DEPARTMENT OF ECOLOGY
State of Washington

Recommended dam safety protocols for burned watershed hydrology calculations

Revised August 2015
Publication no. 15-11-013

Publication and Contact Information

This report is available on the Department of Ecology's website at
https://fortress.wa.gov/ecy/publications/SummaryPages/1511013.html

For more information contact:

Water Resources Program, Dam Safety Office
P.O. Box 47600
Olympia, WA 98504-7600

Phone: 360-407-6872

Washington State Department of Ecology - www.ecy.wa.gov

o Headquarters, Olympia	360-407-6000
o Northwest Regional Office, Bellevue	425-649-7000
o Southwest Regional Office, Olympia	360-407-6300
o Central Regional Office, Yakima	509-575-2490
o Eastern Regional Office, Spokane	509-329-3400

If you need this document in a format for the visually impaired, call the Water Resources Program at 360-407-6872. Persons with hearing loss can call 711 for Washington Relay Service. Persons with a speech disability can call 877-833-6341.

Recommended dam safety protocols for burned watershed hydrology calculations

by
Martin Walther, P.E.
Dam Safety Engineer, Hydrology/Hydraulics specialist
Washington State Dam Safety Office

Water Resources Program
Washington State Department of Ecology
Olympia, Washington

Table of Contents

Table of Contents

This guidance and the associated spreadsheet are intended for use by Professional Engineers only, or by junior engineers under the supervision of a Professional Engineer. Engineers using this information and spreadsheet must make sure their calculations are correctly applied to their project.

Ecology makes no representation or warranty of any kind, whether express or implied, concerning the accuracy, completeness, suitability or utility of any information, apparatus, product, or process discussed herein, and assumes no liability therefor. Neither the State of Washington, the Department of Ecology, nor Ecology's reviewing engineer(s) are authorized to accept any of the design engineer's professional responsibility and/or potential liability.

Acknowledgements

Special acknowledgement goes to Katherine Rowden, hydrologist with the National Weather Service Spokane Office, for helping the Dam Safety Office connect with the USFS Burned Area Emergency Response hydrology references and resources. This was a critical connection for our understanding of the hydrologic impacts that a wildfire can have.

Special acknowledgement also goes to Greg Kuyumjian, hydrologist retired from the U.S.D.A Forest Service, for feedback and guidance to the Dam Safety Office with regard to protocols and procedures for Burned Area Emergency Response (BAER) hydrology computations. This feedback was a significant contribution to the current version of the spreadsheet and this guidance document.

Recommended dam safety protocols for burned watershed hydrology calculations

Introduction

For dams in forested watersheds, fires, floods and failures can happen, and can happen quickly.

The hydrologic effects of wildfires are known to forest hydrologists, but this knowledge seems to have limited circulation outside of forestry circles. This guidance will attempt to share forest hydrology knowledge as it potentially applies in the context of dam safety, and suggests a starting point for developing calculations to assess dam safety for a burned watershed.

The accompanying spreadsheet is available at:
http://www.ecy.wa.gov/programs/wr/dams/GuidanceDocs.html

Background Information

Forest fires can affect burned-area soils by reducing the effective ground cover, reducing the amount of soil structure, and forming water repellent layers that reduce infiltration (Parsons et al, 2010, pg. 10). These changes result in both increased runoff volumes and faster runoff response, such that the post-fire peak discharges can be an order of magnitude or more larger than pre-fire runoff flows, especially in the first couple years after the fire. For dams in burned watersheds, it is probable that their spillways will not be able to pass the dam safety inflow design flood. How would we determine whether this is the case? How would we estimate what size of storm the spillways can pass?

Fortunately, the hydrology calculations are not difficult once the post-fire watershed parameters are known. An accompanying spreadsheet has been developed to perform the calculations for burned watershed conditions. After that, the computation procedures are similar to typical dam safety IDF calculations.

The Washington State Dam Safety Office typically uses the HEC-HMS computer program to perform the hydrology computations, so this guidance is prepared with HEC-HMS in mind, although these principles should be applicable to any hydrology computer program that uses the unit hydrograph approach where hydrologic losses are estimated using either a constant soil infiltration rate or NRCS curve number and the unit hydrograph uses a lag time parameter.

Theory

Changes between pre-fire and post-fire conditions are reflected in changes to the NRCS curve numbers (CN values) for the watershed (USFS-MFSL, 2009). Areas of high and moderate burn severity are assigned very high CN values based on burn severity. Areas of low burn severity are assigned CN values scaled up from the original pre-fire CN values. For unburned areas, CN values are unchanged.

Several computation methods have been developed by USFS Burned Area Emergency Response (BAER) hydrologists (USFS-MFSL, 2009). The following method has been used by BAER hydrologists for fires in Washington State and is used in these calculations. Post-fire CN's are calculated based on burn severity and pre-fire CN as follows:

Burn severity	Post-fire CN
High	95
Mod.	90
Low	Pre-CN + 5
Not	Pre-CN

The changes to the CN values within the watershed will greatly increase the amount of runoff from the watershed in response to precipitation. Per USDA-NRCS NEH-630, chapter 10, the NRCS rainfall-runoff relationship is described by equation 10-11:

$$Q = [\ (P - 0.2\ S)^2\ ] \ /\ [\ P + 0.8\ S\ ]$$

Where $S = 1000 / CN - 10$

Q = runoff, inches

P = precipitation, inches

$P > 0.2\ S$; for $P < 0.2\ S$, $Q = 0$

The runoff Q is calculated for each CN area, then combined to get the weighted runoff from the overall watershed. (See also NEH-630, chapter 10, Example 10-5 on pages 10-13 to 10-16.)

Example calculation:

Watershed with burn severities of 23% high, 32% moderate, 45% low severity as percent of watershed area. Pre-fire CN = 60. Precipitation = 1.00 inch.

CN	S	Runoff	% area	Weighted runoff
95	0.526	0.563	23.0	0.130
90	1.111	0.320	32.0	0.102
65	5.385	0.000	45.0	0.000
60	6.667	0.000	0.0	0.000
			Runoff =	0.232 inch

Overall watershed:

87.3	1.456	0.232	100	0.232 inch

The changes to the CN value for the watershed also affect the time of concentration (T.conc) and unit hydrograph lag time per USDA-NRCS NEH-630, chapter 15, equations 15-4a and 15-4b:

$$\text{UH lag} = [\ L^{0.8}\ (\ S+1)^{0.7}\ ] \ /\ [\ 1900\ Y^{0.5}\ ]$$
$$\text{T.conc} = [\ L^{0.8}\ (\ S+1)^{0.7}\ ] \ /\ [\ 1140\ Y^{0.5}\ ]$$

Where $S = 1000 / CN - 10$

Comparison of post-fire to pre-fire CN's and some algebraic manipulation yields the following equation for the ratio of post-fire to pre-fire times of concentration and UH lag times:

Post/pre-fire ratio = $[(S+1)_{post} / (S+1)_{pre}]^{0.7}$

Example calculation:

Pre-fire T.conc = 100 minutes. Pre-fire UH lag = 60 minutes.
CN_{pre} = 60.0. S_{pre} = 6.667. $(S+1)_{pre}$ = 7.667.
CN_{post} = 87.3. S_{post} = 1.456. $(S+1)_{post}$ = 2.456.

Post/pre-fire ratio = $(2.456 / 7.667)^{0.7} = 0.45$.

Post-fire T.conc = 0.45 x 100 = 45 minutes.
Post-fire UH lag = 0.45 x 60 = 27 minutes.

The pre-fire hydrology model for the dam and watershed just needs to be updated with the post-fire parameters for CN value and UH lag time in order to perform the calculations for the burned watershed. If the watershed has several sub-basins, the calculations for the post-fire parameters need to be done for each sub-basin based on the specific burn severities in each sub-basin.

On a separate but related topic, Dam Safety's experience has been that, when used with our Short duration storm, the CN value determined using standard procedures tends to under-estimate the runoff from the Short storm. To correct for this, we have separate protocols for calculating the CN value to use with the Short dam safety storm. We don't require hydrology calculations to use CN's to estimate hydrologic losses, but if the hydrologist elects to use this method in the calculations, submittals to Dam Safety must use the corrected CN value with the Short dam safety storm. The general CN value is acceptable to use with the Intermediate and Long duration dam safety storms. Our previous guidance on this topic is available from the Dam Safety web site at: http://www.ecy.wa.gov/programs/wr/dams/GuidanceDocs_ne.html.

Calculation procedures

The following procedures should be used in conjunction with the accompanying spreadsheet, available at: http://www.ecy.wa.gov/programs/wr/dams/GuidanceDocs.html. A separate copy of this spreadsheet will be needed for each sub-basin.

1. Compile the following pre-fire data for the watershed or sub-basin: drainage area, pre-fire CN value, time of concentration, unit hydrograph lag time.

2. In Washington State, perform the Technical Note 3 calculations to determine the 25-year rainfall values for the Intermediate and Short duration storms. The calculations will also identify the Climate Region and the specific dam safety storm hyetographs for the Short and Intermediate storms (see item 6 below). The Tech Note 3 spreadsheets and gridded data sets are found in a separate download file available on the Dam Safety web site at: http://www.ecy.wa.gov/programs/wr/dams/GuidanceDocs_ne.html.

In other states, determine the 25-year rainfall values and counterpart storm hyetographs used in your state. This will likely be 24-hour duration to represent the general storm and 1-hour or 2-hour duration, perhaps up to 6-hour duration, to represent the thunderstorm.

3. Find the burn severity acreages from the BAER maps or BAER reports. For fires in central Washington State, maps and reports are posted at the Central Washington Fire Recovery web site: http://centralwashingtonfirerecovery.info/. BAER maps and reports may also be posted on the local Conservation District web site.

   If the BAER team findings are not available, tentative estimates of the area percentages of burn severity may be entered on the spreadsheet, with the intent of updating the area percentages when more accurate information becomes available. The following guidance is offered with regard to ranges of burn severity and area percentages:

	% of drainage area		
Burn severity	mean	mean + std dev	max
High	12%	23%	44%
Mod.	24%	32%	50%
High+Mod.	36%	51%	67%

	% of drainage area		
Burn severity	min	mean - std dev	mean
Low	33%	46%	60%

   For tentative estimates of burn severity percent areas, we recommend using percent areas for high and moderate severity at least as large as these mean values. Of course, larger estimates for high and moderate burned areas should be off-set by a smaller estimate for the low severity area such that the percentages all add up to 100%.

   If a significant portion of the watershed is outside the fire perimeter, the burned watershed should be treated as two smaller sub-basins, one burned and one not burned, in the hydrology model. The burned sub-basin would use the post-fire parameters calculated using these procedures. The unburned sub-basin would use the pre-fire watershed parameters. The two drainage areas combined should equal the original drainage area.

4. After the data are entered into the green cells on the **Fire calcs** tab, cell J-34 is manually adjusted until the runoff depths in cells J-32 and J-36 agree, as shown by the difference value in cell J-37 equal to 0.0000. In cell J-34, the adjustment is made only to the numerical value that is added to the value in cell G-32; the reference to cell G-32 must be kept in cell J-34. This CN value (in cell J-34, copied to cell H-11) is the post-fire CN value to use with the Intermediate and Long duration general storms.

   The spreadsheet also calculates the post-fire time of concentration and unit hydrograph lag time using the post/pre-fire ratio for T.conc and UH lag. The pre-fire time of concentration and unit hydrograph lag time may be calculated by any acceptable method. The spreadsheet will simply scale the pre-fire values to post-fire conditions.

Unless over-ridden, blue cell D-16 calculates the UH lag time as 0.6 x T.conc using the value for T.conc entered in cell D-15. If the user accepts this, leave blue cell D-16 as-is.

5. The **T-storm CN** tab is used to calculate a soil infiltration rate that will estimate a runoff volume equal to that estimated by the post-fire CN value, and then a CN value for the Short dam safety storm (thunderstorm) that will estimate a runoff volume equal to that estimated by the post-fire soil infiltration rate.

   On the **T-storm CN** tab, cell C-24 on page 1 is manually adjusted until the runoff depths in cells J-29 and K-31 agree, as shown by the difference value in cell K-33 equal to 0.0000. The user must adjust the value in C-24 until the correct values show in the other cells.

   After that, cell U-30 on page 5 is manually adjusted until the runoff depths in cells W-31 and X-33 agree, as shown by the difference value in cell X-38 equal to 0.0000. In cell U-30, the adjustment is made only to the numerical value that is added to the value in cell X-36; the reference to cell X-36 must be kept in cell U-30. The user must adjust the value in cell U-30 until the correct values show in cells W-31, X-33 and X-38.

   The results from the calculations on the **T-storm CN** tab are copied back to the **Fire calcs** tab, both at the bottom of the page and also in the section for post-fire parameters near the top of the page.

6. The intermediate and short storm hyetographs for the various climate regions in eastern Washington are listed on the **East storms** tab, and hyetographs for the climate regions in western Washington are listed on the **West storms** tab. If your dam's watershed is not in Climate Region 14, the correct hyetographs from the **East storms** or **West storms** tab must be copied and pasted into the **T-storm CN** tab before doing the calculations on the **T-storm CN** tab as described in item 5. The hyetographs for Region 14 are already listed on the **T-storm CN** tab, so if your watershed is in Region 14, the hyetographs do not need to be changed.

7. Once the post-fire loss parameter (either CN values or constant infiltration rate) and unit hydrograph lag time are determined and entered into the hydrology computer model, the computation procedures are the same as for pre-fire conditions.

   In Washington State, the analysis must consider three scenarios: Short, Intermediate and Long duration storms. For the same design step, each of these storms is equally probable, so the hydrology calculations must compare the results from all three storms to determine which is most critical for this particular dam in terms of high water level in the reservoir and peak discharge out the spillway.

   For the post-fire loss parameter, all three storm scenarios may use the constant infiltration rate as calculated by the spreadsheet.

If the NRCS curve number is used for the loss parameter, the general CN should be used with the Intermediate and Long dam safety storms, and the Short (T-storm) CN should be used with the Short dam safety storm.

If interflow is considered in the analysis, those parameters would be unchanged from pre-fire conditions. Only the surface runoff parameters are updated for post-fire conditions.

8. Consider making several burned watershed model runs to consider:
   a. Possible overtopping by the dam safety inflow design flood. Would the dam be overtopped? If so, by how much and for how long?
   b. What size of storm (both rain depth and recurrence interval) can the spillway pass for burned watershed conditions?
   c. Possible operational measures to improve dam safety. Could some improvement be obtained from a reservoir drawdown? If so: How much drawdown would be needed? How much larger storm could be accommodated?

9. **Decision time: How to keep the dam safe while the watershed recovers from the fire.**

Risk exposure

From the BAER literature, it appears that watershed recovery from fire may take on the order of 3 to 5 years. What recurrence interval over 3 years would be similar in probability as the Design Steps used by Dam Safety? The short answer is a drop of about 3 design steps.

For example:

Pre-fire conditions	Burned watershed
Step 3 (3,000-year)	100-year
Step 4 (10,000-year)	Step 1 (500-year)
Step 5 (30,000-year)	Step 2 (1000-year)

This information is offered for purposes of risk comparison only, with a view toward helping dam owners and engineers make informed decisions regarding their risk exposure after the fire and how to keep their dam safe while the watershed recovers. For example, if a combination of spillway capacity and reservoir operations can pass the post-fire runoff from a storm three design steps below the original pre-fire dam safety design step, the dam owner and their engineer would know that they are about the same level of risk as for pre-fire conditions in their watershed.

At this time, Dam Safety is not requiring every dam to design, or to re-design, their spillways to pass an inflow design flood from a burned watershed. If this changes in the future, the protocols will be developed in an open, peer-reviewed process, or through rulemaking if required.

In the meantime, decisions with regard to spillway modifications are up to the dam owner and their engineer. Proposed spillway modifications will require prior notice to Dam Safety, with the procedures for concurrence or approval by Dam Safety to be determined on a project-specific basis.

Summary comments

This spreadsheet is intended to be public domain, to assist hydrologists and hydraulic engineers to perform hydrologic calculations for burned watershed conditions that they might not have previously encountered in their profession experience. As stated earlier, the engineer retains full responsibility for making sure the hydrologic calculations are correctly applied to their specific project.

For modifications to the dam, spillway or other appurtenant structures, engineers from the Dam Safety Office are available to provide technical assistance regarding dam design and construction and related engineering analyses, so please feel free to contact us early in the planning stages for your project.

Feedback and questions regarding this analytical approach and these spreadsheets are welcome, and should be directed to Marty Walther at:

Phone: 360-407-6420
Fax: 360-407-7162
E-mail: mwal461@ecy.wa.gov
Regular mail: Washington State Department of Ecology, Dam Safety Office, PO Box 47600, Olympia, WA 98504.

Wildfires and Dams: Key Information for Engineers, Hydrologists, and Dam Safety Officials

Magnitude of fire impacts on hydrology

- Runoff peak discharge can be an order of magnitude larger than pre-fire flows.
- Be hyper-sensitive to rainfall, especially more intense storms such as thunderstorms.
- Expect increased vulnerability to debris flows (mudslides), which can block spillways and/or impede access to the dam.

Availability of information from BAER teams

- The USFS Burned Area Emergency Response (BAER) teams have been down this trail before. The Moscow Forestry Sciences Lab web site has guidance materials for post-fire runoff calculations at: http://forest.moscowfsl.wsu.edu/BAERTOOLS/. Other BAER publications at: http://forest.moscowfsl.wsu.edu/cgi-bin/engr/library/searchpubkeys.pl.
- For specific fires, the BAER teams compile burned area and burn severity maps and reports. For fires in central Washington State, maps and reports are posted at the Central Washington Fire Recovery web site: http://centralwashingtonfirerecovery.info/. BAER maps and reports may also be posted on the local Conservation District web site. On specific request, BAER hydrologists have been willing to share a copy of their calculations for specific watersheds, at least with Dam Safety.

Spillway features

Critical spillway features that need to be evaluated:

- Log-boom or other barrier to divert floating debris
- Diversion berm to divert debris flows from adjacent hill slopes
- Erosion cut-off features or other armoring to resist erosion of the spillway channel.

Communication

- Communication between dam owners and dam safety officials soon after the fire is important.
- Connect with and obtain information from the BAER teams for specific fires. The BAER teams will be very busy and may not know where the dams of concern are, so Dam Safety staff should expect to take the initiative to make these connections and information requests.

References and Resources

BAER State and Private Team. *Burned Area Emergency Response (BAER) Report for Carlton Complex Fire (State and Private Lands)*. BAER State and Private Team. September 2014.

BAER USFS Team. *BAER Analysis Briefing for Carlton Complex Northeast*. BAER USFS Team. October 2014.

Cerrelli, G.A. *FIRE HYDRO, A Simplified Method for Predicting Peak Discharges to Assist in the Design of Flood Protection Measures for Western Wildfires*. In: Proceedings of the ASCE 2005 Watershed Management Conference – Managing Watersheds for Human and Natural Impacts, pp. 935-941. ASCE. July 2005.

Cerrelli, G.A. *Fire Hydrology Version 1.3 spreadsheet* (*FireHydrologyVer1.3.xls*). Microsoft Excel spreadsheet. USDA-NRCS. 2001. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/manage/hydrology/?cid=stelprdb1097776

Cerrelli, G.A. *Fire Hydrology Version 1.3 User Notes* (*FireHydrologyUserNotes.doc*). Microsoft Word document. USDA-NRCS. 2001. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/manage/hydrology/?cid=stelprdb1097776

Hawkins, R.H., and A. Barreto-Munoz. ***WILDCAT5 for Windows Rainfall-Runoff Hydrograph Model – User's Manual and Documentation***. U.S. Forest Service, Rocky Mountain Research Station. September 2011.

National Weather Service, Spokane Office. *Historical Perspective of 21 August 2014 Rainfall Event*, compiled by Ron Miller and Katherine Rowden. NWS Spokane. September 2014.

Parsons, A., P.R. Robichaud, S.A. Lewis, C. Napper and J.T. Clark. ***Field Guide for Mapping Post-Fire Soil Burn Severity***. General Technical Report RMRS-GTR-243. U.S. Forest Service, Rocky Mountain Research Station. October 2010.

U.S. Army Corps of Engineers. ***HEC-HMS Hydrologic Modeling System***, version 4.0. USACE Hydrologic Engineering Center (Davis, CA). 2013.

U.S. Forest Service, Moscow Forestry Sciences Laboratory. *Burned Area Emergency Response Tools for Post-Fire Peak Flow and Erosion Estimation*. USFS/RMRS/MFSL, May 2009 – http://forest.moscowfsl.wsu.edu/BAERTOOLS/ROADTRT/Peakflow/CN/supplement.html.

U.S. Geological Survey. ***StreamStats: A Water Resources Web Application*** *(application for Washington State)*. USGS – http://water.usgs.gov/osw/streamstats/Washington.html. Reports for Benson Creek watershed generated August 2014, September 2014.

USDA Natural Resources Conservation Service. ***Web Soil Survey – Custom Soil Resource Report for Okanogan County***. USDA-NRCS – http://websoilsurvey.nrcs.usda.gov. Reports for Benson Creek watershed generated August 2014, September 2014.

USDA Soil Conservation Service. ***National Engineering Handbook Section 4 -- Hydrology***. USDA-SCS. 1972. See Chapters 10 and 15.

USDA Natural Resources Conservation Service. ***National Engineering Handbook Section 630 -- Hydrology***. USDA-NRCS. 2004. See Chapters 10 and 15.

Walther, M.D. ***Dam Safety Incident Report – Benson Creek Flood, August 2014***. Washington State Department of Ecology Publication No. 14-11-011. September 2014. https://fortress.wa.gov/ecy/publications/SummaryPages/1411011.html.

Walther, M.D. ***Dam Safety Incident Report – Computerized Rainfall-Runoff Model for Benson Creek***. Washington State Department of Ecology Publication No. 15-11-002. January 2015. https://fortress.wa.gov/ecy/publications/SummaryPages/1511002.html.