2 33 Year Peak Flood	47.3	ft^3/s	11.5	194	103
5 Year Peak Flood	86.8	ft^3/s	26.3	286	82.4
10 Year Peak Flood	130	ft^3/s	44.1	384	73
25 Year Peak Flood	199	ft^3/s	71.3	556	68.4
50 Year Peak Flood	260	ft^3/s	94.1	716	67.7
100 Year Peak Flood	325	ft^3/s	116	912	69
200 Year Peak Flood	399	ft^3/s	138	1160	71.6
500 Year Peak Flood	509	ft^3/s	165	1570	77

For this example, the flow of interest is the 500-year peak flood, which has a value of 509 cubic feet per second (cfs, or ft^3/s as displayed in the report). Values are also given for the lower and upper prediction intervals, and the standard error for the regression equation. The user has the option to use the average value shown or select flow values within the prediction interval.

Spillway Capacity

The next step is to evaluate the spillway capacity to determine if it is large enough to pass the peak 500-year discharge, or 509 cfs. The earthen spillway has a trapezoidal shape, or a configuration similar to that shown in Figure 1, with the following cross section dimensions at the crest:

Bottom width (or weir length at the crest):	20 feet
Side slopes:	2 horizontal : 1 vertical
Breadth:	30 feet
Maximum height at crest:	4 feet

The maximum breadth from Table 1 is 15 feet, but C remains fairly constant for breadths 10 feet or higher. For this example, C is chosen to be 2.63 for all depths of water above the crest.

The weir length, L, is the average water width over the depth of flow, to accommodate the trapezoidal shape. Using the equation $Q = CLH^{1.5}$, Table 2 provides the spillway discharge, Q, for different water depths, H.

TABLE 1. STAGE-DISCHARGE TABLE FOR EXAMPLE SPILLWAY.

H (ft)	L (ft)	Q (cfs)
0	20	0
0.5	21	19.5
1	22	57.9
1.5	23	111.1
2	24	178.5
2.5	25	259.9
3	26	355.3
3.5	27	465.0
4	28	589.1

For this example, the spillway has the capacity to pass 509 cfs at a depth of approximately 3.7 feet at the crest, with approximately 0.3 feet of freeboard.

CONSIDERATIONS AND CAUTIONS

This is a simplified approach to determining spillway capacity and its ability to pass a 500-year flood. The results should be understood as having inherent error. There are some considerations and cautions of which the engineer should be aware.

The 500-year peak discharge is developed from regression equations that provide an estimated value, but they do have fairly liberal margins of error. The estimate has a wide predicted interval band of values that are possible given the data used in determining the regression equation. The engineer needs to use judgement on what is an adequate value for the basin in question.

For the spillway, it may have the capacity at the crest to pass the required flow, but other factors need to be considered. Erosion in an earthen or vegetated channel is inevitable. The engineer is cautioned to try to evaluate the extent of erosion possible and the consequences if the spillway were to fail due to erosion.

If the existing spillway is inadequate using the methods described above, options for consideration include:

1. Developing a rainfall runoff model where the reservoir attenuates the flood peak (routes the flood) using techniques described in Technical Note 1. Note that the engineering

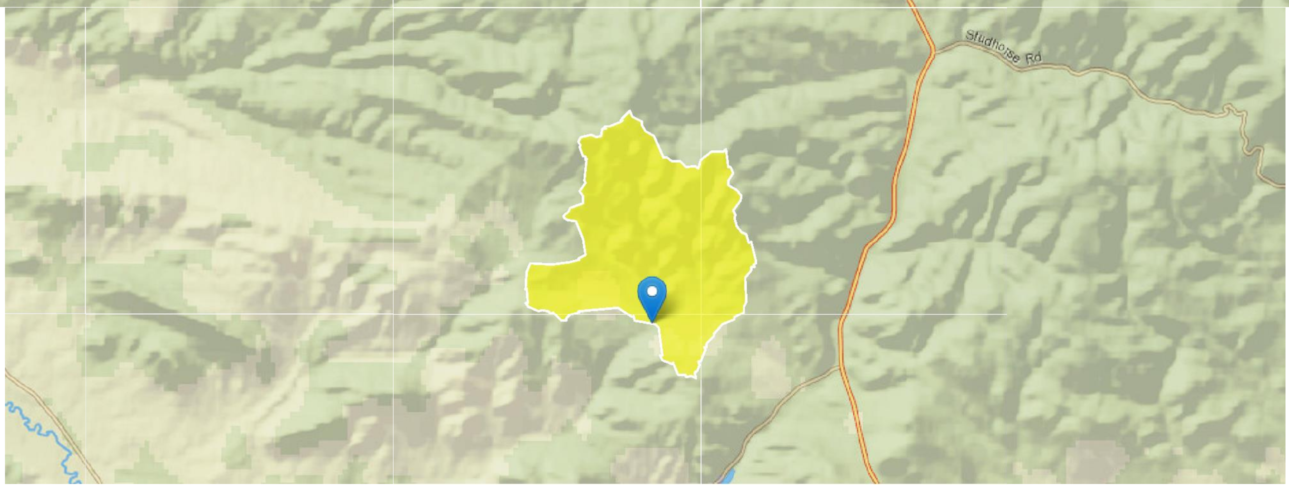
analysis involved to develop a rainfall runoff model can be costly and must be done by qualified individual.

2. Provide additional spillway depth. Note that this could contribute to additional erosion and may not be a good idea, particularly if there is no other means to passively control the reservoir level, such as a drop inlet structure.
3. Provide engineered erosion protection or reinforcement of the spillway channel.
4. Raise the dam to provide additional capacity. Note, this is only a reasonable option if the dam crest is significantly wide to begin with, so that the addition of fill does not create a narrow crest width that does not meet accepted standards, or create over-steepened upstream and downstream slopes.
5. Provide additional capacity and passive reservoir control with a high-level outlet pipe. Note this is only a reasonable option if the drainage area is small, the existing spillway is not significantly undersized, and there are other benefits to installing a high-level oveflow pipe.

APPENDIX A – STREAMSTATS REPORT

StreamStats Report

Region ID: MT
Workspace ID: MT20200505202528095000
Clicked Point (Latitude, Longitude): 46.67780, -110.93185
Time: 2020-05-05 14:25:45 -0600



Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
CONTDA	Area that contributes flow to a point on a stream	6.1	square miles
EL6000	Percent of area above 6000 ft	35.3	percent

Peak-Flow Statistics Parameters[UpYellow CentMount Region BasinC 2015 5019F]

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500 Year Peak Flood	509	ft^3/s	165	1570	77

Peak-Flow Statistics Citations

Sando, Roy, Sando, S.K., McCarthy, P.M., and Dutton, D.M.,2016, Methods for estimating peak-flow frequencies at ungaged sites in Montana based on data through water year 2011: U.S. Geological Survey Scientific Investigations Report 2015–5019–F, 30 p. (https://doi.org/10.3133/sir20155019)

Application Version: 4.3.11