

Hydrology Training Series

Watershed Yield

Module Description

Objectives

Upon completion of this module, the participant will be able to:

1. List and describe the factors that affect watershed yield.
2. Describe the sources and methods used to determine watershed yield.
3. Compute watershed yield using Figure 4, Chapter 11, Engineering Field Manual.

The participant should be able to perform at ASK Level 3 (Perform with Supervision) after completing this module.'

Prerequisite

Module 101 - Introduction to Hydrology.

Who May Take The Module

This module is intended for an SCS personnel who calculate runoff using the Engineering Field Manual.

Content

This module presents factors affecting watershed yield, sources and methods used to determine watershed yield, and two methods for estimating watershed yield.

Introduction

Factors Affecting Watershed Yield

Watershed Factors

Watershed yield is the amount of natural runoff (usually expressed as annual runoff) from a watershed measured as actual streamflow at a given location. The study of watershed yield includes the seasonal and monthly variations (timing) of the runoff. Hydrologic investigations to determine watershed yield are important for water supply projects, such as irrigation, municipal and industrial or recreation projects, especially where storage is proposed.

Watershed yield is affected by most of the same factors that affect storm runoff (soils, cover, condition, moisture condition, and precipitation factors such as amount, duration, intensity, etc.). To a greater extent, however, annual watershed yield is also affected by climatic regions, temperature, evaporation and transpiration, and seasonal variations of precipitation and temperature.

One of the problems associated with listing and trying to classify the factors affecting watershed yield is the interdependence of these factors. Almost all of the factors are somehow related to each other.

Factors that affect watershed yield may be broken into two broad categories:

1. Watershed or physiographic factors.
2. Meteorological or climatic Factors.

Physical factors

One type of watershed factor can be described as physical. This type includes:

1. Soil factors - such as infiltration rate and water holding capacity.
2. Cover factors - such as land use, cover type, cover condition and conservation treatment.
3. Geologic factors - such as inflow and outflow from ground water formations, especially where influenced by limestone or lava terraces, and topographic conditions such as lakes and swamps.

Geomorphic factors

Another group of watershed factors that can affect watershed yield are geomorphic factors. These include:

1. Size and shape of watershed.
2. Average slope of watershed.
3. Orientation or aspect - whether the slope is towards the north or south.
4. Average elevation.
5. Drainage density - miles of stream per drainage area, milmi².
6. Latitude and longitude.

Channel factors

Still other watershed factors are those relating to the stream channel itself. These include the following:

1. Top width.
2. Flow area.
3. Wetted perimeter.
4. Depth.

Meteorologic Factors

Meteorologic factors that affect watershed yield include the following:

1. Annual precipitation - probably the most important factor.
2. Annual temperature.
3. Evaporation and transpiration.
4. Climatic region.
5. Snow depth.

Determining Watershed Yield

Sources

There are many sources for determining watershed yield, and there are as many variable quantities as there are sources. When using reports, maps, equations or any other source, be sure you are fully aware of the limitations for that method. Properly used, you can produce good estimates using most of the sources available.

Some sources for determining watershed yield include:

1. U.S. Geological Survey - these include regional regression equations as well as state reports and maps.
2. U.S. Bureau of Reclamation - these include both reports and procedures.
3. U.S. Soil Conservation Service - snow surveys and cooperative river basin reports.
4. River Basin Commission reports.
5. States' Water Resources agencies reports - including maps and equations. These are limited in areas.
6. Rules of Thumb - k; always, there are rules of thumb for everything, including watershed yield.

Methods

The method used to estimate watershed yield will depend upon the importance of the estimate.

Stream gaging stations

In some cases, for perennial or seasonal streams, it is justified to establish a stream gaging station. By correlating one or two years of record with a nearby long record gage, a good estimate of the average annual yield can be obtained.

It is possible to make estimates within a range of plus or minus fifteen percent of the annual yield by measuring stream flow once each month and comparing the daily mean discharge with that of a nearby gaging station for the same day.

It is important to recognize the variability of runoff within a watershed. Expect the runoff from a small tributary above a stream gage to vary only with the size of the areas. Small areas may have either a much higher or lower yield per unit area than the larger area. Normally, SCS does not make stream flow measurements. However, SCS can use monthly values from another agency in multiple regression analyses.

Runoff maps

Maps of annual runoff, because they are developed from gaged watersheds, have the same limitations concerning watershed size and runoff as the gaged watersheds. Used properly, runoff maps can be useful references and, in many instances, can provide the accuracy needed.

In humid climates, the annual yield of small watersheds may be smaller than for larger watersheds because significant baseflow may occur in the large watersheds. In semiarid areas, the reverse may be true because of channel transmission losses in larger watersheds.

Figure 4 from Chapter 11 of the EFM is shown as Appendix A. Also included in Appendix A is the monthly distribution of annual yield for selected agricultural watersheds. Runoff maps for your area may be available from a number of federal or state agencies.

Regional runoff equations

Equations relating watershed yield to many of the factors we previously discussed have been developed for all parts of the country by the United States Geological Survey (USGS) and other federal and state agencies.

These equations are usually in the form of a power equation:

$$Q = a B^{b_1} C^{b_2}$$

Where:

a is a regression coefficient,

B and C are independent variables,

and b1 and b2 are coefficients.

The most common independent variables are drainage area and annual precipitation. Annual runoff is frequently expressed in terms of mean discharge in cfs, but may also be in acre-feet (ac-ft) or in watershed inches. Be sure you know the units of all variables or parameters before you use the equation. Never apply an equation outside of the range of data used to develop the equation.

Significant channel geometry factors include channel width and depth. It is important to obtain your measurements the same way that those upon which the equation was based were obtained.

A specific equation is only valid in one region of the country. You may want to become familiar with an equation for the region where you live.

Example

An example of a regional equation for annual runoff is:

$$Q_a = .0014A^{.95}P^{1.25}$$

where

Q_a = mean annual runoff, cfs.

A = drainage area, mi^2

p = mean annual precipitation, in

Using the above regional equation, determine annual runoff in inches, if $A = 1000$ ac and $P = 15$ inches.

Solution:

$$A = \frac{1000ac}{\frac{640ac}{mi^2}} = 1.56mi^2$$

$$\begin{aligned} Q_a &= .0014A^{.95}P^{1.25} \\ &= .0014(1.56mi^2)^{.95}(15in)^{1.25} \\ &= (.0014)(1.53)(29.52) \\ &= .063cfs \end{aligned}$$

Conversion factor: 1 cfs = 724 ac-ft/yr

$$Q_a = .063 \left[\frac{ac-ft}{yr} \right] \left[\frac{12in}{1000ac} \right] = .55in$$

Computation of Watershed

Figure 4 in Chapter 11 (1988 Version or later) of the Engineering Field Manual is a map of average annual watershed yield in watershed inches (See Appendix A). Also included in Appendix A is Table A-I, which is a table of monthly distribution (in percent) for selected small watersheds. This table can be used to determine the average monthly runoff. Figure 4 has replaced the information in ES-I014.

The information in Figure 4, can be supplemented by state maps or similar maps printed by local governmental organizations. You should check with your area or state conservation engineer before using local publications.

Example 1

Using Figure 4, what is the estimated average annual watershed yield, in acft, for a 100 ac watershed in the southeast corner of Nebraska?

Solution:

1. Using Figure 4 in Appendix A, locate the southeast corner of Nebraska, and read that the average annual watershed yield is 10 inches.

2. $(100 \text{ ac}) (10 \text{ in}) (1 \text{ ft}/12 \text{ in}) = 83 \text{ ac-ft}$

Example 2

In the previous example what would be the average watershed yield for September, in ac-ft?

Solution:

1. The average annual watershed yield is 83 ac-ft.

2. September receives 13% of the total annual watershed yield for Hastings, Nebraska, which is the nearest station shown in the table.

3. $(83 \text{ ac-ft}) (13/100) = 10.8 \text{ ac-ft}$

Summary

At this point, you should be able to list and describe the factors that affect watershed yield, describe the sources and methods used to determine watershed yield, and compute watershed yield using your Engineering Field Manual.

Always remember the limitations of any method used to calculate runoff or yield, and never exceed those limitations. Your solution is only as good as the information you input into the equation or chart. This is a key point to any calculations you will ever make, and one you should remember.

Retain this Study Guide as a reference until you are satisfied that you have successfully mastered all the methods covered. It will provide an easy review at any time you should encounter a problem., ,

If you have had problems understanding the module or if you would like to take additional, related modules, contact your supervisor.

When you are satisfied that you have completed this module, remove the Certification of Completion sheet (last page of the Study Guide), fill it out, and give it to your supervisor to submit, through channels, to your State or NTC Training Officer.

Appendix A Map and Table

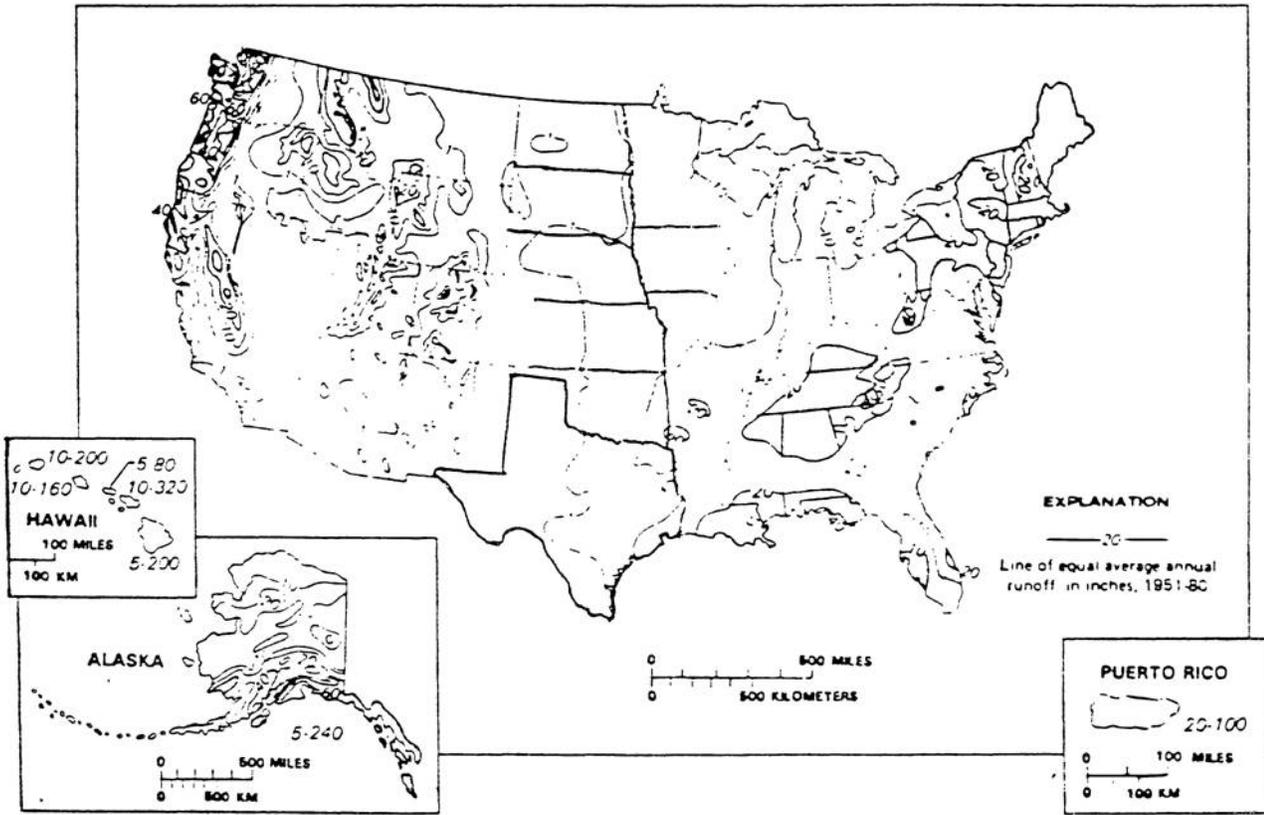


Figure 4. Average annual watershed yield in inches

Note: for activity 2, SE Oregon has a 1 inch average yield

Table A-t. Monthly Distribution (Per Cent of Total) of the Average Annual Yield for Selected Watersheds

Watershed location		Area acres	Years					May
			of record	Jan	Feb	Mar	Apr	
loZ,	Safford	723	14	0	0	0	0	0
AR,	Bentonville	9	8	0	4	6	13	19
CA,	Placerville	41	8	26	32	27	7	0
CO,	Colorado Springs	40	7	0	0	0	0	0
GA,	Watkinsville	19	16	16	10	15	12	3
ID,	Moscow	178	5	17	25	41	5	1
IL,	Edwardsville	290	17	9	11	14	15	10
NE,	Hastings. .	481	17	0	1	3	3	14
OH,	Coshocton	44	16	12	12	22	18	14
OR,	Newburg	13	4	17	26	10	5	3
TX,	Tyter	8	9	10	9	12	13	28
VA,	Staunton	390	6	8	9	9	16	14
WA.	Fennimore	330	17	8	11	16	6	6
Jun	Jul	Aug	Sep	Oct	Nov	De e	Remarks	
0	46	38	12	4	0	0	Range	
25		2	2	8	14	5	2	Pasture
0		0	0	0	0	2	6	Orchard
8		46	42	4	0	0	0	Plains. range
3		9	11	1	2	10	8	Piedmont, cuivated
0		0	0	0	0	1	10	Plateau. prairie
11		8	9	1	3	5	4	50"10 cultivated
37		18	5	13	5	1	0	Plains, cuhivated
7		2	1	2	1	3	6	Woods and brush
2		1	1	1	1	8	25	Orchard, 1500'elev.
4		1	0	0	1	12	10	Wooded
11		8	6	3	13	3	0	Mixed cover
12		12	10	6	5	4	4	Mixed cover

Source: Unpublished AR data

Activity 1

At this time, complete Activity 1 in your Study Guide to review the material just covered. *After* finishing the Activity, compare *your* answers with the solution provided. When you are satisfied that you understand the material, continue with the Study Guide text.

Complete the following problem using the regional equation:

Given:

$$Q_a = .0014A^{.95} p^{1.25}$$

$$A = 2000 \text{ ac}$$

$$P = 13 \text{ in}$$

Q_a , in inches

Find Solution:

Activity 2

At this time, complete Activity 2 in your Study Guide to review the material just covered. *After* finishing the Activity, compare your answers with the solution provided. When you are satisfied that you understand the material, continue with the Study Guide text.

Given:

A watershed of 1000 ac in the southeast corner of Oregon. It can be assumed that the Safford, Arizona, monthly distribution values are typical of the high mountain desert of southeast Oregon.

Find:

The estimated average annual watershed yield and the monthly values.

Solution:

Activity 1-Solution

Complete the following problem using the regional equation:

Given:

$$Q_a = .0014A^{.95}p^{1.25}$$

$$A = 2000 \text{ ac}$$

$$P = 13 \text{ in}$$

Q_a in inches

where Q_a = mean annual runoff, cfs

A = Drainage area, mi²

p = mean annual precipitation, in

Find Solution:

$$1. A = [2000\text{ac}/(640\text{ac}/\text{mi}^2)] = 3.13\text{mi}^2$$

$$2. Q_a = .0014A^{.95}p^{1.25}$$

$$= .0014(3.13 \text{ mi}^2)^{.95} (13\text{in})^{1.25}$$

$$= 0.0014 (2.96)(24.68)$$

$$= 0.102 \text{ cfs}$$

3. Conversion factor: 1 cfs = 724 ac-ft / yr

$$Q_a = .0102 \text{ cfs} [734 (\text{ac-ft/yr})/\text{cfs}] [(12\text{in}/\text{ft})/2000\text{ac}] = .44\text{in}$$

Activity 2 - Solution

Given:

A watershed of 1000 ac in the southeast corner of Oregon. It can be assumed that the Safford, Arizona, monthly distribution values are typical of the high mountain desert of southeast Oregon.

Find:

The estimated average annual watershed yield and the monthly values.

Solution:

1. The average annual watershed yield is 1 inch according to the map in Appendix A.
2. $(1000 \text{ ac}) [(1 \text{ in})/(12 \text{ in/ft})] = 83 \text{ ac-ft}$
3. From Table A-1 in Appendix A:

Month	%	ac-ft
Jan	0	0
Feb	0	0
Mar	0	0
Apr	0	0
May	0	0
Jun	0	0
Jul	46	38
Aug	38	32
Sep	12	10
Oct	4	3
Nov	0	0
Dec	0	0
Total		83

Appendix A Map and Table

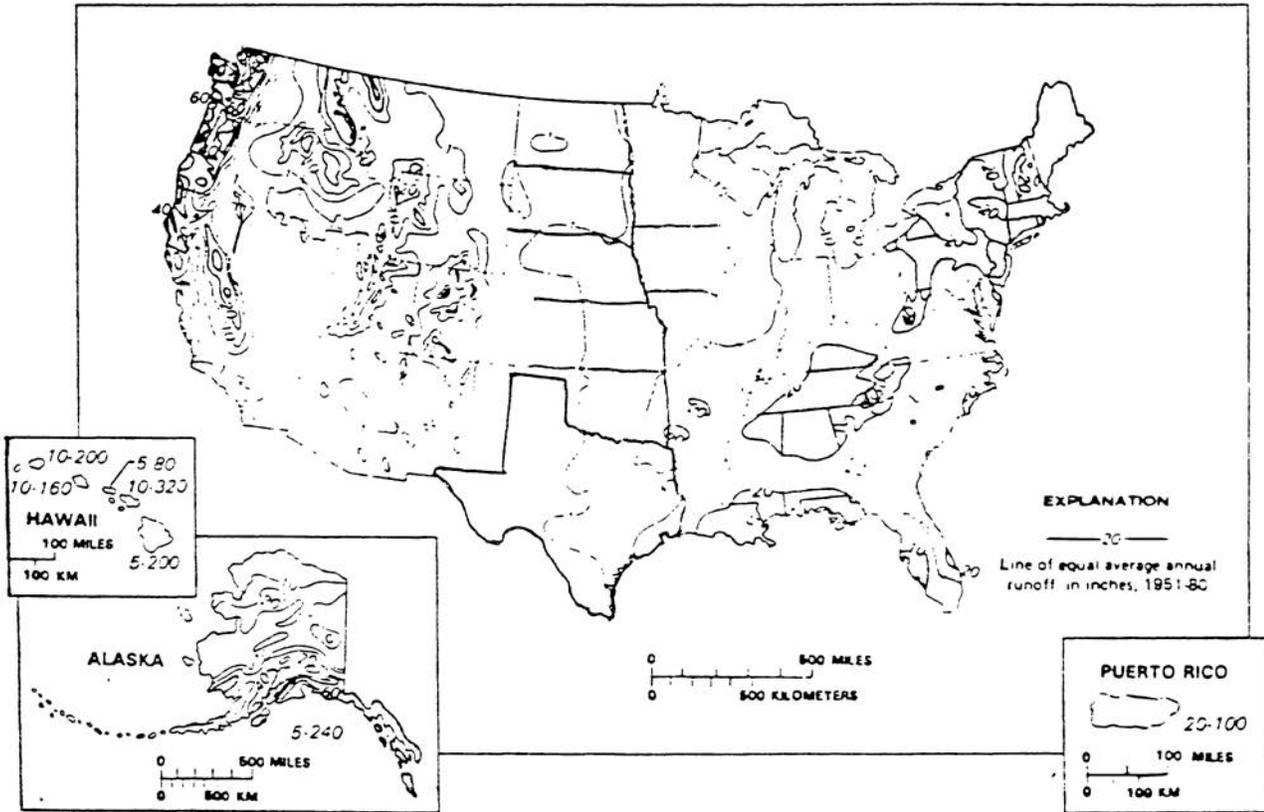


Figure 4. Average annual watershed yield in inches

Note: for activity 2, SE Oregon has a 1 inch average yield

Table A-t. *Monthly Distribution (Per Cent of Total) of the Average Annual Yield for Selected Watersheds*

Watershed location	Area acres	Years of record	Jan	Feb	Mar	Apr	May
AZ, Safford	723	14	0	0	0	0	0
AR, Bentonville	9	8	4	4	6	13	19
CA, Placerville	41	8	26	32	27	7	0
CO, Colorado Springs	40	7	0	0	0	0	0
GA, Watkinsville	19	16	16	10	15	12	3
ID, Moscow	178	5	17	25	41	5	1
IL, Edwardsville	290	17	9	11	14	15	10
NE, Hastings. .	481	17	0	1	3	3	14
OH, Coshocton	44	16	12	12	22	18	14
OR, Newburg	13	4	17	26	10	5	3
TX, Tyler	8	9	10	9	12	13	28
VA, Staunton	390	6	8	9	9	16	14
WA, Fennimore	330	17	8	11	16	6	6

Jun	Jul	Aug	Sep	Oct	Nov	Dec	Remarks
0	46	38	12	4	0	0	Range
25	2	2	8	14	5	2	Pasture
0	0	0	0	0	2	6	Orchard
8	46	42	4	0	0	0	Plains. range
3	9	11	1	2	10	8	Piedmont, cultivated
0	0	0	0	0	1	10	Plateau. prairie
11	8	9	1	3	5	4	50"10 cultivated
37	18	5	13	5	1	0	Plains, cultivated
7	2	1	2	1	3	6	Woods and brush
2	1	1	1	1	8	25	Orchard, 1500'elev.
4	1	0	0	1	12	10	Wooded
11	8	6	3	13	3	0	Mixed cover
12	12	10	6	5	4	4	Mixed cover