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**Natural
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Conservation
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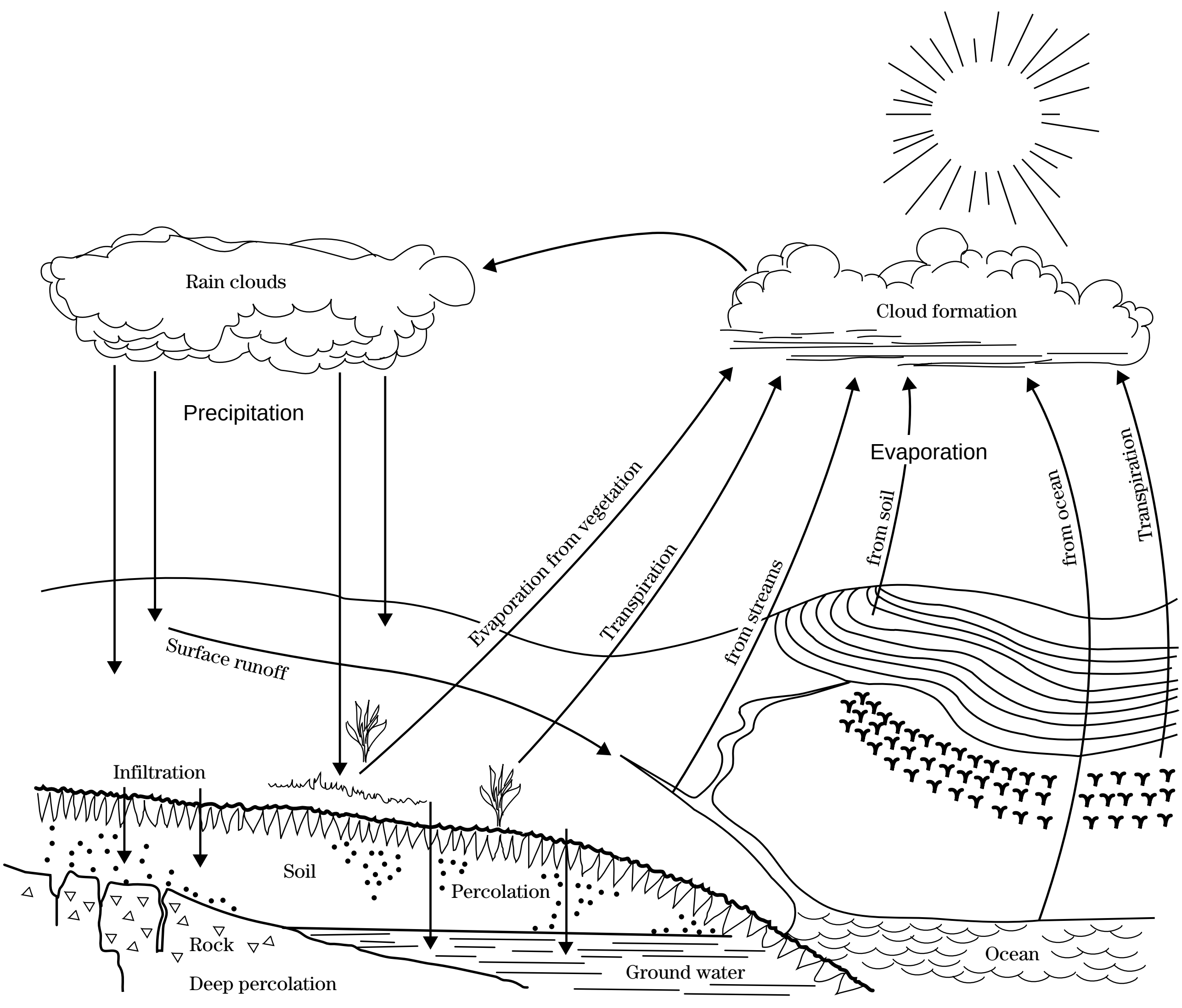
Part 630 Hydrology
National Engineering Handbook

Chapter 12 Hydrologic Effects of Land Use and Treatment



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Chapter 12 Hydrologic Effects of Land Use and Treatment

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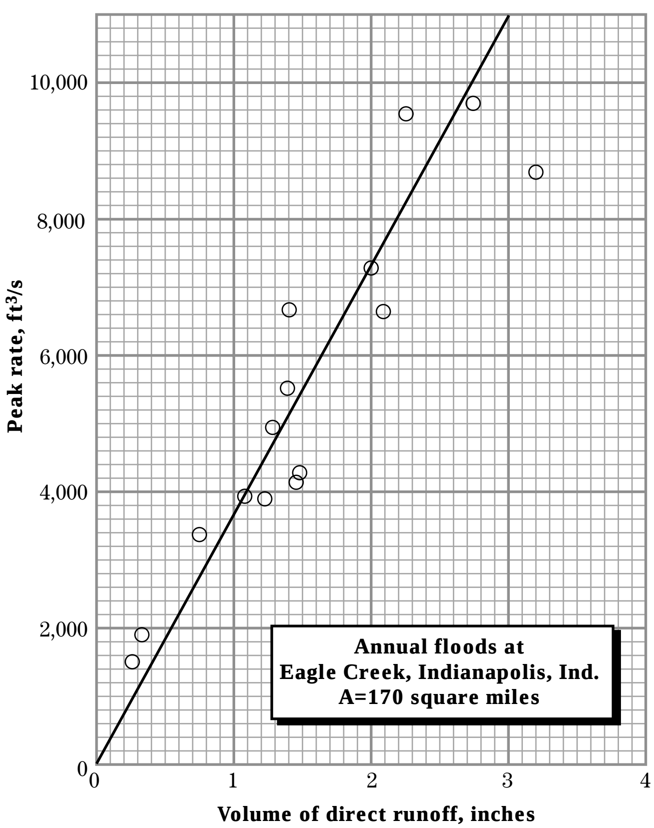
630.1200 General

The hydrologic effects described in chapter 12 are changes in volumes of direct runoff and changes in lag that affect peak rates of direct runoff.

Figure 12–1 Typical peak-volume relationship



630.1201 Volume effects

Land use and treatment measures reduce the volume of direct runoff during individual storms by either increasing infiltration rates or surface storage, or both. Other factors influencing runoff volume generally are of minor importance. Interception increases, for instance, are appreciable only under certain climatic and vegetative conditions and generally need not be considered in Natural Resources Conservation Service's (NRCS) watershed studies.

The unit hydrograph principle states that with other things constant, the peak rate of flow varies directly with the volume of flow. This principle is the basis for proportionate reductions in peaks when volumes are reduced (see National Engineering Handbook (NEH) 630, chapter 16). Figure 12–1 shows a typical peak versus volume relation. The straight line is drawn so that some points are on the line, if possible, with half of the remaining points on one side of the line and the other half on the other side. Drawing a curve is not justified because other important relations must be accounted for (see NEH 630, chapter 16) if greater accuracy is required. The figure shows that a 30 percent reduction in volume gives a 30 percent reduction in the peak rate, and so on.

Table 12–1 shows the principal effects of land use and treatment measures on direct runoff. The degree of effect of any single measure generally depends on the quantity that can be installed. Contour furrows, however, can be made to have a small or a large effect by changing the dimensions of the furrows. The effect of a land use change depends on the change in cover. A change from spring oats to spring wheat would ordinarily be hardly noticeable, while a change from oats to a permanent meadow could have a large effect. Graded terraces with grass outlets to some extent increase overall infiltration and overall storage. These effects are also confused with a lag effect. Lime and fertilizers, by increasing plant or root density, can indirectly reduce direct runoff volumes.

Table 12–1 Principal effects of land use and treatment measures on direct runoff

Measure	Reduction in direct runoff volume because of: Increasing infiltration rates [1/]	Increasing surface storage
Land use that increases plant or root density [2/]	X	
Increasing mulch or litter	X	
Contouring		X
Contour furrowing		X
Level terracing		X
Graded terracing		X

1/ Assuming soils not frozen.
2/ Example: Row crop to grass for hay; poor pasture to good pasture.

630.1202 Lag effects

Lag, as used here, means the delay between the production of direct runoff on upland areas and its appearance at a given cross section in a stream channel. Lag is also described in NEH 630, chapter 15.

Land use and treatment measures can produce lag effects by

- increasing infiltration (reducing surface runoff) and causing the increased infiltration to appear some time later as subsurface flow, or
- causing a delay in the arrival of surface runoff by increasing the flow length or reducing the velocity of flow.

Either effect is best studied by the methods described in NEH 630, chapters 15 and 16. Table 12–2 shows the relative effects of land use and treatment measures on the two types of lag. The subdivisions of small and large watersheds do not depend solely on size in square miles. The methods of chapters 15 and 16 are necessary in quantitative studies of lag.

Table 12–2 Relative effects of land use and treatment measures on types of lag

Measure	Effect on subsurface flow [1/]		Effect of increasing surface flow length or decreasing velocity	
	Small watersheds	Large watersheds	Small watersheds	Large watersheds
Land use changes that increase plant or root density [2/]	Can be large	Can be large	Not usually considered	
Increasing mulch or litter	Can be large	Can be large	Not usually considered	
Contouring	Can be large	Usually negligible	Can be large	Negligible
Contour furrowing	Can be large	Can be large	Not usually considered	
Level terracing	Can be large	Can be large	Not usually considered	
Graded terracing	Usually negligible	Usually negligible	Can be large	Negligible

1/ Assuming soils not frozen.
2/ Examples: Row crop to grass; poor pasture to good pasture.

630.1203 Determination of effects

(a) Determination of effects on volume

The same procedure used in determining the present hydrologic conditions of a watershed is used to estimate future hydrologic conditions. The future effects of land use and treatment changes can be estimated with relatively little additional work. Assuming that present conditions have been studied, the procedure is:

Step 1. Determine the hydrologic soil-cover complex number and antecedent moisture condition (ARC) II for future land use and treatment conditions. (See NEH 630, chapters 7, 8 and 9.)

Step 2. Obtain complex numbers for ARC I and III. (See table 10–1 in NEH 630, chapter 10).

Step 3. Prepare a working table similar to table 12–3.

Step 4. Plot the corresponding present and future values as shown on figure 12–2. For example, plot 0.23 versus 0.02, 0.60 versus 0.l8, and 1.10 versus 0.43, and draw in the curve for ARC I. Do the same for the other conditions.

Step 5. Enter figure 12–2 with the present volume and condition for a storm or flood in the evaluation series and find the future volume on the appropriate curve.

(b) Determination of effects on lag

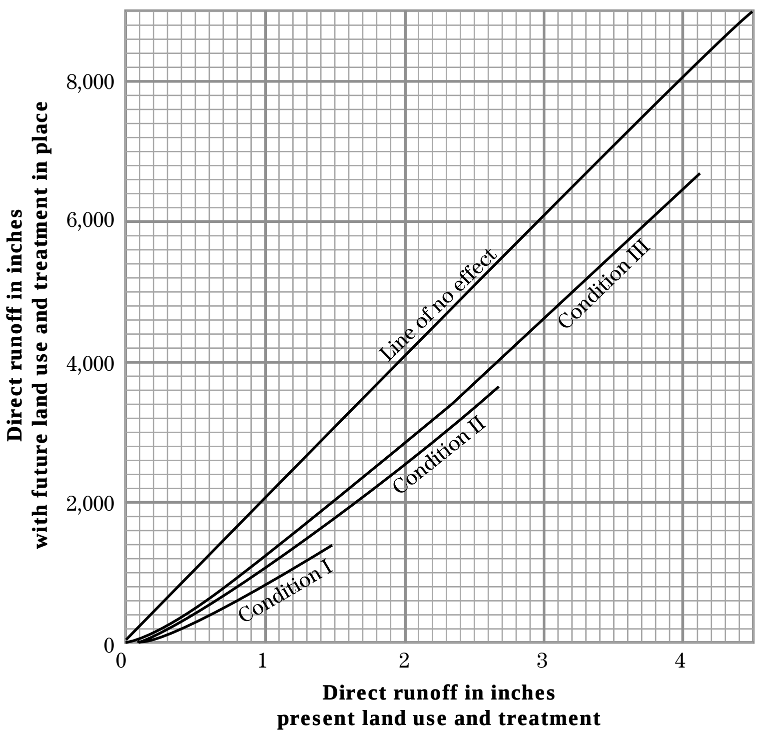
Increased infiltration appearing some time later as subsurface flow is seldom easy to evaluate quantitatively. Fortunately, however, in most flood prevention surveys the changes in the hydrograph because of this lag effect can generally be neglected. Where they cannot, special studies are needed to determine the source areas (which may vary with infiltrated volumes) and watershed retention. The techniques for these special studies have not been fully developed, however, and the results may be controversial.

Table 12–3 Sample working table for estimation of effects of future land use and treatment on direct runoff volumes

Selected values of P	Direct runoff for selected values of P (from fig. 10–1)					
	ARC* I		ARC* II		ARC* III	
	Present	Future	Present	Future	Present	Future
	inches					
0.5	0	0	0	0	0.08	0
1	0	0	.02	0	.35	.12
2	0	0	.38	.11	1.15	.70
3	.23	.02	.97	.50	2.05	1.45
4	.60	.18	1.68	1.03	3.00	2.30
5	1.10	.43	2.46	1.65	3.95	3.20
Curve numbers:	57	45	75	65	91	83

* ARC is antecedent runoff condition.

Figure 12–2 Volume effects of land use and treatment



Quite often the first type of lag (producing increased infiltration) can be assumed to take place in the manner of the second type of lag which causes a delay in surface runoff arrival. The technique that follows can be used to estimate expected changes in hydrograph quantities.

The effect of causing a delay in the arrival of surface runoff by increasing the distance of flow is easily computed when it must be considered. Figure 12–3 shows hydrographs for adjacent treated and untreated watersheds. Additional information is given in J.A. Allis' article "Runoff from Conservation and Non-Conservation Watersheds" (Allis, 1953). Two effects are evident. Some of the reduction in peak rate is a result of the lesser amount of runoff from the treated watershed. Given the data as shown, the expected peak for the treated watershed would be:

$$1.74\frac{(1.35)}{(1.68)} = 1.40 \text{ in / hr}$$

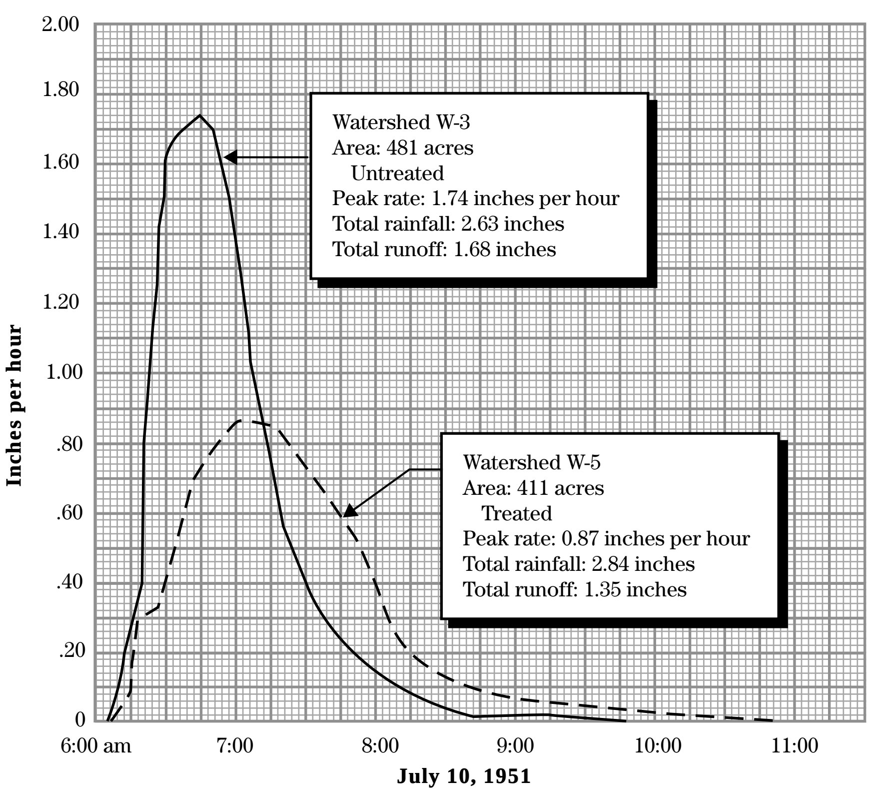
since $\frac{q_1}{Q_1} = \frac{q_2}{Q_2}$

when runoff is uniformly (or nearly so) distributed on each watershed, but the actual value for Watershed W-5 is 0.87 inch per hour. The difference is primarily because of a lag caused by graded terraces and open-end level terraces (which tend to grade).

Following the methods described in NEH 630, chapters 15 and 16, the additional lag can be computed from data in figure 12–3. The time to peak (T_p) for W-3 is about 0.72 hour, and for W-5, about 1.05 hours. The increase in lag (since storm D is essentially identical for both hydrographs) is:

$$1.05 - 0.72 = 0.33 \text{ hour}$$

Figure 12–3 Effects of land use and treatment on lag



Since T_p consists of storm duration and time of concentration (see NEH 630, chapter 16), the changes in either (or both) factors can be studied in a graph similar to that of figure 12–4. The graph shows that, for this case, the second type of lag effect becomes relatively insignificant at about T_p = 5 hours.

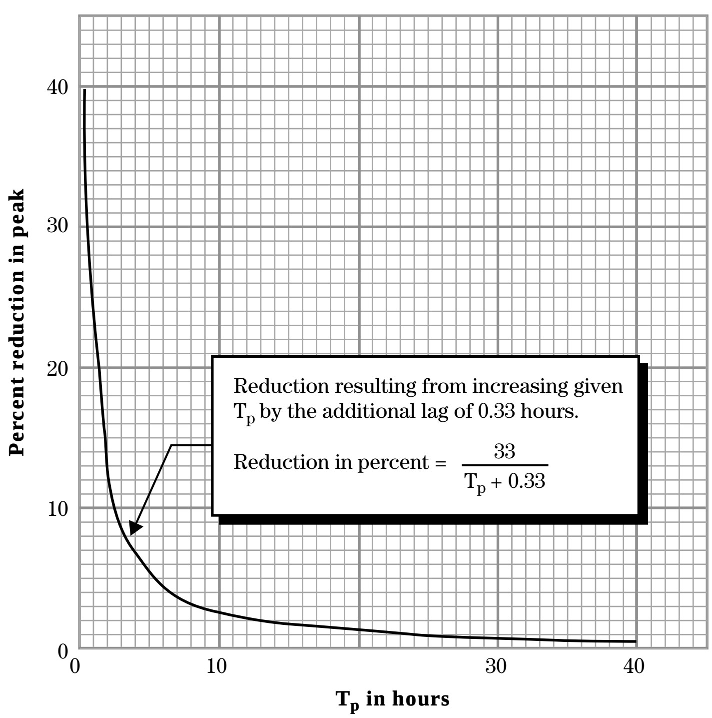
In practice, the second type of lag effect is ordinarily neglected. The technique given above can be used when the second type must be evaluated and, quite often, for evaluations of the first type of lag effect. The altered hydrographs can be reproduced by the methods described in NEH 630, chapter 16.

(c) Determination of effects on snowmelt runoff

The effects of land treatment on snowmelt runoff may vary considerably from the effects on runoff from rainfall. The principal changes in effects partly result from the changes in the measures themselves, and partly because of frost action.

By the time the snow season arrives, cultivation and weathering generally have eliminated the mechanical distinction between straight row and contour farming on cultivated lands. Other effects of contouring generally are small enough to be overshadowed by variations in areal distribution of precipitation and are usually neglected. Graded terracing effects would be confined to the second type of lag and are determined by the method shown. Closed-end level terraces and contour furrows are usually dependent on storage, not infiltration, for their effect, which is therefore calculable. The effect of land use or cover on cultivated land and pasture is small enough to be obscured by the effects of topography, fences, roads, and nearby trees

Figure 12–4 Percent peak reduction by increasing lag 0.33 hour and the corresponding increase in T_p



and shrubs on the distribution of snow on the ground. The effect of crop rotation is similarly obscured.

For land treatment measures to be effective through the snow season, they must either maintain high infiltration rates on soils that have a large water storage potential or maintain surface storage, but seldom both at once. High infiltration rates are maintained by vegetation that provides heavy litter or large depths of humus. Ordinary practices on cultivated land and pasture seldom provide sufficient residue, and such areas need not be considered. Permanent meadows generally provide enough litter and humus to prevent mild frost action, but not enough to be effective against heavy freezes. Commercial forest and woodland effectively maintain infiltration and, when located on a soil with sufficient internal storage capacity, effectively reduce flood runoff from snowmelt. The exception of this is areas of swamps and spruce flats. The Forest Service procedure given in NEH 630, chapter 9 (see fig. 9–1) covers the evaluation of commercial forest and woodland.

Surface storage in closed-end level terraces and in contour furrows can effectively reduce snowmelt runoff as described in the next section. On field-size watersheds, the storage generally must be quite large to control the additional volumes of snowmelt from snow drifting from adjacent smooth fields and caught by the earthwork.

(d) Determination of surface storage effects

Storage in closed-end level terraces and contour furrows can be evaluated on a watershed or subwatershed basis using the equation:

$$Q_s = \frac{A_s\left(Q_o - S_s\right) + A_o Q_o}{A_s + A_o} \qquad [12\text{–}1]$$

where:
- Q_s = runoff with storage in effect, in inches
- A_s = area draining into storage including storage pond area, in square miles
- S_s = storage, in inches
- Q_o = runoff with no storage, in inches
- A_o = area not draining into storage, in square miles

When S_s exceeds Q_o, only the storage equal to Q_o is effective. For example, if S_s = 3.0 inches and Q_o = 1.2 inches, then 1.8 inches of storage have not been used and the effective storage is 1.2 inches. For example, when $S_s > Q_o$, use $A_s (Q_o - S_s) = 0$.

Note: Equation 12–1 and subsequent equations 12–2, 12–4, 12–5a, and 12–5b are for use when runoff and storage volumes are distributed uniformly (or nearly so) on a watershed. When the distribution is not uniform, the watershed is divided into subwatersheds on which the distribution may be considered uniform. See remarks accompanying equations 12–5a and 12–5b.

Infiltration in the storage area, including that caused by increased head, is generally assumed to offset storm rainfall on the storage pond area. When this infiltration is significantly large or small, it can be accounted for on a volumetric basis by changing equation 12–1 to read:

$$Q_s = \frac{A_p\left(P - F\right) + \left(A_s - A_p\right)\left(Q_o - S_s\right) + A_o Q_o}{A_s + A_o} \qquad [12\text{–}2]$$

where:
- A_p = average pond surface area, in square miles
- P = storm rainfall, in inches
- F = total infiltration on the area occupied by the pond, in inches.

If P is less than F, use (P – F) equal to zero. When other data are lacking and the average depth of the pond is less than about 3 feet, F may be approximated using the following equation:

$$F = D\, f_c\left(1.5h + 1\right) \qquad [12\text{–}3]$$

where:
- F = total infiltration on the pond area, in inches
- D = storm duration for equation 12–2, or snowmelt duration for equation 12–4, in hours
- f_c = minimum infiltration rate, in inches per hour
- h = average depth of pond during time D, in feet

Acres or square feet may be used instead of square miles in equations 12–1 and 12–2, but the unit chosen must be used for all the areas in a particular computation.

The effect of storage on snowmelt runoff is generally computed using equation 12–1 because the increase in infiltration caused by head in the pond area is usually negligible because of the temperature. When this infiltration is important, equation 12–2 becomes

$$Q_s = \frac{\left(A_s - A_p\right)\left(Q_o - S_s\right) + A_o Q_o - A_p\left(Q_o - F\right)}{A_s + A_o} \qquad [12–4]$$

unless there is rainfall on the pond surface during the melt period, in which case equation 12–2 is used. The effect of the earthwork in increasing the average depth of snow in an area (by catching drifting snow) is important only in small areas and is generally ignored.

According to unit hydrograph theory, the effect of surface storage on peak rate of flow is proportional to the effect on volume of flow when the storage and runoff are about equally distributed over the watershed:

$$\frac{q_s}{q_o} = \frac{Q_s}{Q_o} \qquad [12–5a]$$

or

$$q_s = q_o \frac{Q_s}{Q_o} \qquad [12–5b]$$

where
q_s = reduced peak
q_o = original peak

Equation 12–5b is adequate for many watersheds. However, when the distribution of Q_o and S_s is not sufficiently uniform or when a watershed has a complex drainage pattern, is unusually shaped, or has channel improvements, q_s must be determined by
- determining the storage effects on a subwatershed basis,
- preparing hydrographs on a subwatershed basis, and
- routing floods.

This routing procedure is often needed for large watersheds because the distribution of Q_o and S_s is nearly always nonuniform on these watersheds.

References

Allis, J.A. 1953. Runoff from conservation and nonconservation watersheds. Agricultural Engineering, Vol. 34, No. 11.

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