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DEPARTMENT OF ENVIRONMENTAL PROTECTION

# EROSION AND SEDIMENT POLLUTION CONTROL PROGRAM MANUAL

## FINAL

**Technical Guidance Number**
**363-2134-008**

**March 2012**

BUREAU OF WATERWAYS ENGINEERING AND WETLANDS
DIVISION OF WETLANDS, ENCROACHMENT AND TRAINING

**DEPARTMENT OF ENVIRONMENTAL PROTECTION**
**Bureau of Waterways Engineering and Wetlands**

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| **DOCUMENT NUMBER:** | 363-2134-008 |
| **TITLE:** | Erosion and Sediment Pollution Control Program Manual |
| **EFFECTIVE DATE:** | March 31, 2012 |
| **AUTHORITY:** | Pennsylvania Clean Stream Law (35 P.S. §§ 691.1—691.1001) and regulations at 25 Pa. Code Chapter 102. |
| **POLICY:** | It is the policy of the Department of Environmental Protection (DEP) to provide guidance and procedures for those engaged in earth disturbance activities on ways to minimize accelerated erosion and resulting sediment pollution to surface waters. |
| **PURPOSE:** | The purpose of this guidance is to inform those engaged in earth disturbance activities and in the preparation of Erosion and Sediment Control (E&S) Plans how to comply with regulations found at 25 Pa. Code Chapter 102. |
| **APPLICABILITY:** | This guidance applies to all those engaged in the preparation of E&S Plans for earth disturbance activities in the Commonwealth of Pennsylvania. |
| **DISCLAIMER:** | The policies and procedures outlined in this guidance are intended to supplement existing requirements. Nothing in the policies or procedures shall affect regulatory requirements.<br><br>The policies and procedures herein are not an adjudication or a regulation. There is no intent by DEP to give the rules in these policies that weight or deference. This document establishes the framework within which DEP will exercise its administrative discretion in the future. DEP reserves the discretion to deviate from this policy statement if circumstances warrant. |
| **PAGE LENGTH:** | 563 pages |
| **DEFINITIONS:** | See 35 P.S. § 691.1 and 25 Pa. Code § 102.1. |

# FOREWORD

The various Best Management Practices (BMPs) described herein are primarily used during earth disturbances associated with land development and construction activities. Other special BMPs for agricultural plowing or tilling activities which provide for the economic viability of farms, maintenance of the land, and protection of Pennsylvania waterways are described in the Natural Resources Conservation Services' ***Pennsylvania Soil and Water Conservation Technical Guide***. An overview of these agricultural BMPs is also provided in ***A Conservation Catalog: Practices for the Conservation of Pennsylvania's Natural Resources*****.** Persons conducting agricultural plowing or tilling activities are encouraged to review the practices described in the catalog and contact their local conservation district or Natural Resources Conservation Service office for more detailed planning information and assistance.

This manual lists various BMPs and design standards which are acceptable in Pennsylvania. BMPs, when designed according to these standards, and properly implemented and maintained, are expected to achieve the regulatory standard of minimizing the potential for accelerated erosion and sedimentation, and at the same time to protect, maintain, reclaim and restore water quality and existing and designated uses of surface waters.

This manual contains a selection of performance oriented BMPs that minimize accelerated soil erosion and sedimentation associated with temporary earth disturbance activities. It is a tool for developing erosion and sediment control plans that use basic principles of sound science and reasonable scientific certainty for minimizing accelerated erosion and sedimentation. Erosion and sediment control BMPs associated with earth disturbance activities have undergone extensive research and development to achieve the desired level of BMP effectiveness. Much of the design criteria and supporting calculations have been developed through various technical organizations, academia, and government agencies with expertise of the management practice functionality, standardized test methods and procedures, statistical analysis, and environmental, health and safety considerations. The BMP standards and specifications adopted by the Department are typically identified and used for the specific field applications as a performance-based effluent limitation for sediment and related pollutants. Many of the supporting calculations are assumed and have been incorporated into the standard details and specifications; however, some simple calculations for drainage area, slope steepness and length, or other site-specific feature may need to be identified to apply the practice for the earth disturbance activity. Generally, details and specifications identify the purpose of the BMP, conditions where the BMP applies, planning considerations, design criteria, construction specifications and maintenance procedures.

Alternate BMPs that are not listed in this manual but that provide the same (or greater) level of protection may also be used to attain the regulatory standard. It is incumbent on the person proposing the use of alternative BMPs to demonstrate their effectiveness with appropriate test results or other documentation.

BMPs that fail after installation shall be repaired to function properly or be replaced by alternative BMPs that will serve the intended purpose. For example, if a skimmer in a basin or trap does not function as intended, it may need to be replaced by a perforated riser that functions as intended. Likewise, if unforeseen conditions occur on a site, and the installed BMPs are obviously not effective, then alternate BMPs should be designed and installed. The need for redesign will be determined on a case-by-case basis.

Erosion is a natural process, which occurs with each runoff event. Human activities which remove protective vegetative cover alter topography and runoff patterns and typically increase the rate of erosion to many times that which occurs naturally. It is this accelerated erosion which is regulated by the Department's Chapter 102 regulations. Minimizing accelerated erosion and the resultant sedimentation is the focus of this manual.

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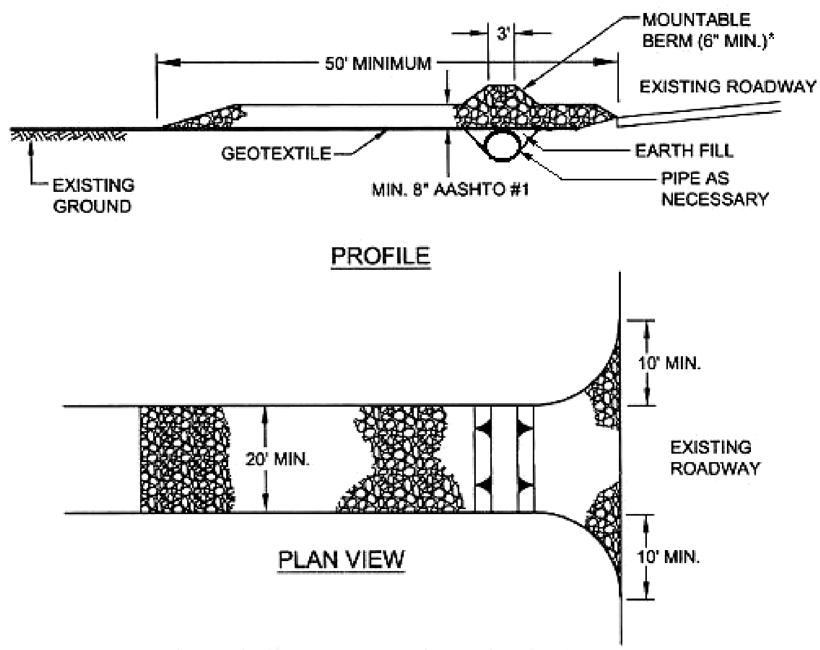
# STANDARD CONSTRUCTION DETAILS

# CHECKLISTS, STANDARD E&S WORKSHEETS, STANDARD NOTES AND REFERENCES

Sediment deposited on public roadways should be removed and returned to the construction site immediately. **Note: Washing the roadway or sweeping the deposits into roadway ditches, sewers, culverts, or other drainage courses is not acceptable.**

Rock construction entrances are not effective sediment removal devices for runoff coming off the roadway above the entrance. Surface runoff should be directed off the roadway by means of appropriate drainage devices described later in this chapter. Where these devices do not discharge to a suitable vegetative filter strip, an appropriately sized sediment trap should be provided. For locations not having sufficient room for a conventional sediment trap, consideration should be given to use of a compost sock sediment trap. Compost sock traps may also be used instead of conventional sediment traps at other points of discharge. Where used, care should be taken to provide continuous contact between the sock and the underlying soil in order to prevent undermining. It is also important to properly anchor the sock (Standard Construction Detail #3-1).

**STANDARD CONSTRUCTION DETAIL # 3-1**
**Rock Construction Entrance**




* MOUNTABLE BERM USED TO PROVIDE PROPER COVER FOR PIPE

Modified from Maryland DOE

**Remove topsoil prior to installation of rock construction entrance. Extend rock over full width of entrance.**

**Runoff shall be diverted from roadway to a suitable sediment removal BMP prior to entering rock construction entrance.**

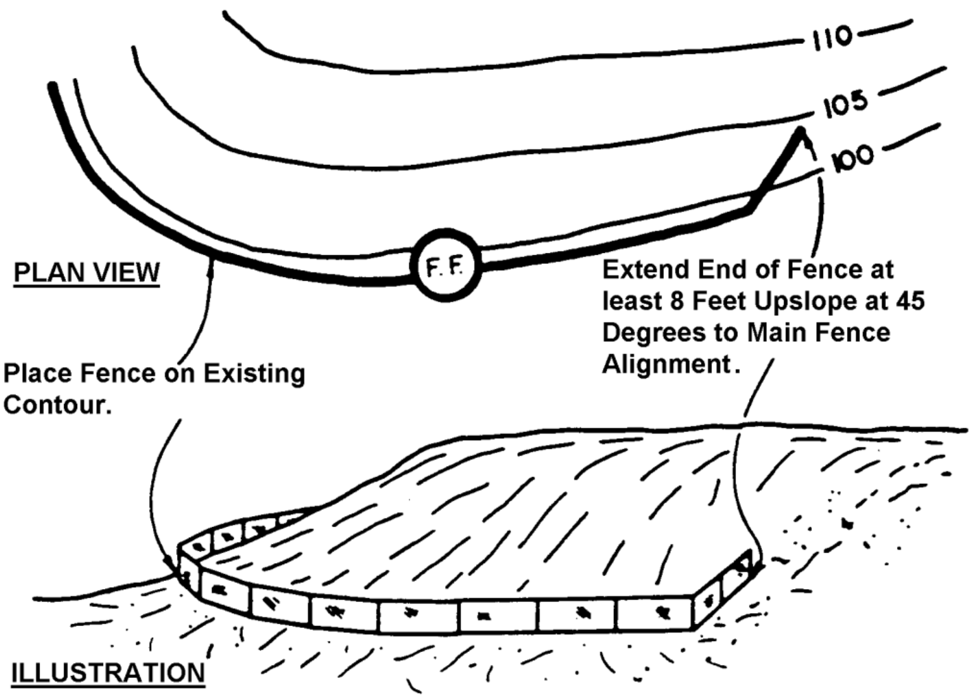
**Mountable berm shall be installed wherever optional culvert pipe is used and proper pipe cover as specified by manufacturer is not otherwise provided. Pipe shall be sized appropriately for size of ditch being crossed.**

**MAINTENANCE: Rock construction entrance thickness shall be constantly maintained to the specified dimensions by adding rock. A stockpile shall be maintained on site for this purpose. All sediment deposited on paved roadways shall be removed and returned to the construction site immediately. If excessive amounts of sediment are being deposited on roadway, extend length of rock construction entrance by 50 foot increments until condition is alleviated or install wash rack. Washing the roadway or sweeping the deposits into roadway ditches, sewers, culverts, or other drainage courses is not acceptable.**

## CHAPTER 4 - SEDIMENT BARRIERS AND FILTERS

Sediment barriers are typically used as perimeter controls for small disturbed areas and as initial protection against sediment pollution during construction of other BMPs such as sediment basins or traps. Each type of sediment barrier has specific advantages and limitations. Care should be exercised in the selection of any sediment barrier to ensure it is suited to the particular site conditions where it is proposed.

**FIGURE 4.1**
**Sediment Barrier Alignment**



PA DEP

Sediment barriers should be installed on existing level grade in order to be effective. Barriers which cross contours divert runoff to a low point where failure usually occurs. The ends of sediment barriers should be turned upslope at 45 degrees to the main barrier alignment for a distance sufficient to elevate the bottom of the barrier ends to the elevation of the top of the barrier at the lowest point. This is to prevent runoff from flowing around the barrier rather than through it. For most locations, a distance of 8 feet will suffice, as shown in Figure 4.1. In locations where the topography is such that the barrier would have to extend for a long distance, a compacted berm tying into the ends of the barrier may be substituted for the upslope extension.

# CHAPTER 1 - REQUIRED E&S PLAN CONTENT

Pa. Code Title 25 Chapter 102.4 (b) requires the "implementation and maintenance of E&S BMPs" to minimize the potential for accelerated erosion and sedimentation, including those activities which disturb less than 5,000 square feet (464.5 square meters)" [102(b)(1)]. It also requires that "a person proposing earth disturbance activities shall develop and implement a written E&S Plan under this chapter if one or more of the following criteria apply [102.4(b)(2)]:

1. The earth disturbance activity will result in a total earth disturbance of 5,000 square feet (464.5 square meters) or more,
2. The person proposing the earth disturbance activities is required to develop an E&S Plan under this chapter or under other Department regulations, or
3. The earth disturbance activity, because of its proximity to existing drainage features or patterns, has the potential to discharge to a water classified as a High Quality or Exceptional Value water under Chapter 93 (relating to water quality standards).."

§102.4(b)(3) requires that the E&S Plan "be prepared by a person trained and experienced in E&S control methods and techniques applicable to the size and scope of the project being designed."

§102.4(b)(4) requires that "unless otherwise authorized by the Department or conservation district after consultation with the Department, earth disturbance activities shall be planned and implemented to the extent practicable in accordance with the following:

1. Minimize the extent and duration of the earth disturbance.
2. Maximize protection of existing drainage features and vegetation.
3. Minimize soil compaction.
4. Utilize other measures or controls that prevent or minimize the generation of increased stormwater runoff."

Perhaps the most neglected and yet the most important aspect of designing an effective E&S plan is knowledge of the specific site in question. It is essential that the plan designer have as complete an understanding of the unique characteristics of the site as possible. Therefore, it is highly recommended that a site visit be scheduled at the earliest practical point in the development of the plan.

Site characteristics that will affect the plan design as well as the construction of the project (e.g., drainage patterns, seeps and springs, steepness and stability of slopes, sinkholes, etc.) should be noted and mapped. Sensitive and special value features (e.g., wetlands, woodlands, flow paths, riparian areas, etc.) should be identified, mapped, and protected as much as possible. A little time well spent in the field can save much time and money due to plan revisions, unforeseen hazards, penalties, and shutdowns. Only after the designer has a good working knowledge of the site should the designer proceed with developing the E&S plan.

The basic concept of providing effective, efficient and practical erosion and sediment control should be considered when determining the locations and types of BMPs. All off-site surface water should be diverted away from areas to be disturbed (wherever feasible); all runoff from disturbed areas should be collected and conveyed to a sediment basin, sediment trap, or other BMP for sediment removal. The extent of the disturbance, as well as the time period between initial disturbance and final stabilization, should be minimized. Existing vegetation, especially existing trees, should be preserved wherever possible (see Appendix I for more information regarding tree preservation). Temporary stabilization must be provided for earth-exposed areas where earthwork is delayed or stopped for a period of 4 or more days, and permanent stabilization must ultimately be provided for all disturbed areas (25 Pa Code § 102.22). Sediment removal treatment for water pumped from excavations is usually needed. Access to the site and removal of mud from vehicle tires before vehicles exit onto existing roadways — public or private — are also required.

25 Pa. Code § 102.4(b)(5) of the Pennsylvania Code requires that the following items be included in the drawings and narrative of an E&S plan for earth disturbance activities:

**1.** ***The existing topographic features of the project site and the immediate surrounding area***. These features should be shown on a map or maps included with or part of the drawings. This requirement applies to off-site borrow and waste areas as well as the project site. Mapping should conform to the standards contained in Appendix D. Cross-sections and profiles are not an acceptable alternative since these do not adequately define existing level contour for sediment barriers or drainage areas for channels, basins, or traps.

**2.** ***The types, depth, slope, locations and limitations of the soils***. The locations of the soils may be delineated on the map or drawing discussed above, or on a separate map of the site. A legible photocopy of a portion of the soil survey maps on which the proposed project can be clearly shown may also be used. The locations of all proposed sediment basins and traps should be shown on any separate or soil survey maps.

The types, depth, slope and limitations of the soils should be included in the narrative portion of the plan or on the plan drawings/maps. Data on the physical characteristics of the soils, such as their texture, resistance to erosion and suitability for intended use is to be included in the narrative report. This information is available from the tables on the USDA, Natural Resources Conservation Service website: http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx. Soils information is also available from the Penn State website at: http://soilmap.psu.edu. However, the data from the Penn State website might not be as current as that from the NRCS website, and, therefore, it should only be used if the county survey has not been updated.

Only those limitations relevant to the proposed project should be cited (e.g. suitability for corn production would not be appropriate for a housing project, but soil erodibility, slope stability, suitability for winter grading, piping tendencies, and potential trench caving would be appropriate). Appendix E lists some of the most common soil use limitations for many of the soils in Pennsylvania. The means to address the identified soils limitations should be included on the drawings. For example, a note to use only certain areas of the site as sources for embankment material for sediment basins or traps, or special fertilization requirements for portions of the project, etc. The intent of Appendix E is to alert designers to potential problems that could arise during construction and afford an opportunity to avoid or minimize those problems by proper design. Simply copying Appendix E into the narrative is not sufficient to meet the requirements of this section.

**3.** ***The characteristics of the earth disturbance activity, including the past, present and proposed land uses and the proposed alteration to the project site.*** Past land uses are the actual land use(s) of the project site for the past 50 years or longer if known, not just the zoning of the land. Present land uses are the dominant land uses of the project site for the 5 years preceding the planned project, not just the zoning of the land. For sites requiring a National Pollutant Discharge Elimination System (NPDES) permit, this information is contained in the completed Notice of Intent (NOI). For non-permitted sites, it should be included in the narrative. Site design and layout should employ an environmentally sensitive approach that minimizes the effect of the development on water, land, and air to the maximum extent practicable. The guidelines for Non-Structural BMPs set forth in Chapter 5 of the Department's Pennsylvania Stormwater Best Management Practices Manual (Document No. 363-0300-002) should be incorporated prior to design of the E&S plan. The proposed alteration to the project area and the limits of the project area should be shown on maps or drawings. These maps should be at the same scale as the original topographic map. The use of the original contour map as a base map, with the new contours superimposed and identified in the legend, should be used to depict the alteration to the area. Such information as the limits of clearing and grubbing, the areas of cuts and fills and the locations of roads, paved areas, buildings and other structures are to be included. Final contours of the project area at an interval that will adequately describe the

## CHAPTER 5 - RUNOFF CALCULATIONS

Numerous methods are available to determine required channel capacity. Two methods, the SCS (now NRCS) Technical Release 55 - Urban Hydrology for Small Watersheds and the Rational Equation are mentioned in this handbook because of their popularity and simplicity. Other methods are also acceptable.

SCS TR-55 Urban Hydrology for Small Watersheds - Technical Release 55 (TR-55) presents simplified procedures to calculate stormwater runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. These procedures are applicable in small watersheds (2,000 acres or less), especially urbanizing watersheds, in the United States. Limits: NRCS type distributions, 24-hour duration rainfall, 10 subwatersheds maximum, minimum 0.1 hour and maximum 10-hour time of concentration.

Designers are referred to http://www.hydrocad.net/tr-55.htm to download the text version or the computer version of TR-55.

Updated rainfall data may be obtained from the National Weather Service's website http://hdsc.nws.noaa.gov/hdsc/pfds/orb/pa_pfds.html either by clicking the location of the site on the website map or by entering the site's latitude and longitude. Data from this website were used to develop Table 5.1. **(Note: Table 5.1 is useful for obtaining a quick initial estimate of rainfall data. However, since these data are not updated, they may not be used for the final design of PCSM BMPs, nor may they be used to determine rainfall intensity "I" for the rational equation.)**

Due to the irregular topography, the maximum sheet flow length to be used for unpaved areas in Pennsylvania is 150 feet with a most likely maximum length of 50-100 feet. The theoretical maximum length of 300 feet is achieved only in unique situations such as uniformly sloped paved parking lots. The maximum flow path length (L) for any disturbed area is 50 feet. It is unlikely that any sheet flow occurs in areas where active earthmoving is taking place, as well as previously disturbed areas that were not restored to approximate original contour. Therefore, the sheet flow equation should not be used for newly graded fill or cut slopes. Runoff from these areas should be considered shallow concentrated flow.

Whenever TR-55 is used to calculate runoff, Worksheets 2, 3, and 4 from TR-55 should be completed and included in the narrative portion of the plan submittal. If computer programs are used which do not provide printouts of these worksheets, the program used as well as the input data should be provided along with the output pages.

Weather Bureau Technical Paper 40, U.S. Department of Commerce, Hershfield, D.M. - Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. T.P. 40 is out of print. However, it is the basis for the maps in TR-55 described above.

# TABLE 5.1
## Pennsylvania Rainfall by County
## (For Use with Technical Release 55 - Urban Hydrology for Small Watersheds)
## NOT TO BE USED WITH THE RATIONAL EQUATION

| COUNTY | 24 HR RAINFALL FOR VARIOUS FREQUENCIES | | | | | | | COUNTY | 24 HR RAINFALL FOR VARIOUS FREQUENCIES | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 yr. | 2 yr. | 5 yr. | 10 yr. | 25 yr. | 50 yr. | 100 yr. | | 1 yr. | 2 yr. | 5 yr. | 10 yr. | 25 yr. | 50 yr. | 100 yr. |
| Adams | 2.52 | 3.02 | 3.77 | 4.43 | 5.48 | 6.45 | 7.59 | Lackawanna | 2.12 | 2.55 | 3.15 | 3.69 | 4.55 | 5.35 | 6.30 |
| Allegheny | 1.97 | 2.35 | 2.88 | 3.30 | 3.90 | 4.40 | 4.92 | Lancaster | 2.51 | 3.02 | 3.85 | 4.56 | 5.63 | 6.56 | 7.59 |
| Armstrong | 2.03 | 2.42 | 2.95 | 3.40 | 4.01 | 4.53 | 5.06 | Lawrence | 1.99 | 2.37 | 2.90 | 3.33 | 3.94 | 4.44 | 4.96 |
| Beaver | 1.97 | 2.35 | 2.87 | 3.30 | 3.90 | 4.40 | 4.91 | Lebanon | 2.50 | 3.02 | 3.84 | 4.55 | 5.64 | 6.59 | 7.67 |
| Bedford | 2.19 | 2.62 | 3.27 | 3.81 | 4.60 | 5.27 | 5.99 | Lehigh | 2.69 | 3.24 | 4.05 | 4.73 | 5.75 | 6.63 | 7.60 |
| Berks | 2.65 | 3.19 | 4.00 | 4.68 | 5.67 | 6.50 | 7.41 | Luzerne | 2.37 | 2.84 | 3.53 | 4.13 | 5.08 | 5.96 | 6.99 |
| Blair | 2.23 | 2.68 | 3.33 | 3.87 | 4.63 | 5.28 | 5.96 | Lycoming | 2.38 | 2.85 | 3.53 | 4.12 | 5.04 | 5.88 | 6.87 |
| Bradford | 2.05 | 2.44 | 2.98 | 3.41 | 3.99 | 4.45 | 4.93 | McKean | 2.08 | 2.48 | 3.03 | 3.48 | 4.13 | 4.66 | 5.21 |
| Bucks | 2.71 | 3.26 | 4.10 | 4.80 | 5.81 | 6.67 | 7.59 | Mercer | 2.05 | 2.44 | 2.99 | 3.43 | 4.07 | 4.58 | 5.13 |
| Butler | 2.02 | 2.40 | 2.93 | 3.37 | 3.98 | 4.49 | 5.02 | Mifflin | 2.36 | 2.83 | 3.52 | 4.10 | 4.95 | 5.68 | 6.49 |
| Cambria | 2.17 | 2.59 | 3.18 | 3.68 | 4.39 | 4.97 | 5.59 | Monroe | 2.63 | 3.16 | 3.92 | 4.60 | 5.68 | 6.70 | 7.91 |
| Cameron | 2.11 | 2.53 | 3.10 | 3.60 | 4.35 | 5.02 | 5.80 | Montgomery | 2.67 | 3.21 | 4.03 | 4.70 | 5.68 | 6.50 | 7.38 |
| Carbon | 2.74 | 3.29 | 4.09 | 4.79 | 5.92 | 6.96 | 8.20 | Montour | 2.35 | 2.82 | 3.50 | 4.09 | 5.05 | 5.94 | 6.99 |
| Centre | 2.20 | 2.64 | 3.29 | 3.82 | 4.58 | 5.22 | 5.91 | Northampton | 2.64 | 3.16 | 3.95 | 4.61 | 5.60 | 6.45 | 7.41 |
| Chester | 2.70 | 3.25 | 4.07 | 4.75 | 5.73 | 6.55 | 7.44 | Northumberland | 2.32 | 2.78 | 3.45 | 4.04 | 4.96 | 5.82 | 6.83 |
| Clarion | 2.09 | 2.49 | 3.05 | 3.50 | 4.14 | 4.67 | 5.22 | Perry | 2.34 | 2.81 | 3.49 | 4.08 | 5.03 | 5.90 | 6.92 |
| Clearfield | 2.13 | 2.54 | 3.12 | 3.60 | 4.28 | 4.85 | 5.44 | Philadelphia | 2.72 | 3.28 | 4.12 | 4.83 | 5.85 | 6.72 | 7.68 |
| Clinton | 2.18 | 2.61 | 3.19 | 3.67 | 4.34 | 4.89 | 5.47 | Pike | 2.45 | 2.94 | 3.64 | 4.26 | 5.23 | 6.13 | 7.20 |
| Columbia | 2.38 | 2.85 | 3.54 | 4.14 | 5.10 | 5.99 | 7.04 | Potter | 2.01 | 2.40 | 2.96 | 3.44 | 4.21 | 4.91 | 5.74 |
| Crawford | 2.08 | 2.49 | 3.04 | 3.50 | 4.14 | 4.67 | 5.23 | Schuylkill | 2.77 | 3.33 | 4.14 | 4.85 | 5.96 | 6.97 | 8.17 |
| Cumberland | 2.35 | 2.82 | 3.50 | 4.11 | 5.08 | 5.97 | 7.02 | Snyder | 2.60 | 3.12 | 3.88 | 4.55 | 5.59 | 6.56 | 7.71 |
| Dauphin | 2.50 | 3.01 | 3.78 | 4.45 | 5.50 | 6.44 | 7.52 | Somerset | 2.06 | 2.46 | 3.08 | 3.61 | 4.44 | 5.16 | 5.97 |
| Delaware | 2.69 | 3.25 | 4.10 | 4.82 | 5.87 | 6.75 | 7.72 | Sullivan | 2.54 | 3.04 | 3.73 | 4.30 | 5.12 | 5.82 | 6.58 |
| Elk | 2.08 | 2.48 | 3.02 | 3.48 | 4.12 | 4.65 | 5.21 | Susquehanna | 2.23 | 2.67 | 3.26 | 3.74 | 4.41 | 4.96 | 5.55 |
| Erie | 2.13 | 2.56 | 3.19 | 3.71 | 4.46 | 5.09 | 5.76 | Tioga | 1.96 | 2.34 | 2.88 | 3.35 | 4.07 | 4.73 | 5.49 |
| Fayette | 2.08 | 2.47 | 3.02 | 3.46 | 4.08 | 4.60 | 5.13 | Union | 2.41 | 2.89 | 3.58 | 4.19 | 5.13 | 6.01 | 7.04 |
| Forest | 2.06 | 2.46 | 3.00 | 3.45 | 4.08 | 4.59 | 5.14 | Venango | 2.05 | 2.45 | 2.99 | 3.44 | 4.07 | 4.58 | 5.12 |
| Franklin | 2.44 | 2.94 | 3.65 | 4.26 | 5.17 | 5.97 | 6.86 | Warren | 2.07 | 2.47 | 3.01 | 3.47 | 4.11 | 4.63 | 5.19 |
| Fulton | 2.27 | 2.73 | 3.39 | 3.93 | 4.73 | 5.40 | 6.13 | Washington | 1.99 | 2.38 | 2.91 | 3.35 | 3.96 | 4.46 | 4.99 |
| Greene | 2.01 | 2.40 | 2.92 | 3.36 | 3.96 | 4.45 | 4.96 | Wayne | 2.38 | 2.86 | 3.53 | 4.12 | 5.03 | 5.86 | 6.83 |
| Huntingdon | 2.21 | 2.65 | 3.29 | 3.83 | 4.60 | 5.25 | 5.94 | Westmoreland | 2.05 | 2.45 | 2.99 | 3.43 | 4.06 | 4.57 | 5.11 |
| Indiana | 2.15 | 2.57 | 3.14 | 3.62 | 4.29 | 4.85 | 5.44 | Wyoming | 2.16 | 2.58 | 3.18 | 3.69 | 4.46 | 5.14 | 5.91 |
| Jefferson | 2.09 | 2.50 | 3.05 | 3.50 | 4.14 | 4.67 | 5.23 | York | 2.45 | 2.96 | 3.80 | 4.53 | 5.65 | 6.64 | 7.76 |
| Juniata | 2.36 | 2.83 | 3.52 | 4.11 | 5.02 | 5.84 | 6.79 | | | | | | | | |

NWS - NOAA Atlas 14, Sept 25-29, 2008

**NOTE: Data from this table may not be used for final design of E&S or PCSM BMPs.**

EXAMPLE : FOREST COUNTY 5 YEAR STORM = 3.00

THE RATIONAL EQUATION is a method for estimating **peak flow rates** in small watersheds (200 acres or less). This method uses or incorporates the following assumptions:

(1) That rainfall occurs uniformly over the drainage area and that the design average rainfall intensity occurs over a period of time equal to the time of concentration of the drainage area.

(2) That the drainage area's time of concentration is the travel time for water to flow from the furthermost point (hydraulically) of the watershed to the downstream point of interest.

(3) That the frequency of runoff equals the frequency of rainfall used in the equation:

$$Q = C\ I\ A$$

Where:
Q = Peak runoff rate in cubic feet per second (cfs)
C = $C_w$ = Runoff coefficient (dimensionless)
(See following steps for explanation of $C_w$)
I = Rainfall intensity (inches/hour)*****
A = Drainage area (acres)

*** NOTE: DO NOT USE TABLE 5.1 TO DETERMINE RAINFALL INTENSITY "I" FOR THE RATIONAL EQUATION**

PROCEDURE (Use Standard E&S Worksheets 9 and 10 for organizing and documenting the parameters used):

Runoff Coefficient (C): Select an appropriate runoff coefficient "C" from Table 5.2. The coefficient chosen should represent the maximum runoff conditions during site construction — not necessarily the pre- or post-construction conditions. For drainage areas with mixed land uses, compute the weighted runoff coefficient ($C_w$) using the following equation:

$$C_w = \frac{(C_1 \times A_1) + (C_2 \times A_2) + \ldots (C_n \times A_n)}{A\ (total)}$$

Where:
$C_w$ = weighted runoff coefficient
$C_n$ = runoff coefficient for the $n^{th}$ subarea
$A_n$ = area (acres) of the $n^{th}$ subarea

## TABLE 5.2
## Runoff Coefficients for the Rational Equation*

| LAND USE | A Soils[1] | | | B Soils[1] | | | C Soils[1] | | | D Soils[1] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | < 2% | 2 - 6% | >6% | < 2% | 2 - 6% | >6% | < 2% | 2 - 6% | >6% | < 2% | 2 - 6% | >6% |
| Cultivated land | 0.08 | 0.13 | 0.16 | 0.11 | 0.15 | 0.21 | 0.14 | 0.19 | 0.26 | 0.18 | 0.23 | 0.31 |
| Pasture | 0.12 | 0.20 | 0.30 | 0.18 | 0.28 | 0.37 | 0.24 | 0.34 | 0.44 | 0.30 | 0.40 | 0.50 |
| Meadow | 0.10 | 0.16 | 0.25 | 0.14 | 0.22 | 0.30 | 0.20 | 0.28 | 0.36 | 0.24 | 0.30 | 0.40 |
| Forest | 0.05 | 0.08 | 0.11 | 0.08 | 0.11 | 0.14 | 0.10 | 0.13 | 0.16 | 0.12 | 0.16 | 0.20 |
| Residential lot size 1/8 acre | 0.25 | 0.28 | 0.31 | 0.27 | 0.30 | 0.35 | 0.30 | 0.33 | 0.38 | 0.33 | 0.36 | 0.42 |
| Residential lot size 1/4 acre | 0.22 | 0.26 | 0.29 | 0.24 | 0.29 | 0.33 | 0.27 | 0.31 | 0.36 | 0.30 | 0.34 | 0.40 |
| Residential lot size 1/3 acre | 0.19 | 0.23 | 0.26 | 0.22 | 0.26 | 0.30 | 0.25 | 0.29 | 0.34 | 0.28 | 0.32 | 0.39 |
| Residential lot size 1/2 acre | 0.16 | 0.20 | 0.24 | 0.19 | 0.23 | 0.28 | 0.22 | 0.27 | 0.32 | 0.26 | 0.30 | 0.37 |
| Residential lot size 1 acre | 0.14 | 0.19 | 0.22 | 0.17 | 0.21 | 0.26 | 0.20 | 0.25 | 0.31 | 0.24 | 0.29 | 0.35 |
| Industrial | 0.67 | 0.68 | 0.68 | 0.68 | 0.68 | 0.69 | 0.68 | 0.68 | 0.69 | 0.69 | 0.69 | 0.70 |
| Commercial | 0.71 | 0.71 | 0.72 | 0.71 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 |
| Streets | 0.70 | 0.71 | 0.72 | 0.71 | 0.72 | 0.74 | 0.72 | 0.73 | 0.76 | 0.73 | 0.75 | 0.78 |
| Open Space | 0.05 | 0.10 | 0.14 | 0.08 | 0.13 | 0.19 | 0.12 | 0.17 | 0.24 | 0.15 | 0.21 | 0.28 |
| Parking | 0.85 | 0.86 | 0.87 | 0.85 | 0.86 | 0.87 | 0.85 | 0.86 | 0.87 | 0.85 | 0.86 | 0.87 |
| Construction Sites - Bare packed soil, smooth | 0.30 | 0.35 | ~~.040~~ 0.40 | 0.35 | ~~.040~~ 0.40 | 0.45 | 0.40 | 0.45 | 0.50 | 0.50 | 0.55 | 0.60 |
| Construction Sites - Bare packed soil, rough | .020 | 0.25 | 0.30 | 0.25 | 0.30 | 0.35 | 0.30 | 0.35 | 0.40 | 0.40 | 0.45 | 0.50 |

* Runoff Coefficients for storm recurrence intervals less than 25 years

Adapted from McCuen, R.H., Hydrologic Analysis and Design (2004)

1. According to the USDA NRCS Hydrologic Soils Classification System

Examples B Soil 4% Pasture C=0.28
B Soil 8% Forest C=0.14
B Soil 4% Residential 1/4 ac. lots C = .29

Rainfall Intensity (I):

Step 1: Calculate Time of Concentration — travel time for the hydraulically longest watershed flow path.

**Sheet Flow (Overland Flow)**

Travel time for sheet flow, up to a maximum of 150 feet, may be estimated by the use of the formula:

$$T_{c(sheet\ flow)} = \left[\frac{2(L)(n)}{3(S)^{0.5}}\right]^{0.4673} \qquad T_{c(sheet\ flow)} = \left[\frac{2(L)(n)}{3(S)^{0.5}}\right]^{0.4673}$$

Where:
- $T_c$ = Time of concentration (minutes)
- L = Length of flow path (ft)
- S = Surface slope (ft/ft)
- n = Roughness coefficient (See Table 5.3)

**NOTE:** The maximum flow path length (L) for any disturbed area is 50 feet. Do not use the sheet flow equation for newly graded fills or cut slopes. Runoff from these areas should be considered shallow concentrated flow.

**TABLE 5.3**
**Roughness Coefficient for Sheet Flow $T_c$ Computations**

| n | Type of Cover |
|---|---|
| 0.02 | Smooth pavement |
| 0.1 | Bare parched soil |
| 0.3 | Poor grass cover |
| 0.4 | Average grass cover |
| 0.8 | Dense grass cover |

(these n values are not for Manning's equation)

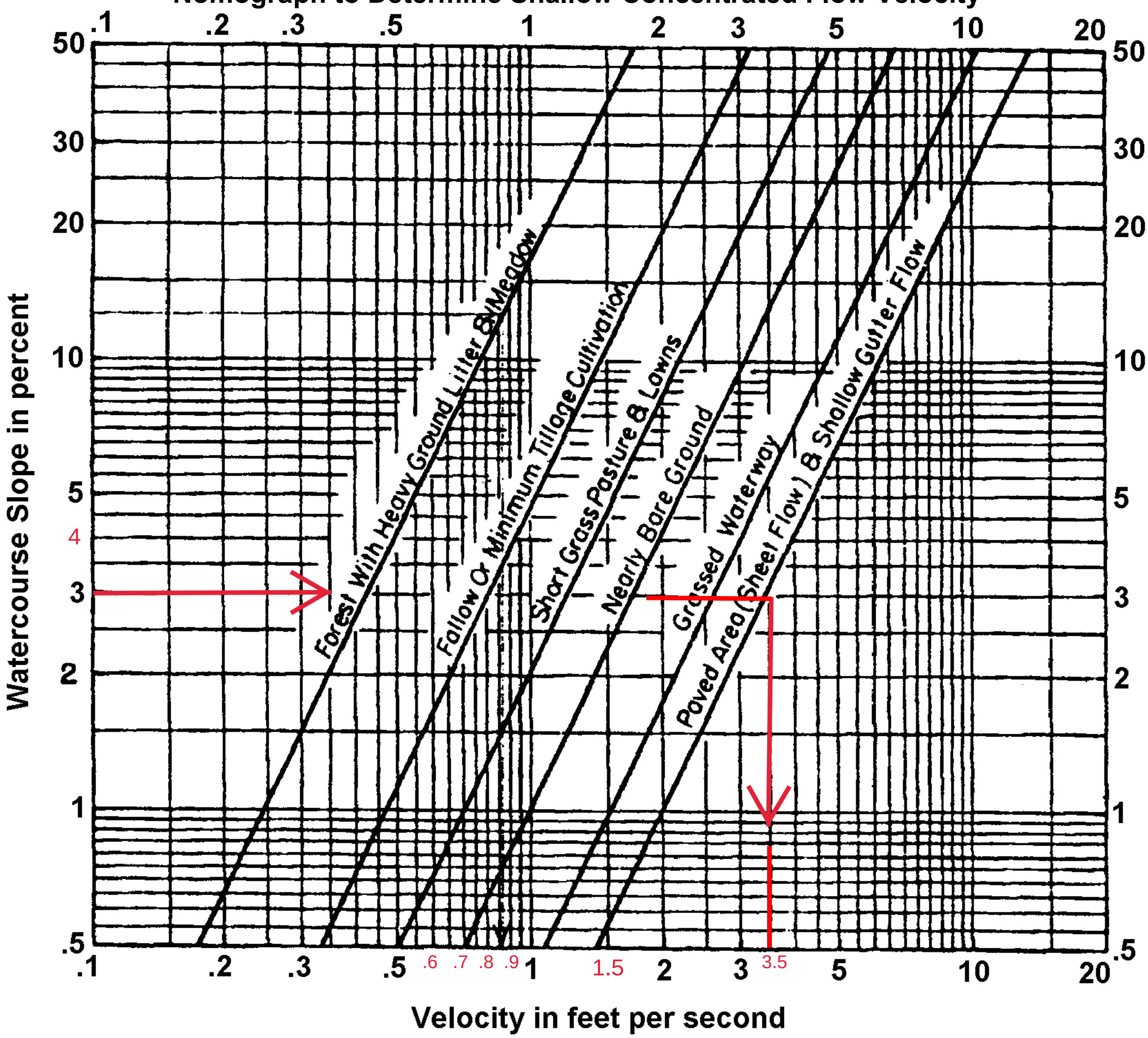
((2*L*n)/(3*(s^.5)))^.4673
Example : Given L =150, s=.02, n =.02

((2*150*.02)/(3*(s^.5))=14.14
14.14^.4673 = 3.44 minutes

**Shallow Concentrated Flow**

That portion of the flow path which is not channelized and cannot be considered sheet flow is considered shallow concentrated flow. The average velocity for shallow concentrated flow may be determined from Figure 5.1, in which average velocity is a function of slope and type of watercourse. **Note:** There is no maximum length for shallow concentrated flow in Pennsylvania.

**FIGURE 5.1**
**Nomograph to Determine Shallow Concentrated Flow Velocity**




TR-55

Example : 3% slope, asphalt
read 3% on left , go right to Asphalt
read down to v= 3.5 fps
READ DIVISIONS CAREFULLY

**Channel Flow**

For open channels, calculate flow velocities by use of Manning's equation. Assume full bank flow conditions.

**Time of Concentration**

Add all flow times (sheet, shallow concentrated, and channel flows) to determine time of concentration ($T_c$) in minutes.

Step 2. Once the time of concentration has been calculated, the rainfall intensity for a 2-year frequency storm can be determined from the following equation[1]:

$$I = \frac{106}{T_c + 17}$$

For a 5- year storm the equation is: $$I = \frac{135}{T_c + 19}$$

For a 10- year storm the equation is: $$I = \frac{170}{T_c + 23}$$

An acceptable alternative to the above equations is the use of Tables 5.4 through 5.9 with Figures 5.2 through 5.12. For this method, determine the appropriate rainfall region map from Table 5.4 using the calculated time of concentration and the design storm event. Locate the project site on the appropriate rainfall region map and identify the rainfall region. Using the rainfall intensity chart for that region and the time of concentration, obtain the rainfall intensity.

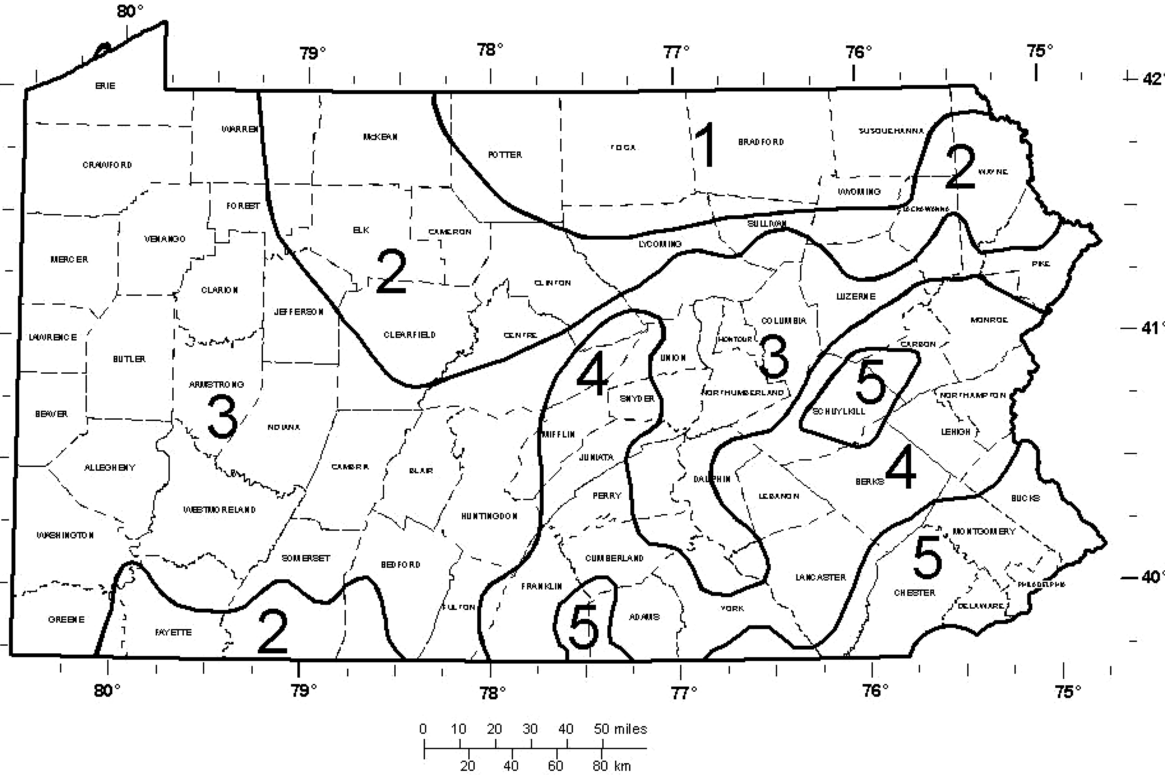
**TABLE 5.4**
**Appropriate Rainfall Region Map for Various Times of Concentration and Frequencies**

| Time of Concentration | Storm Return Frequency (ARI) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
| 5 min | C | C | C | C | B | B | B | - |
| 10 min | C | C | C | C | C | C | C | - |
| 15 min | A | A | A | A | C | C | C | - |
| 30 min | A | A | A | A | A | C | C | - |
| 60 min | A | A | A | A | A | C | C | - |
| 2 hr | E | E | E | E | E | E | E | - |
| 3 hr | E | E | E | E | E | E | E | - |
| 6 hr | D | D | D | D | D | D | D | - |
| 12 hr | F | F | F | F | F | F | F | - |
| 24 hr | F | F | F | F | F | F | F | F |

Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

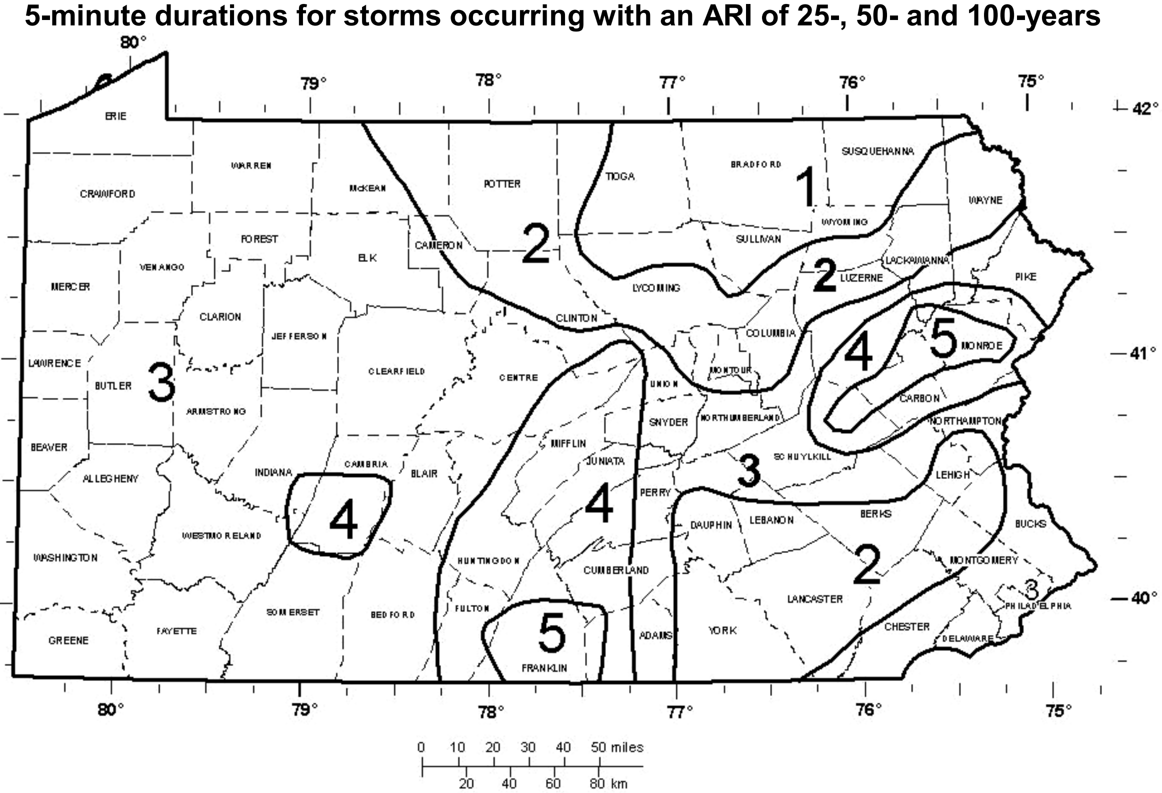
1. Adapted from Lindeberg (2001).

**Figure 5.2 - RAINFALL REGION MAP A**
**15-, 30- and 60-minute durations for storms occurring with an ARI of**
**1-, 2-, 5-, 10-years and 30- and 60-minute durations for storms occurring with an ARI of 25-years**




Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

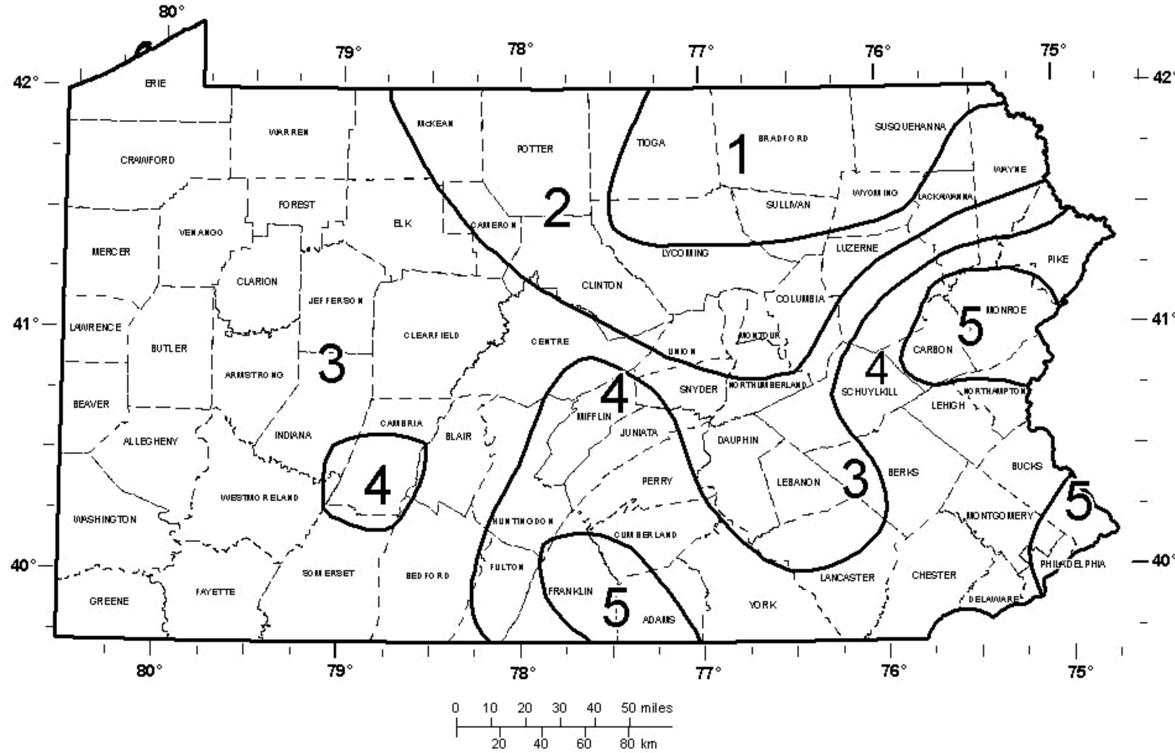
**Figure 5.3 - RAINFALL REGION MAP B**
**5-minute durations for storms occurring with an ARI of 25-, 50- and 100-years**




Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

## Figure 5.4 - RAINFALL REGION MAP C

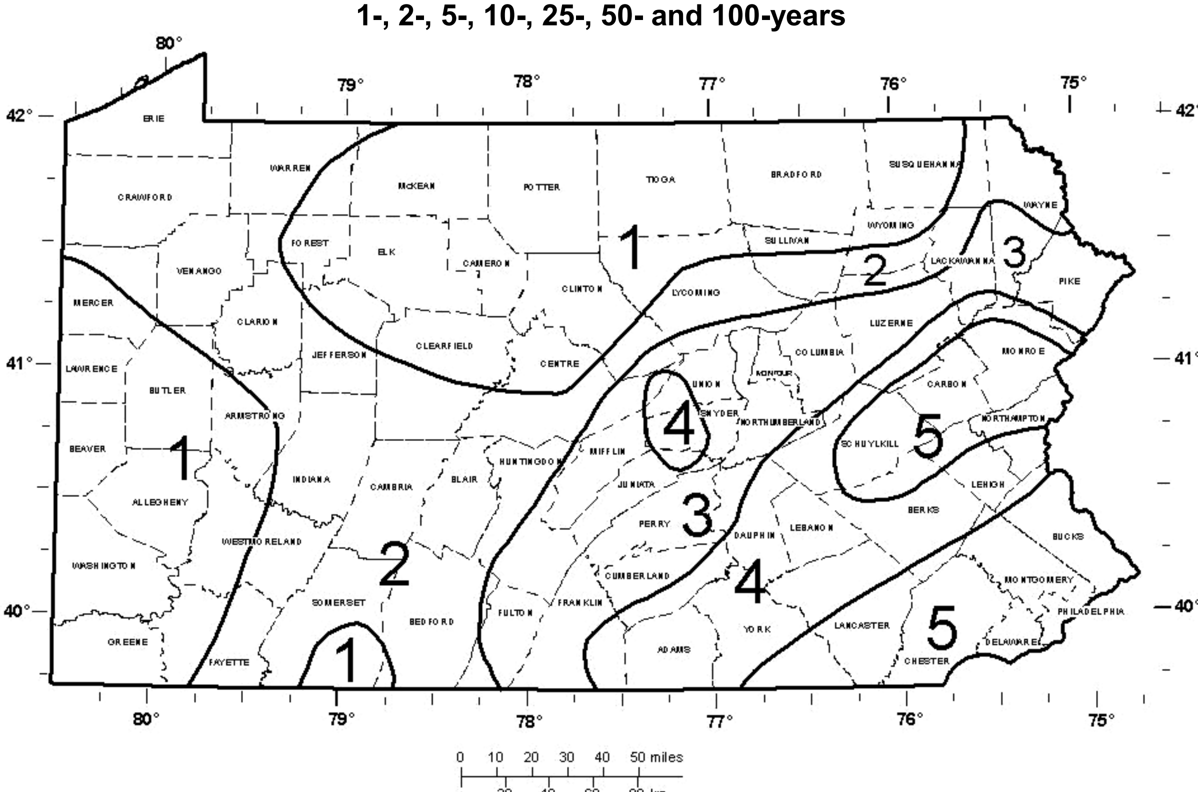
**5- and 10-minute durations for storms occurring with an ARI of 1-, 2-, 5-, and 10-years, 10- and 15-minute durations for storms occurring with an ARI of 25-years and 10-, 15-, 30-, 60-minute durations for storms occurring with an ARI of 50- and 100-years**




Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

## Figure 5.5 - RAINFALL REGION MAP D

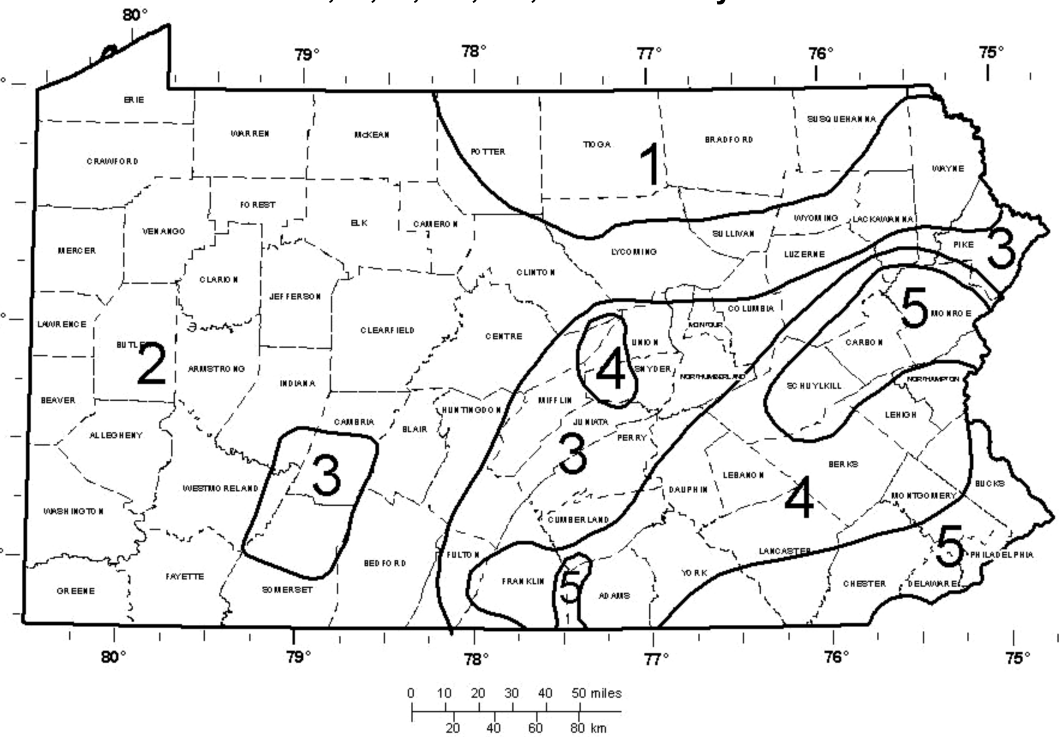
**6-hour durations for storms occurring with an ARI of 1-, 2-, 5-, 10-, 25-, 50- and 100-years**




Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

## Figure 5.6 - RAINFALL REGION MAP E

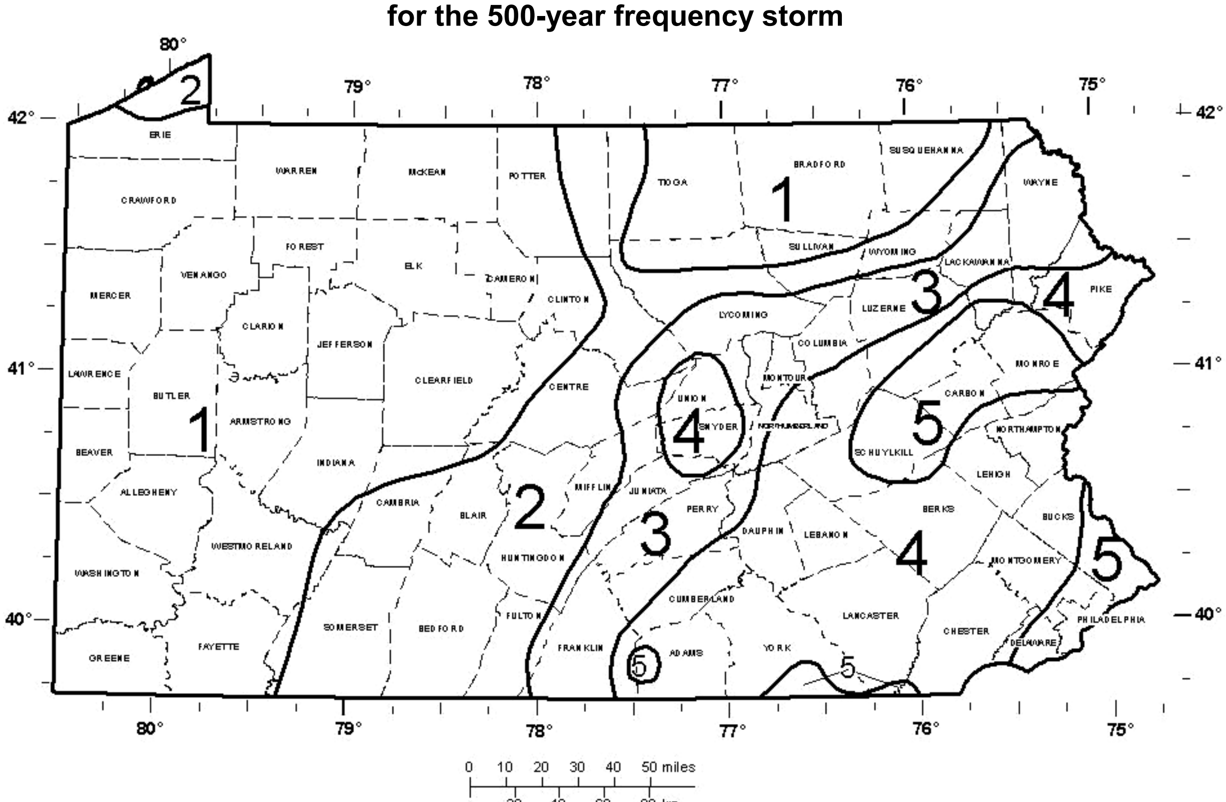
**2- and 3-hour durations for storms occurring with an ARI of 1-, 2-, 5-, 10-, 25-, 50- and 100-years**




Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

## Figure 5.7 RAINFALL REGION MAP F

**12- and 24-hour durations for storms occurring with an average recurrence interval (ARI) of 1-, 2-, 5-, 10-, 25-, 50-, and 100-years and the 24-hour duration for the 500-year frequency storm**



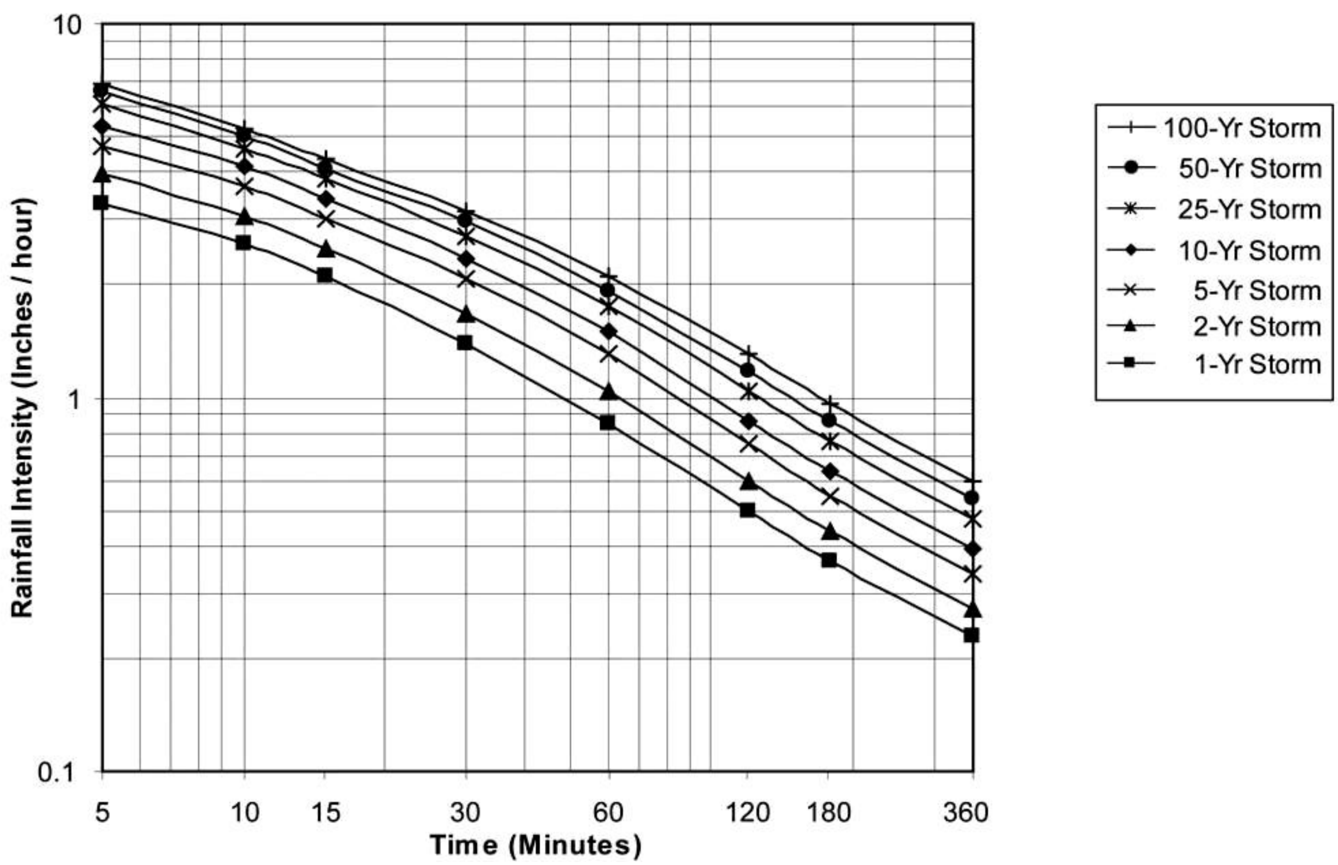

Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

**TABLE 5.5**
**5-Minute through 24-Hour Rainfall Depths for Region 1**

| Time of Concentration | Rainfall Depth (in) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
| **5 min** | 0.28 | 0.33 | 0.39 | 0.45 | 0.51 | 0.55 | 0.58 | - |
| **10 min** | 0.43 | 0.51 | 0.61 | 0.69 | 0.78 | 0.83 | 0.87 | - |
| **15 min** | 0.53 | 0.63 | 0.75 | 0.85 | 0.96 | 1.03 | 1.09 | - |
| **30 min** | 0.70 | 0.84 | 1.03 | 1.18 | 1.36 | 1.47 | 1.57 | - |
| **60 min** | 0.85 | 1.03 | 1.30 | 1.50 | 1.76 | 1.94 | 2.10 | - |
| **2 hr** | 0.99 | 1.19 | 1.49 | 1.74 | 20.8 | 2.35 | 2.62 | - |
| **3 hr** | 1.09 | 1.31 | 1.63 | 1.90 | 2.28 | 2.58 | 2.89 | - |
| **6 hr** | 1.37 | 1.64 | 2.04 | 2.37 | 2.84 | 3.19 | 3.56 | - |
| **12 hr** | 1.69 | 2.02 | 2.49 | 2.91 | 3.52 | 3.97 | 4.46 | - |
| **24 hr** | 2.04 | 2.44 | 2.99 | 3.44 | 4.09 | 4.65 | 5.24 | 6.74 |

Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

**Figure 5.8**
**Rainfall Intensity for 1-year through 100-year Storms for Region 1**



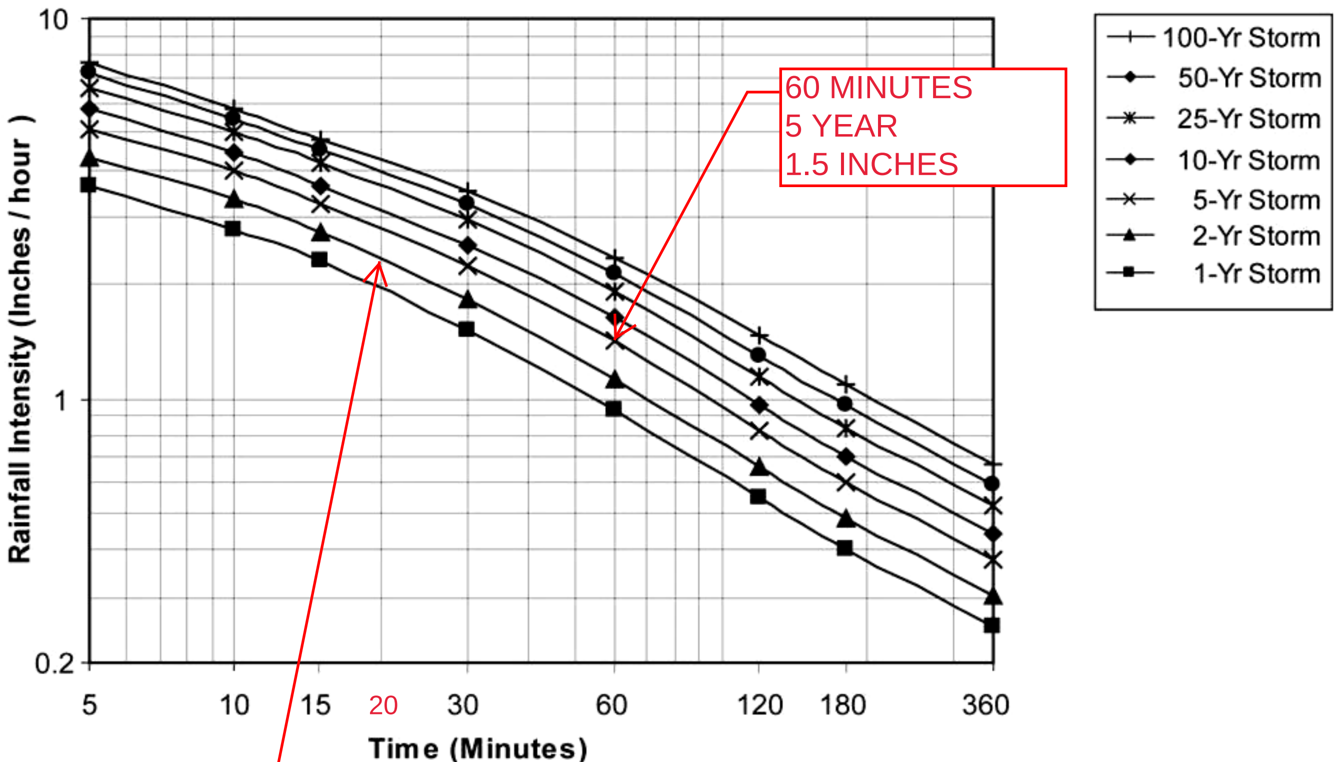

Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

**TABLE 5.6**
**5-Minute through 24-Hour Rainfall Depths for Region 2**

| Time of Concentration | Rainfall Depth (in) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
| **5 min** | 0.30 | 0.36 | 0.43 | 0.48 | 0.55 | 0.60 | 0.64 | - |
| **10 min** | 0.47 | 0.56 | 0.66 | 0.74 | 0.84 | 0.91 | 0.97 | - |
| **15 min** | 0.57 | 0.68 | 0.81 | 0.91 | 1.04 | 1.13 | 1.20 | - |
| **30 min** | 0.76 | 0.92 | 1.12 | 1.27 | 1.47 | 1.61 | 1.74 | - |
| **60 min** | 0.93 | 1.13 | 1.42 | 1.63 | 1.92 | 2.13 | 2.33 | - |
| **2 hr** | 1.09 | 1.32 | 1.65 | 1.92 | 2.29 | 2.60 | 2.94 | - |
| **3 hr** | 1.20 | 1.45 | 1.81 | 2.10 | 2.52 | 2.87 | 3.25 | - |
| **6 hr** | 1.51 | 1.81 | 2.26 | 2.63 | 3.16 | 3.57 | 4.00 | - |
| **12 hr** | 1.86 | 2.23 | 2.76 | 3.23 | 3.92 | 4.47 | 5.06 | - |
| **24 hr** | 2.24 | 2.68 | 3.30 | 3.82 | 4.60 | 5.27 | 6.03 | 8.15 |

Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

**Figure 5.9**
**Rainfall Intensity for 1-year through 100-year Storms for Region 2**




Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

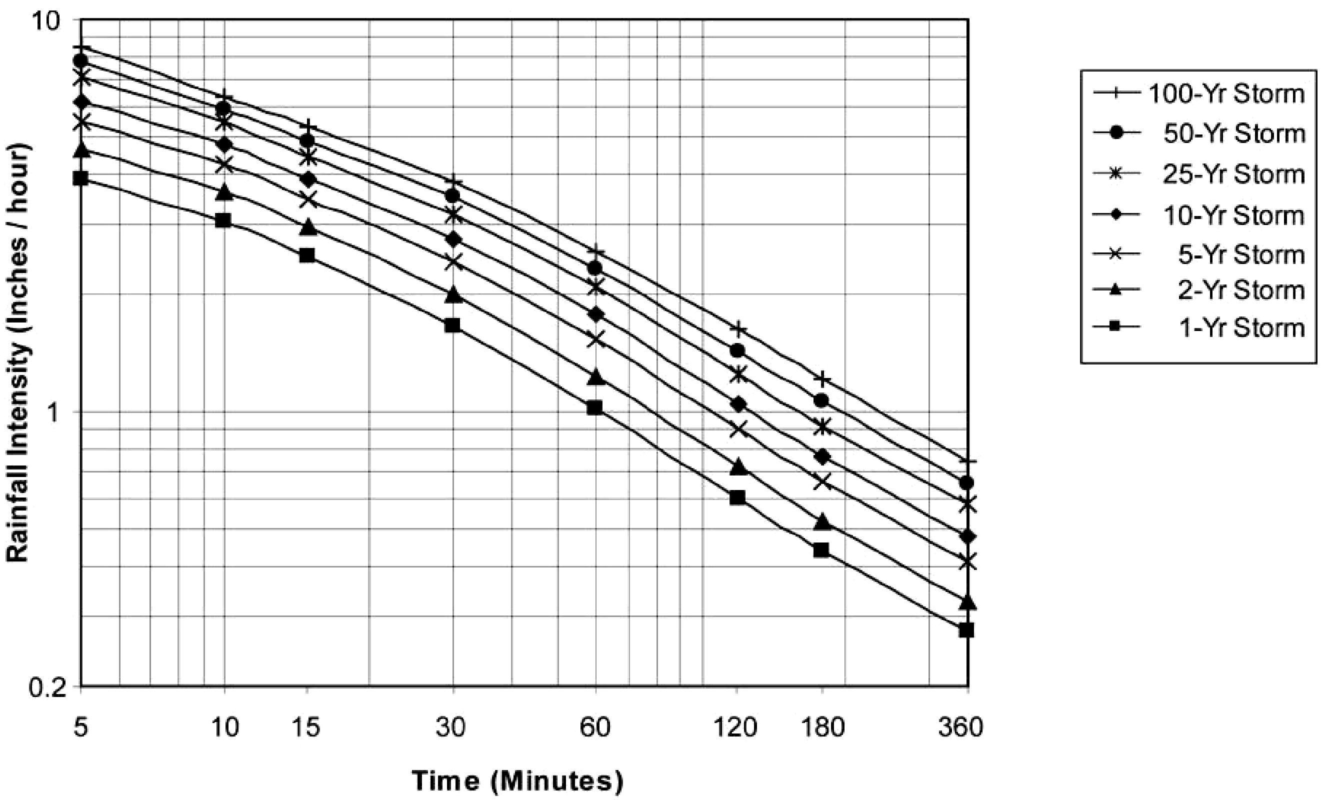
20 MINUTES
2 YEAR
2.3 INCHES

**TABLE 5.7**
**5-Minute through 24-Hour Rainfall Depths for Region 3**

| Time of Concentration | Rainfall Depth (in) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
| **5 min** | 0.32 | 0.39 | 0.46 | 0.51 | 0.59 | 0.65 | 0.71 | - |
| **10 min** | 0.50 | 0.60 | 0.71 | 0.80 | 0.91 | 0.99 | 1.06 | - |
| **15 min** | 0.62 | 0.74 | 0.88 | 0.98 | 1.12 | 1.22 | 1.32 | - |
| **30 min** | 0.82 | 0.99 | 1.20 | 1.37 | 1.59 | 1.75 | 1.92 | - |
| **60 min** | 1.01 | 1.23 | 1.53 | 1.77 | 20.8 | 2.32 | 2.57 | - |
| **2 hr** | 1.19 | 1.44 | 1.81 | 2.10 | 2.51 | 2.85 | 3.26 | - |
| **3 hr** | 1.31 | 1.58 | 1.98 | 2.30 | 2.77 | 3.16 | 3.62 | - |
| **6 hr** | 1.64 | 1.98 | 2.48 | 2.89 | 3.48 | 3.95 | 4.45 | - |
| **12 hr** | 2.03 | 2.44 | 3.03 | 3.55 | 4.33 | 4.97 | 5.66 | - |
| **24 hr** | 2.44 | 2.92 | 3.61 | 4.20 | 5.10 | 5.90 | 6.83 | 9.57 |

Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

**Figure 5.10**
**Rainfall Intensity for 1-year through 100-year Storms for Region 3**



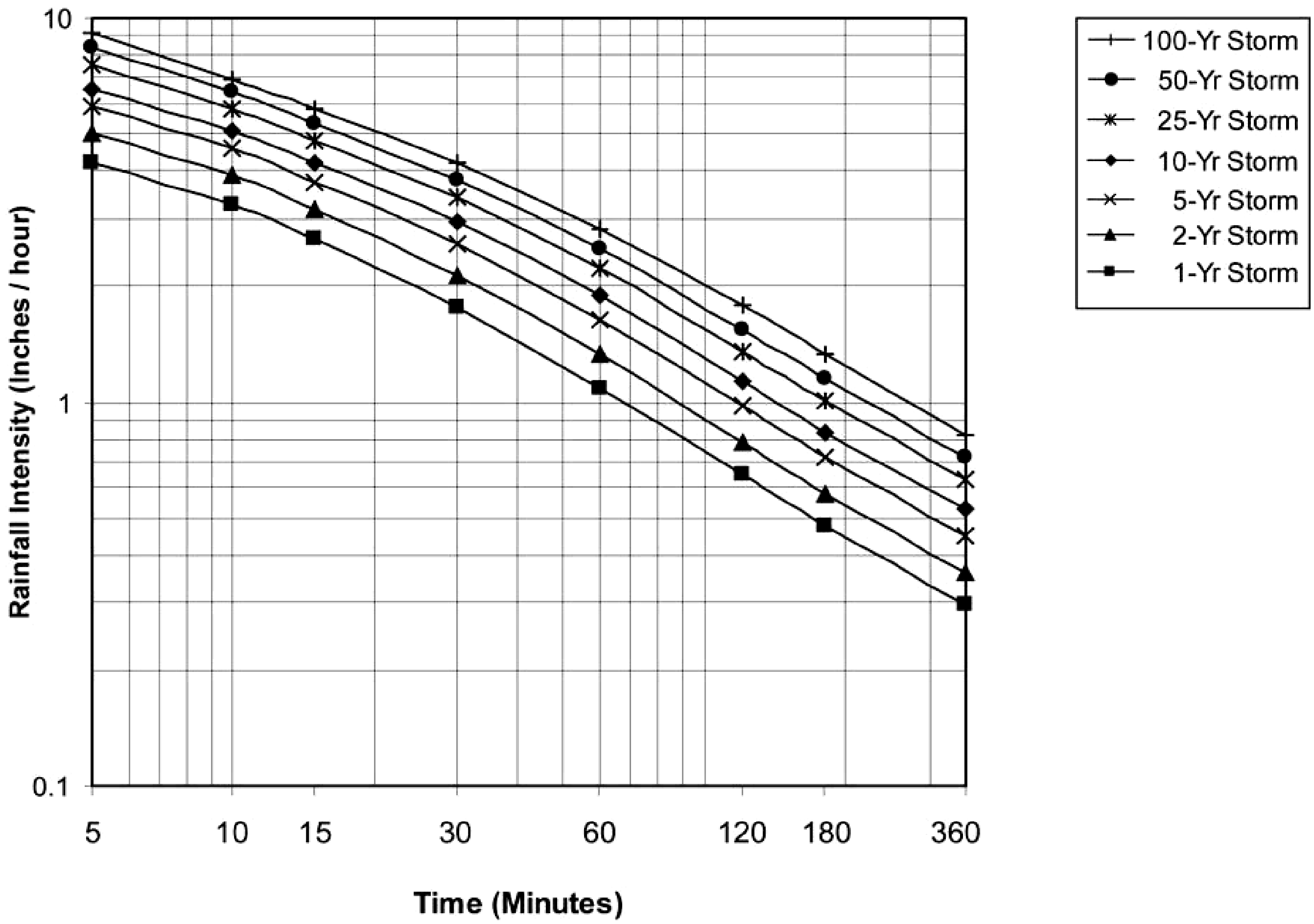

Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

**TABLE 5.8**
**5-Minute through 24-Hour Rainfall Depths for Region 4**

| Time of Concentration | Rainfall Depth (in) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
| **5 min** | 0.35 | 0.42 | 0.49 | 0.55 | 0.63 | 0.70 | 0.77 | - |
| **10 min** | 0.54 | 0.65 | 0.76 | 0.85 | 0.97 | 1.07 | 1.16 | - |
| **15 min** | 0.67 | 0.79 | 0.94 | 1.05 | 1.21 | 1.32 | 1.44 | - |
| **30 min** | 0.88 | 1.07 | 1.29 | 1.47 | 1.71 | 1.90 | 2.09 | - |
| **60 min** | 1.09 | 1.32 | 1.65 | 1.90 | 2.23 | 2.51 | 2.80 | - |
| **2 hr** | 1.29 | 1.57 | 1.96 | 2.28 | 2.72 | 3.09 | 3.58 | - |
| **3 hr** | 1.42 | 1.72 | 2.16 | 2.51 | 3.01 | 3.45 | 3.98 | - |
| **6 hr** | 1.77 | 2.14 | 2.70 | 3.15 | 3.80 | 4.33 | 4.89 | - |
| **12 hr** | 2.20 | 2.65 | 3.29 | 3.87 | 4.74 | 5.46 | 6.26 | - |
| **24 hr** | 2.64 | 3.16 | 3.91 | 4.57 | 5.60 | 6.53 | 7.63 | 10.98 |

Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

**Figure 5.11**
**Rainfall Intensity for 1-year through 100-year Storms for Region 4**



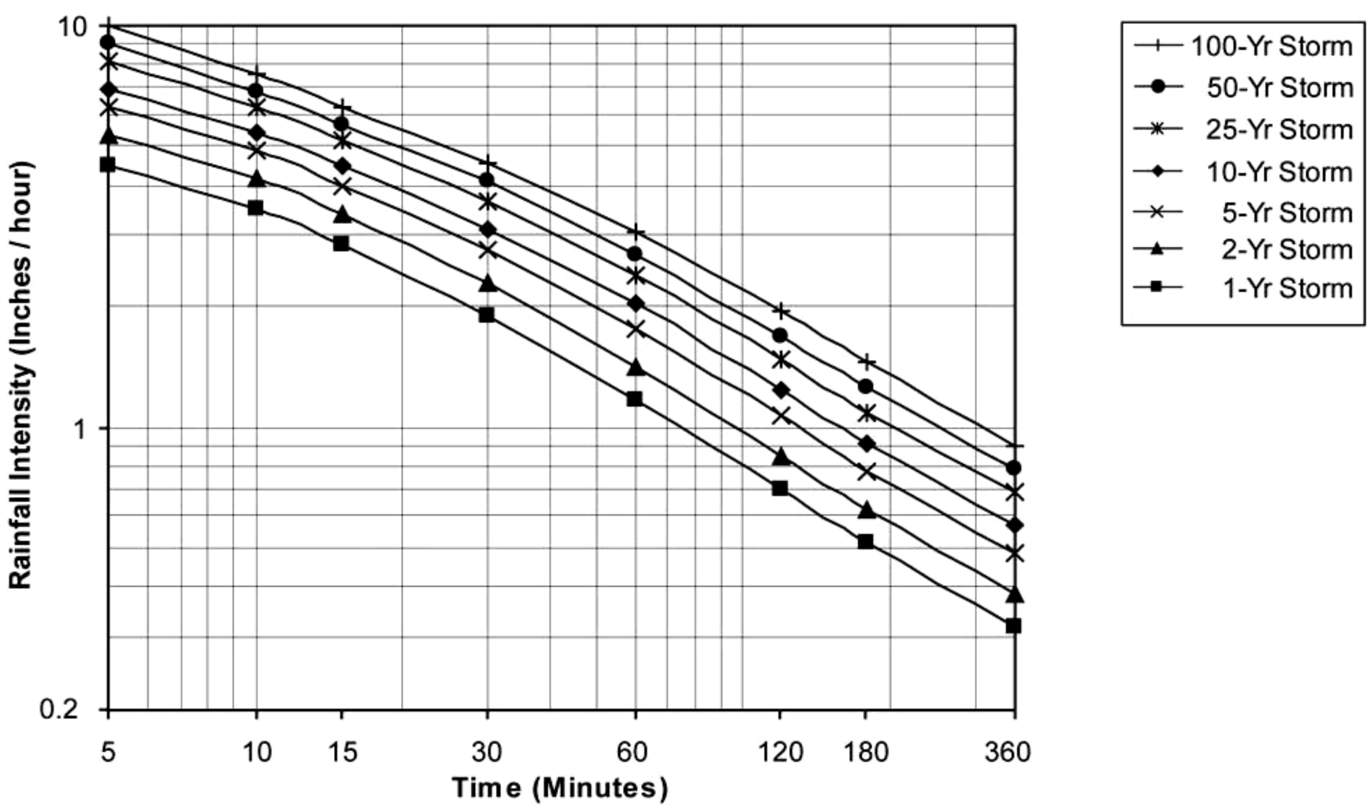

Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

## TABLE 5.9
## 5-Minute through 24-Hour Rainfall Depths for Region 5

| Time of Concentration | Rainfall Depth (in) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 year | 2 year | 5 year | 10 year | 25 year | 50 year | 100 year | 500 year |
| **5 min** | 0.37 | 0.45 | 0.52 | 0.58 | 0.68 | 0.75 | 0.83 | - |
| **10 min** | 0.58 | 0.69 | 0.81 | 0.90 | 1.04 | 1.15 | 1.26 | - |
| **15 min** | 0.71 | 0.85 | 1.00 | 1.11 | 1.29 | 1.42 | 1.56 | - |
| **30 min** | 0.94 | 1.14 | 1.37 | 1.56 | 1.82 | 2.04 | 2.27 | - |
| **60 min** | 1.17 | 1.42 | 1.76 | 2.03 | 2.39 | 2.69 | 3.04 | - |
| **2 hr** | 1.39 | 1.69 | 2.12 | 2.46 | 2.93 | 3.34 | 3.90 | - |
| **3 hr** | 1.53 | 1.86 | 2.33 | 2.71 | 3.25 | 3.75 | 4.34 | - |
| **6 hr** | 1.91 | 2.31 | 2.91 | 3.40 | 4.12 | 4.70 | 5.34 | - |
| **12 hr** | 2.37 | 2.86 | 3.56 | 4.20 | 5.15 | 5.96 | 6.86 | - |
| **24 hr** | 2.83 | 3.40 | 4.22 | 4.95 | 6.10 | 7.16 | 8.43 | 12.40 |

Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

**Figure 5.12**
**Rainfall Intensity for 1-year through 100-year Storms for Region 5**




Adapted from Appendix A of PennDOT Publication 584 (2008 Edition)

Drainage Area (A) - Determine the drainage area in acres. Since drainage areas often change during grading operations, the area to be used is the maximum area tributary to the facility in question during construction. This will not necessarily be either the pre- or post-grading drainage areas.

Perform the calculations to determine the peak flow rate (cfs) for each desired frequency storm.

SAMPLE COMPUTATION

In this example, the peak runoff from a ten-acre watershed (3.5 acres wooded and 6.5 acres in meadow) above a proposed temporary diversion channel will be calculated for a site at State College, PA. From the NRCS soil map, it is determined that the site is located in soils belonging to the Opequon-Hagerstown complex (Hydrologic soil group C). The channel is 1,000 feet long, and the longest flow path above the channel is 435 feet (285 feet through meadow and 150 feet through woods). The slope immediately above the channel is 8% and wooded, while the meadow portion has a 3% slope. The proposed channel is trapezoidal, 2 feet deep and 2 feet wide at the bottom with 2H:1V side slopes. The channel has a uniform bed slope of 0.01 ft/ft; a grass lining with a temporary liner is provided. The 2-yr, 1-hour rainfall is 1.15 inches.

Determine the Weighted Runoff Coefficient ($C_w$).

The forest is mature, so ground litter is light. Therefore, a value of ~~0.40~~ 0.16 is chosen for the wooded area. The meadow is native grasses, so a value of ~~0.15~~ 0.28 is chosen.

Using the equation for a weighted runoff coefficient:

$$C_w = \frac{(C_1 \times A_1) + (C_2 \times A_2)}{A\ (\text{total})} = \frac{(.40 \text{ X } 3.5) + (.15 \text{ X } 6.5)}{(3.5 + 6.5)} = \frac{1.4 + .98}{10} = .24$$

Calculate the Time of Concentration ($T_c$).

Sheet Flow - The maximum sheet flow length is 150 feet. From the soils map, it is determined that a significant component of this soil type is poorly drained. Therefore, a flow length less than the maximum is appropriate; 100 feet is selected. A value of 0.8 is chosen for the "n" value of the meadow (Table 5.3). By plugging this figure into the Overland Flow equation, we can calculate a travel time of 14.55 minutes.

Shallow Concentrated Flow - Since only 100 feet of the 435' flow path is sheet flow, the remainder (335') is considered shallow concentrated. 185 feet of that is still in meadow, while 150 feet is through a wooded area. On Figure 5.1, the watercourse slope of 0.03 ft/ft (3%) is located along the left hand side. Following a horizontal line to the intersection with the "Fallow or Minimum Tillage Cultivation" line, the average velocity (0.8 fps) is read along the bottom. This is the average velocity of the runoff for the remainder of the meadow flow path. The travel time for shallow concentrated flow though meadow is (185/0.8) ÷ 60 seconds per minute = 3.85 minutes. Similarly, the 150' flow path through the woods (8% slope) has an average velocity of 0.70 ft/sec for a travel time of 3.57 minutes.

Channel Flow - In this portion of the calculation, the proposed channel dimensions are used to estimate the travel time within the temporary channel. Using Manning's equation, the flow velocity within the channel is calculated to be 3.95 fps. By dividing the length of the channel (1,000 ft) by the average velocity, the travel time for this segment is determined to be 4.22 minutes (1,000/3.95 ÷ 60 seconds per minute).

Total Time of Concentration ($T_c$) is the sum of the sheet flow, shallow concentrated, and channel flow (14.55 + 3.85 + 3.57 + 4.22 = 26.19 minutes).

Determine Rainfall Intensity (I)

$$I = \frac{106}{T_c + 17} = \frac{106}{26.19 + 17} = \frac{106}{\sout{45.19}} = 2.45 in/hr$$

43.19

Calculate the peak runoff rate for a 2-year frequency storm using the Rational Equation:

Q = C × I × A
Q = .24 x 2.45 X 10 = 5.9 cfs

If this had been proposed as a permanent channel, the ten-year frequency rainfall depth would be required.

$$I = \frac{170}{T_c + 23} = \frac{170}{26.19 + \sout{26}} = \frac{170}{\sout{52.19}} = \sout{3.26 in}/hr$$

3.46

23 49.19

Q = .24 X 3.26 X 10 = 7.8 cfs

Q=.24x3.46x10 = 8.3 cfs

If Tables 5.4 through 5.9 and Figures 5.2 through 5.12 are used, the appropriate rainfall region map would be Map A (Figure 5.2). State College is located in Region 3 on Map A. Therefore, using Figure 5.10, an intensity of 2.2 in/hr would be determined for the 2-year frequency storm, while the 10-year storm intensity would be 3.1 inches. Obviously these figures would result in peak runoffs slightly less than those calculated using the equations. However, the differences should not result in significant changes to any channels designed to convey those flows.

## Determination of Time of Concentration ($T_c$) Using Standard E&S Worksheet # 9

NOTE: These tables are intentionally blank and should by filled in by the plan preparer.

**OVERLAND FLOW** "Longest" time

| PATH NUMBER | LENGTH L (ft) | "n" VALUE | AVERAGE SLOPE S (ft/ft) | TIME - $T_{of}$ (minutes) |
|---|---|---|---|---|
| DC-1 | 100 | 0.8 | 0.08 | 14.55 |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

$$T_{c(sheet\ flow)} = \left[\frac{2(L)(n)}{3(S)^{0.5}}\right]^{0.4673}$$

**0.02** smooth pavement
**0.1** bare parched soil
**0.3** poor grass cover
**0.4** average grass cover
**0.8** dense grass cover
**(L = 150' maximum)**

**SHALLOW CONCENTRATED FLOW:** "Lesser" Time

| PATH NUMBER | LENGTH (ft) | TYPE OF COVER | AVERAGE SLOPE (ft/ft) | V (ft/sec) | TIME - $T_{sc}$ (minutes) |
|---|---|---|---|---|---|
| DC-1 | 185 | Meadow | 0.03 | 0.80 | 3.85 |
| | 150 | Woods | 0.08 | 0.70 | 3.57 |
| | | | | | |
| | | | | | |
| | | | | SUM | 7.42 |

14.55+7.42+4.22= 26.19

**CHANNEL FLOW:** "Quickest" Time

| PATH NUMBER | LENGTH (ft) | AREA (sq. ft.) | AVERAGE SLOPE (ft/ft) | WETTED PERIMETER (ft) | HYDRAULIC RADIUS (ft) | MANNING'S n | V (ft/sec) | CHANNEL TIME-$T_{ch}$ (minutes) | $T_c$* (minutes) |
|---|---|---|---|---|---|---|---|---|---|
| DC-1 | 1,000 | 12 | 0.01 | 10.9 | 1.1 | 0.04 | 3.95 | 4.22 | 26.19 |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

**CHANNEL DIMENSIONS:**

| PATH NUMBER | BOTTOM WIDTH (ft) | LEFT SIDE SLOPE (H:V) | RIGHT SIDE SLOPE (H:V) | TOTAL DEPTH (ft) | TOP WIDTH (ft) |
|---|---|---|---|---|---|
| DC-1 | 2.0 | 2:1 | 2:1 | 2.0 | 10.0 |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

* $T_c$ = Overland Flow Time + Shallow Concentrated Flow Time + Channel Flow Time

# Determination of Peak Runoff (Q) Using the Rational Formula and Standard Worksheet E&S # 10

NOTE: These tables are intentionally blank and should by filled in by the plan preparer.

**DETERMINE WATERSHED "C" VALUES**

| CHANNEL NUMBER | DRAINAGE AREA NUMBER | TYPE OF COVER | C VALUE | AREA (acres) | (C X A) | $C_W$ |
|---|---|---|---|---|---|---|
| DC-1 | A | Woods | 0.13 | 3.5 | 0.46 | .28 |
| | B | Meadow | 0.36 | 6.5 | 2.34 | |
| | Total | | | 10.0 | 2.80 | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

.24 on p 123 but ok

**DETERMINE RAINFALL INTENSITY:**

| CHANNEL NUMBER | $T_c$ | Rainfall Depth $R_2$ | $R_5$ | $R_{10}$ | Rainfall Intensity $I_2$ | $I_5$ | $I_{10}$ |
|---|---|---|---|---|---|---|---|
| DC-1 | 26.19 | 2.6 | | | 2.7 | | |
| | | | | | | | |
| | | | | | 2.45 | | |
| | | | | | | | 3.46 |
| | | | | | | | |

used cuve 5.10?

used formula p114

**DETERMINE PEAK RUNOFF RATES (Q = C x I x A)**

| CHANNEL NUMBER | $C_W$ | I (inches/hr) | A (acres) | $Q_2$ (cfs) | $Q_5$ (cfs) | $Q_{10}$ (cfs) |
|---|---|---|---|---|---|---|
| DC-1 | 0.28 | 2.7 | 10 | 7.6 | | |
| | | | | | | |
| 2 year | 0.24 | 2.45 | 10 | 5.9 | | |
| | | | | | | |
| 10 year | 0.24 | 3.46 | 10 | | 8.3 | |

from p 124

from p 124

## CHAPTER 6 - RUNOFF CONVEYANCE BMPs

The purpose of this chapter is to provide plan preparers with methods and procedures, examples, work forms and references to other commonly applied methods for the design of channels, berms, slope pipes, and other structures used to convey runoff around a work area or to a sediment removal facility. Methods listed or referenced in this chapter are generally considered to be the most commonly used methods and procedures in the field of erosion and sediment control. However, the listed or referenced materials are not all inclusive and the Department will, on a case-by-case basis, accept other methods and procedures that are correctly selected and applied by persons qualified and/or licensed to perform such computations. The Department encourages the use of methods and procedures listed or referenced in this manual. Such use will facilitate review of E&S plans by the Department or a conservation district.

**In general, runoff conveyance BMPs have little, if any, potential for sediment removal and are not ABACT BMPs for special protection watersheds. However, they may be used to make other BMPs that are ABACT work more effectively.**

### CHANNELS

Channels are used for several purposes. Collector channels are used to collect runoff from disturbed areas and convey it to a sediment removal facility prior to discharge into receiving surface waters. Diversion channels are used to divert runoff from undisturbed upslope areas and convey it around areas of earth disturbance. Conveyance channels are used to convey discharges from sediment removal facilities or stormwater outfalls to receiving surface waters. (NOTE: Berms, whether used as diversions or collectors, should be designed and stabilized in the same manner as channels.) In steep slope situations (bed slope $\geq$ 10%) consideration should be given to the use of slope pipes (Standard Construction Detail # 6-5).

Design temporary channels to convey the required capacity ($Q_r$), which is either 1.6 cfs/acre or the calculated peak discharge from a 2-year/1-hour storm event. In special protection watersheds, design temporary channels to convey 2.25 cfs/acre or the peak discharge from a 5-year/1-hour storm. Design all permanent channels to convey either 2.75 cfs/acre or the calculated peak discharge from a 10-year/1-hour storm event. If the Rational Method is used, it is recommended that Standard E&S Worksheets # 9 and # 10 be used to determine the required capacity ($Q_r$).

Designs for temporary and permanent channels should include calculations that clearly demonstrate that the channels have sufficient capacity to safely convey the design flows to the points of discharge and that the channel beds and side slopes will be stable. Standard E&S Worksheet # 11 should be used for this purpose.

Align all channels and berms so as to provide positive drainage throughout. Sharp turns, high angles of confluence, and very low gradients (< 1% bed slope) should be avoided wherever possible. Channels typically require protective linings. The permissible velocity design method may be used for linings of channels with bed slopes less than 10%, while the allowable shear method is acceptable for all channel bed slopes. Use of rock check dams is not an acceptable alternative to a properly designed channel lining. Wherever it is necessary for construction vehicles to cross one of these channels, an adequately sized temporary crossing pipe with clean rock fill and clean rock approaches should be provided.

The permissible velocity or allowable shear stress used for lining design should be sustainable for a reasonable period of time (20 minutes minimum). Using a manufacturer's permissible velocity or allowable shear stress that is only sustainable for a short period of time can result in failure of the channel lining during design storm events; therefore the long-term values should be used for design purposes.

Channels requiring protective liners should be either trapezoidal or parabolic in cross-section. V-shaped channels are not recommended for channels having fabric or geotextile liners due to the tendency for gaps to be left under the lining at the bottom of the channel. Where it is necessary to construct V-shaped channels with fabric or geotextile liners, manufacturer's recommendations or PennDOT PUB 72 9RC-73M standards should be strictly followed.

**Manning's Equation** - Flow capacity and velocity in open channels are typically computed by use of Manning's equation. Use of this equation (including derivative forms) is recommended by the Department:

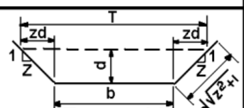
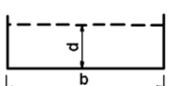
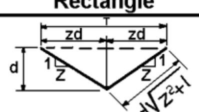
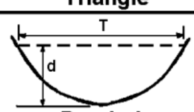
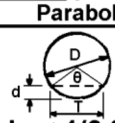
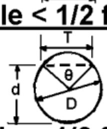
$$Q=\frac{1.486}{n} a r^{2/3} s^{1/2}$$

and

$$V=\frac{1.486}{n} r^{2/3} s^{1/2}$$

Where:
- Q = Quantity of flow (cfs)
- V = Velocity (fps)
- n = Manning's coefficient of roughness
- a = Cross-sectional area of channel (sq. ft)
- P = Wetted perimeter of channel (ft)
- r = Hydraulic radius of channel (ft) = a/P
- s = Slope of channel bottom (ft/ft)

**TABLE 6.1**
**Geometric Elements of Channel Sections**

| Section | Area a | Wetted Perimeter P | Hydraulic Radius r | Top Width T |
|---|---|---|---|---|
|  Trapezoid | $bd + zd^2$ | $b + 2d\sqrt{z^2+1}$ | $\frac{bd + zd^2}{b + 2d\sqrt{z^2+1}}$ | $b + 2zd$ |
|  Rectangle | $bd$ | $b + 2d$ | $\frac{bd}{b + 2d}$ | $b$ |
|  Triangle | $zd^2$ | $2d\sqrt{z^2+1}$ | $\frac{zd}{2\sqrt{z^2+1}}$ | $2zd$ |
|  Parabola | $\frac{2}{3}dT$ | $T + \frac{8d^2}{3T}$ [1] | $\frac{2dT^2}{3T^2+8d^2}$ [1] | $\frac{3a}{2d}$ |
|  Circle < 1/2 full [2] | $\frac{D^2}{8}\left(\frac{\pi\theta}{180} - \sin\theta\right)$ | $\frac{\pi D\theta}{360}$ | $\frac{45D}{\pi\theta}\left(\frac{\pi\theta}{180} - \sin\theta\right)$ | $D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$ |
|  Circle > 1/2 full [3] | $\frac{D^2}{8}\left(2\pi - \frac{\pi\theta}{180} + \sin\theta\right)$ | $\frac{\pi D(360-\theta)}{360}$ | $\frac{45D}{\pi(360-\theta)}\left(2\pi - \frac{\pi\theta}{180} + \sin\theta\right)$ | $D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$ |

[1] Satisfactory approximation for the interval $0 < d/T \le 0.25$
When $d/T > 0.25$, use $p = 1/2\sqrt{16d^2 + T^2} + \frac{T^2}{8d}\sinh^{-1}\frac{4d}{T}$

[2] $\theta = 4\sin^{-1}\sqrt{d/D}$
[3] $\theta = 4\cos^{-1}\sqrt{d/D}$
} Insert θ in degrees in above equations

National Engineering Handbook, Section 5, ES-33

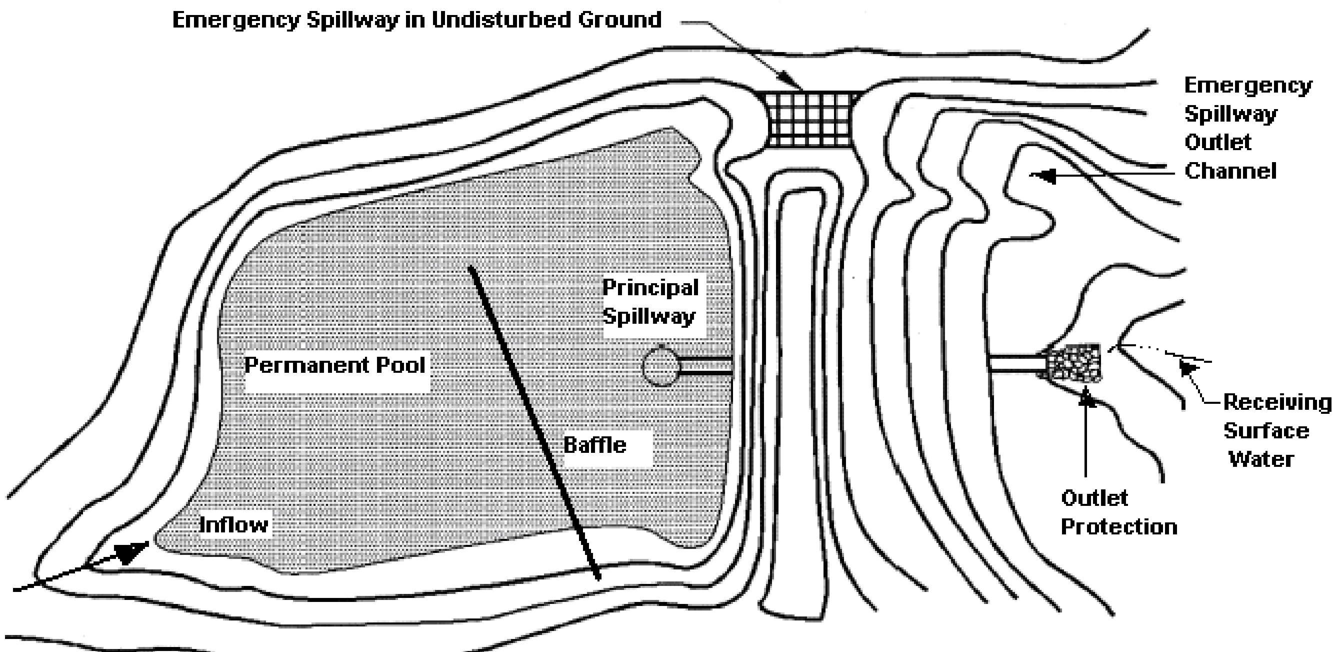
**TABLE 6.9**
**Recommended n Values to be Used with Manning's Equation When Doing Stability Analyses of Receiving Streams**

**Design values should be utilized unless documentation is provided (narrative/calculations) to show that another value within the minimum and maximum range is appropriate.**

| Surface | Min. | Design | Max. |
|---|---|---|---|
| Asphalt Lining | | 0.015 | |
| Brick in cement mortar; brick sewers | 0.012 | 0.015 | 0.017 |
| Concrete-lined channel | 0.012 | 0.015 | 0.018 |
| Cement-rubble surface | 0.017 | | 0.030 |
| Neat cement surfaces | 0.010 | 0.012 | 0.013 |
| Plastic-lined channel | 0.012 | | 0.014 |
| Shotcrete | 0.016 | | 0.017 |
| Asbestos Cement Pipe | | 0.009 | |
| Concrete pipe | 0.012 | 0.015 | 0.016 |
| Vitrified Clay Pipe | 0.010 | 0.013 | 0.017 |
| Common-clay drainage tile | 0.011 | 0.012 | 0.017 |
| Semi-circular metal flumes, smooth | 0.011 | | 0.015 |
| Corrugated | 0.023 | 0.025 | 0.030 |
| Channels and ditches | | | |
| Earth, straight and uniform | 0.017 | 0.023 | 0.025 |
| Rock cuts, smooth and uniform | 0.025 | 0.030 | 0.035 |
| jagged and irregular | 0.035 | 0.040 | |
| Dredged earth channels | 0.025 | 0.028 | 0.033 |
| Earth bottom, rubble sides | 0.028 | 0.030 | 0.035 |
| Natural Streams | | | |
| 1. Clean, straight bank, full stage no rifts or deep pools | 0.025 | | 0.033 |
| 2. Same as 1, but some weeds and stones | 0.030 | | 0.040 |
| 3. Winding, some pools and shoals, clean | 0.033 | | 0.045 |
| 4. Same as 3, lower stages, more ineffective slope and sections | 0.040 | | 0.055 |
| 5. Same as 3, same weeds and stone | 0.035 | | 0.050 |
| 6. Same as 4, stony sections | 0.045 | | 0.060 |
| 7. Sluggish river reaches, rather weedy or with very deep pools | 0.050 | | 0.080 |
| 8. Very weedy reaches | 0.075 | | 0.150 |

Adapted from Table 3.1 in *Applied Hydrology and Sedimentology for Disturbed Areas*

## FIGURE 7.1
## Sediment Basin

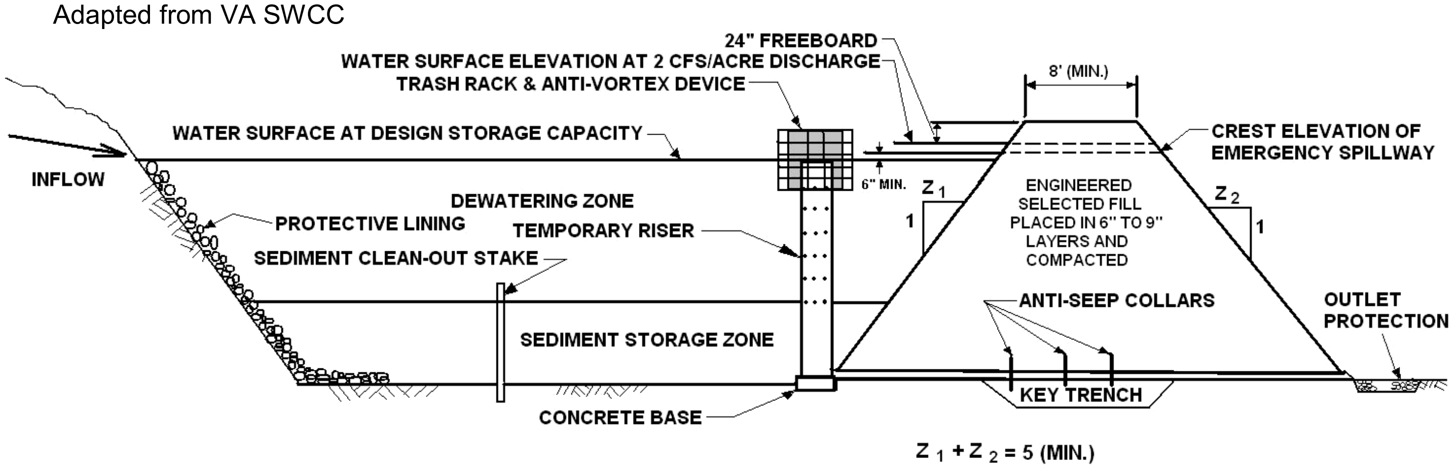



$$\text{AVERAGE WIDTH (W)} = \frac{\text{AREA AT ELEVATION 3}}{\text{L}}$$

WHERE: L = MAXIMUM LENGTH OF BASIN AT ELEVATION 3

**PLAN VIEW**

Adapted from VA SWCC




PA DEP

**TYPICAL SECTION**

**NOTE: This figure is for illustration purposes only and should not be used as a construction detail.**

STORAGE VOLUME CRITERIA

A sediment storage zone of 1,000 cubic feet per disturbed acre within the watershed of the basin is required. The elevation at which the required capacity is provided should be marked on a clean-out stake located near the center of the basin. Accumulated sediment should be removed from the basin whenever it reaches that elevation on the clean-out stake.

A dewatering zone volume of 5,000 cubic feet for each acre tributary to the basin — disturbed and undisturbed — is also to be provided. Reductions in the dewatering zone are allowed for the factors listed below. However the minimum required dewatering zone is at least 3,600 cubic feet per acre. The dewatering zone volume is in addition to the sediment storage volume. No reduction in dewatering zone volume will be permitted in basins located in special protection watersheds; such basins should also use principal spillways that dewater from the top 6 inches of the dewatering zone or have permanent pools greater than or equal to 18 inches deep.

(1) A reduction of 700 cubic feet per acre may be claimed for basins with principal spillways that dewater from the top 6 inches of the dewatering zone.

(2) A reduction of 700 cubic feet per acre for basins with permanent pools greater than or equal to 18 inches average depth. The sediment storage zone is in addition to the permanent pool.

(3) A reduction of 350 cubic feet per acre for basins with flow length to average basin width ratios of 4L:1W or greater at the top of the dewatering zone.

(4) A reduction of 350 cubic feet per acre for basins with dewatering times ranging from 4 to 7 days.

**NOTE: The applicant should demonstrate in the calculations and/or on the plan drawings that the requirements have been met for each volume reduction claimed.**

DESIGN PROCEDURE

**Determine Required Storage and Discharge Capacities**

Standard E&S Worksheet #12 is to be used for this purpose.

1. The drainage area to be used is the maximum area that will be tributary to the basin during construction at the project site. Since watersheds often change during grading operations, roadway construction, installation of sewer lines, and construction of buildings and parking lots, the maximum drainage area is not necessarily the pre- or post-construction drainage area. This area may overlap an adjacent drainage area to another basin. The watershed areas used to size basins should be delineated on the E&S plan maps. If this is not possible or undesirable due to clutter, a legible copy of the work map(s) used to size the basin(s) should be provided.

2. The disturbed area includes all areas that will be disturbed during the life of the basin whether they are all disturbed at the same time or not.

3. Using the criteria above, calculate the required sediment storage volume, and dewatering zone volume.

4. Calculate the required discharge capacity as 2 cfs/acre — disturbed and undisturbed — or the routed 25-year, 24-hour storm.

# CHAPTER 8 - SEDIMENT TRAPS

## GENERAL CONSIDERATIONS

Sediment Traps may be designed to function as temporary facilities, or incorporated into the Stormwater Management System upon completion of the project. In the latter case, the trap should be dewatered, cleaned, and stabilized prior to its conversion to a detention pond. Standard Construction Detail # 7-18, found in Chapter 7 - Sediment Basins, is a detail of a recommended "Sediment Basin or Sediment Trap Sediment Storage Dewatering Facility," which may be used for this purpose.

Field conditions, ease of construction, and trapping efficiency should be considered in choosing the configuration of a sediment trap. There are, however, certain design requirements that should be satisfied for all sediment traps. Standard E&S Worksheet # 19, Sediment Trap Design Data, should be used for organizing and submitting sediment trap data.

Wherever possible, sediment traps should be located below all proposed areas of disturbance. Locating traps within proposed grading areas typically results in a major portion of the earthmoving taking place without benefit of the trap being in place that was designed to handle runoff from the disturbed areas. Collector channels should enter a trap on the upslope side so that they do not adversely affect the storage capacity of the trap.

Consideration should be given to how the location of any proposed trap will be accessed. If a proposed location is not easily accessible, special attention should be given to any access roads that will need to be constructed, as in Chapter 3 on Site Access.

Intersection of a trap by proposed or existing sewer lines, utility lines, roadways, or other structures should be avoided wherever possible. Wherever this is not possible, the plan should address how the integrity/capacity of the trap will be maintained.

Location of traps on steep slopes or on unstable soils should be avoided wherever possible. Where this is not possible, the plan should address how failure of the trap will be avoided. Sediment traps may not be located within stream channels or in wetlands.

Compost filter sock traps may be used for some locations where a temporary sediment trap would be used as long as the installation procedure for such a trap is followed and the type of sock used is suitable for the length of time the trap will be in use. For more information about these types of sediment traps, see Chapter 3 on Site Access.

## DESIGN CRITERIA

1. The maximum permissible drainage area is 5.0 acres.

2. Access to proposed and existing traps should be provided in accordance with the standards provided in Chapter 3. Such accesses should be maintained for the life of the trap. When no longer needed, accesses should be regraded and stabilized in accordance with Chapter 11 – Stabilization Methods and Standards.

3. Sediment traps should have a minimum storage volume of 2,000 cubic feet for each acre of contributing drainage area (disturbed and undisturbed), 700 cubic feet/acre should be considered sediment storage, and 1,300 cubic feet/acre should be considered dewatering zone. Supporting computations should be provided for irregularly shaped traps — Standard E&S Worksheet #14 is recommended for this purpose.

4. Greater surface area increases the trapping efficiency of a sediment trap. For sediment traps located in fine-textured soils (e.g. sandy clay, silty clay, silty clay loam, clay loam, and clay), the minimum surface area in square feet of the storage volume should be 5,300 times the number of contributory drainage acres. For example, a trap with a 5 acre drainage area would need 26,500 square feet of surface area. A trap with a storage volume surface area of approximately 115' X 230' would meet this requirement. Where this is not possible, consideration should be given to the use of a soil stabilizer or compost on disturbed surfaces or using a sediment forebay or a turbidity curtain to increase trap efficiency.

5. Sediment Traps which will be converted into infiltration basins should be constructed in compliance with the Pennsylvania Stormwater Best Management Practices Manual.

6. A stone berm similar to that shown in Standard Construction Detail # 7-3 is recommended for traps that will be converted to stormwater basins. The volume of the berm should be subtracted from the calculated storage volume of the trap.

7. A minimum flow length to width ratio of 4L:1W should be provided for all traps located in special protection watersheds (HQ or EV). A minimum ratio of 2:1 should be provided for all other traps. Minimum length (L) of flow through a trap is 10 feet unless the trap is constructed around an inlet structure. If baffles are needed to achieve this flow length to width ratio, Figure 7.5 and Standard Construction Detail # 7-14 in Chapter 7 may be used for their design. An acceptable alternative is the use of a sediment forebay or turbidity curtain.

8. Sediment traps should discharge to stable, erosion resistant areas and not create offsite stormwater problems. Wherever a trap must discharge down a long or steep slope, consideration should be given to using a barrel/riser or skimmer type spillway in conjunction with a temporary slope pipe. Suitable outlet protection should be provided at the pipe outfall. **NOTE: Any trap not outletting directly to a waterway should not increase rate of runoff onto an adjoining property without an easement from the property owner. Supporting evidence should be provided to show that the discharge will not cause accelerated erosion.**

9. Minimum trap storage depth is 2.0 feet. (Minimum 1' for sediment and 1' minimum for dewatering zone)

10. Traps should be able to dewater the dewatering zone completely. Wherever total dewatering is desired, adequate filtering should be provided.

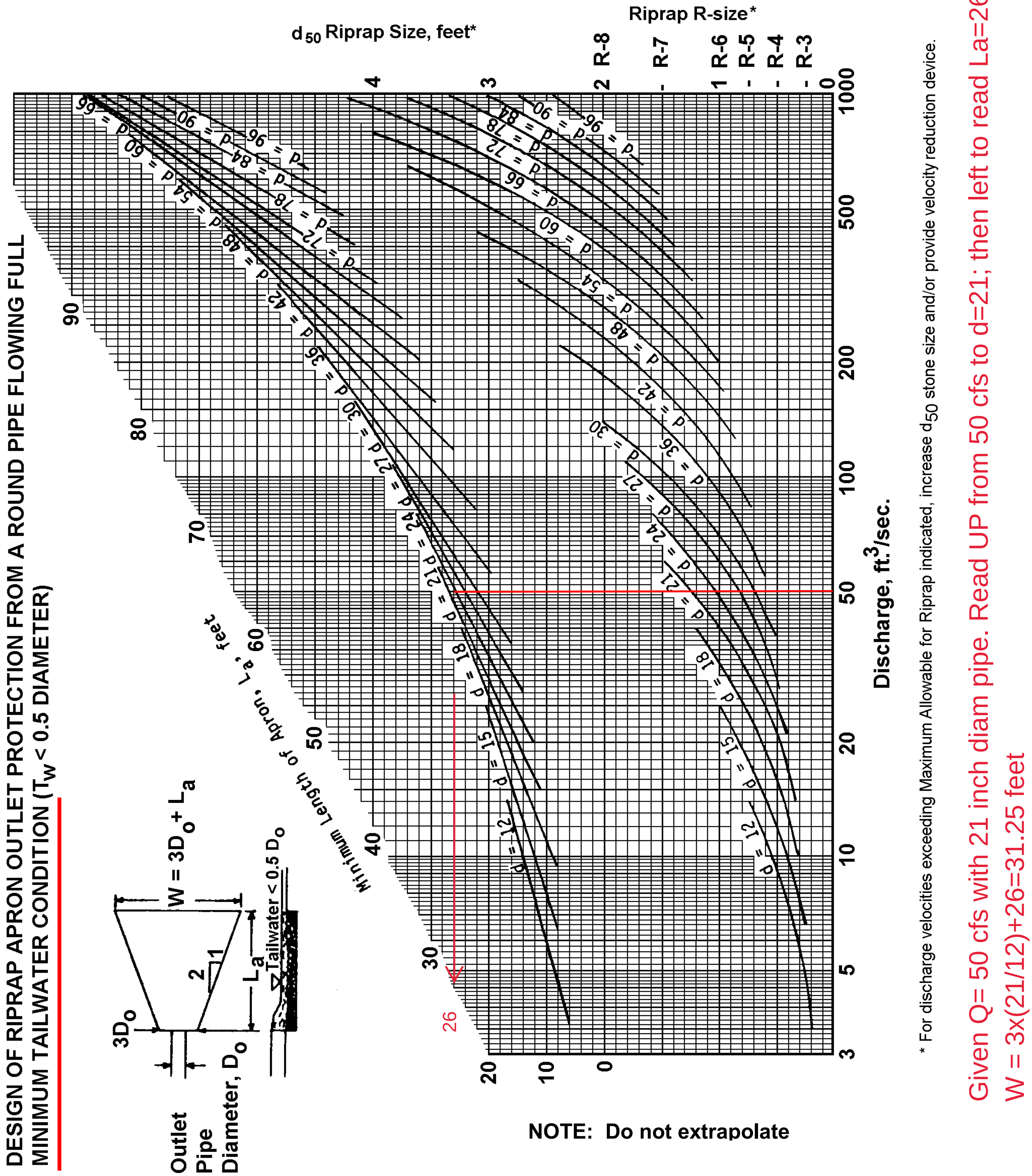
11. Maximum constructed embankment height is 5.0 feet unless the berm is constructed as a permanent stormwater management basin with a corresponding increase in top width. For any sediment trap that will be converted to a permanent stormwater facility, consideration should be given to whether a key trench is needed. See Chapter 7 for more information regarding key trenches.

12. Minimum embankment top width is 5.0 feet.

13. Maximum embankment side slopes are 2H:1V.

14. Minimum freeboard above maximum design water level is 12 inches.

## FIGURE 9.3
## Riprap Apron Design, Minimum Tailwater Condition



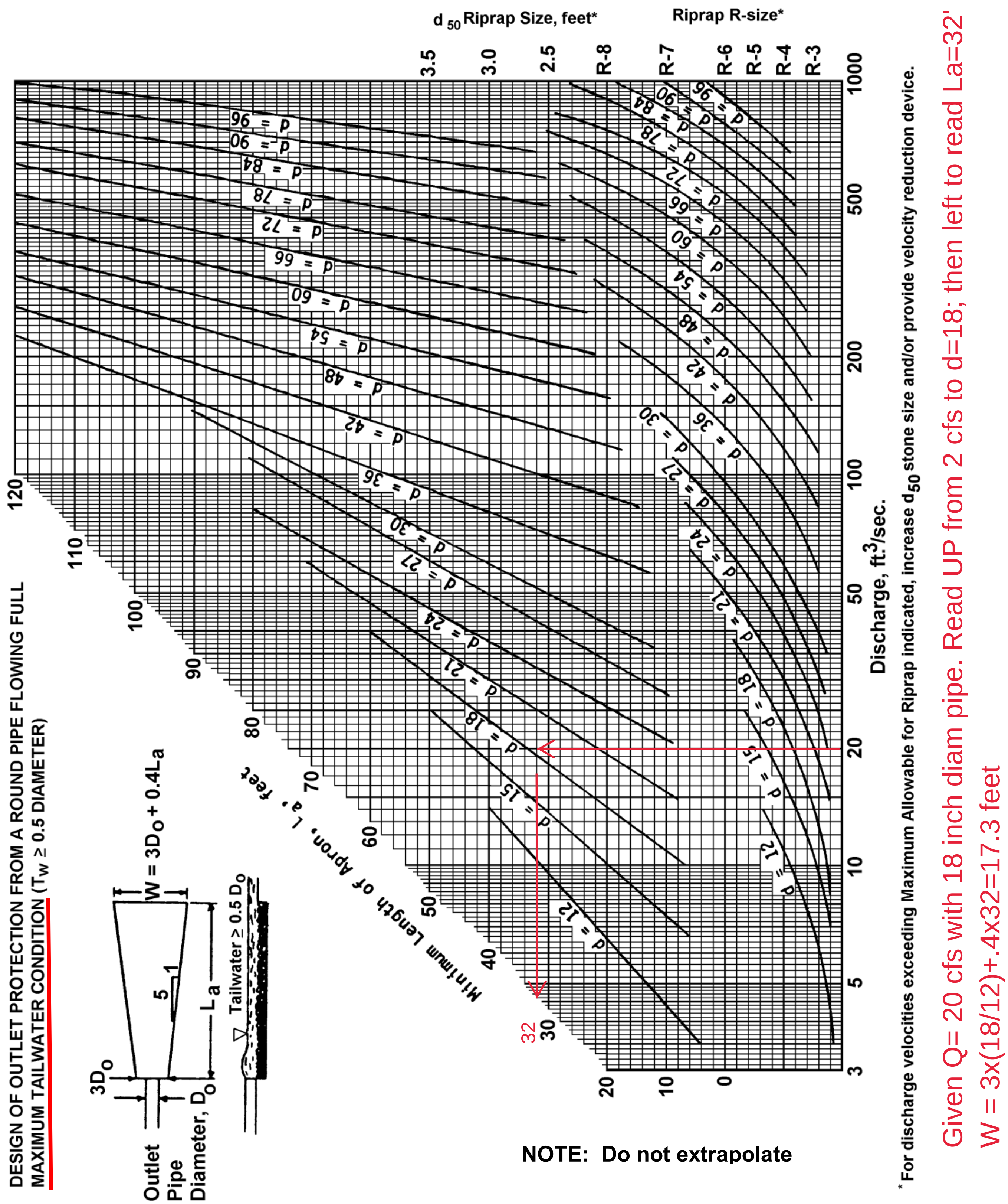

Adapted from USDA - NRCS

Given Q= 50 cfs with 21 inch diam pipe. Read UP from 50 cfs to d=21; then left to read La=26'

W = 3x(21/12)+26=31.25 feet

**Not to be used for Box Culverts**

**FIGURE 9.4**
**Riprap Apron Design, Maximum Tailwater Condition**




Adapted from USDA - NRCS

**Not to be used for Box Culverts**