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Guidance for Estimation of Time of Concentration in Texas for Low-Slope Conditions

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0-6382 Establish Effective Lower Bounds of Watershed Slope for Traditional Hydrologic Methods

Product P-1:

Guidance for Estimation of Time of Concentration in Texas for Low-Slope Conditions

Description

Formal guidance for estimation of time of concentration (critical storm duration) for watersheds characterized as having limited topographic slope is provided in this product. Limited topographic slope watersheds are those watersheds having main-channel slopes less than about 0.3 percent or 0.003 dimensionless[1]. Cleveland and others (2011) explains that this choice of threshold slope is intended to provide a smooth transition from typical to low slope conditions.

Main-channel slope S_0 is computed as the change in elevation from the watershed divide to the watershed outlet divided by the curvilinear distance of the main channel (primary flow path) between the watershed divide and the outlet (Roussel and others, 2005).

The authors emphasize that there is ambiguity in the meaning of low slope watersheds and the primary objective of this project is for objective mitigation for conditions in which the engineer computes $S_0 \to 0$ (slope effectively vanishing). The guidance described in this product is an adaptation and extension of the supplement in Roussel and others (2005, pp. 33–34). That supplement is extended here to watersheds with limited topographic slope. Such watersheds are predominant in the High Plains and Coastal Regions of Texas.

Low Slope Procedures

Implementing the report guidance requires three steps, which are enumerated below.

1. Determine the flow direction and main channel slope. If there is ambiguity in direction, then the situation is likely a low slope condition.
2. Using the computed slope and judgement of flow direction ambiguity, determine whether to apply a low–slope offset or not by the following decision guidelines.
   (a) If the main channel slope is greater than 0.003 (0.3-percent), then proceed using typical methods — the situation is NOT low slope.

[1] These values are the threshold slope where modified methods should be considered. These values should not be confused with the offset value of 0.05 percent or 0.0005 dimensionless.

(b) If the main channel slope is between 0.002 and 0.003 (0.2 to 0.3 -percent), the situation is transitional — the engineer uses judgement on whether to use the low slope adjustment or not. If flow direction ambiguity is present, treat as low slope.

(c) If the main channel slope is less than 0.002 (0.2-percent), the situation is low slope, proceed to the next step.

3. Apply the Kerby-Kirpich approach (below) or other approach, but use a slope offset of 0.0005. That is, use the computed slope and add the value 0.0005 to the computed slope as in Equation 1.

$$S_{\text{low slope}} = S_0 + S_{LB} = S_0 + 0.0005 \tag{1}$$

where S_0 is the computed slope, and the offset, S_{LB}, is 0.0005 (dimensionless).

The remainder of the product duplicates content from Cleveland and others (2011) and explains the Kerby-Kirpich approach from Roussel and others (2005) with the low slope application adjustment.

The Modified Kerby Method

For small watersheds where overland flow is an important component of overall travel time, the Kerby (1959) method modified for a base slope can be used. The Modified Kerby equation is

$$T_c = K(L \times N)^{0.467}(S_{LB} + S_0)^{-0.235}, \tag{2}$$

where T_c is overland flow time of concentration, in minutes; K is a units conversion coefficient, in which $K = 0.828$ for traditional units and $K = 1.44$ for SI units; L is overland-flow length, in feet or meters as dictated by K; N is a dimensionless retardance coefficient; S_{LB} is a base slope value that provides mitigation for vanishing topographic slope; and S_0 is dimensionless slope of terrain conveying the overland flow. In the development of the Kerby equation, the length of overland flow was as much as about 1,200 feet (366 meters). Hence, this length is considered an upper limit and shorter values in practice generally are expected. The dimensionless retardance coefficient used is similar in concept to the well-known Manning's roughness coefficient; however, for a given type of surface, the retardance coefficient for overland flow will be considerably greater than Manning's n for open-channel flow. Typical values for the retardance coefficient are listed in Table 1.

The Modified Kirpich Method

For channel-flow component of runoff, the Modified Kirpich (1940) equation is

$$T_c = KL^{0.770}(S_{LB} + S_0)^{-0.385}, \tag{3}$$

Table 1: Typical values of retardance coefficient N of Kerby (1959) method for overland flow

Generalized terrain description	**Dimensionless retardance coefficient (N)**
Pavement	0.02
Smooth, bare, packed soil	0.10
Poor grass, cultivated row crops, or moderately rough packed surfaces	0.20
Pasture, average grass	0.40
Deciduous forest	0.60
Dense grass, coniferous forest, or deciduous forest with deep litter	0.80

where T_c is the time of concentration, in minutes; K is a units conversion coefficient, in which $K = 0.0078$ for traditional units and $K = 0.0195$ for SI units; L is channel-flow length, in feet or meters as dictated by K; S_{LB} is a base slope value that provides mitigation for vanishing main channel slope; and S_0 is dimensionless main-channel slope.

Application

The example application of the Modified Kerby-Kirpich method from Cleveland and others (2011) is repeated to illustrate the low slope offset concept.

A schematic of the longitudinal profile and other properties of the example watershed is shown in Figure 1. For this example, suppose a hydraulic design is needed to convey runoff from a watershed with a drainage area of 0.5 square miles. On the basis of field examination and topographic maps, the length of the main channel from the watershed outlet (the design point) to the watershed divide is 5,280 feet. Elevation of the watershed at the outlet is about 3,400 ft. From a topographic map, elevation along the main channel at the watershed divide is estimated to be 3,401.1 feet. The analyst assumes that overland flow will have an appreciable contribution to the time of concentration for the watershed. The analyst estimates that the length of overland flow is about 500 ft. The area representing overland flow is average grass ($N = 0.40$). The slope for the overland-flow component is 0.03 percent ($S_0 = 0.0003$).

Time of overland flow

For the overland-flow T_c, the analyst applies the Kerby equation

$$T_c = 0.828(500 \times 0.40)^{0.467}(0.0003)^{-0.235}, \tag{4}$$

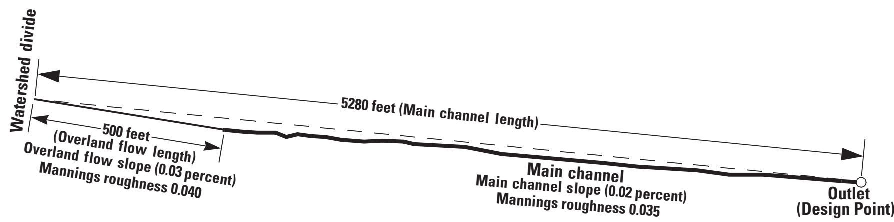

Figure 1: Schematic of longitudinal profile of main channel for example computations

from which T_c is about 73 minutes. In the analyst's professional opinion, this result might be greater than anticipated. The overland flow slope is not very large, particularly when compared with a value typical of many applications (about 0.01). Therefore, the analyst believes a low slope setting is possible and decides to reevaluate the overland flow T_c given a low slope assumption.

For the overland-flow T_c, the analyst applies the modified Kerby equation with a base slope suggested by the authors that represents a transition from gravitationally dominated flow to differential depth driven flow. Using the base slope of $S_{LB} = 0.0005$, the modified Kerby equation is

$$T_c = 0.828(500 \times 0.40)^{0.467}(0.0005 + 0.0003)^{-0.235}, \tag{5}$$

from which T_c is about 53 minutes, which is about 20 minutes less than the previous computation.

Time of main channel flow

For the channel T_c, the analyst applies the Kirpich equation, but first dimensionless main-channel slope is required

$$S_0 = \frac{3401.1 - 3400}{5280} = 0.00021 \tag{6}$$

or about 0.021 percent. For this application, the overland flow length is subtracted from the main channel length[2], such that $L = 5280 - 500 = 4780$ ft. The value for slope and the channel length are used in the Kirpich equation

$$T_c = 0.0078(5280 - 500)^{0.770}(0.00021)^{-0.385}, \tag{7}$$

[2]Depending on the particular watershed, it is not always the case that the characteristic overland flow length for estimating the overland flow T_c is colinear with the main channel. In some cases, the characteristic overland flow component is not aligned with the main channel. One of the authors (Thompson) chooses several candidate locations on a watershed to estimate the characteristic (representative) overland flow T_c, estimates T_c for those locations, and then chooses a reasonable value.

from which T_c is about 138 minutes. Similar to the result from the overland flow analysis, the analyst believes a low slope condition has been encountered and decides to reevaluate the main channel T_c under that assumption.

For the channel T_c, the analyst applies the modified Kirpich equation with a base slope suggested by the authors that represents a transition from gravitationally dominated flow to differential depth driven flow. Using the base slope of $S_{LB} = 0.0005$, the modified Kirpich equation is

$$T_c = 0.0078(5280 - 500)^{0.770}(0.0005 + 0.00021)^{-0.385}, \tag{8}$$

from which T_c is about 87 minutes, which is 51 minutes shorter than the previous computation.

Consideration of the watershed time values

The values for watershed T_c are:

- Adding the overland flow and channel flow components of T_c from the Kerby-Kirpich approach gives a watershed T_c of about 211 minutes $(73 + 138)$.
- Adding the overland flow and channel flow components of T_c from the modified Kerby-Kirpich approach gives a watershed T_c of about 140 minutes $(53 + 87)$.

For design purposes, the $T_c = 140$ minutes is preferred. The $T_c = 211$ minutes is too long.

Finally, as a quick check, the analyst can evaluate the T_c by using an ad hoc method representing T_c, in hours, as the square root of drainage area, in square miles. For the example, the square root of the drainage area yields a T_c estimate of about 0.71 hour or about 42 minutes, which is expected to be considerably less than the previous two estimates of watershed T_c because the estimate is based on community engineering experience in Texas with normal (not low slope) watersheds.

References

Kerby, W.S., 1959, Time of concentration for overland flow: Civil Engineering, v. 29, no. 3, 174 p.

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