NATIONAL ENGINEERING HANDBOOK

SECTION 4

HYDROLOGY

# CHAPTER 11. ESTIMATION OF DIRECT RUNOFF FROM SNOWMELT

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# CHAPTER 11. ESTIMATION OF DIRECT RUNOFF FROM SNOWMELT

This chapter gives methods for estimating snowmelt runoff volumes for flood damage evaluations. Methods of snowmelt forecasting, for irrigation and similar purposes, are described in the Snow Survey Handbook of the Service.

Details of the thermodynamics of snowmelt are omitted from this chapter because of their limited value in the methods presented here. Some standard references are:

Clyde, George D. - Snow-melting characteristics. Technical Bulletin 231, August 1931. Utah Agricultural Experiment Station, Logan, Utah.

Light, Phillip - Analysis of high rates of snowmelting. Pages 195-205, Transactions of the American Geophysical Union, 1941.

Wilson, W. T. An outline of the thermodynamics of snowmelt. Pages 182-195, Transactions of the American Geophysical Union, 1941.

## Significance of Snowmelt Floods

Bankfull capacities in csm are normally greater for small watersheds than for large ones. Since snowmelt rates are relatively low in csm there may be flooding on large watersheds when streams on small watersheds are flowing less than bankfull.

The hydrologist acquainted with an area will know the relative importance of snowmelt as a source of flooding in that are. In doubtful cases the data normally gathered by interview for an historical flood series will usually define the character of flood flows. In other instances, the runoff records will show how important snowmelt flooding is. It is seldom necessary to make detailed hydrologic investigations into the matter.

## Methods of Estimation

Regional analysis

This method is one of the most useful for snowmelt floods. See Chapter 2 for details of the method.

Degree-day method, ungaged watersheds

This method is widely used because of its adaptability to usual data conditions. Similar methods going into more detail are available but seldom applicable because of lack of required data.

The degree-day method uses the equation:

$$M = K\,D \tag{11-1}$$

where $M$ = the watershed snowmelt in inches per day.

$K$ = a constant that varies with watershed and climatic conditions.

$D$ = the number of degree-days for a given day.

A degree-day is a day with an average temperature one degree above $32^\circ$ F. Maximum and minimum temperatures, as found in "Climatological Data," are averaged to get the daily average temperature. A day with an average of $40^\circ$ F. gives eight degree-days; with an average of $51^\circ$ F., nineteen degree days. The general form of the method is given below. A working arrangement of the data is shown on table 11-1. In most cases the table can be condensed. The steps in the method are:

1. Using precipitation stations or snow survey data, show either (a) the total available water equivalent at the beginning of the melt season (table 11-1) or (b) the precipitation and the water equivalent by days (table 11-2). The first procedure is used where there is generally only one melt period per year; the second, where melt periods occur intermittently through the winter and spring. Water equivalent is the depth of water, in inches, that results from melting a given depth of snow, and it is dependent on both depth and density of snow. Snow surveys give field determinations of water equivalents. Where such surveys are not made, it is customary to use one-tenth of the snow depth as the depth of water equivalent.

2. For temperature stations in the watershed, tabulate average temperatures for the melt periods. (Note: maximum and minimum values as given in "Climatological Data" can be averaged mentally to avoid tabulation of averages below $33^\circ$ F.)

Table 11-1. Estimation of snowmelt by degree-day method. One melt period

| Dates | Watershed average temperature °F. 1/ | Degree-days | Estimated snowmelt 2/ | Total available water equivalent |
|---|---|---|---|---|
| | | | Inches | Inches |
| April 5 | 32 | 0 | 0 | 4.50 |
| 6 | 35 | 3 | .18 | 4.32 |
| 7 | 34 | 2 | .12 | 4.20 |
| 8 | 36 | 4 | .24 | 3.96 |
| 9 | 48 | 16 | .96 | 3.00 |
| 10 | 43 | 11 | .66 | 2.34 |
| etc. | etc. | etc. | etc. | etc. |

1/ Average of two stations; adjusted for altitude.

2/ Using K = 0.06 in equation 11-1.

Table 11-2. Estimation of snowmelt by degree-day method. Intermittent melt period.

| Dates | Precipitation | Water equivalent 1/ | Degree-days | Snowmelt: Potential 2/ | Snowmelt: Estimated | Remaining water equivalent |
|---|---|---|---|---|---|---|
| | Inches | Inches | | Inches | Inches | Inches |
| Nov 3 | 0.85 | 0.08 | | | | 0.08 |
| Nov 4-18 | | | | | | .08 |
| Nov 19 | | | 5 | 0.30 | 0.08 | 0 |
| Nov 20-29 | | | | | | 0 |
| Nov 30 | 3.80 | .38 | | | | .38 |
| Dec 1-24 | | | | | | .38 |
| Dec 25 | 4.15 | .42 | | | | .80 |
| Dec 26-Jan 18 | | | | | | .80 |
| Jan 19 | .52 | .05 | | | | .85 |
| Jan 20-Feb 2 | | | | | | .85 |
| Feb 3-20 | 6.92 | .69 | | | | 1.54 |
| Feb 21-Mar 14 | | | | | | 1.54 |
| Mar 15 | 14.24 | 1.42 | | | | 2.96 |
| Mar 16-28 | | | | | | 2.96 |
| Mar 29 | | | 3 | .18 | .18 | 2.78 |
| Mar 30 | | | 11 | .66 | .66 | 2.12 |
| Mar 31 | | | 22 | 1.32 | 1.32 | .80 |
| Apr 1-9 | | | | | | .80 |
| Apr 10 | | | 7 | .42 | .42 | .38 |
| Apr 11 | | | 32 | 1.92 | .38 | 0 |

1/ One-tenth of snow depth.
2/ Using K = 0.06 in equation 11-1.

3. Adjust the average temperatures to the average watershed elevation, using the method given below in Adjustment of temperatures for altitude. This step is omitted when elevation data are crude or otherwise unreliable.

4. Compute the watershed average daily temperatures by averaging the station averages (adjusted for altitude, if desirable).

5. Subtract 32° F. from each watershed average daily temperature to get the degree-days per day.

6. Use equation 11-1 to get an estimate of the potential snowmelt for each day. See K factors below for selection of K.

7. Where the daily potential is not greater than the water equivalent remaining on the watershed, it is shown as an estimate of snowmelt.

Once the estimates of snowmelt are obtained, they are used to obtain hydrographs as described in Chapter 16.

Some hydrologists suggest that the effects of infiltration be subtracted from the estimated snowmelt. However, the K factors as generally developed already include the effects of infiltration. The effects of measures such as contour furrows are obtained as described in Chapter 12. The effects of reservoirs, levees, etc. are obtained as usual.

Refinements in the degree-day method are best made by first improving the accuracy of determinations of snow depth and areal distribution on the watershed. When these are known within small limits of error, then water equivalents should be refined, since the 1/10 ratio is a rough approximation. Refinements in K factors should come last.

Degree-day method, gaged watershed
The degree-day method has a very limited use, if any at all, for flood evaluations on gaged watersheds. When gaging station data are available, those data should be used to estimate flood peaks and volumes on other portions of the watershed.

Adjustment of temperatures for altitude
In general, air temperatures decrease about 3° to 5° for every 1,000 feet of rise in altitude. Other factors influence this "lapse rate," so that refinements are not justified, and an average decrease of 4° F. per 1,000 feet rise should be used.

Example 11-1--A watershed with an average elevation of 4,600 feet had temperature station readings of 38° F. at a 5600-foot elevation, and 48° F. at a 3000-foot elevation. The average temperature for the watershed is then:

$$(38) - \frac{4}{1000}(4600 - 5600) = 42.0$$

$$(48) - \frac{4}{1000}(4600 - 3000) = 41.6$$

Sum: 83.6

Average: 41.8

Round off to: 42

While further refinements, such as weighting, can be made, they are seldom justified.

K factors

The constant K in equation 11-1 is known to vary not only from watershed to watershed, but also from day to day on a given watershed. It is seldom possible to do more than make a broad estimate of K. An average value of 0.06 can be used. The following table may be of assistance in special cases:

Table 11-3. K factors

| Condition | K |
|---|---|
| Extremely low runoff potential | 0.02 |
| Average heavily-forested areas; north-facing slopes of open country | .04 - .06 1/ |
| Average | .06 |
| South-facing slopes of forested areas; average open country | .06 - .08 1/ |
| Extremely high runoff potential | .30 |

1/ Recommended by A. L. Sharp.

Concordant flow method
The method of Chapter 2 can be simplified to estimate both peaks and volumes of snowmelt runoff, when at least one streamflow record is available. The method is very similar to the Regional analysis method mentioned above and in Chapter 2.

The volume of snowmelt for an ungaged subwatershed is the same as that for the gaged watershed, assuming equal coverage of snow over both areas. Where it is possible to estimate the amounts or degrees of snow coverage, the snowmelt volumes in inches may be taken as directly proportional to snow depth or degree of coverage. For example, if there is a 3.2" snowmelt runoff from a gaged watershed of 82 square miles with 76 percent of the watershed having snow cover, then a subwatershed of 12 square miles and 100 percent snow cover will have an estimated runoff of:

$$3.2 \frac{(100)}{(76)} = 4.2 \text{ inches.}$$

Note that area in square miles is not used in the computation unless acre-feet are needed. If instead of the percents the gaged watershed is known to have an average of 16.2 inches of snow-depth and the ungaged subwatershed 20.4 inches, then the runoff for the subwatershed is:

$$3.2 \frac{(20.4)}{(16.2)} = 4.0 \text{ inches.}$$

Other factors can be brought in, but here again refinement is not justified.

Peaks of snowmelt runoff can be obtained as described in Chapter 16.

Other methods
Where intensive study has been or can be made of a watershed, more detailed and more accurate methods of estimating snowmelt runoff can be used.