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Part 630 Hydrology

National Engineering Handbook

Chapter 12: Hydrologic Effects of Land Use and Land Treatment

Acknowledgements

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Authors and Contributors: This September 2017 revised document was prepared by the Curve Number Task Group of the Watershed Management Technical Committee, Environmental Water Resources Institute (EWRI) of the American Society of Civil Engineers. The major authors and contributors have been, in alphabetical order: Hunter Birckhead, P.E., M.ASCE; James V. Bonta, Ph.D., P.E., F.ASCE; Donald Frevert, Ph.D., P.E., D.WRE(Ret), F.ASCE; Claudia Hoeft, P.E., F.ASCE (USDA NRCS liaison); Richard H. Hawkins, Ph.D., P.E., F.EWRI, F.ASCE (Task Group chair); Rosanna La Plante, P.E., M.ASCE; Michael E. Meadows, Ph.D., P.E., F.ASCE; Julianne Miller, A.M.ASCE; Steven C. McCutcheon, Ph.D., P.E., D.WRE(Ret), F.EWRI, F.ASCE; Glenn Moglen, Ph.D., P.E., F.EWRI, F.ASCE; David Powers, P.E., D.WRE, F.ASCE; John Ramirez-Avila, Ph.D., ING., M.ASCE; E. William Tollner, Ph.D., P.E., M.ASCE, F.ASABE (American Society of Agricultural and Biological Engineers [ASABE] representative), Joseph A. Van Mullem, P.E., M.ASCE; Tim J. Ward, Ph.D., P.E., F.EWRI, F.ASCE (Task Group co-chair),; and Donald E. Woodward, P.E., F.ASCE (Task Group co-chair).

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630.1200 General

Chapter 12 describes the effects that runoff volume has on hydrograph shape and timing. The chapter includes techniques for estimating the effects. The hydrologic effects described are changes in volumes of direct runoff and changes in lag that affect peak rates of direct runoff. The descriptions do not include effects on hydrograph shape. Procedures in this chapter are now implemented in readily available computer programs. This chapter also discusses the impacts of changing land use and of fires on the runoff volume.

630.1201 Volume effects

Land use and land treatment measures reduce the volume of direct runoff during individual storms by either increasing infiltration rates, increasing surface storage, or both. Other factors influencing runoff volume generally are of minor importance. Interception increases, for example, are appreciable only under certain climatic and vegetative conditions and generally need not be considered in Natural Resources Conservation Service (NRCS) watershed studies. However, by increasing the volume or amount of vegetation, the volume of runoff can be reduced. The reverse is also true. Reduction of vegetation caused by over grazing or other land use can increase the volume of runoff by compaction of the soil and reducing the evapotranspiration.

The unit hydrograph principle states that, with other things constant, the peak rate of flow varies directly with the volume of flow (runoff). This principle is the basis for proportionate reductions in peaks when volumes are reduced (see National Engineering Handbook (NEH) 630, Chapter 16 (USDA NRCS, 1999)).

Table 12–1 lists the principle effects of land use and treatment measures on direct runoff. The degree of effect of any single measure generally depends on the extent and quality of the treatment that can be installed. Contour furrows can be built to have a small or a large effect by changing the dimensions of the furrows. The primary effect of a land use change depends on the change in cover. A change from spring oats to spring wheat would ordinarily be barely noticeable, while a change from oats to a permanent meadow could have a large effect. Graded terraces with grass outlets increase overall infiltration and overall storage to some extent. Lime and fertilizers, by increasing plant or root density, can indirectly reduce direct runoff volumes. There are other soil amendments that are being employed and low impact developments (LIDs) in urbans areas, such as compost, are commonly used. Other soil amendments include zeolite, gypsum, and liquid amendments such as ammonium laureth sulfate.

Table 12- 1. Principle effects of land use and land 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
Soil additives	X	

[1]Assuming soils are 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 location in a stream channel. Lag is also described in NEH 630, Chapter 15 (USDA NRCS, 1999).

Land use and treatment measures can produce lag effects by a) increasing infiltration (reducing surface runoff) and causing the increased infiltration to appear some time later as subsurface flow, or b) causing a delay in the arrival of surface runoff by increasing the flow length or by reducing the velocity of flow from added flow resistance.

Either effect is best studied by the methods described in NEH 630, Chapters 15 and 16 (NRCS, 1999). 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, but on a combination of varying soils and land use and drainage area. The methods of Chapters 15 and 16 are necessary in quantitative studies of lag. The use of computer models is advised in many watershed studies to estimate the impact of land use change and land treatment measures on peak flows in a watershed.

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

Measure	**Effects on subsurface flow[1]**		**Effect of increasing surface flow length or decreasing velocity**	
	Small watersheds	Large watersheds	Small watersheds	Large watersheds
Land use that increases 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	---	Can be large	
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 are not frozen; [2] Example: Row crop to grass for hay; poor pasture to good pasture.

630.1203 Determination of Effects of Land Use Change

(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 runoff condition (ARC) II for future land use and treatment conditions (See NEH 630, Chapters 7, 8 and 9).

Step 2. Obtain Curve Numbers for ARC I, II, and III.

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

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

Selected values of P (inches)	**Direct runoff Q (inches)**[1]					
	---ARC[2] I---		---ARC II---		---ARC III---	
	Present	Future	Present	Future	Present	Future
	56[3]	***44***	***75***	***65***	***89***	***82***
0.5	<0.01	<0.01	0.03	0.01	0.11	0.16
1	0.04	0.01	0.17	0.09	0.40	0.26
2	0.27	0.13	0.65	0.42	1.18	0.87
3	0.65	0.37	1.30	0.92	2.07	1.64
4	1.13	0.70	2.05	1.53	3.00	2.49
5	1.70	1.11	2.86	2.21	3.95	3.38

[1]Computed with Ia = 0.05S; [2]ARC is Antecedent Runoff Condition; [3]Curve Number for given ARC.

(b) Determination of effects on lag

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. Increased infiltration appearing some time later as subsurface flow is seldom easy to evaluate quantitatively. Fortunately, in most flood prevention surveys the changes in the hydrograph because of this lag effect can generally be ignored. Special studies are needed to determine the source areas (which may vary with infiltrated volumes) and watershed retention.

Quite often, lag produced by increased infiltration can be assumed to result from slower drainage from the surface and increased opportunity for infiltration. The slower drainage causes a delay in surface runoff arrival. The technique that follows can be used to estimate expected changes in hydrograph quantities. In practice, lag from increased flow resistance is ordinarily neglected.

(c) Determination of surface storage effects

Under certain situations, watersheds may contain surface storage areas that must be accounted for in runoff computations. For example, storage in closed-end level terraces and contour furrows can be evaluated on a watershed or sub-watershed basis using the equation:

$$Q_s = (A_s(Q_o - S_s) + (A_oQ_o))/(A_s + A_o) \qquad [12\text{-}1]$$

where:

Q_s = runoff with storage in effect, in inches,

A_s = area draining into storage including storage pond area, in square miles (or other area units),

S_s = storage, in inches,

Q_o = runoff with no storage, in inches, and

A_o = area not draining into storage, in square miles (or other area units)

When Ss exceeds Qo, only the storage equal to Qo is effective. For example, if Ss = 3.0 inches and Qo = 1.2 inches, then 1.8 inches of storage have not been used and the effective storage is 1.2 inches. For example, when Ss>Qo, use As (Qo – Ss) = 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 sub-watersheds on which the distribution may be considered uniform (See remarks accompanying Equations [12–5a] and [12–5b]).

Figure 12–1 shows hydrographs for adjacent treated and untreated watersheds. Additional information can be found in Allis (1953). Two effects are evident in Figure 12-1. 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 in Figure 12-1, the estimated peak for the treated watershed would be:

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

because (q1/Q1) = (q2/Q2) when runoff is uniformly (or nearly so) distributed on each watershed. However, the measured peak flow rate 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) in W-5.

Following the methods described in NEH 630, Chapters 15 and 16 (USDA NRCS,1999), the additional lag can be computed from data in Figure 12–1. 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 (because the storm duration is essentially identical for both hydrographs) is (1.05 – 0.72) = 0.33 hour.

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

$$Q_s = (A_p (P - F) + (A_s - A_p)(Q_o - S_s) + A_o Q_o)/(A_s + A_o) \qquad [12–2]$$

where:

Ap = average pond surface area, in square miles,

P = storm rainfall, in inches, and

F = total infiltration on the area occupied by the pond, in inches.

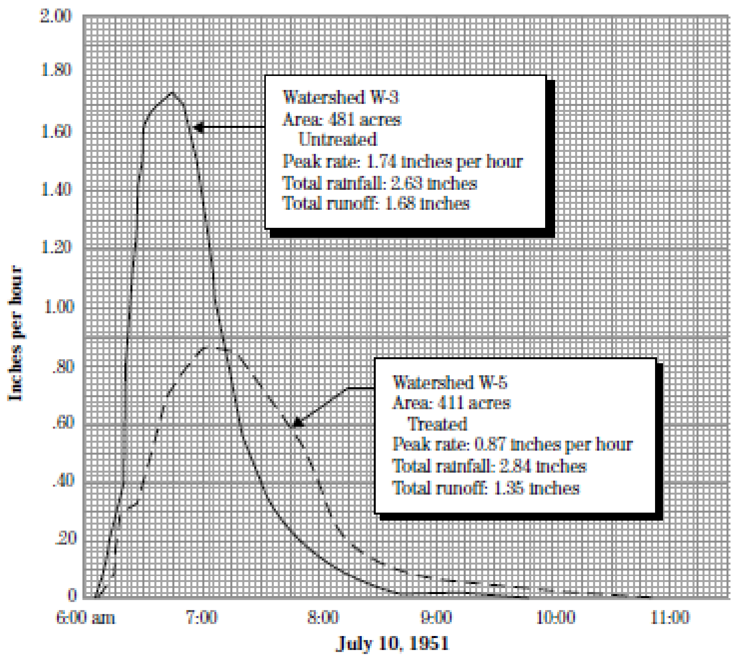

Figure 12- 1. Effects of storage on lag

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:

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

where:

F = total infiltration on the pond area, in inches,

D = storm duration for Equation [12–3],

f_c = minimum infiltration rate, in inches per hour, and

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 units chosen must be compatible 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. Infiltration is important during the snow melt season and when trying to simulate the daily impact of the snow pack melt on the water balance

When this infiltration is important, Equation [12–2] becomes

$$Q_s = ((A_s - A_e)(Q_o - S_s) + A_oQ_o - A_p(Q_o - F))/(A_s + A_o) \qquad [12\text{–}4]$$

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 retaining 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:

$$(q_s/q_o) = (Q_s/Q_o) \qquad [12\text{–}5a]$$

or

$$q_s = q_o\,(Q_s/Q_o) \qquad [12\text{–}5b]$$

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 estimated by determining the storage effects on a sub-watershed basis, preparing hydrographs on a sub-watershed basis, and routing flows.

This routing procedure is often needed for large watersheds of several square miles in size because the distribution of Q_o and S is nearly always **not uniform** on larger watersheds.

(d) Determination of fire effects

The general impacts of fires in either agricultural lands or forests is the destruction of the vegetation. The impact of the fire in many cases is listed as fair, moderate or high. In some cases, for forests, the impact from fire dissipates to the pre-fire conditions within 3-5 years.

In other cases, the properties of the soils have changed because of the fire, specifically the infiltration capacity of the soil is reduced through creation of hydrophobic layers. The USDA Forest Service Rocky Mountain Research Station and the Natural Resource Conservation Service have publications that list suggested pre- and post-fire CNs as well as the impact of fire on soil infiltration rates. The NRCS Hydrology Technical Note No. 4, Hydrologic Analysis of Post-Wildfire Condition (USDA NRCS, 2016), provides guidance and the selection of post-fire CNs based on investigated cases. Wildcat5 (Hawkins and Barreto-Munoz, 2016) for Windows® is a computer program developed for the U.S. Forest Service that can be used to evaluate the impact post-fire conditions.

630.1204 References

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