Washington State Department of Ecology
Water Resources Program / Dam Safety Office

Recommended protocols for using NRCS curve numbers (CN's) with the Dam Safety short duration design storm hyetograph

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Objective

Identify an NRCS/SCS curve number (CN value) that will correctly estimate the runoff volume from a Dam Safety short duration design storm. Dam Safety's experience has been that CN table values consistently underestimate the runoff volume from the Dam Safety short thunderstorm.

Excerpts from NEH-4 (SCS, 1972), Chapter 10

Page 10.2 (top) – Surface runoff occurs when the rainfall rate is greater than the [soil] infiltration rate.

Page 10.3 – The Rainfall-Runoff Relation

The most generally available rainfall data in the United States are the amounts measured at non-recording rain gauges, and it was for the use of such data or their equivalent that the rainfall-runoff relation was developed. The data are totals for one or more storms occurring in a calendar day, and nothing is known about the time distributions. The [rainfall-runoff] relation therefore excludes time as an explicit variable; this means that rainfall intensity is ignored. …..

Page 10.5 (middle) – $Q = [(P - 0.2\,S)^2] / (P + 0.8\,S)$ (eqn. 10.10)
… is the rainfall-runoff relation used in the NRCS method of estimating direct runoff from storm rainfall.

Excerpts from NEH-4, Chapter 10 (continued)

Page 10.5 – Retention Parameters

….. 20 percent of the potential maximum retention S is the initial abstraction I_a, which is the interception, infiltration and surface storage occurring before runoff begins. The remaining 80 percent is mainly the infiltration occurring after runoff begins. This later infiltration is controlled by the rate of infiltration at the soil surface or by the rate of transmission in the soil profile or by the water-storage capacity of the profile, whichever is the limiting factor. …..

Page 10.6a – ….. The parameter CN is a transformation of S, and it is used to make interpolating, averaging and weighting operations more nearly linear. The transformation is:

$$CN = 1000 / (S + 10) \quad \text{or} \quad S = (1000 / CN) - 10 \qquad \text{(eqn. 10.11 \& 10.12)}$$

Discussion

In the typical application of the NRCS curve number method, we do not know the value for S, so we use the published table values for CN. The computer program uses the CN value to compute S (per eqn. 10.12), then uses the retention S and the rainfall P to compute the runoff Q (per eqn. 10.10).

For the Dam Safety storms, we have a complete storm hyetograph, so we can compare at each time step the rainfall intensity with the soil infiltration rate. The soil infiltration rate is typically estimated from soils data found in the Soil Survey for the particular county. With this information, we can perform a spreadsheet calculation to compare the storm hyetograph to a truncated hyetograph with the peak limited by the soil infiltration rate.

The truncated hyetograph represents water losses to soil infiltration, an approximation of the 80% S value as discussed in NEH-4. The difference in the sums between the two hyetographs represents the excess rainfall that becomes surface runoff. This computation serves as a check to verify or refute how well the table value for CN represents water losses to soil infiltration and other abstractions.

Dam Safety's experience has been that CN table values consistently underestimate the runoff volume from the Dam Safety short thunderstorm. We often see runoff volumes on the order of 20% to 40% of the rainfall volume, when a hyetograph calculation using the soil infiltration rate would estimate a runoff volume at least 60% of the rainfall volume. Such a large volume of unaccounted-for water seems to violate the principle of conservation of mass.

The correct application of the NRCS curve number method to the Dam Safety short design storm is to estimate S based on the expected losses to soil infiltration, then to calculate a corrected CN value to use in the hydrology computer program. This is a different approach than most of us are used to, but is consistent with the basic theory from NEH-4.

Computation procedures

1. Required data or estimates.

   The design step is calculated following the procedures and worksheet in Technical Note 2, based on the downstream hazard and the population and resources at risk from a potential dam failure. A spreadsheet to help perform these computations is available in Microsoft Excel 97-2003 format from the Dam Safety web site.

   Design storm precipitation is calculated following the procedures in Technical Note 3 as updated in September 2009, and using the PrecipLookup1-Shrt look-up calculator spreadsheet. The spreadsheets to perform these computations are available in Excel 97-2003 format from the Dam Safety web site.

   The unit hyetograph for the design storm is obtained from Technical Note 3. Electronic copies of the storm hyetographs are available in Excel 97-2003 format from the Dam Safety web site.

   The surficial soil infiltration rate and the seepage rate to deep groundwater are estimated from soils data in the Soil Survey for the particular county or area. The surficial infiltration rate is usually listed in a table of engineering properties or physical properties for the various soils. DSO usually estimates the deep seepage rate based on the hydrologic soil group rather than the specific soils information given in the table. The surficial infiltration rate and the deep seepage rate must be converted from inches/hour to inches/time-step. For the Dam Safety short duration storms, the time step is 5 minutes.

2. Storm hyetograph.

   The storm hyetograph is the unit hyetograph from Tech Note 3 multiplied by the total storm precipitation. Sum all the values in the storm hyetograph to verify the total storm rainfall in inches.

3. Losses to soil infiltration.

   The soil infiltration "hyetograph" is the storm hyetograph with the peak limited to the surficial infiltration rate. Computationally, the infiltration hyetograph equals the minimum value of the storm hyetograph or the infiltration rate in inches/time-step. Sum all the values in the infiltration hyetograph to obtain the total surficial infiltration in inches.

4. Runoff = excess precipitation.

   The total storm rainfall minus the total surficial infiltration is the excess precipitation that cannot infiltrate into the soil and therefore becomes surface runoff. The hydrology computer program must use a CN value that calculates at least this much runoff.

5. Corrected CN value (initial estimate)

   The soil infiltration loss (calculated in item 3) is multiplied by 1.2 (in other words, is increased by 20%) to estimate the total soil retention S, including both infiltration losses and initial abstraction. This value of S is used in eqn. 10.11 from NEH-4 to estimate a corrected CN value. This CN value may be much higher than the table value for the soil type and land use.

6. Corrected CN value (refined estimate)

   The CN value of item 5 is used in eqn. 10.10 from NEH-4 to estimate the runoff from the Dam Safety short duration storm, and which is then compared to the estimated runoff from the hyetograph calculations of item 4. If necessary, the CN value is incrementally revised (usually increased) until the runoff estimated here from eqn. 10.10 agrees with the runoff estimated in item 4 above.

   The refined CN value is then used in the hydrology computer model to calculate the dam safety inflow design flood from the short duration storm. The runoff volume from the computer model should be compared to the runoff estimate from item 4 to verify that the CN value correctly estimates the volume of runoff from the short thunderstorm.

7. Losses to deep groundwater (optional calculation).

   The deep seepage "hyetograph" is the soil infiltration hyetograph with the peak limited to the deep seepage rate. Computationally, the deep seepage hyetograph equals the minimum value of the infiltration hyetograph or the deep seepage rate in inches/time step. Sum all the values in the deep seepage hyetograph to obtain the total losses to deep groundwater in inches.

8. Losses to soil storage (optional calculation).

   Losses to soil storage are estimated based on the depth of the soil surface horizon and the gravity porosity of the soil in the surface horizon. The surface horizon depth is estimated from the soils data listed in the Soil Survey, usually between 12 and 24 inches. I estimate the gravity porosity of the surface horizon from Table 3-3 in my copy of Viessman *et al* (1977) for the particular soil type. Soil porosity as a decimal fraction times the surface horizon depth equals the soil storage volume in inches of water equivalent.

   The soil storage volume plus the losses to deep groundwater represents the total volume of infiltrated water that remains in the ground and does not participate in the surface runoff process during the storm event. I usually check to make sure that the soil storage plus the deep seepage exceeds the soil infiltration volume, which is typically the case for the short thunderstorm.

Spreadsheet calculations

The computation procedures described above have been incorporated into three spreadsheets, one for each of the three short duration storm hyetographs. Each spreadsheet is 3 pages long and was compiled in Excel 97-2003.

To expedite the calculations, the unit hyetographs for the short thunderstorms have already been entered into the spreadsheets, so the user simply needs to select the spreadsheet that corresponds to the climatic region and hyetograph number for their project.

Green shading is used to help identify the cells where key information needs to be entered by the user, and many of the cells that need numerical input are also outlined so they appear as a box. Most of the green cells have "dummy" values in them just as a check to make sure the spreadsheet does the calculations correctly; the parameters in the green cells need to be replaced with project-specific values. The specific item of data needed is usually listed nearby so that a print-out of the spreadsheet will serve as clear file documentation of the calculations performed.

Two of the cells are intended to be interactive: the estimated soil layer for interflow loss to soil porosity, and the corrected CN value for the thunderstorm. A more detailed discussion follows.

The interflow loss to soil porosity is calculated based on the estimated soil layer thickness that stores the infiltrated water. As the estimated soil layer increases, the hyetograph estimate of excess precipitation = runoff volume will decrease to a limiting value. The limiting value is the point at which all of the infiltrated water (shallow infiltration on spreadsheet page 3) goes to deep infiltration or soil porosity loss, with no interflow runoff. I usually increase the estimated active soil layer thickness (cell E-35) by integers until the limiting (minimum) value for excess precipitation = runoff volume (cell K-33) is reached. This will also give the limiting values for the back-calculations of soil retention S and the corresponding CN (cells K-35 and K-36).

(Aside: An upper limit to the estimated soil layer thickness for storage of infiltrated water is the total soil depth entered in cell E-33. The user should be sure to check this, but my experience has been that the limiting value for runoff volume is reached well before the soil layer for infiltration storage approaches the total soil depth.)

The corrected CN value for the thunderstorm (cell H-30) usually needs some further manual adjustment to get the runoff volume calculated based on the CN value (cell J-31) to equal the runoff volume based on the hyetograph estimate (cell K-33). I use trial-and-error in increments of 0.1 until agreement between the two runoff volumes is achieved.

As noted above in calculation step 6, the corrected CN value is then used in the hydrology computer model to calculate the dam safety inflow design flood from the short duration storm. The runoff volume from the computer model should be compared to the runoff estimate from the hyetograph analysis to verify that the CN value correctly estimates the volume of runoff from the short thunderstorm.

Summary comments

At this time, we are requesting the use of corrected CN values only for the dam safety short duration storm. Published table CN values may be used for the intermediate and long duration storms.

The spreadsheets presented here were developed and refined over the past several years, and have been used extensively in engineering reviews of proposals for new dams and in conjunction with periodic inspections of existing dams. These spreadsheets are intended to be public domain, so please feel free to edit and revise them as appropriate for your own specific needs. As always, the engineer retains full responsibility for making sure the hydrologic calculations are correctly applied to their specific project.

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 martin.walther@ecy.wa.gov, or regular mail to Washington State Department of Ecology, Dam Safety Office, PO Box 47600, Olympia, WA 98504.

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