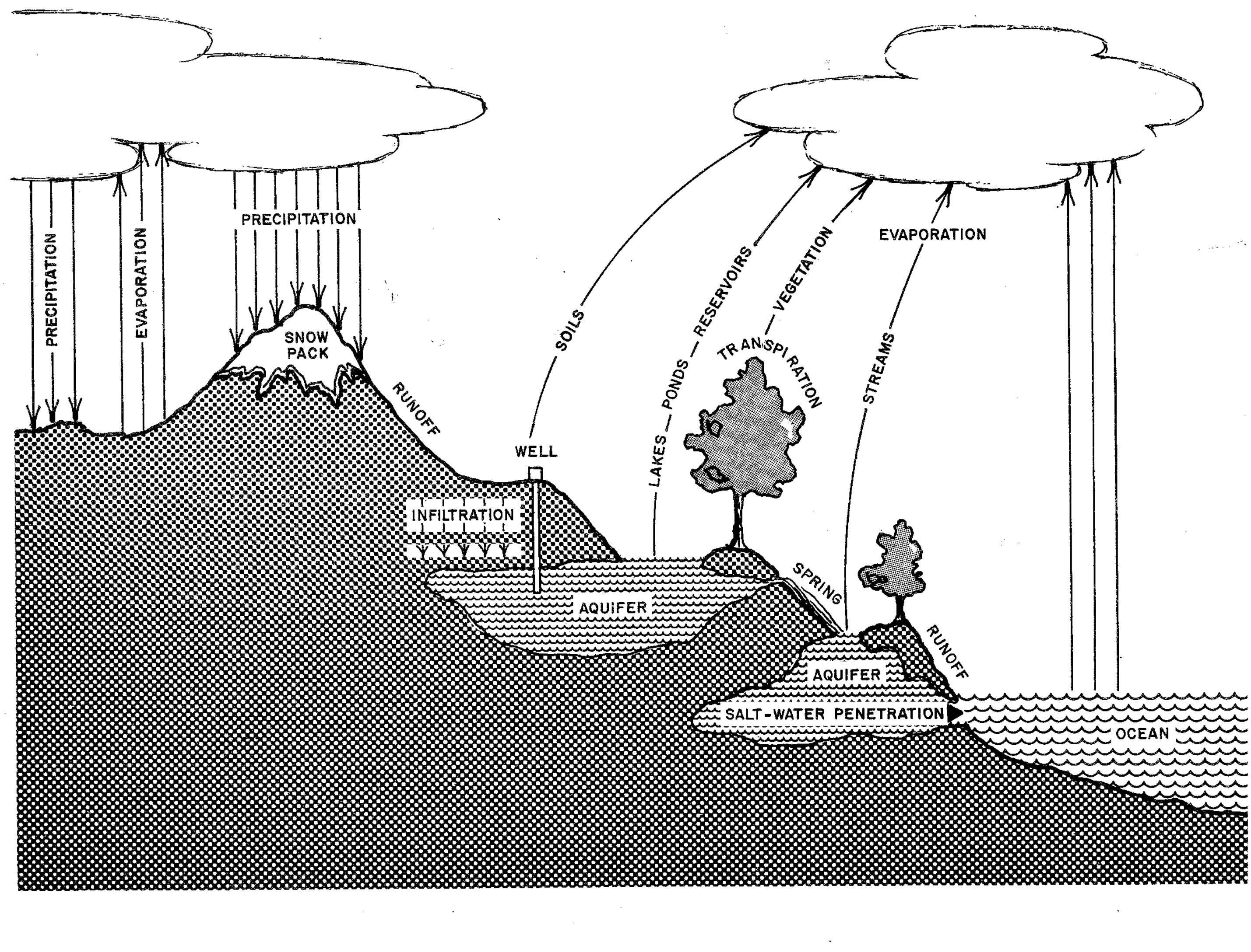
HIGHWAY DRAINAGE MANUAL



Maryland Department of Transportation
State Highway Administration

HIGHWAY DRAINAGE MANUAL

DECEMBER - 1981

MARYLAND DEPARTMENT OF TRANSPORTATION

STATE HIGHWAY ADMINISTRATION

PREFACE

In 1966 House Document 465 was published by the Task Force on Federal Flood Control Policy. Such act was later followed by the 1969 Environmental Protection Act. After numerous intervening legal acts associated with environmental matters, the U.S. Water Resources Council published the following document "A Unified National Program for Flood Plain Management", dated September 1979. Such document sets forth the Federal requirements to meet Executive Order 11998. The State of Maryland, since the formation of the Department of Natural Resources, in 1972, has steadily pursued the task of developing plans for regulating and/or assisting in the regulation of activities within the 100 year flood plain. The Maryland General Assembly in an effort to more closely control State funded activities in the 100 year flood plain, passed the "Flood Hazard Management Act of 1976.

As one of the means for exercising control over activities within the 100 year flood plain, the Water Resources Administration promulgated their "Rules and Regulations governing construction on Non-Tidal Waters and Flood Plains" dated August 11, 1978 and the "Maryland Interim Watershed Management Policy" of 1977. The Federal and State flood plain regulations were in a constant state of change and formation during the entire decade from 1970 to 1980. Such state of change naturally caused considerable confusion in the fields of hydrology and hydraulics especially in relation to highway construction within the 100 year flood plain.

In an effort to eliminate much of the confusion and to set forth criteria State Highway Administration (S.H.A.) deems necessary to meet the Federal and State regulatory requirements, including those of the Federal Highway Administration, the S.H.A. has developed this present document.

While special problems may require unique solutions, the design of most drainage facilities can be accomplished by routine procedures. This criteria will be used in conjunction with the current Standard Plates of the BOOK OF STANDARDS, HIGHWAY AND INCIDENTAL STRUCTURES, Maryland State Highway Administration.

This document prior to its promulgation has been reviewed by the Maryland State Water Resources Administration and the Baltimore Office of the Federal Highway Administration. Since this document is a part of the S.H.A.'s effort to comply with Federal and State regulatory requirements, the need for periodic updating is apparent; therefore, records of persons, firms, etc., utilizing the subject document must be accurately kept for updating purposes. Users cooperation in this matter is respectfully requested.

CONTENTS

PART I - DIVISION OF HIGHWAY DEVELOPMENT

CONTENTS

CONTENTS

PART II - DIVISION OF BRIDGE DEVELOPMENT

CHAPTER 1 - GENERAL

CHAPTER 2 - DESIGN STANDARDS

CONTENTS

PART III

ENVIRONMENT CRITERIA AND PROCEDURES
BUREAU OF LANDSCAPE ARCHITECTURE

PART IV
APPENDICIES
ALL AREAS OF RESPONSIBILITY

INTRODUCTION

A. Organization of Document

This document has been assembled in four parts. Parts I and IV pertain mainly to the hydrologic/hydraulic criteria developed by the Division of Highway Design. Part II has been developed jointly by the Bureau of Project Planning and the Bureau of Bridge Design. Part III has been developed by the Bureau of Landscape Architecture. The reference and Glossary sections of Part IV are applicable to the disciplines of all the S.H.A. responsibility centers.

The Division of Highway Design's Part I and portions of Part IV generally apply to drainage areas less than 400 acres. An exception to the 400 acre criteria is where the hydrologic/hydraulic needs of larger drainage areas can be met with the use of pipe and/or pipe arch construction. (Such work then falls within the Division of Highway Development's area of responsibility). In the event the drainage area is less than 400 acres and concrete box culvert, bridge and/or concrete arch construction is required, the responsibility for such work will fall within the Division of Bridge Development.

The Bureau of Project Planning and Bureau of Bridge Design's Part II generally applies to areas 400 acres or greater. As noted above, regardless of the size of the drainage area, when the structure requirements cannot be met by the use of pipe and/or pipe arch construction, the work will fall within the Division of Bridge Development's area of responsibility.

Part III has been developed by the Bureau of Landscape Architecture. Measures as set forth therein are attempts by the S.H.A. to mitigate impacts caused by S.H.A. activities which fall within the 100 year flood plain.

The Bureau of Project Planning, in addition to Part II, has developed material as necessary for their area of responsbility and has placed same throughout the four parts as needed.

Part IV consists of a glossary, references, design charts and designs aids. The reference and glossary apply to all parts of this document. The design charts apply mainly to Part I, but their use is not necessarily limited to that portion of the document.

B. S.H.A. Objectives:

It should be understood that it is not unlawful to encroach on the base floodplain. S.H.A. procedures do not require nor encourage arbitrary spanning of the base floodplain. The S.H.A. requires identification of practicable alternates to carrying out an action in the floodplain. Attention is directed to pages VI-13 and 14 of the Reference No. 2. "Trade Offs" are referred to on pages II-5 and III-3 of the above reference. The following are objectives of the S.H.A.:

1. to cooperate in a broad and unified effort to prevent uneconomic, hazardous, or imcompatible use and development of the State's flood plains.

2. to avoid longitudinal encroachments, where practicable.

3. to avoid significant encroachments where practicable.

4. to minimize impacts of highway agency actions which adversely affect base flood plains.

5. where practicable, to restore and preserve the natural and beneficial flood plain values that are adversely impacted by highway agency actions.

6. to avoid where practicable, support of imcompatiable flood plain development.

7. to be consistent with the intent of the Standards and criteria of the National Flood Insurance Program, where appropriate.

8. to incorporate "A Unified National Program for Flood Plain Management" of the U.S. Water Resources Council into S.H.A. procedures.

9. to comply with the latest Md. Water Resources Administration's "Rules and Regulations Governing Construction on Non-tidal Waters and Flood Plains" and to comply with the latest W.R.A. "Interim Policy on Storm Water Management, Flood Plain Management, Flood Control and Agricultural Drainage". Attention is directed to the Md. W.R.A. variance of a maximum cumulative backwater increase of 1 foot for bridges and culverts*. The S.H.A. interprets this one foot variance to be consistent with the present State of the art which does not enable one to compute the present and future base flood water surface elevations to a more reasonable degree of accuracy. S.H.A. practice is that when base flood water surface elevations for conditions before and after S.H.A. construction do not change by more than one foot, such computations are interpreted to indicate that there are no reasonably accurate measurable affects on the base flood water surface elevations due to presently proposed S.H.A. construction. Based on such rationale:

   a. When changes in the existing and future base flood water surface elevation are less than one foot the S.H.A. will simply notify by registered letter affected property owners of the hypothetical findings by this Administration.

   b. When changes in the existing and future base flood water surface elevations vary by more than one foot, the S.H.A. will interpret such changes a result of presently proposed S.H.A. construction in the base flood plain. Such additional inundation shall be brought to the attention of affected property owners. Such additional inundated area shall be purchased, placed in designated flood easement or dealt with by means acceptable to the property owner, S.H.A., W.R.A. and F.H.W.A., when applicable.

*W.R.A. variance of backwater increases up to one foot may not be allowed if structures and/or developed property exit within the area of the backwater increase.

c. Design procedures which necessitate the need for trade-offs of W.R.A. and S.H.A. backwater standards should be avoided as a general rule. When such designs are prudently justified, the W.R.A. must be contacted in the early stages of plan development so as to obtain conceptual approvals of designs which increases hypothetical flooding by one foot or more to others, even though such indicated flooding may be of an insignificant nature.

10. to comply with all the latest applicable U.S. Army and U.S. Coast Guard permit programs.

C. Public Involvement

In order to meet the latest Federal and State regulations governing activities in the 100 year flood plain, the S.H.A. has developed procedures for compliance of same. Section C, Chapter 1 of Part II covers this subject in detail, but the concept applies to all 100 year flood plain activity, regardless of watershed size.

D. Location Hydraulic Studies

Such studies are a vital and necessary part of Plan Development. Such studies furnish documentary evidence that other alternatives were considered in detail before the final decisions relative to flood plain activity were adopted. This item is expounded upon in Section D, Chapter I Part II of this document, but the principals and concepts apply to all activities within the 100 year flood plain, regardless of the size of the watershed.

E. Only Practicable Alternative Findings

As a necessary requirement to meet State and Federal regulatory requirements, the S.H.A. must show that any action which includes a significant encroachment has been selected after it has been proven that such selected action constitutes the only practicable alternate. This subject is dealt with in detail in Section E, Chapter 1 of Part II. Such action applied to all activities in the 100 year flood plain, regardless of the size of the watershed involved.

F. Design Storms

The following criteria for our highway network relates classification to design flood frequency and are to be considered minimum values for maintaining vehicular services:

Highway Needs Inventory

AASHTO Classification		Classification	Design Flood Frequency
Expressways	I	Principal Arterials	100
Arterials	II	Intermediate Arterials	50
	III	Minor Arterials	50
Collectors	IV	Major Collectors	25
	V	Minor Collectors	25
Local Roads & Streets	VI	Local Streets	10

For design purposes, the projected Functional Classification as given in the Maryland State Highway Needs Inventory shall be used. For roads not included in the Maryland State Highway Needs Inventory, the correct classfication can be obtained from the S.H.A.'s Bureau of Highway Statistics.

On all new construction or on all rehabilitation projects, drainage structures should be properly sized in order that the appropriate design flood frequency does not inundate the highway.

1. For Ramps to Interstate the System:

   Encroachments on base flood plains by ramps for traffic interchange with Interstate highways may be designed to permit inundation of the ramp from floods smaller than the 100 year design flood where traffic service will not be unduly reduced however, they may not flood from any lesser storm than the cross roads they service. Such ramps shall be posted for flooding, if such floding occurs for storms less than the 25 year storm. The need for such posting must be shown on the construction plans and provided for in the Special Provisions.

2. For Frontage Roads:

   Encroachments on base flood plains by Interstate highway service roads or frontage roads may be designed to permit inundation of the road from the 50 year design flood or design floods smaller than the 50 year design flood except at locations where lower design standards for the service road would interfere with the performance of hydraulic structures for the Interstate roadway or where higher standards can be shown to be warranted. Such service roads inundated by design storms smaller than the 25 year design storms shall be posted for flooding. The need for such posting shall be indicated on the construction plans and provided for in the Special Provisions

G. Level of Environmental Studies by Project Planning:

1. Project Planning studies will identify the design feasibility and acceptability of flood plain involvement and the conceptual mitigation thereto.

2. Close coordination and consultation with the Divisions of Development will continue during Phase II, III and IV work activities. This will especially be true where significant encroachments were identified.

3. Design Year flood frequency criteria may be different for each facility. Criteria, based on the highway classification, shall be considered minimum criteria - the element of risk must also be a design consideration.

4. Generally, the 50 year design flood criteria will be used for all bridge structures on arterial highways. Such criteria is a minimum. For additional details see Section H - Chapter 2 of Part II.

5. The Draft Environmental Impact Statement/Environmental Assessment will identify the 100 year flood plain and conceptually indicate the impacts for each alternate under consideration. The detail of the study would

depend on the signficance of the flood plain involvement. However, studies will always portray the maximum tolerable impacts for the alternates considered, so that the Administrator may consider the "worse case impact", along with the mitigation proposed in the decision making process.

6. The Final Environmental Impact Statement/FONSI will, if required, provide the necessary engineering and environmental detail necessary, for review by the review and permit agencies, for those significant encroachments and offer the review parties the opportunity to weigh and judge the proposals and thus ease permit action during final design.

LIST OF TABLES AND CHARTS

LIST OF TABLES AND CHARTS (CONT'D)

PART I

CRITERIA AND PROCEDURES

FOR

HYDROLOGIC AND HYDRAULIC COMPUTATIONS

FOR

DRAINAGE AREAS LESS THAN 400 ACRES

MARYLAND STATE HIGHWAY ADMINISTRATION

DIVISION OF HIGHWAY DEVELOPMENT

PART I

CHAPTER 1 - DESIGN CRITERIA

Section A. SHA COMPUTATIONS

Hydrologic computations for all State highway Administration design projects shall be made in accordance with the following:

1. All storm drain systems shall be designed using the Rational method.
2. All other storm water facilities draining five (5) acres or less shall be designed using the Rational Method.
3. All cross culverts and storm water management facilities shall be designed using the SCS computer program TR-20.

A detailed discussion of the Rational Method is given in Chapter 2 Section A-1. The SCS Method is described in Section A-2. The design of Culverts, Storm Drains and Stormwater Management Facilities is given in Chapters 3, 4, and 5 respectively.

All SHA projects require approval from the Water Resources Administration (WRA). Projects effecting water courses draining more than 400 acres or more than 100 acres for natural or (recreational) trout streams (as determined by the Department of Natural Resources) require a permit for "Construction on Non-Tidal Waters and Floodplains. Design of these projects as for all projects will be designed herein with one (1) additional set of computations. After each facility is designed it should be analyzed using the ultimate discharge. The ultimate discharge is that discharge which would occur if the watershed was fully developed in accordance with existing zoning. This shall be done for the 100 year storm. This information shall be used to determine if there is any possible hazard to structures downstream, due to increase discharge or upstream, due increased backwater. This information shall be submitted to the WRA.

Design of these projects shall meet the Rules and Regulations set forth in the 1978 Department of Natural Resources 08.05.03.01 Construction in Non-Tidal Waters and Floodplains and Section 8-905 of the Natural Resources Article Annotated Code of Maryland which is reprinted below:

8-905. Flood control measures in State construction projects.

(a) Before actual construction of all State planned or financed construction projects, the Department shall determine whether a project creates a surface water runoff which may cause or add to on-site or downstream flooding hazards, taking into consideration natural conditions, existing storm drainage, future development of watershed and flood control structures.

(b) If the Department determines that an additional flooding hazard will be created by a project, and cannot be taken care of by natural features, the Department shall require storm water management or retention measures to be included in the project. (1976, ch. 659.)

Section B - PRIVATE DEVELOPMENT

1. General

It is desirable that storm drain and storm water management facilities for all private developments be designed to conform with the SHA criteria set forth in this publication. However, the degree of control exercised by the State Highway Administration will differ according to the extent to which the developer's construction is directly involved with State Highway facilities.

All inlets, pipes and other storm drain facilities constructed within the State Highway Administration's right of way must conform with the same criteria used for the design of State Highway Administration projects and must be reviewed and approved by the State Highway Administration.

If the proposed drainage facilities from the development are to connect directly to State Highway Administration drainage facilities from upstream or downstream, the on-site storm drain facilities must conform with the State Highway Administration's criteria. If the development itself drains toward the state highway, the storm water management facilities must also conform with this criteria. Plans for these projects must be reviewed and approved by the State Highway Administration.

If the proposed drainage facilities do not connect directly to State Highway Administration drainage facilities, the State Highway Administration will review the on-site drainage system and storm water management facilities. Compliance with the State Highway Administration's comments will not be mandatory; but if the developer elects not to comply, the State Highway Administration will hold the developer liable for damages to the highway and for corrective action should flooding of the highway result from the developer's construction.

The following procedures will be used in reviewing hydrologic computations submitted to the State Highway Administration and it is recommended that they be used by the developer's engineer in preparing his design computations.

1. All storm drain systems will be reviewed using the Rational Method.

2. All storm water facilities draining five (5) acres or less will be reviewed using the Rational Method.

3. All cross culverts and storm water management facilities draining more than five (5) acres will be reviewed using the "United States Soil Conservation Service Hydrograph Method" utilizing either (1) the TR-20 computer program or (2) the TR-55 tabular Hydrograph Method.

2. Control Structures

If the developer's control structure is connected directly to a State Highway Administration culvert, some means of physical access must be provided at the right-of-way line. The Control structures must be sized for proper 2-year, 10-year, and 100-year release rates regardless of the size of the pipe or orifice requred. (See Chapter IV-Stormwater Management)

In all cases the designer should consult federal, local and other state agencies for additional storm water management regulations.

PART 1

CHAPTER 2 - BASIC CONCEPTS

Section A.

Hydrology - In the design of drainage facilities, the basic computation is the determination of runoff. This can be done by either of two (2) methods: the Rational Method, or the SCS (Soil Conservation Service) Method.

1. The Rational Method - The basic formula for use with this method is:

   $Q = CiA$ (1)

   For use in this manual, to include a modification factor, it will be expressed in the following form:

   $Q = Cii_fA$ (2)

   where:

   Q = the rate of flow at the point of investigation (in cubic feet per second)

   C = the coefficient of runoff

   i = the rainfall intensity for the storm duration and return frequency (in inches per hour)

   i_f = the intensity coefficient

   A = the drainage area (in acres)

If reasonable estimates of runoff are to be obtained, care must be exercised in the selection of the values of "C" and "i" to be used.

a. Runoff Coefficient - The runoff coefficient shall be selected on the basis of the types of contributing areas or surfaces. Where heterogeneous areas or surfaces are encountered, a weighted value of the runoff coefficient shall be used. In the determination of the weighted "C" value, each parcel of area shall be assigned a "C" value based upon: soil type, slope, ground cover and/or type of development.

   Soil Type - The authority for determining soil types for use with this criteria will be the United States Department of Agriculture "Soil Survey" which is published in separate volumes for each county. For those not familiar with these reports, the following steps are suggested:

1) Using the Soil Survey for the county involved locate the project site on the maps at the end of the report and note the map symbols involved. e.g. (GgC2, MeD2, etc.)

2) Immediately before the photo map section will be found a listing of map symbols together with the names of the "soil mapping units" that they identify and the pages on which the appropriate description will be found.

3) Each of these units can be converted to one of four hydrologic soil groups by use of Tables SHA-61.1-401.1A; or 401.1B.

HYDROLOGIC SOIL GROUPS

Group A --- Soils having high infiltration rates even when thoroughly wetted, consisting chiefly of deep, well to excessively drained sands and/or gravels. These soils have a high rate of water transmission and would result in a low runoff potential.

Group B --- Soils having moderate infiltration rates when thoroughly wetted, consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission and a moderate runoff potential.

Group C --- Soils having a slow infiltration rate when thoroughly wetted, consisting of (1) soils with a layer that impedes the downward movement of water, or (2) soils with moderately fine to fine texture and a slow infiltration rate. These soils have a slow rate of water transmission and a high runoff potential.

Group D --- Soils having very slow infiltration rates when thoroughly wetted, consisting chiefly of (1) clay soils with a high swelling potential; (2) soils with a high permanent water table; (3) soils with claypan or clay layer near the surface; and (4) shallow soils over nearly impervious materials. These soils have a very slow rate of water transmission and a very high runoff potential.

If more than one soil group is involved, the limits of each group should be outlined on the drainage area map to aid in computing the 'C' factor for each land use or ground cover.

Soil	Group
Adelphia	B
Albrights	C
Aldino	D
Allegheny	B
Alloway	D
Altavista	C
Andover	D
Armagh	D
Ashby	C
Ashton	B
Athol	B
Atkins	D
Augusta	C
Aura	B
Avrock	C
Baile	D
Baltimore	B
Barclay	C
Bayboro	D
Belmont	B
Beltsville	C
Benevola	B
Berks	C
Bermudian	B
Bertie	C
Berwyn	C
Bibb	D
Birdsboro	B
Bladen	D
Bourne	C
Bowmansville	D
Braddock	B
Brandywine	C
Brinkerton	D
Brooke	C
Bucharan	C
Bucks	B
Bulertown	C

Soil	Group
Calvert	D
Calvin	C
Captina	C
Cardiff	B
Caroline	C
Catoctin	C
Cavode	C
Chalfont	D
Chandler	C
Chavies	B
Chester	B
Chewacla	C
Chillum	C
Choptank	A
Christiana	C
Chrome	D
Clymer	B
Codorus	C
Colbert	D
Colemantown	D
Collington	B
Colt's Neck	B
Comus	B
Conestoga	B
Congaree	B
Conowingo	C
Cookport	C
Corydon	C
Croom	C
Croton	D
Dekalb	B
Delanco	C
Donlonton	C
Downer	B
Drayston	C
Duffield	B
Dunmore	C
Dunning	D

Soil	Group
Edgemont	B
Edom	C
Elioak	B
Elk	B
Elkins	D
Elkton	D
Elliber	A
Elsinboro	B
Ernest	C
Etowah	B
Evesboro	A
Exum	C
Fairfax	B
Fallsington	D
Fauquier	B
Fort Mott	B
Frankstown	B
Frederick	B
Freneau	D
Galestown	A
Gilpin	C
Gleneig	B
Glenville	C
Golts	B
Greenwich	B
Guthrie	D
Hagerstown	B
Hatboro	D
Hazel	C
Highfield	B
Hollinger	C
Holston	B
Howell	B
Huntington	B
Hyattsville	B
Hyde	D

Soil	Group
Iredell	D
Iuka	C
Jimtown	D
Johnsburg	D
Johnstown	D
Joppa	A
Keansburg	D
Kedron	C
Kelly	D
Keyport	C
Kinkora	D
Klej	B
*Klinesville	C/D
Laidig	C
Lakeland	A
Lamington	D
Landisburg	C
Lansdale	B
Lantz	D
Largent	C
Leadvale	C
Leetonia	B
Legore	C
Lehew	B
Lehigh	C
Lenoir	D
Leon	C
Leonardtown	D
Lewisberry	B
Lickdale	D
Lindside	C
Linganore	C
Litz	C
Loysvillew	C

Soil	Group
Magnolia	B
Manor	B
Marr	B
Matapeake	B
Matawan	C
Matapex	C
Meckesville	C
Melvin	D
Mench	B
Monmouth	C
Monongahela	C
Montalto	B
Montevallo	C
Mt. Airy	A
Muck	D
Muirkirk	B
Murrill	B
Myersville	B
Neshaminy	B
Nolo	C
Norfolk	B
Norton	B
Ochlockonee	B
Osier	D
Othello	D
Penn	C
Philo	C
Plummer	D
Pocomoke	D
Pope	B
Portsmouth	D
Purdy	D

Soil	Group
Raitan	B
Rayne	B
Readington	C
Relay	B
Roanoke	D
Robertsville	D
Rohrersville	D
Rowland	C
Rumford	B
Rutledge	D
Sassafras	B
Sequatchie	B
Shelocta	B
Showell	C
Shrewsberry	D
St. Johns	D
Stanton	D
Steinsburg	B
Strasburg	C
Sunnyside	B
Talladega	C
Talleyville	B
Teas	C
Thurmont	B
Trego	C
Tuxedo	D
Tyler	C
Ungers	B
Urbana	B
Warners	C
Watchung	D
Waynesboro	B
Wayside	B
Wehadkee	D
*Weikert	C/D
Westmoreland	C
Westphalia	B
Wharton	C
Whiteford	B
Wickham	B
Wiltshire	C
Woodstown	C
Worsham	D

*Dual Classification is for Drained/Undrained Conditions

HYDROLOGIC SOIL GROUPS
MARYLAND STATE HIGHWAY ADMINISTRATION

SHA-61.1 - 401.1B

Slope - Photogrammetric Maps, U.S.G.S. Quadrangle maps or preliminary survey should be used to determine existing ground slopes. Construction plans and site grading plans will provide data for determining the proposed ground slopes.

Ground Cover - Aerial Photographs may be used to make a preliminary determination of ground cover in rural areas, but this data should always be confirmed by a field inspection of the entire drainage area. Values of the 'C' factor are selected from Table SHA 61.1-401.0 Part 1 RURAL LAND USES OR PARTS 2A and B - AGRICULTURAL LAND USES.

Type of Development - Whenever plans are available for either existing or proposed developed areas, the drainage area should be reduced to roof areas, various types of paved areas, and areas of various vegetative types. If detailed plans are not available, the 'C' factor can be computed for general catagories to reflect slope and soil group and, in the case of residential lot development, actual lot size. Urban land use "C" factors are listed on part 3 of Table SHA 61.1-401.0.

The formula for the weighted 'C' factor is:

$$C_w = \frac{C_1A_1 + C_2A_2 \ldots + C_iA_i}{A_1 + A_2 + A_i} \qquad (3)$$

Where A_1, A_2 ... A_i are subareas within a drainage area C_1, C_2 ... C_i are corresponding runoff coefficients for the subareas.

This formula may be expanded for any number of subareas, A_i.

Part 1 Rational Formula Coefficients for SCS Hydrologic Soil Groups (A, B, C, D)

Rural Land Uses

1) Storm Frequencies of Less Than 25 Years
2) Storm Frequencies of 25 Years or Greater

Land Use	Treatment/ Practice	Hydrologic Condition	A			B			C			D		
			0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+
Pasture or range		poor	0.23 0.27	0.25 0.29	0.26 0.31	0.31 0.36	0.33 0.37	0.34 0.39	0.37 0.42	0.38 0.43	0.39 0.44	0.40 0.45	0.41 0.46	0.42 0.47
		fair	0.12 0.15	0.13 0.17	0.15 0.19	0.24 0.28	0.25 0.30	0.27 0.32	0.31 0.36	0.33 0.37	0.34 0.39	0.36 0.40	0.37 0.41	0.38 0.43
		good	0.07 0.09	0.09 0.11	0.10 0.13	0.18 0.22	0.20 0.24	0.22 0.26	0.27 0.32	0.29 0.33	0.31 0.35	0.32 0.37	0.34 0.38	0.35 0.40
	Contoured	poor	0.11 0.13	0.12 0.16	0.14 0.18	0.22 0.26	0.24 0.28	0.26 0.30	0.33 0.37	0.34 0.39	0.36 0.40	0.39 0.44	0.40 0.45	0.41 0.46
		fair	0.06 0.07	0.07 0.08	0.08 0.10	0.17 0.21	0.19 0.23	0.21 0.25	0.28 0.32	0.30 0.34	0.31 0.36	0.35 0.39	0.36 0.41	0.37 0.42
		good	0.03 0.05	0.04 0.06	0.06 0.08	0.11 0.13	0.12 0.14	0.14 0.15	0.24 0.28	0.26 0.30	0.28 0.32	0.31 0.36	0.33 0.37	0.34 0.39
Meadow			0.06 0.08	0.08 0.11	0.10 0.14	0.10 0.13	0.14 0.18	0.19 0.22	0.12 0.16	0.17 0.20	0.22 0.26	0.15 0.21	0.20 0.25	0.25 0.32
Wooded		poor	0.10 0.12	0.12 0.14	0.13 0.16	0.13 0.16	0.15 0.19	0.20 0.23	0.16 0.19	0.19 0.23	0.25 0.28	0.18 0.22	0.22 0.27	0.26 0.33
		fair	0.06 0.08	0.08 0.10	0.09 0.12	0.10 0.13	0.13 0.17	0.18 0.21	0.11 0.15	0.15 0.18	0.20 0.24	0.13 0.18	0.18 0.22	0.23 0.29
		good	0.05 0.06	0.07 0.09	0.08 0.11	0.08 0.11	0.11 0.15	0.15 0.18	0.10 0.13	0.13 0.17	0.17 0.21	0.12 0.15	0.15 0.19	0.21 0.25

PART 2A Rational Formula Coefficients for SCS Hydrologic Soil Groups (A, B, C, D)

Agricultural Land Uses

1) Storm Frequencies of Less Than 25 Years
2) Storm Frequencies of 25 Years or Greater

Land Use	Treatment/ Practice	Hydrologic Condition	A 0-2%	A 2-6%	A 6%+	B 0-2%	B 2-6%	B 6%+	C 0-2%	C 2-6%	C 6%+	D 0-2%	D 2-6%	D 6%+
Fallow	Straight row		0.41 0.57	0.48 0.64	0.53 0.69	0.60 0.70	0.66 0.76	0.71 0.80	0.72 0.83	0.78 0.88	0.82 0.91	0.84 0.95	0.88 0.97	0.91 0.98
Row Crops	Straight row	poor	0.31 0.45	0.36 0.50	0.39 0.54	0.54 0.65	0.58 0.70	0.62 0.73	0.70 0.82	0.74 0.86	0.77 0.88	0.75 0.86	0.78 0.88	0.80 0.89
		good	0.24 0.38	0.30 0.44	0.35 0.49	0.43 0.60	0.48 0.64	0.52 0.67	0.61 0.75	0.65 0.77	0.68 0.79	0.73 0.83	0.76 0.85	0.78 0.86
	Contoured	poor	0.28 0.43	0.34 0.48	0.39 0.52	0.51 0.64	0.55 0.68	0.59 0.71	0.61 0.73	0.65 0.76	0.68 0.78	0.70 0.84	0.74 0.86	0.77 0.88
		good	0.21 0.33	0.26 0.38	0.30 0.42	0.41 0.56	0.45 0.60	0.49 0.64	0.55 0.69	0.59 0.72	0.63 0.74	0.63 0.74	0.66 0.76	0.68 0.77
	Contoured and terraced	poor	0.26 0.38	0.30 0.42	0.34 0.46	0.38 0.52	0.42 0.57	0.46 0.62	0.50 0.66	0.54 0.70	0.57 0.74	0.56 0.69	0.59 0.72	0.61 0.74
		good	0.20 0.34	0.24 0.37	0.27 0.40	0.31 0.45	0.35 0.49	0.39 0.53	0.45 0.61	0.48 0.64	0.51 0.67	0.55 0.68	0.58 0.70	0.60 0.72
Small grain	Straight row	poor	0.24 0.37	0.28 0.40	0.32 0.43	0.43 0.59	0.47 0.63	0.51 0.66	0.62 0.73	0.65 0.76	0.68 0.78	0.72 0.84	0.74 0.86	0.76 0.87
		good	0.23 0.35	0.26 0.38	0.29 0.41	0.42 0.57	0.45 0.60	0.48 0.63	0.57 0.70	0.60 0.73	0.62 0.75	0.71 0.83	0.73 0.85	0.75 0.86

PART 2B Rational Formula Coefficients for SCS Hydrologic Soil Groups (A, B, C, D)

Agricultural Land Uses

1) Storm Frequencies of Less Than 25 Years
2) Storm Frequencies of 25 Years or Greater

Land Use	Treatment/ Practice	Hydrologic Condition	A 0-2%	A 2-6%	A 6%+	B 0-2%	B 2-6%	B 6%+	C 0-2%	C 2-6%	C 6%+	D 0-2%	D 2-6%	D 6%+
Small Grain	Contoured	poor	0.21 0.33	0.26 0.38	0.30 0.42	0.38 0.53	0.42 0.57	0.46 0.61	0.55 0.69	0.59 0.72	0.62 0.75	0.63 0.75	0.65 0.77	0.67 0.78
		good	0.17 0.29	0.22 0.34	0.27 0.38	0.33 0.50	0.38 0.54	0.42 0.58	0.54 0.67	0.58 0.70	0.61 0.73	0.62 0.74	0.65 0.76	0.67 0.77
	Contoured and terraced	poor	0.18 0.30	0.22 0.34	0.26 0.37	0.32 0.46	0.36 0.50	0.40 0.53	0.52 0.65	0.55 0.68	0.58 0.71	0.56 0.70	0.59 0.72	0.61 0.73
		good	0.16 0.28	0.20 0.32	0.24 0.35	0.31 0.44	0.35 0.48	0.38 0.51	0.45 0.62	0.48 0.64	0.50 0.66	0.55 0.68	0.58 0.70	0.60 0.71
Closed-seeded legumes or rotation meadow	Straight row	poor	0.25 0.37	0.30 0.42	0.35 0.46	0.44 0.60	0.48 0.64	0.52 0.67	0.62 0.74	0.65 0.77	0.68 0.80	0.73 0.83	0.76 0.85	0.78 0.86
		good	0.15 0.20	0.19 0.24	0.23 0.28	0.31 0.47	0.35 0.50	0.38 0.53	0.55 0.67	0.58 0.70	0.60 0.72	0.63 0.75	0.65 0.77	0.66 0.78
	Contoured	poor	0.23 0.35	0.28 0.40	0.32 0.44	0.41 0.56	0.45 0.60	0.49 0.63	0.57 0.70	0.60 0.73	0.63 0.76	0.62 0.74	0.65 0.77	0.67 0.79
		good	0.14 0.24	0.18 0.28	0.21 0.31	0.30 0.42	0.34 0.46	0.37 0.49	0.45 0.61	0.48 0.64	0.51 0.66	0.58 0.71	0.60 0.73	0.61 0.74
	Contoured and terraced	poor	0.21 0.33	0.26 0.38	0.30 0.42	0.34 0.50	0.38 0.54	0.42 0.57	0.51 0.67	0.54 0.70	0.57 0.72	0.58 0.71	0.60 0.73	0.61 0.74
		good	0.07 0.20	0.10 0.24	0.13 0.28	0.28 0.40	0.32 0.44	0.35 0.47	0.44 0.61	0.47 0.63	0.49 0.65	0.52 0.68	0.54 0.70	0.56 0.71

PART 3 Rational Formula Coefficients for SCS Hydrologic Soil Groups (A, B, C, D)

Urban Land Uses

1) Storm Frequencies of Less Than 25 Years
2) Storm Frequencies of 25 Years and Greater

Land Use	Treatment/ Practice	Hydrologic Condition	A			B			C			D		
			0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+
Paved Areas & Impervious Surfaces			0.85 0.95	0.86 0.96	0.87 0.97	0.85 0.95	0.86 0.96	0.87 0.97	0.85 0.95	0.86 0.96	0.87 0.97	0.85 0.95	0.86 0.96	0.87 0.97
Open Space- Lawns etc.			0.08 0.11	0.12 0.15	0.15 0.19	0.11 0.15	0.16 0.20	0.21 0.26	0.14 0.19	0.19 0.24	0.24 0.32	0.20 0.25	0.24 0.29	0.28 0.37
Industrial			0.67 0.85	0.68 0.85	0.68 0.86	0.68 0.85	0.68 0.86	0.69 0.86	0.68 0.86	0.69 0.86	0.69 0.87	0.69 0.86	0.69 0.86	0.70 0.88
Commercial			0.71 0.88	0.71 0.88	0.72 0.89	0.71 0.89	0.72 0.89	0.72 0.89	0.72 0.89	0.72 0.89	0.72 0.90	0.72 0.89	0.72 0.89	0.72 0.90
Residental														
Lot Size 1/8 acre			0.25 0.33	0.28 0.37	0.31 0.40	0.27 0.35	0.30 0.39	0.35 0.44	0.30 0.38	0.33 0.42	0.38 0.49	0.33 0.41	0.36 0.45	0.42 0.54
Lot Size 1/4 acre			0.22 0.30	0.26 0.34	0.29 0.37	0.24 0.33	0.29 0.37	0.33 0.42	0.27 0.36	0.31 0.40	0.36 0.47	0.30 0.38	0.34 0.42	0.40 0.52
Lot Size 1/3 acre			0.19 0.28	0.23 0.32	0.26 0.35	0.22 0.30	0.26 0.35	0.30 0.39	0.25 0.33	0.29 0.38	0.34 0.45	0.28 0.36	0.32 0.40	0.39 0.50
Lot Size 1/2 acre			0.16 0.25	0.20 0.29	0.24 0.32	0.19 0.28	0.23 0.32	0.28 0.36	0.22 0.31	0.27 0.35	0.32 0.42	0.26 0.34	0.30 0.38	0.37 0.48
Lot Size 1 acre			0.14 0.22	0.19 0.26	0.22 0.29	0.17 0.24	0.21 0.28	0.26 0.34	0.20 0.28	0.25 0.32	0.31 0.40	0.24 0.31	0.29 0.35	0.35 0.46

b. Time of Concentration - The time of concentration is defined as the interval of time required for the flow at the point of investigation to become a maximum. Since the designer will work with several storm frequencies the computation should be simplified by determining the time of concentration for the 10 year frequency storm and using this time for all frequencies. In the case of homogeneous drainage areas, the time of concentration will be the total time required for the runoff to flow from the most hydraulically remote point in the drainage area to the point of investigation. The same method applies to heterogeneous drainage areas that have a higher "CA product" in the most distant portions of the drainage area. However, in the case of heterogeneous drainage areas where the most distant portions have a lower "CA product" than the portions nearest the point of investigation, that may not be valid. In this instance maximum flow may occur before runoff from the most distant portions of the drainage area has reached the point of investigation. When this occurs, both the time of concentration and the drainage area should be reduced to reflect this condition. The flow path should be carefully selected to be representative of the drainage area as a whole. For example, panhandle shaped drainage areas may yield extremely long times of concentration that are not typical for the watershed. It is suggested that more than one path be investigated. When a time of less than five minutes is encountered, a five minute duration will be used to determine the intensity. However, the actual time will be used to calculate the total time of concentration for the watershed.

The times of concentration (t_c) is the sum of the time increments for all types of flow such as: overland flow (t_o), swale flow (t_s), ditch flow (t_d), gutter flow (t_g) and pipe flow (t_p), each if applicable. For "Overland Flow" the surface roughness coefficients and maximum allowable flow lengths are obtained form SHA-61.1-402.0 and t_o is read from the nomograph SHA-61.1-402.1. The total length of overland flow should not exceed 400 feet except over paved areas. It is assumed that within this distance some form of concentrated flow will occur.

All other time increments (t_s, t_d, t_g, and t_p) are obtained by estimating the average velocity in each reach and dividing it into the total length of that reach. This is done by Manning's formula or the appropriate chart whenever available. For t_s and t_d this is a trial and error procedure as follows: (refer to figure 1)

FIG. I

t_c @ point A is known

Assume an average velocity, V, in the ditch or swale and calculate t_c @ point B.

Use this time to compute the discharge in the ditch. Using the appropriate chart, read the instantaneous velocity V_i. Calculate the average velocity V_a by taking 75% of V_i. If $V_a = V$, the assumption is correct. Continue on to the next section.

If $V_a \neq V$, Use V_a as the next assumption. Continue this process until $V_a = V$.

RECOMMENDED "N" VALUES
FOR USE WITH CHART SHA-61.1-402.1

AVERAGE "N" VALUES

RURAL AND NATURAL AREAS

TYPE OF SURFACE	"N"
CULTIVATED FIELDS	0.30
PASTURE OR AVERAGE GRASS	0.40
WOODS	0.60

PAVED AND DEVELOPED AREAS

TYPE OF SURFACE	"N"
PAVED SURFACE	0.02
COMMERCIAL OR INDUSTRIAL DEVELOPMENT	0.05
ACROSS AVERAGE HIGHWAY PAVEMENT AND SHOULDER TO SURFACE DRAIN DITCH	0.10
APARTMENT DEVELOPMENT	0.10
RESIDENTIAL DEVELOPMENT	0.20

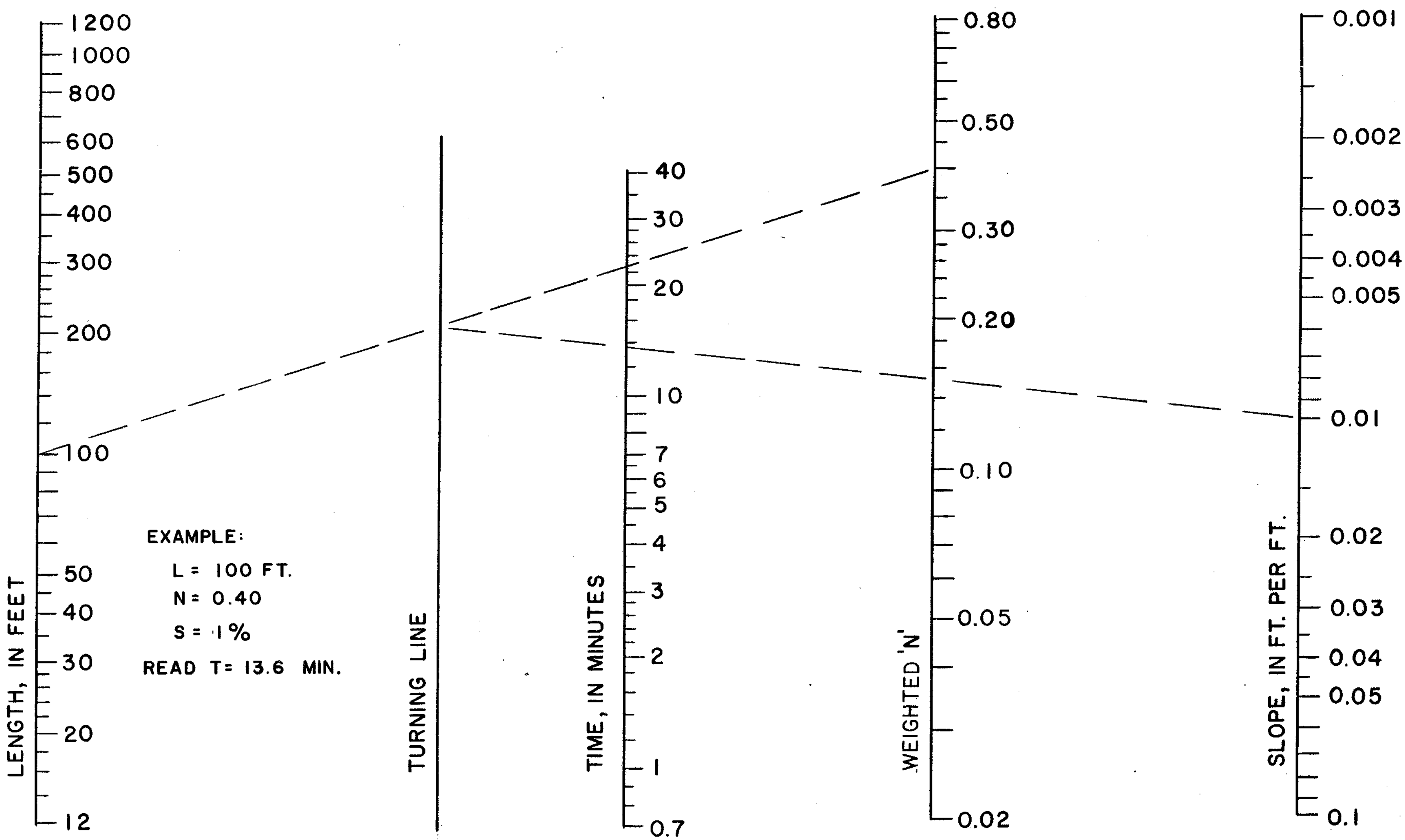
THE ENTIRE OVERLAND SHEET FLOW TIME MUST BE DETERMINED BY A SINGLE COMPUTATION. IT CAN NOT BE COMPUTED IN SEGMENTS. IF MORE THAN ONE TYPE OF SURFACE IS INVOLVED IN THE FLOW PATH, COMPUTE A WEIGHTED "N" PROPORTIONAL TO THE LENGTH OF FLOW OVER EACH SURFACE.

OVERLAND FLOW LENGTH

ON ERODABLE SURFACES THE MAXIMUM ALLOWABLE OVERLAND FLOW LENGTH IS 400 FEET. HOWEVER, THE DESIGNER SHOULD CONSIDER SLOPE AND SOIL TYPE BEFORE DEFINING THE OVERLAND FLOW LENGTH.

ON NON-ERODABLE SURFACES THERE IS NO LIMIT ON OVERLAND FLOW LENGTH. IT IS DETERMINED FROM CONTOURS ALONE. OVERLAND FLOW MUST NEVER BE CONTINUED BEYOND THE POINT AT WHICH PLANS OR CONTOURS INDICATE THE PRESENCE OF GUTTER, SWALE OR OTHER WATERCOURSE.

FOR RECOMMENDED VALUES OF 'N' AND 'L' SEE TABLE SHA-61.1-402.0



OVERLAND SHEET FLOW

MARYLAND STATE HIGHWAY ADMINISTRATION

SOURCE ARTICLE BY W.S. KERBY
MARCH 1959 ISSUE
'CIVIL ENGINEERING'

SHA-61.1-402.1
REVISED 1-1-77

The work of computing an estimated time of concentration through existing swales and ditches and along curb and gutter sections can be shortened with little loss of accuracy by using Charts SHA-61.1 -402.3 to 402.7 to determine approximate average velocity.

Two swale flow charts are provided having manning 'n' values appropriate for either grass (n=0.06) or paved (n=0.015) linings.

To determine the average velocity, the following procedure should be used:

1) Determine the drainage area for overland flow to the top of the swale, (A_o) and the corresponding runoff coefficient (C_o).

2) Determine the additional area which will drain laterally into this swale between the top and bottom of its reach, (A_s) and its corresponding runoff coefficient (C_s).

3) The average AC product in this reach will then be (A_oC_o) + 1/2 (A_sC_s).

4) Using the time at the top of the swale reach (which is also the overland time) find i_5 as described in paragraphs c and d.

5) Compute $Q_5 = i_5 [A_oC_o + 1/2(A_sC_s)]$

6) Compute the average slope of the swale reach and enter Chart SHA-61.1 - 402.3 or 402.4 with this slope and Q_5. Read the average velocity.

7) Divide the length of the swale reach by the average velocity to determine the flow time in the swale reach, (t_s)

8) Time of concentration to the bottom of the swale reach is then $t_o + t_s$.

Two ditch flow charts are provided having Manning 'n' values appropriate for either grass (n=0.04) or paved (n=0.015) linings. These charts are used from the end of the swale flow through defined ditches of any size. The following procedure, similar to that used for swale flows, should be used for ditches:

1) Determine the additional area which will drain laterally into the ditch between the top and bottom of its reach, (A_d) and its corresponding runoff coefficient (C_d.)

2) The average AC product in this reach will then be (A_oC_o) + (A_sC_s) + 1/2(A_dC_d)

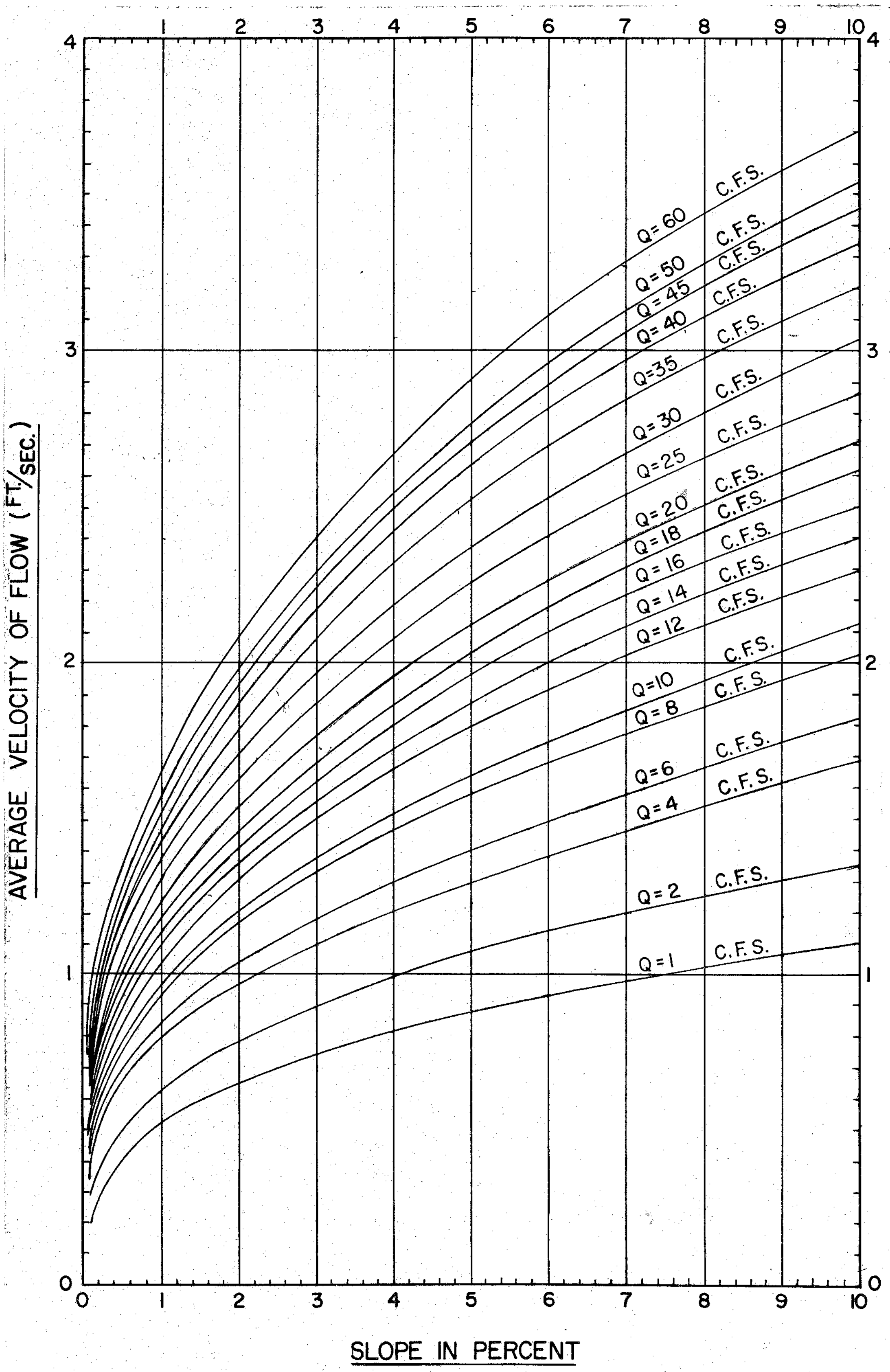
3) Using the time at the top of the ditch reach (which is the total of overland and swale flow times) find i_5.

4) Compute $Q_5 = i_5 [A_oC_o + (A_sC_s) + 1/2(A_dC_d)]$

5) Compute the average slope for the ditch reach and enter Chart SHA-61.1 - 402.5 or 402.6 with this slope and Q_5 and read the average velocity.

When curb and gutter flow forms a part of the flow path, average velocity can be determined from Chart SHA-61.1 - 402.7 by entering the chart with the street grade and reading the velocity directly.

The method outlined above is intended to save work in determining the time of concentration to some point of investigation and no attempt should be made to use the above charts as a substitute for Manning charts when designing ditches or swales or evaluating their operation since they will not supply instantaneous velocity or depth of flow.

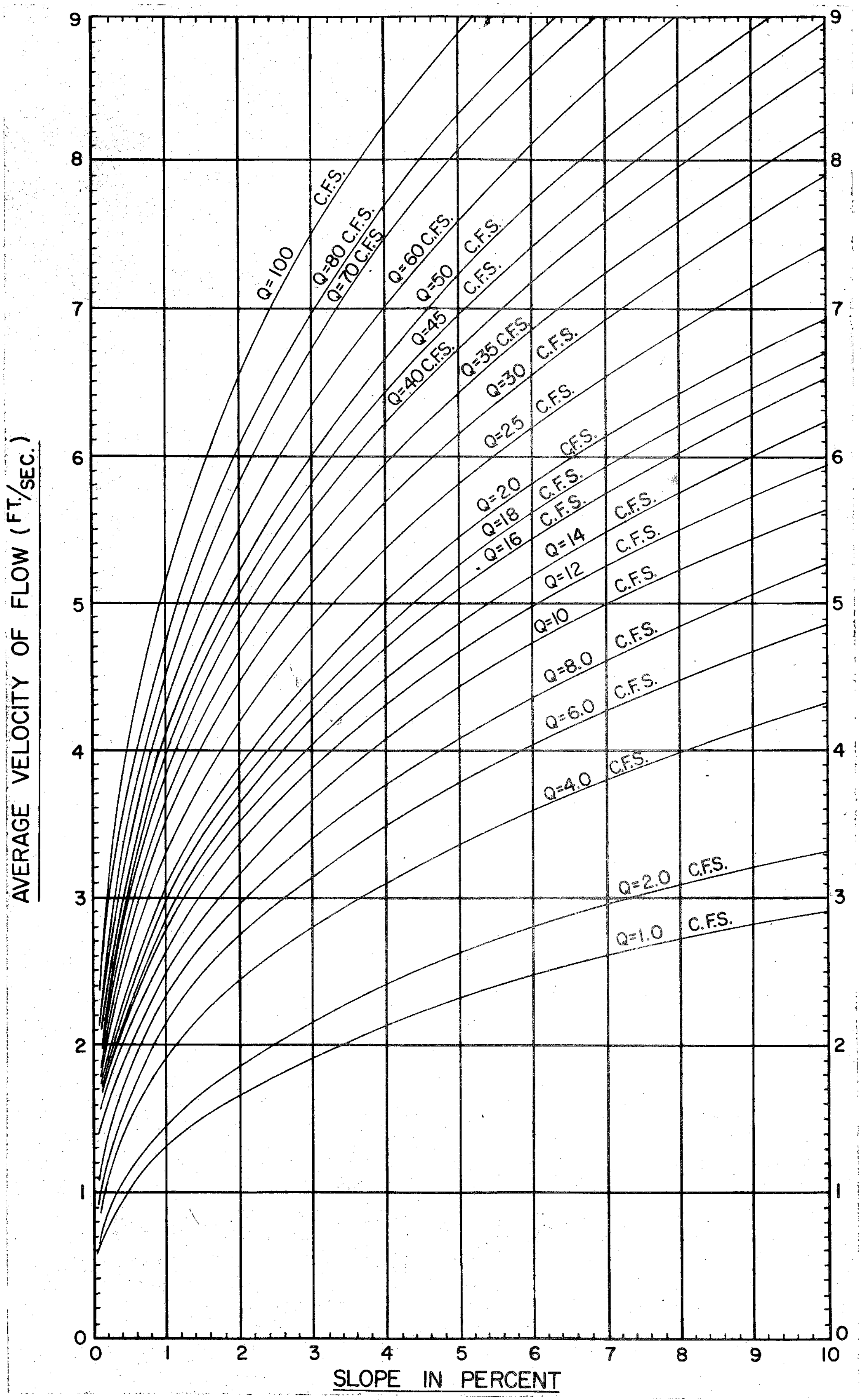


SWALE FLOW VELOCITY

(N=0.06)

8/5/80

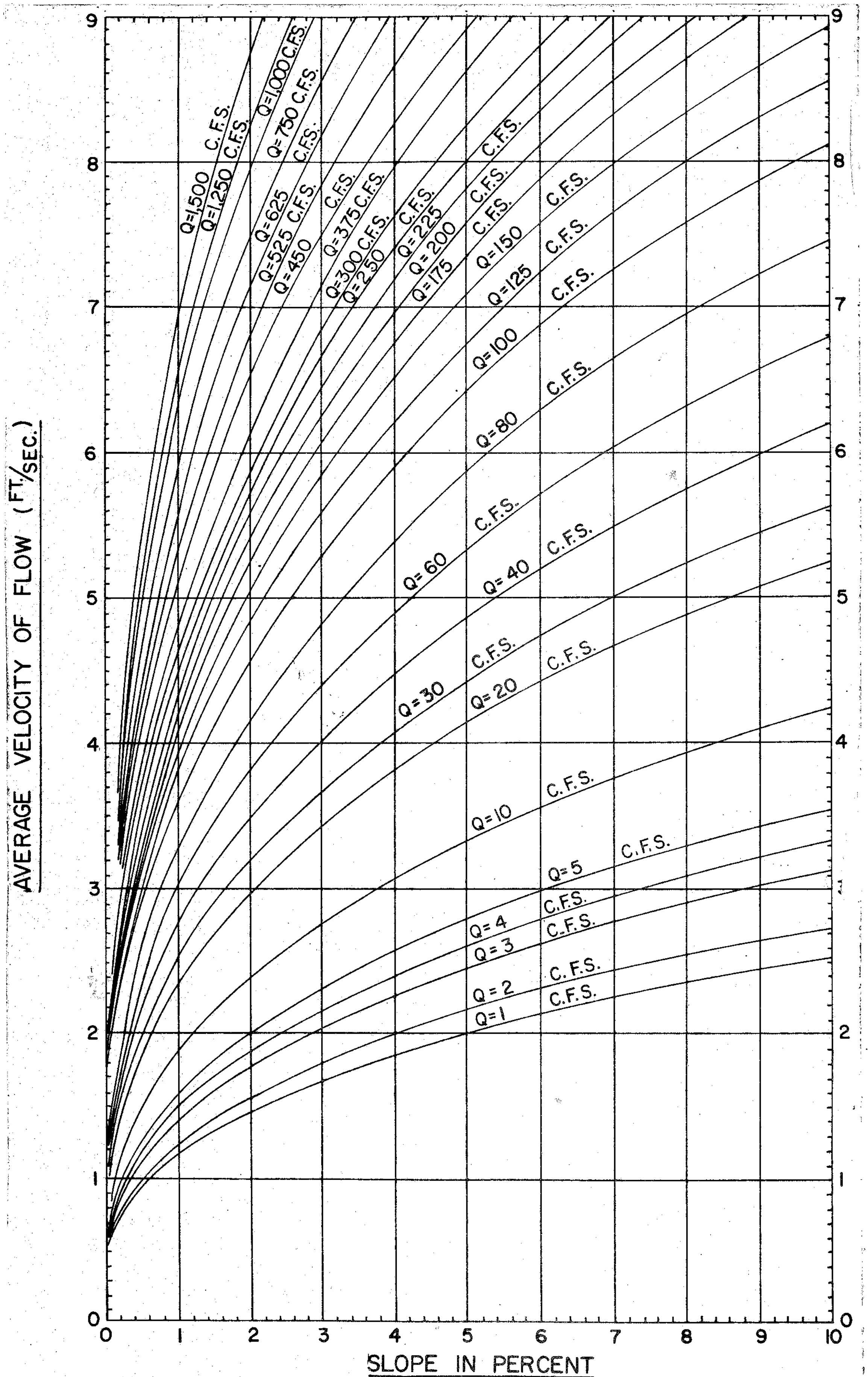
MARYLAND STATE HIGHWAY ADMINISTRATION I-2-A-17 SHA-61.1-402.3



SWALE FLOW VELOCITY

(N=0.015)

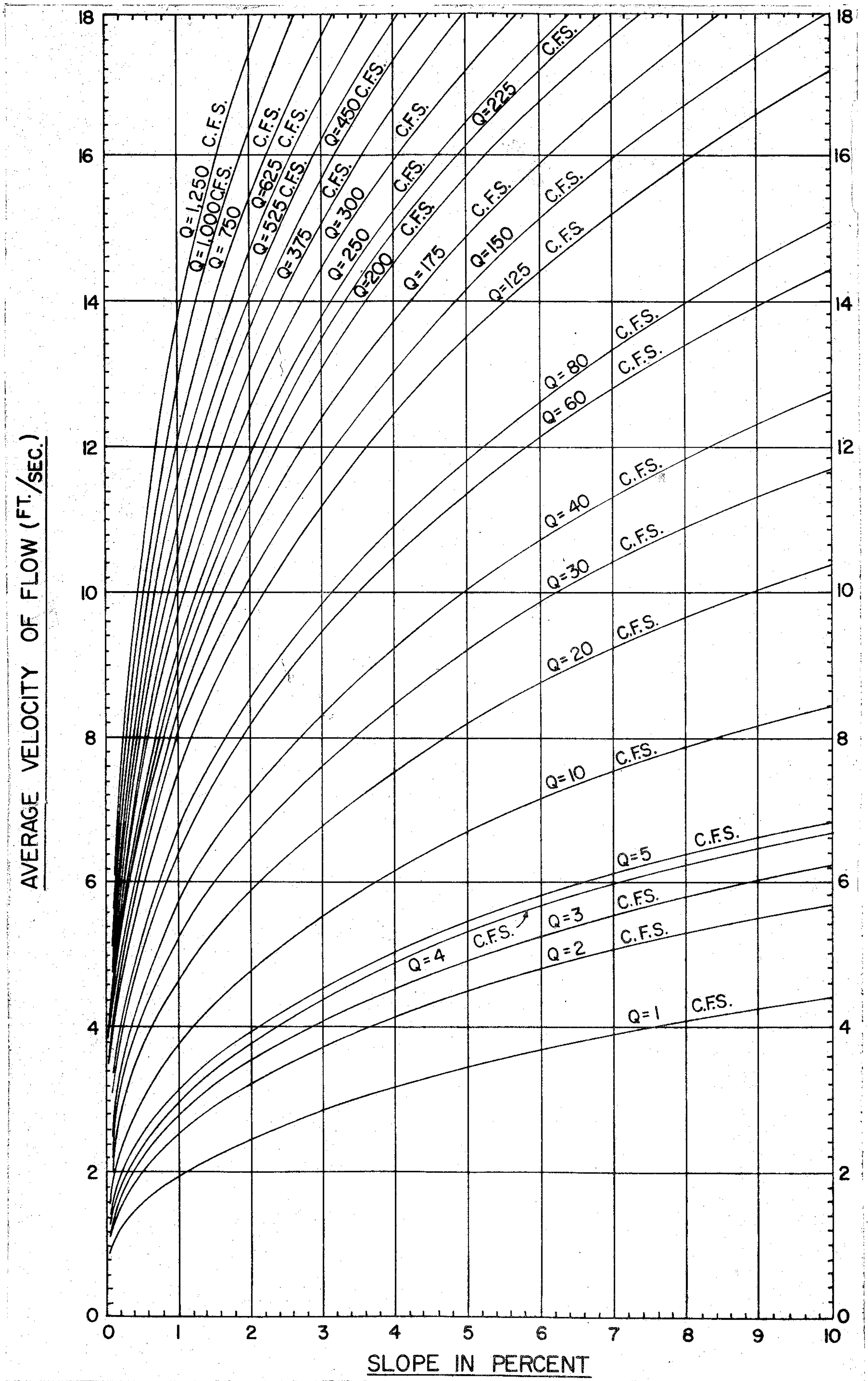
8/5/80



DITCH FLOW VELOCITY

(N=0.04)

8/5/80

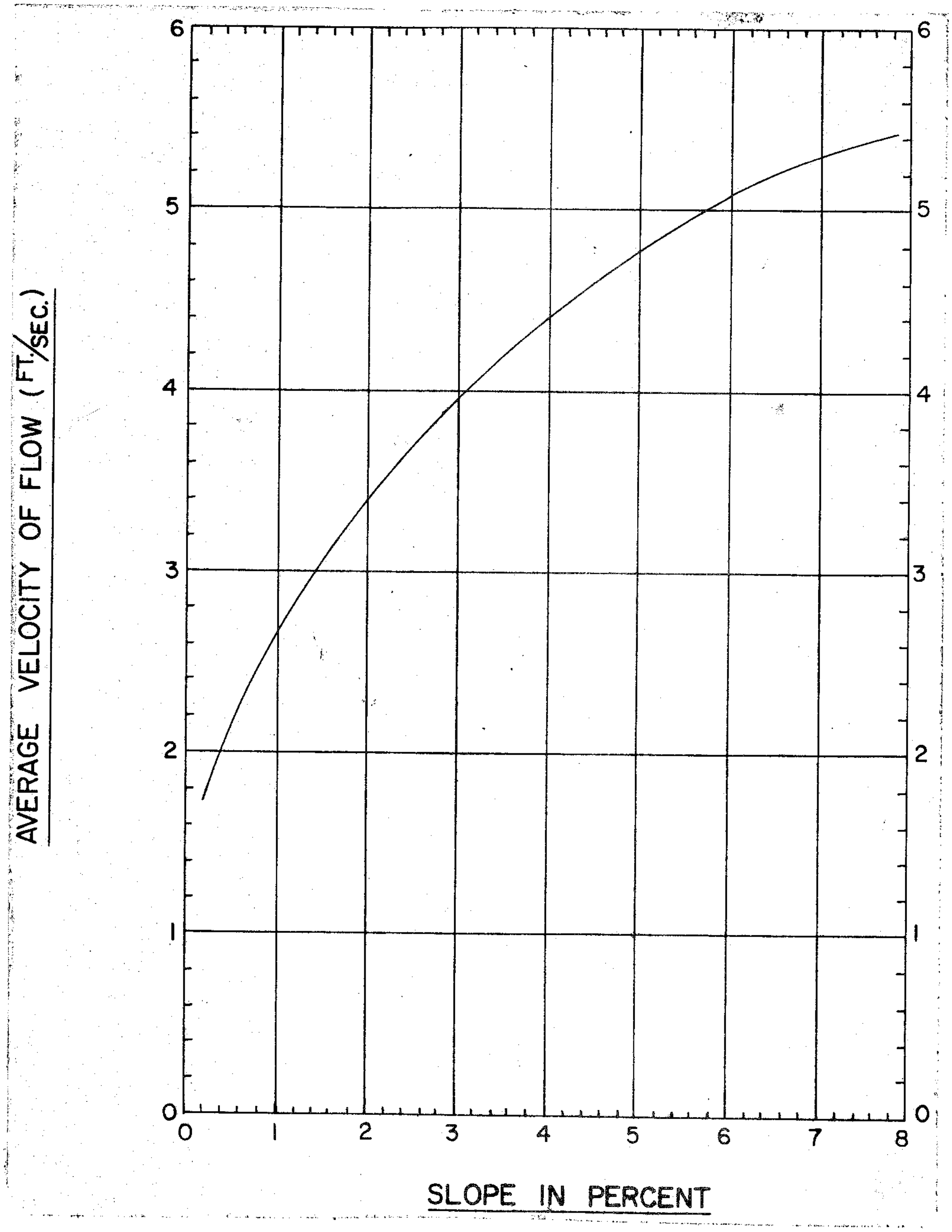


DITCH FLOW VELOCITY

(N = 0.015)

8/5/80

MARYLAND STATE HIGHWAY ADMINISTRATION I-2-A-23 SHA-61.1-402.6



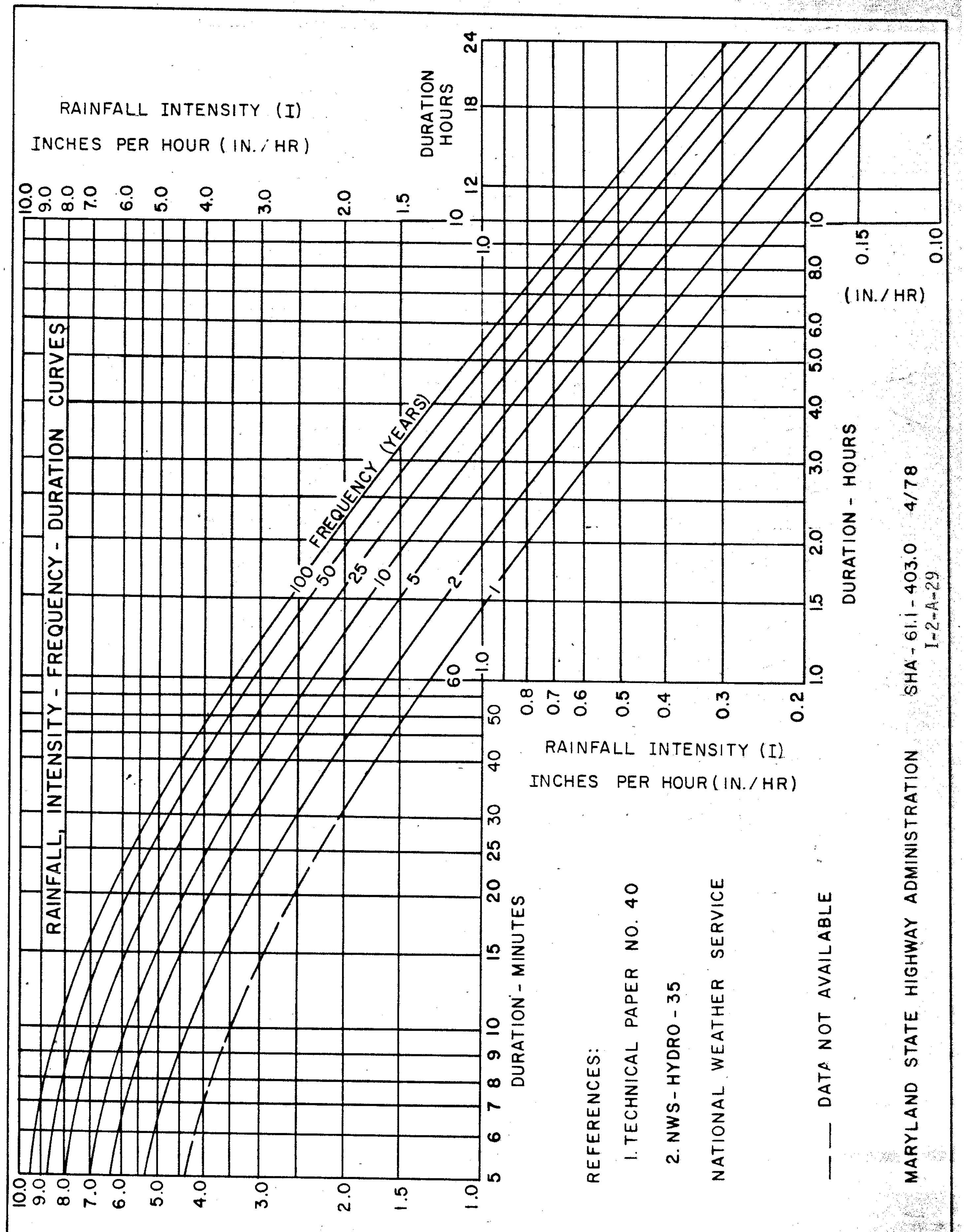
GUTTER FLOW VELOCITY

c. Rainfall Intensity - To determine the maximum discharge from a watershed, for a given storm frequency and duration, the designer should use the rainfall intensity for which the drainage area will yield the greatest peak discharge. This is assumed to occur when the duration of the storm equals the time of concentration. The basic intensity for this storm is read directly from Chart SHA-61.1-403.0 or from Tables SHA 61.1-403.01A thru K.

d. Rainfall Intensity Coefficient - Due to the geographic effects of the Appalachian mountains and the Chesapeake Bay, rainfall intensity varies throughout the state. To account for these effects, the basic intensity is modified by a rainfall intensity coefficient found in the SHA-61.1-403 series charts. The design intensity is determined as follows:

Using the SHA-61.1-403.0 chart with a duration range that includes the time of concentration, locate the site and interpolate the proper intensity coefficient. Multiply the basic intensity from Chart SHA 61.1 - 403.0 by the above factor to obtain the design intensity. The SHA 61.1-403 chart used by the designer will, of course, change where the time of concentration reaches 10.0 minutes and 40.0 minutes, respectively.

e. Drainage Area - The drainage area contributing runoff to the point of investigation should first be outlined on a topographic map. Before making any computations, the limits of the drainage area should be field checked, especially drainage areas with existing storm sewer systems. These systems may divert runoff into or away from the area under study. After determining the actual limits of the watershed, the area must be computed in acres.



RAINFALL, INTENSITY - FREQUENCY - DURATION CURVES
RAINFALL INTENSITY (I)
INCHES PER HOUR (IN./HR)
10.0 9.0 8.0 7.0 6.0 5.0 4.0 3.0 2.0 1.5 1.0
DURATION HOURS
24 18 12 10
FREQUENCY (YEARS)
100 50 25 10 5 2 1
(IN./HR)
0.10 0.15
DURATION - HOURS
1.0 1.5 2.0 3.0 4.0 5.0 6.0 8.0 10
60
0.2 0.3 0.4 0.5 0.6 0.7 0.8
DURATION - MINUTES
5 6 7 8 9 10 15 20 25 30 40 50
RAINFALL INTENSITY (I)
INCHES PER HOUR (IN./HR)
REFERENCES:
1. TECHNICAL PAPER NO. 40
2. NWS - HYDRO - 35
NATIONAL WEATHER SERVICE
— — DATA NOT AVAILABLE
MARYLAND STATE HIGHWAY ADMINISTRATION
SHA - 61.1 - 403.0 4/78
I-2-A-29

RAINFALL, INTENSITY - FREQUENCY - DURATION
(INCHES PER HOUR)

	RETURN PERIOD (YEARS)						
MIN.	1	2	5	10	25	50	100
5.00	4.40	5.38	6.39	7.00	8.00	8.70	9.50
5.10	4.38	5.36	6.37	6.98	7.97	8.68	9.48
5.20	4.36	5.33	6.34	6.95	7.94	8.66	9.46
5.30	4.34	5.31	6.32	6.93	7.91	8.64	9.44
5.40	4.32	5.28	6.29	6.91	7.88	8.62	9.42
5.50	4.30	5.26	6.27	6.89	7.85	8.60	9.40
5.60	4.28	5.23	6.25	6.86	7.82	8.58	9.38
5.70	4.26	5.21	6.22	6.84	7.79	8.56	9.36
5.80	4.24	5.18	6.20	6.81	7.76	8.54	9.34
5.90	4.22	5.16	6.17	6.79	7.73	8.52	9.32
6.00	4.20	5.13	6.15	6.77	7.70	8.50	9.30
6.10	4.18	5.10	6.12	6.75	7.68	8.48	9.27
6.20	4.16	5.06	6.10	6.72	7.67	8.46	9.24
6.30	4.14	5.03	6.07	6.70	7.66	8.44	9.21
6.40	4.12	5.00	6.04	6.68	7.64	8.42	9.18
6.50	4.10	4.97	6.02	6.66	7.63	8.40	9.15
6.60	4.08	4.93	5.99	6.63	7.61	8.38	9.12
6.70	4.06	4.90	5.96	6.61	7.60	8.36	9.09
6.80	4.04	4.87	5.93	6.59	7.58	8.34	9.06
6.90	4.02	4.83	5.91	6.56	7.57	8.32	9.03
7.00	4.00	4.80	5.88	6.54	7.55	8.30	9.00
7.10	3.99	4.80	5.86	6.52	7.53	8.28	8.98
7.20	3.97	4.79	6.49	6.49	7.50	8.25	8.96
7.30	3.96	4.79	5.83	6.47	7.48	8.23	8.94
7.40	3.94	4.78	5.81	6.45	7.45	8.20	8.92
7.50	3.93	4.78	5.80	6.43	7.45	8.18	8.90
7.60	3.91	4.77	5.78	6.40	7.40	8.15	8.88
7.70	3.90	4.77	5.76	6.38	7.38	8.13	8.86
7.80	3.88	4.76	5.74	6.36	7.35	8.10	8.84
7.90	3.87	4.76	5.73	6.33	7.33	8.08	8.82
8.00	3.85	4.75	5.71	6.31	7.30	8.05	8.80
8.10	3.83	4.73	5.68	6.30	7.27	8.03	8.78
8.20	3.81	4.70	5.66	6.28	7.24	8.00	8.76
8.30	3.79	4.68	5.63	6.27	7.21	7.98	8.74
8.40	3.77	4.65	5.61	6.25	7.18	7.95	8.72
8.50	3.75	4.63	5.58	6.24	7.15	7.93	8.70
8.60	3.73	4.60	5.55	6.23	7.12	7.90	8.68
8.70	3.71	4.58	5.53	6.21	7.09	7.88	8.66
8.80	3.69	4.55	5.50	6.20	7.06	7.85	8.64
8.90	3.67	4.53	5.48	6.18	7.03	7.83	8.62
9.00	3.65	4.50	5.45	6.17	7.00	7.80	8.60
9.10	3.64	4.48	5.43	6.14	6.98	7.78	8.57
9.20	3.62	4.47	5.40	6.11	6.95	7.76	8.54
9.30	3.61	4.45	5.38	6.08	6.93	7.74	8.51
9.40	3.59	4.43	5.35	6.05	6.91	7.72	8.48
9.50	3.58	4.42	5.33	6.02	6.89	7.70	8.45
9.60	3.56	4.40	5.30	5.98	6.86	7.68	8.42
9.70	3.55	4.38	5.28	5.95	6.84	7.66	8.39
9.80	3.53	4.36	5.25	5.92	6.82	7.64	8.36
9.90	3.52	4.35	5.23	5.89	6.79	7.62	9.33
10.00	3.50	4.33	5.20	5.86	6.77	7.60	8.30

USE S.H.A. - 61.1 - 403.1 FOR RAINFALL INTENSITY FACTORS

RAINFALL, INTENSITY - FREQUENCY - DURATION
(INCHES PER HOUR)

	RETURN PERIOD (YEARS)						
MIN.	1	2	5	10	25	50	100
10.10	3.49	4.32	5.19	5.84	6.75	7.58	8.28
10.20	3.48	4.30	5.17	5.83	6.73	7.56	8.26
10.30	3.46	4.29	5.16	5.81	6.72	7.54	8.24
10.40	3.45	4.28	5.14	5.80	6.70	7.52	8.22
10.50	3.44	4.27	5.13	5.78	6.68	7.50	8.20
10.60	3.43	4.25	5.12	5.76	6.66	7.48	8.18
10.70	3.42	4.24	5.10	5.75	6.64	7.46	8.16
10.80	3.40	4.23	5.09	5.73	6.63	7.44	8.14
10.90	3.39	4.21	5.07	5.72	6.61	7.42	8.12
11.00	3.38	4.20	5.06	5.70	6.59	7.40	8.10
11.10	3.37	4.19	5.05	5.68	6.57	7.38	8.08
11.20	3.36	4.18	5.03	5.67	6.55	7.36	8.06
11.30	3.34	4.16	5.02	5.65	6.54	7.34	8.04
11.40	3.33	4.15	5.00	5.64	6.52	7.32	8.02
11.50	3.32	4.14	4.99	5.62	6.50	7.31	8.00
11.60	3.31	4.13	4.98	5.60	6.48	7.29	7.98
11.70	3.30	4.12	4.96	5.59	6.46	7.27	7.96
11.80	3.28	4.10	4.95	5.57	6.45	7.25	7.94
11.90	3.27	4.09	4.93	5.56	6.43	7.23	7.92
12.00	3.26	4.08	4.92	5.54	6.41	7.21	7.90
12.10	3.25	4.07	4.91	5.52	6.39	7.19	7.88
12.20	3.24	4.05	4.89	5.51	6.37	7.17	7.86
12.30	3.22	4.04	4.88	5.49	6.35	7.15	7.84
12.40	3.21	4.03	4.86	5.47	6.33	7.13	7.82
12.50	3.20	4.02	4.85	5.46	6.32	7.11	7.80
12.60	3.19	4.00	4.84	5.44	6.30	7.09	7.78
12.70	3.18	3.99	4.82	5.42	6.28	7.07	7.76
12.80	3.16	3.98	4.81	5.40	6.26	7.05	7.74
12.90	3.15	3.96	4.79	5.39	6.24	7.03	7.72
13.00	3.14	3.95	4.78	5.37	6.22	7.01	7.70
13.10	3.13	3.94	4.77	5.35	6.20	6.99	7.68
13.20	3.12	3.93	4.75	5.34	6.18	6.97	7.66
13.30	3.10	3.91	4.74	5.32	6.17	6.95	7.64
13.40	3.09	3.90	4.72	5.31	6.15	6.93	7.62
13.50	3.08	3.89	4.71	5.29	6.13	6.92	7.60
13.60	3.07	3.88	4.70	5.27	6.11	6.90	7.58
13.70	3.06	3.87	4.68	5.26	6.09	6.88	7.56
13.80	3.04	3.85	4.67	5.24	6.08	6.86	7.54
13.00	3.03	3.84	4.65	5.23	6.06	6.84	7.52
14.00	3.02	3.83	4.64	5.21	6.04	6.82	7.50
14.10	3.01	3.82	4.63	5.19	6.02	6.80	7.48
14.20	3.00	3.80	4.61	5.18	6.00	6.78	7.46
14.30	2.98	3.79	4.60	5.16	5.99	6.76	7.44
14.40	2.97	3.78	4.58	5.15	5.97	6.74	7.42
14.50	2.96	3.77	4.57	5.13	5.95	6.72	7.40
14.60	2.95	3.75	4.56	5.11	5.93	6.70	7.38
14.70	2.94	3.74	4.54	5.10	5.91	6.68	7.36
14.80	2.92	3.73	4.53	5.08	5.90	6.66	7.34
14.90	2.91	3.71	4.51	5.07	5.88	6.64	7.32

USE S.H.A. - 61.1 - 403.2 FOR RAINFALL INTENSITY FACTORS

RAINFALL, INTENSITY - FREQUENCY - DURATION
(INCHES PER HOUR)

	RETURN PERIOD (YEARS)						
MIN	1	2	5	10	25	50	100
15.00	2.90	3.70	4.50	5.05	5.86	6.62	7.30
15.10	2.89	3.69	4.49	5.04	5.85	6.60	7.28
15.20	2.89	3.68	4.48	5.02	5.83	6.59	7.26
15.30	2.88	3.67	4.46	5.01	5.82	6.57	7.25
15.40	2.87	3.66	4.45	5.00	5.81	6.55	7.23
15.50	2.86	3.65	4.44	4.99	5.80	6.54	7.21
15.60	2.85	3.64	4.43	4.97	5.78	6.52	7.19
15.70	2.85	3.63	4.42	4.96	5.77	6.50	7.17
15.80	2.84	3.62	4.40	4.95	5.76	6.48	7.16
15.90	2.84	3.61	4.39	4.93	5.74	6.47	7.14
16.00	2.83	3.60	4.38	4.92	5.73	6.45	7.12
16.10	2.82	3.59	4.37	4.91	5.72	6.43	7.10
16.20	2.82	3.58	4.35	4.89	5.70	6.42	7.08
16.30	2.81	3.57	4.34	4.88	5.69	6.40	7.06
16.40	2.81	3.56	4.33	4.87	5.67	6.39	7.04
16.50	2.80	3.55	4.32	4.86	5.66	6.37	7.03
16.60	2.79	3.54	4.30	4.84	5.65	6.35	7.01
16.70	2.79	3.53	4.29	4.83	5.63	6.34	6.99
16.80	2.78	3.52	4.28	4.82	5.62	6.32	6.97
16.90	2.78	3.51	4.26	4.80	5.60	6.31	6.95
17.00	2.77	3.50	4.25	4.79	5.59	6.29	6.93
17.10	2.76	3.49	4.24	4.78	5.58	6.27	6.91
17.20	2.76	3.48	4.23	4.76	5.56	6.26	6.89
17.30	2.75	3.47	4.21	4.75	5.55	6.24	6.88
17.40	2.74	3.46	4.20	4.74	5.54	6.22	6.86
17.50	2.74	3.45	4.19	4.73	5.53	6.21	6.84
17.60	2.73	3.44	4.18	4.71	5.51	6.19	6.82
17.70	2.72	3.43	4.17	4.70	5.50	6.17	6.80
17.80	2.71	3.42	4.15	4.69	5.49	6.15	6.79
17.90	2.71	3.41	4.14	4.67	5.47	6.14	6.77
18.00	2.70	3.40	4.13	4.66	5.46	6.12	6.75
18.10	2.69	3.39	4.12	4.65	5.45	6.10	6.73
18.20	2.69	3.38	4.10	4.63	5.43	6.09	6.71
18.30	2.68	3.37	4.09	4.62	5.42	6.07	6.69
18.40	2.68	3.36	4.08	4.61	5.40	6.06	6.67
18.50	2.67	3.35	4.07	4.60	5.39	6.04	6.66
18.60	2.66	3.34	4.05	4.58	6.02	6.62	6.64
18.70	2.66	3.33	4.04	4.57	5.36	6.01	6.62
18.80	2.65	3.32	4.03	4.56	5.35	5.99	6.60
18.90	2.65	3.31	4.01	4.54	5.33	5.98	6.58
19.00	2.64	3.30	4.00	4.53	5.32	5.96	6.56
19.10	2.63	3.29	3.99	4.52	5.31	5.94	6.54
19.20	2.63	3.28	3.98	4.50	5.29	5.93	6.52
19.30	2.62	3.27	3.96	4.49	5.28	5.91	6.51
19.40	2.61	3.26	3.95	4.48	5.27	5.89	6.49
19.50	2.61	3.25	3.94	4.47	5.26	5.88	6.47
19.60	2.60	3.24	3.93	4.45	5.24	5.86	6.45
19.70	2.59	3.23	3.92	4.44	5.23	5.84	6.43
19.80	2.58	3.22	3.90	4.43	5.21	5.82	6.42
19.90	2.58	3.21	3.89	4.41	5.20	5.81	6.40

USE S.H.A. - 61.1 - 403.2 FOR RAINFALL INTENSITY FACTORS

RAINFALL, INTENSITY - FREQUENCY - DURATION
(INCHES PER HOUR)

	RETURN PERIOD (YEARS)						
MIN.	1	2	5	10	25	50	100
20.00	2.57	3.20	3.88	4.40	5.19	5.79	6.38
20.10	2.56	3.19	3.87	4.39	5.18	5.78	6.37
20.20	2.56	3.18	3.86	4.38	5.17	5.77	6.35
20.30	2.55	3.17	3.85	4.37	5.15	5.75	6.34
20.40	2.55	3.16	3.84	4.36	5.14	5.74	6.33
20.50	2.54	3.16	3.84	4.35	5.13	5.73	6.32
20.60	2.53	3.15	3.83	4.34	5.12	5.72	6.30
20.70	2.53	3.14	3.82	4.33	5.11	5.71	6.29
20.80	2.52	3.13	3.81	4.32	5.09	5.69	6.28
20.90	2.52	3.12	3.80	4.31	5.08	5.68	6.26
21.00	2.51	3.11	3.79	4.30	5.07	5.67	6.25
21.10	2.50	3.10	3.78	4.29	5.06	5.66	6.24
21.20	2.50	3.09	3.77	4.28	5.05	5.65	6.23
21.30	2.49	3.08	3.76	4.27	5.03	5.64	6.21
21.40	2.49	3.07	3.75	4.26	5.02	5.63	6.20
21.50	2.48	3.07	3.74	4.25	5.01	5.62	6.19
21.60	2.47	3.06	3.73	4.24	5.00	5.60	6.18
21.70	2.47	3.05	3.72	4.23	4.99	5.59	6.17
21.80	2.46	3.04	3.71	4.22	4.97	5.58	6.15
21.90	2.46	3.03	3.70	4.21	4.96	5.57	6.14
22.00	2.45	3.02	3.69	4.20	4.95	5.56	6.13
22.10	2.44	3.01	3.68	4.19	4.94	5.55	6.12
22.20	2.44	3.00	3.67	4.18	4.93	5.54	6.10
22.30	2.43	3.00	3.66	4.17	4.92	5.52	6.09
22.40	2.42	2.99	3.65	4.16	4.91	5.51	6.08
22.50	2.42	2.98	3.65	4.15	4.90	5.50	6.07
22.60	2.41	2.97	3.64	4.14	4.88	5.49	6.05
22.70	2.40	2.96	3.63	4.13	4.87	5.48	6.04
22.80	2.39	2.96	3.62	4.12	4.86	5.46	6.03
22.90	2.39	2.95	3.61	4.11	4.85	5.45	6.01
23.00	2.38	2.94	3.60	4.10	4.84	5.44	6.00
23.10	2.37	2.93	3.59	4.09	4.83	5.43	5.99
23.20	2.37	2.92	3.58	4.08	4.82	5.42	5.98
23.30	2.36	2.91	3.57	4.07	4.80	5.41	5.96
23.40	2.36	2.90	3.56	4.06	4.79	5.40	5.95
23.50	2.35	2.90	3.55	4.05	4.78	5.39	5.94
23.60	2.34	2.89	3.54	4.04	4.77	5.37	5.93
23.70	2.34	2.88	3.53	4.03	4.76	5.36	5.92
23.80	2.33	2.87	3.22	4.02	4.74	5.35	5.90
23.90	2.33	2.86	3.51	4.01	4.73	5.34	5.89
24.00	2.32	2.85	3.50	4.00	4.72	5.33	5.88
24.10	2.31	2.84	3.49	3.99	4.71	5.32	5.87
24.20	2.31	2.83	3.48	3.98	4.70	5.31	5.85
24.30	2.30	2.82	3.47	3.97	4.68	5.29	5.84
24.40	2.30	2.81	3.46	3.96	4.67	5.28	5.83
24.50	2.29	2.81	3.46	3.95	4.66	5.27	5.82
24.60	2.28	2.80	3.45	3.94	4.65	5.26	5.80
24.70	2.28	2.79	3.44	3.93	4.64	5.25	5.79
24.80	2.27	2.78	3.43	3.92	4.62	5.23	5.78
24.90	2.77	2.77	3.42	3.91	4.61	5.22	5.76

USE S.H.A. - 61.1 - 403.2 FOR RAINFALL INTENSITY FACTORS

RAINFALL, INTENSITY - FREQUENCY - DURATION
(INCHES PER HOUR)

	RETURN PERIOD (YEARS)						
MIN.	1	2	5	10	25	50	100
25.00	2.26	2.76	3.41	3.90	4.60	5.21	5.75
25.10	2.26	2.76	3.40	3.89	4.59	5.20	5.74
25.20	2.25	2.75	3.40	3.89	4.58	5.19	5.73
25.30	2.25	2.75	3.40	3.88	4.58	5.18	5.72
25.40	2.24	2.74	3.39	3.88	4.57	5.17	5.71
25.50	2.24	2.74	3.39	3.87	4.56	5.17	5.70
25.60	2.24	2.73	3.38	3.86	4.55	5.16	5.69
25.70	2.23	2.73	3.38	3.86	4.54	5.15	5.68
25.80	2.23	2.72	3.37	3.85	4.54	5.14	5.67
25.90	2.22	2.72	3.37	3.85	4.53	5.13	5.66
26.00	2.22	2.71	3.36	3.84	4.52	5.12	5.65
26.10	2.22	2.71	3.36	3.83	4.51	5.11	5.64
26.20	2.21	2.70	3.35	3.83	4.50	5.10	5.63
26.30	2.21	2.70	3.35	3.82	4.50	5.10	5.62
26.40	2.20	2.69	3.34	3.82	4.49	5.09	5.61
26.50	2.20	2.69	3.34	3.81	4.48	5.08	5.60
26.60	2.20	2.68	3.33	3.80	4.47	5.07	5.59
26.70	2.19	2.68	3.33	3.80	4.46	5.06	5.58
26.80	2.19	2.67	3.32	3.79	4 46	5.06	5.57
26.90	2.18	2.67	3.32	3.79	4.45	5.05	5.56
27.00	2.18	2.66	3.31	3.78	4.44	5.04	5.55
27.10	2.18	2.65	3.30	3.77	4.43	5.03	5.54
27.20	2.17	2.65	3.30	3.77	4.42	5.02	5.53
27.30	2.17	2.64	3.29	3.76	4.42	5.01	5.52
27.40	2.16	2.64	3.29	3.76	4.41	5.00	5.51
27.50	2.16	2.63	3.28	3.75	4.40	5.00	5.50
27.60	2.16	2.62	3.27	3.74	4.39	4.99	5.48
27.70	2.15	2.62	3.27	3.74	4.38	4.98	5.47
27.80	2.15	2.61	3.26	3.73	4.38	4.97	5.46
27.90	2.14	2.61	3.26	3.73	4.37	4.96	5.45
28.00	2.14	2.60	3.25	3.72	4.36	4.95	5.44
28.10	2.14	2.60	3.25	3.71	4.35	4.94	5.43
28.20	2.13	2.59	3.24	3.71	4.34	4.93	5.42
28.30	2.13	2.59	3.24	3.70	4.34	4.93	5.41
28.40	2.12	2.58	3.23	3.70	4.33	4.92	5.40
28.50	2.12	2.58	3.23	3.69	4.32	4.91	5.39
28.60	2.12	2.57	3.22	3.68	4.31	4.90	5.38
28.70	2.11	2.57	3.22	3.68	4.30	4.89	5.37
28.80	2.11	2.56	3.21	3.67	4.30	4.89	5.36
28.90	2.10	2.56	3.21	3.67	4.29	4.88	5.35
29.00	2.10	2.55	3.20	3.66	4.28	4.87	5.34
29.10	2.10	2.55	3.20	3.65	4.27	4.86	5.33
29.20	2.09	2.54	3.19	3.65	4.26	4.85	5.32
29.30	2.09	2.54	3.19	3.64	4.26	4.84	5.31
29.40	2.08	2.53	3.18	3.64	4.25	4.83	5.30
29.50	2.08	2.53	3.18	3.63	4.24	4.83	5.29
29.60	2.08	2.52	3.17	3.62	4.23	4.82	5.28
29.70	2.07	2.52	3.17	3.62	4.22	4.81	5.27
29.80	2.07	2.51	3.16	3.61	4.22	4.80	5.26
29.90	2.06	2.51	3.16	3.61	4.21	4.79	5.25

USE S.H.A. - 61.1 - 403.2 FOR RAINFALL INTENSITY FACTORS

RAINFALL, INTENSITY - FREQUENCY - DURATION
(INCHES PER HOUR)

	RETURN PERIOD (YEARS)						
MIN.	1	2	5	10	25	50	100
30.00	2.06	2.50	3.15	3.60	4.20	4.78	5.24
30.20	2.05	2.49	3.14	3.59	4.19	4.77	5.22
30.40	2.05	2.49	3.13	3.58	4.18	4.75	5.21
30.60	2.04	2.48	3.12	3.56	4.16	4.74	5.19
30.80	2.04	2.48	3.11	3.55	4.15	4.72	5.18
31.00	2.03	2.47	3.10	3.54	4.14	4.71	5.16
31.20	2.02	2.46	3.09	3.53	4.13	4.69	5.14
31.40	2.02	2.45	3.08	3.52	4.11	4.68	5.13
31.60	2.01	2.45	3.07	3.50	4.10	4.66	5.11
31.80	2.01	2.44	3.06	3.49	4.08	4.65	5.10
32.00	2.00	2.43	3.05	3.48	4.07	4.63	5.08
32.20	1.99	2.42	3.04	3.47	4.06	4.62	5.07
32.40	1.98	2.42	3.03	3.46	4.05	4.60	5.05
32.60	1.98	2.41	3.03	3.44	4.03	4.59	5.04
32.80	1.97	2.41	3.02	3.43	4.02	4.57	5.02
33.00	1.96	2.40	3.01	3.42	4.01	4.56	5.01
33.20	1.95	2.39	3.00	3.41	4.00	4.55	4.99
33.40	1.95	2.39	2.99	3.40	3.98	4.53	4.98
33.60	1.94	2.38	2.98	3.38	3.97	4.52	4.96
33.80	1.94	2.38	2.97	3.37	3.95	4.50	4.95
34.00	1.93	2.37	2.96	3.36	3.94	4.49	4.93
34.20	1.92	2.36	2.95	3.35	3.93	4.48	4.91
34.40	1.92	2.36	2.94	3.34	3.92	4.46	4.90
34.60	1.91	2.35	2.93	3.32	3.90	4.45	4.88
34.80	1.91	2.35	2.92	3.31	3.89	4.43	4.87
35.00	1.90	2.34	2.91	3.30	3.88	4.42	4.85
35.20	1.89	2.33	2.90	3.29	3.87	4.40	4.83
35.40	1.89	2.32	2.89	3.28	3.85	4.39	4.82
35.60	1.88	2.32	2.88	3.26	3.84	4.37	4.80
35.80	1.88	2.31	2.87	3.25	3.82	4.36	4.79
36.00	1.87	2.30	2.86	3.24	3.81	4.34	4.77
36.20	1.86	2.29	2.85	3.23	3.80	4.33	4.75
36.40	1.86	2.29	2.84	3.22	3.79	4.32	4.74
36.60	1.85	2.28	2.83	3.20	3.77	4.30	4.72
36.80	1.85	2.28	2.82	3.19	3.76	4.28	4.71
37.00	1.84	2.27	2.81	3.18	3.75	4.27	4.69
37.20	1.83	2.26	2.80	3.17	3.74	4.26	4.68
37.40	1.82	2.26	2.79	3.16	3.72	4.24	4.66
37.60	1.82	2.25	2.79	3.14	3.71	4.23	4.65
37.80	1.81	2.25	2.78	3.13	3.69	4.21	4.63
38.00	1.80	2.24	2.77	3.12	3.68	4.20	4.62
38.20	1.79	2.23	2.76	3.11	3.67	4.18	4.60
38.40	1.79	2.22	2.75	3.10	3.66	4.17	4.59
38.60	1.78	2.22	2.74	3.08	3.64	4.15	4.57
38.80	1.78	2.21	2.73	3.07	3.63	4.14	4.56
39.00	1.77	2.20	2.72	3.06	3.62	4.12	4.54
39.20	1.76	2.19	2.71	3.05	3.61	4.11	4.52
39.40	1.76	2.19	2.70	3.04	3.59	4.09	4.51
39.60	1.75	2.18	2.69	3.02	3.58	4.08	4.49
39.80	1.75	2.18	2.68	3.01	3.56	4.06	4.48
40.00	1.74	2.17	2.67	3.00	3.55	4.05	4.46

USE S.H.A. - 61.1 - 403.2 FOR RAINFALL INTENSITY FACTORS

RAINFALL, INTENSITY - FREQUENCY - DURATION
(INCHES PER HOUR)

	RETURN PERIOD (YEARS)						
MIN	1	2	5	10	25	50	100
40.00	1.74	2.17	2.67	3.00	3.55	4.05	4.46
40.20	1.73	2.16	2.66	2.99	3.54	4.04	4.45
40.40	1.73	2.15	2.65	2.98	3.53	4.02	4.43
40.60	1.72	2.14	2.64	2.97	3.52	4.01	4.42
40.80	1.72	2.14	2.63	2.96	3.51	4.00	4.41
41.00	1.71	2.13	2.62	2.96	3.50	3.99	4.39
41.20	1.70	2.12	2.61	2.95	3.49	3.97	4.38
41.40	1.70	2.11	2.60	2.94	3.48	3.96	4.37
41.60	1.69	2.10	2.59	2.93	3.47	3.95	4.35
41.80	1.69	2.09	2.58	2.92	3.46	3.93	4.34
42.00	1.68	2.09	2.57	2.91	3.45	3.92	4.33
42.20	1.67	2.08	2.56	2.90	3.44	3.91	4.31
42.40	1.67	2.07	2.55	2.89	3.43	3.90	4.30
42.60	1.66	2.06	2.55	2.89	3.41	3.88	4.29
42.80	1.66	2.05	2.54	2.88	3.40	3.87	4.28
43.00	1.65	2.04	2.53	2.87	3.39	3.86	4.26
43.20	1.64	2.04	2.52	2.86	3.38	3.85	4.25
43.40	1.64	2.03	2.51	2.85	3.37	3.83	4.24
43.60	1.63	2.02	2.50	2.84	3.36	3.82	4.22
43.80	1.63	2.01	2.49	2.83	3.35	3.81	4.21
44.00	1.62	2.00	2.48	2.82	3.34	3.79	4.20
44.20	1.61	1.99	2.47	2.82	3.33	3.78	4.18
44.40	1.61	1.99	2.46	2.81	3.32	3.77	4.17
44.60	1.60	1.98	2.45	2.80	3.31	3.76	4.16
44.80	1.60	1.97	2.44	2.79	3.30	3.74	4.14
45.00	1.59	1.96	2.43	2.78	3.29	3.73	4.13
45.20	1.59	1.96	2.42	2.77	3.28	3.72	4.12
45.40	1.58	1.95	2.42	2.77	3.28	3.72	4.11
45.60	1.58	1.95	2.41	2.76	3.27	3.71	4.10
45.80	1.57	1.94	2.41	2.76	3.26	3.70	4.09
46.00	1.57	1.94	2.40	2.75	3.26	3.69	4.08
46.20	1.56	1.94	2.40	2.74	3.25	3.69	4.07
46.40	1.56	1.93	2.39	2.74	3.25	3.68	4.06
46.60	1.55	1.93	2.39	2.73	3.24	3.67	4.05
46.80	1.55	1.92	2.38	2.73	3.23	3.67	4.04
47.00	1.54	1.92	2.38	2.72	3.23	3.66	4.03
47.20	1.54	1.92	2.37	2.71	3.22	3.65	4.02
47.40	1.53	1.91	2.37	2.71	3.21	3.64	4.01
47.60	1.53	1.91	2.36	2.70	3.21	3.64	4.01
47.80	1.52	1.90	2.36	2.70	3.20	3.63	4.00
48.00	1.52	1.90	2.35	2.69	3.19	3.62	3.99
48.20	1.51	1.90	2.35	2.68	3.19	3.61	3.98
48.40	1.51	1.89	2.34	2.68	3.18	3.61	3.97
48.60	1.50	1.89	2.34	2.67	3.17	3.60	3.96
48.80	1.50	1.88	2.33	2.67	3.17	3.59	3.95
49.00	1.49	1.88	2.33	2.66	3.16	3.59	3.94
49.20	1.49	1.88	2.32	2.65	3.16	3.58	3.93
49.40	1.48	1.87	2.32	2.65	3.15	3.57	3.92
49.60	1.48	1.87	2.31	2.64	3.14	3.56	3.91
49.80	1.47	1.86	2.31	2.64	3.14	3.56	3.90
50.00	1.47	1.86	2.30	2.63	3.13	3.55	3.89

USE S.H.A. 61.1 - 403.3 FOR RAINFALL INTENSITY FACTORS

RAINFALL, INTENSITY - FREQUENCY - DURATION
(INCHES PER HOUR)

	RETURN PERIOD (YEARS)						
MIN.	1	2	5	10	25	50	100
50.2	1.47	1.85	2.29	2.62	3.12	3.54	3.88
50.4	1.46	1.85	2.29	2.62	3.11	3.53	3.87
50.6	1.46	1.84	2.28	2.61	3.10	3.52	3.86
50.8	1.46	1.84	2.27	2.60	3.09	3.51	3.85
51.0	1.45	1.83	2.27	2.59	3.09	3.49	3.84
51.2	1.45	1.82	2.26	2.59	3.08	3.48	3.83
51.4	1.45	1.82	2.25	2.58	3.07	3.47	3.82
51.6	1.44	1.81	2.25	2.57	3.06	3.46	3.81
51.8	1.44	1.81	2.24	2.57	3.05	3.45	3.80
52.0	1.44	1.80	2.23	2.56	3.04	3.44	3.79
52.2	1.43	1.79	2.23	2.55	3.03	3.43	3.78
52.4	1.43	1.79	2.22	2.54	3.02	3.42	3.77
52.6	1.43	1.78	2.21	2.54	3.02	3.40	3.76
52.8	1.43	1.78	2.20	2.53	3.01	3.39	3.75
53.0	1.42	1.77	2.20	2.52	3.00	3.38	3.74
53.2	1.42	1.76	2.19	2.51	2.99	3.37	3.73
53.4	1.42	1.76	2.18	2.51	2.98	3.36	3.72
53.6	1.41	1.75	2.18	2.50	2.97	3.35	3.71
53.8	1.41	1.75	2.17	2.49	2.96	3.34	3.70
54.0	1.41	1.74	2.16	2.49	2.95	3.33	3.69
54.2	1.40	1.73	2.16	2.48	2.95	3.31	3.68
54.4	1.40	1.73	2.15	2.47	2.94	3.30	3.67
54.6	1.40	1.72	2.14	2.46	2.93	3.29	3.66
54.8	1.39	1.72	2.14	2.46	2.92	3.28	3.65
55.0	1.39	1.71	2.13	2.45	2.91	3.27	3.64
55.2	1.39	1.71	2.13	2.45	2.90	3.27	3.63
55.4	1.38	1.70	2.12	2.44	2.89	3.26	3.62
55.6	1.38	1.70	2.12	2.44	2.89	3.26	3.61
55.8	1.38	1.69	2.12	2.43	2.88	3.25	3.60
56.0	1.37	1.69	2.11	2.43	2.87	3.25	3.60
56.2	1.37	1.69	2.11	2.42	2.86	3.24	3.59
56.4	1.37	1.68	2.11	2.42	2.86	3.24	3.58
56.6	1.36	1.68	2.10	2.41	2.85	3.23	3.57
56.8	1.36	1.67	2.10	2.41	2.84	3.23	3.56
57.0	1.36	1.67	2.10	2.41	2.83	3.22	3.55
57.2	1.35	1.67	2.09	2.40	2.83	3.22	3.54
57.4	1.35	1.66	2.09	2.40	2.82	3.21	3.53
57.6	1.35	1.66	2.09	2.39	2.81	3.21	3.53
57.8	1.35	1.65	2.09	2.39	2.80	3.20	3.52
58.0	1.34	1.65	2.08	2.38	2.80	3.20	3.51
58.2	1.34	1.65	2.08	2.38	2.79	3.19	3.50
58.4	1.34	1.64	2.08	2.38	2.78	3.19	3.49
58.6	1.33	1.64	2.07	2.37	2.77	3.18	3.48
58.8	1.33	1.63	2.07	2.37	2.77	3.18	3.47
59.0	1.33	1.63	2.07	2.36	2.76	3.17	3.46
59.2	1.32	1.63	2.06	2.36	2.75	3.17	3.46
59.4	1.32	1.62	2.06	2.35	2.74	3.16	3.45
59.6	1.32	1.62	2.06	2.35	2.74	3.16	3.44
59.8	1.31	1.61	2.05	2.34	2.73	3.15	3.43
60.0	1.31	1.61	2.05	2.34	2.72	3.15	3.47

USE S.H.A. 61.1 - 403.3 FOR RAINFALL INTENSITY FACTORS

RAINFALL, INTENSITY - FREQUENCY - DURATION
(INCHES PER HOUR)

	RETURN PERIOD (YEARS)						
MIN.	1	2	5	10	25	50	100
61.0	1.30	1.60	2.03	2.32	2.70	3.12	3.40
62.0	1.29	1.59	2.01	2.30	2.68	3.10	3.37
63.0	1.28	1.57	2.00	2.29	2.66	3.07	3.35
64.0	1.27	1.56	1.98	2.27	2.63	3.05	3.32
65.0	1.26	1.55	1.96	2.25	2.61	3.02	3.30
66.0	1.24	1.54	1.94	2.23	2.59	3.00	3.27
67.0	1.23	1.52	1.92	2.21	2.57	2.97	3.25
68.0	1.22	1.51	1.91	2.20	2.55	2.95	3.22
69.0	1.21	1.50	1.89	2.18	2.53	2.92	3.20
70.0	1.20	1.49	1.87	2.16	2.51	2.90	3.17
71.0	1.19	1.47	1.85	2.14	2.49	2.87	3.15
72.0	1.18	1.46	1.83	2.12	2.46	2.85	3.12
73.0	1.17	1.45	1.82	2.11	2.44	2.82	3.10
74.0	1.16	1.44	1.80	2.09	2.42	2.80	3.07
75.0	1.15	1.43	1.78	2.07	2.40	2.77	3.05
76.0	1.13	1.41	1.76	2.05	2.38	2.74	3.02
77.0	1.12	1.40	1.74	2.03	2.36	2.72	3.00
78.0	1.11	1.39	1.73	2.02	2.34	2.69	2.97
79.0	1.10	1.38	1.71	2.00	2.31	2.67	2.95
80.0	1.09	1.36	1.69	1.98	2.29	2.64	2.92
81.0	1.08	1.35	1.67	1.96	2.27	2.62	2.90
82.0	1.07	1.34	1.65	1.94	2.25	2.59	2.87
83.0	1.06	1.33	1.64	1.93	2.23	2.57	2.85
84.0	1.05	1.31	1.62	1.91	2.21	2.54	2.82
85.0	1.04	1.30	1.60	1.89	2.19	2.52	2.80
86.0	1.02	1.29	1.58	1.87	2.17	2.49	2.77
87.0	1.01	1.28	1.56	1.85	2.14	2.47	2.75
88.0	1.00	1.26	1.55	1.84	2.12	2.44	2.72
89.0	0.99	1.25	1.53	1.82	2.10	2.42	2.70
90.0	0.98	1.24	1.51	1.80	2.08	2.39	2.67
91.0	0.97	1.23	1.50	1.79	2.07	2.37	2.65
92.0	0.97	1.22	1.49	1.78	2.05	2.36	2.64
93.0	0.96	1.22	1.48	1.76	2.04	2.34	2.62
94.0	0.96	1.21	1.48	1.75	2.03	2.33	2.61
95.0	0.95	1.20	1.47	1.74	2.02	2.31	2.59
96.0	0.94	1.19	1.46	1.73	2.00	2.30	2.57
97.0	0.94	1.18	1.45	1.72	1.99	2.28	2.56
98.0	0.93	1.17	1.44	1.70	1.98	2.27	2.54
99.0	0.93	1.17	1.43	1.69	1.97	2.25	2.53
100.0	0.92	1.16	1.42	1.68	1.95	2.24	2.51

USE S.H.A. 61.6 - 403.3 FOR RAINFALL INTENSITY FACTORS

RAINFALL, INTENSITY - FREQUENCY - DURATION
(INCHES PER HOUR)

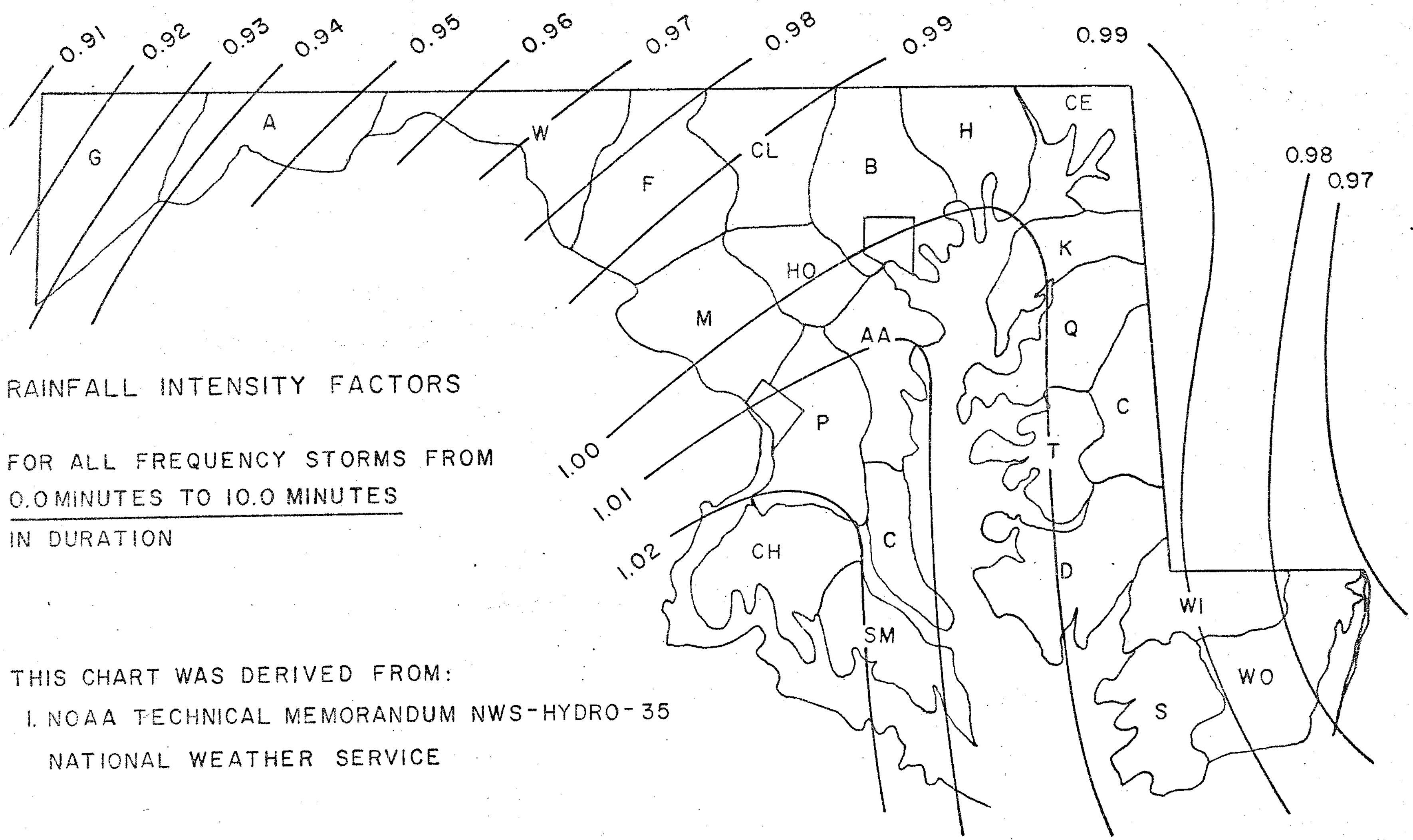
	RETURN PERIOD (YEARS)						
MIN.	1	2	5	10	25	50	100
101.0	0.91	1.15	1.41	1.67	1.94	2.22	2.49
102.0	0.91	1.14	1.41	1.66	1.93	2.21	2.48
103.0	0.90	1.13	1.40	1.64	1.92	2.19	2.46
104.0	0.90	1.12	1.39	1.63	1.90	2.18	2.45
105.0	0.89	1.12	1.38	1.62	1.89	2.16	2.43
106.0	0.88	1.11	1.37	1.61	1.88	2.14	2.41
107.0	0.88	1.10	1.36	1.60	1.86	2.13	2.40
108.0	0.87	1.09	1.35	1.58	1.85	2.11	2.38
109.0	0.87	1.08	1.35	1.57	1.84	2.10	2.37
110.0	0.86	1.07	1.34	1.56	1.83	2.08	2.35
111.0	0.85	1.07	1.33	1.55	1.81	2.07	2.33
112.0	0.85	1.06	1.32	1.54	1.80	2.05	2.32
113.0	0.84	1.05	1.31	1.52	1.79	2.04	2.30
114.0	0.84	1.04	1.30	1.51	1.78	2.02	2.29
115.0	0.83	1.03	1.29	1.50	1.76	2.01	2.27
116.0	0.82	1.02	1.28	1.49	1.75	1.99	2.25
117.0	0.82	1.02	1.28	1.48	1.74	1.98	2.24
118.0	0.81	1.01	1.27	1.46	1.73	1.96	2.22
119.0	0.81	1.00	1.26	1.45	1.71	1.95	2.21
120.0	0.80	0.99	1.25	1.44	1.70	1.93	2.19
121.0	0.80	0.99	1.24	1.43	1.69	1.92	2.18
122.0	0.79	0.98	1.24	1.43	1.68	1.91	2.17
123.0	0.79	0.98	1.23	1.42	1.67	1.91	2.16
124.0	0.78	0.97	1.22	1.41	1.67	1.90	2.15
125.0	0.78	0.96	1.22	1.41	1.66	1.89	2.14
126.0	0.78	0.96	1.21	1.40	1.65	1.88	2.12
127.0	0.77	0.96	1.21	1.40	1.64	1.87	2.11
128.0	0.77	0.95	1.20	1.39	1.63	1.86	2.10
129.0	0.76	0.95	1.19	1.38	1.62	1.86	2.09
130.0	0.76	0.94	1.19	1.38	1.61	1.85	2.08
131.0	0.76	0.94	1.18	1.37	1.60	1.84	2.07
132.0	0.75	0.93	1.17	1.36	1.60	1.83	2.06
133.0	0.75	0.93	1.17	1.36	1.59	1.82	2.05
134.0	0.74	0.92	1.16	1.35	1.58	1.81	2.04
135.0	0.74	0.92	1.16	1.35	1.57	1.81	2.03
136.0	0.74	0.91	1.16	1.34	1.56	1.80	2.01
137.0	0.73	0.91	1.14	1.33	1.55	1.79	2.00
138.0	0.73	0.90	1.14	1.33	1.54	1.78	1.99
139.0	0.72	0.90	1.13	1.32	1.54	1.77	1.98
140.0	0.72	0.89	1.12	1.31	1.53	1.76	1.97

USE S.H.A. 61.6 - 403.3 FOR RAINFALL INTENSITY FACTORS

RAINFALL, INTENSITY - FREQUENCY - DURATION
(INCHES PER HOUR)

	RETURN PERIOD (YEARS)						
MIN.	1	2	5	10	25	50	100
141.0	0.72	0.89	1.12	1.31	1.52	1.76	1.96
142.0	0.71	0.88	1.11	1.30	1.51	1.75	1.95
143.0	0.71	0.88	1.10	1.29	1.50	1.74	1.94
144.0	0.70	0.87	1.10	1.29	1.49	1.73	1.93
145.0	0.70	0.87	1.09	1.28	1.48	1.72	1.92
146.0	0.70	0.86	1.09	1.28	1.47	1.71	1.90
147.0	0.69	0.86	1.08	1.27	1.47	1.71	1.89
148.0	0.69	0.85	1.07	1.26	1.46	1.70	1.88
149.0	0.68	0.85	1.07	1.26	1.45	1.69	1.87
150.0	0.68	0.84	1.06	1.25	1.44	1.68	1.86
151.0	0.68	0.84	1.06	1.24	1.43	1.67	1.85
152.0	0.67	0.83	1.05	1.24	1.43	1.66	1.84
153.0	0.67	0.83	1.05	1.23	1.42	1.66	1.84
154.0	0.67	0.83	1.04	1.23	1.41	1.65	1.83
155.0	0.66	0.82	1.04	1.22	1.41	1.64	1.82
156.0	0.66	0.82	1.03	1.21	1.40	1.63	1.81
157.0	0.66	0.81	1.03	1.21	1.40	1.62	1.80
158.0	0.65	0.81	1.03	1.20	1.39	1.61	1.79
159.0	0.65	0.81	1.02	1.20	1.38	1.61	1.79
160.0	0.65	0.80	1.02	1.19	1.38	1.60	1.78
161.0	0.64	0.80	1.01	1.18	1.37	1.59	1.77
162.0	0.64	0.80	1.01	1.18	1.36	1.58	1.76
163.0	0.64	0.79	1.00	1.17	1.36	1.57	1.75
164.0	0.63	0.79	1.00	1.17	1.35	1.56	1.74
165.0	0.63	0.79	1.00	1.16	1.35	1.56	1.74
166.0	0.63	0.78	0.99	1.15	1.34	1.55	1.73
167.0	0.62	0.78	0.99	1.15	1.33	1.54	1.72
168.0	0.62	0.77	0.98	1.14	1.33	1.53	1.71
169.0	0.62	0.77	0.98	1.14	1.32	1.52	1.70
170.0	0.61	0.77	0.97	1.13	1.31	1.51	1.69
171.0	0.61	0.76	0.97	1.12	1.31	1.51	1.69
172.0	0.61	0.76	0.96	1.12	1.30	1.50	1.68
173.0	0.60	0.76	0.96	1.11	1.29	1.49	1.67
174.0	0.60	0.75	0.96	1.11	1.29	1.48	1.66
175.0	0.60	0.75	0.95	1.10	1.28	1.47	1.65
176.0	0.59	0.74	0.95	1.09	1.28	1.46	1.64
177.0	0.59	0.74	0.94	1.09	1.27	1.46	1.64
178.0	0.59	0.74	0.94	1.08	1.26	1.45	1.63
179.0	0.58	0.73	0.93	1.08	1.26	1.44	1.62
180.0	0.58	0.73	0.93	1.07	1.25	1.43	1.61

REFER DIRECTLY TO REFERENCE NO. 2 ---------- USE S.H.A. 61.6 - 403.3 FOR RAINFALL INTENSITY FACTORS



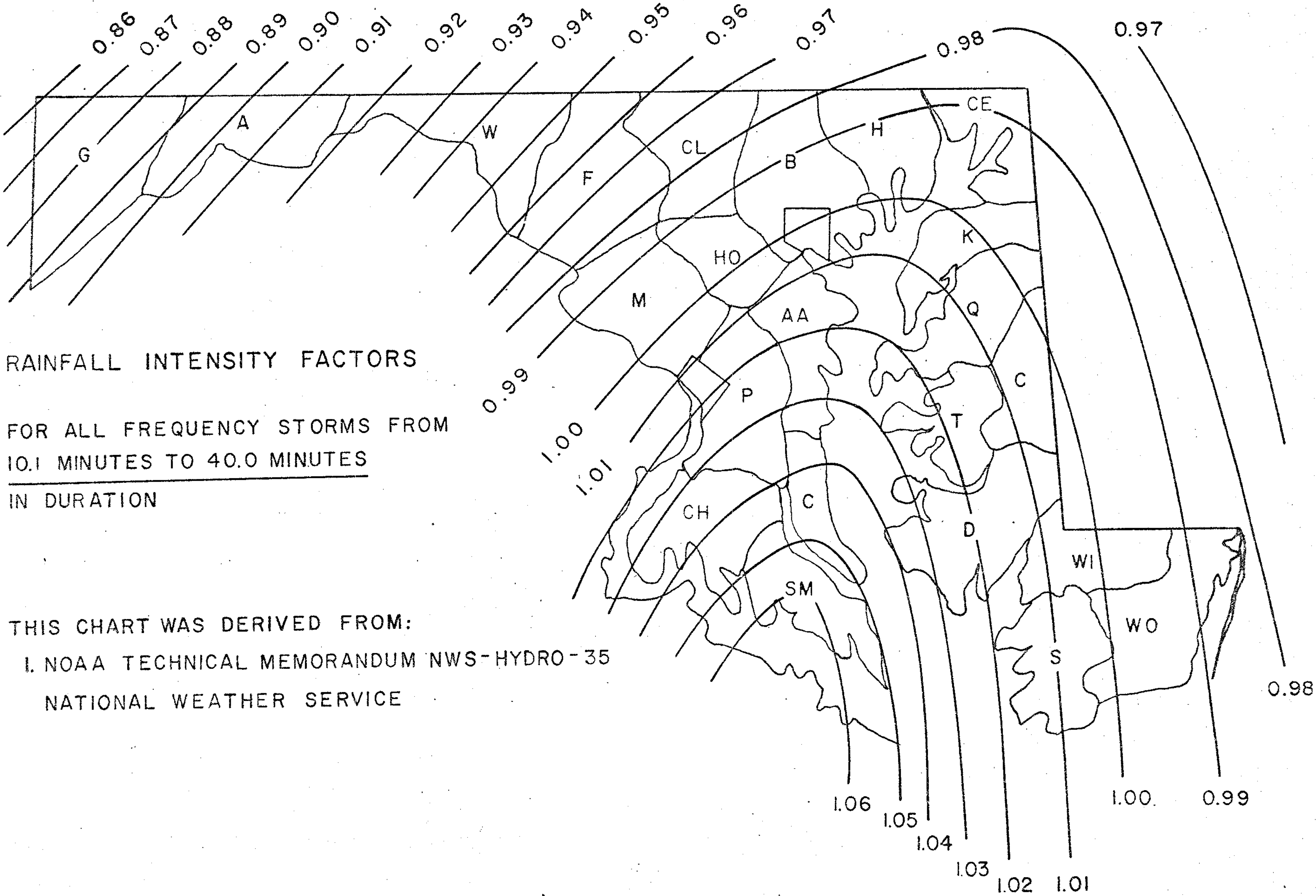
RAINFALL INTENSITY FACTORS

FOR ALL FREQUENCY STORMS FROM
0.0 MINUTES TO 10.0 MINUTES
IN DURATION

THIS CHART WAS DERIVED FROM:

1. NOAA TECHNICAL MEMORANDUM NWS-HYDRO-35
NATIONAL WEATHER SERVICE

MARYLAND STATE HIGHWAY ADMINISTRATION 4-78 SHA 61.1-403.1



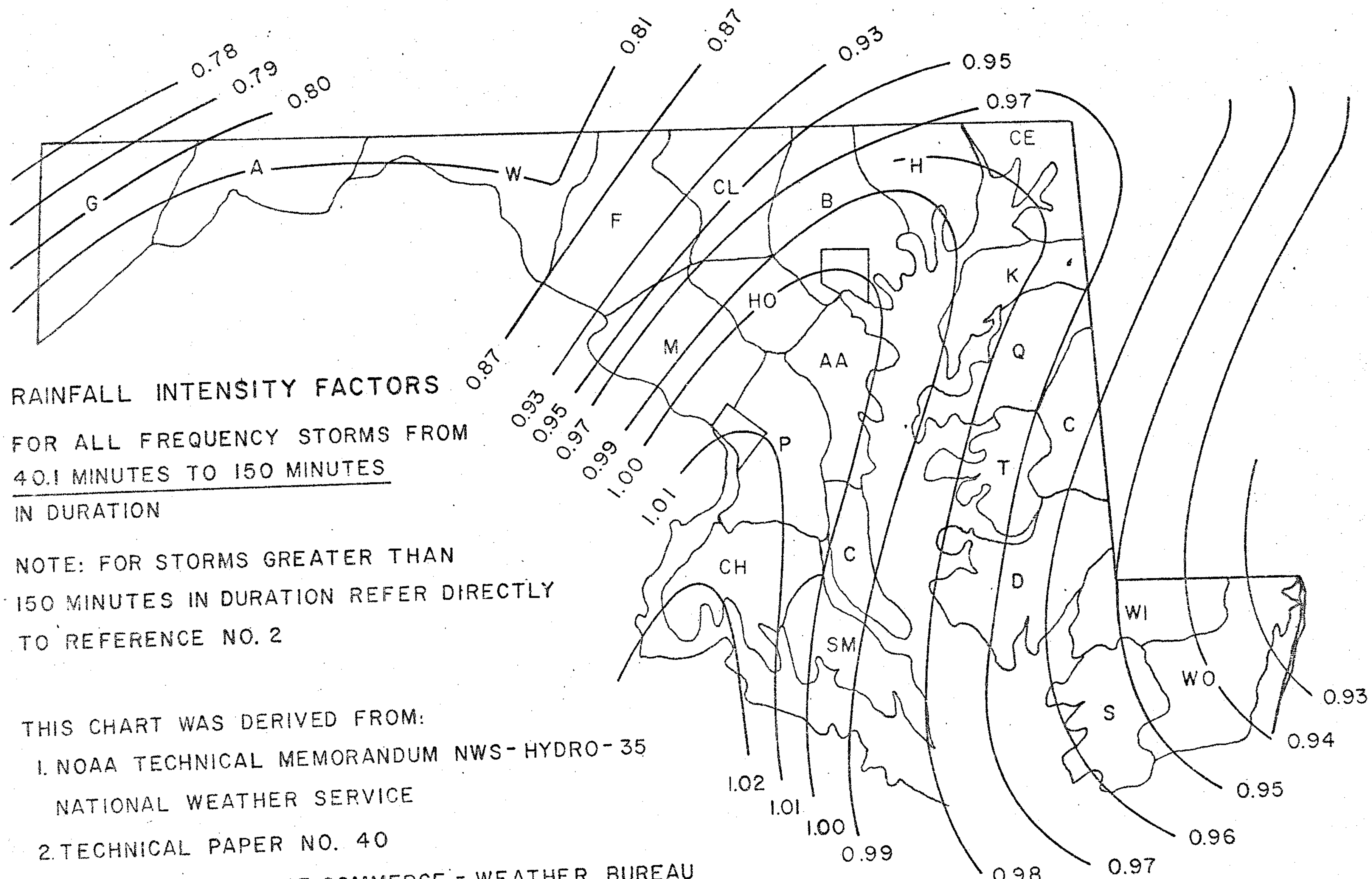
RAINFALL INTENSITY FACTORS

FOR ALL FREQUENCY STORMS FROM
10.1 MINUTES TO 40.0 MINUTES
IN DURATION

THIS CHART WAS DERIVED FROM:

1. NOAA TECHNICAL MEMORANDUM NWS-HYDRO-35
NATIONAL WEATHER SERVICE

MARYLAND STATE HIGHWAY ADMINISTRATION 4-78 SHA 61.1-403.2



RAINFALL INTENSITY FACTORS

FOR ALL FREQUENCY STORMS FROM
40.1 MINUTES TO 150 MINUTES
IN DURATION

NOTE: FOR STORMS GREATER THAN 150 MINUTES IN DURATION REFER DIRECTLY TO REFERENCE NO. 2

THIS CHART WAS DERIVED FROM:

1. NOAA TECHNICAL MEMORANDUM NWS-HYDRO-35
   NATIONAL WEATHER SERVICE
2. TECHNICAL PAPER NO. 40
   U.S. DEPARTMENT OF COMMERCE - WEATHER BUREAU

SHA 61.1 - 403.3

MARYLAND STATE HIGHWAY ADMINISTRATION 4-78

2. The Soil Conservation Service methods - The basic technical references for the SCS methods are the National Engineering Handbook - Section 4 - Hydrology, and the SCS Engineering Field Manual.

The detailed procedures for using TR-20 may be found in the SCS Technical Release No. 20 "Computer Program for Project Formulation - hydrology."

The detailed procedures for using TR-55 may be found in the SCS Technical Release No. 55 - "Urban Hydrology for Small Watersheds."

a. Runoff Curve Numbers - The RCN shall be selected on the basis of the characteristics of the contributing areaas or surfaces. In selecting the RCN, the following parameters must be considered: Hydrologic Soil Group, ground cover and/or land use.

Hydrologic Soil Group - The Authority for determining soil types for use with this method will be the United States Department of Agriculture "Soil Survey" which is published in separate volumes, one (1) for each County. Each soil type is classified into one of the four Hydrologic Soil Groups, A, B, C, or D. A list of all soil types in Maryland and the corresponding Soil Group for each is given in tables SHA - 61.1-401.1A; 401.1B.

To determine the soil group on a project, refer to Section A-1.

If more than one soil group is involved, the limits of each group should be outlined on the drainage area map to aid in computing the RCN for each land use or ground cover.

Whenever plans are available for either existing or proposed developed areas, the drainage area should be reduced to roof areas, various types of paved areas, and areas of various vegetative types.

If detailed site plans are not available, the watershed can be reduced to various types of development, i.e., residential, industrial or commercial. Which ever method is used, the appropriate RCN may be obtained using chart SHA-61.1-401.2. The general values for "residential", "commercial" and "industrial" areas should only be used when detailed plans are not available.

Where heterogenous drainage areas are encountered, a weighted value of RCN will be used. The formula for the weighted RCN is as follows:

$$RCN_w = \frac{RCN_1 A_1 + RCN_2 A_2 + \ldots + RCN_i A_i}{A_1 + A_2 + \ldots + A_i} \qquad (4)$$

Where A_1, A_2 and A_i are subareas within the watershed, and RCN_1, RCN_2, and RCN_i are the corresponding runoff curve numbers for these subareas. This formula may be expanded for any number of subareas.

RUNOFF CURVE NUMBERS

RURAL AREAS

	HYDROLOGIC SOIL GROUP			
	A	B	C	D
Wooded:				
Poor - No mulch, small trees or brush	45	66	77	83
Fair - Grazed, some mulch	36	60	73	79
Good - Protected from grazing, Heavy mulch and shrubs cover soil	25	55	70	77
Pasture: (Native or improved grassland reserved for grazing)				
Poor - Heavily grazed, Plant cover on less than 50% of area	68	79	86	89
Fair - Not heavily grazed, Plant cover on 50% to 75% of area	49	69	79	84
Good - Lightly grazed, Plant cover on more than 75% of area	39	61	74	80
Meadow: (Grass grown for hay crop)	30	58	71	78
Cultivated:				
Fallow: (Plowed, no crop planted)	77	86	91	94
Row Crop: (Corn, soybeans, tomatoes, etc. spaced about 3 1/2' apart)	72	81	88	91
Small Grain: (Wheat, oats, barley, etc.)	65	76	84	88
Water Surfaces	100	100	100	100

Source - Ref. #9 Appendix 2

RUNOFF CURVE NUMBERS

URBAN AREAS

	HYDROLOGIC SOIL GROUP A	B	C	D
Open Spaces, Lawns, Parks, Golf courses, Cemeteries				
Grass covers 75% or more of area	39	61	74	80
Grass covers 50% to 75% or area	49	69	79	84
Paved Areas, Roofs	98	98	98	98
Streets and Roads				
Paved, Curb and Gutter	98	98	98	98
Hard Surfaced (Includes R/W)	74	84	90	92
Gravel	76	85	89	91
Dirt (Includes R/W)	72	82	87	89
Residential Development				
Row Houses or Town Houses	80	85	90	95
1/8 acre lots Average 65% impervious	77	85	90	92
1/4 acre lots Average 38% impervious	61	75	83	87
1/3 acre lots Average 30% impervious	57	72	81	86
1/2 acre lots Average 25% impervious	54	70	80	85
1 acre lots Average 20% impervious	51	68	79	84
2 acre lots	47	66	77	81
Newly Graded area, no vegetation	81	89	93	95
Commercial and Business Areas 85% impervious	89	92	94	95
Industrial Areas 72% impervious	81	88	91	93

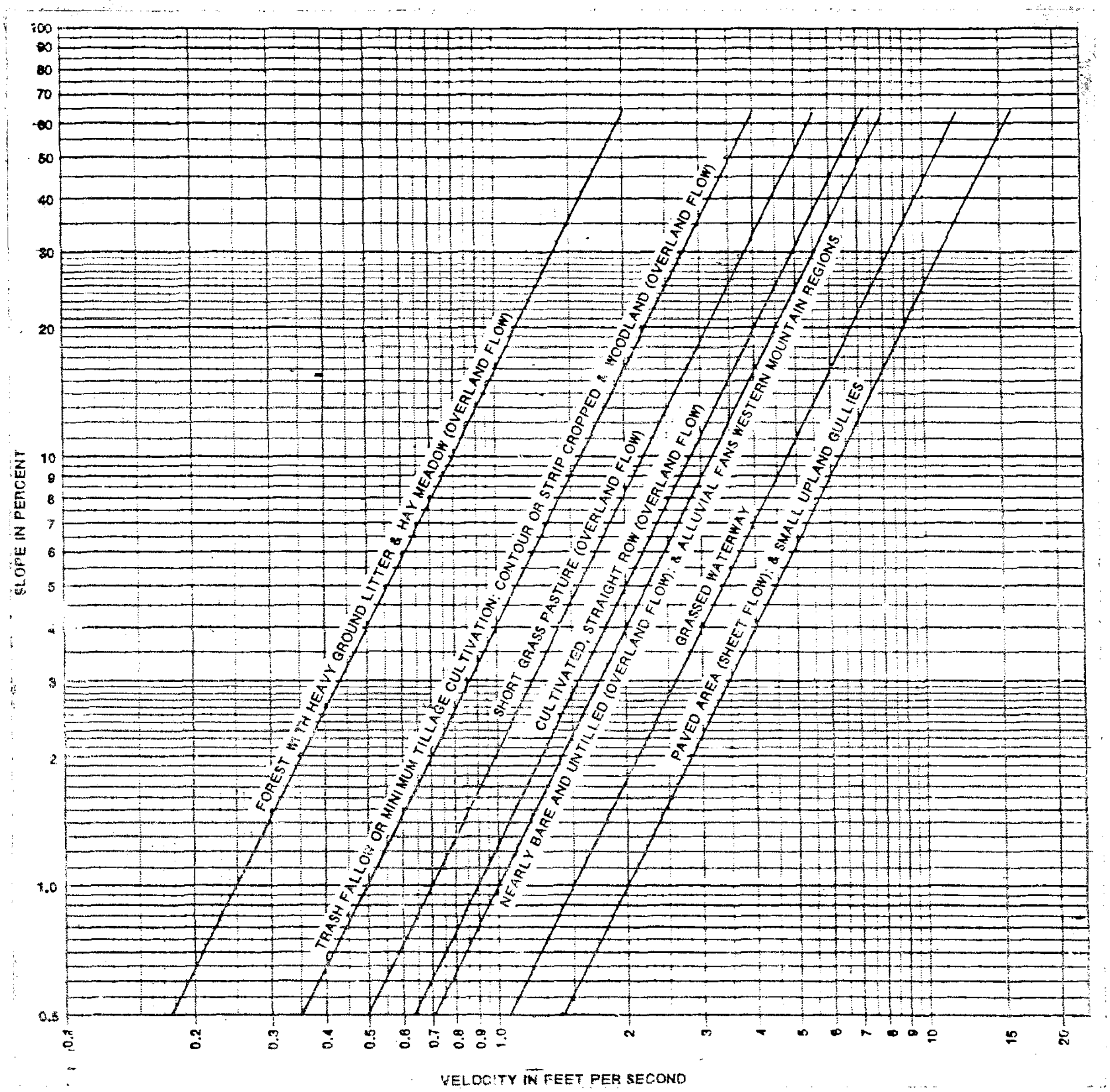
Source - Ref. # 26 Appendix 2

SHA-61.1 401.2B

b. Time of Concentration - When using either the TR-20 or the TR-55 method, the time of concentration will be determined by the velocity method using the appropriate curve from chart SHA-61.1.-402.2 and Manning's Formula (See Chapter 2, Section B-1). The curves for overland flow shall be used unless the flow type can be defined as a 'grass waterway' or an 'upland gully'. For estimating flow times in pipes and open channels where the cross-section is known, Manning's Formula should be used assuming full flow in pipes and bank-full flow in channels.

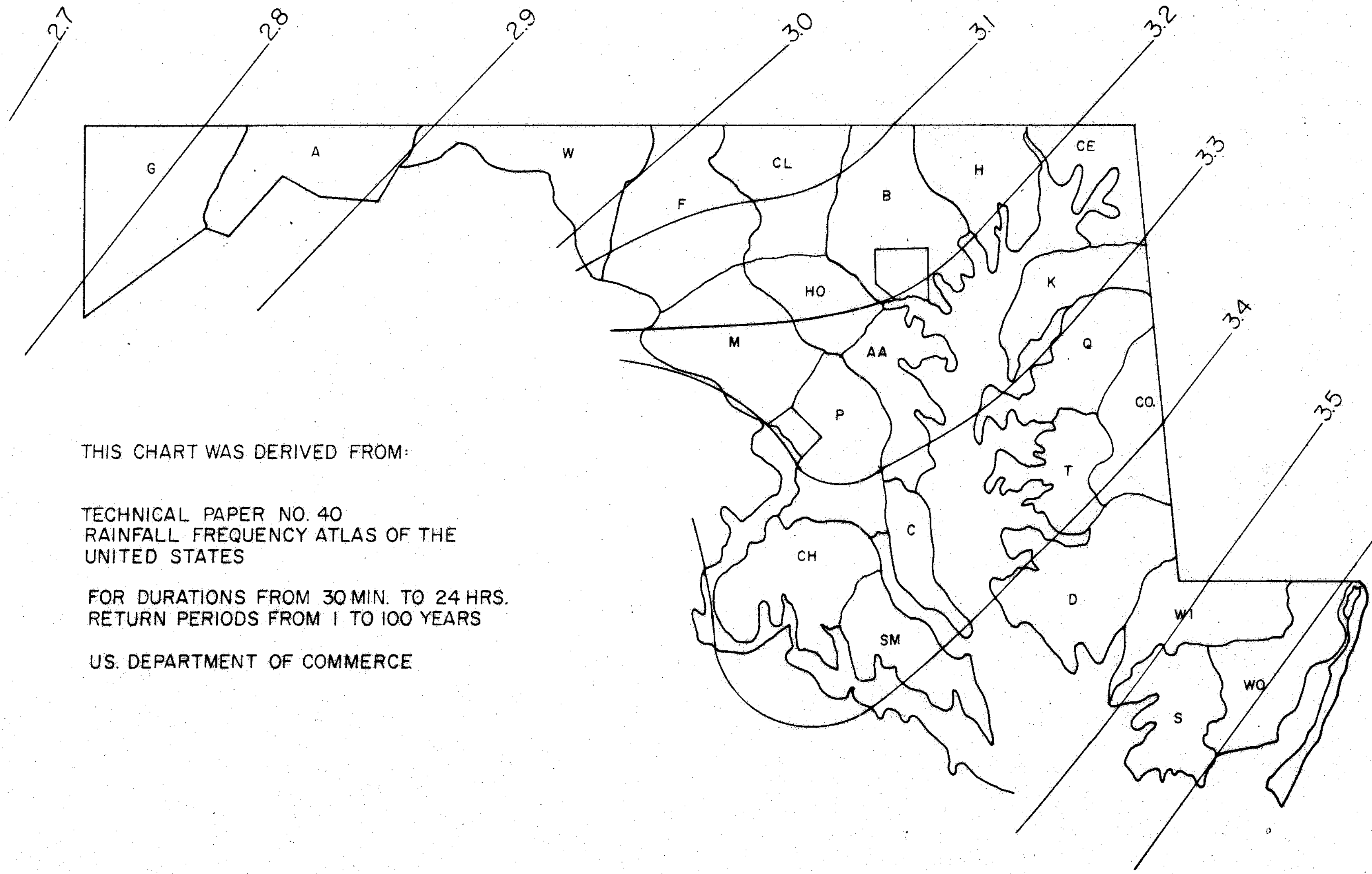
c. Rainfall Data - The design rainfall for the SCS methods is the 24 hour storm . The required imput is the rainfall depth in inches for the desired return frequency and the geographic location of the watershed. This data may be obtained from Charts SHA 61.1 - 403.4 thru 403.9.

d. Drainage on the Eastern Shore - When computing runoff hydrographs for drainage areas on the eastern shore (using TR-20) the 24-hour Dimensionless Unit Hydrograph for use on the DELMARVA Peninsula should be used. This data is found on Table SHA-61.1 - 403.99.



VELOCITIES FOR UPLAND METHOD OF ESTIMATING T_C

MARYLAND STATE HIGHWAY ADMINISTRATION 8/5/80 SHA-61.1-402.2



THIS CHART WAS DERIVED FROM:

TECHNICAL PAPER NO. 40
RAINFALL FREQUENCY ATLAS OF THE
UNITED STATES

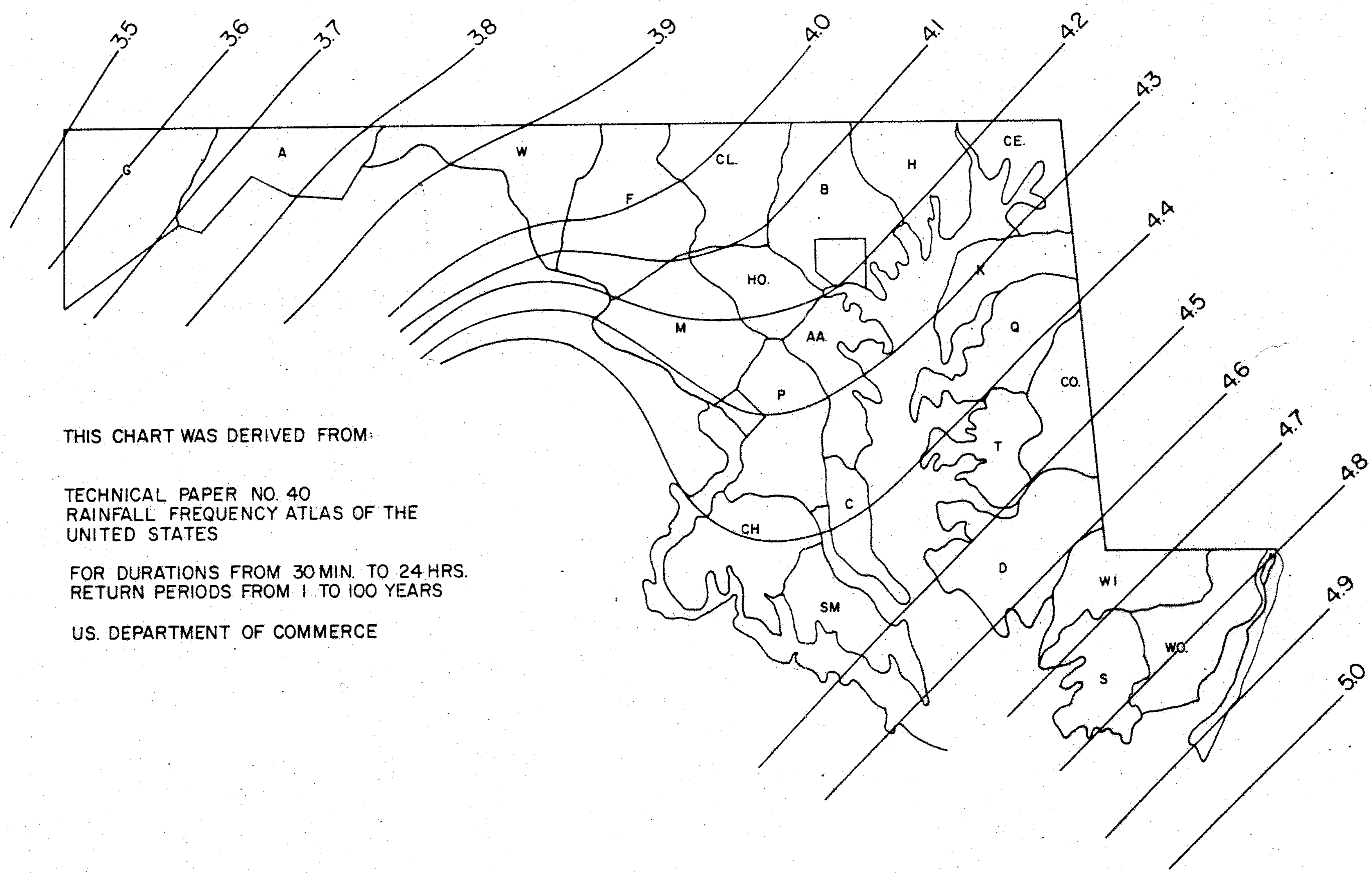
FOR DURATIONS FROM 30 MIN. TO 24 HRS.
RETURN PERIODS FROM 1 TO 100 YEARS

U.S. DEPARTMENT OF COMMERCE

2 YEAR - 24 HOUR RAINFALL - INCHES

MARYLAND STATE HIGHWAY ADMINISTRATION 7/80 SHA-61.1-403.4

I-2-A-55



THIS CHART WAS DERIVED FROM:

TECHNICAL PAPER NO. 40
RAINFALL FREQUENCY ATLAS OF THE
UNITED STATES

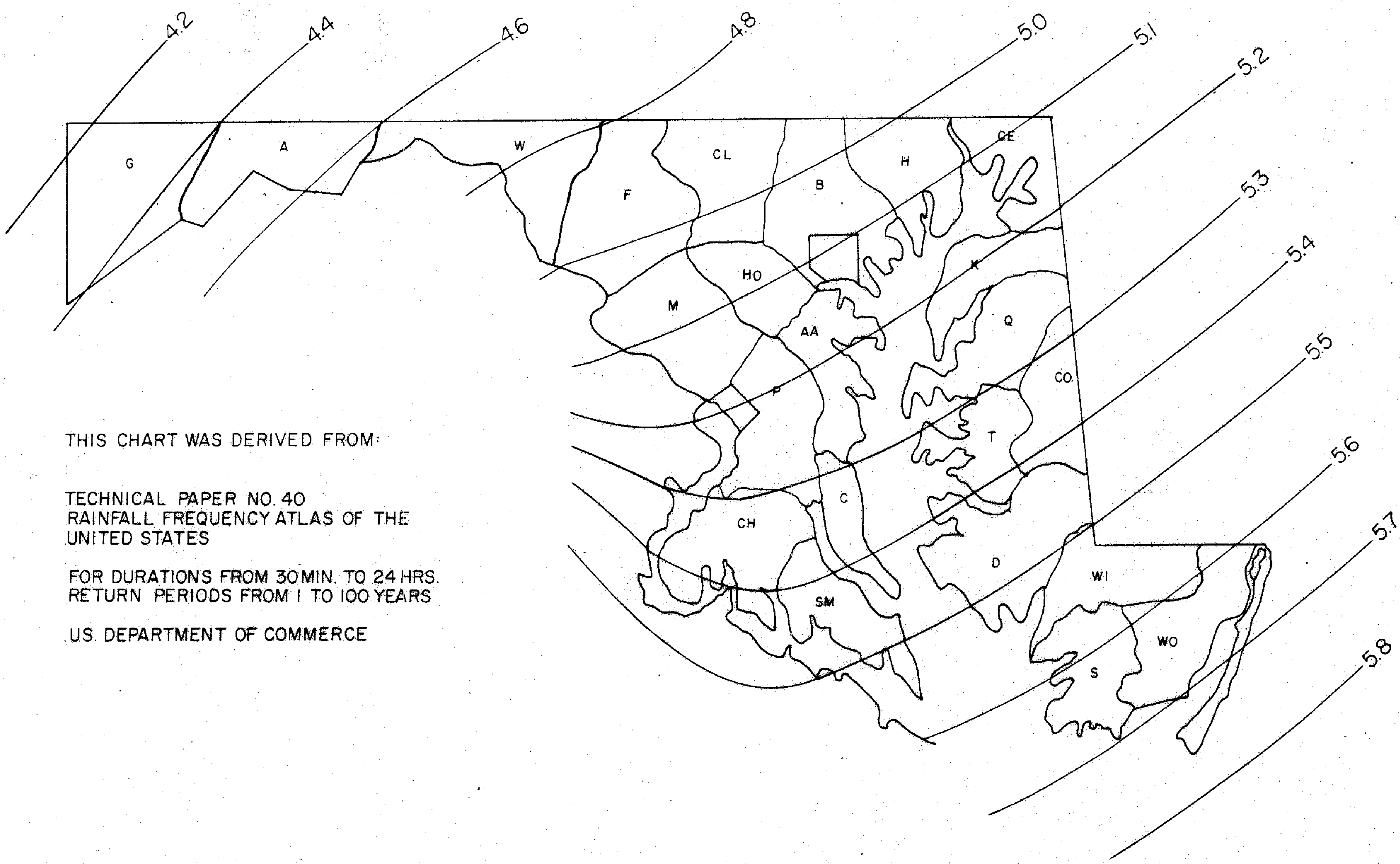
FOR DURATIONS FROM 30 MIN. TO 24 HRS.
RETURN PERIODS FROM 1 TO 100 YEARS

US. DEPARTMENT OF COMMERCE

5 YEAR - 24 HOUR RAINFALL - INCHES

MARYLAND STATE HIGHWAY ADMINISTRATION 7/80 SHA-61.1-403.5

I-2-A-57



THIS CHART WAS DERIVED FROM:

TECHNICAL PAPER NO. 40
RAINFALL FREQUENCY ATLAS OF THE
UNITED STATES

FOR DURATIONS FROM 30 MIN. TO 24 HRS.
RETURN PERIODS FROM 1 TO 100 YEARS

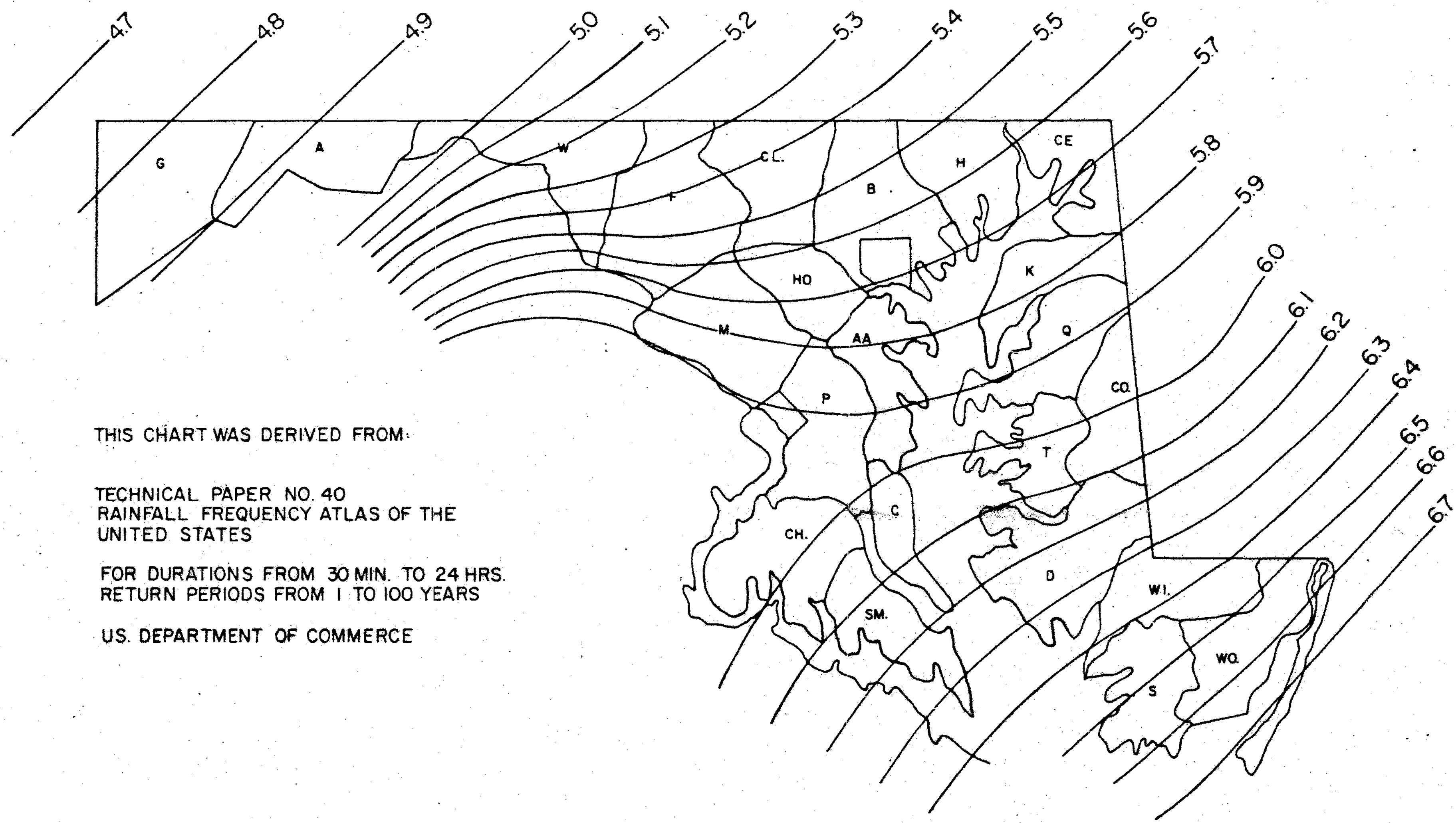
US. DEPARTMENT OF COMMERCE

10 YEAR - 24 HOUR RAINFALL - INCHES

MARYLAND STATE HIGHWAY ADMINISTRATION 7/80 SHA-61.1-403.6

I-2-A-59

I-2-A-61



THIS CHART WAS DERIVED FROM:

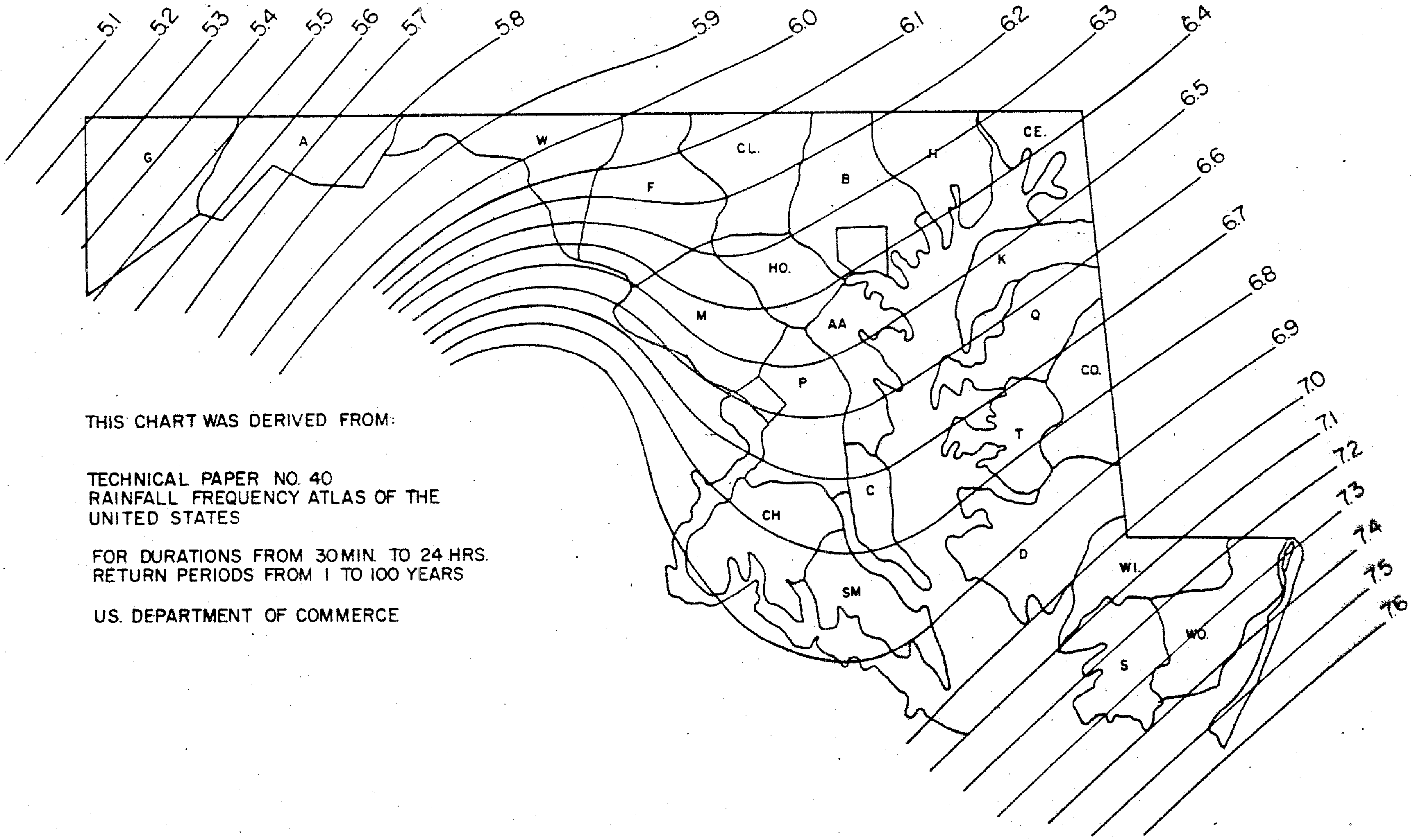
TECHNICAL PAPER NO. 40
RAINFALL FREQUENCY ATLAS OF THE
UNITED STATES

FOR DURATIONS FROM 30 MIN. TO 24 HRS.
RETURN PERIODS FROM 1 TO 100 YEARS

US. DEPARTMENT OF COMMERCE

25 YEAR - 24 HOUR RAINFALL - INCHES

MARYLAND STATE HIGHWAY ADMINISTRATION | 7/80 | SHA-61.1-403.7



THIS CHART WAS DERIVED FROM:

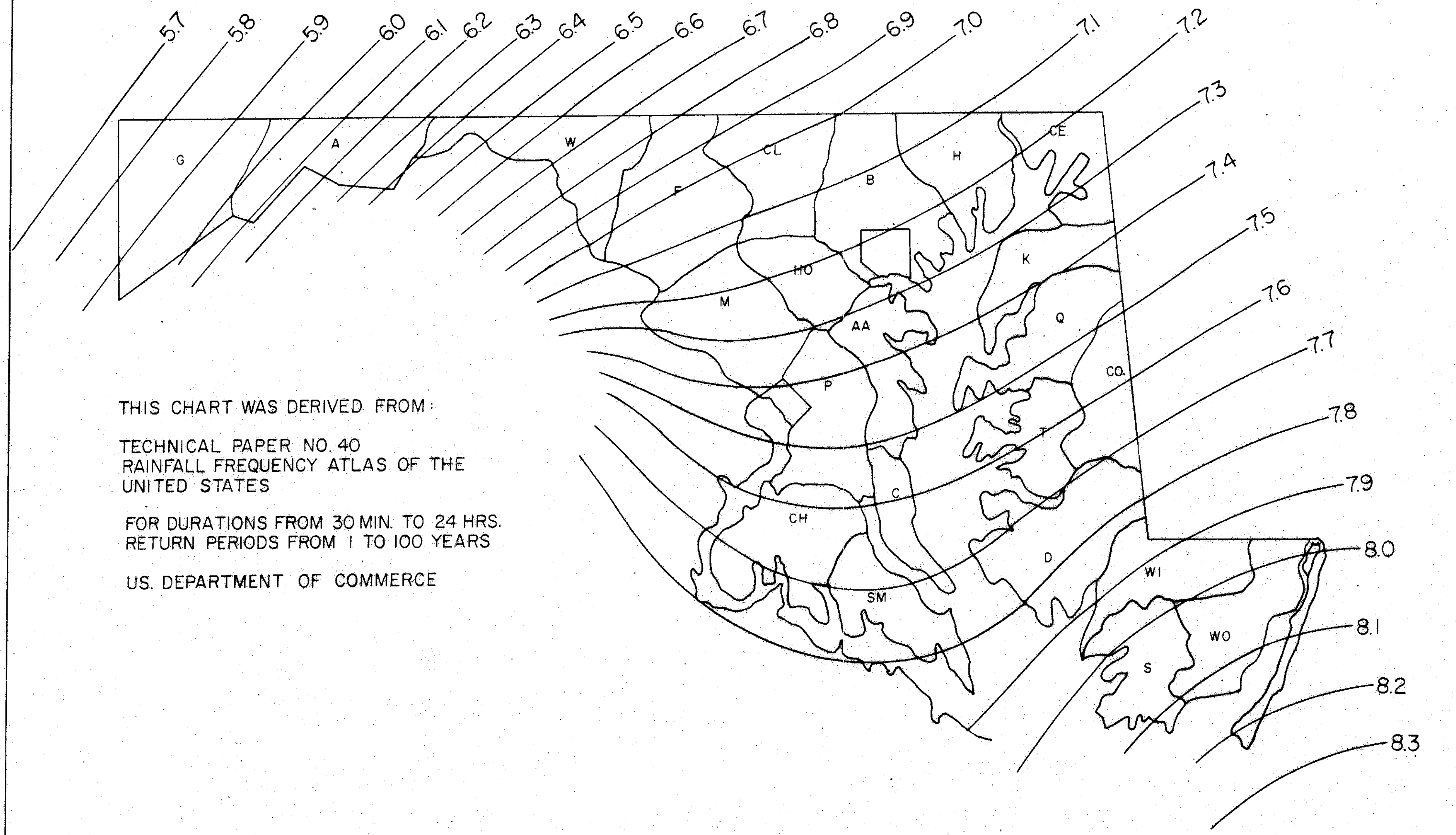
TECHNICAL PAPER NO. 40
RAINFALL FREQUENCY ATLAS OF THE
UNITED STATES

FOR DURATIONS FROM 30 MIN. TO 24 HRS.
RETURN PERIODS FROM 1 TO 100 YEARS

US. DEPARTMENT OF COMMERCE

50 YEAR - 24 HOUR RAINFALL - INCHES

MARYLAND STATE HIGHWAY ADMINISTRATION 7/80 SHA-61.1-403.8



100 YEAR - 24 HOUR RAINFALL - INCHES

MARYLAND STATE HIGHWAY ADMINISTRATION 7/80 SHA.-61.1-403.9

I-2-A-65

DATA CODE	TABLE NAME		DATA FIELD #1	DATA FIELD #2	DATA FIELD #3	DATA FIELD #4	DATA FIELD #5	CARD NO./ IDENTIFICATION

IMPORTANT: Line out unused cards. Data fields require decimal points. KEYPUNCHER: Left justify data fields.

DIMENSIONLESS TIME INCREMENT (Last entry must be for dimensionless time 1.0)

DATA CODE	TABLE NAME		DATA FIELD #1	DATA FIELD #2	DATA FIELD #3	DATA FIELD #4	DATA FIELD #5	CARD NO./ IDENTIFICATION
4	DIMHYD			0.02				

Enter successive entries left to right with initial entry for time = 0. Fill last row of data with last entry of table.

DATA CODE	TABLE NAME		DATA FIELD #1	DATA FIELD #2	DATA FIELD #3	DATA FIELD #4	DATA FIELD #5	CARD NO./ IDENTIFICATION
8			0.0	0.111	0.356	0.655	0.896	
8			1.000	0.929	0.828	0.737	0.656	
8			0.584	0.521	0.465	0.415	0.371	
8			0.331	0.296	0.265	0.237	0.212	
8			0.190	0.170	0.153	0.138	0.123	
8			0.109	0.097	0.086	0.076	0.066	
8			0.057	0.049	0.041	0.033	0.027	
8			0.024	0.021	0.018	0.015	0.013	
8			0.012	0.011	0.009	0.008	0.008	
8			0.006	0.006	0.005	0.005	0.0	
9	ENDTBL		NOTE: This card must be the last card of this table					

NOTE: The peak factor for this hydrograph is 284.

DIMENSIONLESS HYDROGRAPH TABLE DISCHARGE VS. TIME

24-HOUR DIMENSIONLESS UNIT HYDROGRAPH FOR USE IN THE DELMARVA PENNINSULA

e. TR-20 Input Data - The TR-20 Users Manual should be consulted for each project. However, the following is offered as an order of procedure for collecting the data needed to complete the "Standard Control", "Structure Data" and "Stream Cross Section" Data Forms.

GENERAL

1. Delineate the overall drainage area to the point of investigation and the subarea to each point at which a program subrouting will be performed.

2. Assign an identifying number to each cross point at which a subroutine may be performed. Numbers may be 001 to 120.

3. Assign an identifying number to each structure at which the "RESVOR" subroutine may be performed. Numbers may be from 01 to 60.

STANDARD CONTROL SHA-61.1 - 484

1. "RUNOFF" - Determine the area in square miles to four decimal places. Compute the weighted runoff curve number for antecent moisture condition II considering soil type, land use and/or ground cover. Compute the time of concentration in hours to four decimal places.

2. "RESVOR" - Determine the invert elevation of structure.

3. "REACH" - Reach is identified by the number of cross section at the lower end. Length of reach is determied by survey or scaled from maps or plans.

STRUCTURE DATA SHA-61.1 - 480

For each structure at which a "RESVOR" subroutine will be performed, compute the discharge for various elevations of headwater and the storage at each of these elevations. A maximum of twenty elevations can be used. The range should be form the invert elevation through the maximum headwater at which the structure can be expected to operate. The elevation increments need not be uniform and should include those elevations at which some definite change takes place in the structure operation or the shape of the storage area. Discharge through culverts should consider inlet control and outlet control. Weir flow, if present, should be included. Culvert discharge for entrance control should be determined from the appropriate entrance control nomograph when available or approximated using formula #7 given in Chapter 2, Section B-3. Culvert discharge for outlet control should be computed using formulas #8 and #9 given in Chapter 2, Section B-4. Weir flow is computed by formula #16 Chapter 5, Section C. Discharges are expressed in cubic feet per second.

Storage increments should be computed from contours using the product of average water surface and depth. The storage volume is expressed in acre-feet.

STREAM CROSS SECTION DATA SHA-61.1 - 481

If the cross section points have been properly located, a typical channel or ditch may be selected which is representative is the natural or artifical channel reach above the designated cross section point to which a "REACH" subroutine will be performed. Compute the channel discharge at various water surface elevations at the "typical" location. The range should be from the invert elevation to the maximum water surface elevation which is expected to be encountered. A maximum of twenty elevations may be used but the increment between elevations need not be uniform. Elevations should be included where breaks in the cross slopes occur. Discharges may be taken from a Manning ditch chart, if a suitable one is available, or computed from the Manning Formula. See formula #5 as given Chapter 2, Section B. The discharge should be expressed in cubic feet per second.

The area of the cross section of the water at the various elevations should be computed by simple geometry and stated in square feet.

Section B

Hydraulics

1. Manning's Formula shall be used for the design of culverts, pipes, channels, ditches, and other waterways where pressure operation is not encountered. It is given as follows:

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

where

V = instantaneous velocity (in feet per second)

r = hydraulic radius (in feet)

s = slope (in feet per foot)

n = roughness coefficient

Commonly used values of "n" may be selected from Tables SHA-61.1-404.1A and 1B. Additional roughness coefficients may be found in Appendix A of No. 3 of the Hydraulic Design Series - "Design Charts for Open Channel Flow". For cross sections for which design charts are not available, Manning's Formula may be solved by the nomograph on Chart SHA-61.1-404.0. Design charts, based on the Manning Formula, for most pipes and frequently used ditches will be found in Appendix 3. Care should be taken to make necessary adjustments when available charts are based on "n" values other than those shown in the Table.

Some charts are provided with auxiliary scales (labeled Q_n and V_n) so that they may be used for any value of 'n'. To use these scales:

1) Find Q_n by multiplying Q by the desired value of 'n'.

2) To find velocity, intesect Q_n with the slope line and read the V_n scale. Divide V_n by 'n'.

3) To find depth, intersect Q_n with the slope line and read the depth directly.

4) Critical depth and critical velocity are independent of roughness and can be read directly by entering the chart with Q (not Q_n) through the basic Q scale and intersecting the critical curve.

5) Friction slope and friction velocity for culverts are found by entering the chart with Q_n and intersecting the depth line which is equal to the value of h_o as defined in Section B-4 Outlet Control Headwater. Friction slope is read directly at this point. Read friction velocity on the V_n scale. Divide V_n by 'n'.

The designer may also use charts which are not provided with auxiliary scales when working with an 'n' value differing from the 'n' for which the chart was prepared.

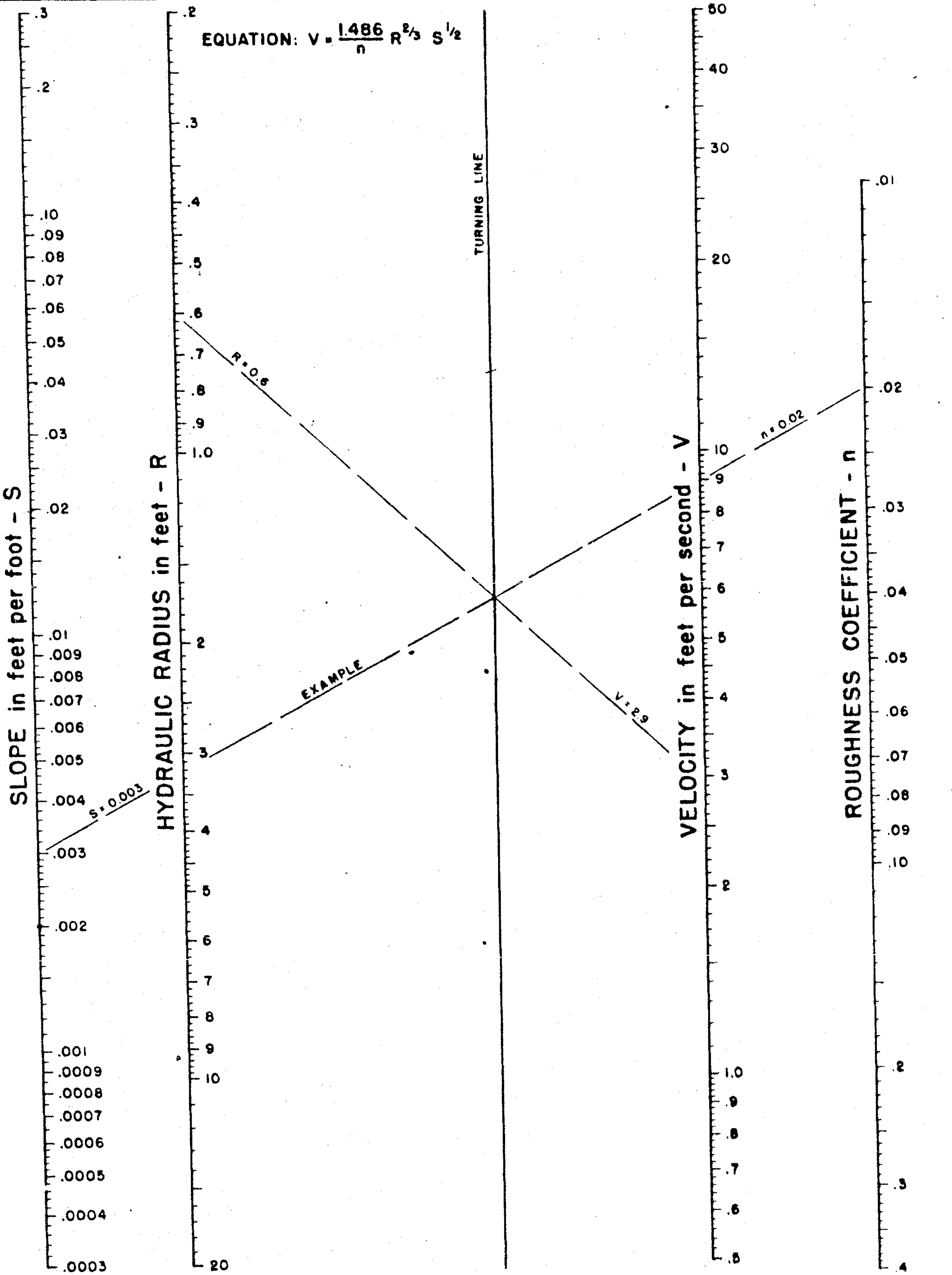
1) Adjust the design Q by multiplying it by the ratio of the desired 'n' value to the chart 'n' value, that is, n (desired)÷n (chart).

2) To find velocity enter the chart with the adjusted Q and intersect the slope line. Read the velocity and correct it by dividing by the same ratio that was used to adjust the design Q.

3) To find depth, intersect the adjusted Q and the slope line and read the depth directly.

4) Critical depth and critical velocity are independent of roughness and can be read directly by entering the chart with Q (not adjusted and intersecting the critical curve).

5) Friction slope and friction velocity for culverts can be found by entering the chart with the adjusted Q and intersecting the depth line equal to the value of h_0 as defined in Seciton B-4 Outlet Control Headwater. Friction slope is read directly at this point. Read friction velocity on the velocity scale and correct it by dividing by the same ratio that was used to adjust the design Q.



NOMOGRAPH FOR SOLUTION OF MANNING'S EQUATION

MARYLAND STATE HIGHWAY ADMINISTRATION 7/7/54 SHA-61.1-404.0

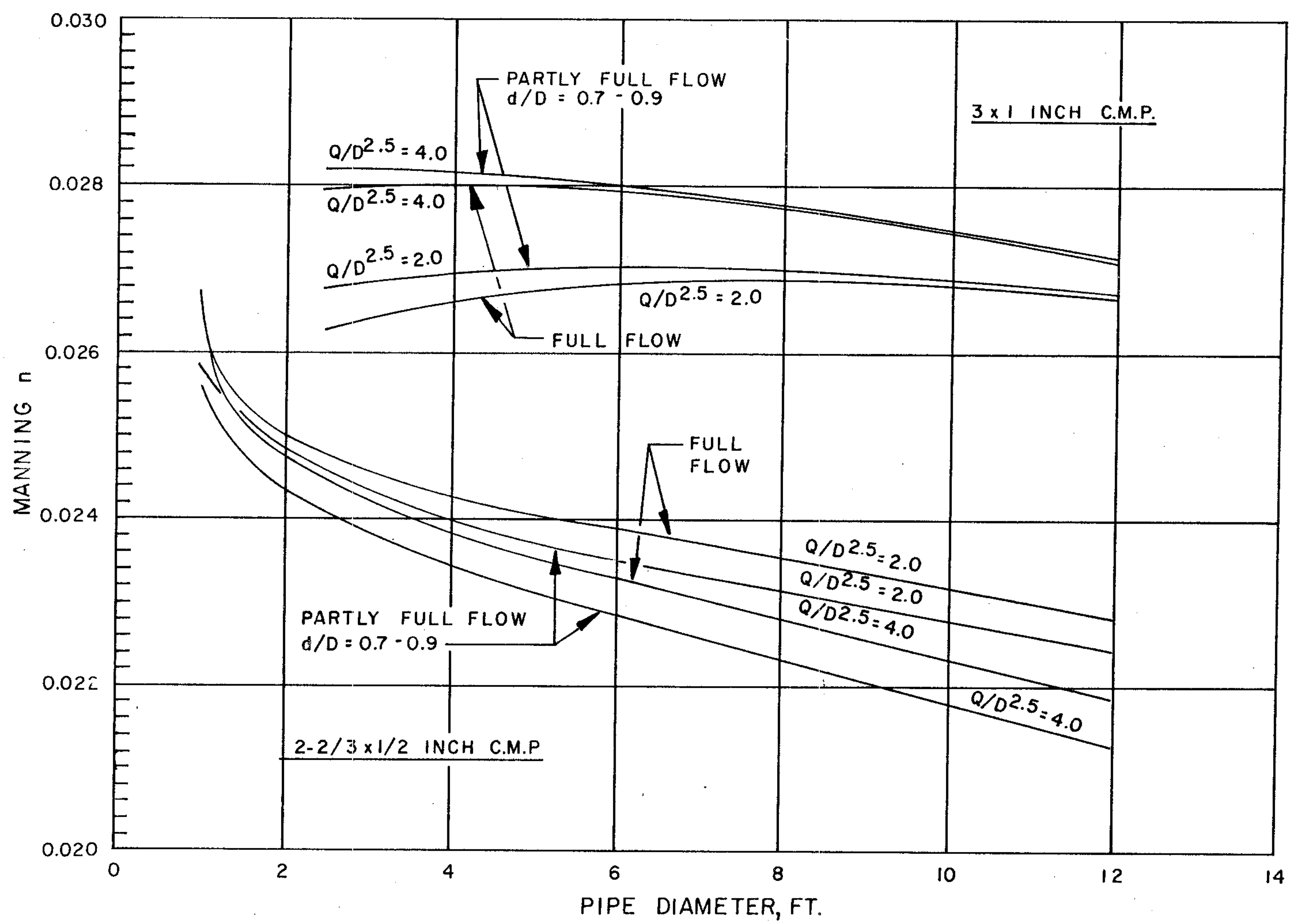
MANNING'S ROUGHNESS COEFFICIENT 'n'

Culverts	Value of "n"
Concrete pipe, vitrified clay pipe & cast iron pipe	.013
Corrugated Steel/Aluminum Alloy Pipe 2 2/3 x 1/2 helical corrugations	
12"-36" diameter	0.019
42"-96" diameter	0.014
Corrugated Steel/Aluminum Alloy Pipe 3 x 1 helical corrugations	
36"-84" diameter	0.021
96"-144" diameter	0.024
Corrugated Steel/Aluminum Alloy Pipe 2 2/3 x 1/2 annular corrugations	0.024
Corrugated Steel/Aluminum Alloy Pipe 3 x 1 annular corrugations	0.028
Structural Plate Pipe 6x2 corrugations	0.034
Corrugated Steel/Aluminum Alloy Pipe Arch	0.024
Corrugated Steel/Aluminum Alloy Pipe 25% paved invert full flow	0.021
Corrugated Steel/Aluminum Alloy Pipe Arch 40% paved invert full flow	0.020
Corrugated Steel/Aluminum Alloy Pipe 100% paved	0.013
Tunnel Liner Plate	0.04 - 0.045
Monolithic Concrete box culverts	.015

Limitations - While it is true that helical corrugated metal pipe may have a lower 'n' value than annular corrugated metal pipe, care should be exercised in the use of the reduced values. Since the low values depend upon the development of spiral flow across the entire cross-section of pipe, the designer must assure himself that fully developed spiral flow can occur in his design situation. It is recommended that the 'n' values for annular pipe be used under the following conditions:

1. Partly full flow in the pipe
2. Extremely high sediment load
3. Short Culverts less than 20 diameters
4. Non-circular pipes
5. Partially paved pipes

Gutters, Ditches and Channels	Value of "n"
Concrete or bituminous lined channels	0.013
Bituminous concrete paving with concrete gutter	0.015
Grass gutters & ditches, flow greater than 6"	.040
Grass gutters & ditches, flow less than 6"	.060
Gabions	0.030
Rip-Rap	Ref. to Chart SHA-61.1-405.1
Channels not maintained, uncut weeds & brush	.08 - .12
Earth gutters and ditches	.025
Ditches in rock	.037
Seed and Mulch	.030
Soil Stabilization Matting	.030
Natural Stream channels	.035 - .150

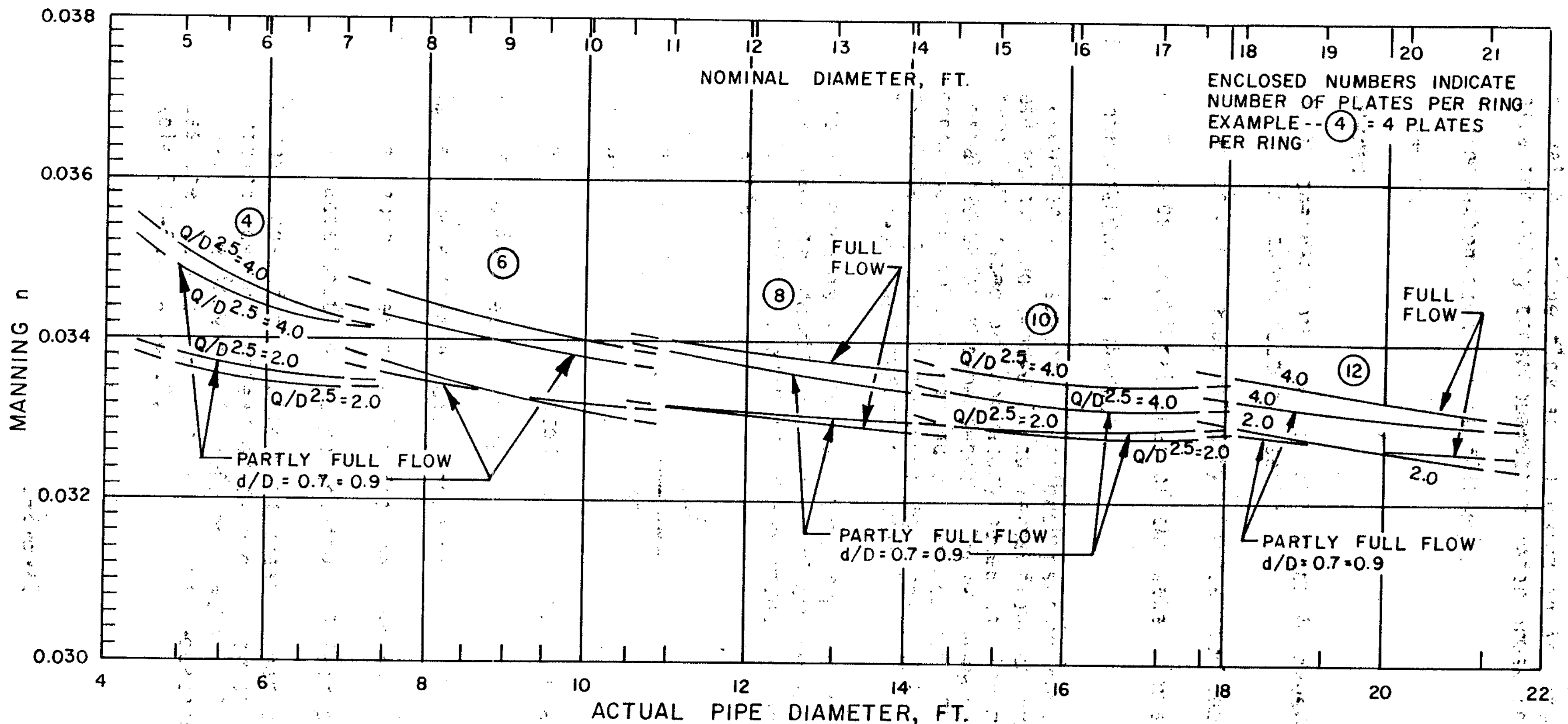


MANNING n VERSUS DIAMETER FOR 2-2/3-BY 1/2-INCH AND 3-BY 1-INCH ANNULAR CORRUGATED METAL PIPE

MARYLAND STATE HIGHWAY ADMINISTRATION

7/80

SHA.61.1 - 404.2



MANNING n VERSUS DIAMETER FOR 6- BY 2-INCH ANNULAR STRUCTURAL PLATE CORRUGATED METAL PIPE

MARYLAND STATE HIGHWAY ADMINISTRATION 7/80 SHA-61.1-404.3

2. The Continuity Equation -- This equation expresses a relationship which is valid for the flow at any point in any open channel, culvert, or pipe including those operating under pressure.

The equation is given as follows:

$$Q = VA \qquad (6)$$

where:

Q = the rate of flow at the point of investigation (in cubic feet per second)

V = Instantaneous velocity (in feet per second)

A = cross sectional area of the water (in square feet)

3. Entrance Control Headwater

Headwater - discharge relationships for the various types of circular, elliptical and pipe-arch culverts flowing under entrance (inlet control) are based on laboratory research with models and verified in some instances by prototype tests. These research data were analyzed and nomographs for determining culvert capacity for inlet control were developed by the Division of Hydrographic Research, Bureau of Public Roads. (see Chart SHA-61.1 - 420).

When nomographs are not available for the culvert under investigation, the headwater depth required to discharge a given flow under entrance (inlet) control operation may be approximated by the following procedure:

$$HW = d_n + (1 + K_e) \frac{V_n^2}{2g} \qquad (7)$$

where:

HW = the headwater depth at the upstream end of the pipe (in feet)

d_n = Normal depth (in feet)

K_e = the entrance loss coefficient

V_n = normal velocity (in feet per second)

g = acceleration due to gravity (in feet per second, per second)

If the slope of the culvert is greater than critical slope use d_c (critical depth) instead of d_n and V_c (critical velocity) instead of V_n. (See Appendix II reference #22a). The value of the entrance loss coefficient (K_e) for use in this equation shall be taken from Table SHA-61.1 - 406.0.

NOTE: When obtaining critical values from pipe charts, use the principle scales on those charts.

4. Outlet Control Headwater

To compute the headwater depth at a culvert which is operating with outlet control, the following procedure should be used:

$$H = S_f L + (1 + K_e) \frac{V_f^2}{2g} \qquad (8)$$

where:

H = Difference between headwater and tailwater elevations (in feet)

H_o = actual tailwater depth or $\frac{D + d_c}{2}$ whichever is greater (in feet)

S_f = Friction slope (in feet per foot) See note.

NOTE: The values of S_f and V_f are determined by entering the pipe chart with the discharge and intersecting the depth line at $d = h_o$. S_f and V_f are read directly from the pipe chart. However, when charts are not available (different cross sections or roughness), the value of S_f can be computed by charts SHA-61.1 - 406.1 and 406.2.

K_e = the entrance loss coefficient

V_f = Friction velocity (in feet per second)

g = Acceleration due to gravity (in feet per second, per second)

Nomographs for full flow only based on formula (8) are found in the Chart Series SHA-61.1 - 421.

Note that 'H' is <u>not</u> the headwater depth, but is the difference between the headwater and tailwater elevations. To find the headwater depth, use the following formula:

$$HW = H + h_o - S_o L \qquad (9)$$

where:

HW = the headwater depth at the upstream end of the pipe (in feet)

H = difference between headwater and tailwater elevation (in feet)

h_o = actual tailwater depth or $\frac{D + d_c}{2}$ whichever is greater (in feet)

S_o = actual slope of the culvert (in feet per foot)

L = Length of the culvert (in feet)

D = Diameter of rise of culvert (in feet)

d_c = critical depth (in feet) See note under inlet control

*NOTE: The values of S_f and V_f are determined by entering the pipe chart with the discharge and intersecting the depth line at $d = h_o$, S_f and V_f are read directly from the pipe chart. However, when charts are not available (different cross sections or roughness), the value of S_f can be computed by charts SHA-61.1 - 406.1 and 406.2.

ENTRANCE LOSS COEFFICIENTS

Type of Structure and Design of Entrance	Coefficient K_e
Pipe, Concrete	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end)	0.2
Square-edge	0.5
Rounded (radius = 1/12D)	0.2
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Pipe or Pipe-Arch, Corrugated Metal	
Projecting from fill, (no headwall)	0.9
Headwall or headwall and wingalls	
Square-edge	0.5
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrell dimension	0.2
Wingwalls at 30 to 75 to barrell	
Square-edged at crown	0.4
Crown edge rounded to radius of 1/12 barrell dimension	0.2
Wingwalls at 10 to 25 to barrell	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7

*NOTE: "End Section conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to headwall in both inlet and outlet control.

COMPUTATION OF FRICTION SLOPE

$S_f = (nV_f)^2\ (K_f)$ WHERE

n = MANNING'S COEFFICIENT (SEE CHART - SHA-61.1-404.1)

$V_f = \frac{Q}{AREA}$ K_f = FRICTION SLOPE COEFFICIENT ($\frac{1}{2.2082 r^{4/3}}$)

VALUES OF K_f FOR CORRESPONDING VALUES OF R

R = HYDRAULIC RADIUS = AREA OF PIPE / PERIMETER OF PIPE

r	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.1	9.76	8.59	7.67	6.88	6.23	5.68	5.21	4.81	4.46	4.15
.2	3.87	3.63	3.41	3.22	3.04	2.88	2.73	2.60	2.47	2.36
.3	2.25	2.16	2.07	1.99	1.91	1.84	1.77	1.70	1.65	1.59
.4	1.54	1.49	1.44	1.40	1.35	1.31	1.28	1.24	1.20	1.17
.5	1.14	1.11	1.08	1.06	1.03	1.01	.981	.958	.936	.915
.6	.895	.875	.857	.839	.821	.804	.788	.772	.757	.743
.7	.729	.715	.702	.689	.677	.665	.653	.642	.631	.620
.8	.610	.600	.590	.581	.571	.562	.554	.545	.537	.529
.9	.521	.514	.506	.499	.492	.485	.478	.472	.465	.459
1.0	.453	.447	.441	.435	.430	.424	.419	.414	.409	.404
1.1	.399	.394	.389	.385	.380	.376	.372	.367	.363	.359
1.2	.355	.351	.347	.344	.340	.336	.333	.329	.326	.322
1.3	.319	.316	.313	.310	.307	.304	.301	.298	.295	.292
1.4	.289	.286	.284	.281	.279	.276	.273	.271	.269	.266
1.5	.264	.261	.259	.257	.255	.253	.250	.248	.246	.244
1.6	.242	.240	.238	.236	.234	.232	.230	.229	.227	.225
1.7	.223	.221	.220	.218	.216	.215	.213	.212	.210	.208
1.8	.207	.205	.204	.202	.201	.199	.198	.197	.195	.194
1.9	.192	.191	.190	.189	.187	.186	.185	.183	.182	.181
2.0	.180	.179	.177	.176	.175	.174	.173	.172	.171	.169
2.1	.168	.167	.166	.165	.164	.163	.162	.161	.160	.159
2.2	.158	.157	.156	.155	.155	.154	.153	.152	.151	.150
2.3	.149	.148	.147	.147	.146	.145	.144	.143	.143	.142
2.4	.141	.140	.139	.139	.138	.137	.136	.136	.135	.134
2.5	.133	.133	.132	.131	.131	.130	.129	.129	.128	.127
2.6	.127	.126	.125	.125	.124	.124	.123	.122	.122	.121
2.7	.120	.120	.119	.119	.118	.118	.117	.116	.116	.115
2.8	.115	.114	.114	.113	.113	.112	.112	.112	.111	.110
2.9	.109	.109	.108	.108	.108	.107	.107	.106	.106	.105
3.0	.105	.104	.104	.103	.103	.102	.102	.101	.101	.101
3.1	.1002	.0998	.0993	.0989	.0985	.0981	.0977	.0972	.0968	.0964
3.2	.0960	.0956	.0952	.0948	.0945	.0941	.0937	.0933	.0929	.0925
3.3	.0921	.0918	.0914	.0911	.0907	.0903	.0900	.0896	.0893	.0889
3.4	.0886	.0882	.0879	.0875	.0872	.0869	.0865	.0862	.0859	.0855
3.5	.0852	.0849	.0846	.0843	.0839	.0836	.0833	.0830	.0827	.0824
3.6	.0821	.0818	.0815	.0812	.0809	.0806	.0803	.0800	.0797	.0794
3.7	.0791	.0788	.0786	.0783	.0780	.0777	.0775	.0772	.0769	.0766
3.8	.0764	.0761	.0758	.0756	.0753	.0750	.0748	.0745	.0743	.0740
3.9	.0738	.0735	.0733	.0730	.0728	.0725	.0723	.0720	.0718	.0716
4.0	.0713	.0711	.0708	.0706	.0704	.0701	.0699	.0697	.0695	.0692
4.1	.0690	.0688	.0686	.0683	.0681	.0679	.0677	.0675	.0673	.0670
4.2	.0668	.0666	.0664	.0662	.0660	.0658	.0656	.0654	.0652	.0650
4.3	.0648	.0646	.0644	.0642	.0640	.0638	.0636	.0634	.0632	.0630
4.4	.0628	.0626	.0624	.0622	.0621	.0619	.0617	.0615	.0613	.0611
4.5	.0610	.0608	.0606	.0604	.0602	.0601	.0599	.0597	.0595	.0594
4.6	.0592	.0590	.0589	.0587	.0585	.0583	.0582	.0580	.0578	.0577
4.7	.0575	.0574	.0572	.0570	.0569	.0567	.0566	.0564	.0562	.0561
4.8	.0559	.0558	.0556	.0555	.0553	.0552	.0550	.0549	.0547	.0546
4.9	.0544	.0543	.0541	.0540	.0538	.0537	.0535	.0534	.0533	.0531
5.0	.0530	.0528	.0527	.0525	.0524	.0523	.0521	.0520	.0519	.0517

TABLE OF FRICTION SLOPE COEFFICIENTS, K_f

MARYLAND STATE HIGHWAY ADMINISTRATION 8/78 SHA-61.1-406.1

COMPUTATION OF FRICTION SLOPE

$S_f = (nV_f)^2 \; (K_f)$ WHERE

n = MANNING'S COEFFICIENT (SEE CHART - SHA-61.1-404.1)

$V_f = \frac{Q}{AREA}$ K_f = FRICTION SLOPE COEFFICIENT ($\frac{1}{2.2082 r^{4/3}}$)

VALUES OF K_f FOR CORRESPONDING VALUES OF R

R = HYDRAULIC RADIUS = AREA OF PIPE / PERIMETER OF PIPE

r	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
5	.0530	.0516	.0503	.0490	.0478	.0466	.0455	.0455	.0435	.0425
6	.0415	.0406	.0398	.0389	.0381	.0373	.0365	.0358	.0351	.0345
7	.0338	.0332	.0326	.0320	.0314	.0308	.0303	.0298	.0293	.0288
8	.0283	.0278	.0274	.0269	.0265	.0261	.0257	.0253	.0249	.0246
9	.0242	.0238	.0235	.0232	.0228	.0225	.0222	.0219	.0216	.0213
10	.0210	.0207	.0205	.0202	.0199	.0197	.0194	.0192	.0190	.0187
11	.0185	.0183	.0181	.0179	.0177	.0175	.0173	.0171	.0169	.0167
12	.0165	.0163	.0161	.0160	.0158	.0156	.0154	.0153	.0151	.0150
13	.0148	.0147	.0145	.0144	.0142	.0141	.0140	.0138	.0137	.0136
14	.0134	.0133	.0132	.0130	.0129	.0128	.0127	.0126	.0125	.0124
15	.01224	.01213	.01203	.01192	.01182	.01172	.01162	.01152	.01142	.01132
16	.01123	.01114	.01105	.01096	.01087	.01078	.01069	.01061	.01052	.01044
17	.01036	.01028	.01020	.01012	.01004	.00996	.00989	.00982	.00974	.00967
18	.00960	.00953	.00946	.00939	.00932	.00925	.00919	.00912	.00906	.00900
19	.00893	.00887	.00881	.00875	.00869	.00863	.00857	.00851	.00845	.00840
20	.00834	.00829	.00823	.00818	.00812	.00807	.00802	.00797	.00792	.00787
21	.00782	.00777	.00772	.00767	.00762	.00758	.00753	.00748	.00744	.00739
22	.00735	.00730	.00726	.00722	.00717	.00713	.00709	.00705	.00700	.00696
23	.00692	.00688	.00684	.00680	.00677	.00673	.00669	.00665	.00661	.00658
24	.00654	.00651	.00647	.00643	.00640	.00636	.00633	.00630	.00626	.00623
25	.00620	.00616	.00613	.00610	.00607	.00603	.00600	.00597	.00594	.00591
26	.00588	.00585	.00582	.00579	.00576	.00573	.00570	.00567	.00565	.00562
27	.00559	.00556	.00554	.00551	.00548	.00546	.00543	.00540	.00538	.00535
28	.00533	.00530	.00528	.00525	.00523	.00520	.00518	.00515	.00513	.00511
29	.00508	.00506	.00504	.00501	.00499	.00497	.00495	.00493	.00490	.00488
30	.00486	.00484	.00482	.00479	.00477	.00475	.00473	.00471	.00469	.00467
31	.00465	.00463	.00461	.00459	.00457	.00455	.00453	.00451	.00449	.00448
32	.00446	.00444	.00442	.00440	.00439	.00437	.00435	.00433	.00431	.00430
33	.00428	.00426	.00424	.00423	.00421	.00419	.00418	.00416	.00415	.00413
34	.00411	.00410	.00408	.00407	.00405	.00403	.00402	.00400	.00399	.00397
35	.00396	.00394	.00393	.00391	.00390	.00388	.00387	.00385	.00384	.00382
36	.00381	.00380	.00378	.00377	.00375	.00374	.00373	.00371	.00370	.00369
37	.00367	.00366	.00365	.00363	.00362	.00361	.00360	.00358	.00357	.00356
38	.00354	.00353	.00352	.00351	.00350	.00348	.00347	.00346	.00345	.00344
39	.00342	.00341	.00340	.00339	.00338	.00337	.00336	.00334	.00333	.00332
40	.00331	.00330	.00329	.00328	.00327	.00326	.00324	.00323	.00322	.00321
41	.00320	.00319	.00318	.00317	.00316	.00315	.00314	.00313	.00312	.00311
42	.00310	.00309	.00308	.00307	.00306	.00305	.00304	.00303	.00302	.00302
43	.00301	.00300	.00299	.00298	.00297	.00296	.00295	.00294	.00293	.00292
44	.00292	.00291	.00290	.00289	.00288	.00287	.00286	.00285	.00285	.00284
45	.00283	.00282	.00281	.00280	.00280	.00279	.00278	.00277	.00276	.00276
46	.00275	.00274	.00273	.00272	.00272	.00271	.00270	.00269	.00268	.00268
47	.00267	.00266	.00265	.00265	.00264	.00263	.00263	.00262	.00261	.00260
48	.00260	.00259	.00258	.00257	.00257	.00256	.00255	.00255	.00254	.00253
49	.00253	.00252	.00251	.00251	.00250	.00249	.00248	.00248	.00247	.00247
50	.00246	.00245	.00245	.00244	.00243	.00243	.00242	.00241	.00241	.00240
51	.00239	.00239	.00238	.00238	.00237	.00236	.00236	.00235	.00235	.00234
52	.00233	.00233	.00232	.00232	.00231	.00230	.00230	.00229	.00229	.00228
53	.00227	.00227	.00226	.00226	.00225	.00225	.00224	.00224	.00223	.00222
54	.00222	.00221	.00221	.00220	.00220	.00219	.00219	.00218	.00218	.00217

TABLE OF FRICTION SLOPE COEFFICIENTS, K_f

MARYLAND STATE HIGHWAY ADMINISTRATION 8/78 SHA-61.1-406.2

PART I

CHAPTER 3 OPEN DRAINAGE

Section A. Ditches, Gutters and Channels

1. General Limitations - Minimum velocity in a paved ditch or gutter shall be 3.0 ft./sec. when flowing full. There is no maximum velocity in paved ditches or channels, but the velocity must be reduced to an acceptable level before being disharged into a unpaved ditch or channel by the use of suitable energy dissipators.

   When a concentrated flow is discharged into a natural stream channel, the velocity of the two year frequency flow shall not exceed the velocity of the two year frequency that existed at the reference point before construction.

   The maximum allowable velocities in ditches and channels for the design storm are given in Table SHA-61.1 - 405.0. Whenever possible, ditches shall be planned to discharge into the same natural outfall to which their drainage area discharged before highway construction or development commenced.

2. Design - Manning's formula, as given in Chapter 2, Section B-1 or the appropriate charts must be used for ditch and channel flow. Values of "n" must be selected from Table SHA-61.1 - 404.1. Linings shall be selected to withstand the maximum instantaneous velocity which shall not exceed the values given in Table SHA-61.1 - 405.0.

3. Median Ditches must be designed considering the ultimate pavement section. The 10 year frequency flow shall remain within the ditch section and the ditch lining shall accomodate that flow.

4. Berm Ditches must be provided at the top of any cut slope where the area draining toward the cut slope is sufficiently large to pose a threat of serious erosion. Capacity and lining should accomodate a 10 year frequency storm.

5. Bench Ditches must be provided when cuts are excessively deep and the accumulation of surface drainage on the cut slope could cause serious erosion. There is no standard for this seldom used ditch and each must be designed individually, usually by the Bureau of Soils and Foundations.

6. Side Ditches must be provided to control runoff along the toe of fill. In some cases they are extended through a cut if a suitable outlet cannot be arranged. In general, this practice should be avoided, as it constitutes a diversion.

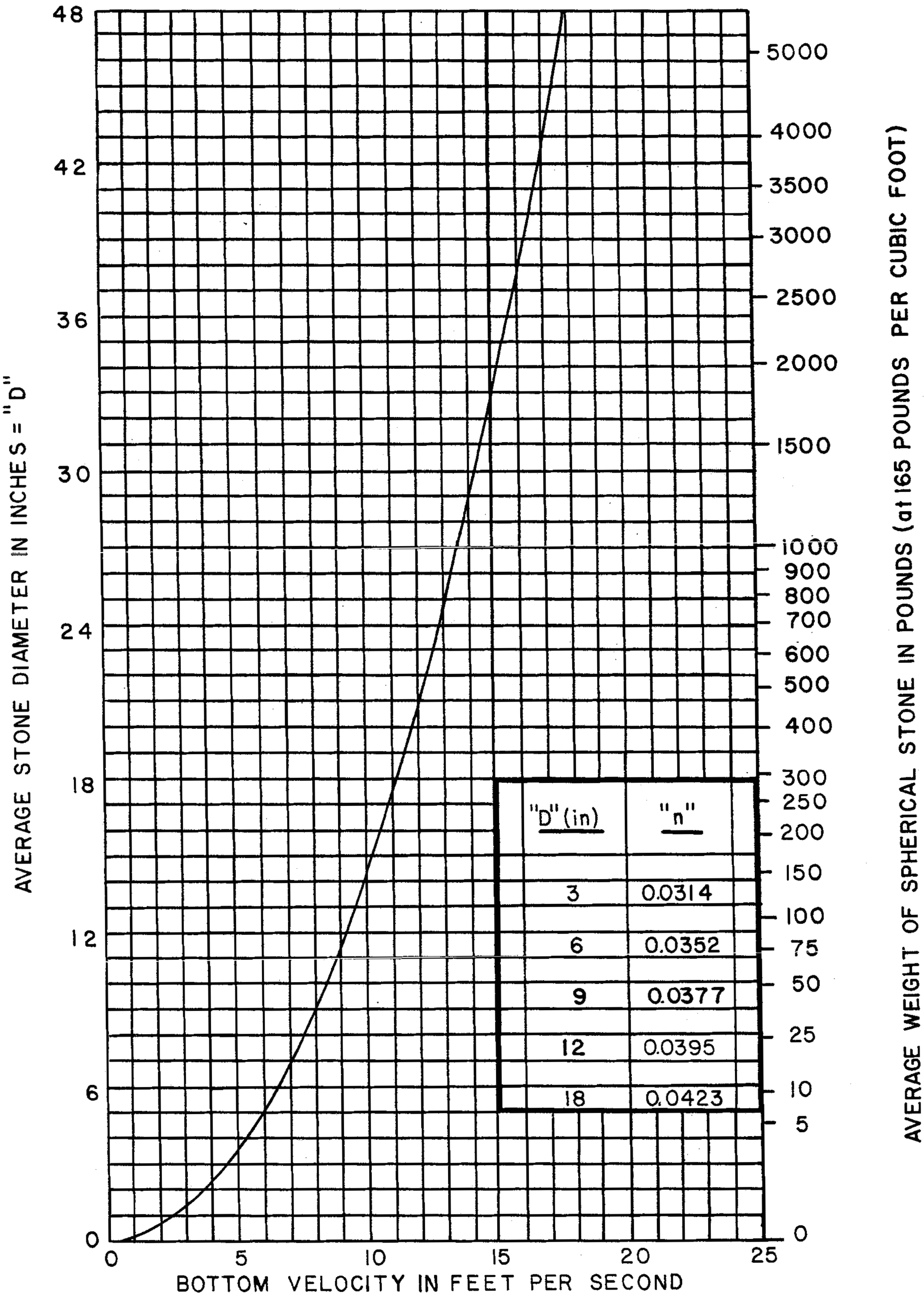
   The typical section (bottom width and/or depth) of side ditches shall be selected to hold the water surface elevation during a 10 year frequency storm at least 9" below the shoulder edge.

7. Surface Drain ditches are normally V-shaped ditches used to collect runoff from the roadway and slopes through cut areas. However, when drainage from side ditches is carried through a cut, a flat bottom ditch must be used. In either case, the water surface elevation during a 10 year frequency storm shall remain at least 9" below the shoulder edge.

8. Outlet Ditches, Inlet Ditches, and Other Channel Improvements. Any ditch which serves as an outlet or inlet for an open culvert, regardless of its primary function, will be designed to accomodate the same runoff that the culvert it serves is designed for.

LIMITING VELOCITIES FOR DITCHES AND CHANNELS

Type of Lining	Allowable velocity Feet per second
For Construction Items	
Seed and Mulch	2.5
Solid Sodding	4
Soil Stabilization Matting	4.5
Concrete Channels	No Max.
Shale and Rock	5.6
Rip-Rap	Refer to Chart SHA-61.1-405.1
For Investigation of Existing Channels	
Earth, without vegetation	1-3
Grains, stiff stemmed grasses	2-3
Bunch grass	2-4
Stiff Clay or clay and gravel	3-5
Fine gravel	5
Meadow type grasses, short pliant blades	5
Well-established grasses, short pliant blades	6
Coarse gravel	6
Shale and Rock	No Max.



FROM USBR

LIMITING VELOCITIES FOR RIP-RAP LINING

MARYLAND STATE HIGHWAY ADMINISTRATION SHA-61.1-405.1

Section B. INLETS

1. General Limitations - It is not necessary to determine the capacity of inlets which intercept ditch flows. The assumption is made that if the proper size pipe is provided to drain the inlet, the inlet will intercept all of the water reaching it.

2. Median Inlets will be spaced for the runoff from the 10 year frequency storm, based on the capacity of the ditch section, but they shall not be more than 1,000 feet apart. Inlets which could be reached by vehicles must have traffic bearing grates.

3. Standard Curb Openings - Curbed pavement sections are commonly used in interchanges and other areas with surface drain or side ditches constructed beyond the curb. In these cases, flow from the curb and gutter section can be discharged to the ditch through Standard Curb Openings. Curb openings should be spaced as outlined in Chapter 4, Section A-1. For design purposes curb openings shall be treated as undepressed curb opening inlets. Chart series SHA-61.1-431 shall be used to determine capacity.

   In areas where the difference is elevation between the gutter flow line and the ditch flow line is greater than 5 feet, the use of curb openings is not recommended and the designer should use standard curb and gutter inlets discharging to the ditch via pipe. These inlets shall also be spaced as specified for in Chapter 4, Section A-1. Standard curb openings should not be used in areas where future sidewalk or storm drain construction may be expected.

Section C. PIPE CULVERTS

1. General Limitations

Metallic coated corrugated metal pipes (ASSHTO Designation M36-81I) under a state highways shall be a minimum of 14 gauge and 16 gauge under entrances. Minimum gauge based on height of cover must be determined in accordance with AASHTO Specifications Section 1.9.2. Height of fill limits for commonly used steel gauges and pipe sizes are given in Tables SHA-61.1 - 407.0 thru 407.2. Height of fill limits for top and side plates of structural plate pipes are given in Table SHA 61.1-407.3. The bottom plates will be of the next heavier gauge. Corrugated Aluminum Alloy pipes (AASHTO Designation M 196-80I) may be used only with permission of the Chief-Bureau of Highway Design. The procedure for computing the required gauge of any corrugated metal pipe is explained in Appendix 4.

The standard design item for State projects is corrugated steel pipe with 2 2/3" X 1/2" helical corrugation. Pipe with 3" X 1" and/or annular corrugations should only be considered under extremely high fills.

All corrugated metal pipes will not be bituminous coated unless tests of the water indicate a definite need for it. All concrete pipes shall be a minimum of Class IV strength when used within the SHA right-of-way. Maximum height of fill allowed over concrete pipe is determined from Table SHA-61.1 - 407.4 and is measured from the top of the pipe to the crown of the pavement. Minimum cover for all pipes shall be 0.75 feet measured from the top of the pipe to the bottom of the road metal or at least a total of one foot in non-traffic areas. Vitrified clay liners shall be used only when tests of the water indicate a definite need for it. Elliptical concrete pipe larger than 53" X 34" shall not be used in the State Highway Administration Right of Way where subject to H-20 loading. Multiple lines of pipe or pipe arches shall be spaced so that adjacent outside surfaces are as follows:

Diameter or span less than 48" - not less than two feet apart.

Diameter or span greater than 48" - one half diameter or three feet apart, whichever is less.

Pipe end sections should not be substituted for endwalls if:

1) Skew of pipe is greater than 60 degrees to the normal.
2) The pipe carries a constant flow.

Transverse pipes may not be smaller than 18 inches in diameter. Where the length of pipe exceeds 60 feet, the minimum is 24 inches in diameter.

Corrugated metal pipe arch culverts or reinforced concrete elliptical culverts may be used only when lack of available cover makes use of round pipes impractical or when their use is dictated by hydraulic considerations.

HEIGHT OF COVER LIMITS*
for Helically Corrugated Steel Pipe
2 2/3" x 1/2" Corrugations

Thickness / Size (Pipe Diameter or Arch Pipe Span)	18.Ga. .052"	16 Ga. .064"	14 Ga. .079"	12 Ga. .109"	10 Ga. .138"	8 Ga. .168"
12"	137	162	195	**	**	**
15	90	103	119	154	**	**
18	69	77	86	106	**	**
21	59	63	69	82	**	**
24	53	56	60	68	77	**
27	***	51	54	60	66	73
30	***	48	50	55	59	64
36	***	45	46	49	51	54
42	***	43	44	46	47	49
48	-	42	43	44	45	46
54	-	-	42	43	44	45
60	-	-	-	42	43	43
66	-	-	-	***	42	43
72	-	-	-	***	42	42
78	-	-	-	***	***	42
84	-	-	-	-	***	42
90	-	-	-	-	***	***
96	-	-	-	-	***	***

3" x 1" Corrugations

Thickness / Size (Pipe Diameter or Arch Pipe Span)	16 Ga. .064"	14 Ga. .079"	12 Ga. .109"	10 Ga. .138"	8 Ga. .168"
36"	61	67	77	89	100
42	54	57	64	71	78
48	49	52	56	61	66
54	47	48	51	55	58
60	45	46	49	51	53
66	44	45	47	48	50
72	43	44	45	47	48
78	43	43	44	45	46
84	42	43	43	44	45
90	42	42	43	44	44
96	***	42	42	43	44
102	***	42	42	43	43
108	***	***	42	42	43
114	-	***	42	42	42
120	-	-	42	42	42
126	-	-	-	42	42
132	-	-	-	41	42
138	-	-	-	41	42
144	-	-	-	***	41

* Values computed according to AASHTO Specifications for Bridges Section 1.9.2 Current Edition and Interim

** and *** See notes on table SHA 61.1-407.2

HEIGHT OF FILL LIMITS*
for Annular Corrugated Steel Pipe
Riveted - 2 2/3" X 1/2" Corrugation

Thickness / Size (Pipe Diameter or Arch Pipe Span)	16 Ga. .064"	14 Ga. .079"	12 Ga. .109"	10 Ga. .138"	8 Ga. .168"	
12"	92	101	**	**	**	
15	74	80	104	**	**	
18	61	67	86	**	**	
21	53	57	74	**	**	Single Rivet
24	46	50	65	68	**	
27	41	44	57	60	63	
30	37	40	52	54	56	
36	30	33	43	45	47	
42	34	44	46	47	49	
48	30	41	44	45	46	
54	-	36	43	44	45	Double Rivet
60	-	-	42	43	43	
66	-	-	*	42	43	
72	-	-	*	42	42	
78	-	-	*	***	42	
84	-	-	-	***	42	
90	-	-	-	***	***	
96	-	-	-	***	***	

Riveted - 3" X 1" Corrugation

Thickness / Size (Pipe Diameter or Arch Pipe Span)	16 Ga. .064"	14 Ga. .079"	12 Ga. .109"	10 Ga. .138"	8 Ga. .168"
36"	53	66	77	89	100
42	45	56	64	71	78
48	39	49	56	61	66
54	35	44	51	55	58
60	31	39	49	51	53
66	29	36	47	48	50
72	26	33	45	47	48
78	24	30	44	45	46
84	22	28	42	44	45
90	21	26	39	44	44
96	***	24	36	43	44
102	***	23	34	41	43
108	***	***	32	39	43
114	***	***	31	37	41
120	-	-	29	35	39
126	-	-	***	33	37
132	-	-	-	32	35
138	-	-	-	30	34
144	-	-	-	***	32

*Values computed according to AASHTO Specifications for Bridges Section 1.9.2 Current Edition and Interim

** and *** See notes on table SHA 61.1-407.2

HEIGHT OF COVER LIMITS*
Corrugated Coated Steel Pipe
Helical - 125mm x 25mm Corrugation

Thickness Diameter (Pipe Diameter or Arch Pipe Span)	16 Ga. .064"	14 Ga. .079"	12 Ga. .109"	10 Ga. .138"	8 Ga. .168"
48	49	52	56	61	66
54	47	48	52	55	58
60	43	46	49	51	53
66	39	45	47	48	50
72	36	44	45	47	48
78	33	42	44	45	46
84	31	39	43	44	45
90	29	36	43	44	44
96	***	34	43	43	44
102	***	32	42	43	43
108	***	***	42	42	43
114	-	***	40	42	42
120	-	-	38	42	42
126	-	-	-	42	42
132	-	-	-	42	42
138	-	-	-	41	42
144	-	-	-	***	41

*Values computed according to AASHTO Specifications for Bridges Section 1.9.2 Current Edition and Interim

** and *** These notes apply to Tables 407.0, 407.1, 407.2 and 407.3.

** These sizes are not generally fabricated in these gauges

*** These pipes are fabricated but are not in accordance with AASHTO specifications

HEIGHT OF COVER LIMITS
Corrugated Steel Pipe
Structural Plate - 6" X 2" Corrugation

Thickness Diameter Size (Pipe Diameter or Arch Pipe Span)	12 Ga. .109"	10 Ga. .138"	8 Ga. .168"	7 Ga. .188"	5 Ga. .218"	3 Ga. .249"	1 Ga. .280" 4 Bolts /Ft.	1 Ga. .280" 6 or 8 Bolts/Ft.
60"	46	68	90	96	106	116	126	126
66	42	62	78	82	90	97	105	105
72	38	57	69	73	78	84	90	90
78	35	53	63	66	70	75	79	79
84	33	49	59	61	64	68	72	72
90	31	45	55	57	60	63	66	66
96	29	43	53	54	57	59	61	61
102	27	40	51	52	54	56	58	58
108	25	38	49	50	52	53	55	55
114	24	36	47	49	50	52	53	53
120	23	34	45	48	49	50	51	51
126	22	32	42	47	48	49	50	50
132	21	31	40	46	47	48	49	49
138	20	30	39	44	46	47	48	48
144	19	28	37	43	45	46	47	47
150	18	27	36	41	45	45	46	46
156	17	26	34	39	44	45	45	45
162	17	25	33	38	44	44	45	45
168	16	24	32	36	44	44	44	44
174	16	23	31	35	42	44	44	44
180	15	23	30	34	41	43	44	44
186	15	22	29	33	40	43	43	43
192	14	21	28	32	38	43	43	43
198	***	20	27	31	37	43	43	43
204	***	20	26	30	36	42	43	43
210	***	19	25	29	35	41	43	43
216	***	***	25	28	34	40	42	42
222	***	***	24	27	33	39	42	42
228	***	***	23	27	32	38	42	42
234	***	***	23	26	31	37	41	42
240	***	***	***	25	31	36	40	42
246	***	***	***	25	30	35	39	42
252	***	***	***	***	29	34	38	42
258	-	-	-	***	28	34	37	42
264	-	-	-	-	28	33	36	42
270	-	-	-	-	27	32	35	41
276	-	-	-	-	***	31	34	41
282	-	-	-	-	-	31	34	41
288	-	-	-	-	-	30	33	41
294	-	-	-	-	-	***	32	40
300	-	-	-	-	-	***	32	40
306	-	-	-	-	-	-	31	39
312	-	-	-	-	-	-	***	***

*Values computed according to AASHTO Specifications for Bridges Section 1.9.2 Current Edition and Interim

** and *** See notes on table SHA 61.1-407.2

MAXIMUM ALLOWABLE FILL HEIGHT OVER CIRCULAR AND ELLIPTICAL REINFORCED CONCRETE PIPE

Inside Diameter (In.)	Class IV	Class V	Rise x Span (In.)	Class HE-IV
12	No Limit	No Limit	14 x 13	21.6
15	44.7	No Limit	19 x 30	19.0
18	26.6	No Limit	22 x 34	20.3
21	22.4	No Limit	24 x 38	21.5
24	20.3	84.3	27 x 42	22.7
27	19.0	47.4	29 x 45	22.7
30	18.7	41.8	32 x 49	23.4
33	19.6	44.1	34 x 53	24.0
36	20.5	45.8	38 x 60	24.8
42	21.9	48.0	43 x 68	25.5
48	22.9	49.1	48 x 76	26.0
54	23.7	49.5	53 x 83	26.3
60	24.3	49.6	59 x 91	26.7
66	24.8	49.4	63 x 98	26.8
72	25.2	49.2	68 x 106	27.1
78	25.5	48.9	72 x 113	27.2
84	25.7	48.6	77 x 121	27.3
90	25.9	48.3	82 x 128	27.5
96	26.1	48.0	87 x 136	27.7
102	26.2	47.7	92 x 143	27.8
108	26.4	47.4	97 x 151	27.8
114	26.5	47.1	106 x 166	27.9
120	26.5	46.9	116 x 180	27.9
126	26.6	46.6		
132	26.7	46.4		
138	26.7	46.2		
144	26.7	46.0		

2. Pipe Culverts for Highways on New Locations - Structures for highways on new locations must be designed to accomodate the runoff based on existing conditions from, at least, the design flood.

   In Appendix B of the Maryland State Highway Needs Inventory, Functional Classification is defined. The Design Flood Frequency for these classifications is as follows:

AASHTO Classification	Highway Needs Inventory Classification	Minimum Overtopping Design Flood Frequency
Expressways	I Principal Arterials	100
Arterial	II Intermediate Arterials	50
	III Minor Arterials	50
Collectors	IV Major Collectors	25
	V Minor Collectors	25
Local Roads & Streets	VI Local Streets	10

   For design purposes, the projected Functional Classification as given in the Maryland State Highway Needs Inventory shall be used. For roads not included in the Maryland State Highway Needs Inventory, the correct classification can be obtained from S.H.A.'s Bureau of Highway Statistics.

   For each highway category and design flood, the headwater pool within our right-of-way will be allowed to reach the edge of pavement.

   As no grading will be permitted in the two-year channel, that portion of the structure to be located in the channel must have the capacity to handle the two-year runoff. The remainder of the structures, if any, may be placed in the floodplain. If necessary, the floodplain may be regarded to accomodate these additional culverts.

   In no event, regardless of the Design Flood, may the new 100 year flood plain be increased above the elevation which existed prior to construction. If the vertical alignment is such that the lowest pavement edge is above the existing 100 year floodplain, the culvert must be designed to pass the 100 year flood. Any increase in the 100 year floodplain due to increased runoff must be contained within the right of way or easement.

3. Pipe Culverts for Rehabilitated or Dualized Highways - Old or collapsed culverts should be replaced with culverts with the same capacity. If the design flood for that class of highway flooded the road, the culvert size may be increased to accommodate the design flood and lower the headwater to the edge of pavement.

4. Design - When the headwater pool at the entrance to a culvert of any given size can be confined, it may be said that the depth of the headwater pool will increase until sufficient head has been built to pass the flow at the rate that it arrives at the culvert. This head may be required to:

1) provide the energy necessary to get the required flow into the culvert, or

2) provide the energy necessary to move the required flow through the culvert and discharge it. The head will build up to satisfy either 1 or 2, whichever is greater.

When the greater head is required to direct a given flow into the culvert, the culvert is said to be operating under inlet control. Typically, the Manning chart will indicate that the culvert is flowing only partially full. Practical measures which can be taken to reduce the required head when the rate of flow and pipe size are fixed are:

1) Add a headwall to protruding pipes
2) Round the edge of the headwall opening

When the greater head is required to move a given flow through the culvert and discharge it, the culvert is said to be operating with outlet control. Typically, the Manning's pipe chart will indicate that the culvert is flowing under pressure when this type of operation is encountered and/or the culvert will be found to be discharging against considerable tailwater. Practical measures which can be taken to reduce the required head when the rate of flow and pipe size are:

1) Increase the slope of the pipe
2) Decrease the roughness coefficient

When these measures are insufficient, it may be necessary to increase pipe size.

Form SHA-61.1-490 shall be completed for the hydraulic design of all open culverts.

The HW/D relationship required to complete the "Entrance Control: portion of this form should be obtained from nomographs which have been prepared from experimental data. When a nomograph is not available for the type and size of pipe involved of when the solution is beyond the limits of the nomograph, an aproximate value of HW can be estimated by using the entrance control formula #7 given in Chapter 2, Section B-3.

The determination of Head for use in completing the outlet control portion of the form can be made from a nomograph or directly from the formula which the nomograph was derived. See formulas #8 and #9 given in Chapter 2, Section B-4. IN ALL CASES, BOTH THE INLET CONTROL AND OUTLET CONTROL PORTIONS OF THE FORM MUST BE COMPLETED.

When terrain is flat and pipes occur in series with relatively short intervening ditches, (as in interchange areas) the designer must check back to be sure that the headwater pool from any given pipe has not caused a tailwater for the previous pipe and thereby shifted control from entrance control to outlet control. When a pipe has an inlet structure on its upper end, compute the headwater, by treating it as headwall.

D. Box Culverts

For box culvert design and analysis, the charts provided in Appendix 3 for vertical sided channels may be used. Do not allow the depth of flow to exceed the height of the box. For flows at or above "full flow", compensation for additional friction against the roof of the box culvert is provided by adjusting the discharge. This adjustment is made by the equation:

$$Q' = Q \left(\frac{2B + 2D}{B + 2D} \right)^{2/3} = Q \times (\text{adjustment factor*}) \qquad (10)$$

*See table below for adjustment factors.

where:

Q' = the adjusted discharge (in cubic feet per second)
Q = the actual discharge (in cubic feet per second)
B = the width of the box culvert (in feet)
D = the height of the box culvert (in feet)

Headwater computations for box culverts are made similar to pipe headwater computations. (See Chapter 3, Section C-4).

D/B	Factor
1.00	1.21
.80	1.24
.75	1.25
.667	1.27
.60	1.28
.50	1.31
.40	1.34

PART I

CHAPTER 4 STORM DRAIN SYSTEMS

Section A. Structures

1. Inlets

a. General Limitations

In addition to those required in sumps, inlets must arbitrarily be located upgrade of all public road connections and bridges. Inlets must be provided in superelevation transistions approximately 50 feet up grade of the section where the cross slope is 0.00 (level section)

Curb and gutter inlets will be spaced with the runoff from the two year storm. Reticular grate inlets or SHA standard curb opening inlets will be used in all cases, except on interstate roadways or with permission of the Chief, Bureau of Highway Design. Form SHA-61.1 - 490 must be completed for all inlets spacing, including sump inlets.

b. Inlets on Grade

Inlets on grade shall be spaced to pick-up at least 85% of the total gutter flow and the maximum allowable spread of flow in the curb and gutter section shall be 8 feet. The amount of gutter flow intercepted by an individual inlet and the spread in the gutter section shall be obtained from the appropriate charts. The gutter flow approaching any inlet must be adjusted to reflect the bypass from the previous inlet.

Where the standard concrete barrier is used, it shall be treated as a curb and inlets shall be spaced on a 2 year storm as detailed above. The spread of water shall not be allowed to encroach on the travelway.

Where relatively flat grades would result in reticular type grate inlets being spaced closer than 100 feet in order to obtain 85% interception, the design shall be modified to obtain 80% interception through these areas. In these cases, the allowable spread will remain eight feet.

The design and evaluation of SHA standard curb opening inlets will be made using a value for the local depression of 1.5 inches. This value is subject to change.

The performance of existing curb opening inlets and parallel bar grates may be evaluated using the appropriate charts.

c. Sump Inlets

Sump inlets must be designed on a two year frequency storm with 100% pickup and a limiting spread of eight feet. If more than one inlet is required to stay within prescribed limits, the additional inlet(s) must be placed at point(s) where the gutter grade is 0.2 feet above the low point. The designer should use charts for the specific type of inlet when available. When charts are not available an inlet grate may be evaluated using the following formula:

$$Q = 3.0\ (PH^{3/2}) \qquad (11)$$

where:

Q = Capacity (in cubic feet per second)

P = perimeter of grate opening (ignoring bars) (in feet)

h = head over grate (in feet)

This formula is strictly applicable only where h is less than 0.4 feet. When this is greater than 0.4 feet, see Appendix 2, Reference #6. In order to compensate for clogging, grate inlets (with no curb opening) will be designed with the assumption that only 75% of the total grate perimeter is usable. If the grate is adjacent to the curb, the perimeter will first be reduced by the length of the side at the curb and will then be multiplied by 75% to get the length of perimeter for design.

Combination inlets in sump areas will be designed with the full usable perimeter and the curb opening will be considered as a factor of safety against clogging.

2. Manholes must be provided when the length of pipe exceeds 400 feet and at all junctions and bends, where in the designer's judgement, a means of physical access may be necessary for maintenance purposes.

3. Bend Structures shall be provided on all storm drains which are 30 inches in diameter and larger, and when the length of bend, as computed by equation (12), is greater than 5.0 feet. The radius of bend should be a minimum of 2 1/2 times the pipe diameter. Bend structures may be designed using formulas (12) and (13).

$$T = R \operatorname{Tan} 1/2 \Delta \qquad (12)$$

$$L = \frac{2 \pi R}{360} \qquad (13)$$

where:

L = the length of bend (in feet)

Δ = the deflection angle (in degrees)

R = the radius of the center line of the bend (in feet)

T = the tangent length (in feet)

B. Pipes

1. General Limitations

The limitations for reinforced concrete and corrugated metal pipe for use in storm drains shall be the same as those listed for culverts in Chapter 3 - Section C-I.

Corrugated metal pipe arch culverts or reinforced concrete elliptical culverts may be used only when lack of available cover makes use of round pipes impractical or when their use is dictated by hydraulic considerations. In closed systems, longitudinal pipes shall not be less than 15 inches in diameter between the first two structures and not less than 18 inches thereafter. (See figure 2 below).

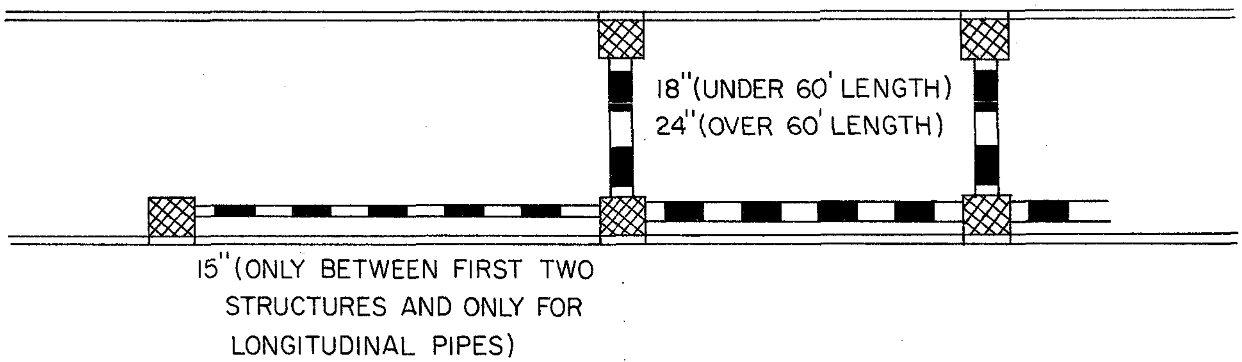


FIG. 2

2. Design

All closed systems shall be sized initially so that the full flow capacity is slightly greater that the computed 10 year frequency flow. The hydraulic gradient for the 25 year storm must be below the top of manhold covers and inlet grates, and below the top of curb for the 100 year storm. In determining the hydraulic gradient, using Manning's Formula (or charts derived from Manning's Formula) with the proper roughness coefficient 'n', as selected from Table SHA-61.1-404.1. The desirable minimum velocity in pipes flowing full shall be three (3) feet per second.

Although on grade inlets are spaced to pick up only a portion of the gutter flow for the two year storm (see Chapter 4, Section A-1), storm drain pipes shall be designed to carry the total flow from the design storm at any location. Form SHA-61.1-492 shall be completed for the initial (10 year) sizing of storm drains.

C. Hydraulic Gradient Calculations

1. Beginning Elevation

All hydraulic gradient calculations must comply with Chapter 4, Section B-2 and be recorded on Form SHA-61.1-493. When a free outfall is expected, new systems should be designed by beginning the hydraulic gradient at the outfall with an elevation equal to the invert elevation plus the diameter (or rise) of the pipe to be used. Existing systems with an elevation equal to the invert elevation at the outfall plus the depth of flow in the pipe.

For systems without free outfalls, the hydraulic gradient should be started with an estimated or (when possible) the computed tailwater elevation.

When the proposed storm drain discharges into an existing storm drain system, the beginning elevation for the hydraulic gradient can be determined as follows:

a. If sufficient data is available, calculate the hydraulic gradient through the existing system and extend it through the proposed system (for each design storm).

b. If the gradient in the existing system cannot be computed, select the highest structure in the existing system which will flood <u>away</u> from the SHA roadway and assume a flooding condition at this structure, i.e., begin the gradient at this structure using the grate or manhole cover elevation as the hydraulic gradient elevation.

2. Pipe and Structure Losses

a. General

After determining the beginning elevation, E_1, calculate the headloss H_f due to friction in the pipe from point 1 to point 2.

(See figure 3)

$$H_f = S_f L \qquad (14)$$

where:

H_f = Headloss (in feet)

S_f = Frictional slope of the pipe (in feet per foot)

NOTE: S_f for outlet Control is determined by entering the pipe chart with the desired discharge Q, and intersecting the the depth line at $d = h_o = \frac{d_c + D}{2}$ or the hydraulic gradient at the previous structure whichever is greater.

L = Length of pipe between structures (in feet)

This headloss is now added to the beginning elevation, E_1. This new elevation, E_2, is the hydraulic gradient at point 2. Now calculate the headloss due to structure A. The magnitude of the structure loss is dependent on the type of structure (i.e. inlet, manhole, or bend) and the angle between the incoming and outgoing pipes. It is computed by the following formula.

$$H_b = \frac{K_b V_f^2}{2g} \qquad (15)$$

where:

h_b = Headloss (in feet)

k_b = Headloss coefficient (See SHA-61.1 - 408.0)

V_f = Frictional Velocity in the outlet pipe (in feet per second. The velocity for the given q and d = h_o)

g = Acceleration due to gravity (in feet per second, per second).

This loss may also be determined by the appropriate chart. The structure loss at a field connection is the same as that for a manhole.

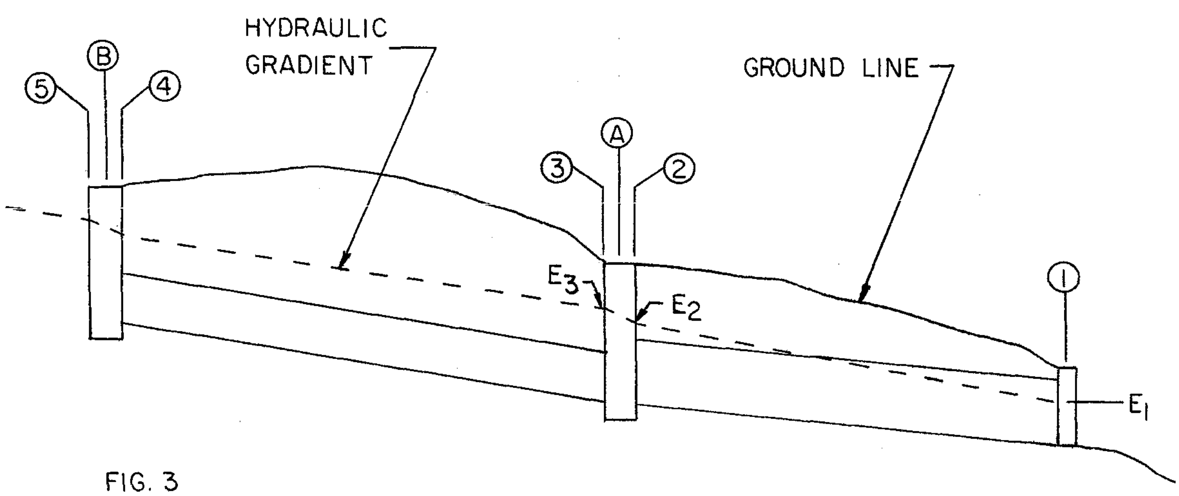
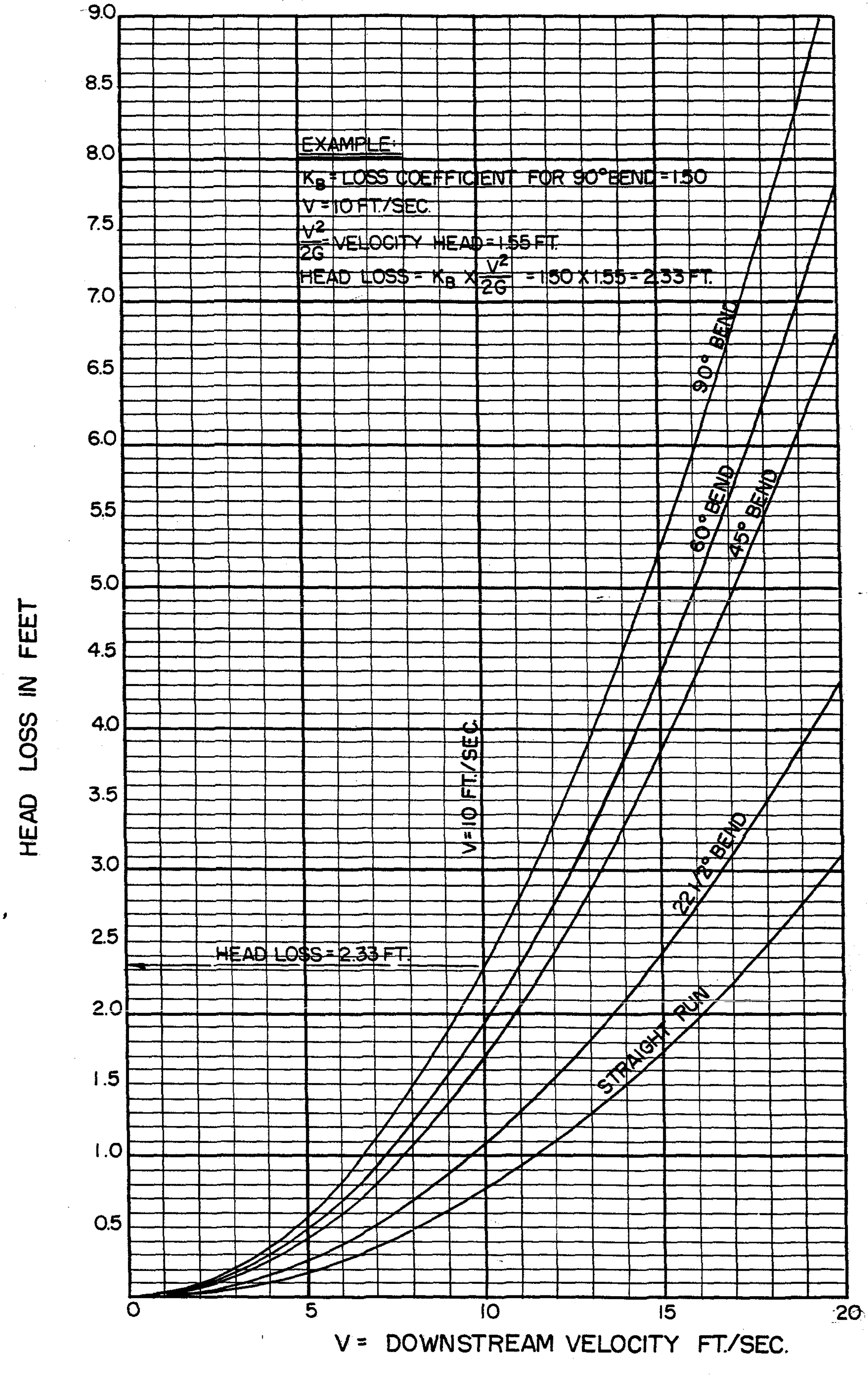


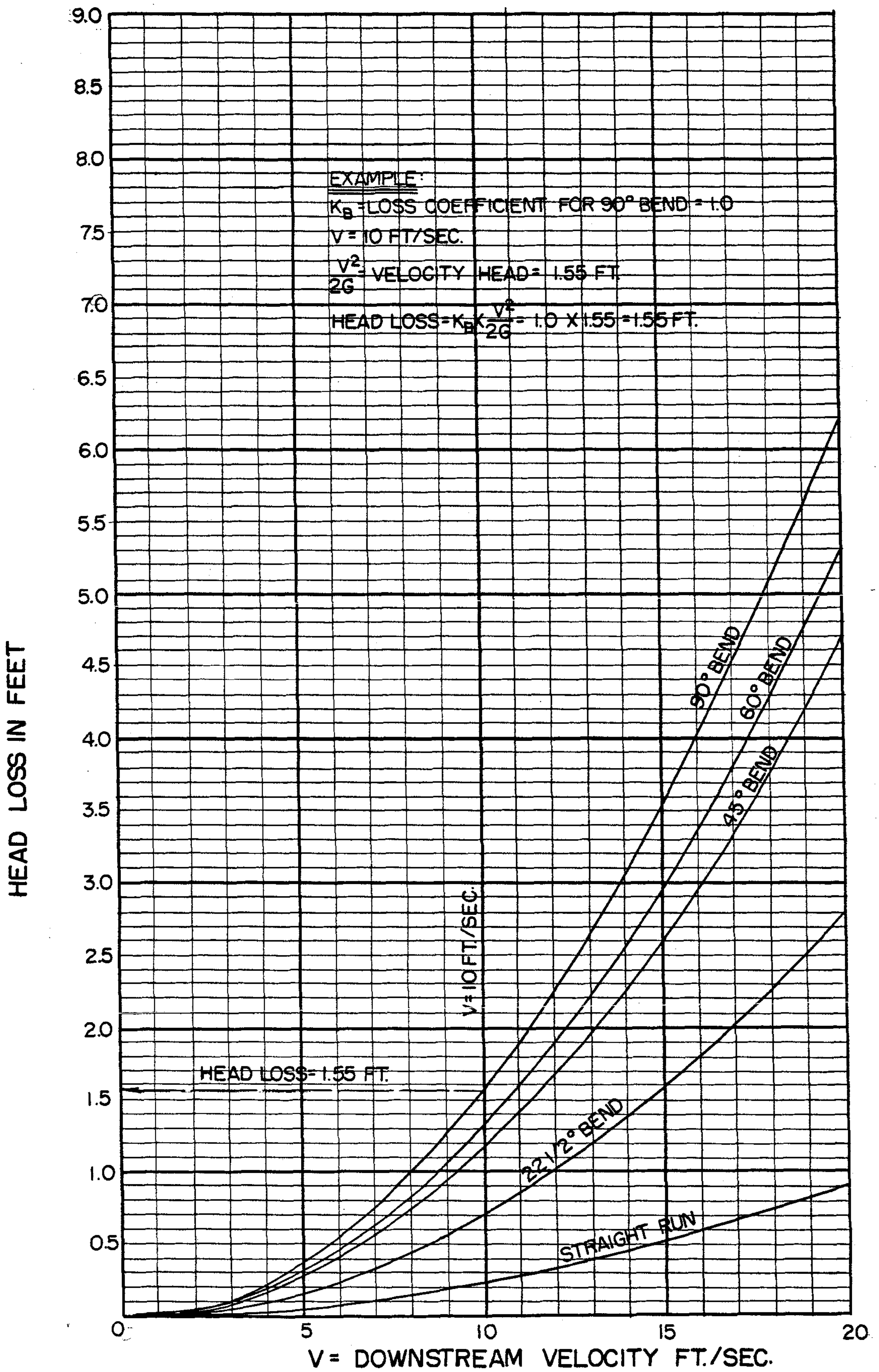
FIG. 3

TABLE OF K_b VALUES

ANGLE	INLET	MANHOLE	BEND STRUCTURE	ANGLE	INLET	MANHOLE	BEND STRUCTURE
0	.50	.15	0.01	46	1.11	.76	0.18
1	.51	.16	0.01	47	1.12	.76	0.19
2	.52	.18	0.02	48	1.13	.77	0.19
3	.53	.19	0.02	49	1.14	.78	0.19
4	.54	.20	0.03	50	1.15	.78	0.19
5	.54	.22	0.03				
6	.55	.22	0.03	51	1.16	.79	0.19
7	.56	.24	0.04	52	1.17	.80	0.19
8	.57	.26	0.05	53	1.18	.80	0.19
9	.58	.27	0.05	54	1.19	.81	0.20
10	.59	.28	0.06	55	1.20	.82	0.20
				56	1.21	.82	0.20
11	.60	.30	0.06	57	1.22	.83	0.20
12	.61	.31	0.07	58	1.23	.84	0.20
13	.62	.34	0.07	59	1.24	.84	0.20
14	.62	.34	0.07	60	1.25	.85	0.20
15	.63	.35	0.08				
16	.64	.36	0.08	61	1.26	.85	0.20
17	.65	.38	0.09	62	1.27	.86	0.20
18	.66	.39	0.09	63	1.27	.86	0.20
19	.67	.40	0.09	64	1.28	.87	0.20
20	.68	.42	0.10	65	1.29	.87	0.20
				66	1.30	.88	0.21
21	.69	.43	0.10	67	1.31	.88	0.21
22	.70	.44	0.11	68	1.32	.89	0.21
23	.71	.46	0.11	69	1.32	.89	0.21
24	.73	.47	0.11	70	1.33	.90	0.21
25	.74	.48	0.12				
26	.76	.50	0.12	71	1.34	.91	0.21
27	.78	.51	0.13	72	1.35	.91	0.21
28	.80	.52	0.13	73	1.36	.91	0.21
29	.82	.54	0.13	74	1.37	.92	0.22
30	.83	.55	0.14	75	1.37	.92	0.22
				76	1.38	.93	0.22
31	.85	.56	0.14	77	1.39	.93	0.22
32	.87	.58	0.14	78	1.40	.94	0.22
33	.89	.59	0.14	79	1.41	.94	0.22
34	.90	.60	0.14	80	1.42	.95	0.23
35	.92	.62	0.15				
36	.94	.63	0.15	81	1.42	.95	0.23
37	.96	.64	0.16	82	1.43	.96	0.23
38	.98	.66	0.16	83	1.44	.96	0.23
39	.99	.67	0.16	84	1.45	.97	0.24
40	1.01	.68	0.17	85	1.46	.97	0.24
				86	1.47	.98	0.24
41	1.03	.70	0.17	87	1.47	.98	0.24
42	1.05	.71	0.17	88	1.49	.99	0.25
43	1.06	.72	0.17	89	1.49	.99	0.25
44	1.08	.74	0.18	90	1.50	1.00	0.25
45	1.10	.75	0.18				

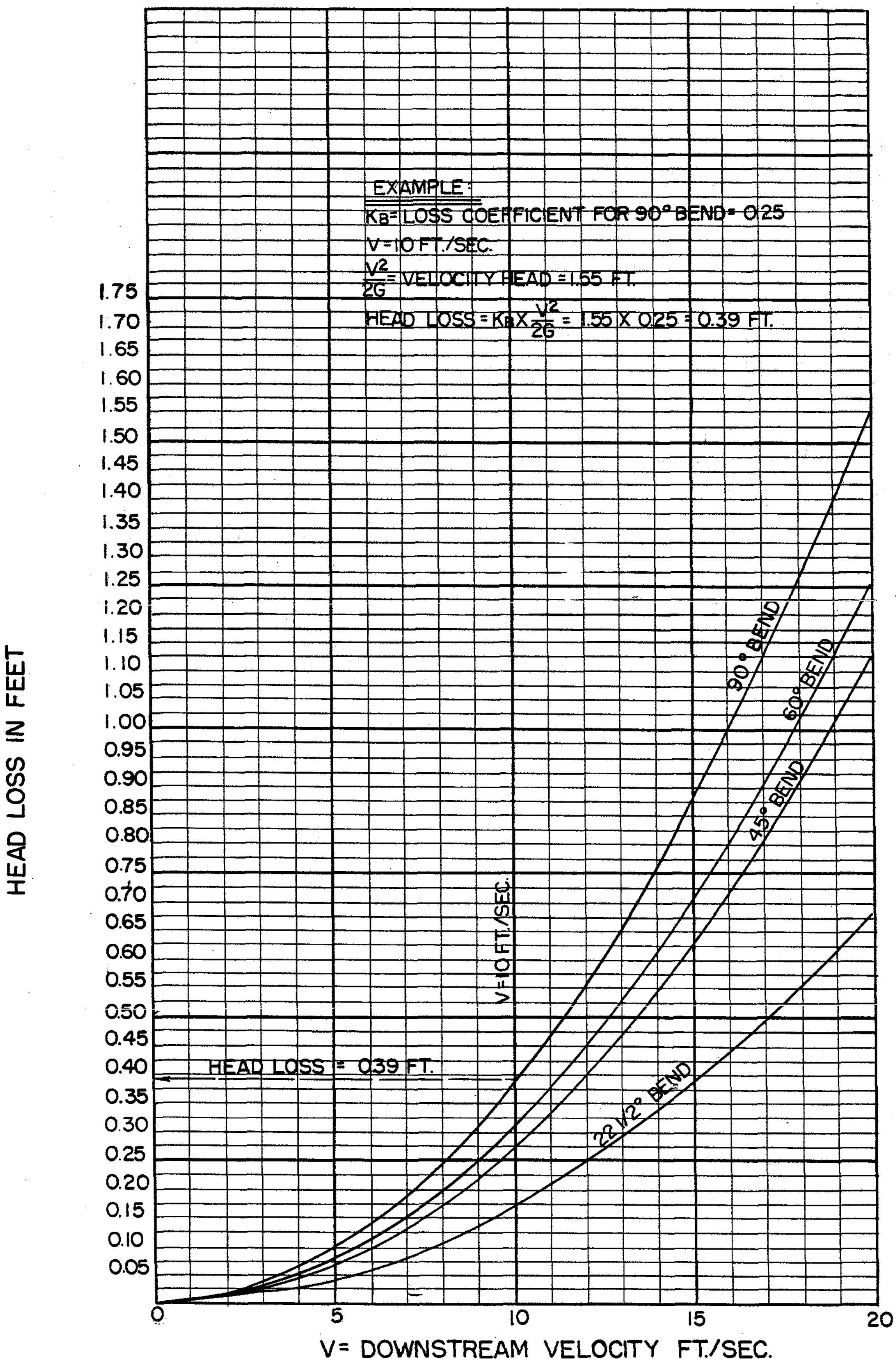


HEAD LOSSES IN INLETS



HEAD LOSSES IN MANHOLES

MARYLAND STATE HIGHWAY ADMINISTRATION 10/5/64 SHA-61.1-408.2



HEAD LOSSES IN BENDS (R= 2 1/2 X PIPE DIA.)

MARYLAND STATE HIGHWAY ADMINISTRATION 10/5/64 SHA-61.1-408.3

The structure loss, H_b, is now added to the hydraulic gradient. This elevation, E_3, is the new beginning elevation to compute the hydraulic gradient up to structure B. Repeat this procedure for the entire system.

Note: The last structure at the top of a closed system (i.e. Inlets) shall be treated as a headwall and the head water computed as outlined for open culverts with the tailwater equal the hydraulic gradient in the previous structure.

b. Junctions

When two pipes feed into one structure the controlling angle is determined by the following method.

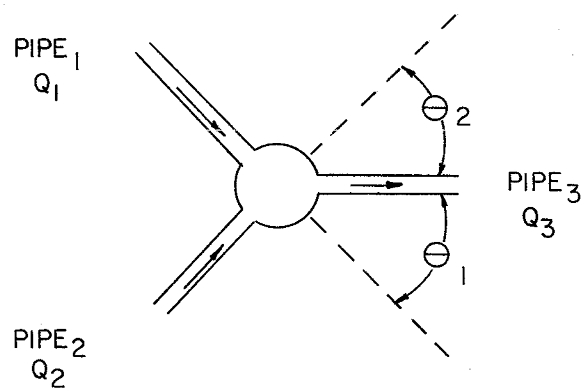


FIG. 4

Using the 10 year frequency data from From SHA-61.1-492:

Determine $V_{1/3}$ the friction velocity of Q_1 in pipe 3
Determine $V_{2/3}$ the friction velocity of Q_2 in pipe 3
With $V_{1/3}$ and θ_1 determine the structure loss $L_{\theta 1}$
With $V_{2/3}$ and θ_2 determine the structure loss $L_{\theta 2}$
If $L_{\theta 2}$ is greater, θ_2 is the controlling angle θ_c
If $L_{\theta 1}$ is greater, θ_1 is the controlling angle θ_c

The controlling angle is used to calculate the loss in that structure. Determine the friction velocity of Q_3 in pipe 3 and use θ_c for H_b, the head loss at that structure.

3. General Limitations

When the hydraulic gradient is being computed, the designer must have available either a profile of the system or a list of invert elevations and structure flooding elevations against which each computed gradient elevation may be checked.

After computing the friction loss in a section of pipe and determining the hydraulic gradient elevation at the upstream end of that section, the designer should also compute the normal depth elevation at this point. When a pipe is flowing less than full (not under pressure) the elevation and the water surface elevation at any point are the same. This depth of flow is called the normal depth.

The normal depth elevation is the normal depth plus the invert elevation at that point. If the computed hydraulic gradient elevation is lower than the normal depth elevation, the gradient must be adjusted to the normal depth elevation at that point.

Each time a structure loss is computed and added to the hydraulic gradient, the resulting gradient elevation should be compared to the flooding elevation for the structure. Of course, structures without surface access cannot flood and need not be checked. When the gradient exceeds the prescribed limits, two practical measures are available to reduce the gradient elevation without changing alignment and/or structure type:

a. Lower the entire system or if one section of pipe flows at normal depth, lower the section of the system above that pipe.

b. Increase the capacity of the pipe immediately below the flooding structure by increasing size and/or decreasing roughness coefficient or, when this is not sufficient, by use of multiple pipes.

   When it is necessary to increase pipe size, care must be taken to avoid the creation of a future maintenance problem resulting from discharging a pipe of greater cross section into a pipe of lesser cross section. Pipe size adjustments may have to be made downstream, several sections below the one at which flooding is experienced in order to keep the sizes in proper sequence. This is largely a trial and error procedure. If these measures are insufficient or impractical, the designer should investigate changing alignment in order to lower the gradient.

PART I

CHAPTER 5 STORM WATER MANAGEMENT

A. Objective

The concept of storm water management has been adopted to control the rate of runoff from any watershed. To be effective, it must be practiced by all parties, including both public agencies and private developers, who are engaged in changing land use.

The goal is to stabilize the rate of runoff which each subsequent downstream property owner must accept and convey through his property, to prevent any increase in the floodplain, to prevent channel erosion and property damage. When achieved, it should keep existing problems from worsening and prevent new problems which otherwise would have developed.

The State Highway Administration has a two-fold interest in the concept of storm water management.

First, as an Agency engaged in changing existing land use by the construction of highways, it is responsible for the construction of drainage and storm water management facilities that will comply with State laws and regulations.

Second, as a downstream property owner, the State Highway Administration must concern itself with the activities of upstream developers whose increased runoff could endanger the highway and its users.

For illustrative information on the following section see figures 5 and 6.

B. Projects Requiring Management

Storm water management is required on all State Highway Administration projects where an increase in the discharge rate from the right of way would result from:

1. An increase in the runoff coefficient or runoff curve number.

2. A concentration of runoff at a given point.

3. An unavoidable diversion of runoff from another watershed.

4. A shortening of the time concentration.

C. Allowable Discharge - The maximum allowable discharge, Q_a, from the point of investigation, for any given storm frequency shall be the same as that for existing conditions. Analyses must be made for State Highway Administration projects using design storm of return periods of 2-years, 10-years and 100-years. Generally, the point of investigation shall be that point at which the runoff leaves the right of way. The values of Q_a for the 2-year, 10-year and 100-year storms are determined as follows:

1. Calculate the existing runoff, Q_e, generated from the drainage area.

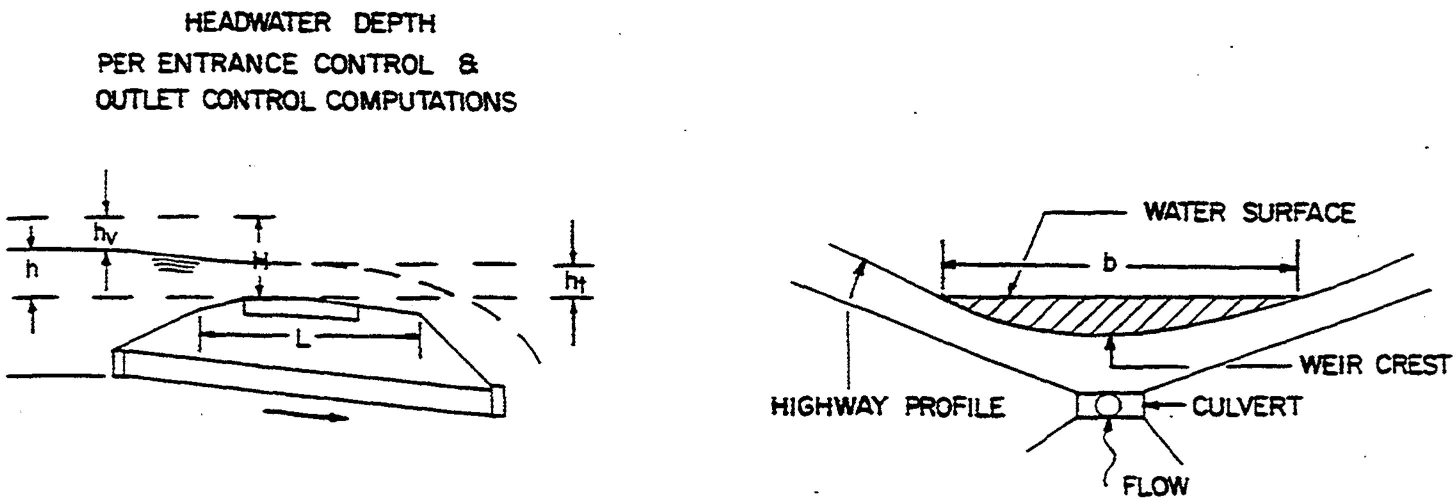
2. Then determine what portion of that discharge is actually being discharged from the right of way.

If a structure, such as a highway culvert, exists at this location, the allowable discharge Q_a may be less than the existing runoff Q_e. The allowable discharge must be restricted to that part of the existing runoff that is actually being discharged through the culvert and across the pavement (if the existing culvert is not adequate). When there is no sizeable depression at the pipe entrance and the culvert is located at a highway sump, the assumption may be made that all of the existing runoff crosses the highway and, therefore, $Q_e = Q_a$.

If storage presently exists, as in a headwater pool, the designer must determine the amount of water that is being stored and the amount that is actually being discharged by routing the runoff hydrograph through the existing structure. Discharge through the pipe is determined by the usual entrance control and outlet control computations. Flow over the road is computed as follows:

The geometry and flow pattern for a highway embankment are illustrated on figure 7A and 7B. Under free-flow conditions critical depths occur near the crown line. The head is referred to the elevation of the crown line. The head is referred to the elevation of the crown, and the length, L, in direction of flow is the distance between the top points of the upstream and downstream embankment faces. The height of the embankment faces has no influence on the discharge coefficient.

Figure 7A and 7B



The discharge equation for flow over roadways is referred to the total head, H, and is

$$Q = CbH^{3/2}, \qquad (16)$$

where

Q = discharge,
C = coefficient of discharge,
b = length of the flow section along the road normal to the direction of flow, and
H = total head = $h + V_1^2/2g$.

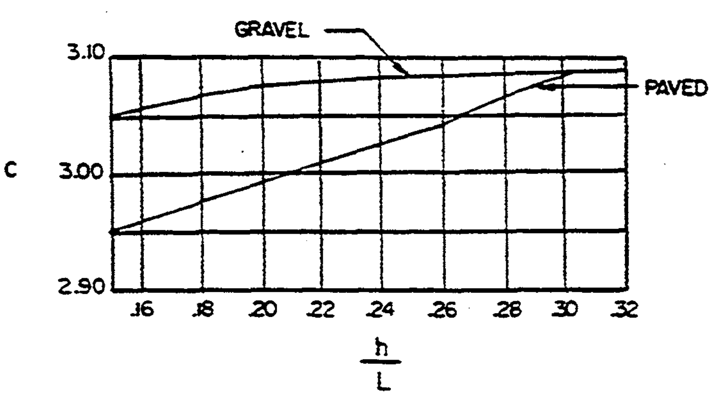
Because of shallow depths over the road and very flat longitudinal slope (normal to flow) of the roadway, it is often difficult to determine the length of the flow section, b, to be used in equation 16. It is thus convenient to assume that the elevation of the water surface at the crown line of the roadway (where b is measured) is equal to five-sixths of the maximum value of H for the section.

Extensive studies of flow over roadways were reported by Yarnell and Nagler (1930) and by Kindsvater (1964). These studies indicate that the discharge coefficient for free flow is a function of h/L when h/L is greater than 0.15. Below this value the coefficient is a function of the head, h, and roughness of the roadway.

The discharge coefficient is defined as a function of h/L on figure 7C for the condition $h/L > 0.15$. The upper curve should be used for paved highways and the lower curve for graveled highways.

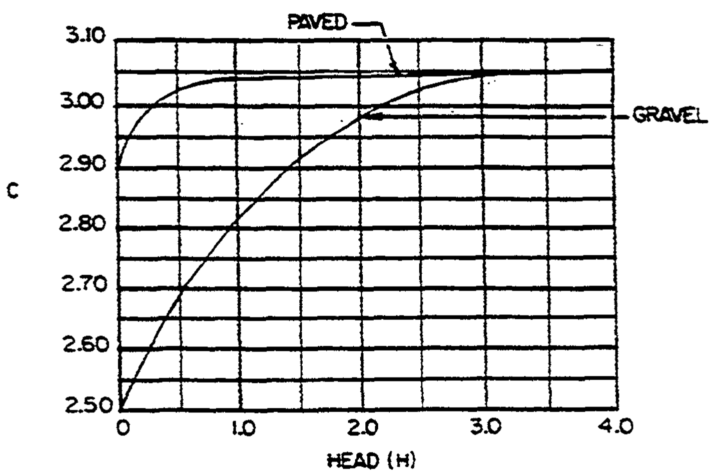
The discharge coefficient is defined as a function of head for the condition $h/L < 0.15$ on figure 7D. The upper curve should be used for paved highways and the lower gravel highways.

FIG. 7C



D. ...RGE COEFFICIENTS FOR HIGHWAY EMBANKMENTS FOR h/L RATIOS $>$ 0.15

FIG. 7D

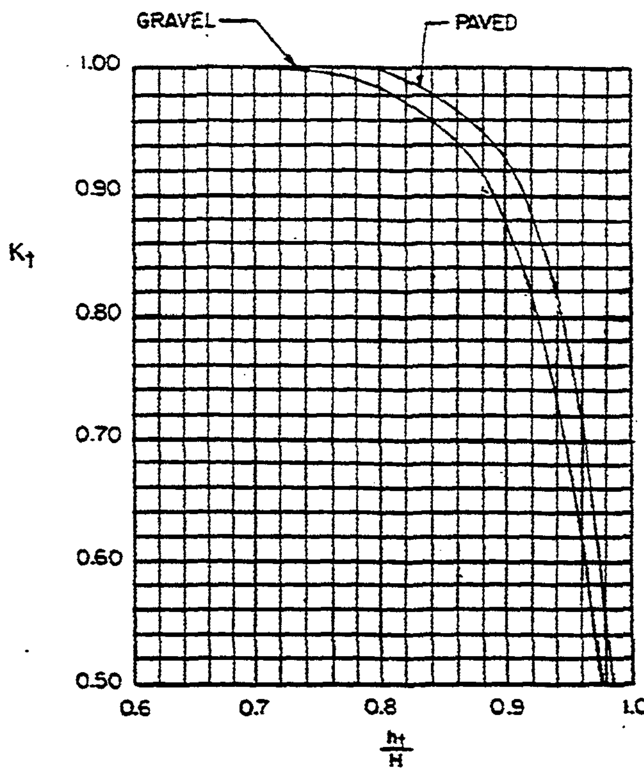


DISCHARGE COEFFICIENTS FOR HIGHWAY EMBANKMENTS FOR h/L RATIOS $<$ 0.15

Submerged highway embankments

The degree of submergence of a highway embankment is defined by the ratio h_1/H as illustrated on figure 7A. The effect of submergence on the discharge coefficient is expressed by the factor k_1, and the relation of k_1 to degree of submergence for paved and gravel surfaces is shown on figure 7E. The factor k_1 is multiplied by the discharge coefficient for free-flow conditions to obtain the discharge coefficient for submerged conditions.

If the degree of submergence is greater than 0.9, the computed discharge may not be reliable. However, in some indirect measurements the portion of the total flow which passes over the road as compared to that which went through the bridge may be small, and thus a greater error can be tolerated in this computation.



ADJUSTMENT FACTOR k_t FOR SUBMERGED HIGHWAY EMBANKMENT

FIG. 7E

If the culvert is located at a point where the highway is on grade, as contrasted with one in a sump, all of the runoff reaching the culvert may not cross the highway at the culvert location. If the estimated flow to the culvert exceeds its capacity, the designer should determine where the excess runoff escapes. The following escape routes should be checked:

1. Away from the highway to another outfall.
2. Across the road as sheet flow but reaching another outfall.
3. Downgrade to the next highway culvert.

The discharge from the existing culvert must not be increased and the excess runoff, bypassing this culvert, should not be diverted from its present course.

D. Required Storage

1. Preliminary Design

The actual storage volume required to compensate for any increase in runoff can only be determined by a trial and error procedure of routing a runoff hydrograph through a management structure. For preliminary design, the required storage may be estimated by one (1) of the following methods:

a. When designing by the Rational Method.

$$S = (Q_p - Q_a)\ (t_c)$$

for each storm frequency

where:

S = required storage (in cubic feet)
t_c = time of concentration (in seconds) (existing)
Q_p = proposed peak discharge (in cfs)
Q_a = allowable release rate (in cfs)

b. When designing by the SCS TR-55 Method.

V_s, the volume of storage, is detemined by the method outlined in Chapter 7 of TR-55.

c. When using the TR-20 Method.

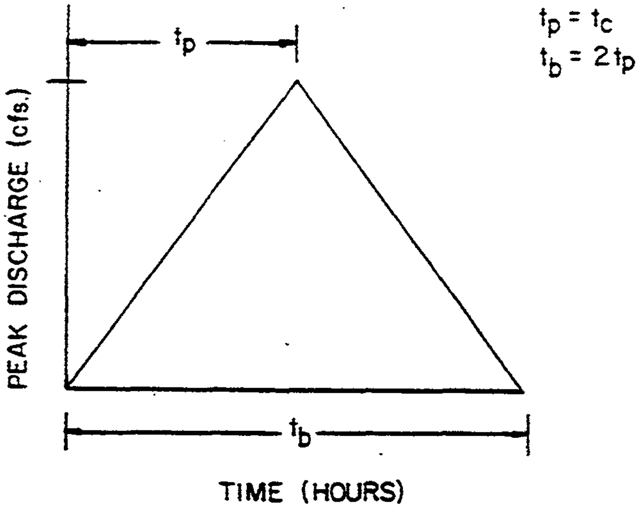
V_s, the volume of storage, may be estimated by running the subroutine "RUNOFF" for the watershed for existing and proposed conditions. Utilizing the output option of volume of runoff, the increase due to construction will be the difference in these two values.

NOTE: Each of these methods is for preliminary estimates of storage only. The final volume depends on the intricate interaction of the shape and orientation of the facility itself and configuration of the control structure. Final design can only be accomplished through trial and error by routing the runoff hydrograph through the facility.

2. Final Design

a. When designing by the Rational Method, the runoff hydrograph will be computed as follows:

(1) Compute the peak discharge as outlined in Chapter I Section A-1.
(2) Construct a triangular hydrograph as shown in Figure 8.



(3) This hydrograph can either be routed by 'storage indication' or with the TR-20 subroutine "RESVOR." It can also be added to other hydrographs to form composite hydrographs.

b. When using TR-55 the runoff hydrograph should be computed by using the tabular hydrographs given in that publication.

c. When using TR-20 the runoff hydrograph is computed simply by using the subroutine "RUNOFF."

d. Once the runoff hydrograph has been computed, it can be routed through the facility to determine the outflow condition. If the release rates do not meet the design criteria, the size or shape of the pond and/or the size or type of release structure may be changed through trial and error in order to obtain the desired results.

E. Detention Facility Types

1. Highway Projects

Detention areas adjacent to State Highway Administration culverts or grassed areas in medians or interchanges will probably prove to be the most practical and economical means of meeting storage requirements, although in some cases, underground storage may be necessary.

Detention may be accomplished upstream or downstream from the highway. Practical considerations, such as the amount of storage required, cost or availability of the right of way or easement, cost of the facility and the amount of maintenance needed to assure reliable operation will all influence the location. When a sizeable amount of storage capacity is required, storage upstream from the highway will usually prove more practical since the highway embankment will serve to confine the water.

The storage capacity required to manage a 100 year frequency storm must be provided within the State Highway Administration right-of-way or easement and the maximum storage elevation must not exceed the lowest pavement edge elevation.

The State Highway Administration must acquire any area on which it is responsible for raising the 100 year flood plane elevation.

The Chief, Bureau of Highway Design should be consulted to determine which facilities should be fenced to protect the public.

2. Other Projects

For large amounts of storage, surface storage is a practical and economial solution. If space is a critical factor, expensive underground storage may be required. If underground storage is used, the chamber(s) must be properly vented to fill to its designed capacity.

For small amounts of storage, parking lots or rooftops may provide adequate storage volumes.

If stone filled pits are to be used, some means of positive drainage must be provided. Exceptions to this rule will be considered for pits which are drained by infiltration only; however, the designer must submit detailed supporting computations concerning the action of the water table and soil permeability. In either case, the S.H.A. will only consider 33% of the volume of voids to be available for storage unless filter cloth lining is provided; in which case 100% of the volume of voids may be considered available for storage.

When surface storage is to be impounded against the highway embankment, the available storage must be computed as indicated in figure 9.

F. Release Rate

The release rate from a stormwater management facility must be limited so that the peak discharges at the point of investigation do not exceed the existing discharges at that point. Allowance must be made when existing storage is eliminated and/or when some portion of the developed area is not routed through the stormwater management facility but is released downstream uncontrolled.

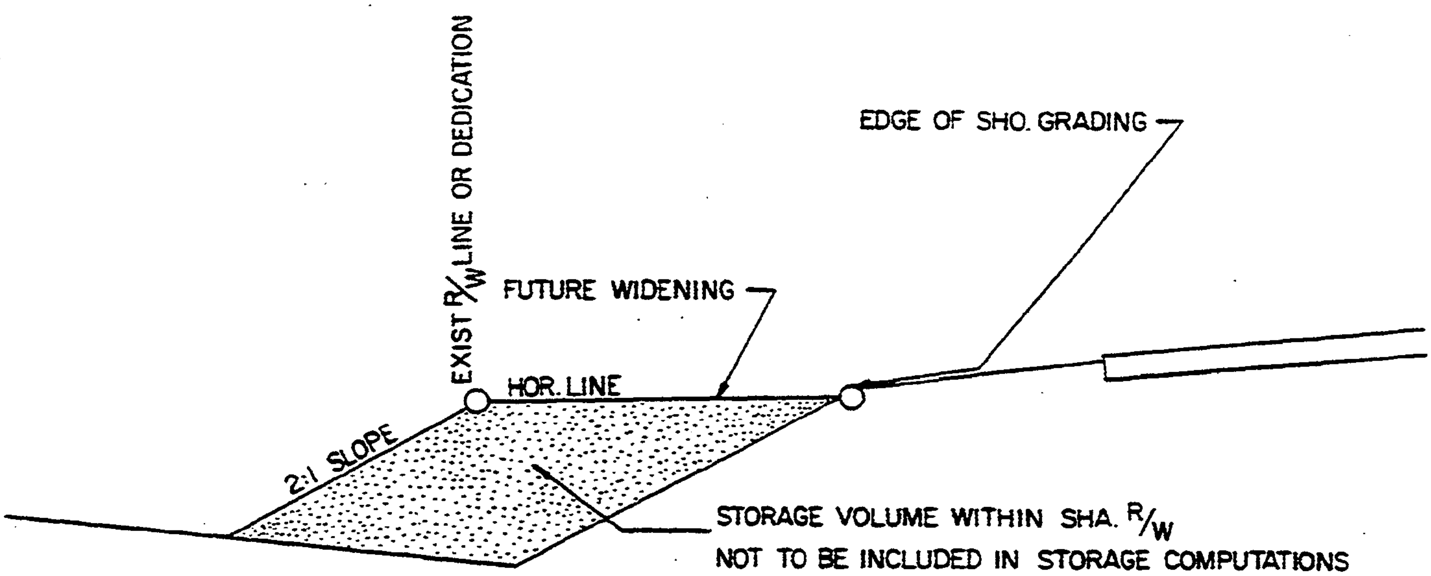


FIG. 9

G. Control Structures

In general, control structures can be any arrangement of simple culverts or "orifice and weir" structures which will provide the multiple stage release required for the 2 year, 10 year and the 100 year storms.

When simple pipes are used, size, roughness and slope should be selected so that culvert operation (either entrance or outlet control) will not discharge more than the allowable release rate when operating under the head resulting from maximum storage.

A transverse highway culvert may not be used as a control structure if it does not provide the proper release rates for all storms. In these cases, the proper release rates will be achieved by a suitable orifice and/or weir type control structure. Orifice and weir structures should be designed using the following formulas:

For the Orifice, See Figure 10 next page.

$$Q = Ca\sqrt{2gh} \qquad (18)$$

where:

Q = Discharge (in cubic feet per second)
C = a Constant (Ref. 19, Appendix 2)

a = the area of the orifice (in square feet)
g = the acceleration due to gravity (in feet per second, per second)
h = the head measured from the water surface to the center of the orifice (in feet)

Values of "C" will be approximately o.60.

However, in most release structures, the orifice will be partially or fully submerged. The same formula is used except the "h" is the difference in water surface elevations. In all cases, King's "Handbook of Hydraulic" should be consulted for tabulated values of "C" to fit the particular orifice design.

For the weir, the usual design approximates that of a sharp crested weir.

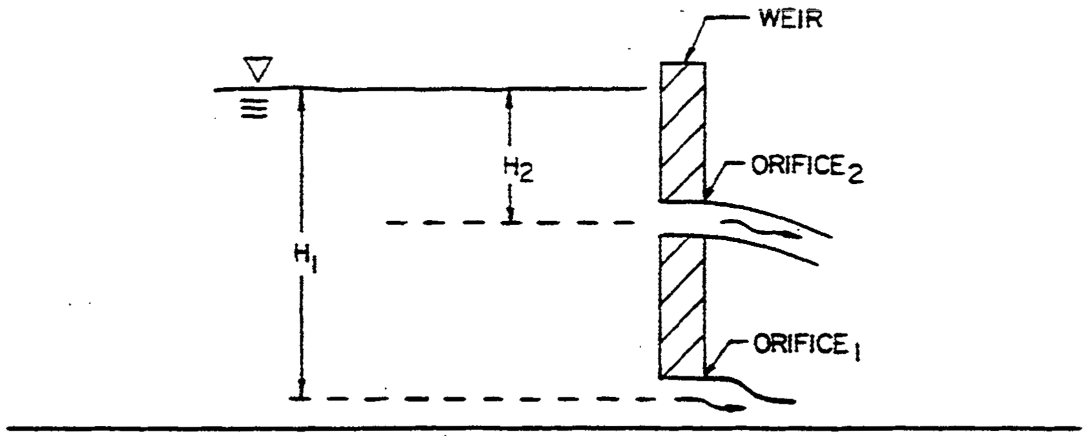
One Formula for which is: See Figure 10 next page

$$Q = 3.33\ LH^{3/2} \qquad (19)$$

where:

Q = discharge (in cubic feet per second)
L = length of the weir (in feet)
H = the head (in feet)

PARTIALLY SUBMERGED ORIFICES



SUBMERGED ORIFICES

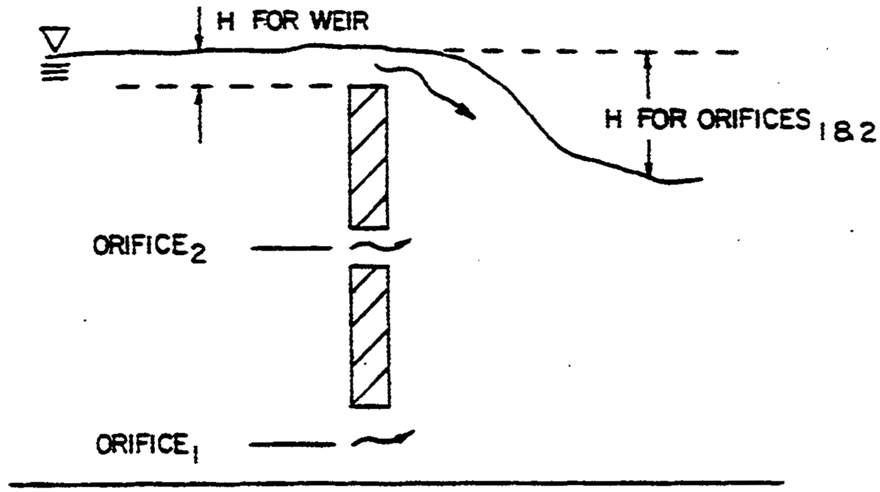


FIG. 10

PART I

CHAPTER 6 KARST TOPOGRAPHY

A. General

Some areas, mainly in Frederick and Washington counties, have underlying limestone strata in which sizeable subsurface channels have been produced by the natural erosive forces of water. Considerable areas may discharge their surface runoff into these channels via "sinkholes" thus reducing the expected flow of surface drainage through normal surface water course. Since these channels are irregular in shape and their subsurface route is unpredictable, their capacity cannot be estimated with any degree of accuracy.

B. Sinkholes as Outfalls

When construction or development activities occur in these areas these channels may be destroyed. Therefore, the designer must consider their operation to be only temporary and if they are to form a part of his drainage scheme, an alternate design must be provided. If the designer elects to use a sinkhole as his outfall, he should also design the remainder of the drainage facilities which will be required to carry the runoff to an adequate surface watercourse in the event of failure of the underground natural drainage and acquire the right of way or easement which would be required for the construction.