Module 216

Watershed Yield

Module Description

Overview

This module describes watershed yield estimates by watershed comparison, basic hydrologic simulation models, simple water budget computation, computer programs that use water yield data, and discusses drought analysis.

Objectives

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

- Determine watershed yield by adjusting data from similar watersheds.
- Make a simple water budget applicable to the participants area by using hydrologic simulation models.
- Describe drought index methods.

Prerequisite

Module 116-Watershed Yield.

Who may take the module

This module is intended for all NRCS personnel involved in using hydrologic models to compute watershed yield, and those who wish to compute watershed yield or water budgets.

Introduction

Watershed yield is a key factor in the design of conservation practices. This module addresses three factors in determining watershed yield:

- Determining watershed yield by adjusting data from similar watersheds.
- Making simple water budgets using simulation models.
- Using drought index methods.

Watershed Yield from Similar Watersheds

Module 116 of this training series listed several methods for estimating watershed yield. These included runoff maps and regional runoff equations. The additional methods for comparing similar watersheds and water budget methods are described in this module.

One method for estimating watershed yield is to compare the watershed with a similar nearby gauged watershed. This is done by using the same parameters determined to be significant in the regional equation. An example will illustrate the application of the method.

The regional equation for water yield in an area was determined by USGS to be

$Q_a = .0165A^{974}P^{1.159}$

where

Q_a = mean annual runoff, cubic feet per second

A = drainage area, mi^2

P = mean annual precipitation, inches

The mean annual runoff of a gauged watershed with a drainage area of 71.3 mi^2 and an average annual precipitation of 31 inches is 34,500 acre-feet. What is the yield of an adjacent watershed with an A of 52.6 mi^2 and P of 24 inches?

The ratio of $Q_{a2/}\ Q_{a1} = (A_{2/}\ A_1)^{.974}\ (P_2/P_1)^{1.159}$

Then

$Q_{a2} = 34500(52.6/71.3)^{.974}\ (24/31)^{1.159}$

= 19,069 acre-feet/year

It should be noted that the assumption was made that known and unknown watersheds have similar characteristics that affect runoff, such as soil, cover, aspect, etc. If this assumption is true, the estimate obtained by the ratio should be better than the estimate made by the regional equation, itself. In this example, the equation would have predicted 22,549 acre-feet per year, or 18 percent more than the similar watershed method.

Another important consideration is that all variables in the regional equation should be used. If they are not, you are assuming the values in both watersheds are equal. In this example, if only the drainage area were determined, the yield of watershed 2 would have been estimated as 25,654 acre-feet, a significantly higher value.

It is important to use the same technique, or the same source map, when determining watershed characteristics that were used to develop the regional equation.

Water Budgets Using Simulation Models

Water budgets are based on the law of conservation of mass. That is, the sum of all inflows minus the sum of all outflows must equal the change in storage.

$$1\text{-}0 = \Delta S$$

The application of this principle may be made with an accounting procedure, hence the term "budget". Quantities are determined over time, typically a year, month, or day. Computer models make computations easy and quick and allow for multiple analysis with various watershed conditions and management alternatives. The Stanford Watershed Model, published by Crawford and Linsley in 1962, was one of the earliest computer hydrologic simulation models. Numerous others have been developed over the years for various purposes. Some of these are: CREAMS, GLEAMS, EPIC, SWRRB, Answers, SSAM, Kentucky Watershed Model, Texas Watershed Model, HSP, ARM, OPSET, U of K Monthly Water Yield, Ohio State University Model, UBC Watershed Model, SWMM, PRMS, etc.

Chapter 20 of NEH4 lists three ways for estimating watershed yield with accounting or water budget methods, depending on the type of runoff to be estimated. These are repeated here for your convenience:

- Yield as a residual of precipitation after transevaporation. (Watersheds where base flow predominates.)

- Yield as an excess of surface supply over watershed surface intake. (Watersheds where surface runoff predominates.)

- Yield derived from diverted flow (such as irrigation project areas).

Base flow watersheds

For the first situation above, where all percolation below the root zone is assumed to return as watershed yield, an example is given in chapter 20 of NEH4. The steps of computation and the example are repeated here.

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 less.

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) type of cover; and (2) areal extent.

5. Compute *potential transevaporation* (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 TR21 and NRCS-TP-96, Washington, DC, 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.

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

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

a. In table 1, computations start with a month when available soil moisture is *fully depleted.* It could start equally well with a month when the soils are *fully saturated.*

b. If there is a break in the year, as in table 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. 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.

1947-1948									
Item (Inches)	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Seasonal Runoff
Average rainfall	5.65	1.04	1.88	2.41	2.34	5.48	10.04	1.34	
Initial soil moisture2	0. 003	2.87	1.74	2.62	3.20	3.20	3.20	3.20	
Total available moisture	5.65	3.91	3.62	5.03	5.54	8.68	13.24	4.54	
Potential evapotranspiration4	2.78	2.17	1.00	0.90	1.00	2.69	3.18	3.89	
Actual transevaporations	2.78	2.17	1.00	0.90	1.00	2.69	3.18	3.89	
Remaining available moisture	2.87	1.74	2.62	4.13	4.54	5.99	10.06	0.65	
Final soil moisture6	2.87	1.74	2.62	3.20	3.20	3.20	3.20	0.65	
Runoff	0.00	0.00	0.00	0.93	1.34	2.79	6.86	0.00	11.92

1948-1949									
Item (Inches)	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Seasonal Runoff
Average rainfall	0.75	0.84	3.53	1.24	2.22	7.34	0.03	0.46	
Initial soil moisture2	0.00	0.00	0.00	2.53	2.87	3.20	3.20	0.05	
Total available moisture	0.75	0.84	3.53	3.77	5.09	10.54	3.23	0.51	
Potential evapotranspiration	2.78	2.17	1.00	0.90	1.00	2.69	3.18	3.89	
Actual transevaporations	0.75	0.84	1.00	0.90	1.00	2.69	3.18	0.51	
Remaining available moisture	0.00	0.00	2.53	2.87	4.09	7.85	0.05	0.00	
Final soil moisture6	0.00	0.00	2.53	2.87	3.20	3.20	0.05	0.00	
Runoff	0.00	0.00	0.00	0.00	0.89	4.65	0.00	0.00	5.54

Table 1. Sample computation by water accounting method.

[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.

Surface runoff watersheds

If runoff is mostly from surface or from quick return flow, then the curve number method of estimating daily runoff may be appropriate. Many models such as EPIC, CREAMS, GLEAMS, listed earlier in this lesson, use values of daily rainfall and the NRCS curve number method to compute runoff. One advantage is that accurate estimates of ET are not needed.

An example is shown in table 2. A small watershed has a curve number of 75. The daily rainfall for a three month period is listed in table 2. For each day of rainfall, the corresponding runoff for curve number 75 is found. Values are then summed for each month and total runoff for the season may be found. This procedure should be repeated for 20 or 30 years of record to arrive at a good average.

The curve number is known to be a variable. The value found in table 9.1 of NEH4 is the mean value for an annual series of maximum values. Mean value should be used in peak runoff analysis. For water yield it may be necessary to adjust a curve number to better fit measured runoff volumes. The curve number may be adjusted to vary at different times of year. These adjustments may be based on soil moisture, crop growth curves, antecedent precipitation, or simply season of year.

Surface runoff can be calculated by a number of other infiltration models. In order to do this effectively, a shorter time period is necessary. Time steps of one hour or less are needed for most infiltration models to work properly. Combinations of both surface runoff and deep percolation runoff models may be appropriate for some conditions.

	March		April		May	
Day	P	Q	P	Q	P	Q
1	.04	0.0				
2					2.72	.78
3					1.60	.20
4						
5						
6			.54	0.0		
7	2.50	.65				
8					0.10	0.0
9						
10						
11	.04	0.0				
12	.02	0.0			3.40	1.23
13			.16	0.0		
14	.74	0.0	.58	0.0		
15						
16						
17					.16	0.0
18						
19					1.24	.08
20						
21						
22						
23						
24			1.24	.08		
25						
26			.63	0.0		
27					.09	0.0
28	.05	0.0			.14	0.0
29	1.37	.12				
30					2.10	.43
31						
Totals	**4.76**	**0.77**	**3.15**	**0.08**	**11.55**	**2.72**

Table 2. Curve Number Runoff as an estimate of Yield.

Whatever method of modeling is used, it is important that model results are checked against measured or regionalized data to verify that the method is working in your location. There are numerous reasons for poor comparisons with actual data:

- The precipitation may not be representative of the entire watershed.
- The ET model may not account for watershed losses adequately (particularly in non-growing seasons).
- The rainfall excess or infiltration model may not be representative of the entire watershed.
- The soils, cover, or climatic conditions of the area, etc. may vary.

Because of numerous modeling problems, comparisons for accuracy need to consider the purpose of the study and the effect of errors on the analysis. Usually long term average annual yields should check with measured data. Although it is normally not necessary for individual annual values to closely match, it is important that the annual variation be maintained. For many applications it is important that the seasonal distribution of runoff be realistic. This is true for reservoir modeling where demand may vary seasonally and for models which predict the fate of fertilizer or pesticides applied at different times of year.

Water Yield as Diverted Flow

A water budget for an irrigation system includes additional inflows and outflows. In arid or semiarid areas irrigation water supplies and losses may far exceed natural rainfall and runoff. Ditch losses and return flows to streams are important to irrigator, environment, fish and wildlife interests.

Ditch losses are usually classified as seepage, operational, or spill losses. In the field there are seepage or deep percolation losses and tailwater losses. Spilled water and runoff normally return to the stream quickly, although this may be at a different location.
Deep percolation water is added to groundwater storage. Part of this storage may be lost to phreatophyte use while the remainder is returned slowly to the stream.

The timing of return flow will follow a recession curve. It may take from several months to over a year for all water to return to the stream. The return flow recession curve is related to characteristics of the aquifer, drainage system in the area, size of the area, and distances to channels or drains. Because of high variability and, normally, lack of knowledge of hydrogeologic characteristics, the return flow recession curve is normally estimated and then adjusted, by trial and error, until outflow distribution agrees with known outflow at a stream gauge. The curve is generally assumed to be an exponential curve which follows the equation

$$R_n = R_0 K^n$$

where R_n is the percentage of return flow for the nth period and K is the declining rate factor. For monthly time steps, R_o typically ranges from 30 to 50 percent and K from 0.8 to 0.5. The sum of R_n cannot exceed 100 percent. Return flow series from each month are added to return flow series from all other months. An example will be used to illustrate the process.

The deep percolation losses during June, July, and August are 1000, 1200, and 500 acre-feet, respectively. Phreatophyte losses are estimated to be 20% of the volume. Fifty percent of the loss returns during the same month (R_o = 50%). The rate of return declines with a factor K = 0.6.

First the return flow rate for each period is calculated.

	sum
$R_o = 50\%$	50%
$R_1 = .50 \times .6 = .30$	80
$R_2 = .30 \times .6 = .18$	98
$R_3 = .18 \times .6 = .11$	100

Then the return flow is calculated for each month and summed.

Month	Inflow	Losses	ToGW	Return (0) .5	(1) .3	(2) .18	(3) .11	Total
June	1000	200	800	400				400
July	1200	240	960	480	240			720
August	500	100	400	200	288	144		632
Sept.	0	0	0	0	120	173	16	309
Oct.	0	0	0	0	0	72	19	91
Nov.	0	0	0	0	0	0	8	8
Totals	2700	540	2160	1080	648	389	43	2160

Water budgets are often illustrated with schematic diagrams. An example of a crop water budget is shown in figure 1. The model illustrated in figure 1 shows inflow from precipitation and irrigation; outflows are from runoff, deep percolation, and transevaporation. All storage is in the root zone layer as soil moisture. Soil moisture is allowed to vary between some limits, usually crop wilting point to field capacity. Potential crop ET may be calculated using TR-21. The amount of irrigation water applied may be available from the farmer, the irrigation district, or from field measurements.

The following example will demonstrate how to use a simple irrigation water budget to estimate deep percolation and irrigation efficiencies. The results may then be used for additional modeling of return flows, etc.

Given:

Potential ET = 18 in,

Available Water Holding Capacity (AWHC)=7.0 in

Irrigation applied when soil moisture=50% AWHC=3.5

Tailwater Runoff=10% of each application

Irrigation water applied=36 in (4 irrigations of 9in each)

Estimate the deep percolation and the actual ET for the season. Hint-look at each irrigation.

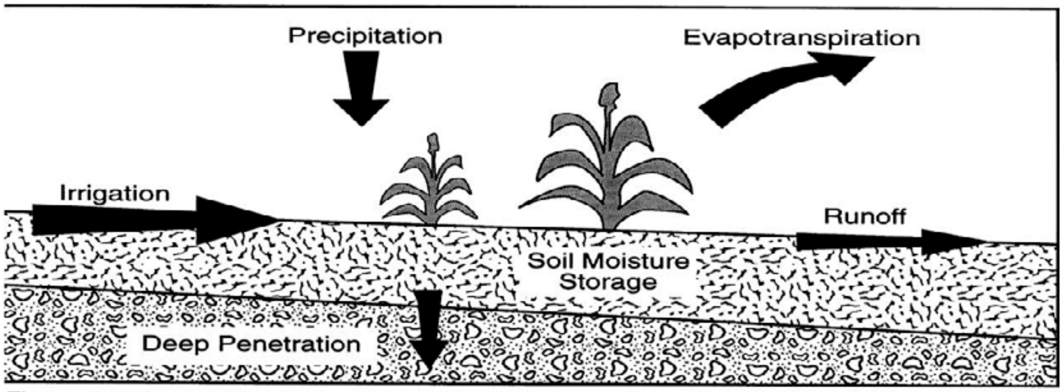

Figure 1. Irrigated field water budget schematic.

Solution: 1-0 = ΔS

I = 9, ΔS = 3.5

O = ET + DP + RO

RO = .1 x 9 = 0.9

ET (for the time of irrigation, a few hours) = 0

then

9-(0.0 + DP + 0.9) = 3.5

DP = 4.6 (per irrigation)

Total DP = 4 x 4.6 = 18.4 in

Total RO = 4 x .9 = 3.6

and over the season

1-0 = ΔS

where ΔS = 0

1=36

0 = ET + DP + RO

0 = ET + 18.4 + 3.6

then 36 = 22 + ET

or ET = 14 in

Drought and Drought Indexes

Drought is relative to any climate. There are many definitions of drought, but the simplest is attributed to Palmer: "A drought is a prolonged and abnormal moisture deficiency." The Palmer Drought Index is developed using the water balance approach. The analysis is based on weekly or monthly water balance, and output from the analysis is an index value ranging from -4 (extreme drought) to +4 (extreme wetness). The index is computed as the difference, accumulated through time, of the actual rainfall and a "climatically appropriate" rainfall. Climatically appropriate rainfall is adjusted for existing conditions of temperature, evaporation, and other components of water balance. Evaporation is computed by the Thornthwaith method, and runoff, percolation, and soil water levels, by a simple water balance model.

In arid and semi arid-areas of the U.S., the Surface Water Supply Index (SWSI) was introduced to provide a more appropriate indicator of water availability than the Palmer Drought Index. The Palmer index is primarily a soil moisture index, the SWSI is an index of snow accumulation, reservoir storage and stream flow, which are more important in arid areas.

Summary

By now, you should have a firm grasp of watershed yield using similar watersheds, water budgets, simulation models, and drought indexes.

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 if 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.

Activity 1

Given

$Q_a = .0165A^{.974}P^{1.159}$ cfs

Watershed 1: Q_{a1} = 34500 acre-feet
$A_1 = 71.3\ mi^2$
$P_1 = 31.0$ in

Watershed 2: $A_2 = 39.5\ mi^2$
$P_2 = 35.0$ in

Find

The annual yield for watershed 2 if watershed 2 is similar to watershed 1.

Activity 2

Given The daily precipitation shown below. A curve number of 70.

Find The runoff for the month.

Day	Precipitation	Runoff
1		
2	3.50	
3	3.35	
4	1.26	
5		
6		
7	0.03	
8		
9		
10		
11		
12	0.36	
13		
14		
15		
16		
17	0.58	
18	0.36	
19		
Z)	0.04	
21	0.05	
Z2		
23		
24		
25		
26		
Z7		
28	0.62	
29		
3J	0.08	
31		
Total	11.43	

Activity 3

Given

During the month of July, the potential ET is 7.0 inches. The available soil moisture storage at the beginning of the month is 4.5 in. At the end of the month S = 5.5 inches. Three irrigations are applied. Each applies 4 inches of gross water. There is no runoff and no rainfall during the month.

Find

The deep percolation loss for the month.

Activity 4

Given

A recession curve from an irrigated area,

RO = 40%

K = 0.50

Find

The return flow in September from a 1000 acre-foot loss in July.

Summary

By now, you should have a firm grasp of watershed yield using similar watersheds, water budgets, simulation models, and drought indexes.

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Activity Solutions

Activity 1

Given

$Qa = .0165A^{.974}P^{1.159}$ cfs

Watershed

Watershed 1: Q_{a1} = 34500 acre-feet

A_l = 71.3 mi^2

P_1= 31.0 in

Watershed 2: A_2 = 39.5 mi^2

P_2 = 35.0 in

Find

The annual yield for watershed 2 if watershed 2 is similar to watershed 1.

Solution

$$Q_{a2}=Q_{a1}\ (A_2/A_1)^{.974}(P_2/P_1)^{1.159}$$

$$=34500(39.5/71.3)^{.974}\ (35/31)^{1.159}$$

=22340 acre-feet

Activity 2

Given

The daily precipitation shown below. A curve number of 70.

Find

The runoff for the month.

Solution

Day	Precipitation	Runoff
1		
2	3.50	1.01
3	3.35	0.92
4	1.26	0.03
5		
6		
7	0.03	0.00
8		
9		
10		
11		
12	0.36	0.00
13		
14		
15		
16		
17	0.58	0.00
18	0.36	0.00
19		
20	0.04	0.00
21	0.05	0.00
22		
23		
24		
25		
26		
27		
28	0.62	0.00.
29		
30	0.08	0.03
31		
Total	11.43	1.99

Activity 3

Given

During the month of July, the potential ET is 7.0 inches. The available soil moisture storage at the beginning of the month is 4.5 in. At the end of the month S = 5.5 inches. Three irrigations are applied. Each applies 4 inches of gross water. There is no runoff and no rainfall during the month.

Find

The deep percolation loss for the month.

Solution

Inflow = 3 x 4 = 12 in

Outflow = ET + DP
= 7.0 + DP

$\Delta S = 5.5 - 4.5 = 1.0$

$1 - 0 = \Delta S$

$12 - (7 + DP) = 1.0$

Deep Perc = 4.0

Activity 4

Given

A recession curve from an irrigated area,

RO = 40%

K = 0.50

Find

The return flow in September from a 1000 acre- foot loss in July.

Solution

$R_n = R_0 K^n$

$R_2 = R_o K_2$

$R_2 = 40 \times (.5)^2 = 10\%$

Then

0.10 x 1000 = *100 acre-feet*