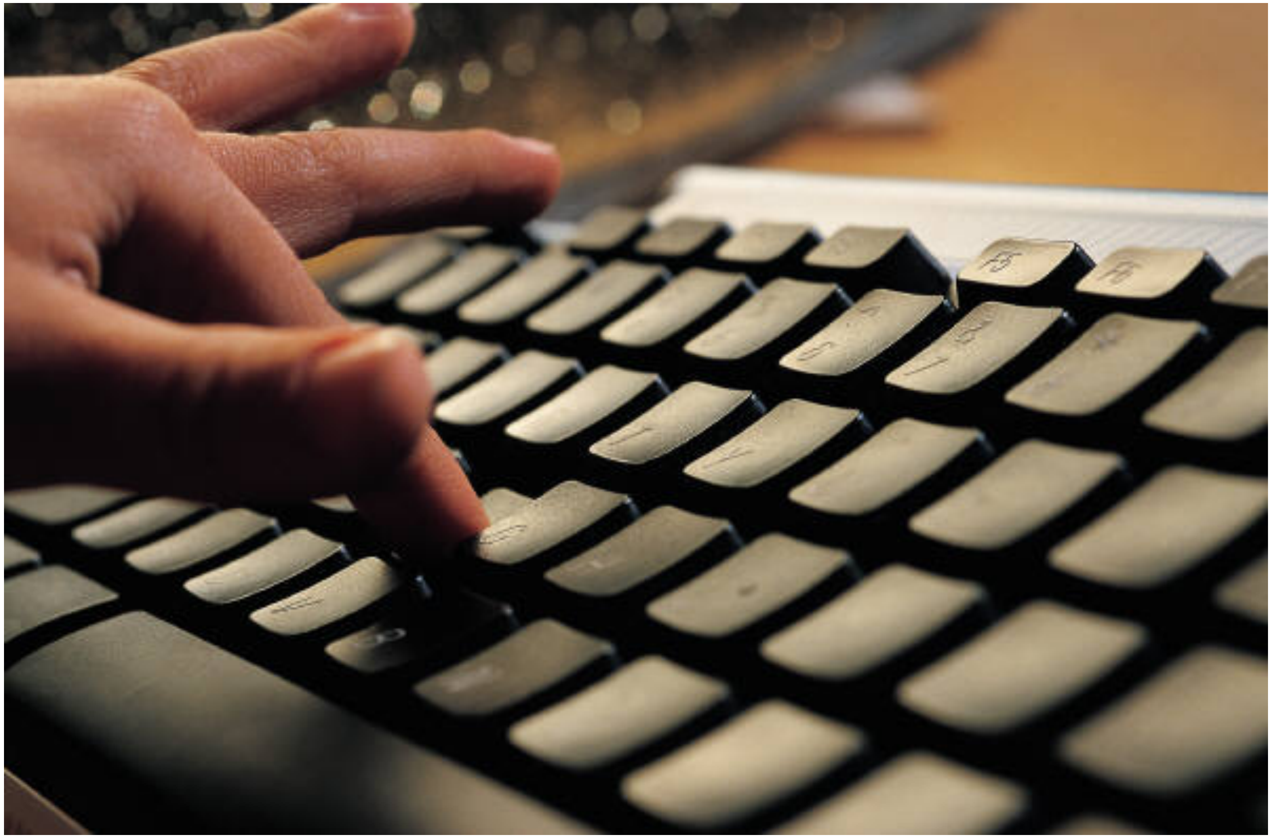
CE 3354 ENGINEERING HYDROLOGY

LECTURE 9: RATIONAL EQUATION METHOD; INTRODUCTION TO HEC-HMS



OUTLINE

- Rational Equation Method
- Introduction to HEC-HMS

RATIONAL EQUATION METHOD

- The rational method is a tool for estimating peak discharge from relatively small drainage areas. (Mulvaney, 1850; Kuichling, 1889)
  - CMM pp. 496-502

$$Q_p = CiA = C\frac{P}{T_c}A$$

ASSUMPTIONS

- Rainfall is distributed uniformly over the drainage area.
- Rainfall intensity is uniform throughout the duration of the storm.
- Response time for the drainage area is less than the duration of peak rainfall intensity.

ASSUMPTIONS

- The rational method does not account for storage in the drainage area. Available storage is assumed to be filled.
- The calculated runoff is directly proportional to the rainfall intensity.
- The frequency of occurrence for the peak discharge is the same as the frequency of the rainfall producing that event.

TYPICAL LIMITATIONS

- Drainage areas less than 200 acres (some jurisdictions allow up to 640 acres)
- Minimum duration is prescribed to prevent "infinite intensity" at short times – typically 10 minutes (some jurisdictions allow 5 minutes)
- No substantial storage (or all storage filled)

TYPICAL PROCEDURE

(1) Area Less than 200 acres?

(2) Estimate T_c

(3) Design Intensity for ARI

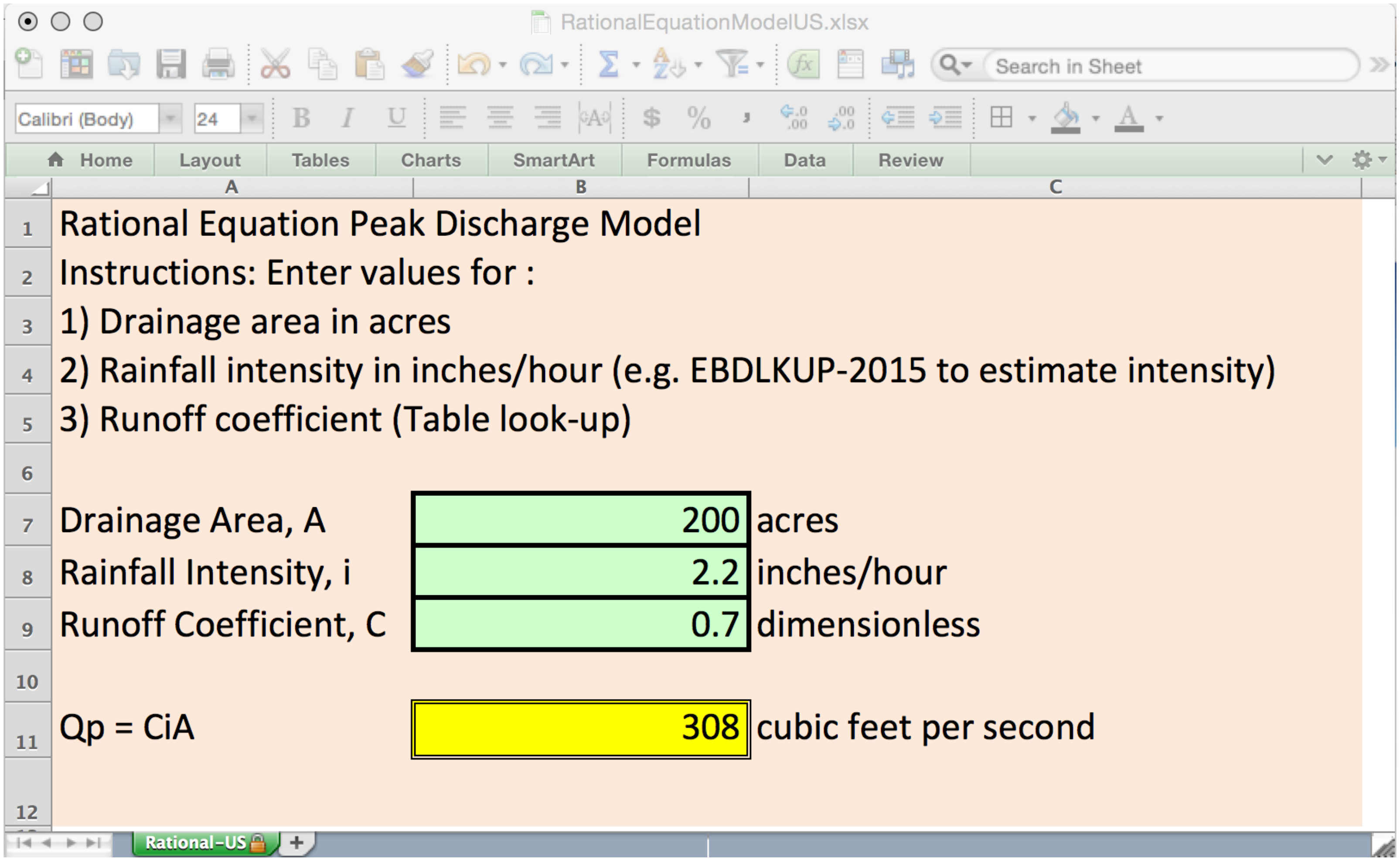
EBDLKUP-2015; NOAA-14

(4) Estimate C

(5) Compute Qp=CiA

(6) Validate/verify

CALCULATION SHEET



RUNOFF COEFFICIENTS

- CMM p. 498

TABLE 15.1.1
Runoff coefficients for use in the rational method

Character of surface	Return Period (years) 2	5	10	25	50	100	500
Developed							
Asphaltic	0.73	0.77	0.81	0.86	0.90	0.95	1.00
Concrete/roof	0.75	0.80	0.83	0.88	0.92	0.97	1.00
Grass areas (lawns, parks, etc.)							
Poor condition (grass cover less than 50% of the area)							
Flat, 0–2%	0.32	0.34	0.37	0.40	0.44	0.47	0.58
Average, 2–7%	0.37	0.40	0.43	0.46	0.49	0.53	0.61
Steep, over 7%	0.40	0.43	0.45	0.49	0.52	0.55	0.62
Fair condition (grass cover on 50% to 75% of the area)							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Good condition (grass cover larger than 75% of the area)							
Flat, 0–2%	0.21	0.23	0.25	0.29	0.32	0.36	0.49
Average, 2–7%	0.29	0.32	0.35	0.39	0.42	0.46	0.56
Steep, over 7%	0.34	0.37	0.40	0.44	0.47	0.51	0.58
Undeveloped							
Cultivated Land							
Flat, 0–2%	0.31	0.34	0.36	0.40	0.43	0.47	0.57
Average, 2–7%	0.35	0.38	0.41	0.44	0.48	0.51	0.60
Steep, over 7%	0.39	0.42	0.44	0.48	0.51	0.54	0.61
Pasture/Range							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Forest/Woodlands							
Flat, 0–2%	0.22	0.25	0.28	0.31	0.35	0.39	0.48
Average, 2–7%	0.31	0.34	0.36	0.40	0.43	0.47	0.56
Steep, over 7%	0.35	0.39	0.41	0.45	0.48	0.52	0.58

Note: The values in the table are the standards used by the City of Austin, Texas. Used with permission.

RUNOFF COEFFICIENTS

- Texas Hydraulic Design Manual

Table 4-10: Runoff Coefficients for Urban Watersheds

Type of drainage area	Runoff coefficient
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.30-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.35-0.40
Apartment dwelling areas	0.30-0.70
Industrial:	
Light areas	0.30-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.30-0.40
Railroad yards	0.30-0.40

RUNOFF COEFFICIENTS

- Oregon Hydraulics Manual – Values similar in most sources

Table 1 Runoff Coefficients for the Rational Method

	FLAT	ROLLING	HILLY
Pavement & Roofs	**0.90**	**0.90**	**0.90**
Earth Shoulders	0.50	0.50	0.50
Drives & Walks	0.75	0.80	**0.85**
Gravel Pavement	**0.85**	**0.85**	**0.85**
City Business Areas	0.80	**0.85**	**0.85**
Apartment Dwelling Areas	0.50	0.60	0.70
Light Residential: 1 to 3 units/acre	0.35	0.40	0.45
Normal Residential: 3 to 6 units/acre	0.50	0.55	0.60
Dense Residential: 6 to 15 units/acre	0.70	0.75	0.80
Lawns	0.17	0.22	0.35
Grass Shoulders	0.25	0.25	0.25
Side Slopes, Earth	0.60	0.60	0.60
Side Slopes, Turf	0.30	0.30	0.30
Median Areas, Turf	0.25	0.30	0.30
Cultivated Land, Clay & Loam	0.50	0.55	0.60
Cultivated Land, Sand & Gravel	0.25	0.30	0.35
Industrial Areas, Light	0.50	0.70	0.80
Industrial Areas, Heavy	0.60	0.80	**0.90**
Parks & Cemeteries	0.10	0.15	0.25
Playgrounds	0.20	0.25	0.30
Woodland & Forests	0.10	0.15	0.20
Meadows & Pasture Land	0.25	0.30	0.35
Unimproved Areas	0.10	0.20	0.30

Note:

- ***Impervious surfaces in bold***
- *Rolling = ground slope between 2 percent to 10 percent*
- *Hilly = ground slope greater than 10 percent*

TIME OF CONCENTRATION

- The value of T_c is important in rational method for estimating rainfall intensity.
- It is also used in other hydrologic models to quantify the watershed response time

TIME OF CONCENTRATION

- Time of concentration (T_c) is the time required for an entire watershed to contribute to runoff at the point of interest for hydraulic design
- T_c is calculated as the time for runoff to flow from the most hydraulically remote point of the drainage area to the point under investigation.

TIME OF CONCENTRATION

- Travel time and T_c are functions of length and velocity for a particular watercourse.
  - A long but steep flow path with a high velocity may actually have a shorter travel time than a short but relatively flat flow path.
  - There may be multiple paths to consider in determining the longest travel time.
  - The designer must identify the flow path along which the longest travel time is likely to occur.

TIME OF CONCENTRATION

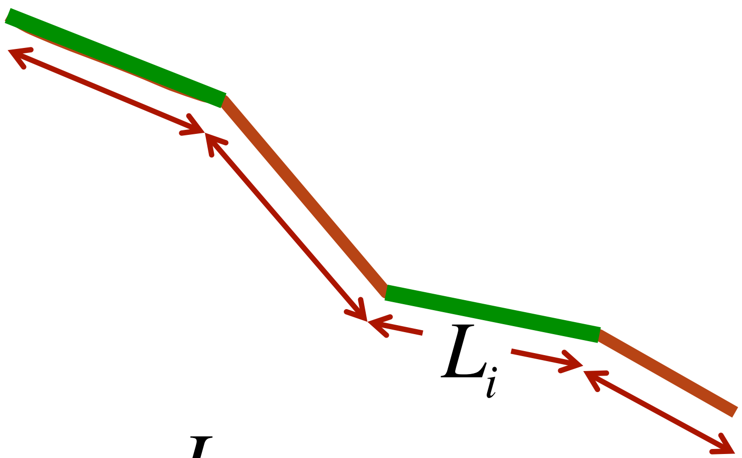
- Various Methods to Estimate Tc
- On the server in readings:
  - CMM pp. 500-501 has several formulas
  - HDS-2 pp. 2-21 to 2-31 has formulas and examples
  - LS pp. 196-198 has several formulas

TIME OF CONCENTRATION

- Examine 3 Methods to Estimate Tc
  - NRCS Upland
  - Kerby-Kirpich
  - NRCS Velocity Method
- Similar in scope; depend on distances, slope, and land surface conditions.

NRCS UPLAND METHOD

- Specify flow path
- Determine cover on flow path
- Determine slope(s) along path
  - Partition into different cover types and slopes along path



- Apply velocity model on each part

$$t_i = \frac{L_i}{V_i}$$

- Sum parts for entire path

$$t = \sum_{i=1}^{N} t_i = \sum_{i=1}^{N} \frac{L_i}{V_i}$$

UPLAND METHOD VELOCITY CHART

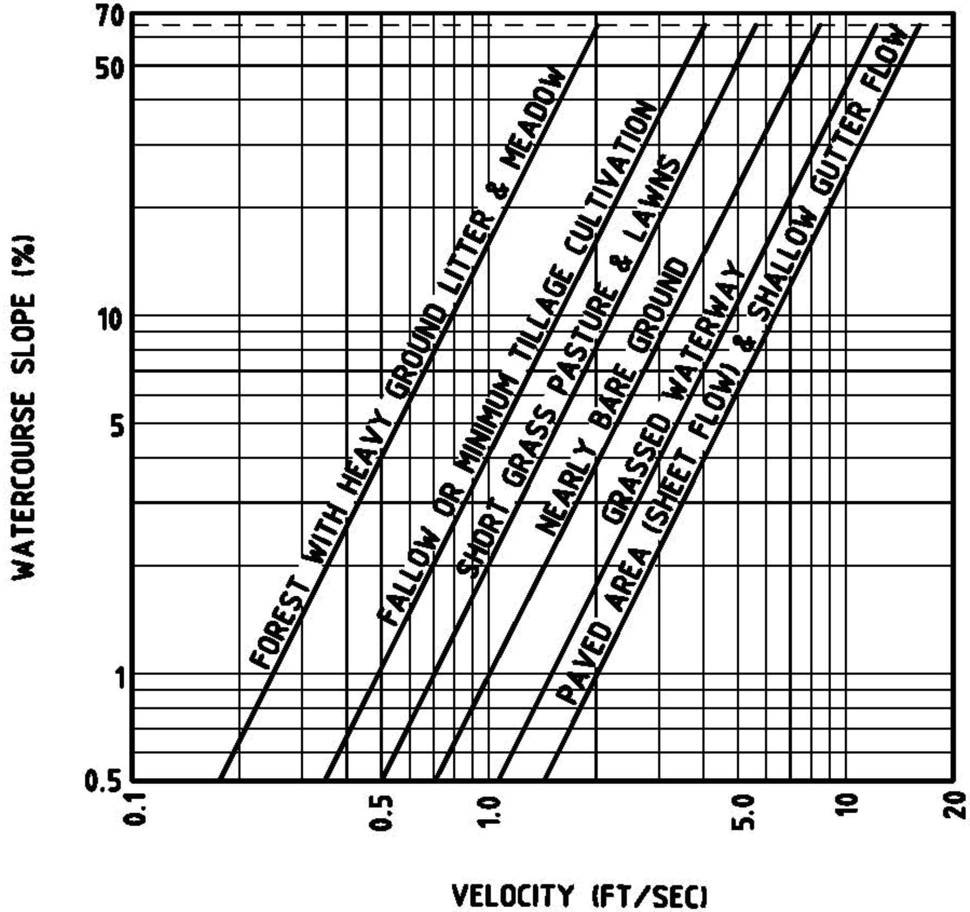


Figure 5-4. Velocities for Upland Method of Estimating Time of Concentration--English (Adapted from the National Engineering Handbook Volume 4)

KERBY-KIRPICH METHOD

- Appropriate for many conditions

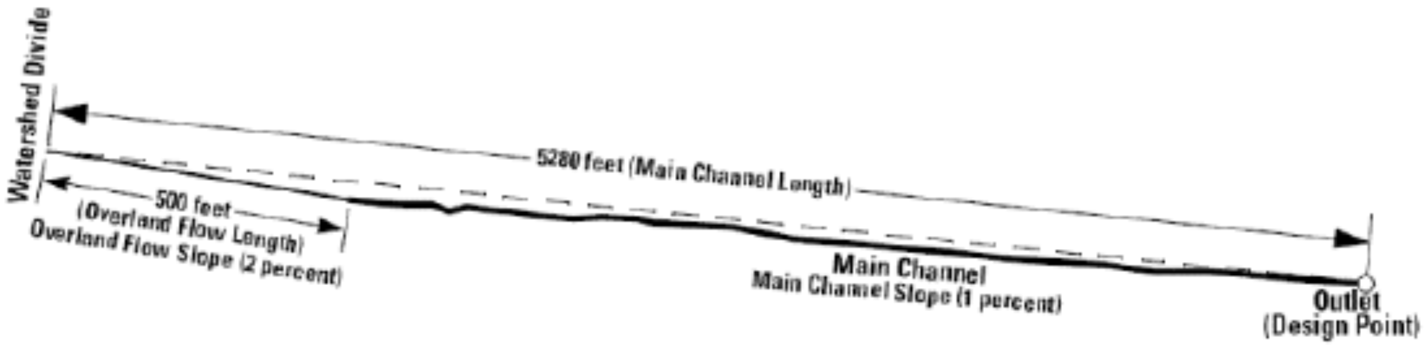


Figure 4-7. Example application of Kerby-Kirpich method

- Compute up to two times:
  overland flow time and channel flow time

KERBY-KIRPICH METHOD

- Overland flow time $T_{ov} = K(L_{ov} \times N)^{0.467}(S)^{(-0.235)}$
- Channel flow time $T_{ch} = K(L_{ch})^{0.770}(S)^{(-0.385)}$
- Combine the two to estimate time of concentration (if there is no channel component, then omit)
  - Overland length < 1200 feet

KERBY-KIRPICH METHOD

Kerby Retardance Coefficient	
Generalized Terrain Condition	Dimensionless Retardance Coefficient (N)
Pavement	.02
Smooth, bare, packed soil	.10
Poor grass, cultivated row crops, or moderately rough packed surfaces	.20
Pasture, average grass	.40
Deciduous forest	.60
Dense grass, coniferous forest, or deciduous forest with deep litter	.80

NRCS METHOD FOR ESTIMATING TC

- Comprised of up to three components
- The sheet and shallow concentrated are of importance in urban systems.

$$t_c = t_{sheet} + t_{shallow-concentrated} + t_{channel}$$

NRCS METHOD FOR ESTIMATING TC

Sheet Flow Time Calculation

Sheet flow travel time is computed as:

$$t_{sh} = \frac{0.007(n_{ol}L_{sh})^{0.8}}{(P_2)^{0.5}S_{sh}^{0.4}}$$

DDF Atlas; NOAA 14

Equation 4-17.

Where:

t_{sh} = sheet flow travel time (hr.)

n_{ol} = overland flow roughness coefficient (provided in Table 4-6)

L_{sh} = sheet flow length (ft) (300 ft. maximum)

P_2 = 2-year, 24-h rainfall depth (in.) (provided in the TxDOT 5-1301-01-1)

S_{sh} = sheet flow slope (ft/ft)

NRCS METHOD FOR ESTIMATING TC

Table 4-6: Overland Flow Roughness Coefficients for Use in NRCS Method in Calculating Sheet Flow Travel Time (Not Manning's Roughness Coefficient) (NRCS 1986)

Surface description		n_{ol}
Smooth surfaces (concrete, asphalt, gravel, or bare soil)		0.011
Fallow (no residue)		0.05
Cultivated soils:	Residue $cover \leq 20$ %	0.06
	Residue cover > 20%	0.17
Grass:	Short grass prairie	0.15
	Dense grasses	0.24
	Bermuda	0.41
Range (natural):		0.13
Woods:	Light underbrush	0.40
	Dense underbrush	0.80

NRCS METHOD FOR ESTIMATING TC

Shallow Concentrated Flow

Shallow concentrated flow travel time is computed as:

$$t_{sc} = \frac{L_{sc}}{3600KS_{sc}^{0.5}}$$

Equation 4-18.

Where:

t_{sc} = shallow concentrated flow time (hr.)

L_{sc} = shallow concentrated flow length (ft)

K = 16.13 for unpaved surface, 20.32 for paved surface

S_{sc} = shallow concentrated flow slope (ft/ft)

NRCS METHOD FOR ESTIMATING TC

Channel Flow

Channel flow travel time is computed by dividing the channel distance by the flow rate obtained from Manning's equation. This can be written as:

$$t_{ch} = L_{ch} \Big/ \left((3600 \frac{1.49}{n} R^{\frac{2}{3}} S_{ch}{}^{\frac{1}{2}}) \right)$$

Equation 4-19.

Where:

t_{ch} = channel flow time (hr.)

L_{ch} = channel flow length (ft)

S_{ch} = channel flow slope (ft/ft)

n = Manning's roughness coefficient

R = channel hydraulic radius (ft), and is equal to $\frac{a}{p_w}$, where: a = cross sectional area (ft^2)

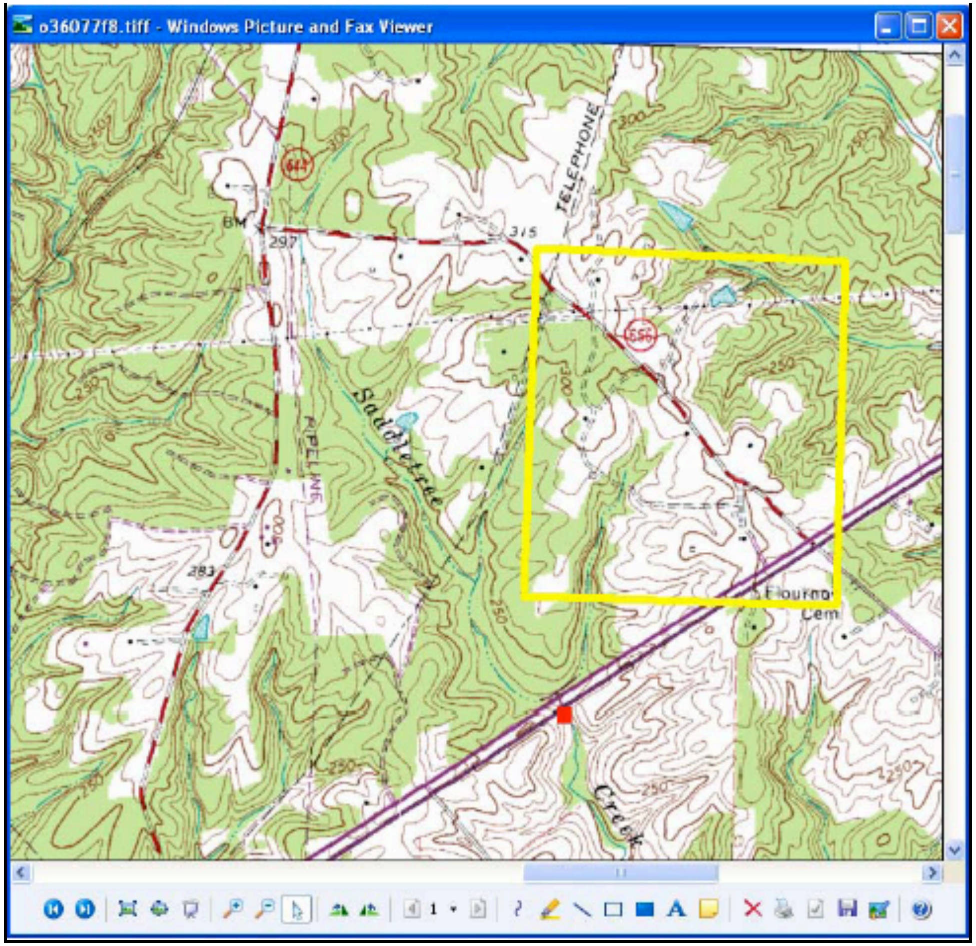
and p_w = wetted perimeter (ft), consider the uniform flow velocity based on bank-full flow conditions. That is, the main channel is flowing full without flow in the overbanks. This assumption avoids the significant iteration associated with other methods that employ rainfall intensity or discharges (because rainfall intensity and discharge are dependent on time of concentration).

EXAMPLE

- Figure to right is a Google-Earth image of a 550 acre watershed in Virginia
- The area is agricultural, Virginia SH 58 runs along the south part of the watershed. The other visible roads are county roads or private (farm) roads.

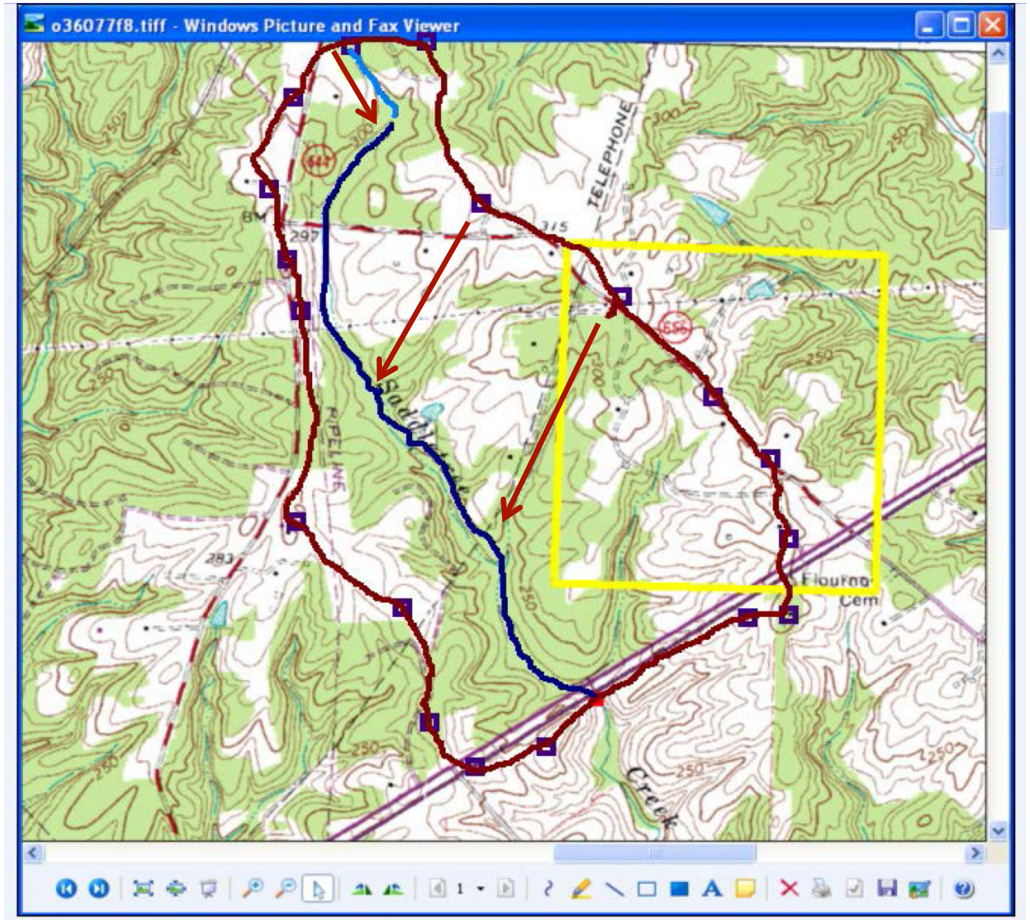
EXAMPLE

- Figure to right is a topographic map of the same area, but without the watershed boundary depicted.
- The outlet is the red square on the map. The yellow square is a reference area of 1000 X 1000 meters.



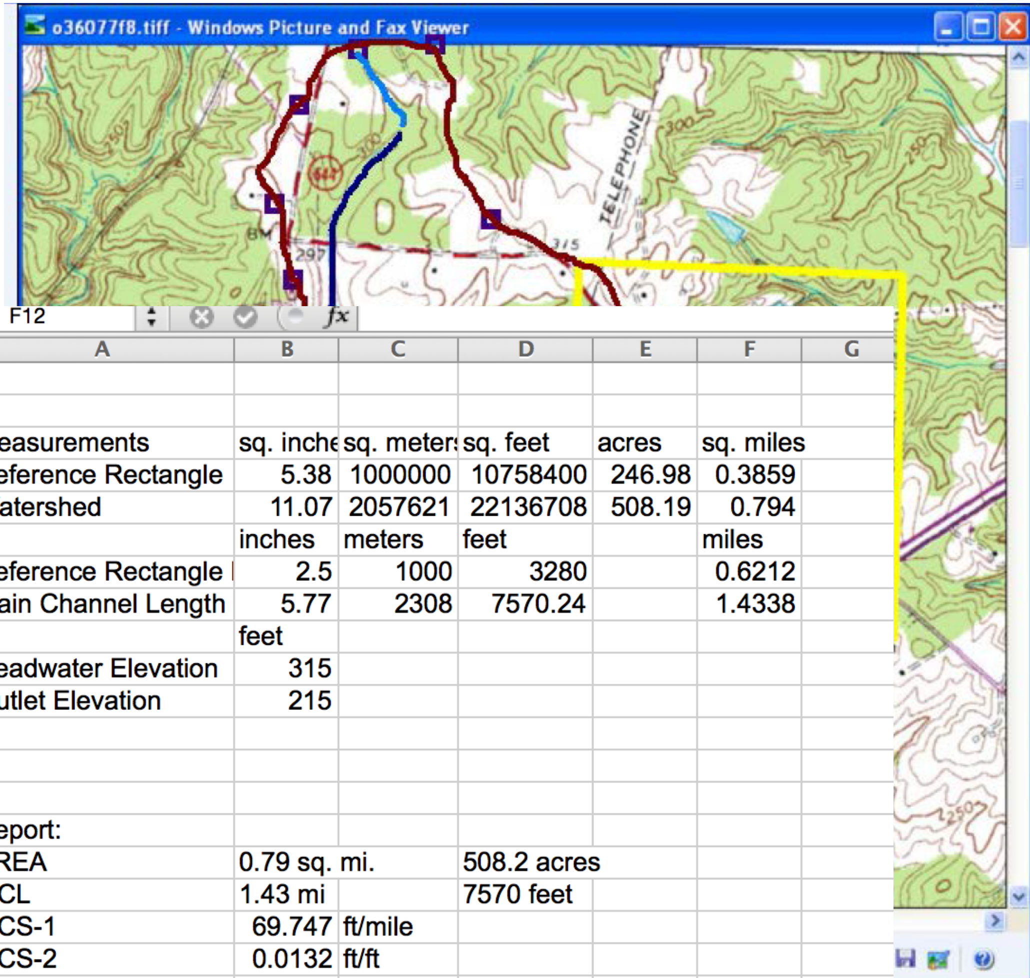
EXAMPLE

- Watershed delineated
- Main channel delineated
- Overland paths indicated



EXAMPLE

- AcrobatPro measure reference area and watershed area
- AcrobatPro measure main channel length
- AcrobatPro measure overland length



F12

	A	B	C	D	E	F	G
1							
2							
3	Measurements	sq. inche	sq. meter	sq. feet	acres	sq. miles	
4	Reference Rectangle	5.38	1000000	10758400	246.98	0.3859	
5	Watershed	11.07	2057621	22136708	508.19	0.794	
6		inches	meters	feet		miles	
7	Reference Rectangle	2.5	1000	3280		0.6212	
8	Main Channel Length	5.77	2308	7570.24		1.4338	
9		feet					
10	Headwater Elevation	315					
11	Outlet Elevation	215					
12							
13							
14							
15	Report:						
16	AREA	0.79 sq. mi.		508.2 acres			
17	MCL	1.43 mi		7570 feet			
18	MCS-1	69.747	ft/mile				
19	MCS-2	0.0132	ft/ft				

EXAMPLE

- Use Kerby-Kirpich to estimate Tc
- Report as
  Tc =67 minutes

F12

	A	B	C	D	E	F
1						
2						
3	Measurements	sq. inche	sq. meter	sq. feet	acres	sq. miles
4	Reference Rectangle	5.38	1000000	10758400	246.98	0.3859
5	Watershed	11.07	2057621	22136708	508.19	0.794
6		inches	meters	feet		miles
7	Reference Rectangle l	2.5	1000	3280		0.6212
8	Main Channel Length	5.77	2308	7570.24		1.4338
9		feet				
10	Headwater Elevation	315				
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13						
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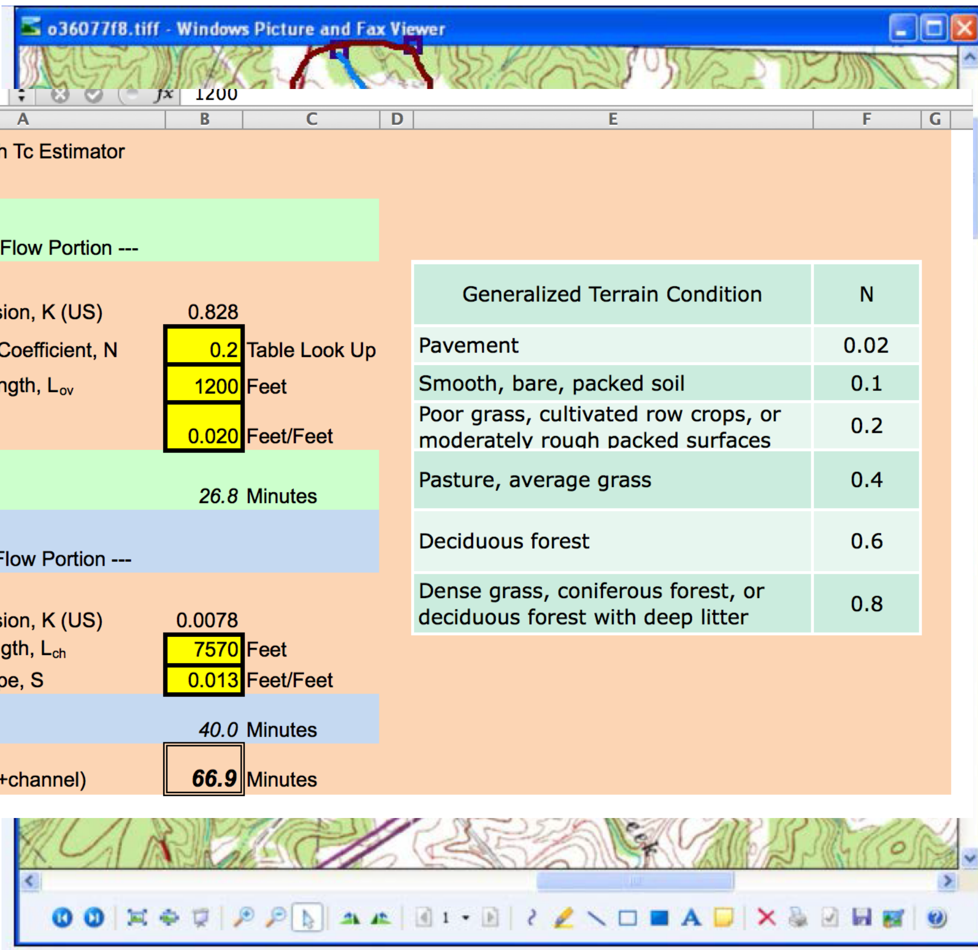

B6 1200

	A	B	C
1	Kerby-Kirpich Tc Estimator		
2			
3	--- Overland Flow Portion ---		
4	Unit Conversion, K (US)	0.828	
5	Retardance Coefficient, N	0.2	Table Look Up
6	Overland Length, L_{ov}	1200	Feet
7	Slope, S	0.020	Feet/Feet
8	Tc-overland	*26.8*	Minutes
9	--- Channel Flow Portion ---		
10	Unit Conversion, K (US)	0.0078	
11	Channel Length, L_{ch}	7570	Feet
12	Channel Slope, S	0.013	Feet/Feet
13	Tc-channel	*40.0*	Minutes
14	Tc (overland+channel)	***66.9***	Minutes

Generalized Terrain Condition	N
Pavement	0.02
Smooth, bare, packed soil	0.1
Poor grass, cultivated row crops, or moderately rough packed surfaces	0.2
Pasture, average grass	0.4
Deciduous forest	0.6
Dense grass, coniferous forest, or deciduous forest with deep litter	0.8

INTRODUCTION TO HEC-HMS

- History
  - Evolved from HEC-1 as part of "new-generation" software circa 1990
  - Integrated user interface to speed up data input and enhance output interpretation
- HMS is a complex and sophisticated tool
  - Intended to be used by a knowledgeable and skilled operator
  - Knowledge and skill increase with use

HEC-HMS

- Data management
  - Graphical User Interface (GUI)
  - Multiple input files
  - Multiple output files
  - Time-series in HEC-DSS
- All files arranged in a "Project"
  - Paths to individual files
  - Can e-mail entire project folders and have them run elsewhere

HEC-HMS

- Conceptualizes precipitation, watershed interaction, and runoff into major elements
  - Meterological model
    - Raingage specifications and assignment to different sub-basins
  - Time-series models
    - Supply input hyetographs
    - Supply observed hydrographs
  - Simulation control
    - Supply instructions of what, when, how to simulate

HEC-HMS

- Conceptualization:
  - Basin and sub-basin description
    - Supply how the system components are interconnected
  - Loss model
    - Supply how rainfall is converted into excess rainfall
  - Transformation model
    - Supply how the excess rainfall is redistributed in time and moved to the outlet

APPLICATIONS

- HEC-HMS is a Hydrologic Model
- Peak Flows
- Hydrographs
  - Hydrograph Routing
    - Stream reaches
    - Reservoirs and detention basins
    - Hydrograph lagging and attenuation
    - Sub-basin modeling (if appropriate)

HEC-HMS

- Precipitation
- Abstractions
  - Fraction of precipitation that does not contribute to runoff (and ultimately discharge)
- Routing
  - Watershed routing
  - Stream (Channel) routing
  - Reservoir (Storage) routing

HEC-HMS EXAMPLE

- Minimal model
  - SCS Type Storm
  - 640 acre watershed – no process models; completely converts rainfall into runoff
  - Illustrate how to mimic rational method by adjusting drainage area
  - Repeat with a 24-hour Texas Hyetograph same location

NEXT TIME

- Loss Processes
  - Evapotranspiration
  - Infiltration
- SCS Curve Number