NATIONAL ENGINEERING HANDBOOK

SECTION 4

HYDROLOGY

CHAPTER 20. WATERSHED YIELD

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Contents

Tables

NATIONAL ENGINEERING HANDBOOK

SECTION 4

HYDROLOGY

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The water yield of a watershed, by years or seasons or months, is used in the planning and design of some watershed projects, especially those involving irrigation. The hydrologist supplies estimates of these yields, as required, or supplies methods adapted to specific local conditions by which others may make the estimates. This chapter contains general methods for estimating water yields on ungaged watersheds, with suggestions for such modifications as local conditions may justify.

Summary of Problems

Watershed yield is dependent on many physical factors, most of which usually cannot be quantitatively determined during ordinary field operations. Methods of estimating yield from ungaged watersheds may be classified as follows:

(a) Using only climatic factors. Examples are graphs or equations using precipitation and temperature, or only precipitation.

(b) Using only geographic location. Examples are maps having lines of equal runoff, or the practice of estimating yield by interpolation between gaged watersheds.

(c) Using watershed and climatic factors. Examples are (1) water accounting method, (2) regional analysis, and (3) use of figure 10-1 and daily rainfall.

The choice of method often rests on the type of runoff to be estimated, which may be classified as:

(a) Yield as a residual of precipitation after evapotranspiration. Examples are watersheds where base flow predominates. Water accounting methods are useful with this type.

(b) Yield as an excess of surface supply over watershed surface intake. Examples are watersheds where surface runoff predominates. Methods using rainfall and infiltration are needed, such as a method utilizing figure 10-1.

(c) Yield as a diverted flow. Examples are watersheds having irrigation projects that get their supply outside of the watershed and their return flows occur inside; or watersheds with surface runoff predominating, whose streams carry return or waste flows from irrigation projects or municipal and industrial plants that pump their supplies from deep wells or receive them from outside the watershed.

Instrumentation and watershed conditions may suggest or govern the choice of method. These conditions may vary with watershed size--that is, instrumentation or methods suitable for a small watershed having surface runoff may be unsuitable for a large watershed (into which the small one drains) that has a high percent of base flow. The conditions may similarly vary with geographic location, the presence of water tables, elevation, aspect, and latitude. Other factors that have influence can also be listed. However, evaluation of the listed and unlisted factors is still more properly a research activity. In practice, the primary factors that can ordinarily be considered for ungaged streams are: (1) streamflow on nearby watersheds, (2) precipitation, (3) hydrologic soil-cover complexes, (4) evapotranspiration, (5) temperature, (6) transmission losses, and (7) base flow accretions.

Determinations of water yield will usually have two types of error, (1) that due to insufficient recognition of the natural fluctuations of yield from year to year, and (2) that due to insufficient recognition of the most important influences on yield in a given watershed. The first type of error can be reduced by working with long records, the second by further studies of all possible major influences. However, increasing the time spent on yield estimates does not always assure greater accuracy in the estimates. Therefore, the methods given below should be considered as giving estimates so broad that the influence of specific factors have large margins of error.

Methods for Estimating Yields

A fuller account of such methods will be given in the National Engineering Handbook, Section 4, Hydrology.

Regional analysis

The general procedure is described in Section 2.8 of the Guide. For water yield, the method is used with annual, seasonal, or monthly flows of gaged watersheds. The slopes of the frequency lines will vary, being flattest for annual yields and becoming steeper (larger R on figure 18-3) as smaller divisions of a year are used.

This method is suitable for estimating the first two types of runoff mentioned above. It is readily adapted to watershed conditions, when data are available, since the watersheds can be selected for whatever factors can be used. However, the factors (and not the regional analysis method) may very strongly govern the accuracy of the results for watershed yield. For example, if one of the important factors on the problem watershed is aspect, and it is too vaguely represented by the gaged watersheds used in the analysis, then the accuracy of the results of the regional analysis will suffer. Transmission losses, for example, may be insufficiently detected by this method, and additional field studies may be required to determine those losses.

Water accounting

This method is suitable for estimating the first type of runoff mentioned above. As presented here, the method is A. L. Sharp's modification and enlargement of a method proposed by C. W. Thornthwaite in Trans. Amer. Geophys. Union, pp. 686-693, April 1944. The transmission loss is not estimated by this method and must be determined by other methods (Chapter 19).

The flow chart in Chapter 10 will assist in understanding the following steps.

1. Obtain soils and land treatment data for the watershed.

2. Obtain estimates of the water-holding capacity of each soil or soil group, expressed as inches depth of water between the amounts at field capacity and wilting point. The soil depth for which this capacity is needed is the depth of the intensive root zone, or 3 feet, whichever is lesser.

3. Compute the water-holding capacity of the watershed, weighting by areal extent of the soils or soil groups.

4. Obtain watershed cover data for the season or seasons for which yields are to be estimated. Data needed are (1) types of cover, and (2) areal extent.

5. Compute potential evapotranspiration (potential ET), or consumptive use by months for each major crop or land use. The Blaney-Criddle method of computing potential ET is generally used as given in "Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data," by Harry F. Blaney and Wayne D. Criddle, Soil Conservation Service, U.S.D.A., SCS-TP-96, Washington, D. C., revised 1952.

6. Compute monthly weighted potential ET for the watershed.

7. Obtain monthly rainfall data for the watershed, for a period of years estimated to be long enough to give adequate yield values (see Chapter 18 on length of record). The estimate of length should be made after previous use of figure 18-3 with other yield data in the vicinity.

8. Compute average rainfall over the watershed, by months, for each year of record.

9. Tabulate rainfall and ET data as shown on table 20-1, and compute runoff, by months, for each year of record.

   (a) In table 20-1, the computation starts with a month when available soil moisture is <u>fully depleted</u>. It could start equally well with a month when the soils are <u>fully saturated</u>.

   (b) If there is a break in the year, as in table 20-1, the first month after the break should have either of the moisture conditions given in (a) above.

   (c) When the precipitation is snowfall, convert to water equivalent (watershed average) before using in line 1 (see Chapter 11 for methods). Watersheds consistently having snowfall on one portion and rainfall on the other should be subdivided and the yields of the subdivisions computed separately, then combined for total watershed yield.

   (d) Work with subdivisions if the watershed soils differ in water-holding capacities by more than about 100% of the smallest capacity or by more than about 1 inch, whichever is greater.

   (e) Work with subdivisions if the watershed precipitation consistently varies widely in amount at different localities. This may be determined using average annual precipitation. The variation over a watershed (or subdivision) should not be greater than about 30% of the smallest value, or about 3 inches, whichever is greater.

10. After completion of the computations for the selected length of record, test the runoff estimates for adequacy of length of record, using the method of Chapter 18. The test should be made with values that will be used in planning or design. For example, if annual values are to be used, when they are tested; if monthly values are to be used, then all October values are tested separately, next all November, and so on. If the length of record is not adequate, additional years of precipitation are added and the yield computations extended.

Transmission losses are subtracted after Step 10. If these losses are proportionately large, it may be necessary to test the modified yields for adequacy of length of record.

Table 20-1. Sample computation by water accounting method.

Line	Item	October	November	December	January	February	March	April	May	Seasonal runoff
	All units in inches				1947 - 1948					
1	1/ Average rainfall	5.65	1.04	1.88	2.41	2.34	5.48	10.04	1.34	
2	2/ Initial soil moisture	0.00 3/	2.87	1.74	2.62	3.20	3.20	3.20	3.20	
3	Total available moisture	5.65	3.91	3.62	5.03	5.54	8.68	13.24	4.54	
4	4/ Potential evapotranspiration	2.78	2.17	1.00	0.90	1.00	2.69	3.18	3.89	
5	5/ Actual evapotranspiration	2.78	2.17	1.00	0.90	1.00	2.69	3.18	3.89	
6	Remaining available moisture	2.87	1.74	2.62	4.13	4.54	5.99	10.06	0.65	
7	6/ Final soil moisture	2.87	1.74	2.62	3.20	3.20	3.20	3.20	0.65	
8	Runoff	0.00	0.00	0.00	0.93	1.34	2.79	6.86	0.00	11.92
					1948 - 1949					
1	1/ Average rainfall	0.75	0.84	3.53	1.24	2.22	7.34	0.03	0.46	
2	2/ Initial soil moisture	0.00 3/	0.00	0.00	2.53	2.87	3.20	3.20	0.05	
3	Total available moisture	0.75	0.84	3.53	3.77	5.09	10.54	3.23	0.51	
4	4/ Potential evapotranspiration	2.78	2.17	1.00	0.90	1.00	2.69	3.18	3.89	
5	5/ Actual evapotranspiration	0.75	0.84	1.00	0.90	1.00	2.69	3.18	0.51	
6	Remaining available moisture	0.00	0.00	2.53	2.87	4.09	7.85	0.05	0.00	
7	6/ Final soil moisture	0.00	0.00	2.53	2.87	3.20	3.20	0.05	0.00	
8	Runoff	0.00	0.00	0.00	0.00	0.89	4.65	0.00	0.00	5.54

1/ Average over the watershed for each month of record.
2/ At start of month. Same as "Final soil moisture" for previous month.
3/ See text, Step 9, notes (a) and (b).
4/ Average annual values for the month.
5/ Total available moisture, or potential ET, whichever is smaller.
6/ At end of month. Same as "Initial soil moisture" for next month. This is never larger than the water-holding capacity determined in Step 3 of the text--in this case, 3.20 inches.

Note: Data are for a West Coast area of the United States, where the June-September precipitation is negligible.

Direct runoff method
Daily rainfall values and figure 10-1 can be used to estimate yields when these are of the second type described. Generally it may be assumed that direct runoff is being estimated. The procedure consists of using the method of Chapter 10 with all rainfalls. Snowmelt runoff is estimated separately using the methods of Chapter 11.

Table 9-1, which is used to determine curve numbers on figure 10-1, gives average values for the year. In using this table for yield estimates it is usually necessary to go into more detail about the cover, so that the weighted hydrologic soil-cover complex number varies not only for antecedent moisture conditions but also for the variation in cover throughout a given year and from year to year.

The direct runoff method is usually very tedious, since all daily precipitation in a long period of record must be accounted for, day by day, using soil-cover complex numbers that vary from month to month or even more often. The laboriousness of the procedure, however, does not guarantee close accuracy in the yield estimate.

Major errors with this method will generally be in the determinations of soil-cover complexes (which will vary through the year) and in antecedent moisture conditions (which will vary not only with precipitation and temperature, but also with soil-cover complexes). This method is more suitable for small watersheds than for large ones, since the large watersheds will have some base flow, which may be a significant proportion of total yield. Estimates by this method generally will have such a margin of error that the effects of individual factors should not be given much significance.

Climatic and geographic factors
In areas where there is no abrupt change in precipitation, hydrologic soil-cover complexes, or geology, yield may be readily estimated using maps with lines of equal runoff. Generalized national maps, such as Plate 1 of U.S.G.S. Circular 52, should be used with great caution. The text of the Circular, page 9, states that "Figure 2 and plate 1 should not be used to estimate runoff from ungaged areas." More localized maps, however, such as those prepared by John H. Dorroh, Jr. for the Southwestern States, will be very useful, especially where the advice of the map's originator may be sought.

K. M. Kent has used a form of the "direct runoff method" described above to prepare typical yield frequency lines for selected soil-cover complex numbers, which are used with a state map giving precipitation indices. Given the soil-cover complex number, the yield for a given frequency is quickly estimated for any locality in that state.

Graphs and equations of precipitation and temperature, or precipitation alone, have been used in the past much more than they are today. Figure 2 of U.S.G.S. Circular 52 is an example (but see remark about Plate 1). Such graphs and equations should be used with great caution since so many factors are ignored.

Discussion

Since so many factors enter into the estimating of yields, and since both the relative importance and quantitative influences of some factors are nearly always unknown, estimates of yield should be conservative, according to the use they will have. The planners and designers who will use the yield estimates will be best able to state the direction and degree of conservativeness required. The hydrologist can obtain the conservativeness by the use of the methods given above, and those in Chapter 18, Frequency Methods.