Chapter 7

Basin Lag

Introduction

Overview

The lag time of a basin is required to calculate runoff hydrographs. Two methods are available to calculate basin lag, the Basin "n" method and the Travel Time Component method. Both methods may be used in any given multi-basin model. This section covers the recommended applications and the equations for each method. A summary of the methods to compute lag time is given below.

Summary of Lag Methods

Method	Application	Required Parameters
Basin "n"	planning level analyses basins with limited conveyance systems	slope of main channel length of main channel length to basin centroid basin "n" coefficient
Travel time components	detailed conveyance system design runoff analyses of existing conveyance systems	land use and slope of overland flow length, slope and size of gutters, pipes, channels

Using SACPRE

SACPRE, the HEC-1 preprocessor provided with this volume, aids the user in calculating the basin lag time. SACPRE uses the equations and design parameters outlined in this section for all lag calculations.

Basin "n" Method

Application

The Basin "n" method of computing lag should be used for:

- planning level analyses
- basins with limited conveyance systems.

Lag Equation

The Basin "n" lag equation, which was originally developed by Snyder[11] and later revised by the U.S. Corps of Engineers and the U.S. Bureau of Reclamation,[17] is expressed as:

$$L_g = Cn\left[\frac{LL_c}{S^{0.5}}\right]^{0.33} \qquad (7\text{-}1)$$

where:

C = 1560 (174)
L_g = Lag Time, min (sec)
L = Length of longest watercourse, measured as approximately 90% of the distance from the point of interest to the headwater divide of the basin, miles (m)
L_c = Length along the longest watercourse measured upstream from the point of interest to a point close to the centroid of the basin, miles (m)
S = Overall slope of the longest watercourse between the headwaters and concentration point, ft/mile (m/m)
n = Basin "n" from Table 7-1.

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Basin "n" Method (continued)

Determining the Basin "n"

The basin "n" value is dependent on the basin land use and the condition of the main drainage course. For basins with mixed land use and/or varying characteristics of the main drainage course, the basin "n" should be weighted for the areas draining to each type of channel development. Table 7-1 contains recommended basin "n" values[3]. The shaded values in Table 7-1 are normally not used. However, these values may be used for planning purposes to estimate the effect of channelization, or to estimate a composite "n" for large areas with mixed land use and channelization.

Table 7-1. Basin "n" for Unit Hydrograph Lag Equation

Basin Land Use	Percent Impervious	Channelization Description	
		Developed Pipe/Channel	Undeveloped Natural
Highways, Parking	95	0.030	0.067
Commercial, Offices	90	0.031	0.070
Intensive Industrial	85	0.032	0.071
Apartments, High Density Res.	80	0.033	0.072
Mobil Home Park	75	0.034	0.073
Condominiums, Med. Density Res.	70	0.035	0.074
Residential 8-10 du/acre (20-25 du/ha), Ext Industrial	60	0.037	0.076
Residential 6-8 du/acre (15-20 du/ha), Low Density Res., School	50	0.040	0.080
Residential 4-6 du/acre (10-15 du/ha)	40	0.042	0.084
Residential 3-4 du/acre (7.5-10 du/ha)	30	0.046	0.088
Residential 2-3 du/acre (5-7.5 du/ha)	25	0.050	0.090
Residential 1-2 du/acre (2.5-5 du/ha)	20	0.053	0.093
Residential .5-1 du/acre (1-2.5 du/ha)	15	0.056	0.096
Residential .2-.5 du/acre (0.5-1 du/ha), Ag Res.	10	0.060	0.100
Residential <.2 du/acre (0.5 du/ha), Recreation	5	0.065	0.110
Open Space, Grassland, Ag	2	0.070	0.115
Open Space, Woodland, Natural	1	0.075	0.120
Dense Oak, Shrubs, Vines	1	0.080	0.150
Shaded values are normally not used.			

Travel Time Component Method: Overview

Application

The Travel Time Component method of computing basin lag should be used for the following applications:

- detailed conveyance system design
- runoff analyses of existing conveyance systems.

Lag Time

The lag time is the sum of the travel time for runoff to flow over or through the conveyance elements in a basin from the most upstream part of the basin to the downstream point of interest. Conveyance elements include:

- overland flow
- gutter flow
- pipe flow
- channel flow.

In equation form it looks like this:

$$\text{Lag time} = T_o+T_g+T_p+T_c$$

where:

T_o = overland flow time of concentration
T_g = gutter flow travel time
T_p = pipe flow travel time
T_c = channel flow travel time

The equations used to calculate the overland flow time of concentration and the velocities in the various conveyance elements are described in the following sections. The travel times in the conveyance elements are obtained by dividing the length of the element by the velocity of flow.

Travel Time Component Method: Determining T_o

Overland Flow

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Popular methods for determining overland flow velocity include the SCS velocity nomograph and the kinematic wave equation. A recently developed kinematic wave empirical equation based on available SCS, COE and FAA overland flow data (Papadakis, 1987) is:

$$T_o = \frac{CL^{0.50}n^{0.52}}{S^{0.31}i^{0.38}} \qquad (7\text{-}2)$$

where:

C = 0.66 (4.09)
T_o = overland flow time of concentration, min (min)
L = overland flow length, ft (m), (Table 7-2, disk)
n = roughness coefficient for overland flow, (Table 7-2,disk)
S = average slope of flow path, ft/ft (m/m)
i = intensity of precipitation, in/hr (mm/hr), (Table 7-3,disk)

Use of the overland time of concentration equation requires an iterative approach: an initial estimate of time of concentration updated by successive estimates of precipitation intensity. In many cases overland flow accounts for a large part of the lag time in a basin.

Standard Overland Flow Times of Concentration

In small basins the overland flow time of concentration can account for the majority of the lag time of the basin. The City and County of Sacramento have provided standard overland flow times of concentration to assure consistent and reasonable values are used to calculate the total lag time. Maximum times of concentration for commercial and residential areas and a range of times of concentration for open space are given in Table 7-4. The land use applies only to the most upstream reach of the basin, prior to entering the gutter or street.

Table 7-4. Standard Overland Flow Parameters

Land Use	Overland Flow Time min	Slope ft/ft (m/m)	Overland "n"	Distance ft (m)
Commercial	3	---	---	---
Residential	9	---	---	---
Open Space	17-44*	.001-.01	0.30	200 (61)
*Computed using equation 7-2 depending on slope.				

Travel Time Component Method: Determining T_g

Gutter Flow

Manning's equation for a triangular channel cross section is used to determine flow velocity and travel times for street gutter flow. The average distance from the overland flow surface to the nearest inlet is divided by flow velocity to obtain street gutter flow time. The gutter flow equation was derived using the following assumptions.

- The cross slope of the street is 0.02 ft/ft (m/m)
- The flow in the gutter is six inches deep and contained by the curb
- The street surface is smooth asphalt or concrete.

$$V_g = \frac{C}{n} S_x^{0.67} S^{0.50} T^{0.67} \tag{7-3}$$

where:

C = 1.12 (0.757)
V_g = velocity of flow in the gutter, ft/s (m/s)
S_x = street cross slope, ft/ft (m/m), design value = 0.02
S = street longitudinal slope, ft/ft (m/m)
T = spread of flow in gutter, d/S_x, ft (m)
d = depth of flow in the gutter, ft (m) design value = 0.5 ft (.15m)
n = Manning's n for pavement, design value = .02

Travel Time Component Method: Determining T_p

Pipe Flow

Manning's Equation can also be used to determine travel time of flow through pipes. Travel time is usually calculated by assuming full pipe flow. Flow velocity is calculated with the equation:

$$V = \frac{C}{n} R^{0.67} S^{0.50} \qquad (7\text{-}4)$$

where:

C = 1.49 (1)
V = velocity in pipe, ft/s (m/s)
R = hydraulic radius, D/4 for full pipe flow, ft (m)
D = diameter of pipe, ft (m)
S = slope, ft/ft (m/m)
n = Manning's n

Travel Time Component Method: Determining T_c

r

Rectangular Channel Flow

A modified Manning's equation for open channel flow is used to derive travel time, velocity, flow and width relationships for rectangular concrete channels. The Manning's equation for rectangular channel flow velocity was derived based on the following assumptions:

- The Mannings "n" value is 0.016
- The width to depth ratio is 2:1.

$$V = Cw^{0.667}S^{0.5} \tag{7-5}$$

where:

C = 37.0 (24.9)
V_c = velocity in a rectangular concrete channel, ft/s (m/s)
w = width, ft (m)
S = slope, ft/ft (m/m)

Given the channel width and slope the equation for flow, in cubic feet per second (cubic meters per second), is:

$$Q = Cw^{2.67}S^{0.5} \tag{7-6}$$

where:

C = 18.5 (12.4)

If design flow is known or estimated the channel width can be calculated by:

$$w = CQ^{0.38}S^{-0.19} \tag{7-7}$$

where:

C = 0.33 (0.38)

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ravel Time Component Method: Determining T_c (continued)

Trapezoidal Channels

A modified Manning's equation is used for open channel flow to derive travel time, velocity, flow and bottom width relationships for trapezoidal grass-lined channels. The following assumptions were made in the derivation of the modified equation:

- Channel side slopes are 3:1, horizontal:vertical
- The channel bottom width equals the depth
- The top width is 7 times the bottom width

$$V = \frac{C}{n} b^{0.67} S^{0.5} \qquad (7\text{-}8)$$

where:

C = 0.995 (0.670)
V = velocity, in feet per second (m/s)
b = bottom width, in feet (m)
n = manning's "n" for channel flow

Given the channel bottom width and slope, the equation for flow, in cubic feet per second (cubic meters per second) is:

$$Q = \frac{C}{n} b^{2.67} S^{0.5} \qquad (7\text{-}9)$$

where:

C = 3.98 (2.68)

If design flow (Q) is known or estimated

$$V = \frac{Q}{4b^2} \qquad (7\text{-}10)$$

$$b = CQ^{0.38} n^{0.38} s^{-0.19} \qquad (7\text{-}11)$$

where:

C = 0.59 (0.70)

Travel Time Component Method: Determining T_c (continued)

Trapezoidal Channels (cont.)

Table 7-5 provides appropriate values of Manning's "n" for various channel types.

Table 7-5. Manning's "n" for Channel Flow

Surface	Manning's "n"
Concrete pipe	0.015
Corrugated metal pipe	0.024
Concrete-lined channels	0.015
Earth channel-straight/smooth	0.022
Earth channel-dredged	0.028
Mowed grass lined channel	0.035
Natural channel-clean/some pools	0.040
Natural channel-winding/some vegetation	0.048
Natural channel-winding/stony/partial vegetation	0.060
Natural channel-debris/pools/rocks/full vegetation	0.070
Floodplain-isolated trees/mowed grass	0.040
Floodplain-isolated trees/high grass	0.050
Floodplain-few trees/shrubs/weeds	0.080
Floodplain-scattered trees/shrubs	0.120
Floodplain-numerous trees/dense vines	0.200

Lag Frequency Factors

Piped Basins with Overland Release

Most existing storm sewer systems in the City and County of Sacramento convey from 2- to 5-year recurrence interval flood peaks. Flows exceeding the storm sewer capacity back up in the streets and either pond, or if an overland release has been provided, flow in the streets or a channel. Lag times, regardless of the method of calculation, should be amended to account for flows exceeding pipe capacities, causing temporary flooding in the streets and thereby increasing lag times. The following multiplication factors given in Table 7-6 are applied to the lag times for piped areas with overland release.

Table 7-6. Lag Multiplication Factors for Overland Release

Frequency (years)	**2**	**5**	**10**	**25**	**50**	**100**	**200**	**500**
Multiplication Factor	1.0	1.0	1.0	1.1	1.2	1.3	1.4	1.5

SACPRE automatically applies the above factors to lag times for the following cases:

- Basin "n" lag time for basins with developed channelization and land use densities greater than residential with 1 to 2 DU/acre (2.5-5 DU/hectare).
- Travel time component lag times for pipe components.

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Lag Frequency Factors (continued)

Piped Basins Without Overland Release

When no overland flow paths exist to allow street flooding to discharge to natural channels, the reduced flow into the channel can be accounted for in various ways depending upon the required accuracy as summarized in the following table.

Accuracy	Method
Least	Increase the lag time by 0.5 to 1.0 hour
Higher	Truncate the hydrograph at the pipe capacity using diversion or storage routing techniques in HEC-1.
Highest*	Develop storage routing parameters that reflect: • pipe capacity • estimated overland release • surface storage in the basin • water surface elevation in the channel for the return interval of interest.

***Guidelines for this method are available from Sacramento County.**