CHAPTER 202

Hydrology

Design Memorandum	Revision Date	Sections Affected
14-02	Feb. 2014	202-3.03, Figure 202-3B, Figure 202-3C

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CHAPTER 202

HYDROLOGY

202-1.0 INTRODUCTION

Highway drainage structures must be sized to convey a specific flow rate, Q, which satisfies some established standard. Determining structure size and type is generally one of the earliest activities undertaken in the design process. Various hydrologic methods can be used to estimate Q. Multiple methods of obtaining estimates can sometimes be used, and the engineer determines the best Q to use at that site. A specific method of determining Q can sometimes be prescribed.

202-1.01 Hydrology Definition

Hydrology is a broad science encompassing many disciplines relating to water. In highway engineering, hydrologic studies are primarily concerned with surface-water runoff and determining design Q. A hydrologic analysis is a prerequisite to identifying flood-hazard areas and determining the locations at which construction and maintenance will be unusually expensive or hazardous.

202-1.02 Exceedance Probability

Exceedance probability is a statistical term that states the probability of a specific value or event being equaled or exceeded. Established rainfall events for design purposes are described, such as 100-year storm, Q_{100}, 1% storm, return period, exceedance probability, etc. The INDOT preferred method of stating a standard rainfall event is as exceedance probability, EP. An established standard can be set as INDOT policy or it may be set by an outside authority such as a city, county surveyor for a legal drain, IDNR, State law, or other jurisdictional agency. Therefore, although the standard may not be originally stated in INDOT's preferred terms, it should be restated as EP.

202-1.03 Q Definition

Q is the common denotation of the total flow rate. It is dimensioned in cubic feet per second for INDOT design. Depending on the project, there can be different Qs of interest. For example, for sizing a bridge based on backwater criteria, the design Q is that for a 1% EP. However, for scour analysis on a new bridge, the 1% EP and the 0.2% EP both should be evaluated. A storm drain, channel, ditch, local driveway, etc. each have a specific EP defined for design purposes.

202-1.04 Estimating Flow Rate

The importance of accurate estimates of *Q* cannot be overstated. An error committed in this part of the design can directly lead to an incorrectly-sized drainage structure. An oversized drainage structure implies that money can be wasted. An undersized structure increases the risk of potential flooding and maintenance issues. Existing-structure size should be considered in designing a replacement structure. Long term legal, financial, or operational impacts can be expected if undersized structures are consistently installed.

Most highway-drainage structures are constructed using taxpayer-supported funding. As such, an INDOT project should present the correct stewardship. The designer should utilize sound hydrologic methodology in the development of the design.

202-2.0 HYDROLOGIC-ANALYSIS PROCEDURES

The following is a discussion of policies and procedures which apply to hydrologic analysis. For more information, see the *AASHTO Highway Drainage Guidelines.*

202-2.01 Data Gathering and Preliminary Studies

The data to be gathered for a hydrologic study includes, but is not limited to, topographic maps, soil maps, aerial photographs, stream-flow records, historical high-water elevations, flood discharges, rainfall curves, or locations of hydraulic features such as reservoirs, water projects, or designated or regulatory floodplains, and contemporaneous interviews with affected property owners.

202-2.02 Hydrologic Factors

Hydrologic factors are site specific and should be evaluated by an engineer proficient in the practice of hydraulic and hydrologic engineering to understand their effect on the runoff from a watershed. Many factors may be subject to alteration over time and whether that potential needs to be addressed should also be evaluated. Some of these factors include the following.

1. Drainage-Basin Characteristics. These include size, shape, slope, land use, geology, soil type, surface infiltration and storage, and the maturity of the watershed's drainage system.

2. Stream-Channel Characteristics. These include geometry and configuration, natural and artificial controls, channel modifications, aggradations or degradations, ice, debris, and routine maintenance.

3. Floodplain Characteristics. A floodplain is defined as a strip of relatively smooth land bordering a stream and is flooded at a time of high water. Due to its continually changing nature, a floodplain or other flood-prone area should to be examined relative to how it can affect or be affected by development. Flooding is a natural and recurring event for a river or stream.

4. Meteorological Characteristics. These include observable weather events which are explained through the science of meteorology. Those events are bound by the variables that exist in the atmosphere: They include temperature, air pressure, water vapor, and the gradients and interactions of each variable, and how they change in time. INDOT's concerns are for intensity and duration of specific storm events. The site-specific data used for an INDOT hydrologic study appears in NOAA Atlas 14.

202-2.03 Determining Drainage Area

With the exception of a very large watershed, a drainage-area boundary should be delineated on a topographic map. The most readily-available topographic maps are USGS Quadrangle maps. Many counties have had more-detailed topographic surveying done that is mapped to 1- or 2-ft contours. The availability of topographic-survey mapping can be determined from the Indiana Geographic Information Council website or by contacting the county surveyor.

Initial area determination can be obtained using computer-based automatic delineation programs. Web-based and easily-accessed programs include USGS STREAMSTATS and HYMAPS-OWL. STREAMSTATS can be accessed at the USGS website. HYMAPS-OWL can be accessed at the Purdue Agricultural and Biological Engineering (ABE) website. The results of these programs should be examined to ensure accuracy, particularly where a railroad track or highway crosses the drainage path, as areas can erroneously be included or excluded which can alter runoff estimates significantly. Aerial photography can be helpful, but field inspection can be required to ensure accuracy. In an area with land improvements, the watershed boundaries can be altered and inconsistent with the determinations made on a topographic map. Adjustments should be made accordingly. Field inspections or consultation with city or county officials may be necessary to determine how the drainage pattern has been modified.

For a very large area it can be impractical to delineate the boundaries. Alternative methods may be used. One publication is *Drainage Areas of Indiana Streams*, which appears on the IDNR Division of Water website. It provides watershed determinations at various points on Indiana streams.

If there are bridges or other developments in the vicinity, other State or local agencies should be contacted as drainage studies may have already been performed that have area determinations that can be of use.

202-2.04 Determination of Soil, Vegetation, and Land-Use Factors

Soil types can be determined from mapping obtained on the NRCS website. These usually should be reclassified as Type A, B, C, or D for determination of the *C* factor for use in the Rational Formula (see Figure 202-2E), or determination of the CN factor for use in hydrographs (see Figure 202-2F). Vegetation and land-use can be determined through field inspection for a small area, and by using aerial photography which is available at various websites. The Purdue HYMAPS-OWL watershed delineation tool also generates a summary of soil types A, B, C, or D, and land use by acres for the watershed. If the watershed delineation has been verified as accurate, this data can then be used to calculate the *C* or CN for the watershed. If a detailed hydrograph is being modeled with numerous sub-areas, the soil, vegetation, and land-use characteristics should be properly determined for each sub-area instead of using an overall average for the total watershed.

202-2.05 Determination of Time of Concentration

The time of concentration, t_c, is the time required for water to flow from the hydraulically most-remote point of the drainage area to the point of concern. Time of concentration is an important variable in many hydrologic methods, including the Rational and Natural Resources Conservation Service, formerly SCS, procedures. For a similar size and type of watershed, the shorter the t_c, the larger the peak discharge.

Water moves through a watershed as a combination of sheet, shallow concentrated, and channelized flow. The type that occurs is a function of the conveyance system and is best determined through field inspection, but can be evaluated using topographic and aerial photographic mapping. TR-55 should be used as the method for determining time of concentration. See Figure 202-2A for the standard TR-55 Worksheet. The TR-55 method of determining time of concentration is applicable for both the Rational Equation and the NRCS, formerly SCS, Peak Flow, or other hydrograph method. In the Rational Equation, t_c is expressed in minutes. In the NRCS procedures, t_c is expressed in hours. If another method is to be used for determining time of concentration, approval from the Office of Hydraulics manager is required.

202-2.05(01) Sheet-Flow Method

In designing a drainage system, the sheet-flow path is not necessarily perpendicular to the contours shown on available mapping. The land will often be graded, and swales will intercept the natural contour and conduct the water to the streets which reduces the time of concentration. Aerial photography is useful in determining obvious variations in the general flow path. Sheet flow should be limited to a maximum length of 100 ft per current TR-55 methodology. However, a smaller length should be used if flow begins to channelize sooner. The equation used for sheet flow is known as the Manning's Kinematic Solution, as follows:

$$t_O = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} S^{0.4}}$$ [Equation 202-2.1]

Where:
- t_O = overland flow time, h
- n = Manning's roughness coefficient for sheet flow
- L = flow length, ft
- P_2 = 2-year, 24-h rainfall, in., from NOAA Atlas 14
- S = slope of hydraulic grade line, or watercourse slope, ft/ft

Sheet flow has its own set of Manning's roughness values which appear in Figure 202-2B. These values will typically be rougher than channel-flow roughness values for the same type of surface because the water flow is very shallow.

202-2.05(02) Shallow-Concentrated-Flow Method

Shallow concentrated flow occurs once sheet flow first begins to channelize. The Upland Method, NRCS 1972, can be used to determine velocity of shallow concentrated flow to estimate time of concentration of that portion. This method relates watershed slope and surface to flow velocity. TR-55 includes the relations for an unpaved area and paved area to determine the travel time for shallow concentrated flow as follows:

Unpaved $V = 16.393\ S^{0.5}$ [Equation 202-2.2]

Paved $V = 20.683\ S^{0.5}$ [Equation 202-2.3]

Where: V = average velocity, ft/s
S = slope of hydraulic gradient, or watercourse slope, ft/ft

This relationship is shown on the logarithmic chart for easier use (see Figure 202-2D). The length of the shallow concentrated flow can then be divided by the velocity to determine the amount of shallow-concentrated-flow time.

202-2.05(03) Open-Channel-Flow Method

An open channel is assumed to begin where the surveyed cross-section information has been obtained, where the channel is visible on an aerial photograph, or where a blue line indicating a stream appears on a United States Geological Survey (USGS) quadrangle sheet. Manning's equation, as follows, can be used to estimate average flow velocity. The velocity is determined for the bank-full elevation.

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \qquad \text{[Equation 202-2.4]}$$

The total time of concentration is the summation of sheet flow, shallow concentrated flow, and open-channel flow.

202-2.05(04) Lag Time

If HEC-HMS is used, lag time should be considered in the total time of concentration. Lag time will be considered as 0.6 times the total time of concentration.

202-2.05(05) Storage and Flood-Control Facility

Storage will not be considered in the total time of concentration unless the pond or reservoir is a government-regulated facility.

202-2.05(06) Storm-Drain-Flow Method

For a storm-drainage system, the time of concentration for an area consists of an inlet time plus the time of flow in a closed conduit or open channel to the design point.

1. Inlet Time. Inlet time is the sum of the time required for water to move across the pavement or overland back of the curb to the gutter using TR-55 methodology, plus the time required for flow to move through the length of gutter to the inlet. If the total time of concentration for pavement-drainage inlets is less than 5 min, a minimum of 5 min should be used to estimate the duration of rainfall. The travel time for gutter flow can be estimated using an average velocity of the flow. The following equation can be used to determine the velocity in a triangular gutter section given the watercourse slope, gutter cross slope, and water spread.

$$V = \frac{1.12}{n} S^{0.5} S_x^{0.67} T^{0.67}$$ [Equation 202-2.5]

Where:
- V = flow velocity in gutter, ft/s
- n = Manning's roughness coefficient for sheet flow from Figure 202-2B
- S = longitudinal slope, ft/ft
- S_x = gutter cross slope, ft/ft
- T = water spread, ft

For a triangular channel with uniform inflow per length and zero flow at the upstream end, the average velocity will occur where the spread is 65% of the maximum. Each inlet should have its own independent time of concentration. Travel time between inlets is not considered.

2. Storm-Drain Time. For ordinary conditions, a storm drain should be sized assuming that it will flow full or almost full for the design discharge. For non-pressure flow, the velocity can be determined using Manning's equation. For a circular pipe flowing full, the equation becomes the following:

$$V = \frac{0.593}{n} D^{2/3} S^{1/2}$$ [Equation 202-2.6]

Where:
- V = average velocity, ft/s
- D = diameter of circular pipe, ft
- S = longitudinal slope, ft/ft

Pipe flow charts can be used to determine the velocity for either full or partially-full flow conditions. If storm-drainage-system pipes will operate under pressure flow, the continuity equation should be used to determine velocity as follows:

$$V = Q/A$$ [Equation 202-2.7]

Where: V = mean velocity of flow, ft/s
Q = discharge in pipe, ft^3/s
A = area of pipe, ft^2

The rational method should be used to determine discharge for a storm-drainage system. Other methods can be incorporated within the design process. However, approval from INDOT must be requested prior to submittal for initial review.

202-2.05(07) Stormwater-Storage-Flow Method

The TR-55 methodology should be used for determining time of concentration of watershed runoff to a storage facility. A unit hydrograph method, using a computer program such as TR-20 or HEC-HMS, should be used to determine pre-development and post-development discharges. Inflow and outflow hydrographs should be developed for existing and proposed conditions. Other computer programs may be used as long as the critical design parameters are identified and documented. See Section 202-4.03(03).

202-2.06 Determination of Precipitation Rate

The standard source for rainfall data to be used in the Rational Method or in the Unit Hydrograph Method is NOAA Atlas 14, Volume 2. It appears on http://www.nws.noaa.gov/oh/hdsc/. Navigate to the PF Data Server and select Indiana. The Rational Method rainfall term, *I*, is stated in in./h, so precipitation intensity should be selected in Data Description. Precipitation depth should be selected for input into the Unit Hydrograph method.

202-2.07 Determining Discharge

The determination of drainage area, runoff factors, time of concentration, and precipitation are used in determining discharge by either the Rational Method or a Unit Hydrograph Method. A computer program, such as TR-20 or HEC-HMS, should be used for the Unit Hydrograph Method. If using the Unit Hydrograph Method, the accepted rainfall distribution is the 50% probability Huff Distribution. The appropriate Quartile should be used based on the time period that is being applied. Sources of information regarding use of the Rational Method or Unit Hydrograph include Indiana LTAP, FHWA, AASHTO, etc. Section 202-3.0 lists other acceptable methods that can be used in determining discharge.

202-3.0 ACCEPTED METHODOLOGIES

202-3.01 Definition

Stream-flow measurements for determining a flood frequency relationship at a site are usually unavailable. Therefore, peak runoff rates and hydrographs can be estimated using statistical or empirical methods. The design discharge should be reviewed for other structures over the stream, historical data, and previous studies including flood-insurance studies. The discharge should be used that best reflects local project conditions with the reasons documented.

A consideration of peak-runoff rate for the design condition is adequate for a conveyance system such as a storm drain or open channel. However, if the design must include flood routing, e.g., storage basin, complex conveyance network, a flood hydrograph is required. Although the development of a runoff hydrograph, which is more complex than estimating peak-runoff rate, is accomplished using computer programs, some methods are adaptable to nomographs or other desktop procedures.

Where feasible, for a large structure, more than one method of computing discharge should be checked, comparing the results to what other structures in the area are designed to convey and the historical data for the area. Engineering judgment should then be used to select the discharge. It is seldom appropriate to only average estimates from the utilized methods. If practical, the method should be calibrated to local conditions and tested for accuracy and reliability. INDOT practice is to use the discharge that best reflects local project conditions with the reasons documented.

202-3.02 Selection of Discharge-Computation Method

The following provides additional guidance on the selection of hydrologic methods. These methods are used in determining the discharge for a culvert or bridge unless otherwise stated. If other methods are desired for use, contact the Office of Hydraulics for approval.

1. Rational Method. This method can be used for a developed area or a small drainage area. It can be used if the drainage area is less than 100 ac in an urban area or less than 200 ac in a rural area. The rational method must be used in the design of each roadway inlet and or storm drain.

2. NRCS (formerly SCS) Unit Hydrograph Method TR-20. This method can be most often used to determine peak discharge and hydrograph for a given drainage basin size. However, the results have less confidence in a very flat drainage basin with potential

watershed storage, or a very large drainage basin. This method is also used for design of a detention/retention pond or storage facility.

3. HEC-HMS. This hydrograph method can be used under the same conditions shown above for TR-20.

4. IDNR Letter of Discharge. The IDNR Letter of Discharge must be requested for a structure that requires a Construction in a Floodway Permit.

5. IDNR Coordinated Discharge Curves. This is the preferred method for a stream for which the information is available. The reference is *Coordinated Discharges of Selected Streams in Indiana*. It also appears on the IDNR-Water website.

6 Streamstats. This method can be used in conjunction with other methods. This method is valuable for setting parameters or justification as to what the appropriate discharge can be.

7. Frequency Analysis of Stream-Gaging Records. This method is considered to have high confidence on a larger watershed for which data is available, since it involves real-time data. The USGS, and the IDNR Division of Water, maintain a database of discharges for various frequencies computed using methodologies included in Water Resources Council Bulletin 17B.

8. Purdue Regression Equations. This method can be used in a rural area for estimating if no other method is available.

9. FEMA. The 1% exceedance probability specified in the applicable FEMA flood-insurance study should be used to analyze impacts of a proposed crossing on a regulatory floodway. However, if the discharge is considered outdated, the discharge based on current methods can be used subject to receiving the necessary regulatory approvals.

202-3.03 Q_{500} Determination for Scour Calculations [Added Feb. 2014]

The following methods, listed by preference, should be used to determine the Q_{500} for scour calculations.

1. Discharge published in a FEMA Flood Insurance Study (FIS). If there is a 0.2% annual EP discharge published by FEMA in a FIS, this discharge should take precedence over any other methodology.

2. Discharge derived from a coordinated discharge curve. The 0.2% annual EP discharge can be estimated by extrapolation from the Coordinated Discharge curves, using the following technique:

   a. Find the drainage area of the stream at the site of interest, and then determine the 10, 25, 50, and 100 year peak values from the graph.
   b. Plot these values on a semi log graph, with the peak discharge on the normal(y) axis, and the inverse of the return interval on the log (x) axis.
   c. Fit a straight line between these points, and the use the equation to derive a value at 0.002 (0.2%).

   See Figure 202-3B for an example.

3. Use a multiplier of the 1% annual EP discharge. If there are no discharges published in the FIS or in a coordinated discharge curve, then the 0.2% annual EP discharge can be derived from the 1% annual EP discharge by use of a multiplier, which varies by region. The different regions and the relevant multiplier are shown in Figure 202-3C. A GIS shape file is also available for download from the Department's Editable Documents page.

202-3.04 Selection of Discharge for Pump Station

The federal design criteria shown in HEC-24, *Highway Stormwater Pump Station Design*, should be followed for a pump station. The hydrological considerations shown in of HEC-24 Sections 5.3 through 5.5 should be utilized.

202-3.05 Selection of Methods Table

See Figure 202-3A for the typical methods choices based on facility.

202-4.0 DOCUMENTATION FOR HYDROLOGY

The following provides an explanation of the submittal requirements for a hydraulic report as it pertains to hydrology. See Chapter 203 for a list what should be included in the hydraulic report.

202-4.01 Culvert or Bridge

202-4.01(01) Narrative

The narrative should discuss the hydrological project background, existing and proposed facilities, upstream and downstream impacts, flooding issues, localized drainage issues, or other special circumstances. Discussion should also consider assumptions, constraints, and special instructions as they pertain to a culvert or bridge.

202-4.01(02) Drainage Area

A topographic map with drainage-area delineation should be provided. The preferred method is a manual delineation. However, for a large drainage area, this can be impractical. Computer-determined delineation such as USGS's STREAMSTATS or Purdue's HYMAPS-OWL may be used, but the determined drainage area should be verified for accuracy. Sometimes an incorrect drainage area is added or subtracted. For a large drainage area, *Drainage Areas of Indiana Streams*, which appears on the IDNR Division of Water website, may also be used. The time-of-concentration path should be shown on the delineation map if TR-55 is being used.

202-4.01(03) Rational or Unit Hydrograph Method

1. Soil Conditions. The submittal should include information pertaining to the value used for runoff. This may include a map of the varying soil characteristics within the watershed, documentation of the values chosen from a runoff table, and calculations used to determine a weighted average value where multiple soil or land-use types exist. The actual runoff tables should not be provided as long as the value used states the vegetation and soil type used to determine that value.

2. Time of Concentration (TR-55). The submittal should include the TR-55 worksheet (see Figure 202-2A), computer spreadsheet or similar spreadsheet that summarizes the time of concentration for sheet, shallow concentrated, or channel flow. Roughness *n* values chosen should refer to, but not necessarily include, the appropriate tables by stating the channel characteristics for that segment.

3. Rainfall. Rainfall information should be provided such as the computer output from NOAA Atlas 14.

4. Hydrograph Computer Program TR-20 or HEC-HMS. The input and the final output should be included in the report. Enough storm events should be run, so that a peak

discharge can be determined. The peak discharge should be highlighted within the output.

5. Site and Aerial Photographs. These should be provided for justification of design values. Site photographs must include views looking upstream and downstream at the crossing location.

202-4.01(04) Other Methods

For all other methods, input or output should be provided to the extent that another reader can identify the discharge determined and the assumptions that were made.

If using tables or charts to document assumptions, the assumption used should be highlighted or identified.

202-4.02 Pavement or Storm Drainage

202-4.02(01) Narrative

The narrative should discuss the hydrological project background, existing and proposed facilities, issues affecting offsite stormwater collection, upstream and downstream impacts, flooding issues, localized drainage issues, or other special circumstances. Discussion should also consider assumptions, constraints, and special instructions.

202-4.02(02) Drainage Area

A scaled topographic map with drainage-area delineation should be provided for each individual inlet or catch basin. The drainage area should include all land within the right of way draining to the inlet or catch basin, plus the off-site area as required.

202-4.02(03) Hydrologic Computations

The accepted method of determining runoff volume is the Rational Method. For required documentation, see Section 202-4.01(03).

202-4.03 Stormwater Storage

202-4.03(01) Narrative

The narrative should discuss the hydrological project background, the type of facility being proposed, i.e., side-ditch detention, subsurface storage, detention pond, retention pond, etc., existing and proposed drainage conditions, soil characteristics, infiltration potential, outfall restrictions, or other special circumstances. Discussion should also consider assumptions, constraints, and special instructions.

202-4.03(02) Drainage Area

A scaled topographic map with drainage-area delineation should be provided for the designed storage system. The watershed should delineate all areas draining to the storage system, including all off-site areas. For special-ditch grades that do not coincide with the roadway profile grade, and involve a side-ditch detention system, the watershed delineation should identify all ditch-grade breaks and be labeled showing high points and drainage-area divides.

202-4.03(03) Hydrologic Computations

Calculations should include a hydrograph method that shows storage volumes and discharges over time. Inflow and outflow hydrographs should be developed for existing and proposed conditions. See Section 202-4.01(03) for the required documentation. The calculations should identify the peak storage volume based upon different inflow storm events. See Section 203-5.0 for specific design criteria. For software modeling, sufficient computational informational and critical-design elements should be referenced for ease of review and understanding for a future analysis. An inflow/outflow discharge and storage-volume table may be required.

202-5.0 REFERENCES

1. AASHTO, *Highway Drainage Guidelines (2007)*, Chapter 2 (Hydrology), Chapter 5 (The Legal Aspects of Highway Drainage), and Chapter 12 (Stormwater Management)

2. AASHTO, *Model Drainage Manual*, 1991, 1997, or 2005.

3. Federal Highway Administration, Hydraulic Engineering Circular No. 19, *Hydrology*, 1994.

4. Highway Extension and Research Project for Indiana Counties and Cities, H-94-6, *Storm Water Drainage Manual*, July 1994.

5. Indiana Department of Natural Resources, *Coordinated Discharges of Selected Streams in Indiana*.

6. Indiana Department of Natural Resources, Division of Water, *Hydrology and Hydraulics in Indiana, Volume 1*, January 1986.

7. NOAA National Weather Service, *Hydrometeorological Design Studies Center*

8. USGS, Water-Resources Investigations Report 84-4134, *Techniques For Estimating Magnitude and Frequency of Floods on Streams in Indiana*.

9. Water Resources Council, Bulletin 17B, *Guidelines for Determining Flood Flow Frequency*, 1981.

TR-55 TIME-OF-CONCENTRATION WORKSHEET

Route: Project No.: Location:
Designer: Date:
Checked By: Date:

Present ☐ Developed ☐

T_c ☐ T_t ☐ Through subarea

A map, schematic, or flow-segments description is attached.

Sheet Flow, applies to T_c only — Segment ID		
1. Surface description, see Figure 202-2B		
2. Manning's roughness coeff., *n*, see Figure 202-2B		
3. Flow length, *L* (total $L \leq 100$ ft)	ft	ft
4. Two-year 24-h rainfall	in.	in.
5. Land slope, *s*	ft / ft	ft / ft
6. $T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}(s)^{0.4}}$	h	h

Total T_t in line 6 for both segments = h

Shallow Concentrated Flow — Segment ID		
7. Surface description, paved or unpaved		
8. Flow length, *L*	ft	ft
9. Watercourse slope, s	ft / ft	ft / ft
10. Average velocity, *V*, see Figure 202-2D	ft / s	ft / s
11. $T_t = \frac{L}{3600V}$	h	h

Total T_t in line 11 for both segments = h

Channel Flow — Segment ID		
12. Cross-sectional flow area, *a*	ft^2	
13. Wetted perimeter, P_w	ft	ft
14. Hydraulic radius, $r = a/P_w$	ft	ft
15. Channel slope, *s*	ft / ft	ft / ft
16. Manning's roughness coeff., *n*, see Figure 202-2C		
17. $V = \frac{1.49r^{2/3}s^{1/2}}{n}$	ft / s	ft / s
18. Flow length, *L*	ft	ft
19. $T_t = \frac{L}{3600V}$	h	h

Total T_t in line 19 for both segments = h

20. Add T_t in lines 6, 11, and 19 to get watershed or subarea T_c or T_t = h

EXAMPLE OF TR-55 TIME OF CONCENTRATION WORKSHEET
Figure 202-2A

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TYPE OF SURFACE	*n* VALUE
Smooth, such as concrete, asphalt, gravel, or bare soil	0.011
Rangeland	0.13
Short Grass	0.15
Cultivated Soil	0.17
Dense Grass	0.24
Light Woods and Underbrush	0.40
Dense Woods and Underbrush	0.80

MANNING'S ROUGHNESS COEFFICIENT, *n*, FOR SHEET FLOW
Adapted from Engman, 1983

Figure 202-2B

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Type of Surface	***n***
Fairly Regular Section	
Some grass and weeds, little or no brush	0.03 - 0.035
Dense growth of weeds, flow greater than weeds height	0.035 - 0.05
Some weeds, light brush on banks	0.035 - 0.05
Some weeds, heavy brush on banks	0.05 - 0.07
Some weeds, dense willows on banks	0.06 - 0.08
Trees within channel, branches submerged during high flow, increase value by	0.01 - 0.02
Irregular Section with Pools, Slight Channel Meander	
Increase value by	0.01 - 0.02
Steep Stream, Trees Only on Steep Banks	
Bottom of gravel, cobbles, and few boulders	0.04 - 0.05
Bottom of cobbles with large boulders	0.05 - 0.07
Floodplain	
Short grass	0.03 - 0.035
High Grass	0.035 - 0.05
Mature field crop	0.04 - 0.06
Scattered brush, heavy weed	0.05 - 0.07
Light brush and trees	0.06 - 0.08
Medium to dense brush and trees	0.10 - 0.16
Heavy stand of timber, few downed trees, little undergrowth	0.10 - 0.12

MANNING'S ROUGHNESS COEFFICIENT, *n*, FOR CHANNEL FLOW
Adapted from Chow, 1970

Figure 202-2C

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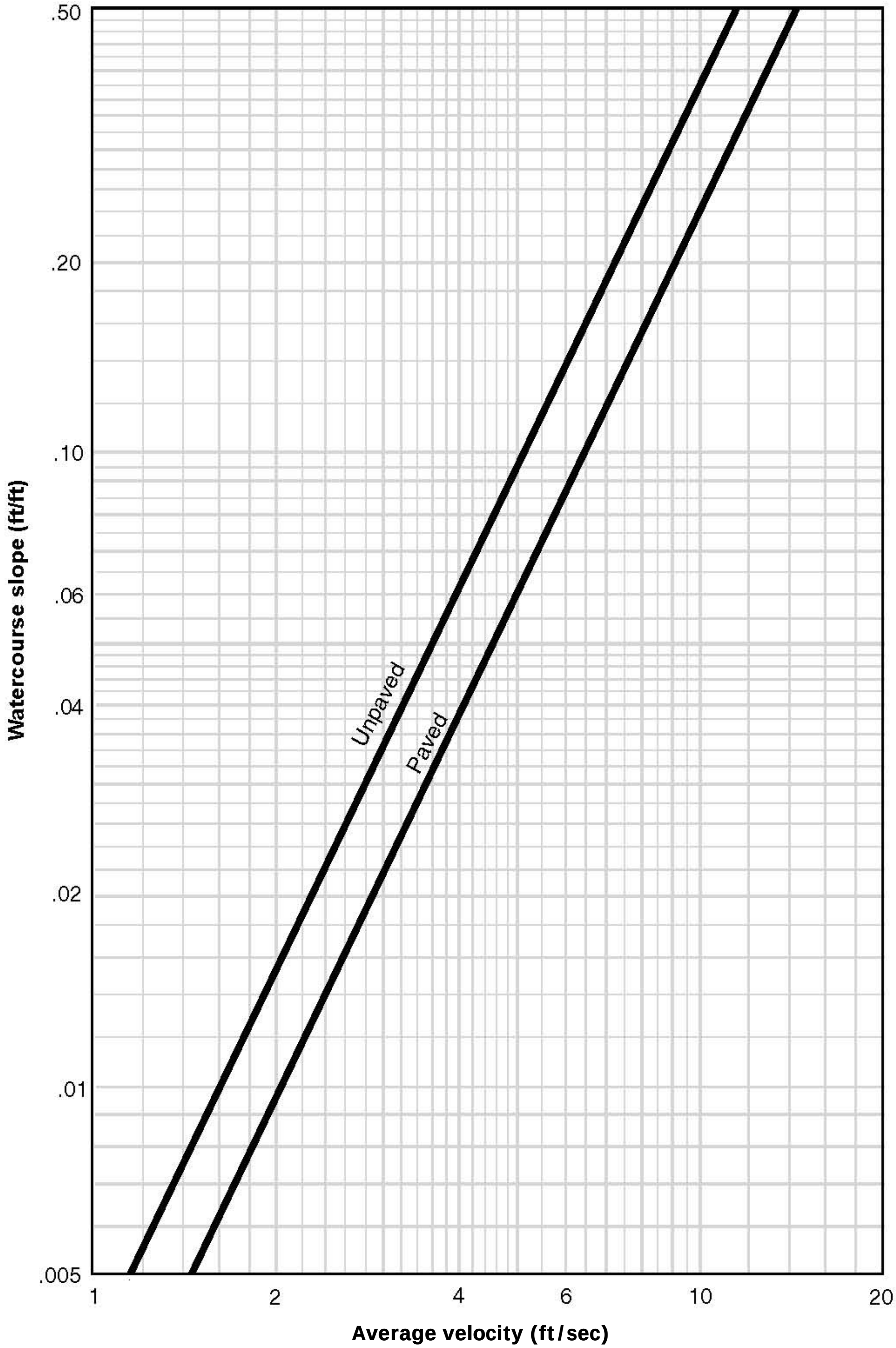

AVERAGE VELOCITIES FOR ESTIMATING TRAVEL TIME FOR SHALLOW CONCENTRATED FLOW

Figure 202-2D

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C Value for Rural Area			
Vegetation and Topography	**Open Sand Loam**	**Clay and Silt Loam**	**Tight Clay**
Woodland			
Flat, $0 \leq$ slope $< 5\%$	0.10	0.30	0.40
Rolling, $5 \leq$ slope $< 10\%$	0.25	0.35	0.50
Hilly, $10 \leq$ slope $\leq 30\%$	0.30	0.50	0.60
Pasture			
Flat, $0 \leq$ slope $< 5\%$	0.10	0.30	0.40
Rolling, $5 \leq$ slope $< 10\%$	0.16	0.36	0.55
Hilly, $10 \leq$ slope $\leq 30\%$	0.22	0.42	0.60
Cultivated			
Flat, $0 \leq$ slope $< 5\%$	0.30	0.50	0.60
Rolling, $5 \leq$ slope $< 10\%$	0.40	0.60	0.70
Hilly, $10 \leq$ slope $\leq 30\%$	0.52	0.72	0.82

C Value for Urban Area	
Character of Surface	**Runoff Coefficient, *C***
Business	
Downtown	0.70 to 0.95
Neighborhood	0.50 to 0.70
Residential	
Single-Family	0.30 to 0.50
Multi-Units, Detached	0.40 to 0.60
Multi-Units, Attached	0.60 to 0.75
Residential Suburban	0.25 to 0.40
Apartment	0.50 to 0.70
Industrial	
Light	0.50 to 0.80
Heavy	0.60 to 0.90
Park, Lawn, Cemetery, Grassy Area	0.10 to 0.25
Railroad Yard	0.20 to 0.35
Unimproved	0.10 to 0.30
Pavement	
Asphalt or Concrete	0.80 to 0.95
Brick	0.70 to 0.85
Other Impervious	0.75 to 0.95
Water Impoundment	1.00

RATIONAL-METHOD RUNOFF COEFFICIENT, *C*
Adapted from Indiana LTAP, 2008

Figure 202-2E

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Runoff Curve Number for Rural Area				
Cover Type	**A**	**B**	**C**	**D**
Brush or Brush-Weed Mixture	35	56	70	77
Meadow	30	58	71	78
Pasture or Rangeland	49	69	79	84
Row Crops	67	76	83	86
Water	100	100	100	100
Woods and Grass, Orchard	43	65	76	82
Woods or Forest	36	60	73	79

Runoff Curve Number for Urban Area				
Cover Type	**A**	**B**	**C**	**D**
Open Space: Lawn or Golf Course				
Fair Condition, grass cover <75%	49	69	79	84
Good Condition, grass cover ≥75%	39	61	74	80
Street or Road				
Paved, open ditches, entire right of way	83	89	92	93
Gravel, open ditches, entire right of way	76	85	89	91
Earth, open ditches, entire right of way	72	82	87	89
Impervious	98	98	98	98
Urban Area				
Commercial or Business, 85% impervious	89	92	94	95
Industrial, 72% impervious	81	88	91	93
Residential Area				
1/8 acre, apartments, 65% impervious	77	85	90	92
1/4 acre, 38% impervious	61	75	83	87
1/3 acre, 30% impervious	57	72	81	86
1/2 acre, 25% impervious	54	70	80	85
1 acre, 20% impervious	51	68	79	84
2 acres, 12% impervious	46	65	77	82
Developing Urban Area				
Newly graded, pervious with no vegetation	57	73	82	86
Water	100	100	100	100

CURVE-NUMBER TABLE
Adapted from NRCS, July 1999

Figure 202-2F

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Facility Description	Methodology					
	Rational Method*	TR-20 or HEC-HMS	IDNR Coordinated Curves	USGS Gaging Information	Stream Stats	Purdue Regression Equations
Culvert	2	2	1	--	3	--
Bridge or Channel, < 5 sq mi drainage area	--	2	1	3	3	3
Bridge or Channel, ≥ 5 sq mi drainage area	--	3	1	2	3	3
Storm Drain and Inlets	1	4	--	--	--	--
Storage Facility	5	1	--	--	--	--
Pumping Station **	--	1	--	--	--	--

Notes: Must use IDNR Discharge Letter if IDNR Permit is required.

1 is the preferred method

2 is the preferred method if 1 is unavailable

3 is the secondary method

4 may be used if a complex facility exists

5 may be used for retention storage with no outlet

* Rational Method may be used only if drainage area is less than 100 ac in an urban area or less than 200 ac in a rural area.

** See HEC-24, Chapters 5.3 – 5.5.

SELECTION OF DISCHARGE-COMPUTATION METHOD

Figure 202-3A

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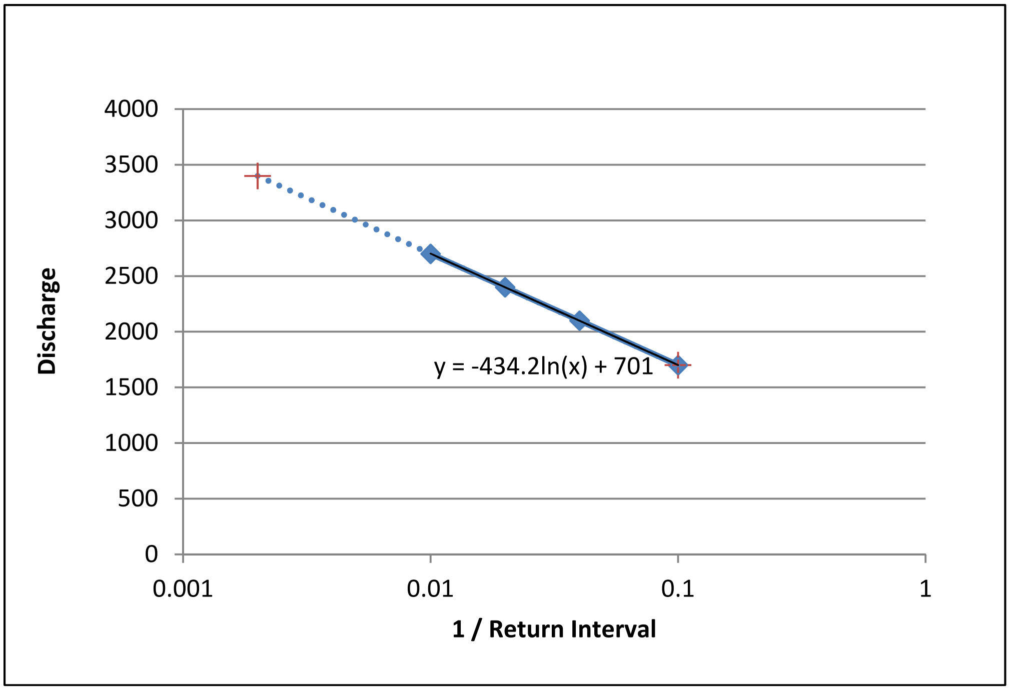
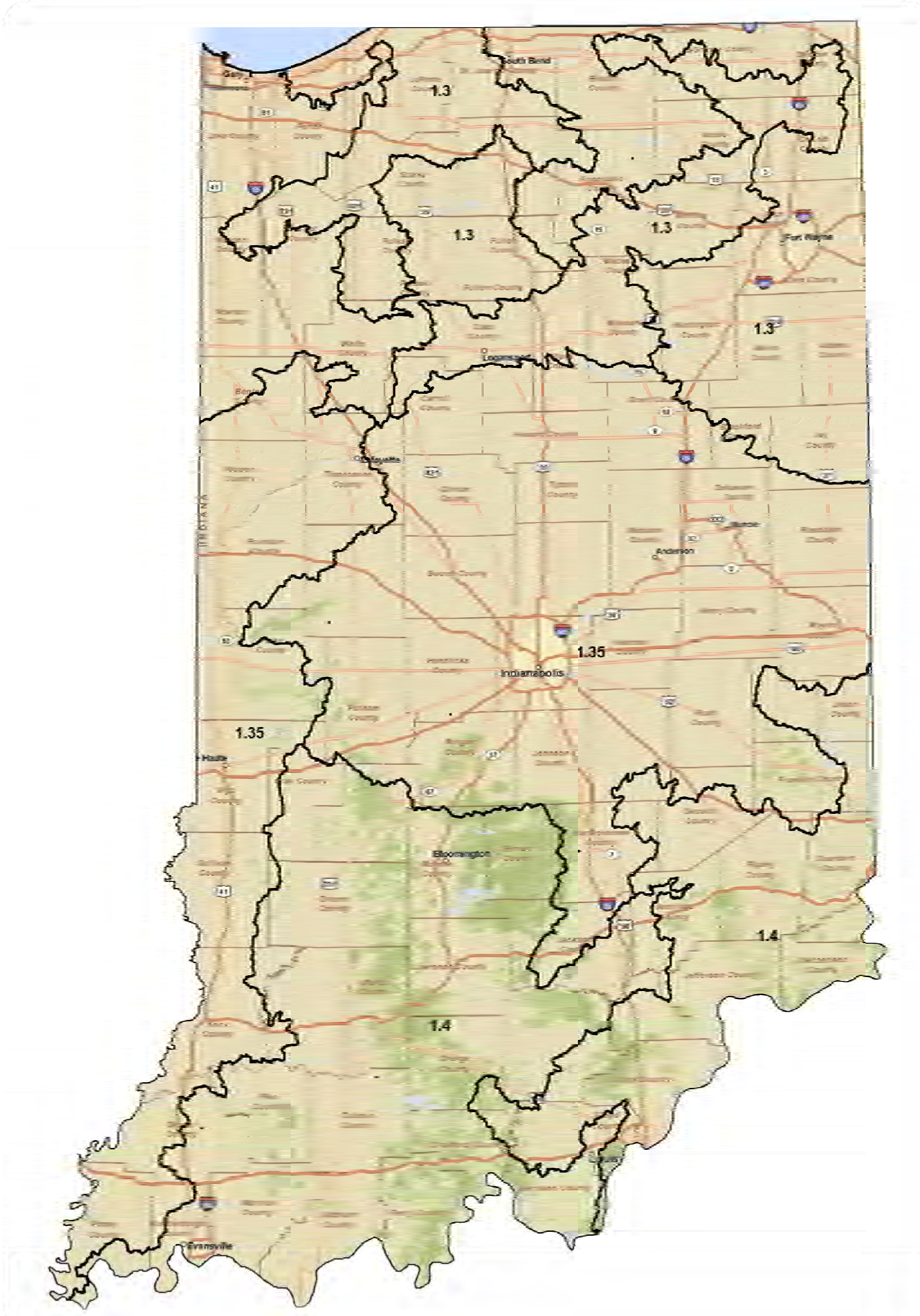


EXAMPLE OF GRAPHICAL METHOD FOR DETERMINING THE 0.2% EP

Figure 202-3B



REGIONAL MULTIPLIERS FOR DETERMINATION OF 0.2% ANNUAL EP

Figure 202-3C

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