SHREVEPORT
Louisiana

DRAINAGE DESIGN STANDARDS

Engineering & Environmental Services Department

www.shreveport.la.gov

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INTRODUCTION

1.1 Purpose of the Design Standards

The purpose of this manual is to provide guidelines and minimum design criteria for the design of new drainage facilities for the City of Shreveport. The manual also applies to existing systems being expanded, modified, upgraded, and rehabilitated, as well as construction of new facilities. These standards are based on commonly practiced engineering principles, pertinent textbooks, and literature. While these standards establish the minimum design requirements, it is not intended to substitute for any professional engineering judgements by the Design Engineer who will assume ultimate responsibility for selection, reference and appropriate application of this manual. Any exceptions to these standards or variation from these standards shall be submitted in writing with detailed justification and calculations to the City's Engineering and Environmental Services (EES) Department. All units of measurement used in this manual are United States standard units unless otherwise noted.

This manual represents the application of accepted principles of surface drainage engineering and is a working supplement to basic information obtainable from standard drainage handbooks and other publications on drainage. The policy statements of this section provide the underlying principles by which all drainage facilities shall be designed. The application of the policy is facilitated by the technical criteria contained in the remainder of the manual.

Recognizing that properly drained storm sewer systems are essential to the general public health and welfare within a metropolitan area as the City of Shreveport. These criteria are intended to serve as a guide for the development of the design of all inlets, catch basins, manholes, storm sewers, open channels and bayous, culverts or other hydraulic and erosion control appurtenances.

Because storm drainage design is a widely variable process subject to situations and conditions beyond the control of the design engineer, cases will undoubtedly occur in which these criteria are not universally applicable. The applicability or non-applicability of any part of these criteria to a particular case will be decided by the City Engineer, and the design engineer shall abide by that decision. Each case, where a variance from the criteria is desired or considered appropriate, shall be brought to the City Engineer's attention and a decision obtained prior to proceeding with design.

1.2 Note to Design Engineer

The Design Engineer shall familiarize themselves with the contents of this manual. The Design Engineer shall update their Master/Guide specifications and/or pertinent City specifications to suit the needs of each individual project. The Design Engineer shall abide by these requirements in completing design.

Numerous drainage manuals and guides were obtained from other states, municipalities, and organizations. Beneficial aspects of these manuals and guides were used in the production of this manual. The most updated versions of all references should be used by designer.

1.3 Master Planning Documents

Mapping other than that required for the General Layout Sheet shall not be a part of the construction plans but shall be submitted at the same time as the construction plans. The maps shall show the various drainage sheds, recorded plats, survey maps or other plans which show the tributary area to be included in the design. The tributary area to each culvert and storm sewer inlet shall be outlined and the drainage area and runoff coefficients noted. A north arrow shall be shown on the map, and a suitable scale to show the overall area should be used.

1.4 Drainage Design Report & Plans

1.4.1 General

The following steps are intended to serve as a general guide in the preparation of a set of storm drainage plans. Adherence to the recommended procedures will produce a uniform drainage design throughout the City of Shreveport and will lead to shorter review and aid in obtaining subsequent approval by the City Engineer's Office.

1. Mapping
   The maps shall show the various drainage sheds, recorded plats, survey maps or other plans which show the tributary area to be included in the design. The tributary area to each culvert and storm sewer inlet shall be outlined and the drainage area and runoff coefficients noted. A north arrow shall be shown on the map and a suitable scale to show the overall area should be used.
2. Surveys
   Survey reference data shall be checked and confirmed with the official records of Shreveport and other recorded information.
3. Utilities
   Existing and proposed utility lines shall be located. Files and other information supplied by local utility companies and city records shall be checked.
4. Existing Information
   The ridge lines or the total surface area of the tributary area shall be determined and a general layout of the proposed storm sewer line established. Correlation with existing storm sewers, ditches, appurtenances, street grades and all other information pertaining to the location of the proposed storm drainage facility shall be checked.

1.4.2 Hydraulics Report

The submittal of preliminary plans should be accompanied with one bound report that is properly indexed, typed and neatly arranged. Pages are to be numbered for referencing purposes when reviews are sent back to the designer. Also include in the report, the name of the firm and designer along with a phone number to contact the designer during normal business hours should questions arise about the design. All submitted reports must have the stamp, date and signature of the Professional Engineer in charge.

The report contents should include the following:

1. Design Classification: Design classification of the project should be noted in the transmittal letter or on the title sheet when a project is submitted to the City Engineer's Office.

2. Site Conditions: Brief commentary should be included describing the conditions of the site, the reasons for the proposed major structure(s) and what kind of effect these structure(s) will have on the site.

3. Design Assumptions: Thorough documentation of all design assumptions and design decisions is critical. All factors, especially judgmental factors, governing the selection of design parameters such as allowable backwater, allowable headwater, permissible velocity, outfall stage, etc., must be documented by the designer. However, the basis for the selection of the limiting factors must be defensible by sound engineering principle. Any decisions reached between the designer and the Project Manager affecting the hydraulic design should also be explained in the document.

4. Calculations: All calculations contributing to the design of the proposed hydraulic structures (i.e., discharge determinations, culvert design, curb capacity determination, inlet locations and sizing, storm sewer design, open channel design, etc.) are to be included in the report. The designer should ensure that the numbers and values shown on the corresponding plans match the calculations submitted. Copies of all hydraulic calculations shall accompany the submittal plans and mapping to facilitate review of the plans.

5. Photographs: When there is a major stream crossing or special design requirements on a site, color photographs showing the conditions should be included in the report.

1.4.3 Preliminary Layout

Prepare drawings of the preliminary layout and grades. Preliminary plans shall include existing drainage map, design drainage map, and plan/profile sheets. The drainage pattern must be compatible with the existing pattern established in the area. The City Engineer's Office should be contacted, and an informal review scheduled with the City Engineer's staff. At this review, ultimate development of the area will be discussed with reference to the proposed drainage improvements. If the City has an overall storm drainage master plan in effect in the area being reviewed, compatibility with the recommended storm sewers will be reviewed. The possibility exists that the preliminary design will need to be field checked as part of the preliminary review for field verification of the drainage shed, critical connections, crossings, slopes, etc. Final design shall proceed only when all portions of the preliminary layout have been reviewed and, if necessary, reconciliations reached by all parties.

1.4.4 Final Submittal

Final plan submittal shall be in accordance with the general requirements for City projects (see Section 1.7 Appendix). The final hydraulics report shall be submitted along with the final plans.

1.5 Standard Specifications & Details

The City of Shreveport has a set of standard specifications and details for design of new drainage facility projects. The manual also applies to existing systems being expanded, modified, upgraded and rehabilitated. These specifications provide the level of expectation of quality for the construction the drainage facility projects. However, the standard specifications and details may not apply to all projects, and therefore the Design Engineer is advised to review these standard documents and update their specifications and/or details as it applies to the project. The Design Engineer can request the latest version of these documents from the City's Engineering and Environmental Services Department.

1.6 Process Summary & Requirements

1.6.1 Plan Review

Three sets of plans shall be submitted to the City. Plans may also be submitted electronically in PDF format. When a project is submitted to the City Engineer's office for review and approval or disapproval the following sequence will occur:

1. One set of prints will be routed through the city departments, i.e., Public Works, Water and Sewerage, etc. for their comments.

2. One set of prints, the maps and the drainage calculations will be reviewed by the City Engineer's Office.

3. After review by all departments, the comments will be added to the remaining set of plans and returned to the original submitter. The City Engineer's Office will retain the other copies of the plan submittal.

4. Should the engineer or owner wish to schedule a meeting to discuss the comments and resolve differences of opinion as to the method of design on a project, the City Engineer or his assistant will be available for same.

5. When the comments have been incorporated into the original set of plans, one set of prints will be returned to the city for a final checks along with the marked-up copy of the original submittal previously returned to the design engineer.

6. If the project is roadway and associated drainage improvement and the owner is going to construct the project with his forces or contractor he shall furnish the city a complete set of "as-built" plans, one hard copy and one electronic copy (PDF and CAD) upon completion of the construction and acceptance of the work by the city.

7. If the project is a drainage improvement only and the city has contracted with an outside consultant to administer the construction of the project, it shall then be the consultant's responsibility to prepare the "as built" plans. As is the case of roadways and roadway drainage projects administered by the city, the city will prepare "as built" plans of projects administered by the City Engineer's office.

1.7 APPENDIX

1.7.1 Project Checklists

1. Plan Review Checklist
2. Drainage Design Report Checklist

Plan Review Checklist

PLAN REVIEW CHECKLIST

PURPOSE:

The purpose of this checklist is to expedite plan review of street, storm drainage, water, and sewer plans requiring approval by the City Engineer, as well as help standardize plans for the City of Shreveport. This checklist is intended to help reviewers and the consultants standardize plans and minimize the probability of misinterpretation by field personnel during construction layout engineering and inspection.

This checklist is intended to be a guide and reference for the submittal and review of design plans. <u>The items listed on the checklist are not to be intended as all-inclusive for every project.</u> Depending on the scope of the project, sheet requirements may or may not include all of the sheets as listed below, or may include additional sheets not listed in this checklist.

INSTRUCTIONS:

1. The checklist is separated into the following sections to correspond to the general requirements of the plan submittal.

   A. Overall Drawing Requirements
   B. General Sheets
   C. Layout Sheets
   D. Right-of-Way Sheet
   E. Plan and Profile Sheet(s)
   F. Standard and Special Detail Sheet(s)
   G. Erosion Control Layout Sheet

2. Fill in the Project Name, City of Shreveport Project Number (if known), and submittal date, on the first page of the checklist.

3. Complete each section of the checklist by checking each appropriate item as shown on the submitted plans.

4. Where items or sections do not apply, insert a “N/A” (non-applicable) in the allotted space provided.

5. Submit completed checklist with plan submittal package.

PLAN REVIEW CHECKLIST

PROJECT NAME: ______________________________

DATE: ______________________________

PROJECT NUMBER: ______________________________

DESIGNER: ______________________________

OVERALL DRAWING REQUIREMENTS

1. _____ Plan Sheet Size is 22" x 34"

2. _____ Plans are drawn to a Horizontal Scale of 1"=20', and a vertical scale of 1"=4'. (Larger scales can be used for increased clarity or conciseness of the plans with prior permission of the City Engineer. Smaller scales can be used in the profile for sewer mains).

3. _____ Each Sheet shall contain a sheet number, the total number of sheets in the plans, and the proper project number.

4. _____ A revision block will be included on each sheet. Revised sheets submitted shall have identifying notations and dates for each revision.

5. _____ All lettering shall be ≥0.125"

6. _____ The design engineer information including name and address is shown on each plan sheet.

7. _____ The final plans and specifications shall be signed, dated and sealed by the responsible engineer(s). Responsible engineer shall be a registered Professional Engineer, licensed to practice in the State of Louisiana.

8. _____ The final set of plans shall be submitted on full size, 20 lb. weight archive-able paper. Specifications shall be printed on 8 ½" X 11" paper. All final sets (plans and specifications) shall be clipped and bound.

9. _____ Once approved, the final set of plans and specifications shall also be submitted electronically to the city. All reference files will be bound into one overall drawing file. The naming format for the drawing files shall be "Project Number, Page #, _, Total Page# (i.e. 01C0011_20, project number is 01C001, the page # is 1, and the total page # is 20). Final plans shall be submitted either in MicroStation or AutoCAD. Final plans (signed, dated and stamped) shall also be submitted in 'pdf' format. Final specifications shall be submitted in both 'Microsoft Word' and 'pdf' formats.

GENERAL SHEETS

General sheets shall include the Title Sheet, Index Sheet, General Notes, Legends and Abbreviation, Hydraulic Profiles, and Pipe, Valve and Equipment Schedules. Project work involving upgrades to existing treatment plants or new treatment plans shall include Process Flow Diagrams. Minimum requirements for each of these sheets are listed below.

TITLE SHEET

The title sheet shall list the following information.

1. _____ All plans shall include this text at the top: "CITY OF SHREVEPORT, LOUISIANA. DEPARTMENT OF ENGINEERING AND ENVIRONMENTAL SERVICES. OFFICE OF THE CITY ENGINEER." Immediately below this text, the name of the project or title, city, and parish shall be listed.

2. _____ Project number

3. _____ Location Map showing project location in relation to streets, railroads, and physical features. The location map shall have a north arrow and appropriate scale. The location map shall show the beginning and end stationing of the project.

4. _____ Vicinity Map showing project location in relation to City of Shreveport map. The vicinity map shall have a north arrow and appropriate scale.

5. _____ For City of Shreveport projects, the Mayor, Director of Engineering and Environmental Services or the Director of the responsible department, and City of Shreveport City Council Members listed by district, shall be shown on the title sheet.

6. _____ Funding information for City of Shreveport projects.

7. _____ The type of construction shall be noted (e.g. asphalt paving, water main replacement, paved ditch construction).

8. _____ Index of sheets shall be included for all projects.

GENERAL NOTES

General notes shall include the following at a minimum:

1. _____ A note stating the following, in bold letters and framed in a box: "CONTRACTOR TO CALL LA. ONE CALL OR THE UTILITY COMPANY"

2. _____ A note stating that the Contractor shall be responsible for protection of existing utilities in the area of work.

3. _____ A note stating that Health and Safety at the jobsite, during construction, shall be the Contractor's responsibility.

4. _____ A note identifying the permits that the Contractor will need to obtain prior to beginning work.

5. _____ A note pertaining to relevant coordinates, datum used in surveys, and adjustment factors (if used).

6. _____ A note stating the following: “REDLINE DRAWINGS SHALL BE PRESENTED TO THE CITY’S REPRESENTATIVE PRIOR TO PAY REQUEST APPROVAL AND FINAL COMPLETION.”

7. _____ A note stating that the City’s standard specifications will be used for the project.

8. _____ If required, a note regarding demolition activities, directing the Contractor to contact the City regarding preferences in salvaging demolished items.

9. _____ If required, a note pertaining to disposal of demolished items in compliance with prevailing regulations.

10. _____ If required, a note pertaining to design standards used (e.g. design speed, design storm, etc.)

QUANTITY SUMMARY SHEET

A summary of quantities shall be included for all projects that includes the item description, item number, unit for pricing, and quantity. Items shall be numbered per the current edition of the Shreveport Standard Specifications for Infrastructure Improvements. Any items not listed in the Standard Specifications shall be numbered beginning with S-1, followed by S-2, etc. The method of payment shall be listed if it is not stated in the Standard Specifications.

LEGENDS & ABBREVIATIONS

All legends and abbreviations used in the plans shall be listed in these sheet(s). For smaller jobs, it may be possible to merge this with the General Notes sheet. For complex projects, separate sheets for legends and abbreviations may be required for each discipline.

HYDRAULIC PROFILES

Hydraulic profiles may not be required for all projects; they are required for certain treatment plant projects, pump station and piping projects. Where required, such profiles shall be constructed for each structure, piping junction as required. It shall be developed for current, design, and future flows.

PIPE, VALVE & EQUIPMENT SCHEDULES

These schedules may only be required for certain projects. The Design Engineer shall list these schedules for pipes, valves and/or equipment of certain sizes. When used, the Design Engineer shall list their sizes (diameters, dimensions), type (pipe type, pipe class/schedule, valve type, valve opening, equipment operation type, etc.), capacity (flowrate, throughput, etc.), and electrical sizes (HP, rpm etc.).

LAYOUT SHEETS

Layout sheets shall include Site Layout sheets and Topographic Survey sheets. Requirements for these sheets are stated below.

SITE LAYOUT SHEETS

1. _____ North arrow and scale (scale shall be shown with a scale bar).

2. _____ Name of subdivision and all street names and an accurate tie to at least one quarter section corner. Unplatted tracts should also have an accurate tie to at least one quarter section corner.

3. _____ Boundary line for project area.

4. _____ Location and description of major waterways, water bodies, and drainage facilities within or adjacent to the project area.

5. _____ Name of each utility within or adjacent to the project area and the telephone number of the contact.

6. _____ If applicable to the project, contractor staging area and spoils area.

7. _____ If more than one general layout sheet is required, a match line should be used to show continuation of coverage from one sheet to the next sheet.

TOPOGRAPHIC SURVEY

For most projects survey information can be included in the layout sheets. However, for projects involving pipelines, relevant survey information shall be shown on all applicable plan and profile sheets.

1. _____ North arrow and scale (scale shall be shown with a scale bar).

2. _____ A legend is shown for all symbols and hatches used.

3. _____ Vertical Datum stated, and at least two benchmarks are shown and listed.
The monument number, elevation, northing and easting, and location description shall be shown.

4. _____ Existing contours shown at each foot of elevation (unless other approved).

5. _____ Street names are shown along roadway centerline.

6. _____ Limits of right-of-way is shown on the plan.

7. _____ Call-outs for all objects and features on survey.

8. _____ Existing sewer and storm drainage structures are shown and listed and stationed with rim elevation, pipe size, pipe material, and pipe invert elevation.

9. _____ Underground stormwater, sanitary sewer, and waterlines are shown and labeled with size and material type.

10. _____ All utility structures such as electrical vaults, power poles, guy wires, gas meters, water meters, water vaults, telephone poles, telephone vaults, are shown and called out with station and offset.

11. _____ All overhead and underground utility lines are shown and labeled.

12. _____ Utility servitudes are shown and labeled.

13. _____ Culverts are shown and labeled with pipe material, pipe size, flow line elevation, and station and offset at each end. Any extension of an existing culvert is shown and labeled.

14. _____ Landscape features such as trees, shrubs, and site amenities are shown and labeled with station and offset.

15. _____ Property lines are shown. Property including owner, address, lot number is shown.

16. _____ The survey information is shown for at least 50 feet beyond the project limits. Additional data and details may be needed depending on the scope of the project.

17. _____ All driveway locations are shown on the plan, stationed to the center of driveway. The width and material type of driveway is listed.

18. _____ The sidewalks are shown on the plan. The type of material is called out on the plan. Any ramps are shown.

19. _____ Delineate any and all Special Flood Hazard Areas (SFHA) and regulatory floodways.

20. _____ The survey is signed and stamped by a licensed surveyor in the State of Louisiana.

GRADING PLAN

1. _____ North arrow and scale (scale shall be shown with a scale bar).

2. _____ A legend is shown for all symbols and hatches used.

3. _____ Show clearly labeled onsite and adjacent offsite existing and proposed contours.

4. _____ Delineate any and all Special Flood Hazard Areas (SFHA) and regulatory floodways. State base flood elevation if applicable.

5. _____ Show existing and proposed lot lines and lot numbers.

6. _____ Finished pad and/or floor elevations shown for all lots.

7. _____ Clearly show all walls and label top/bottom elevations of wall at key locations.

8. _____ Provide point elevations to ensure proper drainage and adequate ADA routing where applicable.

9. _____ Drainage clarified by flow arrows, high points, sags, ridges, and valley gutters.

RIGHT-OF-WAY SHEETS

These sheets may be issued by themselves or attached to Design Reports and Specifications. Right-Of-Way sheets shall include the following information:

1. _____ Parcel number.

2. _____ Lot number.

3. _____ Subdivision.

4. _____ Name of current owner.

5. _____ Servitude takings (Should be labeled as P-# for Right-of-way, D-# for drainage, T-# for temporary construction) with dimensions.

6. _____ Right-of-way takings.

7. _____ Geographical Number.

8. _____ Plat sheets are to be 8 ½"x11".

PLAN AND PROFILE SHEETS

Plan and Profile sheets shall include Site Civil sheets, Construction Signage sheets, Pavement Markings sheets, Architectural sheets, Structural sheets, Process Mechanical sheets, Mechanical sheets, Electrical sheets and Instrumentation and Control sheets. The requirements for these sheets may vary depending on the project scope. Not all of these sheets are discussed in detail in this section. Overall requirements for these sheets are listed below.

SITE CIVIL PLANS

1. _____ North arrow and scale (scale shall be shown with a scale bar) (Horizontal scale of 1"=20').
2. _____ Elevation and location of all applicable bench marks.
3. _____ Show Right-of-Way boundaries and limits and associated dimensions.
4. _____ Street names are shown along roadway centerline along with stationing. Show road alignments with 100' stationing labels and stationing at points of curve, tangent, and intersection.
5. _____ Detailed locations of proposed structures, process units, piping, vaults, and other items. Provide station and offset.
6. _____ Show all existing and proposed utilities such as water, sanitary sewer, storm sewer, electric, gas, oil, telephone, fiber optics, and other such items located in conformance with the best information available or by field surveys, and identified as to size, type of utility, and type of material. Sanitary sewers and storm sewers shall show direction of flow.
7. _____ Sanitary sewer manholes and storm sewer inlets/boxes shall be properly labeled and need to state the flow line elevation, rim elevation, and if applicable size of the structure, gutter elevation, and top of curb elevation.
8. _____ Show all utility servitudes. Dimension and label width and ownership of servitude(s).
9. ____ All existing and known proposed improvements shall be identified as to type, size, material, etc., as may be applicable. Existing conditions need to be screened back (presented as a lighter line color) on the drawing.
10. _____ Proposed work needs to be obviously darker on the drawings than the existing conditions.
11. _____ Show the flow line and top of bank of existing open channels and the centerline and top of bank of proposed open channels.
12. _____ Show pipeline stationing along the centerline. A uniform system designating the pipes and structures shall be used.
13. _____ Show complete centerline curve data for each curve along with points, bearings, curvature, and tangency.
14. _____ Profile grade line identified on plan.
15. _____ Show all existing and proposed intersecting streets with their centerline station angle of intersection, width of right-of-way, pavement width, and sidewalk location. The drawing shall be dimensioned to show the distance from back of curb to back of curb, from back of curb to sidewalk, width of sidewalk, and from back of sidewalk to property line.
16. _____ Show all curve information for streets and curbs, including radius size, beginning and ending points of curve (station and offset), and the radius point (station and offset).

17. _____ At intersecting streets show distances or stations locating points of tangency of curb radii to be installed. (i.e. station and offset)

18. _____ Super-elevation table for curves.

19. _____ Pavement markings. (Can be on a separate plan sheet)

20. _____ Proposed Signage. (Can be on a separate plan sheet)

21. _____ Show all railway information if applicable; their ownership, right-of-way width, angle of intersection and location.

22. _____ Show boring locations if available.

23. _____ Limits of clearing shall be shown on the plan. All encroachments or excess right-of-way is clearly shown on the plan.

24. _____ The plans shall dimension location/spacing of utilities.

25. _____ Callout pipe size, material and service type on plans (ex: 24-PVC-SFM for 24" PVC sewer force main)

26. _____ Callout valve sizes, valve types, and fittings (ex: 42-BFV for 42 inch Butterfly Valve)

27. _____ Identify the Control Points and Bench Marks. Callout Northings and Eastings of all manholes, pipe fittings, valves, corners of buildings, paving, roads, etc.

28. _____ All replaced driveways are called out by station and offset to the center of the new driveway. Also the total square yardage of the new driveway is shown on the call out. Any driveway over 5% will need to have a driveway profile in the plan set.

29. _____ Include drainage plans for applicable concrete pad drawings.

SITE CIVIL PROFILES

30. _____ The profile shall have a horizontal scale of 1"=20', and a vertical scale of 1"=4', unless approved by the City Engineer.

31. _____ Existing and proposed grade elevations are shown.

32. _____ Depth and location of existing or proposed utilities and sanitary sewers where such information is available, or in the case where the depth is not known, approximate elevations shall be used and noted as approximate. Each facility shall be properly identified.

33. _____ Proposed pipes shall be shown as double solid lines properly showing the height of the pipe.

34. _____ Show all manholes, inlets and junction boxes, with structure designation (structure number and type), station and offset, top of structure elevation, and flow lines of pipes entering and leaving the structure. Flow line elevations shall be shown at the edge of the structure.

35. _____ Label sanitary and storm sewer pipes between manholes, inlets, and junction boxes with the distance between the inside faces of the structures, the gradient, pipe size, and type of material.

36. _____ Open channel profiles with the proposed flow line, gradient, the depth of special protection (if required), existing left and right bank elevations and the height of levees (if required). The typical section for the ditch shall be shown for specific reaches.

37. _____ At vertical curves, show station and elevation at point of vertical curve, point of intersection, point of tangency, "k" value, required vertical curve length and the actual vertical curve length, and other required points to maintain a maximum horizontal distance between noted elevations of 20 feet.

38. _____ Show stations for intersecting centerlines of streets.

39. _____ Show top of curb elevations on "turn-outs" for intersecting streets having a grade change of 2% or greater.

40. _____ The separation between utilities is shown.

41. _____ The cover over the water pipe is shown.

42. _____ The water surface profile or hydraulic grade line is shown.

CONSTRUCTION SIGNAGE SHEETS (If Applicable)

1. _____ North arrow and scale.

2. _____ Spacing between signs/traffic control devices are dimensioned.

3. _____ Street names are shown.

4. _____ Beginning and end of project is shown and stationed.

5. _____ Show detour routes if applicable.

6. _____ A legend of the proposed signs, or the plan clearly indicate the type of sign/traffic control device to be used.

PAVEMENT MARKING SHEETS (If Applicable)

1. _____ North arrow and scale.

2. _____ Lane widths are dimensioned.

3. _____ Taper and transition lengths are dimensioned.

4. _____ Stripe spacing is dimensioned.

5. _____ Stripe type, colors, and sizes are labeled.

6. _____ Any required stripe removal is shown.

7. _____ Any curved striping has a length, radius, beginning and end of curve. Radius point is shown on the plans.

8. _____ Stripes are extended the length of the stacking distance.

9. _____ All pavement symbols are shown and detailed in the plans. (Arrows, "ONLY", etc.)

ARCHITECTURAL SHEETS (If Applicable)

1. _____ Include a General Architectural Notes sheet.

2. _____ Include a Legends & Abbreviations sheet if required.

3. _____ Include Code Plans as applicable to the project.

4. _____ Include Floor Plans as required.

5. _____ Show Building Elevation and Section sheets depicting all applicable demolition, modification and construction activities.

6. _____ Include Standard Architectural Details sheet as required.

STRUCTURAL SHEETS (If Applicable)

1. _____ Include a General Structural Notes sheet(s).

2. _____ Include a Legends & Abbreviations sheet if required.

3. _____ Include Overall Plans and Sections if required.

4. _____ Include structural sheets for all applicable installations/equipment/structures that include:

   a. _____ Pertinent dimensions.

   b. _____ Type of concrete to be used.

   c. _____ Type of metal to be used.

   d. _____ Rebar size, location, numbers, spacing and clearances.

5. _____ Include a Standard Structural Details sheet.

PROCESS MECHANICAL SHEETS (If Applicable)

1. _____ Include a General Process Mechanical Notes sheet(s).

2. _____ Include a Legends & Abbreviations sheet if required.

3. _____ Include an overall Process Mechanical plan if required. Plan shall include layout dimensions, interior clearances, wall thicknesses

4. _____ Include Plans and Profiles of associated/affected Structures. In certain cases, more than one plan or profile sheet may be required. All associated dimensions, and clearances shall be clearly called out.

5. _____ Include Plans and Profiles of associated process equipment with dimensions, and clearances clearly called out.

6. _____ Fittings, piping and valves shall be clearly marked. Pertinent fixtures, fittings, and supports shall also be indicated.

7. _____ Call out pipe sizes, pipe material, and type of service (ex: 4-SS-AA for 4 inch Stainless Steel Aeration Air service line).

8. _____ Call out valve size, valve type, and fittings (ex: 12-PV for 12 inch plug valve)

9. _____ Include a standard Process Mechanical Details sheet(s).

MECHANICAL SHEETS (If Applicable)

1. _____ Include a General Mechanical Notes sheet(s). Notes shall include applicable codes and regulations.

2. _____ Include a Legends & Abbreviations sheet if required.

3. _____ Include an overall Mechanical Plan sheet. This sheet shall include pertinent HVAC and Plumbing sheets.

4. _____ Include separate sheet(s) for HVAC equipment. Sheet shall show locations of HVAC equipment, clearances from other equipment, and include an HVAC equipment schedule.

5. _____ Include separate sheet(s) for Plumbing equipment, piping, fixtures, and fittings. When required, plumbing sheets shall also include Plumbing Equipment schedule.

6. _____ Include a standard Mechanical Details Sheet.

ELECTRICAL SHEETS (If Applicable)

Depending on the nature of the project, it may be possible to combine some of these sheets.

1. _____ Include a sheet(s) for General Electrical Notes.

2. _____ Include a Legends & Abbreviations sheet if required.

3. _____ Include an Electrical Site Plan as required.

4. _____ Include an Area Classification Plan.

5. _____ Include One Line drawings for the project.

6. _____ Include a Power and Instrumentation Plan.

7. _____ Include Riser Diagrams.

8. _____ Include Electrical Plan Sheets for each affected area.

9. _____ Include a Grounding Plan.

10. _____ Include Light Fixture Plan Sheets for each affected area.

11. _____ Include Electrical Plans for each affected area or process unit.

12. _____ Include Panelboard and Fixture Schedules if required.

13. _____ Include a separate sheet(s) for standard Electrical Details.

INSTRUMENTATION & CONTROL SHEETS (If Applicable)

Depending on the nature of the project, it may be possible to combine some of these sheets.

1. _____ Include a sheet(s) for General Instrumentation & Control Notes.

2. _____ Include a Legends & Abbreviations sheet if required.

3. _____ Include a Systems Architecture sheet(s) if required.

4. _____ Include a P&ID sheet(s) if required.

5. _____ Include a sheet(s) for Loop Diagrams if required.

6. _____ Include a sheet(s) for standard Instrumentation and Controls Details.

CROSS SECTIONS

1. _____ Drawn to a scale of 1"=10'H, 1"=1'V, or 1"=20'H, 1"=2'V

2. _____ Existing and proposed surfaces shown. (Including sidewalks)

3. _____ Cut and fill quantities are shown at each section.

4. _____ Station is shown at each section.

5. _____ Typical roadway or ditch sections are shown.

6. _____ Drainage and utilities are shown on the sections.

7. _____ Right of way limits are shown on the sections.

STANDARD AND SPECIAL DETAILS

1. _____ Appropriate City of Shreveport Standard Details included.

2. _____ Special Details showing dimensions, material requirements, and other information necessary for construction.

3. _____ Additional Standard Details by the Design Engineer to cover the scope and requirements of the project.

EROSION CONTROL/ STORMWATER POLLUTION PREVENTION PLAN LAYOUT SHEET

1. _____ North arrow and scale (scale shall be shown with a scale bar).

2. _____ Show the project limits.

3. _____ Show the project clearing limits and list the total disturbed acreage.

4. _____ Existing and proposed contours clearly shown/labeled.

5. _____ Existing and proposed drainage inlets/facilities shown.

6. _____ Stockpile areas are indicated on the plan.

7. _____ Construction entrances are indicated on the plan.

8. _____ Best Management Practices locations and details.

9. _____ Temporary erosion control measures are indicated on the plan.

10. _____ Sedimentation basin provided for disturbed areas 10 acres or greater.

11. ______ Areas to be sodded or seeded shown and specified.

12. ______ Areas of permanent erosion control (other than vegetation) are shown and specified.

COMMENTS AND NOTES

Drainage Design Report Checklist

DRAINAGE DESIGN REPORT CHECKLIST

PURPOSE:

The purpose of this checklist is to expedite plan review of storm drainage requiring approval by the City Engineer. This checklist is intended to be a guide and reference for the submittal and review of the draiange design report and preparation of a set of storm drainage plans. The items listed on the checklist are not to be intended as all-inclusive for every project. Depending on the scope of the project, additional items not listed in this checklist may be required.

INSTRUCTIONS:

1. The checklist is separated into the following sections.

    A. Overall Report Requirements

    B. Mapping

    C. Report

2. Fill in the Project Name, City of Shreveport Project Number (if known), and submittal date, on the first page of the checklist.

3. Complete each section of the checklist by checking each appropriate item as shown on the submitted plans.

4. Where items or sections do not apply, insert a "N/A" (non-applicable) in the allotted space provided.

5. Submit completed checklist with drainage design report submittal.

DRAINAGE DESIGN REPORT CHECKLIST

PROJECT NAME: ____________________

DATE: ____________________

PROJECT NUMBER: ____________________

DESIGNER: ____________________

OVERALL REPORT REQUIREMENTS

1. _____ Report shall be printed on 8 ½" X 11" paper and bound.

2. _____ Pages are to be numbered.

3. _____ All lettering shall be ≥0.125"

4. _____ The Project Name and City of Shreveport Project Number (if known),

5. _____ The design engineer information including name, address, and phone number.

6. _____ The final report shall be signed, dated and sealed by the responsible engineer(s). Responsible engineer shall be a registered Professional Engineer, licensed to practice in the State of Louisiana.

7. _____ The final report shall also be submitted electronically to the city in ‘pdf’ format.

MAPPING

The maps shall show the various drainage sheds, recorded plats, survey maps, or other plans which show the tributary area to be included in the design.

1. _____ North arrow and scale (scale shall be shown with a scale bar).

2. _____ Sheet Size shall be 22" x 34".

3. _____ Vicinity Map showing project location in relation to City of Shreveport map. The vicinity map shall have a north arrow and appropriate scale.

3. _____ Existing drainage map with contours clearly shown for tributary area to be included in the design, Include both onsite and offsite information if the project area is part of a larger tributary area.

4. _____ Design drainage map with contours clearly shown for tributary area to be included in the design, Include both onsite and offsite information if the project area is part of a larger tributary area.

5. _____ Show proposed lot drainage on plans if applicable.

6. _____ Drainage clarified by flow arrows, high points, sags, ridges, and valley gutters.

7. _____ Existing and proposed drainage structures shown and designated.

8. _____ The tributary area and sub areas to each culvert and storm sewer inlet shall be delineated and labeled.

9. _____ Provide drainage area, runoff coefficient, time of concentration, intensity, and discharge for each culvert or inlet structure.

10. _____ Show peak runoff rates for drainage areas (Q = CIA) as per drainage requirements section.

11. _____ Existing and proposed storm lines and open channels shown and designated.

12. _____ Summary of drainage calculations for each storm line or ditch section (flow, size, slope, velocity, and capacity).

13. _____ Cross-sections and flow data for all swales and open channels provided.

14. _____ Positive overflow provided at all low points, servitudes provided as needed.

15. _____ Drainage servitudes delineated and labeled.

16. _____ Delineate any and all Special Flood Hazard Areas (SFHA). (State effect development will have on these areas)

REPORT

Refer to Section 1.4.2 Hydraulics Report for specifics.

1. _____ Design classification

2. _____ Project description and site conditions commentary.

3. _____ Design assumptions.

4. _____ Design calculations.

4. _____ Street flow computation table showing depth and spread.

4. _____ Culvert or inlet summary report.

4. _____ Storm sewer summary report.

4. _____ Storm sewer profile with hydraulic grade line shown.

4. _____ Ditch design summary.

5. _____ Photographs as needed.

COMMENTS AND NOTES

Table of Contents

Section 2

HYDROLOGY

2.1 General

This chapter contains the procedures, accepted methodologies, and pertinent information such as rainfall charts, maps, and tables that are needed for hydraulic analysis of development areas. For this manual, hydrology will consist of estimating stormwater runoff discharge rates and/or runoff volume from precipitation for the design of drainage systems. This manual is not intended to be an all-inclusive instructional. The designer should be familiar with applicable methods or reference other technical resources as required to complete the analysis with appropriate computations. These criteria are intended to serve as a guide for the development of the design of all inlets, catch basins, drainage appurtenances, open channels and bayous, culverts or other hydraulic and erosion control appurtenances. The criteria shall not be limited to design of new facilities but shall also apply to the upgrading of existing City facilities where necessitated by inadequate capacity. All state and federal stormwater requirements (i.e. SWPPP, USACE Permit, etc.) must be met in addition to any requirements set forth in this document. In the case of any conflict, the more stringent standard shall govern.

2.2 Documentation Procedures

It is the designer's responsibility to document the hydrologic analyses performed for the development of the drainage design. Where state roadways are affected refer to the LADOTD Hydraulics Manual and conform to roadway drainage design requirements and best practices.

The documentation should contain drainage area maps, hand calculations, computer model input, and output (as appropriate). The designer should provide adequate information on all hand calculation sheets to accurately identify the project design. This information should, at a minimum, include project description, location, calculation methods, list of assumptions made for analysis, name of responsible party performing the calculations, and date the calculations are developed.

2.3 Design Criteria

Storm drainage structures should be designed based on the design frequencies in Table 2-1 such that there is no significant increase to the flood hazard of adjacent property or existing waterways. Design frequencies shall be consistent with good engineering practices while the requirements in this document shall be considered minimum. When a storm frequency is selected for a specific location, the designer is implying that the estimated effect of a larger storm on property, traffic, and the environment does not justify constructing a larger structure at the time. Also, it should be noted that designing for small, frequent storms can result in traffic interruptions and potential damage to property. Designer shall provide justification for storm frequency selection.

Table 2-1 Design Storm Frequency

Drainage Classification	Frequency
Roadway Grade, Bridges, Cross Drains, Side Drains under arterial and collector roads	25-yr
Main Drainage Channels	25-yr
Storm Sewers and Inlets, Cross drains, Side drains	10-yr
Detention or Retention Features	25yr

Use a 100-year frequency storm to determine the hydraulic gradient in special flood hazard areas. Arterial street underpasses and other critical areas shall be designed to remain passable by emergency equipment for a 100-year frequency storm.

2.4 Runoff Determination and Peak Discharge

The quantity of surface runoff reaching a development drainage feature or outlet is determined by hydrologic analysis of the appropriate regional rainfall events and characteristics of the watershed. Generally, only peak runoff rate is used as a design parameter in design of development drainage features and outlet structures. There are circumstances where runoff hydrograph(s) may be required for the design, such as when considering upstream storage volume in the design of culverts and reservoir routing.

Peak design rates of runoff are to be based on the watershed conditions expected to exist 20 years in the future. The development of peak discharge rates shall allow the design to minimize the damage and hazard of flooding to the extent practicable.

Accepted methods of runoff determination are:

1. Rational Method
2. Natural Resources Conservation Service Method (formerly Soil Conservation Service)
3. Gauged Station Data
4. United States Geological Survey Method

The Rational Method shall be used as the primary method of runoff determination for watershed areas of 200 acres or less. The NRCS Method is to be used for drainage areas of 200 to 2,000 acres. When available, gauged station data can be used. It should be noted, however, this data can be fairly limited since it only represents larger stream flows that are being monitored. The USGS method may also be used for very large development areas, those in excess of 2,000 acres.

Table 2-2 Drainage Area Sizing Table Per Method

Drainage Area	Method and Source
200 Acres or less	Rational Method
200 - 2,000 Acres	Natural Resources Conservation Service (NRCS)
2,000 Acres and above	United States Geological Survey (USGS)

2.4.1 Rational Method

The rational method is recommended for sites 200 acres or less. The rational method was developed to predict peak flow rates for small, urban watersheds. This method neglects flow variations with time and watershed flow routing. More detailed information on the use of this method is available online and from the following resources:

- ASCE Manual of Engineering Practices No. 37, Chapter IV, Design and Construction of Sanitary and Storm Sewers, 1993.
- Highway Hydrology, Hydraulic Design Series No. 2, FHWA, Washington, D.C. 2nd Edition, October 2002.

The Rational method equation is:

$$Q = CiA \qquad \text{Eq. 2-1}$$

Where: Q = Peak runoff rate (ft^3/s)
C = Runoff coefficient (Table 2-3)
i = Average rainfall intensity for a duration equal to the time of concentration (in/hr) (See Fig. 2-1)
A = Drainage area contributing to point under design (acres)

1. Runoff Coefficient, C

   The runoff coefficient, C, represents the ratio of rate of runoff to the rate of rainfall at an average intensity (i) when the entire drainage area is contributing. The runoff coefficient is a function of land use conditions as well as slope, rainfall intensity, infiltration, and other abstractions. The runoff coefficient can be calculated with two common methods. The first is to utilize known soil properties, infiltration rates, and slopes which come from field surveys and Natural Resource Conservation Service (NRCS) and other agencies for soil conditions. The second method of calculating the runoff coefficient is to utilize tables developed for various types of surface conditions and land use. The following Table 2-3 provides general guidelines for the selection of runoff coefficients. See Figure 2A-1 in the Appendix for additional runoff coefficients.

Table 2-3 Runoff Coefficients

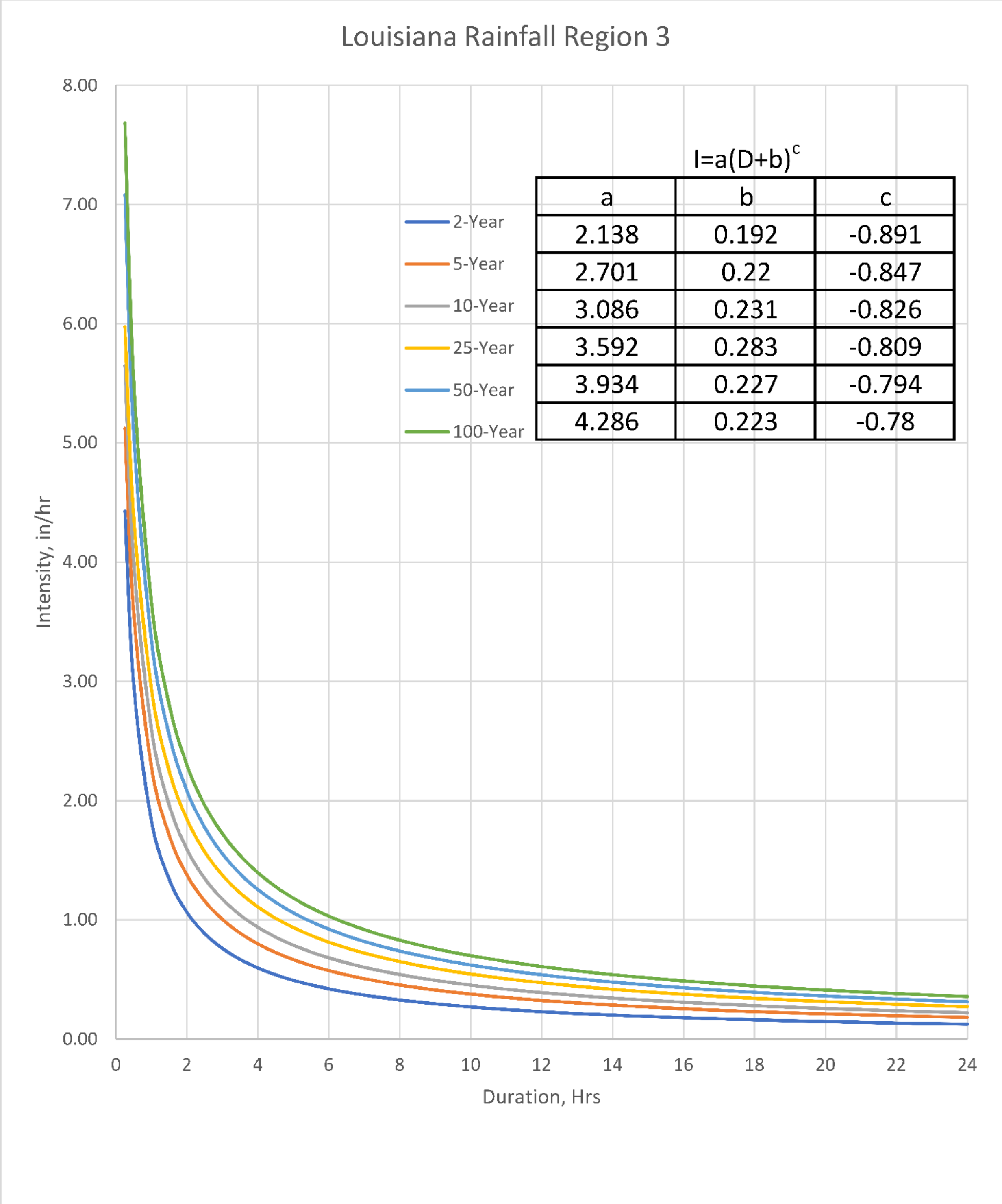
Surface Type and Condition	Runoff Coefficients
Rural	
Concrete or asphalt pavement	0.8-0.9
Gravel roadways and shoulders	0.4-0.6
Bare earth	0.2-0.9
Steep grassed areas (2H:1V)	0.5-0.7
Turf Meadows	0.1-0.4
Forested areas	0.1-0.3
Cultivated fields	0.2-0.4
Urban	
Residential, about 30% impervious area	0.25-0.4
Residential, about 60% impervious area	0.3-0.6
Commercial/industrial, about 60% impervious area	0.5-0.8
Commercial/industrial, about 90% impervious area	0.6-0.9
Parks, cemeteries	0.1-0.25
Playgrounds	0.2-0.35
Railroad yard	0.2-0.4
Unimproved areas	0.1-0.3

2. Time of Concentration

The time of concentration, t_c, for the rational method represents the time at which all areas of the watershed that will contribute runoff are just contributing to the outlet. Time of concentration (TC) is defined as the flow time from the most remote point in the drainage area to the point under consideration. Usually it is considered to be composed of time of concentration for drainage inlets plus time of flow in pipes. This time is used to select the rainfall intensity for the Rational method. The storm length is considered to be equal to t_c in order to estimate the peak discharge. Depending on the watershed specifics, the t_c can be calculated empirically with equations Eq. 2-2, 2-3, 2-4, or 2-5 listed in the NRCS method described next in this chapter or through methods that the designer determines appropriate (documentation of any method used should be included). The t_c should not be less than 5 minutes for smaller watersheds and 10 minutes for larger watersheds. Intensity (i) becomes unacceptably large for t_c less than 5-10 minutes.

3. Intensity

Louisiana Region 3 rainfall intensity curve based on time of concentration Figure 2-1 is shown below. NOAA Atlas 14 can be used to obtain precipitation intensity estimates for specific sites. The website is https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html, if this source is used, include the data in the project record.



$I=a(D+b)^c$

a	b	c
2.138	0.192	-0.891
2.701	0.22	-0.847
3.086	0.231	-0.826
3.592	0.283	-0.809
3.934	0.227	-0.794
4.286	0.223	-0.78

Figure 2-1 Region 3 Rational Method Rainfall Intensity Curve

4. Procedures

The following steps are applicable to the Rational Method once the designer has selected this method for determining design discharge:

1. Determine drainage area.
2. Calculate runoff coefficient.
3. Determine time of concentration.
4. Determine rainfall intensity.
5. Calculate design discharge (stormwater runoff).
6. Verify that any sub-area does not provide higher runoff.

2.4.2 NRCS Method

The NRCS method is used to estimate peak runoff rates of ungauged watersheds of 200 to 2,000 acres. This method can be used in rural and urban watersheds. This method employs empirical relationships between rainfall and runoff that allows estimation of design discharges on ungauged watersheds by development of parameters describing the watershed. Runoff rates and volume are influenced by rainfall depth, rainfall distribution, rainfall duration, and rainfall events. The equations for this method include factors for watershed size, shape, slope, soil type, and land use which affect the peak runoff rate.

1. Time of Concentration

Time of Concentration (T_c) is defined as the total time for water from the hydraulically most distant point in a watershed to travel to the watershed design outlet or a specific design point. The factors that affect (T_c) include the length of flow, the slope of the flow path, and the roughness of the flow path. T_c can consist of overland flow (sheet flow & shallow concentrated flow), pipe flow, channelized flow or combinations of these per applicable watershed conditions. When combining times for flow types, the time for each portion is calculated as an individual travel time (t_t). The individual travel times for each flow type are summed to determine T_c.

$$Tc = t_{t1} + t_{t2} + \cdots + t_{tn} \qquad \text{Eq. 2-2}$$

There are multiple accepted methods that have been established to calculate travel time for overland flow, pipe flow, channel flow, gutter flow, etc. The designer shall be responsible for documenting the selected methodology and the reasons for selection. Generally speaking, the NRCS TR-55 methodology, Manning's equation (Manning's n values are readily available and should be documented by the designer), etc. are acceptable. It is important to note, there may be multiple shallow concentrated and channel segments depending on the nature of the flow path. More detailed information on the use of this method is available online and from the following resource:

- Urban Hydrology For Small Watersheds, Technical Release No. 55, USDA Natural Resources Conservation Service, January 2009.

Table 2-4 Manning's "n" for overland flow

Manning's "n" [1]	Surface Description
0.015	Concrete (rough or smoothed finish)
0.016	Asphalt
0.05	Fallow (no residue)
	Cultivated Soils:
0.06	Residue Cover ≤ 20%
0.17	Residue cover > 20%
	Grass:
0.15	Short-grass prairie
0.24	Dense grasses [2]
0.13	Range (natural)
	Woods: [3]
0.40	Light underbrush
0.80	Dense underbrush
1 The Manning's n values are a composite of information compiled by Engman (1986).	
2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.	
3 When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.	

A. Sheet flow is shallow flow over land surfaces, which usually occurs in the headwaters of streams. Sheet flow will occur for only very short distances. Sheet flow for both natural (undeveloped) and developed conditions should be limited to no more than 100 feet. Sheet flow for developed conditions should be based on the actual pavement or grass conditions for areas that are already developed and should be representative of the anticipated land use within the headwater area in the case of currently undeveloped areas. In a typical residential subdivision, sheet flow may be the distance from one end of the lot to the other or from residence to the edge of the lot. In some heavily urbanized drainage areas, sheet flow may not exist in the headwater area. The NRCS method employs the following equation, 2-3, which is a modified form kinematic wave equation, for the calculation of the sheet flow travel time.

$$T_t = 0.42(nL)^{0.8} / ((P_2)^{0.5} s^{0.4}) \qquad \text{Eq. 2-3}$$

Where,

T_t = Sheet flow travel time in minutes
L = Length of the reach in ft.
n = Manning's n (see Table 2-4)
P_2 = 2-year, 24-hour rainfall in inches (see Table 2-8)
s = Slope of the ground in ft/ft

B. After a maximum of approximately 100 feet, sheet flow normally becomes shallow concentrated flow collecting in swales, small rills, and gullies. Shallow concentrated flow is assumed to not have a well-defined channel and has flow depths of 0.1 to 0.5 feet. The travel time for shallow concentrated flows can be computed by equations 2-4 and 2-5. These two equations are based on the solution of Manning's equation with different assumptions for n (Manning's roughness coefficient) and r (hydraulic radius, ft). For unpaved areas, n is 0.05 and r is 0.4; for paved areas, n is 0.025 and r is 0.2.

Unpaved - $T_t = L/(60(16.1345)(s)^{0.5})$ Eq. 2-4

Paved - $T_t = L/(60(20.3282)(s)^{0.5})$ Eq. 2-5

Where,

T_t = Travel time for shallow concentrated flows in minutes
L = Length of the reach in ft.
s = Slope of the ground in ft/ft

C. The velocity in an open channel or a storm drain at less than full flow can be determined by using Manning's Equation. Channel velocities may also be determined by using backwater profiles. For open channel flow, average flow velocity is normally determined by assuming a bank-full condition. Note that the channel flow component of the time of concentration may need to be divided into multiple segments in order to represent significant changes in channel characteristics.

For storm drain flow under pressure conditions (hydraulic grade line is higher than the lowest crown of a storm drain) the following equation should be applied:

$V = Q/A$ Eq. 2-6

Where:

V = Average velocity, ft/s
Q = Design discharge, cfs
A = Cross-sectional area, ft2

Flow travel time through a channel can be calculated by the following equation:

$T_t = \Sigma(L_i/60V_i)$ Eq. 2-7

Where:

L_i = The i-th channel segment length, ft
V_i = The average flow velocity within the ith channel segment, ft/s
T_t = Total Flow travel time through the channel, min

2. Drainage Area

Drainage area can be determined from field surveys, topographic maps; or USGS 7.5 minute quadrangle (quad) maps. USGS quad maps are useful to the designer when delineating drainage areas, elevations, channels, etc.

3. Hydrologic Soil Groups

Runoff generation is influenced by soil properties and are considered in the runoff estimation. Available soil survey maps should be used to determine soil types for the watershed. Soil survey maps are available online through the web soil survey at https://www.nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId=LA.

The soils have been classified into 4 Groups shown in Table 2-5 below. This information is also available in the LADOTD Hydraulics Manual.

Table 2-5 Hydrologic Soil Group Descriptions

Soil Group	Description
A	Low runoff potential with high infiltration rates even when thoroughly wetted. Water readily passes through, typically well to excessively drained gravels and sands (>0.30 in/hr)
B	Moderate infiltration rates when thoroughly wetted. Moderately well to well drained soils with moderately fine to moderately coarse textures (0.15 to 0.30 in/hr)
C	Low infiltration rates when thoroughly wetted. Soils with a layer that impedes infiltration or soil with moderately fine to fine texture (0.05 to 0.15 in/hr)
D	High runoff potential with low infiltration rates when thoroughly wetted. Clay soils with high swelling potential, soils with permanent high water table, soils with clay pan or layer at/near the surface, or shallow soil over impervious material (0 to 0.05 in/hr)

Table 2-6 Hydrologic Classification of Soils in Louisiana for MLRA 131 and 133B per Bulletin Number 889 of the LSU AgCenter

Series Name	Hydrologic Group*	Series Name	Hydrologic Group*	Series Name	Hydrologic Group*	Series Name	Hydrologic Group*
Acadia	D	Eastwood	C	Lotus	A	Rigolette	D
Alaga	A	Elysian	B	Lucy	B	Rilla	B
Allemands	D	Flo	A	Mahan	B	Robinsonville	B
Anacoco	D	Foley	D	Malbis	C	Roxana	B
Angie	C	Forestdale	D	Mantachie	C	Ruple	B
Armistead	C	Fountain	D	Maurepas	D	Ruston	B
Ashford	D	Frizzell	C	Mayhew	D	Sacul	C
Attoyac	D	Frost	D	Mckamie	D	Sailes	B
Bayoudan	C	Gallion	B	McLaurin	B	Sardis	C
Bearhead	B	Galvez	C	Mer rouge	C	Saucier	C
Bellwood	D	Glenmora	C	Merryville	D	Savannah	C
Bernaldo	B	Glenwild	C	Metcalf	D	Sawyer	C
Besner	B	Goldman	C	Meth	C	Schriever	D
Betis	A	Gore	D	Mhoon	D	Severn	B
Bibb	B/D	Gramercy	D	Mollicy	D	Sharkey	D
Bienville	A	Groom	D	Moreland	D	Shatta	C
Bistineau	B	Gurdon	D	Morse	D	Smithdale	B
Blevins	B	Guyton	D	Muskogee	C	Smithton	D
Bodcau	D	Haggerty	C	Myatt	B/D	Soiler	D
Bonn	D	Harahan	D	Nacogdoches	B	Sonnier	D
Bossier	D	Harleston	B	Natchitoches	D	Sostien	D
Boswell	D	Hebert	D	Newellton	D	Sterlington	B
Bowie	B	Herty	D	Niwana	B	Stough	C
Boykin	B	Hornbeck	C	Norwood	B	Sugartown	C
Briley	B	Iberia	D	Nugent	A	Tensas	D
Buxin	D	Iuka	C	Ochlockonee	B	Tippah	C
Caddo	D	Jena	B	Oktibbeha	D	Trep	C
Cahaba	B	Keiffer	B	Oliver	C	Una	D
Caplis	B	Keithville	C	Olla	B	Urbo	D
Caspiana	B	Kirvin	B	Ora	C	Vacherie	C
Corrigan	D	Kisatchie	C	Osier	B/D	Vick	D
Coushatta	B	Kolin	C	Ouachita	B	Waller	B/D
Cypress	D	Larue	B	Oula	D	Warnock	B
Darbonne	C	Latanier	D	Perry	D	Watsonia	C
Darley	C	Latonia	B	Pheba	C	Wolfpen	B
Doucette	B	Leaf	D	Pinetucky	C	Woodtell	C
Dowling	D	Lebeau	D	Portland	D	Wrightsville	D
Dubach	B	Letney	B	Prentiss	C	Yorktown	D
Dundee	D	Libuse	C	Providence	C	Zenoria	D
Dupuy	D	Loreauville	D	Rayburn	D		

* Dual hydrologic soil groups are provided for certain wet soils that can be adequately drained. The first letter applies to the drained condition, the second to the undrained surface condition.

4. Curve Number

Hydrologic soil group and land use of the watershed are used to determine the runoff curve number for the watershed. Table 2-7 includes runoff curve number (CN) values for various hydrologic classifications of soil and land use. The runoff CN selected should represent watershed conditions expected 20 years in the future. Weighted runoff CN should be used when mixed watershed soil classes are present.

Table 2-7 Runoff Curve Number (CN) for Land Uses

Land Use		Hydrologic Soil Group			
		A	B	C	D
Woods / Forest Land		37	61	74	80
Pasture / Range Land		52	70	80	85
Cultivated Land		67	76	83	86
Commercial land Business Area (85% impervious)		89	92	94	95
Industrial Districts (72% impervious)		81	88	91	93
Paved Parking lots, roofs, driveways, etc.		98	98	98	98
Open Spaces (lawn, parks, golf courses, cemeteries, etc.[1]					
Good Condition: 75% or more of area is grass cover		39	61	74	80
Fair Condition: 50 to 75% of area is grass cover		49	69	79	84
Poor Condition: <50% of area is grass cover		68	79	86	89
Residential					
Avg. Lot Size	Avg. % Impervious[2]				
1/8 acre or less	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acre	12	46	65	77	82
Paved Streets & Roads					
Streets with curbs & storm drains		98	98	98	98
Roads with open ditches		83	89	92	93
Gravel		76	85	89	91
Dirt		72	82	87	89

Notes: Above values based on Antecedent Moisture Condition II (ACM-II). For CN estimations of other ACM limits refer to the NRCS website.
Average runoff condition and Ia=0.2S.
1-CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open spaces.
2-Average impervious area was used to develop the composite CNs (imp. area CN=98, perv. area CN equal open space in good condition).

5. Design Input

The topography is assumed to be such that you have relatively uniform surface flow into channels, drains, and streams. The peak runoff rates are approximately the same as rates determined by preparing flood hydrographs and valley flood routing to the design outlet point.

The drainage basin should be used to determine:

- Drainage area (A) in acres.
- Hydraulic length of the watershed in feet.
- Average watershed land slope in percent.
- Soil type(s) and hydrologic soil groups in the drainage area Louisiana Rainfall Region III.

Determine the runoff curve number (CN) or weighted runoff curve number (CN) to be assigned to each drainage area. Caddo Parish and the remainder of the Northwest corner of Louisiana is in Region III of the Louisiana Rainfall Regions developed by the Louisiana Transportation Research Center (LTRC). The 24-hour rainfall duration for Region III from Table 2-8 below should be used to determine the rainfall amount in inches for the design frequency storm.

Table 2-8 Louisiana Rainfall Depth (inches)

Return Period (Years)	Duration (Hours)	Region III Depth (inches)
2	6	2.8
	12	3.2
	24	3.6
5	6	3.7
	12	4.3
	24	4.9
10	6	4.4
	12	5.1
	24	5.8
25	6	5.3
	12	6.2
	24	7.0
50	6	6.0
	12	7.0
	24	8.0
100	6	6.8
	12	7.9
	24	9.0

Rainfall data is also available on NOAA Precipitation Frequency Data Server (https://hdsc.nws.noaa.gov/hdsc/pfds/) for a wider range of return periods and durations. Specific latitude and longitude can be used to obtain site specific data.

2.4.3 Gauged Stations

The United States Geological Survey (USGS) is responsible for a continuous program of stream gauging to gather data on stream discharge, flow, high water stages, etc. This data can be used in calculations when available and applicable. Due to the nature of the stream gauging, it may not be available or applicable for smaller development areas and areas away from larger stream/river systems. The USGS publishes the gauge data collected on a yearly basis. The U.S. Army Corps of Engineers (USACE) also gauges sites around the state which may be used in calculations. For more information concerning gauges contact the USGS or New Orleans or Vicksburg office of the USACE. The USGS website may be used to locate specific gauged stations: https://waterdata.usgs.gov/nwis/rt. The USACE website may be used to locate specific gauged stations in the Red River Basin: https://rivergages.mvr.usace.army.mil/WaterControl/new/layout.cfm

The Federal Highway Administration maintains a publication for methods used in determining the peak discharge from gauge data. This publication is the HDS-2 – Highway Hydrology. This publication is available on the FHWA website. The most updated version of this publication should be used for reference.

2.4.4 USGS Regression Method

The USGS method uses an isohyetal line map representing annual rainfall data. Figure 2-2 should be used to determine annual rainfall for the USGS Method. Additional information on the USGS Procedure can be found from the following sources:

- The National Flood-Frequency Program – Methods for Estimating Flood Magnitude and Frequency in Rural Areas in Louisiana, USGS Fact Sheet 099-01 2001.
- Floods in Louisiana, Magnitude and Frequency – 5th Edition Technical Report No. 60, United States Department of the Interior, Geological Survey, Baton Rouge, LA, 5th Edition, 1998.
- Highway Hydrology, Hydraulic Design Series No. 2, FHWA, Washington, D.C., 2nd Edition, Oct. 2002.
- Flood Characteristics of Urban Watersheds in the United States, USGS Water-Supply Paper 2207, United States Department of the Interior, Geological Survey, 1984.

Gauge station locations and specific site data can be found at the USGS website and from Floods in Louisiana, Magnitude and Frequency. When gauge data is unavailable or insufficient for design of ungauged locations, the National Streamflow Statistics (NSS) Program can be utilized. The NSS Program replaces the NFF program and contains all the functionality and equations previously used in the NFF program. The NSS program modifies the 1998 USGS computer modeling program Region-of-Influence Regression Model (RIRM). This method develops a new set of equations each time the program is run. Based on user inputs (drainage area, main channel slope and mean annual precipitation) for the ungauged site the program selects similar basin and climatic characteristics and uses this data in the regression analysis. The USGS program is based on annual maximum discharge data for natural, unaltered streams. The North-Western corner of Louisiana is classified as Pine Hills physiographic division. The following regression equations are for the Pine Hills rural regions of Louisiana:

$$Q_2 = 5.8DA^{0.744}SLP^{0.374}(AP - 35)^{0.796} \quad \text{Eq. 2-8}$$
$$Q_5 = 13.3DA^{0.760}SLP^{0.385}(AP - 35)^{0.694} \quad \text{Eq. 2-9}$$
$$Q_{10} = 19.5DA^{0.768}SLP^{0.392}(AP - 35)^{0.658} \quad \text{Eq. 2-10}$$
$$Q_{25} = 28.0DA^{0.778}SLP^{0.401}(AP - 35)^{0.629} \quad \text{Eq. 2-11}$$
$$Q_{50} = 34.6DA^{0.785}SLP^{0.407}(AP - 35)^{0.616} \quad \text{Eq. 2-12}$$
$$Q_{100} = 41.2DA^{0.791}SLP^{0.412}(AP - 35)^{0.610} \quad \text{Eq. 2-13}$$
$$Q_{500} = 56.0DA^{0.803}SLP^{0.425}(AP - 35)^{0.608} \quad \text{Eq. 2-14}$$

Where:
Q_x = Peak discharge for X recurrence intervals (ft^3/s)
DA = Contributing drainage area (mi^2)
SLP = Channel slope (ft/mi) measured between two points, one at 10% of channel length the other at 85% of the channel length
AP = Mean annual precipitation (in), see Figure 2-2

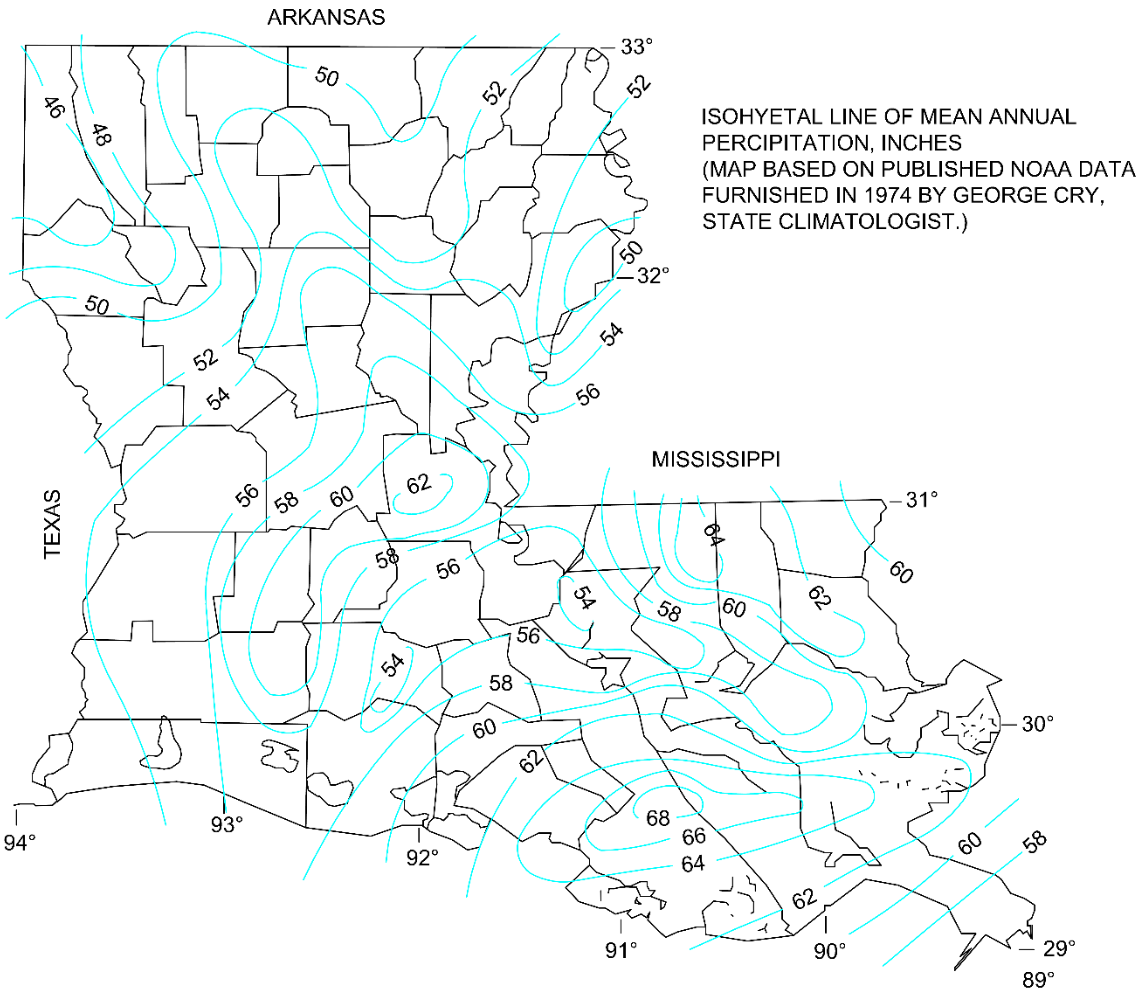


Figure 2-2

Additional information can be used to improve the runoff estimates. See the USGS Fact Sheet 099-01 for further information.

The NSS program is for use in rural areas of Louisiana but not urban areas. Peak discharge in urban areas can be calculated following procedures outlined below. USGS or RIRM should not be used where dams, detention structures, or other man-made works will have a substantial effect on annual maximum discharge. USGS NSS or RIRM should not be utilized for channels that have been dredged or are affected by backwater. When using programs designed for rural areas, the engineer should remain conservative with calculations modifying for urbanization. All assumptions should be thoroughly documented.

1. Basin and Climatic Characteristics

The following Table 2-9 provides allowable ranges of the different basin and climatic characteristics for use with the regional regression equations in the Pine Hills region. Basin and climatic characteristics for ungauged sites that do not fall within the ranges will result in a warning or error.

Table 2-9 Regional Regression Equations Variables Ranges

Basin and Climatic Characteristics	Allowable Ranges
Drainage Area	0.009 to 2,947 mi^2
Main Channel Slope	0.85 to 247 ft/mi
Mean Annual Precipitation	47 to 65 in

2. Urbanization Modification

The USGS method basic regression equations estimate the peak discharge for ungauged rural sites. Urbanization typically increases the peak discharge. The following equations adjust the peak discharges obtained from the RIRM regression equations:

$$UQ_2 = 13.2A^{0.21}(13 - BDF)^{-0.43}RQ_2^{0.73} \quad \text{Eq. 2-15}$$
$$UQ_5 = 10.6A^{0.17}(13 - BDF)^{-0.39}RQ_5^{0.78} \quad \text{Eq. 2-16}$$
$$UQ_{10} = 9.51A^{0.16}(13 - BDF)^{-0.36}RQ_{10}^{0.79} \quad \text{Eq. 2-17}$$
$$UQ_{25} = 8.68A^{0.15}(13 - BDF)^{-0.34}RQ_{25}^{0.80} \quad \text{Eq. 2-18}$$
$$UQ_{50} = 8.04A^{0.15}(13 - BDF)^{-0.32}RQ_{50}^{0.81} \quad \text{Eq. 2-19}$$
$$UQ_{100} = 7.70A^{0.15}(13 - BDF)^{-0.32}RQ_{100}^{0.82} \quad \text{Eq. 2-20}$$
$$UQ_{500} = 7.47A^{0.16}(13 - BDF)^{-0.30}RQ_{500}^{0.82} \quad \text{Eq. 2-21}$$

Where:
- UQ_X = Urban peak discharge for X recurrence intervals (ft^3/s)
- A = Contributing drainage area. In urban areas drainage systems sometimes cross topographic divides. Such drainage changes should be accounted for when computing A (mi^2)
- RQ_x = Peak discharge for an equivalent rural drainage basin the same hydrologic area as the urban basin, for recurrence interval of X years. Equivalent rural peak discharges are computed from the rural equations (ft^3/s)
- BDF = Basin development factor, an index of the prevalence of the urban drainage improvements, see Figure 2-3

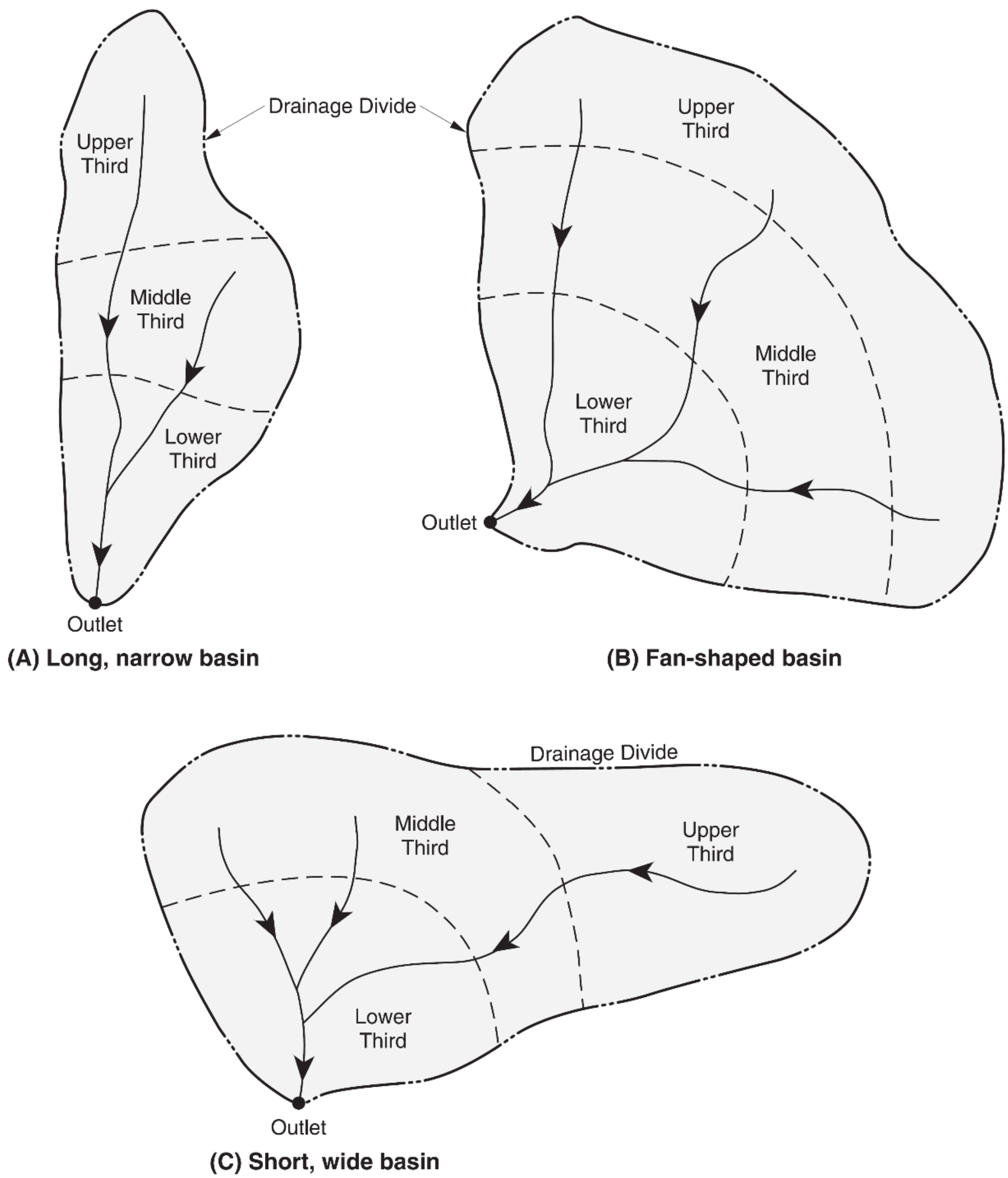


Figure 2-3 Typical Drainage Basin Shapes and Subdivision into Basin Thirds

2-A Basin Development Factor (BDF)

The BDF accounts for drainage development and runoff response in urban areas. It is typically relatively simple to determine from drainage maps and field inspection of the drainage basin.

First the drainage area basin is divided into upper, middle, and lower thirds on the drainage map. Each third should account for approximately 1/3 of the contributing drainage. If multiple streams are present within a section, then the travel distance of the streams within that section should be equal. The travel distance between the areas does not need to be equal, only within the 3 sub-areas. Engineering judgment can be used to subdivide more complex basins than those shown in Fig. 2-3. Precise measurements are not required.

There are four drainage-system codes used to develop the BDF. They are as follows:

- Channel Modifications; (i.e. straightening, enlarging, deepening, etc.) for main drainage channels and principle tributaries. Referenced modifications are assigned a code of one. Fifty (50%) percent of the main drainage channels and principle tributaries must be improved for this to be prevalent. If less than 50% a code of zero should be assigned.
- Channel Linings; if more than 50% of main drainage channel(s) length has been lined with impervious materials, a code of one should be assigned. If less than 50% then a code of zero should be assigned.
- Storm Drains; (enclosed drainage structures) if more than 50% of the main drainage channels or secondary tributaries within a sub-area are storm drains then a code of one should be assigned. If less than 50% then a code of zero should be assigned.
- Curb and Gutter Streets; if more than 50% of a sub-area is urbanized or 50% of the streets and highways are curb and gutter construction then a code of one should be assigned. If less that 50% then a code of zero should be assigned.

The BDF is the sum of the assigned codes. With three subareas and four drainage aspects per subarea the maximum BDF value for a fully urbanized drainage basin can be 12. A basin may be partially urbanized and have a BDF of zero. BDF can be used when projecting future or intermediate development.

2.5 Acceptable Computer Programs

The following are additional computer programs that will be allowed for developing computer models for use in design. There are many other computer programs available that may be used to develop flood/runoff hydrographs and therefore this is not an extensive list. Use of other programs not listed herein must be prior approved by the City Engineer. The City of Shreveport does not specify a particular method be used but does require all results/output files be included with design submission. The following table identifies the ease of use for each system and whether the system is free or has an associated cost.

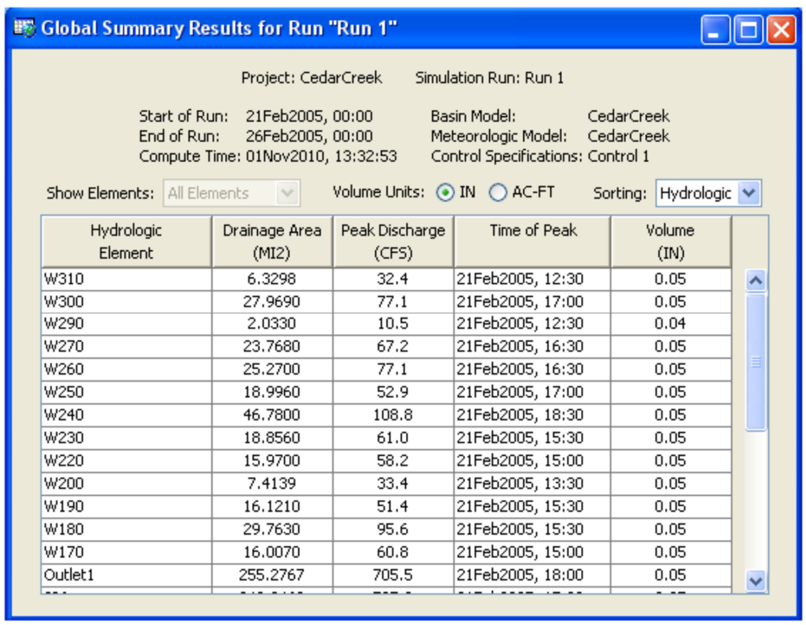
Table 2-10 Computer Programs and Accessibility

Computer Model	Input Difficulty	Cost
HEC – HMS	Medium	No
Win TR-55	Low	No
HydroCAD	Medium	Yes
HEC-RAS	Medium	No
SWMM	Medium/High	No
NSS (National Stream Flow Statistics)	Low	No
HYDRWIN (Louisiana State)	State Help Available	No
HydraFlow CAD	Medium	Yes

2.5.1 HEC-HMS

The Hydrologic Modeling System (HEC-HMS) is a hydrologic rainfall-runoff model developed by the U.S. Army Corps of Engineers that is based on the rainfall-runoff prediction originally developed and released as HEC-1. HEC-HMS is used to compute runoff hydrographs for a network of watersheds. The model evaluates infiltration losses, transforms precipitation into runoff hydrographs, and routes hydrographs through open channel routing. A variety of calculation methods can be selected including NRCS/SCS curve number or Green and Ampt infiltration; Clark, Snyder or NRCS/SCS unit hydrograph methods; and Muskingum, Puls, or lag routing methods. Precipitation inputs can be evaluated using a number of historical or synthetic methods and one evapotranspiration method. HEC-HMS is used in combination with HEC-RAS for calculation of both the hydrology and hydraulics of a stormwater system or network. Supplemental analysis tools are available for model optimization, forecasting streamflow, depth-area reduction, assessing model uncertainty, erosion and sediment transport, and water quality.

https://www.hec.usace.army.mil/software/hec-hms/


Global Summary Results for Run "Run 1"

Project: CedarCreek Simulation Run: Run 1

Start of Run: 21Feb2005, 00:00 Basin Model: CedarCreek
End of Run: 26Feb2005, 00:00 Meteorologic Model: CedarCreek
Compute Time: 01Nov2010, 13:32:53 Control Specifications: Control 1

Show Elements: All Elements Volume Units: IN AC-FT Sorting: Hydrologic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (IN)
W310	6.3298	32.4	21Feb2005, 12:30	0.05
W300	27.9690	77.1	21Feb2005, 17:00	0.05
W290	2.0330	10.5	21Feb2005, 12:30	0.04
W270	23.7680	67.2	21Feb2005, 16:30	0.05
W260	25.2700	77.1	21Feb2005, 16:30	0.05
W250	18.9960	52.9	21Feb2005, 17:00	0.05
W240	46.7800	108.8	21Feb2005, 18:30	0.05
W230	18.8560	61.0	21Feb2005, 15:30	0.05
W220	15.9700	58.2	21Feb2005, 15:00	0.05
W200	7.4139	33.4	21Feb2005, 13:30	0.05
W190	16.1210	51.4	21Feb2005, 15:30	0.05
W180	29.7630	95.6	21Feb2005, 15:30	0.05
W170	16.0070	60.8	21Feb2005, 15:00	0.05
Outlet1	255.2767	705.5	21Feb2005, 18:00	0.05

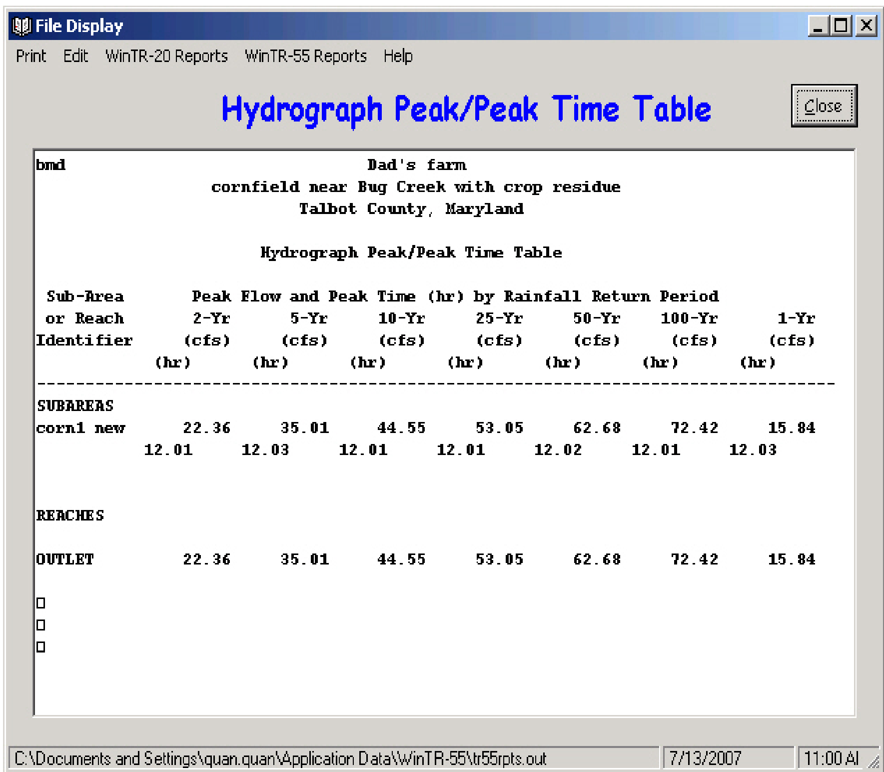
Figure 2-4 Example HEC-HMS summary table results (Hydrologic Modeling using Hec-HMS, Venkatesh Merwade, Purdue University, 2012)

There is an older version of HEC-HMS that runs with the Environmental Systems Research Institute's (ESRI) ArcHydro software which is HEC-GeoHMS. The combination of the two software will allow terrain processing, terrain morphology, watershed processing, attribute tools, and network tools. The two software will process LiDAR or digital elevation models with LAGAP data and LSU Atlas Soils Maps to delineate sub-basins, soil classification, and curve numbers. The most current version of HEC-HMS (version 4.8 April 2021) incorporates the GIS tools previously included in HEC-GeoHMS.
https://www.hec.usace.army.mil/software/hec-geohms/

2.5.2 WIN TR-55

Technical Release 55 (TR-55; Urban Hydrology for Small Watersheds) was developed as a simplified procedure to calculate storm runoff volume, peak rate of discharge, hydrographs and storage volumes in small urban watersheds. The latest version is a full windows based computer program. This is a single-event rainfall-runoff small watershed hydrologic model. The WinTR-55 generates hydrographs from both urban and agricultural areas at selected points along the stream system. Hydrographs are routed downstream through channels and/or reservoirs. Multiple sub-areas can be modeled within the watershed. A rainfall-runoff analysis can be performed on up to ten sub-areas and up to ten reaches. The total drainage area modeled cannot exceed 25 square miles.

https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1042901



bmd

Dad's farm
cornfield near Bug Creek with crop residue
Talbot County, Maryland

Hydrograph Peak/Peak Time Table

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period 2-Yr (cfs) (hr)	5-Yr (cfs) (hr)	10-Yr (cfs) (hr)	25-Yr (cfs) (hr)	50-Yr (cfs) (hr)	100-Yr (cfs) (hr)	1-Yr (cfs) (hr)
SUBAREAS							
corn1 new	22.36	35.01	44.55	53.05	62.68	72.42	15.84
	12.01	12.03	12.01	12.01	12.02	12.01	12.03
REACHES							
OUTLET	22.36	35.01	44.55	53.05	62.68	72.42	15.84

Figure 2-5 Example Win TR-55 summary table results (NRCS WinTR55 Tutorial)

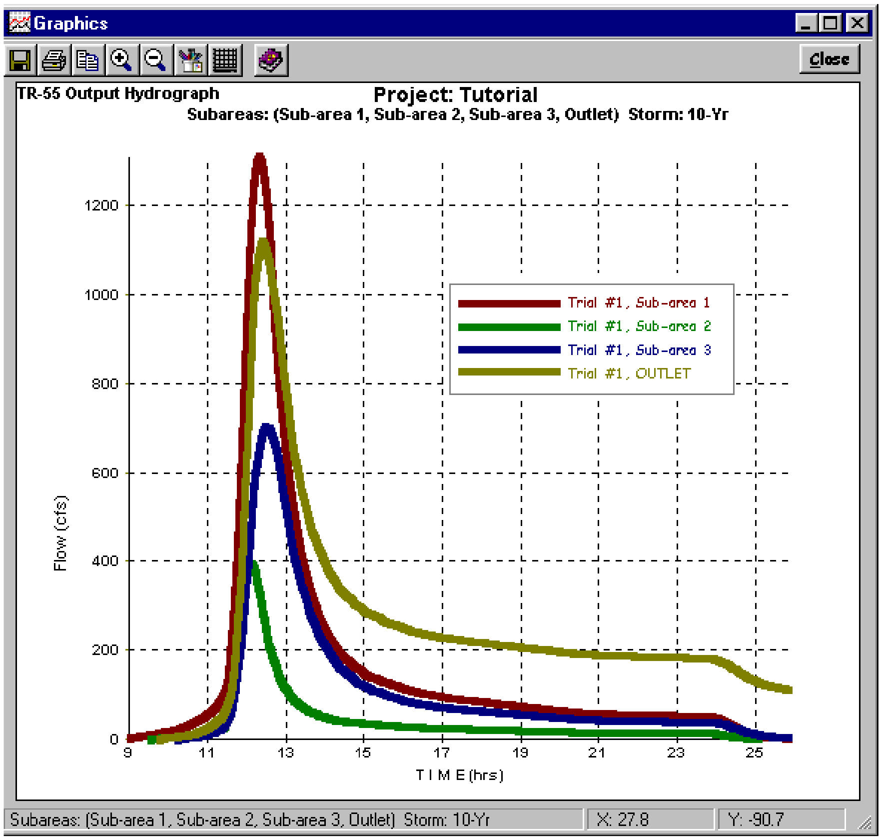


Figure 2-6 Example Win TR-55 Output Plot results (NRCS WinTR55 Tutorial)

2.5.3 HydroCAD

HydroCAD is a computer aided design program for modeling the hydrology and hydraulics of stormwater runoff. Runoff hydrographs are computed using the NRCS/SCS runoff equation and the NRCS/SCS dimensionless unit hydrograph. The program computes runoff hydrographs, routes flows through channel reaches and reservoirs, and combines hydrographs at confluences of the watershed stream system. HydroCAD has the ability to simulate backwater conditions by allowing the user to define the backwater elevation prior to simulating a rainfall event. This program is useful for any type and any size system.

https://hydrocad.net/info.htm

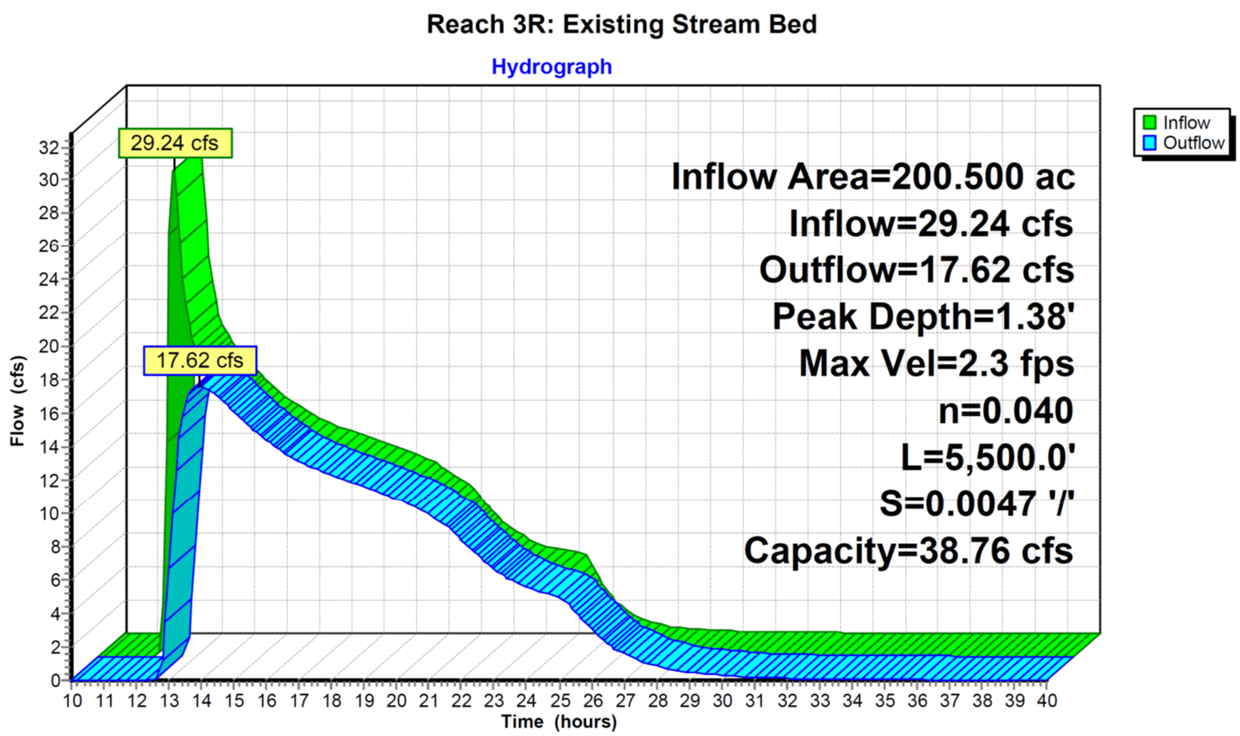
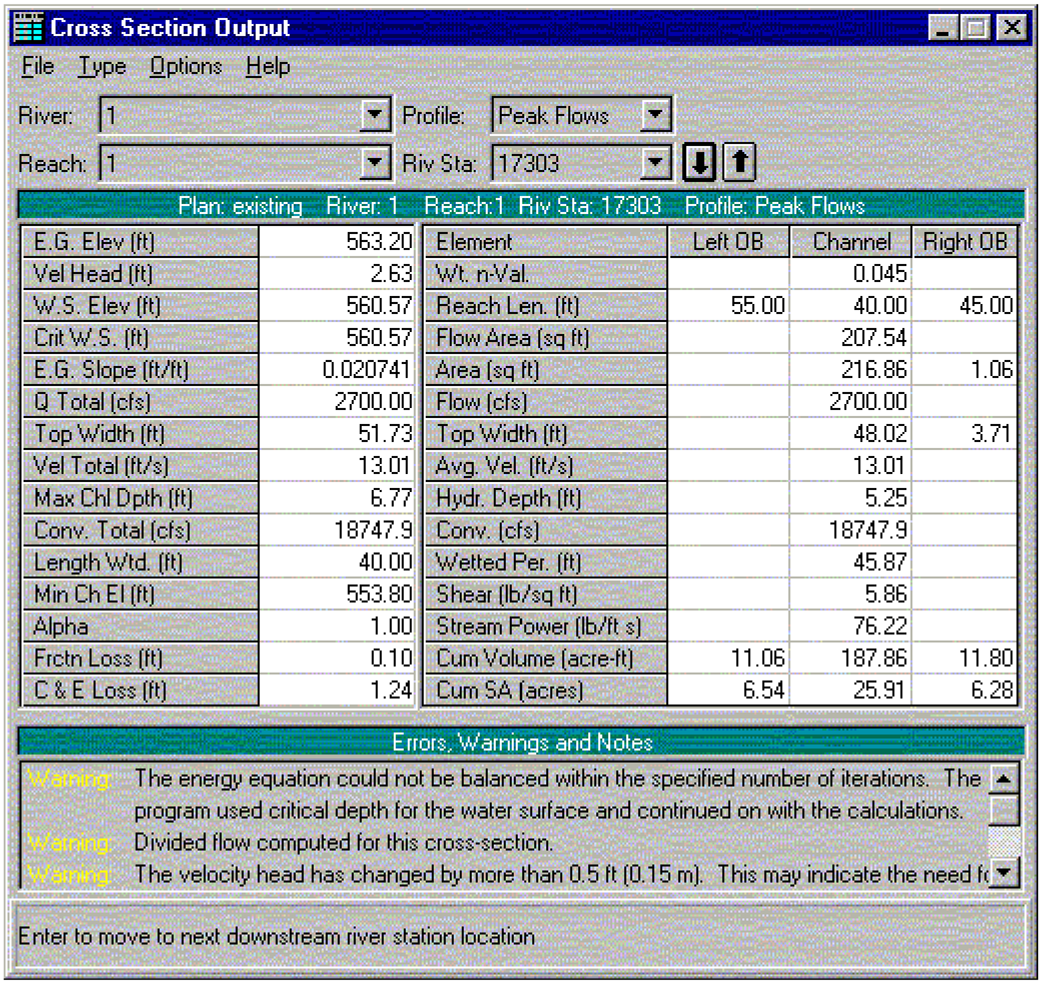


Figure 2-7 Example HydroCAD Reach results (HydroCAD.net)

2.5.4 HEC-RAS

HEC-RAS is a river hydraulics model developed by the U.S. Army Corps of Engineers to compute one-dimensional water surface profiles for steady or unsteady flow. This program uses the solution of the one-dimensional energy equation with energy losses evaluated for friction and contraction and expansion losses in order to compute water surface profiles. In areas with rapidly varied water surface profiles, HEC-RAS uses the solution of the momentum equation. HEC-RAS utilizes the hydrologic results that are developed in HEC-HMS. https://www.hec.usace.army.mil/software/hec-ras/



E.G. Elev (ft)	563.20
Vel Head (ft)	2.63
W.S. Elev (ft)	560.57
Crit W.S. (ft)	560.57
E.G. Slope (ft/ft)	0.020741
Q Total (cfs)	2700.00
Top Width (ft)	51.73
Vel Total (ft/s)	13.01
Max Chl Dpth (ft)	6.77
Conv. Total (cfs)	18747.9
Length Wtd. (ft)	40.00
Min Ch El (ft)	553.80
Alpha	1.00
Frctn Loss (ft)	0.10
C & E Loss (ft)	1.24

Element	Left OB	Channel	Right OB
Wt. n-Val.		0.045	
Reach Len. (ft)	55.00	40.00	45.00
Flow Area (sq ft)		207.54	
Area (sq ft)		216.86	1.06
Flow (cfs)		2700.00	
Top Width (ft)		48.02	3.71
Avg. Vel. (ft/s)		13.01	
Hydr. Depth (ft)		5.25	
Conv. (cfs)		18747.9	
Wetted Per. (ft)		45.87	
Shear (lb/sq ft)		5.86	
Stream Power (lb/ft s)		76.22	
Cum Volume (acre-ft)	11.06	187.86	11.80
Cum SA (acres)	6.54	25.91	6.28

Figure 2-8 Example HEC-RAS calculated values results
(http://www.ce.utexas.edu/prof/maidment/grad/tate/research/RASExercise/webfiles/hecras.html#results)

There is an older version of HEC-HMS that runs with ESRI ArcHydro software called HEC-GeoRAS. The most current version of HEC-RAS (version 6.1) incorporates the GIS tools previously included in HEC-GeoRAS.

2.5.5 SWMM

Stormwater Management Model (SWMM) is a hydraulic and hydrologic modeling system that also has a water quality component. SWMM is a dynamic rainfall-runoff and water quality simulation model, primarily but not exclusively for urban areas, for single-event or long-term (continuous) simulation. The system is capable of both single-event and continuous simulation on catchments and natural drainage, for prediction of flows, stages and pollutant concentrations. A modeler can simulate all aspects of the urban hydrologic and quality cycles, including rainfall, snow melt, surface and subsurface runoff, flow routing through drainage network, storage and treatment.

https://www.epa.gov/water-research/storm-water-management-model-swmm

**************************	Volume	Depth
Runoff Quantity Continuity	acre-feet	inches
**************************	----------	--------
Total Precipitation	3.000	3.000
Evaporation Loss	0.000	0.000
Infiltration Loss	1.749	1.749
Surface Runoff	1.257	1.257
Final Storage	0.000	0.000
Continuity Error (%)	-0.222	

Figure 2-9 Example SWMM calculated values results

(https://swmm5.org/2017/08/14/epa-swmm5-tutorial-with-images-for-swmm-5-1-012/)

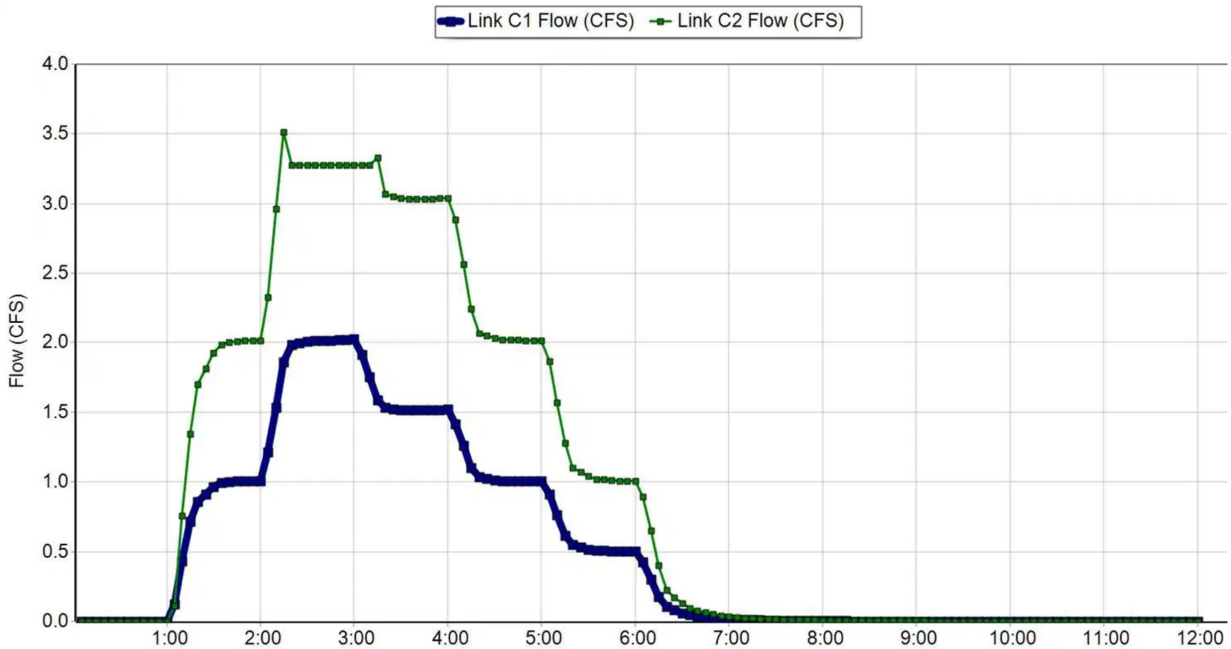


Figure 2-10 Example Plot of SWMM calculated values results

(https://swmm5.org/2017/08/14/epa-swmm5-tutorial-with-images-for-swmm-5-1-012/)

2.5.6 NSS

The U.S. Geological Survey (USGS) developed and published regression equations estimating the magnitude and frequency of floods for every State and a number of metropolitan areas in the United States, and regression equations for estimating other streamflow statistics. These equations were compiled into the National Streamflow Statistics (NSS) Program. This program works through an access database. The system provides estimates of various streamflow statistics for sites in rural (non-regulated) ungaged basins as well as flood frequencies in urban areas. NSS has the capability to develop hydrographs of estimated floods and create flood-frequency curves.

https://water.usgs.gov/osw/programs/nss/summary.html

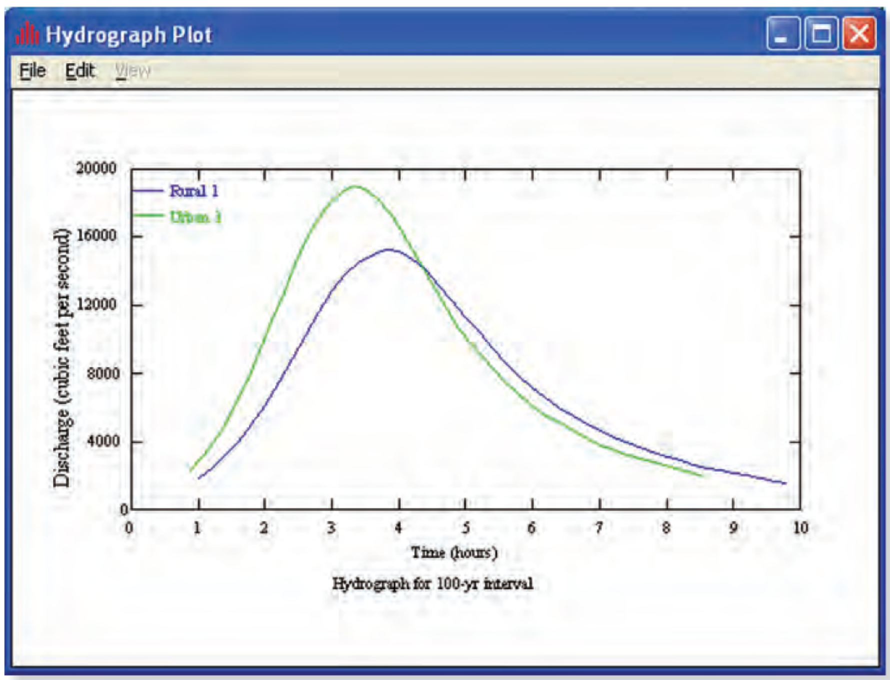
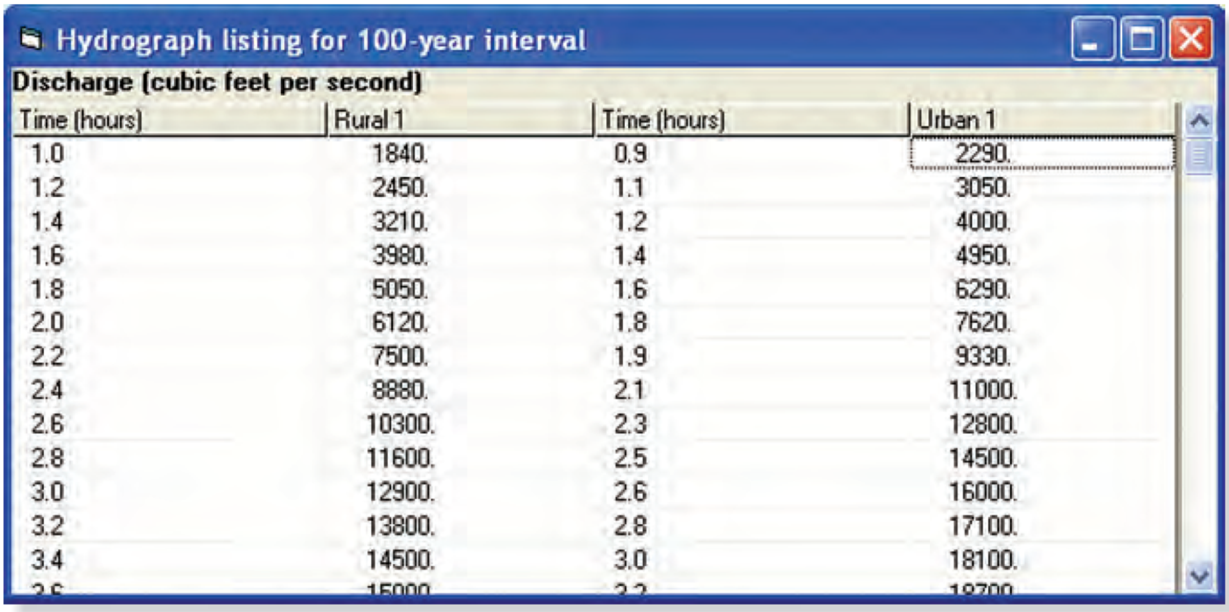


Figure 2-11 Example Plot of NSS calculated values results
(https://pubs.usgs.gov/tm/2006/tm4a6/)



Hydrograph listing for 100-year interval

Discharge (cubic feet per second)

Time (hours)	Rural 1	Time (hours)	Urban 1
1.0	1840.	0.9	2290.
1.2	2450.	1.1	3050.
1.4	3210.	1.2	4000.
1.6	3980.	1.4	4950.
1.8	5050.	1.6	6290.
2.0	6120.	1.8	7620.
2.2	7500.	1.9	9330.
2.4	8880.	2.1	11000.
2.6	10300.	2.3	12800.
2.8	11600.	2.5	14500.
3.0	12900.	2.6	16000.
3.2	13800.	2.8	17100.
3.4	14500.	3.0	18100.

Figure 2-12 Example List Window for example site
(https://pubs.usgs.gov/tm/2006/tm4a6/)

2.5.7 HYDRWIN (Louisiana State)

The HYDR Programs were developed by the Louisiana Department of Transportation and Development (LA DOTD). These programs are in accordance with the guidelines set in the "LA DOTD Hydraulics Manual" (2011 Edition). A consultant may request use of these programs only when under contract with LA DOTD.

http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Public_Works/Hydraulics/Pages/Hydraulics_Software.aspx

```
     LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT      HYDR1110-XXXXXX
     HYDRAULICS SECTION
     DESIGNER: DOTD ENGINEER                DATE: 0X-XX-XXXX
Remarks: Test data for hydr1110 - English units

                      STATE PROJECT NUMBER   000-00-0000

                         NORMAL WATER SURFACE PROGRAM

     **********************************************************************

              STATION                              1+00
              NUMBER OF POINTS                             9
              DESIGN DISCHARGE (CFS)                    486.
              CHANNEL SLOPE (FT./FT.)                 .00180
     OUTPUT:
              NORMAL WATER SURFACE ELEVATION           11.02
              AREA OF OPENING (SQ. FT.)               146.25
              AVERAGE VELOCITY (FPS)                    3.32

     **********************************************************************

     CHANNEL CROSS-SECTION:

         DISTANCE (FT.)      ELEVATION     ROUGHNESS COEFFICIENT

                .0            11.50
                                                   .060
              49.0            11.00
                                                   .060
             128.0            10.40
                                                   .060
             138.0             5.90
                                                   .030
             142.0             4.60
                                                   .030
             148.0             5.90
                                                   .030
             155.0            10.00
                                                   .060
             180.0            11.00
                                                   .060
             320.0            11.50

     ***************************************************************

    STAGE        Q

     11.00      483.
     10.00      321.
      9.00      204.
      8.00      115.
      7.00       51.
      6.00       13.
      5.00         .
```

Figure 2-13 Example HYDRWIN Output Example

2.5.8 HydraFlow CAD

HydraFlow is an extension included with Civil 3D. Several different types of programs can be used to assist in the creation of storm water reports, analyze watersheds, and create hydraulic analysis of streams, rivers, and storm sewers. Civil 3D has four separate external applications that can be used to create storm water analysis, hydraulic analysis, create runoff from historical and synthetic storms, plan and model flood control measures, and analyze the hydrologic properties of watersheds, inlets, culverts, and storm sewer networks. These programs are accessible in the Design Panel of Civil 3D.

https://knowledge.autodesk.com/search-result/caas/video/youtube/lesson/145520-courseId-100343.html

1

Hydrograph Report

Hydraflow Hydrographs Extension for Autodesk® Civil 3D® 2019 by Autodesk, Inc. v2019.2 Thursday, 07 / 1 / 2021

Hyd. No. 2

SCS

Hydrograph type	= SCS Runoff	Peak discharge	= 840.28 cfs
Storm frequency	= 25 yrs	Time to peak	= 746 min
Time interval	= 2 min	Hyd. volume	= 5,045,650 cuft
Drainage area	= 400.000 ac	Curve number	= 79
Basin Slope	= 2.0 %	Hydraulic length	= 1900 ft
Tc method	= LAG	Time of conc. (Tc)	= 38.81 min
Total precip.	= 5.77 in	Distribution	= Type III
Storm duration	= 24 hrs	Shape factor	= 484

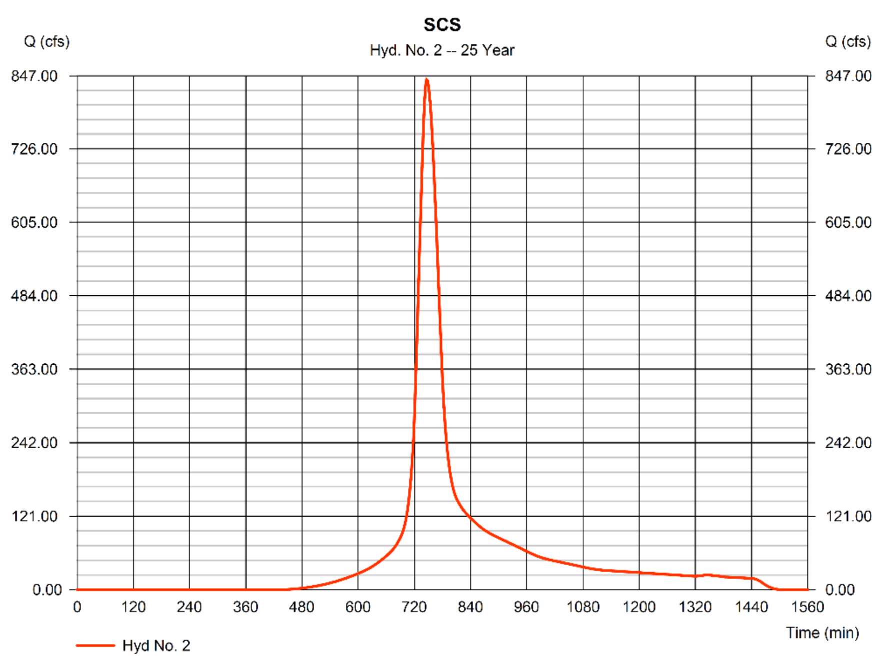


Figure 2-14 Example 1 HydraFlow Output Example

1

Hydrograph Report

Hydraflow Hydrographs Extension for Autodesk® Civil 3D® 2019 by Autodesk, Inc. v2019.2 Thursday, 07 / 1 / 2021

Hyd. No. 1

Rational Method

Hydrograph type	= Rational	Peak discharge	= 11.06 cfs
Storm frequency	= 25 yrs	Time to peak	= 12 min
Time interval	= 1 min	Hyd. volume	= 7,962 cuft
Drainage area	= 2.000 ac	Runoff coeff.	= 0.85
Intensity	= 6.505 in/hr	Tc by User	= 12.00 min
IDF Curve	= Shreveport.IDF	Asc/Rec limb fact	= 1/1

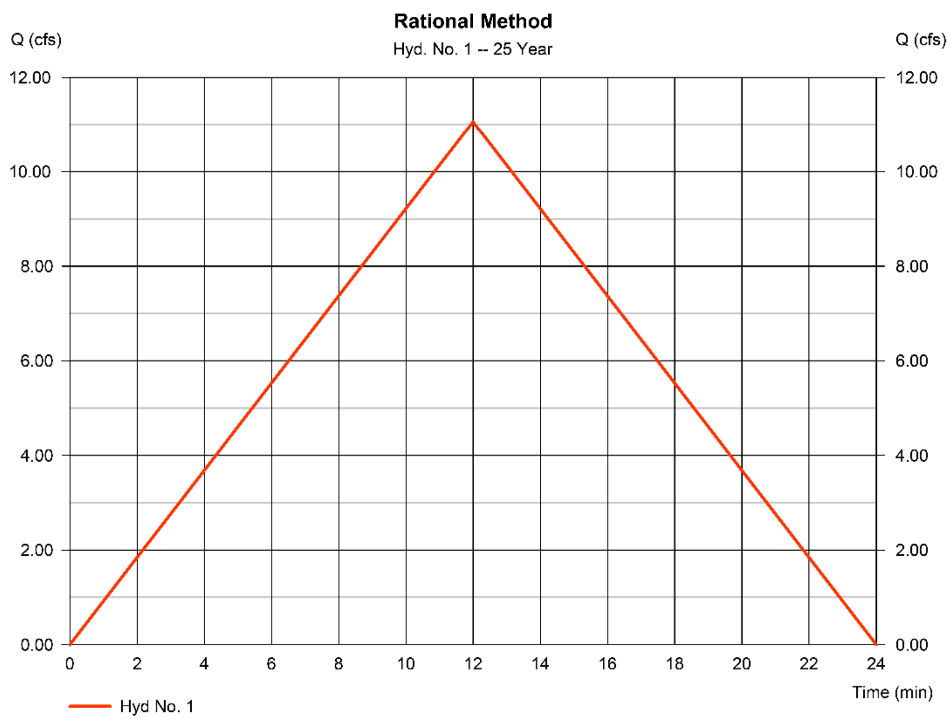


Figure 2-15 Example 2 HydraFlow Output Example

2.6 Appendix

2.6.1 References

(1) Glenn A. Hearne, United States Geological Survey, "U.S. Geological Survey Water-Supply Paper 2206, 1985. "https://books.google.com/books?id=tj9SAQAAMAAJ&pg=RA1-PA13&lpg=RA1-PA13&dq=uq2+%3D+13.2&source=bl&ots=hMN32DiPwR&sig=ACfU3U39AWYXqsbPg4cWO8hJxbl09mwcMw&hl=en&sa=X&ved=2ahUKEwjE7q6E86jmAhUIS6wKHarrA90Q6AEwAHoECAgQAQ#v=onepage&q=uq2%20%3D%2013.2&f=false"

(2) National Resource Conservation Service, 02 Feb. 2020, "https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm"

(3) United States Department of Transportation, Federal Highway Administration, Urban Drainage Design

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(5) Tennessee Department of Transportation Design Division, "Drainage Manual", 2007, "https://www.tn.gov/tdot/roadway-design/design-standards/drainage-manual.html"

(6) American Association of State Highway and Transportation Officials, "Drainage Manual," 2014.

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(8) Iowa State University Institute for Transportation, "Design Manual Chapter 2 - Stormwater 2B - Urban Hydrology and Runoff," 2013.

(9) Austin, Texas, "Drainage Criteria Manual," 2020.

(10) United States Department of Agriculture, "Urban Hydrology for Small Watersheds TR-55," June 1986.

(11) Geosyntec Consultants, Stormwater BMP Guidance Tool, "A Stormwater Best Management Practices Guide for Orleans and Jefferson Parishes," October 2010.

(12) United States Geological Survey, 01 Feb. 2020, "https://waterdata.usgs.gov/nwis/nwis"

(13) United States Department of Transportation, Federal Highway Administration, Hydraulic Design Series No. 2, Second Edition, "Highway Hydrology," October 2002. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif02001.pdf

(14) Minnesota Pollution Control Agency, "Minnesota Stormwater Manual," 02 Feb. 2020, https://stormwater.pca.state.mn.us/index.php?title=Main_Page

(15) Louisiana Department of Transportation and Development, "2011 Hydraulics Manual," 2011.

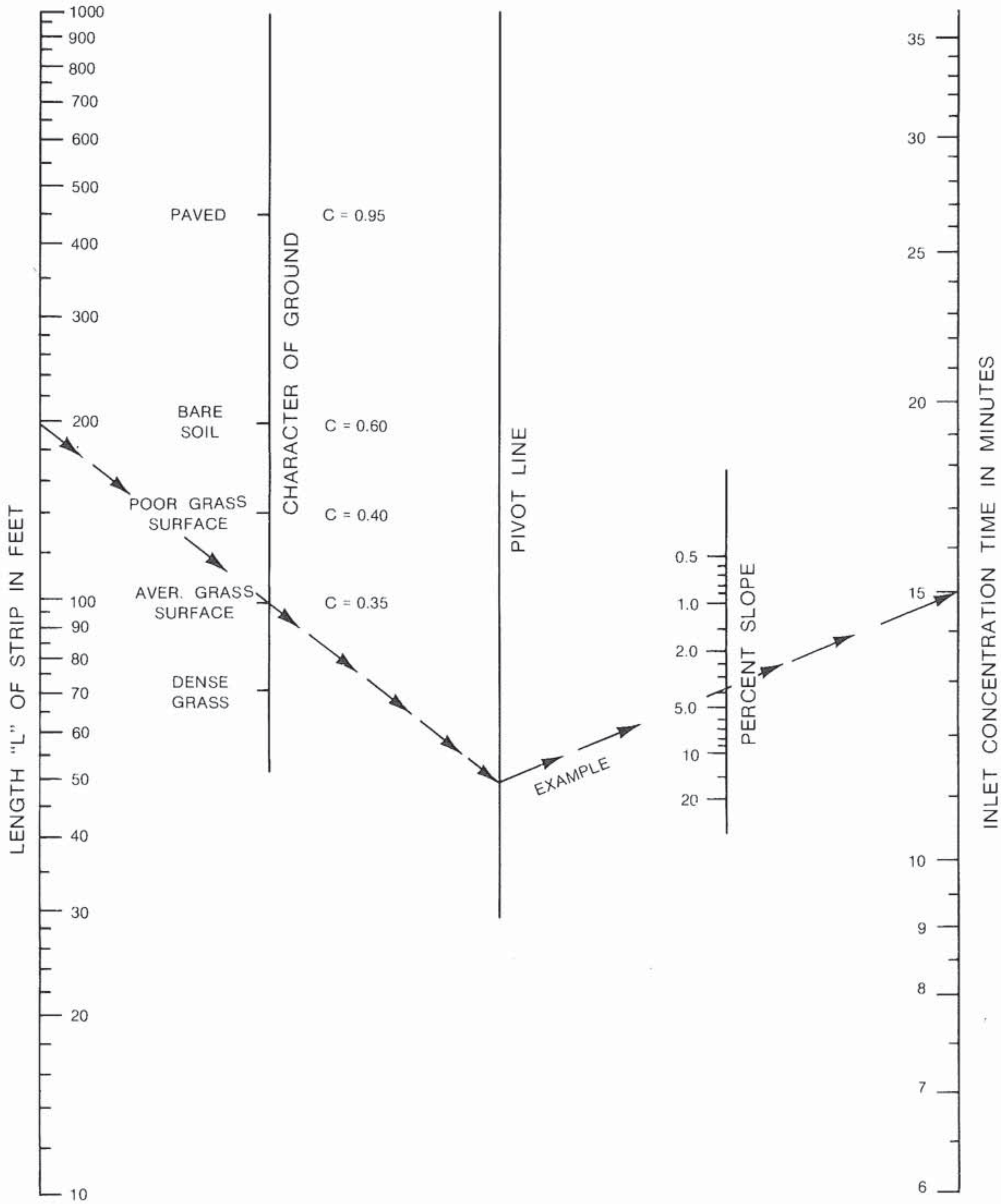
(16) Georgia Department of Transportation, "Drainage Design for Highways," 2018.

2.6.2 Figures

Description of Area	Runoff Coefficients
Business:	
Downtown Areas	0.70 to 0.95
Neighborhood Areas	0.50 to 0.70
Residential:	
Single-Family Areas	0.30 to 0.50
Multi-Units, detached	0.40 to 0.60
Multi-Units, attached	0.60 to 0.75
Residential (suburban)	0.25 to 0.40
Apartment dwelling areas	0.50 to 0.70
Industrial:	
Light Areas	0.50 to 0.80
Heavy Areas	0.60 to 0.90
Parks, cemeteries	0.10 to 0.25
Playgrounds	0.20 to 0.35
Railroad yard areas	0.20 to 0.40
Unimproved areas	0.10 to 0.30

Figure 2A-1 – Runoff Coefficients

FIGURE 2A-1



OVERLAND FLOW TIME

FROM: ROAD DESIGN MANUAL–LOUISIANA DEPARTMENT OF HIGHWAYS

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

Table of Contents

Section 3

CULVERT AND STORM DRAIN PIPE MATERIALS AND INSTALLATION

3.1 General

This section presents standards and practices for specifying culvert and storm drain pipe materials and installation of all culverts used in cross drains, side drains, median drains, and storm drains (storm sewers).

3.2 Pipe Types

In general, the selection of size for a proposed culvert or storm drain pipe involves specifying the most economical structure that will adequately convey the required design flow. Once the layout of the proposed structure has been established on the site, the pipe selection process consists of evaluating the hydraulic performance of different size and type options until an optimum design is achieved. Listed below are acceptable pipe types:

RCP – Reinforced Concrete Pipe
RCPA – Reinforced Concrete Pipe Arch
CMP – Corrugated Metal Pipe
CMPA – Corrugated Metal Pipe Arch
CAP – Corrugated Aluminum Pipe
CAPA – Corrugated Aluminum Pipe Arch
CSP – Corrugated Steel Pipe
CSPA – Corrugated Steel Pipe Arch
PCCSP – Polymer Coated Corrugated Steel Pipe
PCCSPA – Polymer Coated Corrugated Steel Pipe Arch
BCCSP – Bituminous Coated Corrugated Steel Pipe
BCCSPA – Bituminous Coated Corrugated Steel Pipe Arch
PP – Plastic Pipe (PVC, HDPE, Polypropylene, Etc.)
RPVCP – Ribbed Polyvinyl Chloride Pipe: (ASTM F794 or ASTM F949)
CPEPDW – Corrugated Polyethylene Pipe Double Wall: (AASHTO M294 – Type S)

3.3 Permitting from Other Agencies

3.3.1 Pipes Under Railroads

When it is necessary to place or replace a culvert or storm drain pipe under a railroad or within the right-of-way of a railroad, the designer should contact the specific Railroad Company to determine the required type of pipe material to be placed under the railroad track or within their right-of-way and to obtain required permits from the Railroad Company.

3.3.2 Pipes Under State Highways

When it is necessary to place or replace a culvert or storm drain pipe under a state highway or within the right-of-way of a state highway, LADOTD design criteria will govern. The designer is required to contact and obtain the required permits from LADOTD.

3.4 Design Service Life for Culverts and Storm Drain Pipe

The design service life is defined as the estimated expectancy of how many years the pipe material will last before failure. Table 3-1 lists the minimum design service life for culverts.

Table 3-1 Design Service Life for Culverts and Storm Drain Pipe

APPLICATION	DESIGN SERVICE LIFE	JOINT TYPE
Storm Drain Pipe (Outfall)	50 years	T3
Cross Drain Pipes for: Urban Arterial Rural Arterial Urban Collector (4 Lanes) Rural Collector (4 Lanes) Suburban Arterial	70 years	T3
Cross Drain Pipes for: Urban Collector (2 Lanes) Rural Collector (2 Lanes) Urban Local Rural Local Suburban Collector	50 years	T2
Side Drains	30 years	T1

The designer should contact the City Engineering Department to obtain road classifications.

3.5 Minimum Pipe Sizes

All culverts shall have a minimum diameter of 18-inches for circular pipe or equivalent for alternate shapes. Cross drains for arterial and collector streets shall have a minimum diameter of 24 inches for circular pipe or equivalent for alternate shapes. The minimum diameter for private driveway culverts within the right-of-way shall be 15 inches. The minimum box culvert size shall be 4 feet wide by 3 feet high, unless approved by the City Engineer.

3.6 Gage & Coating Requirements

The service life for metal pipe is dependent on soil and water conditions where the pipe is installed. Gage (thickness) and bituminous coating for corrugated metal pipes shall be selected in accordance to the latest Louisiana Department of Transportation (LADOTD) EDSM II.2.1.6 and Standard Plan SAM-1.
All metal pipe shall be shall be a minimum of 14 gage.

3.7 Joint Types

The type of joints required for each structure classification, (Storm Drain Pipe, Cross Drain Pipe or Side Drain), shall be the following:

(T1) Type 1 Joints.
This joint type shall be used for side drains under driveways and similar installations. Type 1 Joints are combination of gasket material and joint configuration are to prevent infiltration. Type 2 or 3 Joints may be used as an alternative to Type 1 Joint. See LADOTD specifications for more detailed information.

(T2) Type 2 Joints.
This joint type shall be used for cross drains under roadways, including turnouts. Type 2 Joints are a combination of gasket material and joint configuration meets the 5 psi hydrostatic pressure test. See LADOTD specifications for more detailed information.

(T3) Type 3 Joints.
This joint type shall be used for storm drain systems, flumes, and siphons. The Type 3 Joints are a combination of gasket material and joint configuration meets the 10 psi hydrostatic pressure test. See LADOTD specifications for more detailed information.

3.8 Fill Height and Cover Requirements

3.8.1 Limits of Fill Height and Cover

3.8.1.1 Maximum fill height is measured from the crown of the pipe to the top of the surfacing.

3.8.1.2 Minimum cover is measured from the crown of the pipe to the top of the subgrade. Refer to Section 5.2.3 for minimum cover over pipes. Additional cover may be needed and is to be adequate for H-20 loading when final surface is in place. It is the contractor's responsibility to provide additional adequate cover to protect the pipe, if needed, during construction if heavier construction loads are to be driven over or close to the drainage structure.

3.8.2 Corrugated Steel Pipe Allowable Fill Heights

Allowable fill heights for various metal gages for corrugated steel and corrugated aluminum pipes (or pipe arches) are given in LADOTD Standard Plan SAM-1.

3.8.3 Plastic Pipe Allowable Fill Heights

The minimum cover for all plastic pipe types and sizes is 12 inches. Refer to manufacturer's recommendations for maximum fill height for plastic pipes.

3.8.4 Reinforced Concrete Pipe Allowable Fill Heights

Generally, Class III reinforced concrete pipe is used unless the allowable fill height for Class III reinforced concrete pipe is exceeded. Recommended allowable fill heights are:

a. 18 ft for Class III reinforced concrete pipe
b. 26 ft for Class IV reinforced concrete pipe
c. 40 ft for Class V reinforced concrete pipe

3.8.5 Reinforced Concrete Box Culverts Allowable Fill Heights

Refer to LADOTD Standard Plans for allowable fill heights for RCB.

3.9 Multiple Pipes

A multiple pipe installation is the placement of two or more pipes or pipe arches in a single trench or embankment condition. Table 3-2 provides minimum spacing between multiple pipes and pipe arches. The dimensions shown are minimum distances between multiple lines of pipes or pipe arches. The maximum number of pipes allowed in a multiple pipe installation is four (4); unless otherwise approved by the City Engineer.

Table 3-2 Minimum Spacing for Multiple Lines of Pipes or Arch Pipes

Diameter/Round Equivalent Diameter (inches)	Round Pipes Minimum Spacing (ft – inches)	Arch Pipes Minimum Spacing (ft – inches)
≤24”	1’ – 0”	1’ – 0”
30”	1’ – 3”	1’ - 0”
36”	1’ – 6”	1’ – 3”
42”	1’ – 9”	1’ – 5”
48”	2’ – 0”	1’ – 8”
54”	2’ – 3”	1’ – 10”
60”	2’ – 6”	2’ – 1”
66”	2’ – 9”	2’ – 3”
72”	3’ – 0”	2’ – 6”
78”	3’ – 0”	2’ – 8”
84”	3’ – 0”	2’ – 10”
90”	3’ – 0”	3’ – 0”
96”	3’ – 0”	3’ – 0”
102” or larger	3’ – 0”	3’ – 0”

3.9.1 Skewed Multiple Pipe

The distance between two or more pipes or pipe arches is measured perpendicular to the pipe or pipe arch even when they are to be installed on a skew.

3.10 Pipe Bedding

Bedding is the earth or other material on which a culvert is supported. An important function of the bedding is to assure uniform support along the barrel of each culvert section. Standard Plan 1001-1 gives general guidelines of placement of the bedding.

3.11 Pipe Installations

There are two major classes of installation: trench installation and embankment installation. Figure 3-1 illustrates various types of pipe installations.

3.11.1 Embankment Installation

The most common type of installation used for culverts is the embankment installation where embankment fill is placed over the pipe and above existing ground surface. Embankment installation is further broken down into positive and negative projecting. The positive projecting type covers those installations where the pipe is bedded with its top anywhere from existing ground level to 90% of the nominal pipe diameter above existing ground. The negative projecting embankment type covers those installations where the pipe is bedded in a trench with its top below the existing ground surface.

3.11.2 Trench Installation

Trench installation covers those installations where the pipe is placed in a trench with no fill above existing ground surface. Trench installation is the type most commonly used in urban subsurface systems.

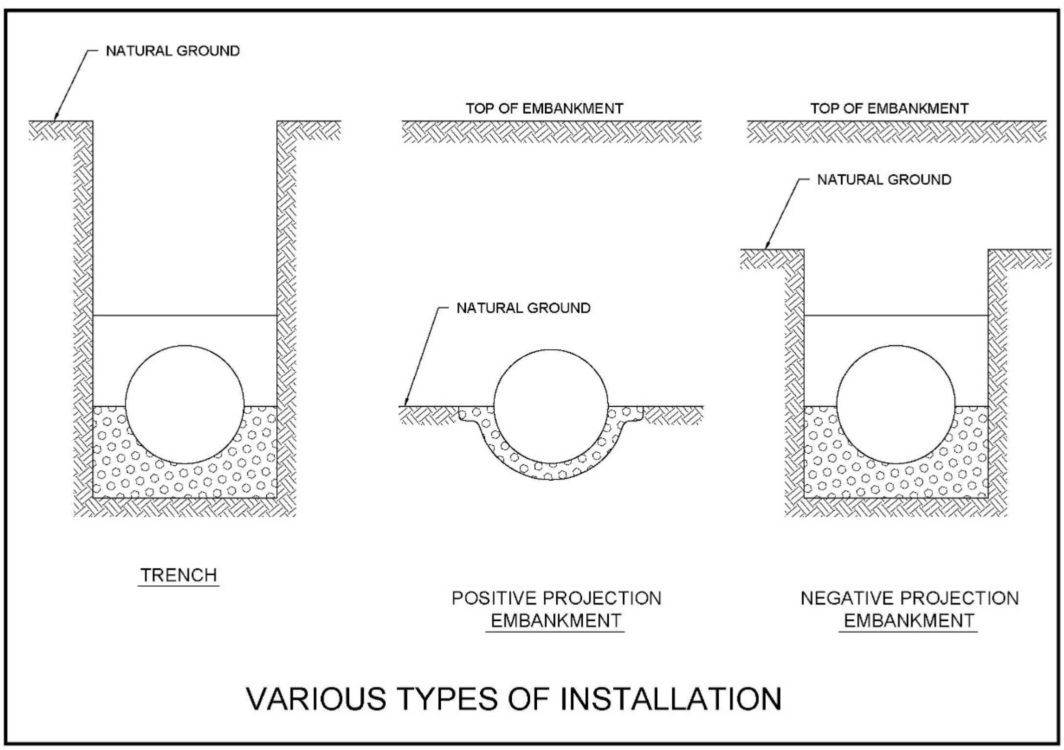


Figure 3-1 Typical Culvert Installations

3.12 Pipe Separation from Other Utilities

The design engineer shall provide a minimum horizontal separation greater than or equal to 3 feet (outside-to-outside) and vertical separation of greater than 12 inches (outside-to-outside) from sanitary sewer mains. When the vertical separation is less than 12 inches, a neoprene pad shall be placed between the storm drain pipe and the sanitary sewer pipe.

The design engineer shall provide a minimum of 6 feet (outside-to-outside) horizontal separation and a minimum of 2 feet (outside-to-outside) vertical separation from water mains.

For other utilities, the design engineer shall provide a minimum horizontal separation greater than or equal to 3 feet (outside-to-outside) and a minimum vertical clear separation of 18 inches (outside-to-outside) between the other utility and storm drain pipe.

3.13 Pipes to Be Bored or Jacked

Occasionally, construction limitations require pipes to be bored or jacked. Boring and pipe jacking operations shall be in accordance with Section 1006 of the City of Shreveport Standard Specifications. In general, pipes 30" in diameter and greater shall be jacked, and pipes less than 30" in diameter shall be bored. Slurry augering will not be permitted without prior approval from the City Engineer.

3.14 Appendix

3.14.1 References

(1) Louisiana Department of Transportation and Development, “2011 Hydraulics Manual”, 2011

(2) Louisiana Department of Transportation and Development, “Engineering Directives and Standards (EDSM) No. II.2.1.1”, Sept. 30, 2005

(3) Louisiana Department of Transportation and Development, “Engineering Directives and Standards (EDSM) No. II.2.1.6”, Feb. 4, 2005

(4) Louisiana Department of Transportation and Development, “Engineering Directives and Standards (EDSM) No. II.2.1.13”, Oct. 26, 2005

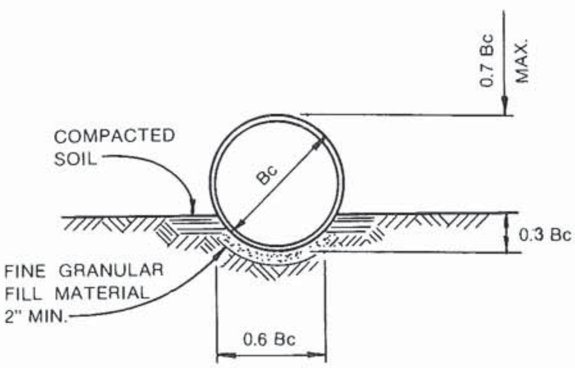
(5) City of Shreveport, Department of Public Works, “Design Criteria for Storm Sewers and Appurtenances”, April 1975

3.14.2 Figures

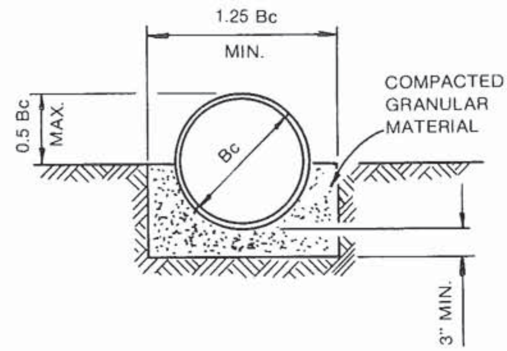
FIGURE 3A-1

PIPE BEDDINGS

EMBANKMENT BEDDINGS

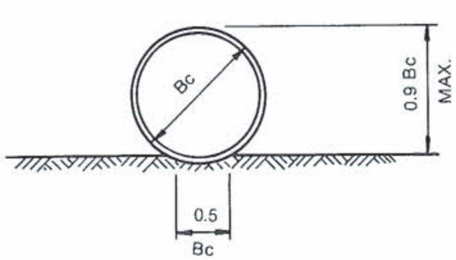


SHAPED SUBGRADE AT
GRANULAR FOUNDATION

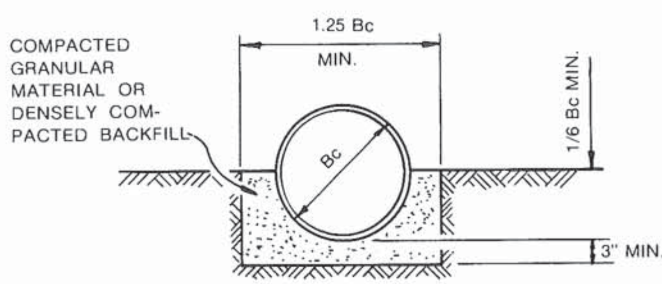


GRANULAR FOUNDATION

CLASS B



SHAPED SUBGRADE



GRANULAR FOUNDATION

CLASS C

NOTE: FOR ROCK AND OTHER INCOMPRESSIBLE MATERIALS THE TRENCH SHOULD BE OVEREXCAVATED A MIN. OF 6"- REFILL WITH GRANULAR MATERIAL.

Table of Contents

Section 4

PAVEMENT DRAINAGE DESIGN

4.1 – Overview

Pavement drainage shall consist of managing and reducing the depth and spread of storm water runoff to a predetermined amount which will afford a minimum amount of interference to vehicular and pedestrian traffic for a specific design storm through the adequate sizing and locating of curb inlets, grate inlets, and parking lot drains.

4.2 General Criteria

The following items comprise the general criteria for pavement drainage:

4.2.1 Rainfall Intensity

Refer to Chapter 2.3 for design frequency.

4.2.2 Street Function and Classification

Although streets play an important role in stormwater collection and conveyance, the primary function of a street or roadway is to provide for safe passage of vehicular traffic at a specified level of service. If stormwater systems are not designed properly, this primary function will be impaired. To ensure that this does not happen, streets and roadways are classified for drainage purposes based on traffic volume, parking practices and other criteria (Wright-McLaughlin Engineers 1969). The four street classifications are:

1. Local and Residential: Low-speed traffic for residential or industrial area access.
2. Collector: Low/moderate-speed traffic providing service between local streets and arterials.
3. Arterial: Moderate/high-speed traffic moving through urban areas and accessing freeways.
4. Freeway: High-speed travel, generally over long distances.

Table 4-1 Street Classification for Drainage Purposes

STREET CLASSIFICATION	FUNCTION	SPEED/NUMBER OF TRAFFIC LANES	SIGNALIZATION AT INTERSECTIONS	STREET PARKING
Local & Residential	Provides access to residential and industrial areas	Low speed / 2 lanes	Stop Signs	One or both sides of the street
Collector	Collects and convey traffic between local and arterial streets	Low to Moderate speed 2 to 4 lanes	Stop signs or traffic signals	One or both sides of the street
Arterial	Delivers traffic between urban centers and from collectors to freeways	Moderate to high speed 4 to 6 lanes	Traffic signals (controlled access)	Usually Prohibited
Freeway	Provides rapid and efficient transport over long distances	High-speed 4 to 6 lanes	Separated interchanges (limited access)	Always prohibited

4.2.3 Permissible Depth and Spread of Water

Limiting the depth and spread of water flowing in streets is necessary to prevent flooding of adjacent properties and to allow for passage of vehicles during rain events. The flow of water in gutters of typical streets during the design storm shall not exceed the top of curb or six (6) inches, whichever is the lesser depth for streets and emergency access lanes. No curb overtopping is permitted, and the spread shall maintain within the following width requirements:

a. Parking Lots — Drains on parking lots and other off-street areas shall be located for intercepting and detaining runoff that would otherwise flow directly onto city streets. A maximum of six (6) inches of ponding is recommended on parking lots.

a. Local and Residential — Flow may spread to crown of street.

b. Collector Streets — Flow spread limited so that an equivalent of one lane is free of water for 2-lane roadways or one lane in each direction for 4-lane roadways.

c. Arterial Streets — Flow spread limited so that one lane is free of water in each direction and should not flood more than two lanes in both directions.

d. Freeway — No encroachment of water is allowed on any lanes of travel.

4.2.4 Bypass

Flow bypassing each inlet must be included in the total gutter flow to the next inlet downstream. Refer to Section 4.6.1.c.4 for additional discussion of inlet efficiency and bypass. A bypass of 10 to 20 percent per inlet results in a more economical drainage system. Bypass will not be permitted at bridge ends, where flow is across pavements, and runoff from private property to public property, natural stream channel, or adjacent property.

4.2.5 Pavement Slopes

Both the longitudinal and cross (transverse) slope of a street are important in calculating hydraulic capacity. The standard cross slope for pavement design shall be 2.5%, except where necessary in superelevation, or to adequately design intersections for smooth traffic and drainage flow. The minimum longitudinal slope of new pavement shall be 0.4%.

4.3 - GUTTER FLOW

4.3.1 General

The capacity of gutter flow in curbed pavement assists in determining the proper inlet type and casting and inlet spacing. Many factors affect the flow capacity of gutters. These factors work together to provide a safe limit in storm water encroachment into driving lanes and parking areas.

4.3.2 Gutter flow capacity

Gutter flow capacity can be found using the nomograph in Figure 4A-2 and can be calculated using Equation 4-1 below.

Equation assumptions are:

a. S_x = 2.5% or 0.025 ft/ft
b. S_L= Longitudinal slope (minimum longitudinal slope of new pavement shall be 0.004 ft/ft or 0.4%)
c. n = 0.016 (Manning's n-values vary depending on situation)
d. A minimum of 75% of design flow shall be intercepted by the inlet
e. Total gutter width = 3.0 feet (consists of 6-inch wide curb and 30-inch wide gutter section, typically cast-in-place concrete.)
f. Maximum curb height = 6 inches
g. Maximum allowable gutter flow for the 25-year event is 10 cubic feet per second.
h. S_x is equivalent across both the pavement and gutter.

$$Q = [0.56\,(S_x^{1.67} S_L^{0.50} T^{2.67})]/n \qquad \text{Eq. 4-1}$$

Where:

Q = flow (cubic feet per second)
S_x = pavement cross slope. (ft/ft)
S_L = average longitudinal slope of gutter (ft/ft)
T = top width of flow extending from face of curb to street (feet)
n = Manning's roughness coefficient

Recommended values of Manning's "n" for pavement roughness shall be:

Concrete Gutter, troweled finish 0.012
Asphalt Pavement:
Smooth Texture..........0.013
Rough Texture..........0.016
Concrete Gutter – Asphalt Pavement

Smooth……………………………………………………………………0.013
Rough……………………………………………………………………0.015

Concrete Pavement
Float Finish……………………………………………………………0.014
Broom Finish…………………………………………………………0.016

For Gutters with small slope, where sediment may
accumulate, increase the above values of "n" by……………………0.002

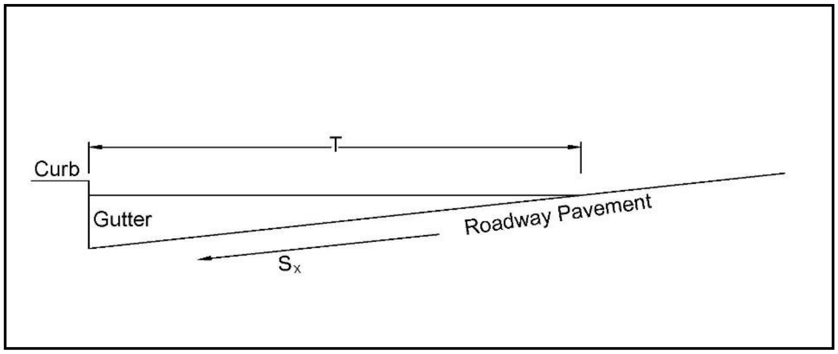


Figure 4-3 Curb and Pavement Section

4.4 Inlet Placement

Inlets must be placed at each location where surface runoff flow should be interrupted and transitioned into storm drain pipe flow. Inlets can be placed in roadside ditches, grass or lined swales, parking or pavement area depressions and in roadway or parking area curbs and gutters.

4.4.1 General

Inlets shall be installed immediately upstream of street intersections, pedestrian crosswalks, handicap ramps, and where required to control spread and depth of flow. Preferred spacing of inlets is 200 feet and in no case shall inlets be spaced greater than 500-feet along both sides of a road along a given storm drain pipe.

4.4.2 Low Points or Sumps

One inlet positioned in the low point of the curb line on residential and collector streets is generally sufficient unless excessive depths of ponded water area encountered. Three (3) inlets should be placed at low points on arterial streets. One inlet should be located at the low point and one on each side (where physically practical) at the point where the gutter grade is about 0.2 feet above the low point. The additional inlets reduce the volume of water reaching the low point inlet, provides a backup relief for the removal of most water in case the low point inlet becomes clogged and helps reduce the deposit of sediment on the pavement caused by low velocities associated with flat grades near the low point inlet. Combination inlets may be used with approval from the city engineer. Refer to Chapter 4 in HEC 22: Urban Design Manual for more detailed information and discussion on combination inlets.

4.4.3 Intersections

Inlets are to be placed at the upgrade side of street approaches as required, preferably not in curb returns. On all streets, the maximum gutter flow across intersections shall not be greater than:

Longitudinal Gutter Slope	Flow Cubic Feet Per Second (cfs)
0.5%	0.30
1.0%	0.45
2.0%	0.60
3.0%	0.70
4.0%	0.85
5.0% and Over	1.00

Valley gutters can be useful in diminishing the deterioration of pavement, particularly at intersections where flows tend to concentrate. Valley gutters cannot be used at the intersection of two (2) thoroughfare or arterial streets. At the intersection of two (2) collector streets or local streets, the valley gutter may be used. At the intersection of two (2) different types of streets, a valley gutter may be used across the smaller street only.

4.4.4 Bridge Ends

Where a bridge is located on a continuous grade, approaching gutter flow will not be permitted to flow onto the bridge. Inlets are to be located outside the approach slab to intercept the flow at the upper bridge end.

4.4.5 Flow Across Pavements

Where the pavement is warped in transitions between super elevated and normal sections, water shall be picked up prior to the cross-slope change.

4.4.6 Pedestrian Crosswalk

Gutter flow across all major pedestrian crosswalks shall be limited as provided for street intersections.

4.4.7 Offsite and Side Drainage

Runoff from developments outside the roadway should be collected as required in a stormwater detention facility and only connected to discharge into the right-of-way, the natural or improved drainage channels or easements by the control discharge from the detention facility.

SECTION 4.5 - INLET TYPES AND DESIGN

4.5.1 General

Inlets shall be located as necessary to remove the flow based on the design storm and accommodate spread widths and permissible spread of water as stated in Section 4.2.3. The hydraulic efficiency of storm drain inlets varies with the amount of gutter flow, street grade, street crown and the geometry of the inlet.

The lowering of the standard height of the street crown shall be allowed for the purposes of obtaining additional hydraulic capacity.

4.5.2 Methods and Computer Software

The hydraulic design of inlets shall be analyzed using methods set forth in Chapter 4 in HEC 22: Urban Design Manual. The following is a list of acceptable modeling software:

a. The LADOTD computer program HYDR 6000: "Inlet Spacing"

b. HYDROFLOW Storm Sewers Extension for Autodesk Civil 3D

c. Hydraulic Toolbox

4.5.3 Inlet Types

Storm drain inlets are designed to collect and convey runoff to a storm drainage system. The two main types of inlets are curb inlets, which provide an opening at the curb, and grate inlets, which provide an opening in the gutter. These inlets may be used individually or combined to intercept drainage on grade or in slumps (low points). Inlets used by the City of Shreveport generally fall within three (3) categories, with curb-opening type inlets being most preferred, refer to Figure 4-1.

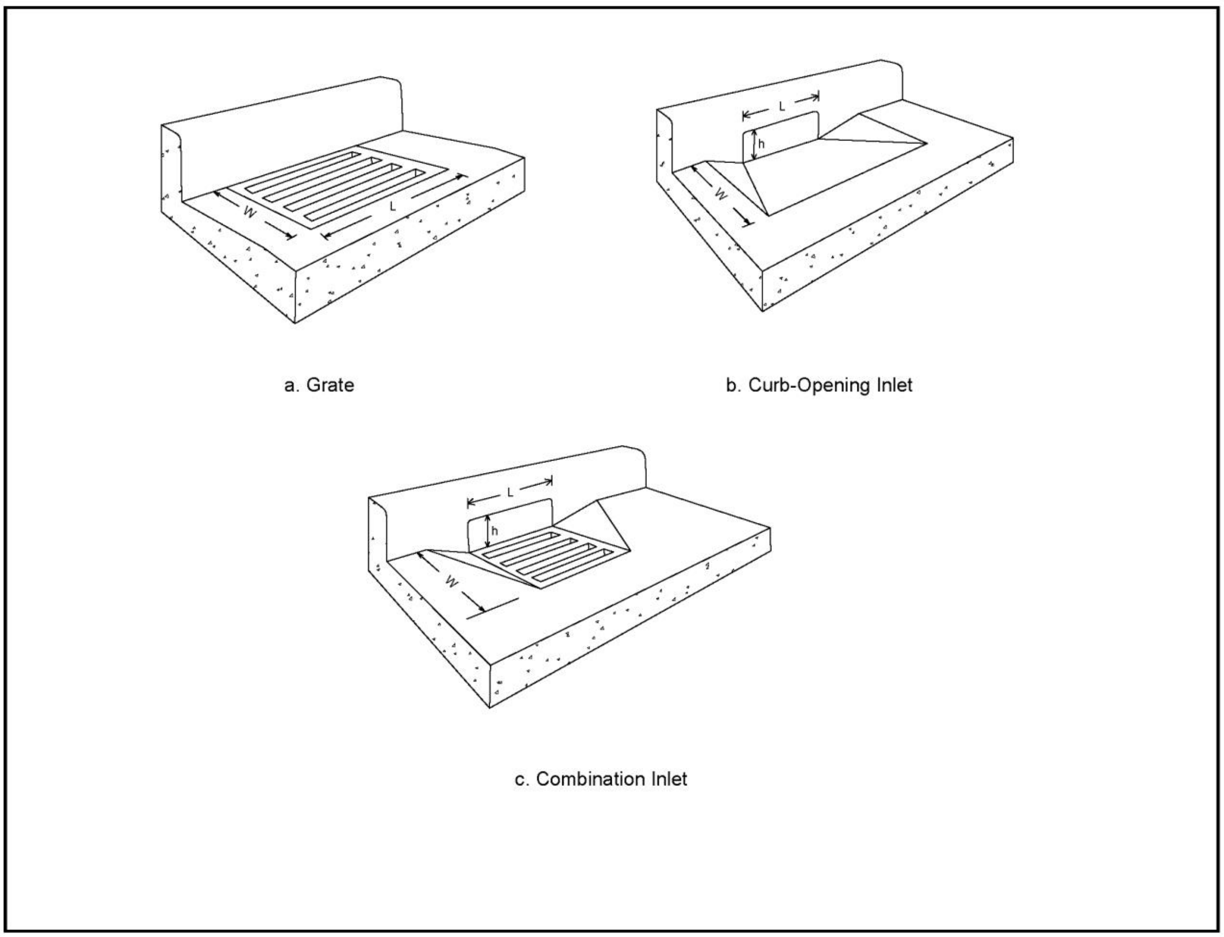


Figure 4-1 Inlet Types (HEC22)

4.5.4 Inlet Capacity

Inlets on grade are spaced as necessary to intercept gutter flow as runoff travels downstream. The capacity of an inlet on grade is dependent on the longitudinal slope of the roadway (gutter), the cross-slope of the pavement, the shape of the inlet (if the inlet is recessed or depressed), and the type of inlet.

The inlet shall be sized to allow approximately 20% of the flow to bypass to the next downstream inlet.

Inlets tend to become clogged with debris, lowering the capacity of the inlet by reducing the effective clear openings. All calculated inlet capacities shall include a reduction for clogging from Table 4-2.

Table 4-2 Inlet Clogging Factors, CF

INLET TYPE	CONDITION	CLOGGING FACTOR
Curb	Continuous Grade Sump	0.8 0.8
Grate	Continuous Grade Sump Transverse Bars	0.6 0.5 0.5
Combination	Continuous Grade Sump	1.0 1.0

4.6 Curb Opening Inlet Design

4.6.1 On Grade

a. General – Curb inlets are effective in the drainage of street and highway pavements where flow depth at the curb is sufficient for the inlet to perform efficiently. Curb openings are less susceptible to clogging and offer little interference with traffic operation. The capacity of a curb opening inlet on a continuous grade varies with the depth of the water at the inlet entrance and the length of opening. This depth is dependent on the amount of depression of the flow line at the inlet, the pavement cross slope, longitudinal slope and the pavement roughness. The efficiency of an inlet is increased by allowing part of the flow to bypass.

b. Methods for Determining Inlet Capacity – Curb inlets usually function as weirs, and capacity is dependent on the depth of flow in the gutter, the length of the inlet and if applicable, the depression of the inlet. The length of the curb inlet required for total interception of gutter flow on a pavement section with a uniform cross slope is expressed in Equation 4-2.

c. Design Procedure – The steps to be used in inlet design calculations are:

1. Determine discharge, Q, in the gutter for the first inlet in a system. For other inlets below the first inlet, bypass from upstream inlet must be added to the discharge.

2. Determine the depth of flow in the gutter as outlined in Section 4.3.2 (Gutter flow capacity).

3. If the depth of flow determined is greater than allowed by spread criteria, the inlet should be moved to reduce the discharge. Note that local depression for the inlet has no bearing on spread determination as the spread calculation is assumed to be taken immediately above the inlet depression.

4. Determine the required inlet length based on the gutter flow. This can be determined by using Figure 4A-4. A check for proper inlet length is that an inlet is most effective when the inlet efficiency is 80% to 90%.
   The length of the curb opening required for total interception of gutter flow on a pavement section with a uniform cross slope is:

$$L_T = 0.6Q^{0.42}S_L^{\ 0.3}[1/(nS_x)]^{0.6} \qquad \text{Eq. 4-2}$$

Where L_T = Curb Opening Length (feet)
Q = Gutter flow (cubic feet per second)
S_L = Longitudinal Slope (ft/ft)
S_x = Street Cross Slope (ft/ft)
n = Manning's Roughness Coefficient

For the length of the curb opening required for gutter flow for cantilever inlets, which have a pavement section with a depressed inlet and a composite cross slope, refer to HEC 22-Urban Drainage Design Manual Chapter 4.

Inlet efficiency, E, is the percent of total flow that the inlet will accept, refer to Figure 4A-5. The efficiency of an inlet is affected and is dependent on changes in cross slope, longitudinal slope, total gutter flow, and, to a lesser extent, pavement roughness. Inlet efficiency, E, is defined by the following equation:

$$E = Q_1 / Q \qquad \text{Eq. 4-3}$$

Where E = Inlet Efficiency
Q = Total gutter flow (cubic feet per second)
Q_1 = Intercepted flow (cubic feet per second)

Bypass flow is gutter flow that is not intercepted by an inlet and is defined by the following equation:

$$Q_b = Q - Q_1 \qquad \text{Eq. 4-4}$$

Where Q_b = Bypass flow (cubic feet per second)

For more detail discussion on inlet efficiency, interception capacity and bypass flow, refer to HEC 22-Urban Design Manual Chapter 4.

5. Subtract the discharge intercepted from the gutter flow. Bypass must be added to the next inlet in the system.

6. Continue spacing inlets by these steps until the low point is reached.

4.6.2 Sump (Low Point)

a. General – Curb inlets at low points inside roadway pavement operate under weir conditions until submerged. The inlet capacity is dependent on depth of flow and inlet geometry. See Section 4.4.2 for requirements for multiple inlets at low points. All flow coming to the inlet must be assumed to eventually enter the inlet.

b. Design Procedure – The equation for an inlet acting as a rectangular weir is:

$$Q_{icap} = CF(3.0)(L_T)(d^{1.5}) \qquad \text{Eq. 4-5}$$

Where Q_{icap} = Inlet Capacity (cubic feet per second)
CF = Clogging Factor, see Table 4-2
L_T = Curb Opening Length (feet)
d = depth of flow at inlet (feet)

Equation 4.5 can be used to determine the capacity of a curb inlet at a low point in the grade. All flow coming to the inlet must be assumed to eventually enter in curb inlet.

Enter the nomograph in Figure 4A-6 with any two of the three variables: h, Q/L, H/h, and read the third.

Where:
h = Total height of opening in feet
L = Total length of opening in feet
H = Depth of water at the entrance in feet
Q = Total peak rate of flow to the inlet in cfs

Normally, Q, L and h will be known, and H will be determined from the nomograph. The spread of water on the street will depend upon the cross slope of the pavement.

4.7 - GRATE INLET DESIGN

4.7.1 On Grade

a. General – the capacity of a grate inlet on a continuous grade varies with length of grate, depression, position and spacing of bars and amount of debris that could accumulate on the grate. Grate inlets generally perform better on grade than curb inlets, particularly for longitudinal slopes greater than 3%. However, grate inlets are more susceptible to clogging than curb inlets. The capacity of a grate inlet is proportional to the amount of water flowing over the inlet and the length of the inlet (longitudinal to the roadway). Figure 4-2 shows a cross-section of the street at a grate inlet. The flow above the grate is Q_1, and the flow on the street side of the grate is Q_2.

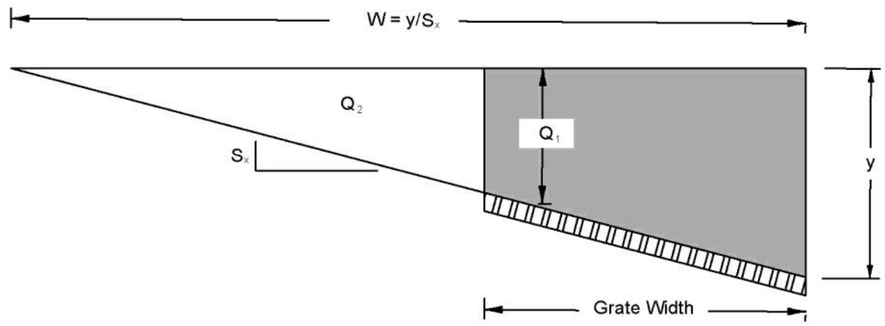


Figure 4-2 Gutter Flow Over a Grate Inlet on Grade

b. Methods for Determining Inlet Capacity – The capacity of the inlet is proportional to the amount of water flowing over the inlet and the length of the inlet.

The flow above the inlet opening is simply calculated as:

$$Q_1 = Q_G - Q_2 \qquad \text{Eq. 4-6}$$

Where: Q_1 = flow above the grate (cubic feet per second)
Q_G = total gutter flow (cubic feet per second)
Q_2 = gutter flow on street side of the grate (cubic feet per second)

The gutter flow on the street side of the grate, Q_2, is calculated by:

$$Q_2 = 0.5572\ (s^{05}\ /\ n)\ z_2\ (y')^{2.667} \qquad \text{Eq. 4-7}$$

Where: $z_2 = 1/S_{x2}$, the transverse slope in the roadway (foot per foot)
y' = depth of flow at the street side of the grate (feet)

The capacity of a non-depressed grate inlet on grade is:

$$Q_{icap} = CF\ [(L_g/L_b)\ Q_1 + Q_L] \qquad \text{Eq. 4-8}$$

Where: Q_{icap} = inlet capacity (cubic feet per second)
CF = Clogging Factor, see Table 4-2
Q_1 = flow above the grate (cubic feet per second)
Q_L = flow intercepted longitudinally by street side of grate (cubic feet per second), given by the standard weir equation:

$$Q_L = 3.0\ (L_g)\ (d')^{1.5} \qquad \text{Eq. 4-9}$$

Where: L_b = length of required clear opening (feet)
L_g = length of clear opening provided (feet). This equation assumes that the bar arrangement does not create splashing and provides 50% opening of the total grate area. When the actual length of bars (L_g) is less than the length needed (L_b), the capacity of the grate is reduces L_g/L_b, otherwise let L_g/L_b = 1 for Q_{icap} calculations.

$$L_b = 0.5V(d + d_b)^{0.5} \qquad \text{Eq. 4-10}$$

Where: V = the mean approach velocity in the grate width (feet per second)

$$V = 2Q_1 / [(W - W')(y - y')] \qquad \text{Eq. 4-11}$$

Where:
y = depth of flow at the curb (feet)
y_b = depth of grate bars (feet)
W = allowable spread (feet)
W' = allowable spread less width of the grate (feet)
y' = depth of flow at the street side of the grate (feet)

c. Design Procedure – the steps to be used in grate inlet design calculations are similar to those described for curb opening inlet design except in Step 4 where inlet length is mentioned, grate size should be substituted.

4.7.2 Sump (Low Point)

a. General – Figure 4A-7 applies when a grate inlet is located in a low point where the water will pond at the grate. The capacity of the grate depends upon the area of the openings, whether the inlet is adjacent to a curb or not (curbed pavement inlets vs. field or parking lot inlets) and the depth of water at the grate.

b. Design Procedure – In general, the following data will be known:

1. A specific grate (size, size openings and size bars)
2. A design discharge, Q.

The steps to be used in grate inlet design are:

1. Compute perimeter

   a. Field or Parking Lot Inlets – Compute the perimeter of the grate opening, P, ignoring the bars. Divide the result by 2. This allows for partial clogging of the grate by assuming that only half of the perimeter will be effective.

   b. Curbed Pavement Inlets – Compute the perimeter of the grate opening using only 3 sides. The side adjacent to the curb is discounted as being unable to permit water flow. Divide this result by 2.

2. Compute the Q/P ratio in either case.

3. For all grate inlets, compute the total area of clear opening, A, excluding the area taken up by bars, and divide by 2. This allows for partial clogging of the grate by assuming that only half of the area will be effective.

4. Compute the Q/A ratio.

5. Enter the chart at the bottom scale using line (a) with the Q/P value and line (b) with the Q/A value and read the required head in feet at the left margin.

6. If the required head falls below 0.4 feet, line (a) only will apply. This is the usual case.

7. If the required head falls above 1.4 feet, line (b) only will apply.

8. If the required head falls between 0.4 feet and 1.4 feet, the actual head will be anywhere between lines (a) and (b) because of the indefinite vortices and eddies over the grate. Use the value that gives the most conservative result, being sure to use line (a) with Q/P and line (b) with Q/A.

4.8 – APPENDIX

4.8.1 References

(1) Louisiana Department of Transportation and Development, “2011 Hydraulics Manual”, 2011

(2) U.S. Department of Transportation, Federal Highway Administration, “Urban Drainage Design Manual, Hydraulic Engineering Circular No. 22, Third Edition”, August 2013

(3) Urban Drainage and Flood Control District, Denver Colorado, “Urban Storm Drainage Criteria Manual, Volume 1”, January 2016

(4) City of Shreveport Department of Public Works, “Drainage Criteria for Storm Sewers and Appurtenances”, April 1975

(5) Haestad Methods, Inc., “Stormwater Conveyance Modeling and Design, First Edition, 2003

(6) City of Austin, Engineering Department, Austin, Texas, “Drainage Criteria Manual”, January 1977

4.8.2 Example Problems

4.8.2.1 EXAMPLE PROBLEM #1: Inlet Spacing (HYDR6000)

GIVEN: A curb and gutter section for a 4-lane street between stations 100+00 and 108+00. The travel lanes are to be 14 feet wide and the cross slope is 0.025 ft/ft. The allowable spread is 14 feet (for one lane to remain open). A plot of the profile is shown below.

Beginning grade: -1.0%	Ending grade: -0.4%
P.I. Station: 102+00	P.I. Station: 106+00
P.I. Elevation: 120.00 ft	P.I. Elevation: 124.00 ft.
400 ft. Vertical Curve	400 ft. Vertical Curve

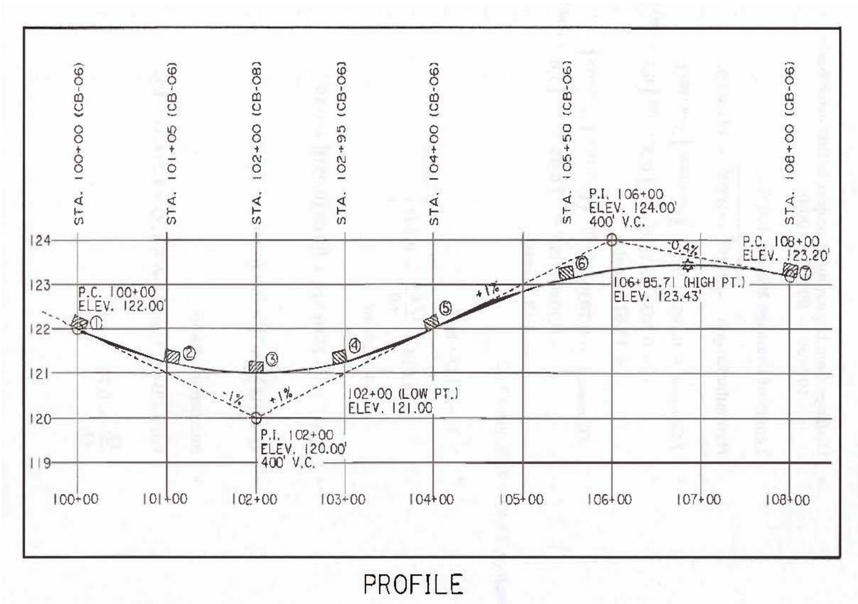


Figure 4-3

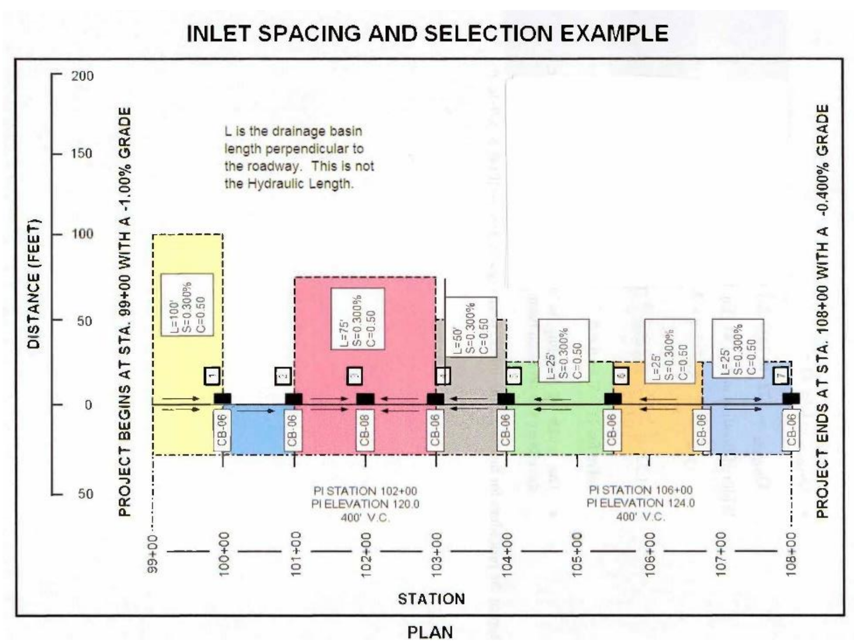
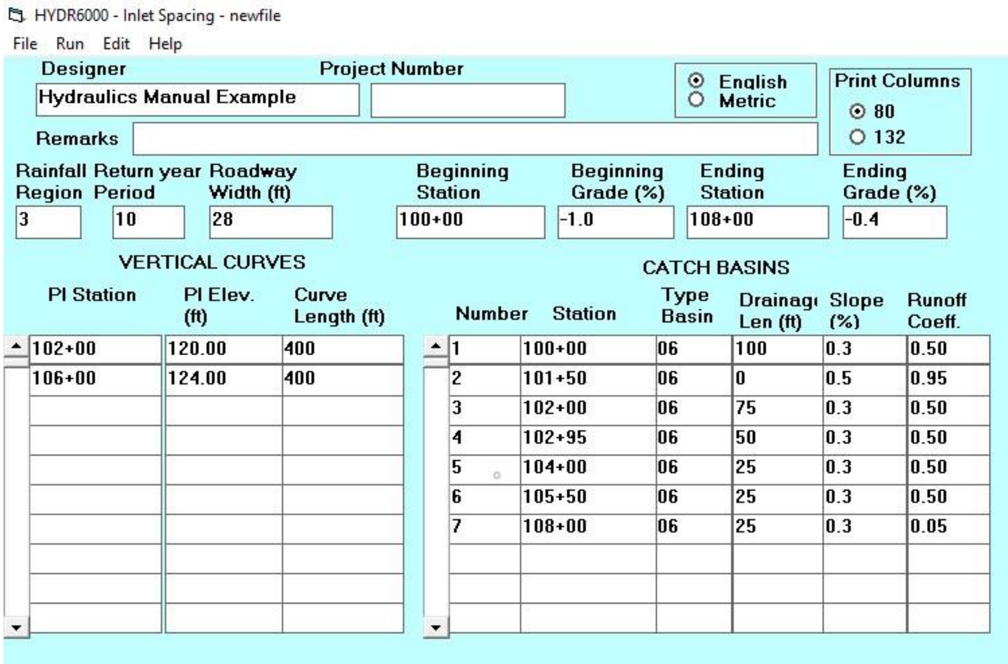


Figure 4-4

FIND: Determine the number of curb inlets needed and the location of these inlets.

SOLUTION: See Figure 4-5 and 4-6 for HYDR6000 inputs and outputs.


HYDR6000 - Inlet Spacing - newfile

File Run Edit Help

Designer: Hydraulics Manual Example

Project Number:

⦿ English ○ Metric

Print Columns: ⦿ 80 ○ 132

Remarks:

Rainfall Region	Return year Period	Roadway Width (ft)	Beginning Station	Beginning Grade (%)	Ending Station	Ending Grade (%)
3	10	28	100+00	-1.0	108+00	-0.4

VERTICAL CURVES

PI Station	PI Elev. (ft)	Curve Length (ft)
102+00	120.00	400
106+00	124.00	400

CATCH BASINS

Number	Station	Type Basin	Drainag Len (ft)	Slope (%)	Runoff Coeff.
1	100+00	06	100	0.3	0.50
2	101+50	06	0	0.5	0.95
3	102+00	06	75	0.3	0.50
4	102+95	06	50	0.3	0.50
5	104+00	06	25	0.3	0.50
6	105+50	06	25	0.3	0.50
7	108+00	06	25	0.3	0.05

Figure 4-5 HYDR6000 INPUT

```
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT      HYDR6000-082098
HYDRAULICS SECTION                                          PAGE    1

DESIGNER: Hydraulics Manual Exampl  DATE: 08-11-2021
STATE PROJECT NUMBER   000-00-0000    REGION: 3
REMARKS:

INPUT:

REGION                     = 3
DESIGN STORM (YEARS)       =     10
NO. OF VERTICAL CURVES     =      2
ROADWAY WIDTH (FEET)       =  28.00
PROJECT BEGIN AT  STATION =       100+00.00
PROJECT END AT STATION     =      108+00.00
GRADE AT THE BEGINNING OF THE PROJECT=    -1.000   PERCENT
GRADE AT THE END OF THE PROJECT       =     -.400   PERCENT


| CURVE  |      PI      |      PI       |
| NUMBER |   STATION    |   ELEVATION   |

     1      102+00.00        120.00
     2      106+00.00        124.00


|---- CATCH BASIN -----|---------- DRAINAGE BASIN -----------|
| NUMBER |   STATION    | TYPE | LENGTH | SLOPE |    RUNOFF    |
|        |              |      | (FEET) |  (%)  | COEFFICIENT |

   1        100+00.00    CB06   100.00    .300        .50
   2        101+50.00    CB06      .00    .500        .95
   3        102+00.00    CB06    75.00    .300        .50
   4        102+95.00    CB06    50.00    .300        .50
   5        104+00.00    CB06    25.00    .300        .50
   6        105+50.00    CB06    25.00    .300        .50
   7        108+00.00    CB06    25.00    .300        .05
```

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LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT      HYDR6000-082098
HYDRAULICS SECTION                                          PAGE    2

DESIGNER: Hydraulics Manual Exampl  DATE: 08-11-2021
STATE PROJECT NUMBER   000-00-0000    REGION: 3
REMARKS:

                  ROADWAY PROFILE
NO. OF VERTICAL CURVES     =      2
ROADWAY WIDTH (FEET)       =  28.00
PROJECT BEGIN AT  STATION =       100+00.00
PROJECT END AT STATION     =      108+00.00
GRADE AT THE BEGINNING OF THE PROJECT=    -1.000   PERCENT
GRADE AT THE END OF THE PROJECT       =     -.400   PERCENT


 VERTICAL CURVE DATA:

CURVE  | LENGTH |    PC     |        PI          |    PT     |   G1    |    G2
NUMBER | (FEET) |  STATION  | STATION   ELEV.   | STATION   |(PERCENT)|(PERCENT

  1     400.00  100+00.00   102+00.00   120.00  104+00.00     -1.000     1.000
  2     400.00  104+00.00   106+00.00   124.00  108+00.00      1.000     -.400

CURVE  | LENGTH |    PI     |      HIGH POINT      |      LOW POINT      |
NUMBER | (FEET) |  STATION  |  STATION   ELEVATION |  STATION  ELEVATION |

  1     400.00   102+00.00                          102+00.00     121.00
  2     400.00   106+00.00   106+85.71     123.43
```

OUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT HYDR6000-082098
YDRAULICS SECTION PAGE 3

ESIGNER: Hydraulics Manual Exampl DATE: 08-11-2021
TATE PROJECT NUMBER 000-00-0000 REGION: 3
EMARKS:

INLET SPACING AND SELECTION
DESIGN STORM = 10 YEARS

RUNOFF COMPUTATIONS:

INLET NO.	INLET TYPE	STATION	DRAINAGE BASIN LENGTH (FT.)	DRAINAGE BASIN WIDTH (FT.)	DRAINAGE BASIN SLOPE (%)	DRAINAGE BASIN AREA (ACRES)	DRAINAGE BASIN RUNOFF COEFF.	TOTAL AREA (ACRES)
1	CB06	100+00.00	100.00	.00	.300	.00	.50	.00
2	CB06	101+50.00	28.00	150.00	.500	.10	.95	.10
3	CB06	102+00.00	75.00	145.00	.300	.25	.50	.34
4	CB06	102+95.00	50.00	105.00	.300	.12	.50	.19
5	CB06	104+00.00	25.00	150.00	.300	.09	.50	.18
6	CB06	105+50.00	25.00	135.71	.300	.08	.50	.17
7	CB06	108+00.00	25.00	114.29	.300	.07	.05	.14

INLET NO.	INLET TYPE	STATION	TOTAL AREA X COEF.	HYDRAULIC LENGTH (FT.)	TIME OF CONC. (MIN.)	RAINFALL INTENSITY (IN./HR.)	Q (CFS)
1	CB06	100+00.00	.000	100.00	11.89	6.21	.000
2	CB06	101+50.00	.092	152.59	6.13	7.65	.701
3	CB06	102+00.00	.213	121.04	12.81	6.03	1.286
4	CB06	102+95.00	.124	116.30	12.61	6.07	.755
5	CB06	104+00.00	.135	152.07	14.01	5.81	.783
6	CB06	105+50.00	.122	138.00	13.49	5.91	.719
7	CB06	108+00.00	.073	116.99	170.89	1.22	.089

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT HYDR6000-082098
HYDRAULICS SECTION PAGE 4

DESIGNER: Hydraulics Manual Exampl DATE: 08-11-2021
STATE PROJECT NUMBER 000-00-0000 REGION: 3
REMARKS:

INLET SPACING AND SELECTION
DESIGN STORM = 10 YEARS

INLET SPACING AND SELECTION:

INLET NO.	INLET TYPE	STATION	Q (CFS)	Q+QBYPASS (CFS)	LONGITUDINAL SLOPE (PERCENT)	WIDTH OF FLOODING (FEET)	INTERCEPTION RATIO
1	CB06	100+00.00	.000	.000	-1.000	.00	.00
2	CB06	101+50.00	.701	.701	-.250	6.95	1.00
3	CB06	102+00.00	1.286	1.286	.000	9.03	1.00
4	CB06	102+95.00	.755	.863	.475	6.66	1.00
5	CB06	104+00.00	.783	.783	1.000	5.58	.86
6	CB06	105+50.00	.719	.719	.475	6.22	1.00
7	CB06	108+00.00	.089	.089	-.400	2.93	1.00

INLET NO.	INLET TYPE	STATION	BYPASS Q (CFS)	BYPASS TO INLET NO.	PROFILE GUTTER ELEV.	REMARKS
1	CB06	100+00.00	.000	2	121.30	INTER RATIO?
2	CB06	101+50.00	.000	3	120.36	
3	CB06	102+00.00	.000	---	120.30	WIDTH FLOOD?
4	CB06	102+95.00	.000	3	120.53	
5	CB06	104+00.00	.108	4	121.30	
6	CB06	105+50.00	.000	5	122.41	
7	CB06	108+00.00	.000	---	122.50	

A RUNOFF COEFFICIENT OF 0.95 WAS USED FOR PAVED ROADWAYS.

Figure 4-6 HYDR6000 OUTPUT

4.8.2.2 EXAMPLE PROBLEM #2: Curb Inlet Capacity – (HYDROFLOW)

GIVEN: A cantilever curb inlet on grade on a local residential street with lane widths of 12.5 feet. The concrete street has a longitudinal slope of 0.75% and a cross slope of 0.025 ft/ft. The length of the cantilever inlet is 10 feet. The maximum allowable spread is to the crown of the street, or 12.5 feet.

FIND: Determine the maximum flow capacity of the inlet to mee the maximum allowable spread on the street.

SOLUTION: The capacity of the cantilever inlet at the maximum allowable spread is 5.75 cfs with 2.774 cfs captured by the inlet and 2.98 cfs bypass. See Figures 4-7 through 4-10 for HYDROFLOW inputs and outputs.

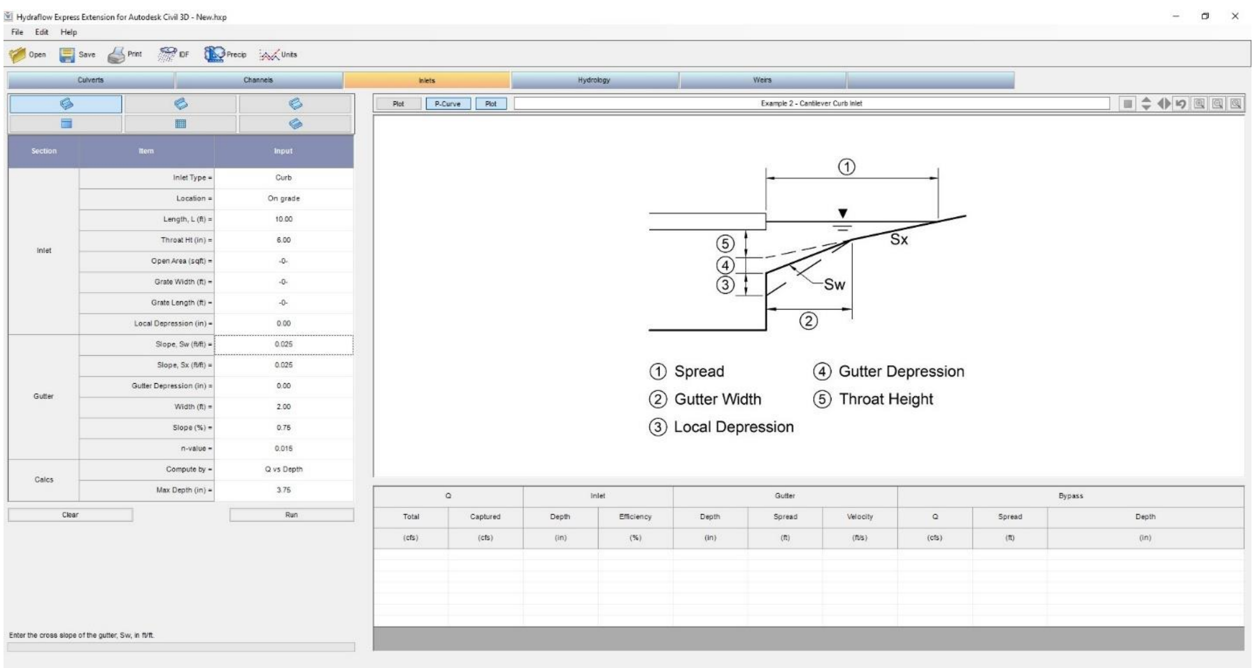


Figure 4-7 HYDROFLOW INPUT

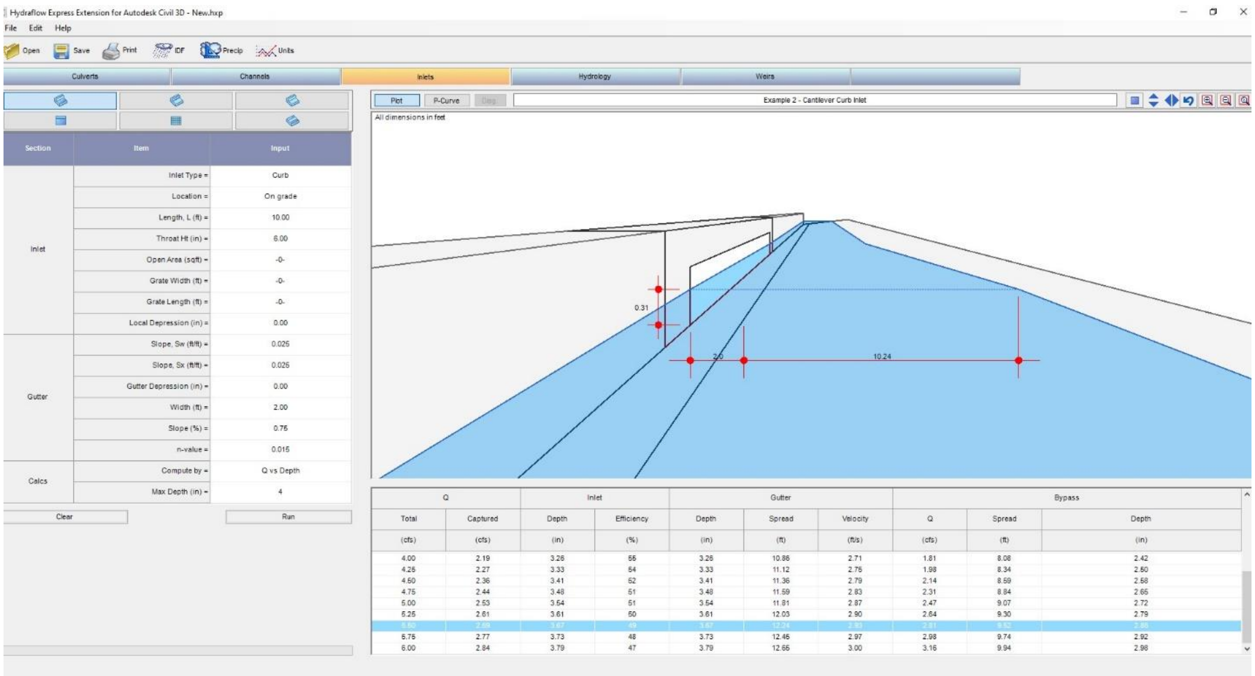


Figure 4-8 HYDROFLOW OUTPUT SCREEN SHOWING HIGHLIGHTED SOLUTION

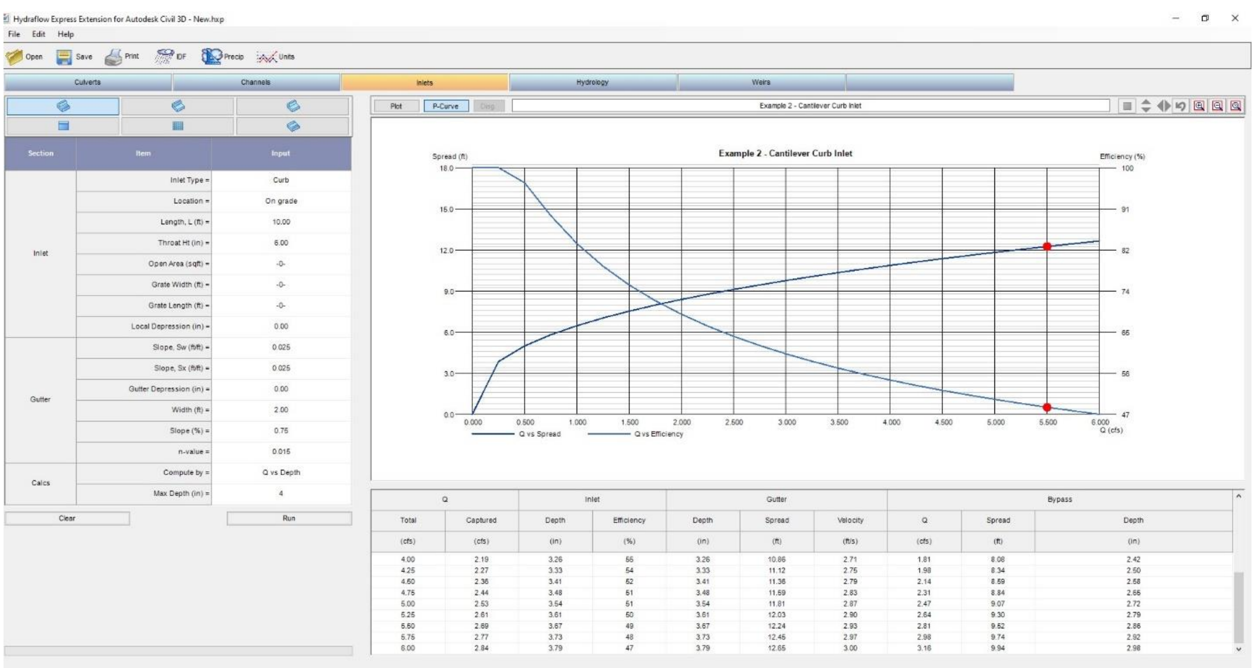


Figure 4-9 HYDROFLOW OUTPUT SCREEN SHOWING PERFORMANCE CURVE

Inlet Report

Hydraflow Express Extension for Autodesk® Civil 3D® by Autodesk, Inc.

Example 2 - Cantilever Curb Inlet

Curb Inlet

Location	= On grade
Curb Length (ft)	= 10.00
Throat Height (in)	= 6.00
Grate Area (sqft)	= -0-
Grate Width (ft)	= -0-
Grate Length (ft)	= -0-

Gutter

Slope, Sw (ft/ft)	= 0.025
Slope, Sx (ft/ft)	= 0.025
Local Depr (in)	= -0-
Gutter Width (ft)	= 2.00
Gutter Slope (%)	= 0.75
Gutter n-value	= 0.015

Calculations

Compute by:	Q vs Depth
Max Depth (in)	= 4

Highlighted

Q Total (cfs)	= 5.50
Q Capt (cfs)	= 2.69
Q Bypass (cfs)	= 2.81
Depth at Inlet (in)	= 3.67
Efficiency (%)	= 49
Gutter Spread (ft)	= 12.24
Gutter Vel (ft/s)	= 2.93
Bypass Spread (ft)	= 9.52
Bypass Depth (in)	= 2.86

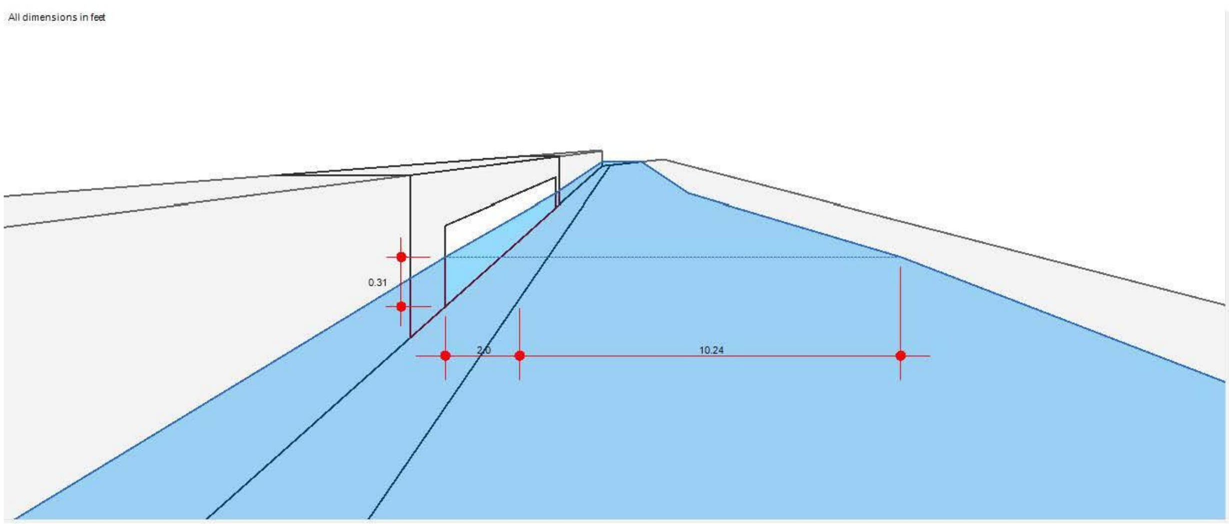


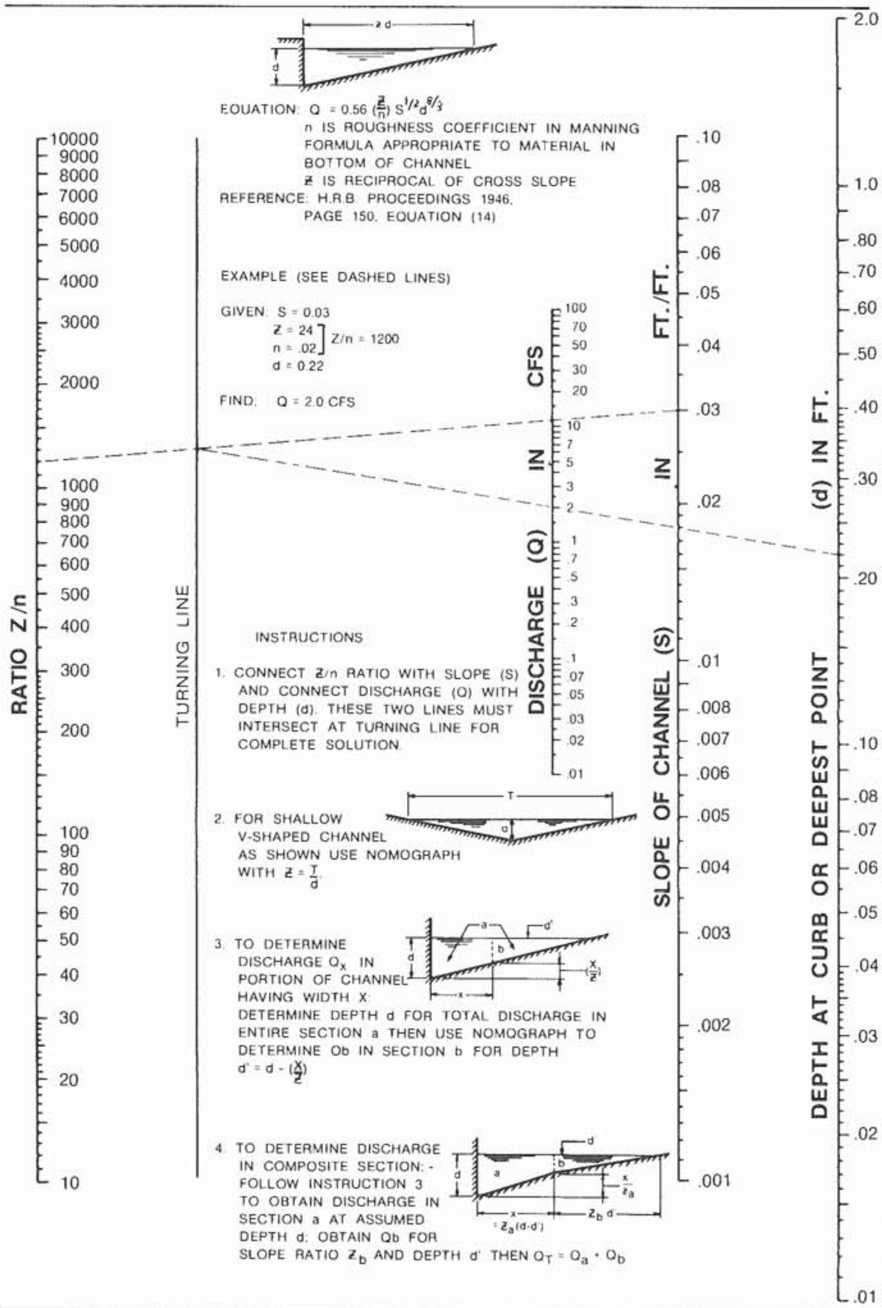
Figure 4-10 HYDROFLOW OUTPUT PRINTED REPORT

4.8.3 Figures

FIGURE 4A-1

	INLET CALCULATIONS	Made by	Date	Job No.
		Checked by	Date	Sheet No.

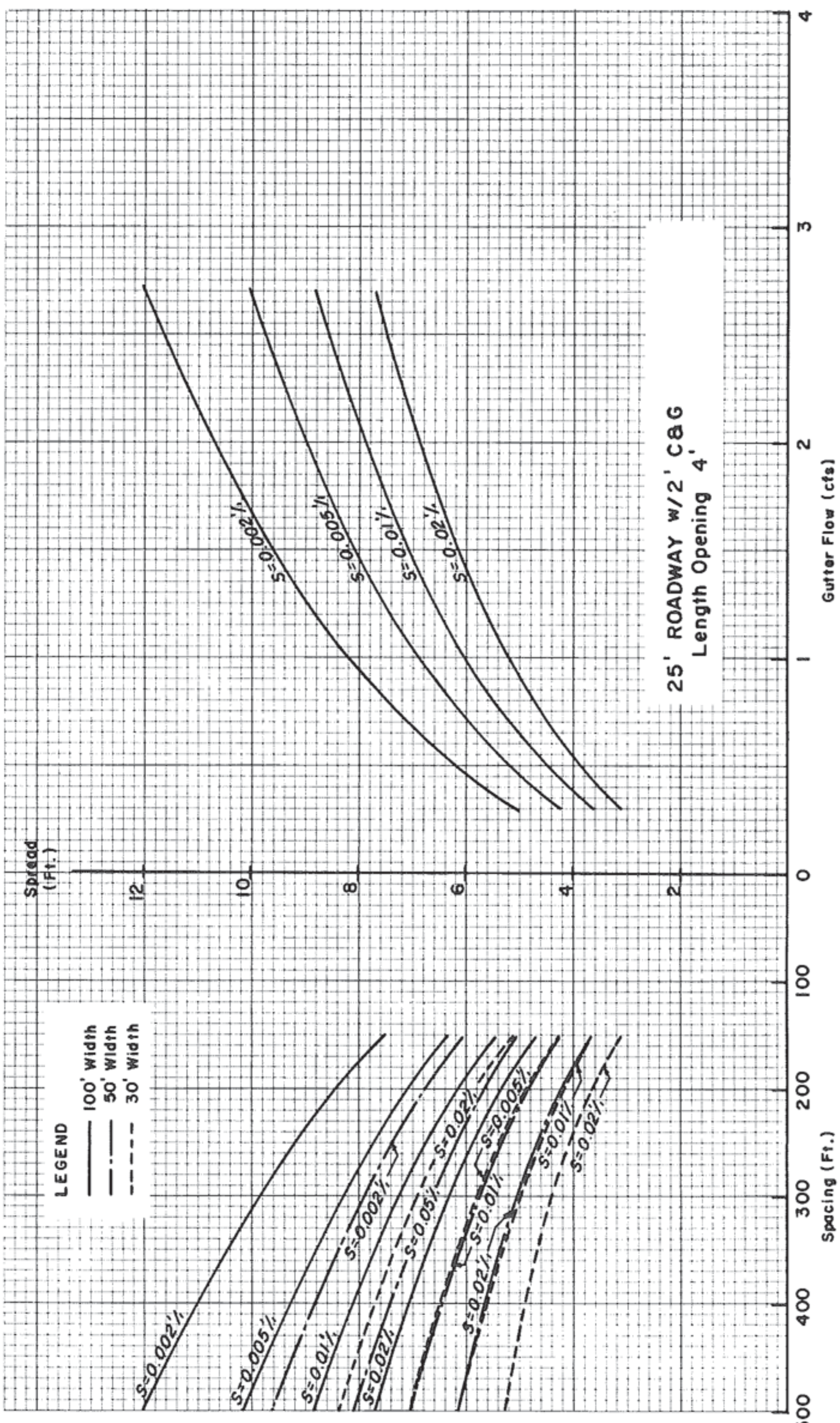
REMARKS ______________________________



Inlet No.	Location	Runoff Discharge: Area A.	C	CA	Tot. CA	Time Min.	I in/hr	Q cfs	Gutter Discharge: L-Sl. ft/ft	X-Sl. ft/ft	By Pass	Q cfs	d ft	Spr'd. ft.	Type	Inlet Discharge: Inter cfs	By Pass	% By Pass

CITY OF SHREVEPORT, LOUISIANA
DEPARTMENT OF PUBLIC WORKS

FIGURE 4A-2

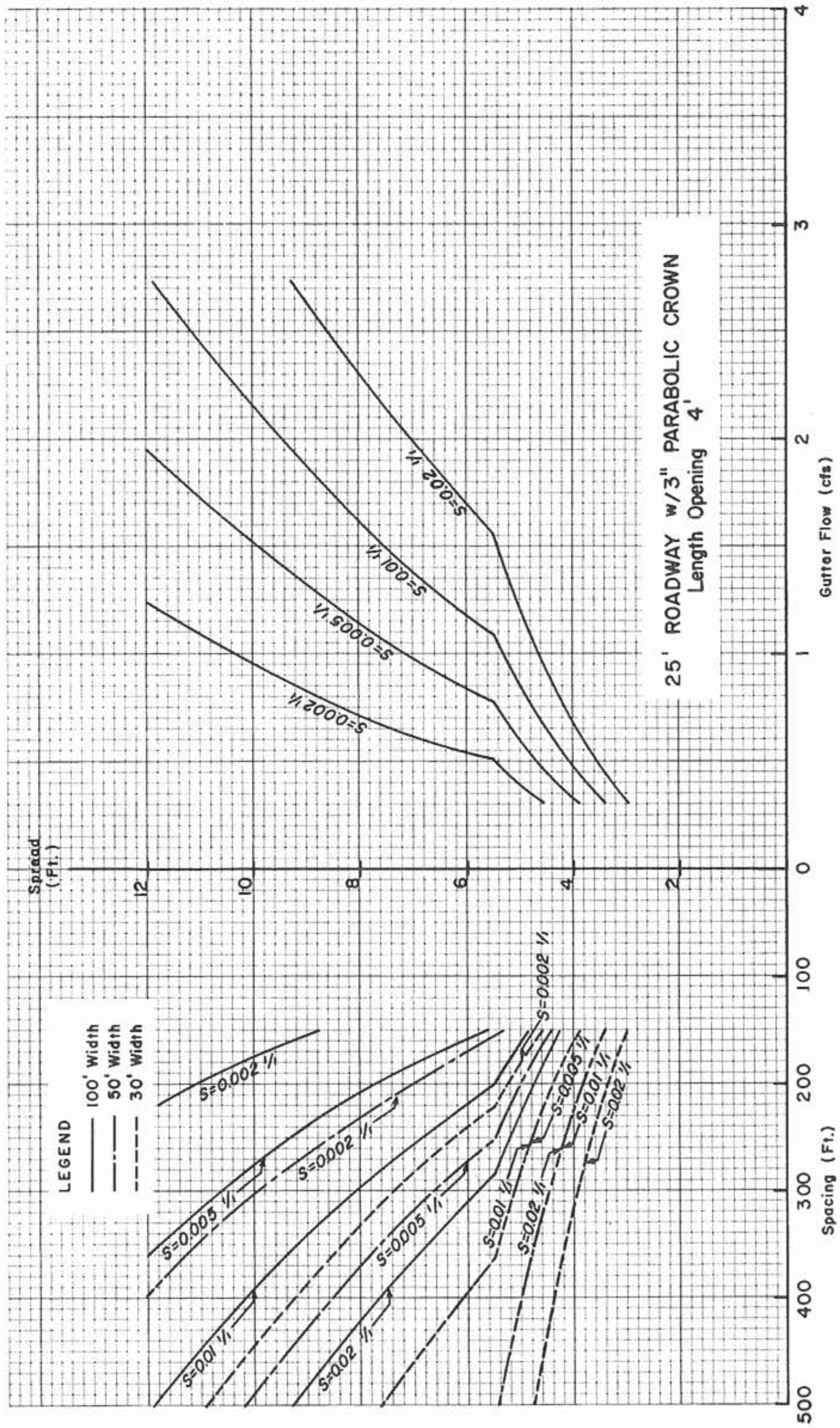


CURB INLET DESIGN CHART

CITY OF SHREVEPORT, LOUISIANA

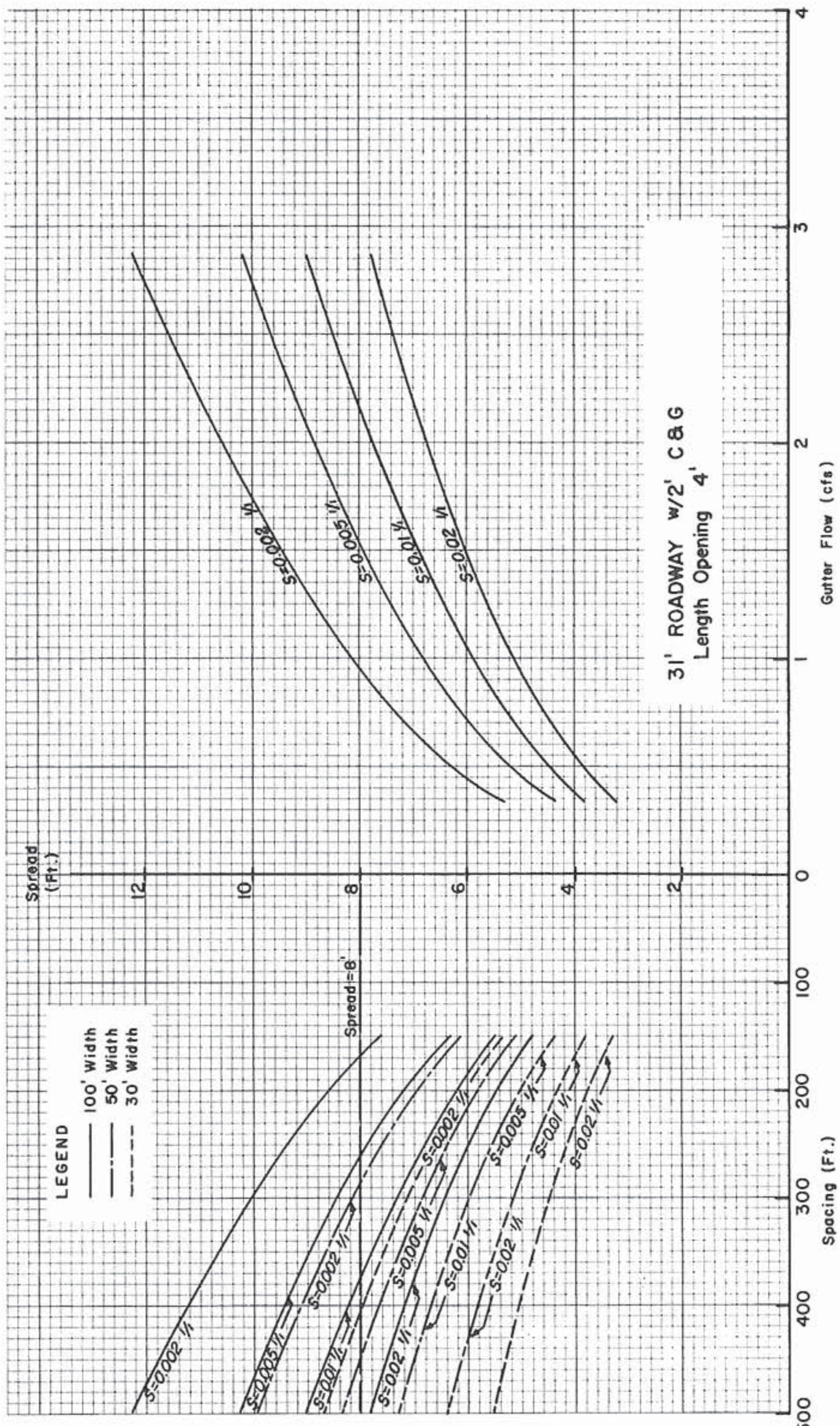
DEPARTMENT OF PUBLIC WORKS

FIGURE 4A-3



CURB INLET DESIGN CHART

FIGURE 4A-4

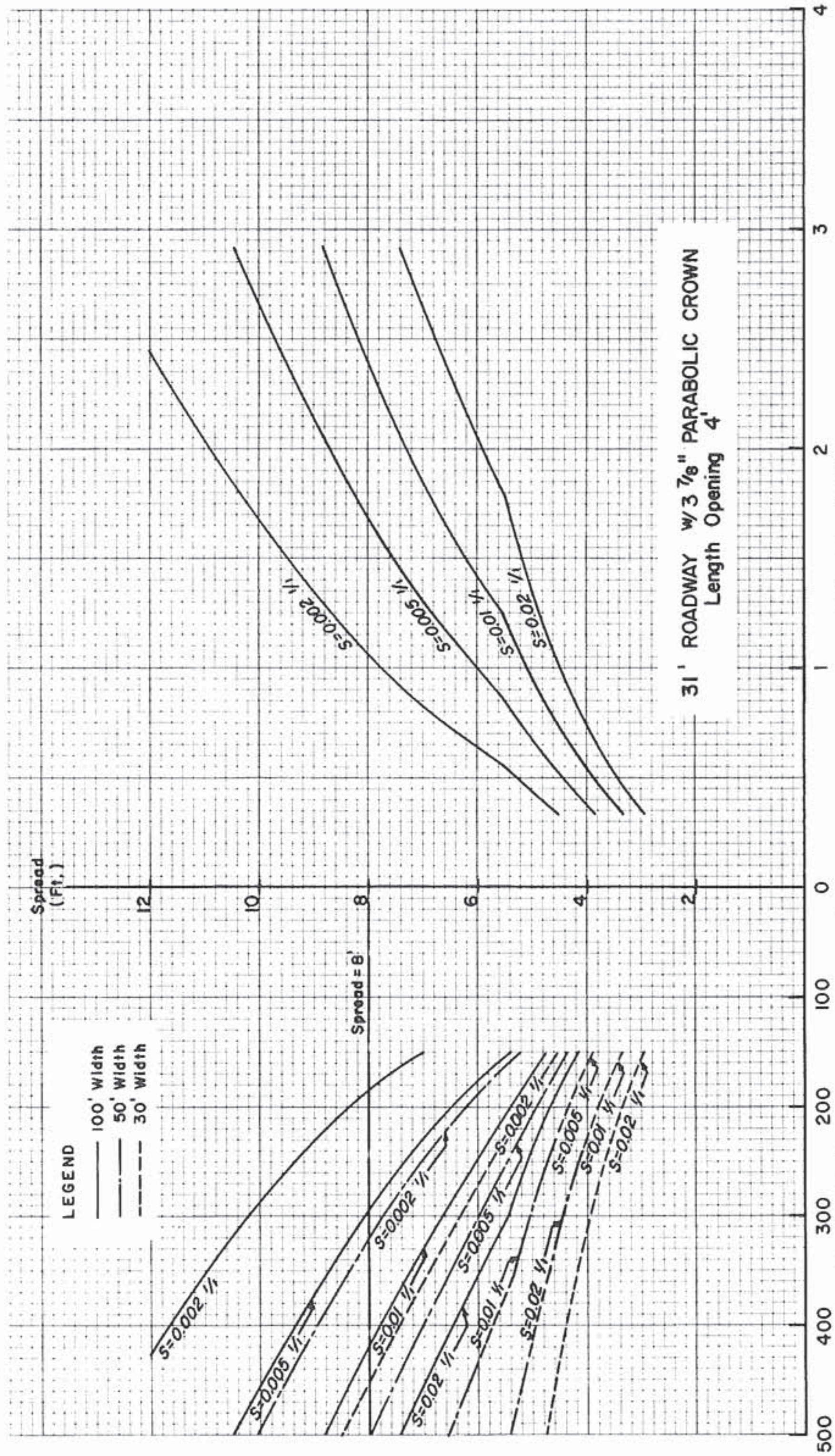


CURB INLET DESIGN CHART

CITY OF SHREVEPORT, LOUISIANA

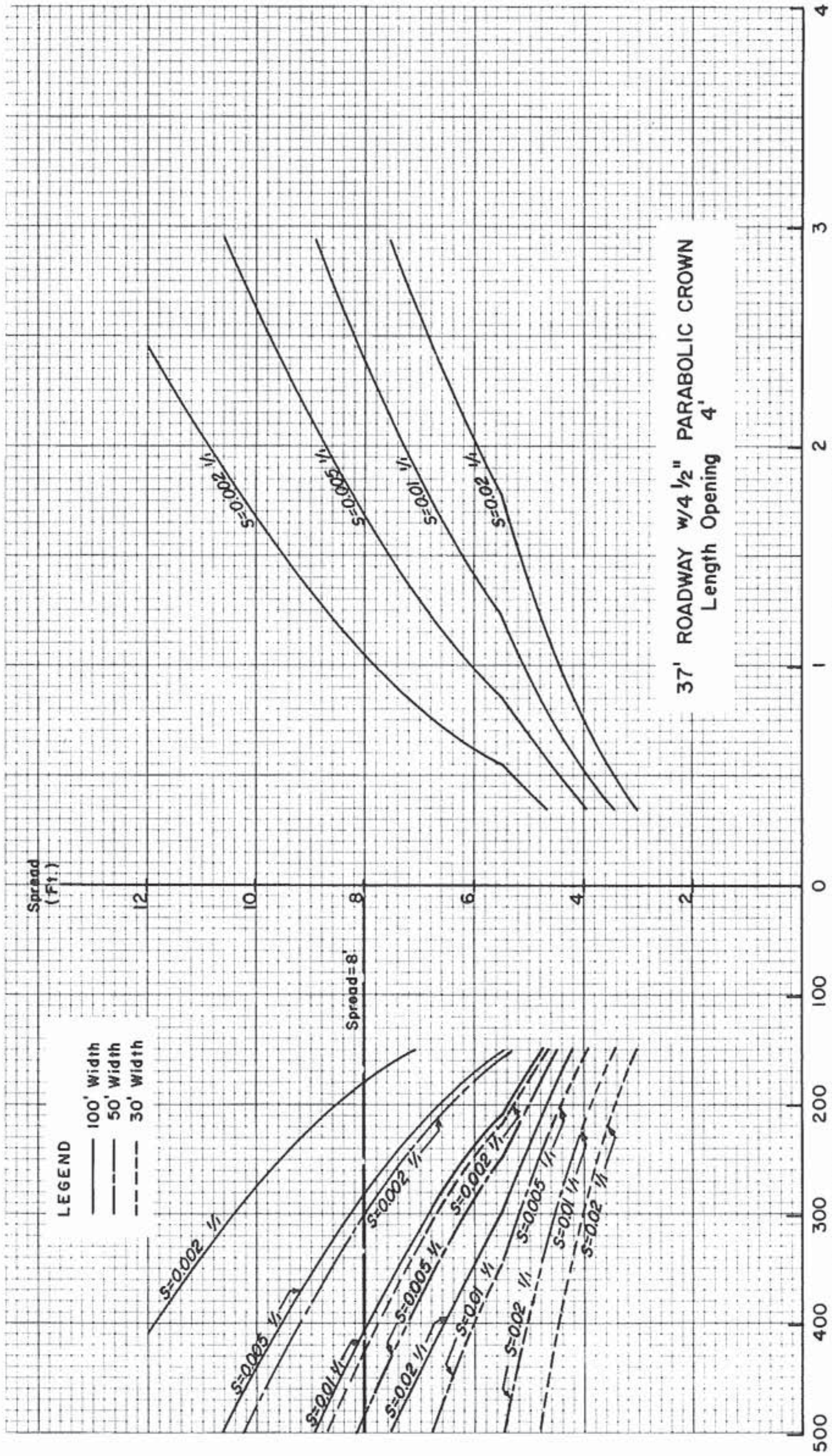
DEPARTMENT OF PUBLIC WORKS

FIGURE 4A-5



CURB INLET DESIGN CHART

FIGURE 4A-6



CURB INLET DESIGN CHART

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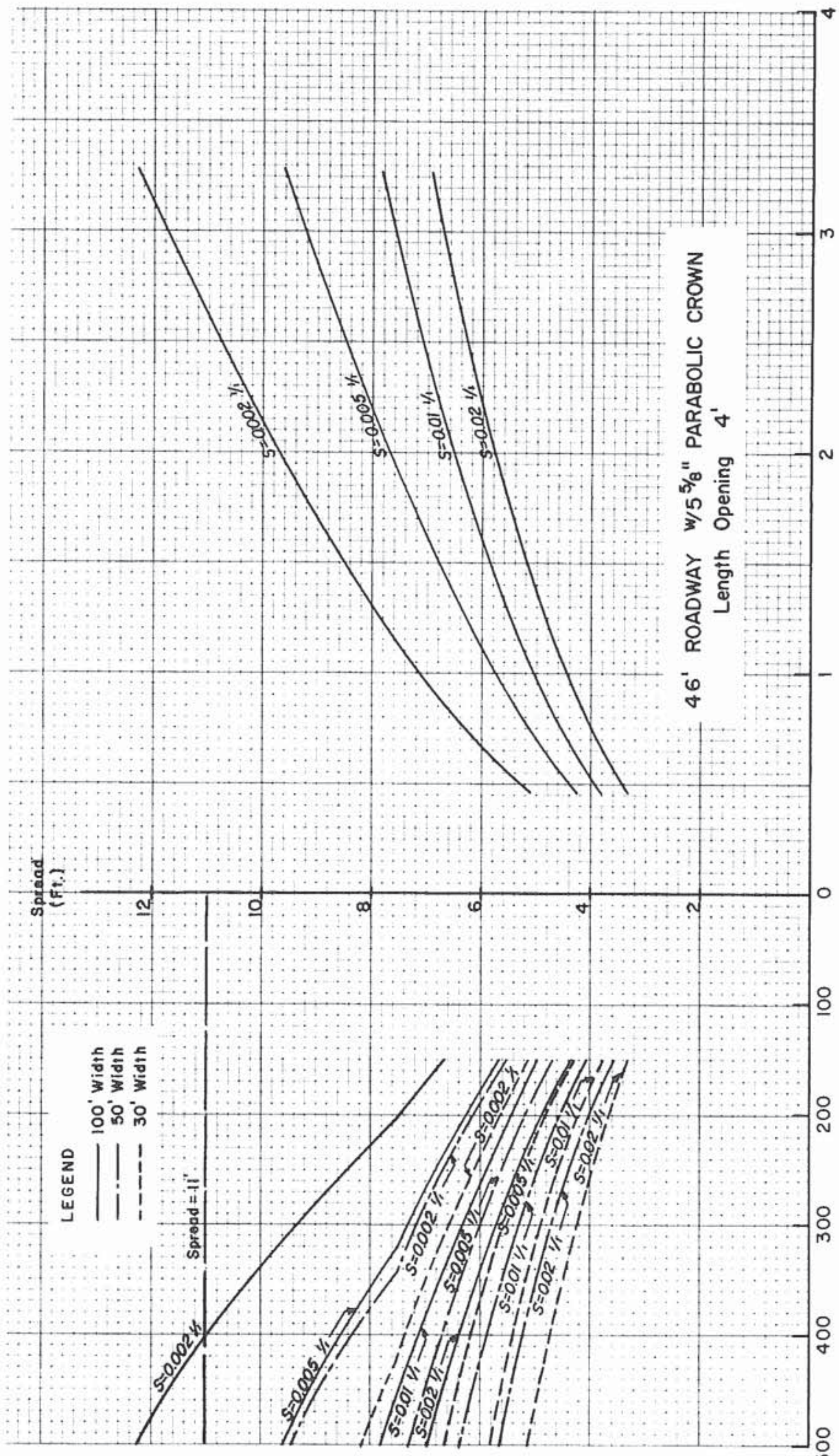
DEPARTMENT OF PUBLIC WORKS

FIGURE 4A-7



CURB INLET DESIGN CHART

CITY OF SHREVEPORT, LOUISIANA

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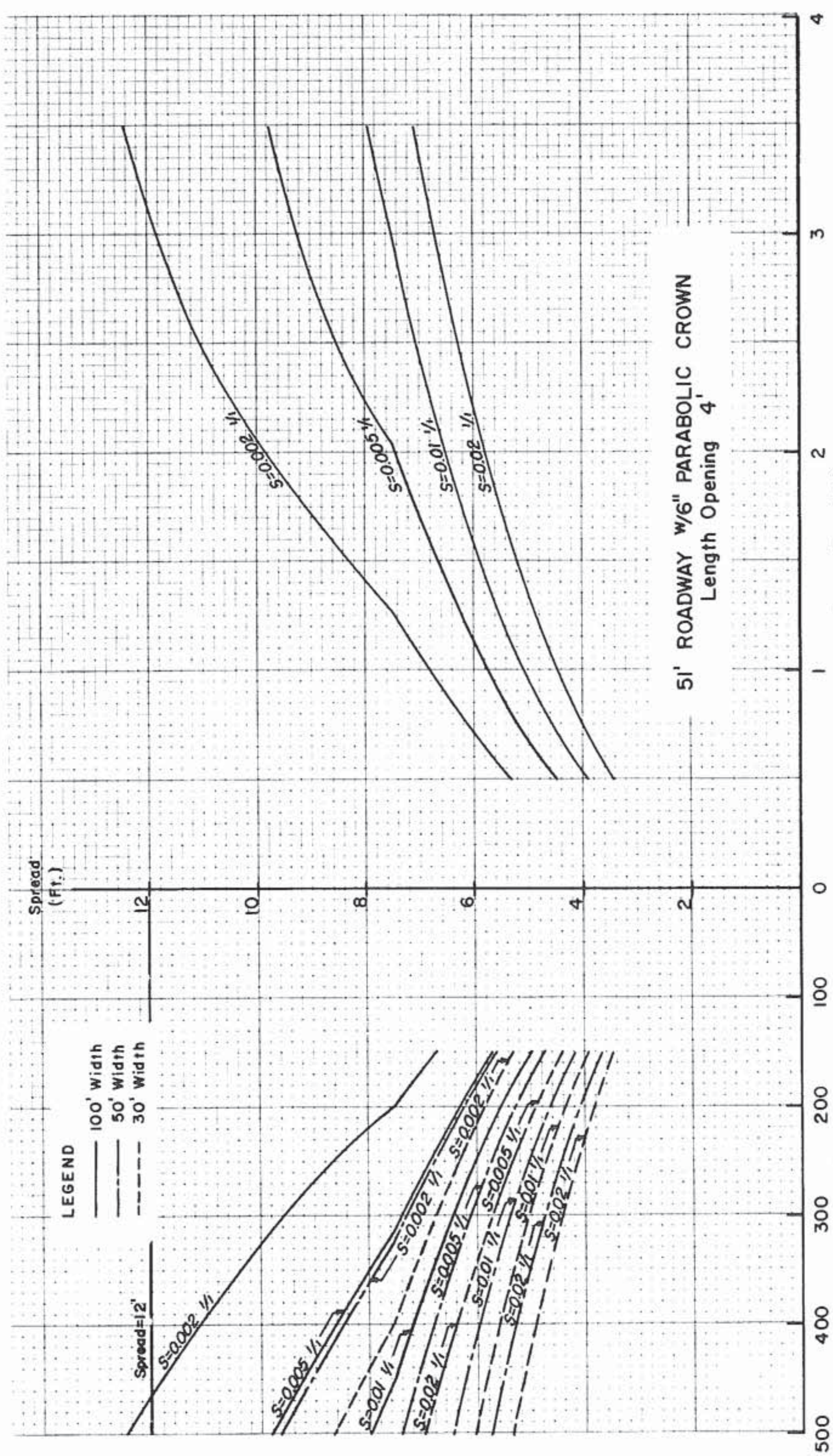
FIGURE 4A-8



CURB INLET DESIGN CHART

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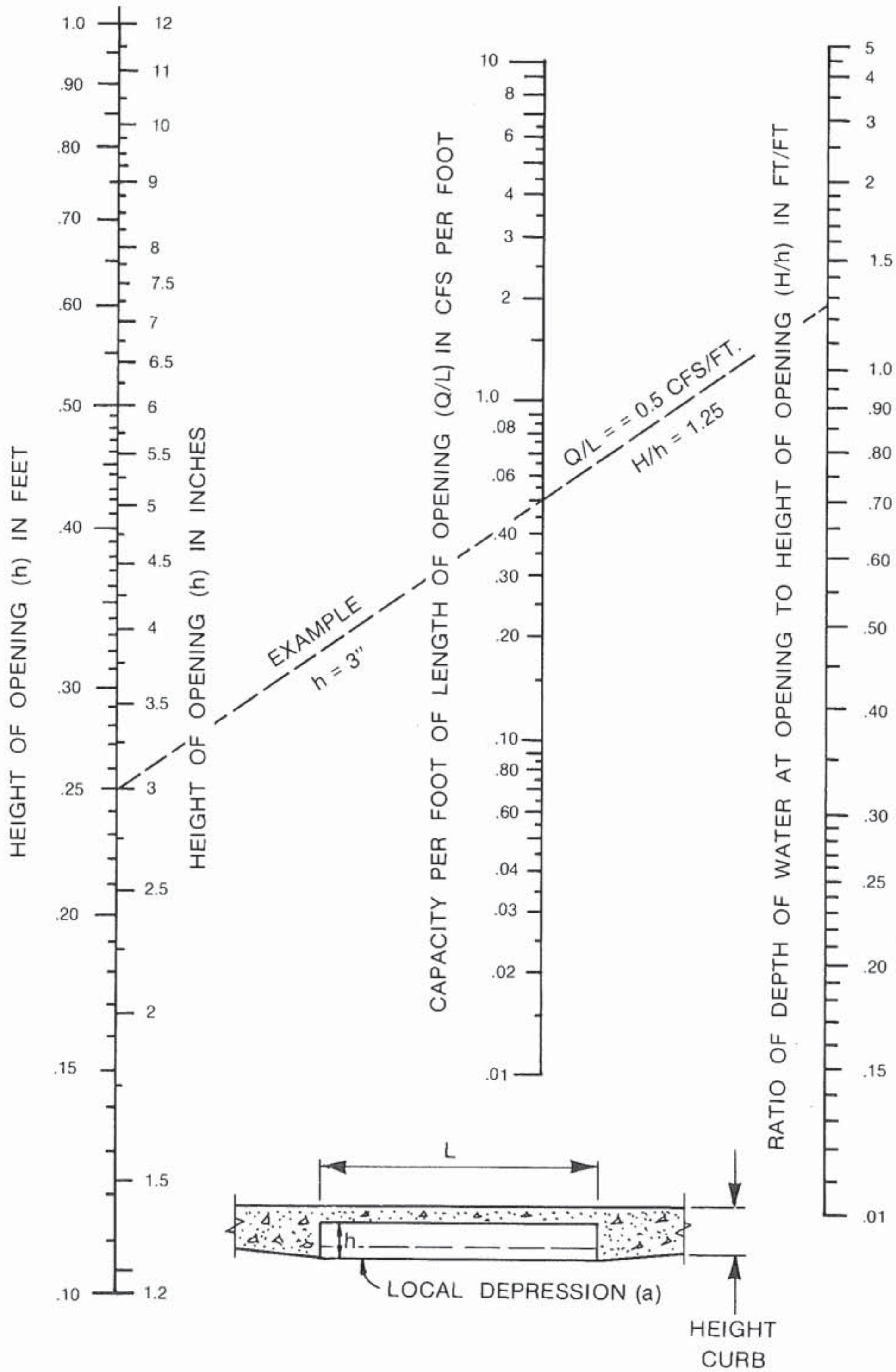
FIGURE 4A-9



CAPACITY OF CURB OPENING INLETS

AT LOW POINT

FIGURE 4A-10

CAPACITY OF GRATE INLET IN SUMP

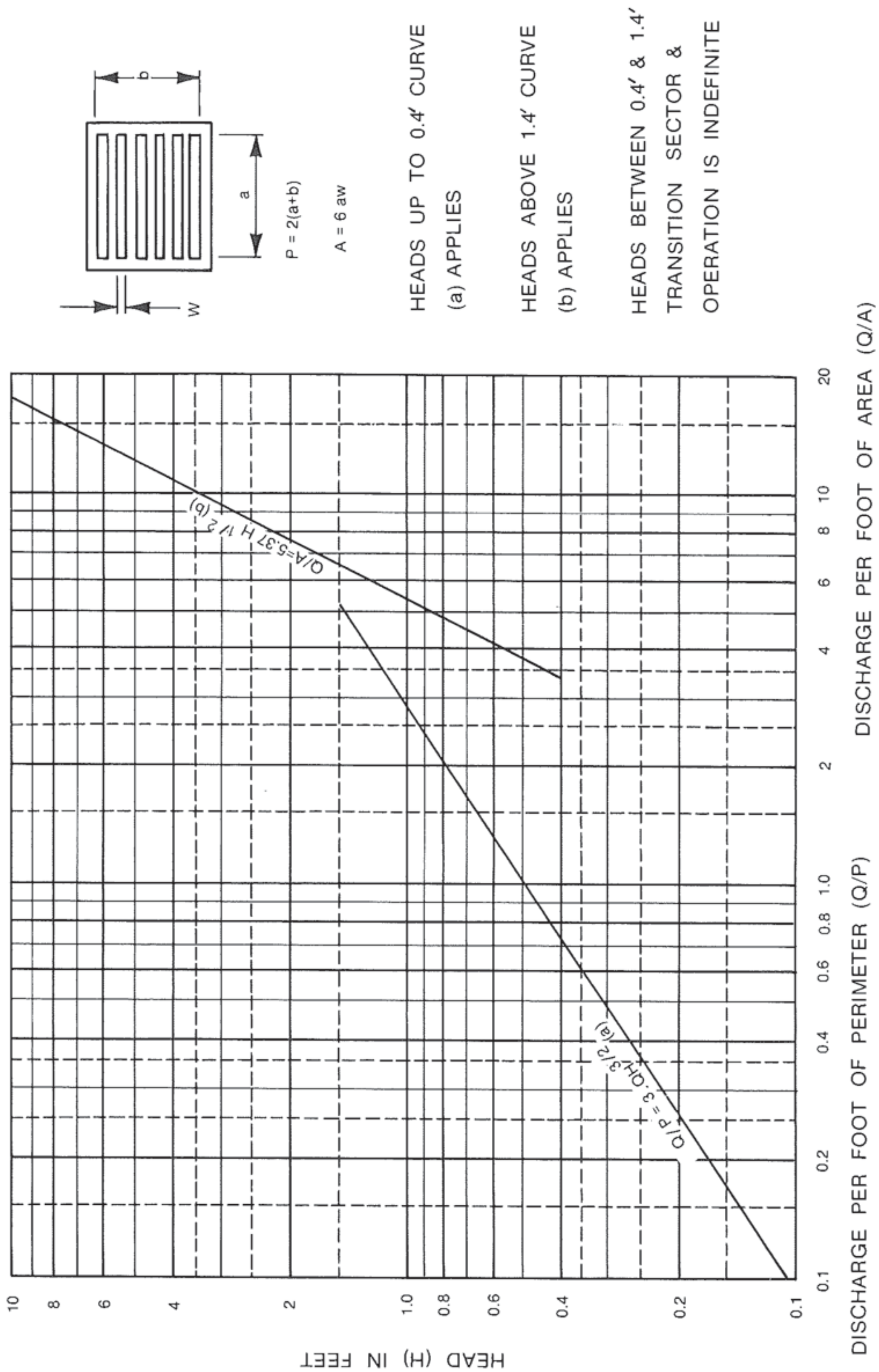


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Table of Contents

Section 5

STORM SEWER DESIGN

5.1 - OVERVIEW

Storm sewers or storm drain pipes shall be used to collect and convey drainage from, across, and through public street rights-of-way, parking lots, and other facilities requiring removal of storm water. The primary function of storm water conveyances is to collect excess storm water from streets, parking lots, open areas, or detention facilities, convey the excess storm water through storm water conveyances and along street right-of-way to discharge into an existing drainage collecting structure or the nearest receiving body of water. The primary objective of the storm sewer system is to prevent flooding of infrastructures and buildings by adequate and efficient routing of rainwater to an outfall. The storm sewer system shall be designed in accordance with the requirements of Chapter 2.3.

SECTION 5.2 - GENERAL CRITERIA

The following items comprise the general criteria for storm sewer drainage:

5.2.1 Rainfall Intensity

Refer to Chapter 2.3 for design frequency.

5.2.2 Minimum Size and Material

The minimum size for all types of storm drain pipes shall be 15-inches. Arch pipe or elliptical pipe may replace round pipe to achieve adequate cover or vertical clearance between pipe and structure of utility. The minimum size for box culvert storm sewers is 4 feet wide by 3 feet high, unless approved by the City Engineer.

Storm drain pipes may be constructed of material shown in Section 3.2 – Pipe Types.

5.2.3 Minimum Cover

Cover over a drainage conduit is from the crown of circular pipe to the top of subgrade and is dependent on the pipe size, material type, expected loads and class of pipe and soil bedding condition.

The cover shall not be less than 18-inches for RCP, RCPA, CMP, CMPA, RPVCP or CPEPDW, 24-inches for PVC.

Reinforced Concrete Box (RCB) sections should normally have a minimum of 12-inches of cover; however, box sections may be designed for direct traffic in special situations with city approval.

5.2.4 Length of Pipe and Manhole/Junction Box Spacing

The maximum length of pipe between access structures (manholes/junction boxes) shall be:

a.	15" pipe	-	150 ft
b.	18" pipe	-	300 ft
c.	24" to 36" pipe	-	400 ft
d.	42" pipe of larger	-	600 ft

5.2.5 Access Structures (Manholes/Junction Boxes)

Manholes or junction boxes shall be placed at all pipe size changes, pipe slope changes, pipe direction changes, and at maximum pipe length locations. Consideration should be given to placing manholes or junction boxes at future collections points.

All manholes and junction boxes are to be reinforced concrete or precast concrete and shall be constructed in accordance with City of Shreveport standard plan details.

5.2.6 Maximum and Minimum Velocities

The minimum velocity within pipe conduits shall be 3 feet per second. This requirement shall protect the ability of the system to convey the design storm by limiting or preventing the accumulation of sediment within closed conduits.

The maximum velocity within pipe conduits shall be 15 feet per second when flowing full. When the velocity is greater than 15 feet per second, the slope of the pipe should be lowered, or the next larger pipe size used until the velocity is less than 15 feet per second.

Slope, along with larger diameter pipes located downstream, must be utilized such that the velocity of flow features a gradual increase, or at a minimum prevent large decreases at changes in geometry and at inlets to prevent sedimentation from occurring.

5.3 Design Procedure

5.3.1 Methods and Computer Software Programs

The hydraulic design of storm sewers shall be analyzed using methods set forth in Chapter 7 in HEC 22: Urban Design Manual. The following is a list of acceptable modeling software:

a. The LADOTD computer program HYDR6020: "Storm Sewer Design"
b. Hydroflow Hydrographs
c. Autodesk Storm and Sanitary Analysis
d. StormCAD
e. other software as approved by the City Engineer

5.3.2 Manual Calculations

Manual calculations can be made using the computation format listed in Section 5.4.

5.3.3 Procedure

The design of a storm sewer system shall be a step by step procedure to optimize design time and plan preparation using the following procedure:

1. Locate all existing drainage structures, storm sewers, ditch systems and utility fixtures which may require consideration.

2. Locate proposed inlets, etc., where required.

3. Layout the proposed conduit system by showing the location of conduits and junction boxes, direction of flow, connection of existing facilities, etc.

4. Calculate the flow, size, and flow lines of each pipe and structure, beginning at the upper end of the system and progressing from structure to structure until the outlet is reached.

5.4 Computation Format

Computations for storm sewers shall be tabulated on a form similar to that shown on Figure 5A-1. The form consists of several sections which are necessary in the design of a storm sewer system as follows:

5.4.1 Pipe Code and Structure

A number is to be assigned to each structure and a like number to the pipe outletting the structure. The location should include the roadway or reference line, the station, and the offset. Type refers to which inlet or manhole is to be used.

5.4.2 Drainage Area and Runoff Coefficients

These values may be obtained from suitable maps and Section 2. Drainage areas and CA values are accumulated as the design proceeds downstream.

5.4.3 Time of Concentration

The Time of Concentration equals the inlet time plus the time of flow in the pipe and accumulates as the design progresses downstream. When two or more branches of a system join, the time of concentration from the junction downstream in the system is based on the longest time of concentration of the joining branches. The time of flow (min.) for a given length of pipe is calculated by dividing the length of pipe (ft.) by the average velocity of flow (ft./min.) in the pipe.

5.4.4 Discharge

This is determined for the Rational Method by multiplying the intensity (I) by the summation of the products of drainage area and runoff coefficients (CA).

5.4.5 Pipe Design

Determine the physical and hydraulic characteristics of the pipe between structures in the system. The diameter, length, slope and invert elevations describe the physical pipe characteristics and the velocity and capacity refer to the hydraulic characteristics of the pipe. All of the above except the length may or may not be a design control and should be investigated separately and in combination with the other variables.

5.4.5.1 Diameter

Pipe sizes in underground systems will be determined by use of the Manning's formula and the Continuity Equation:

$$V = \left(\frac{1.49}{n}\right) R^{2/3} S^{1/2} \qquad Q = AV \qquad \text{Eq. 5-1}$$

where V = mean velocity of flow in feet per second (fps)
n = Manning's coefficient of roughness
R = hydraulic radius (ft.)
S = slope (ft./ft.)
Q = discharge (cfs)
A = area of flow (sq. ft.)

5.4.5.2 Length

The length along the centerline of the pipe from the inside edge of the upper structure to the inside edge of the lower structure. Because hydraulic losses are introduced by changes in alignment in a pipe, such changes should be kept to a minimum. Straight alignments without curves or angular offsets are required.

5.4.5.3 Slope

Slope shall be expressed in percent. All storm sewers shall be designed and constructed to give mean velocities when flowing full of not less than 3 feet per second (fps). Table 5-1 gives minimum slopes for reinforced concrete and corrugated pipe.

Table 5-1 Minimum Pipe Slopes

PIPE DIAMETER (IN.)	MINIMUM SLOPE (%)		
	RCP	PLASTIC PIPES*	CMP
15"	0.28%	0.15%	1.10%
18"	0.22%	0.12%	0.87%
24"	0.15%	0.09%	0.60%

- Smooth Interior Pipes

Minimum slopes for pipes 30" or larger have not been recommended as generally these sized pipes are associated with trunk and main storm sewers and will have sufficient flow in them to maintain a 3 fps velocity. When extenuating circumstances exist which prevent the use of minimum slopes, the City Engineer's concurrence is to be obtained prior to design submittal and a complete explanation of the reasons for the variance shall be included with the design submittal.

It is required to maintain a uniform slope between structures. A junction box or manhole should be placed at the location of a change in slope.

5.4.5.4 Velocity

Refer to section 5.2.6 for minimum and maximum velocities.

5.4.5.5 Capacity

The capacity is the full flow capacity of the pipe at the design slope. The type of material and size of the pipe will affect Manning's coefficient of roughness as shown in Table 5-2.

Table 5-2 Roughness Coefficients

MATERIAL*	ROUGHNESS OR CORRUGATION	MANNING'S "n"
Concrete Pipe	Smooth	0.013
Concrete Boxes	Smooth	0.015
Spiral Rip Metal Pipe	Smooth	0.013
Corrugated Metal Pipe and Pipe-Arch	½" x 2-2/3" Annular	0.025
	½" x 2-2/3" Helical	0.020
	1" x 3"	0.027
	2" x 6" Structural Plate	0.034
	2 ½" x 9" Structural Plate	0.035
Corrugated Polyethylene	Smooth	0.011
Corrugated Polyethylene	Corrugated	0.015
Polyvinyl Chloride (PVC)	Smooth	0.010

*All sizes

5.4.5.6 Invert Elevations

The invert elevation is the flow line of a pipe, the upper invert being the upstream end and the lower invert the downstream end.

It is preferred that the crowns of the pipes entering a junction box match, if possible. If the matching of the pipe crowns at the junction box is not possible, the differential invert elevation between pipes entering and exiting a junction or bend shall adhere to the following criteria:

Condition	**Minimum Elevation Change**
Change in pipe size (All junction angles)	Difference of pipe diameters or heights
No alignment change	0.05' or $\frac{0.2V^2}{2g}$. whichever is greater
90° alignment change	0.10' or $\frac{0.4V^2}{2g}$, whichever is greater
45° alignment change	0.08' or $\frac{0.3V^2}{2g}$, whichever is greater

30° or less alignment change — 0.06' or $\frac{0.2V^2}{2g}$, whichever is greater

5.4.5.7 Conduit Size

Figures 5A-2 through 5A-18 may be used to determine the size conduit required for a given discharge and a given slope for RCP, RCB and CMP. For conduit shapes other than circular or rectangular, or for plastic pipe, the conduit supplier may have these charts available.

5.5 – APPENDIX

5.5.1 References

(1) City of Shreveport, Department of Public Works, “Design Criteria for Storm Sewers and Appurtenances”, April 1975

(2) Louisiana Department of Transportation and Development, “2011 Hydraulics Manual”, 2011

(3) U.S. Department of Transportation, Federal Highway Administration, “Urban Drainage Design Manual, Hydraulic Engineering Circular No. 22, Third Edition”, August 2013

(4) American Concrete Pipe Association, “Concrete Pipe Design Manual”, Third Printing, February 1974

(5) City of Austin, Engineering Department, Austin, Texas, “Drainage Criteria Manual”, January 1977

(6) Haestad Methods, Inc., “Stormwater Conveyance Modeling and Design, First Edition”, 2003

(7) Ft. Wayne, IN, “City Utilities Design Standards Manual Stormwater”, September 13, 2017

5.5.2 Example Problems

5.2.2.1 EXAMPLE PROBLEM #1: Storm Sewer Design (HYDR602)

GIVEN: The layout of a proposed storm sewer system improvement for to serve an existing three city block area of single-family residential area is illustrated below.

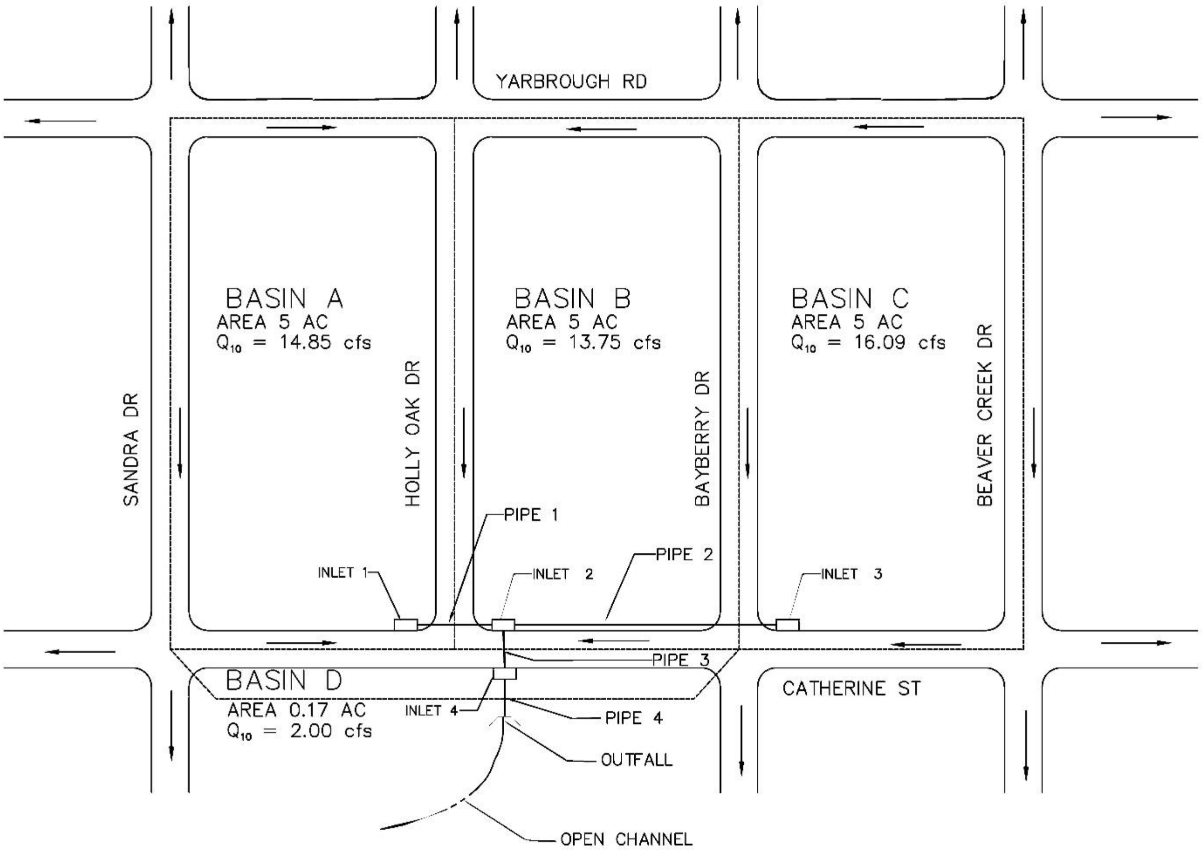

Figure 5-1

FIND: Design the storm sewer pipe system.

SOLUTION: See Figure 5-3 through 5-6 for HYDR6020 inputs and outputs.

PIPE	DIA.	L	SLOPE	VEL.	CAP.	INVERT ELEV.		STREET ELEV.		HGL	
No.	(in.)	(ft.)	(%)	(fps)	(cfs)	Upper	Lower	Upper	Lower	Upper	Lower
1	24	70	0.5	4.73	14.85	207.33	206.98	213.00	212.50	212.30	211.86
2	24	315	0.5	5.12	16.09	208.56	206.99	214.00	212.50	213.83	211.86
3	30	40	0.5	9.10	44.68	206.73	206.53	212.50	212.50	210.58	210.17
4	30	40	0.5	9.51	46.66	206.53	206.33	212.50	210.00	209.47	208.83

Figure 5-2 SUMMARY TABLE

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT HYDR6020-02042000
HYDRAULICS SECTION PAGE 1

DESIGNER: Example No. 1 DATE: 08-12-2021
REMARKS:

STATE PROJECT NUMBER 000-00-0000 REGION: 3

STORM SEWER DESIGN
DESIGN STORM = 10 YEARS
DESIGN STAGE ELEVATION AT OUTFALL = 205.75

INPUT DATA:

LIN NUM	UPP END	LOW END	PIPE LEN (FT)	DRAINAGE HYDL (FT)	DRAINAGE SLOP (%)	DRAINAGE AREA ACRES	RUN OFF COEF	TIME OF CONC	CONST SLOPE FT/FT	PIPE DIAM (IN)	FLOW LINE ELEVATION UPPER	FLOW LINE ELEVATION LOWER	STREET ELEV. (FT)
1	0	2	70	900	1	5	0.60	20	0.005	24	207.33	0	213.0
2	1	2	315	775	0.85	5	0.65	20	0.005	24	208.56	0	214.0
3	2	3	40	825	0.95	5	0.60	20	0.005	30	0	0	212.50
4	3	999	40	330	0.50	0.45	0.95	6	0.005	30	0	0	212.50

Figure 5-3 HYDR6020 INPUT

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT HYDR6020-02042000
HYDRAULICS SECTION PAGE 2

DESIGNER: Example No. 1 DATE: 08-12-2021
REMARKS:

STATE PROJECT NUMBER 000-00-0000 REGION: 3

STORM SEWER DESIGN
DESIGN STORM = 10 YEARS
DESIGN STAGE ELEVATION AT OUTFALL = 205.75

OUTPUT RESULTS - PART 1

LINE NO.	STRUCTURE UPPER END	STRUCTURE LOWER END	PIPE LENGTH (FT)	DRAINAGE AREA DIST (FT)	DRAINAGE AREA SLOPE (%)	DRAINAGE AREA INCR. (ACRE)	DRAINAGE AREA TOTAL (ACRE)	RUNOFF COEFF.	ACRES X COEFF INCR.	ACRES X COEFF TOTAL
1	0	2	70.0	900.0	1.00	5.00	5.00	.60	3.00	3.00
2	1	2	315.0	775.0	.85	5.00	5.00	.65	3.25	3.25
3	2	3	40.0	825.0	.95	5.00	15.00	.60	3.00	9.25
4	3	999	40.0	330.0	.50	.45	15.45	.95	.43	9.68

OUTPUT RESULTS - PART 2

LINE NO.	STRUCTURE UPPER END	STRUCTURE LOWER END	TRAVEL TIME IN PIPE	TIME OF CONCEN.	RAIN-FALL INTENS.	CONST. SLOPE (FT/FT)	REQD. HYDR. SLOPE	Q CAPAC. (CFS)	CONST CLEAR (FT)
1	0	2	.25	20.00	4.95	.0050	.0037	17.33	2.75
2	1	2	1.03	20.00	4.95	.0050	.0043	17.33	2.52
3	2	3	.07	21.03	4.83	.0050	.0101	31.42	2.27
4	3	999	.07	21.10	4.82	.0050	.0110	31.42	2.47

Figure 5-4 HYDR6020 OUTPUT TABLE PART 1 AND 2

LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT HYDR6020-02042000
HYDRAULICS SECTION PAGE 3

DESIGNER: Example No. 1 DATE: 08-12-2021
REMARKS:

STATE PROJECT NUMBER 000-00-0000 REGION: 3

STORM SEWER DESIGN
DESIGN STORM = 10 YEARS
DESIGN STAGE ELEVATION AT OUTFALL = 205.75

OUTPUT RESULTS - PART 3

LINE NO.	STRUCTURE UPPER END	STRUCTURE LOWER END	Q (CFS)	PIPE DIAM (IN)	V FT/SEC	VELOC. HEAD (FT)	FRICT. LOSS (FT)	JUNCTION LOSS (FT)	HYDRAULIC GRADE LINE ELEVATION UPPER	HYDRAULIC GRADE LINE ELEVATION LOWER
1	0	2	14.85	24	4.73	.35	.26	.17	212.30	211.86
2	1	2	16.09	24	5.12	.41	1.36	.61	213.83	211.86
3	2	3	44.68	30	9.10	1.29	.40	1.29	210.58	210.17
4	3	999	46.66	30	9.51	1.40	.44	.70	209.47	208.83

OUTPUT RESULTS - PART 4

LINE NO.	STRUCTURE UPPER END	STRUCTURE LOWER END	FLOW LINE ELEVATION UPPER	FLOW LINE ELEVATION LOWER	STREET ELEV (FT)	HYDRAULIC CLEARANCE (FT)	REMARKS
1	0	2	207.33	206.98	213.00	.70	
2	1	2	208.56	206.99	214.00	.17	
3	2	3	206.73	206.53	212.50	1.92	
4	3	999	206.53	206.33	212.50	3.03	

EXIT LOSS = .00
MANNING'S ROUGHNESS COEFFICIENT OF .012 USED.
1.0 VELOCITY HEAD WAS USED FOR LOSSES AT MANHOLES.
ROADWAY THICKNESS= 8.0 INCHES.

Figure 5-5 HYDR6020 OUTPUT TABLE PART 3 AND 4

5.2.2.2 EXAMPLE PROBLEM #1: Storm Drain Pipe Capacity (HYDROFLOW)

GIVEN:	24-inch PVC	24-inch RCP
	Slope (s) = 0.75%	Slope (s) = 0.75%
	N-value = 0.010	N-value = 0.013

FIND: Calculate and compare the flow capacity of each pipe.

SOLUTION:	24-inch PVC	24-inch RCP
	Q = 27.15 cfs	Q = 20.88 cfs
	Velocity (V) = 9.11 fps	Velocity (V) = 7.01 fps

See Figures 5-6 through 5-9 for HYDRFLOW inputs and outputs.

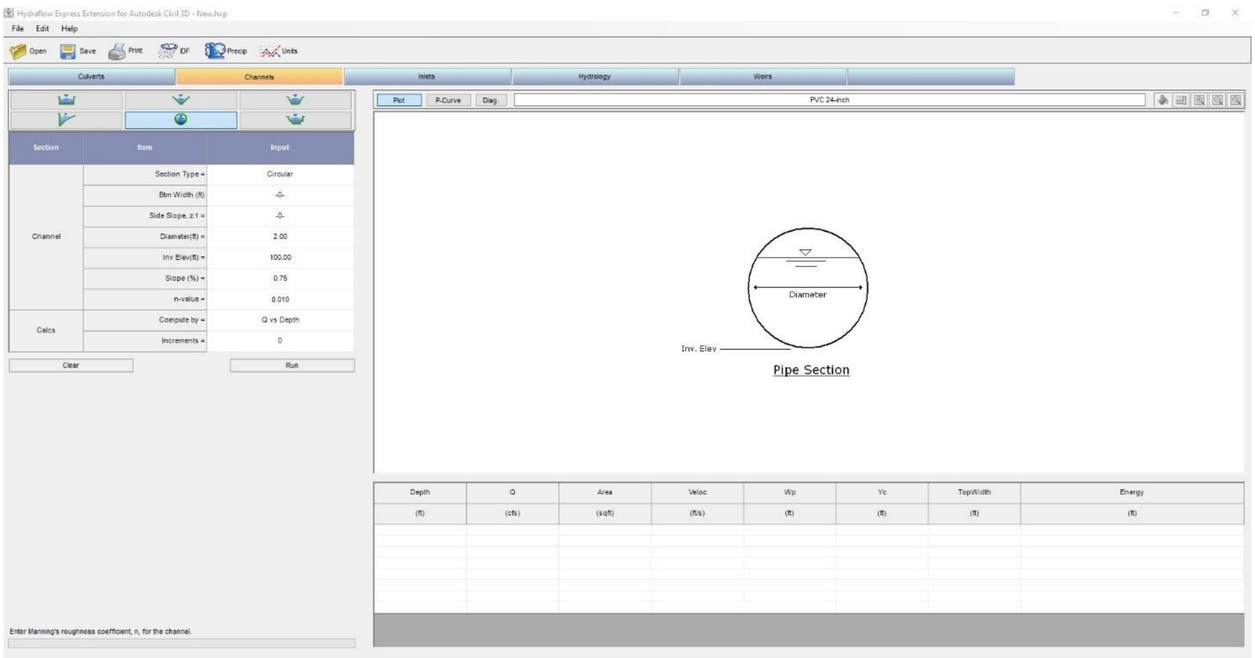

Figure 5-6 HYDRFLOW INPUT (24-inch PVC)

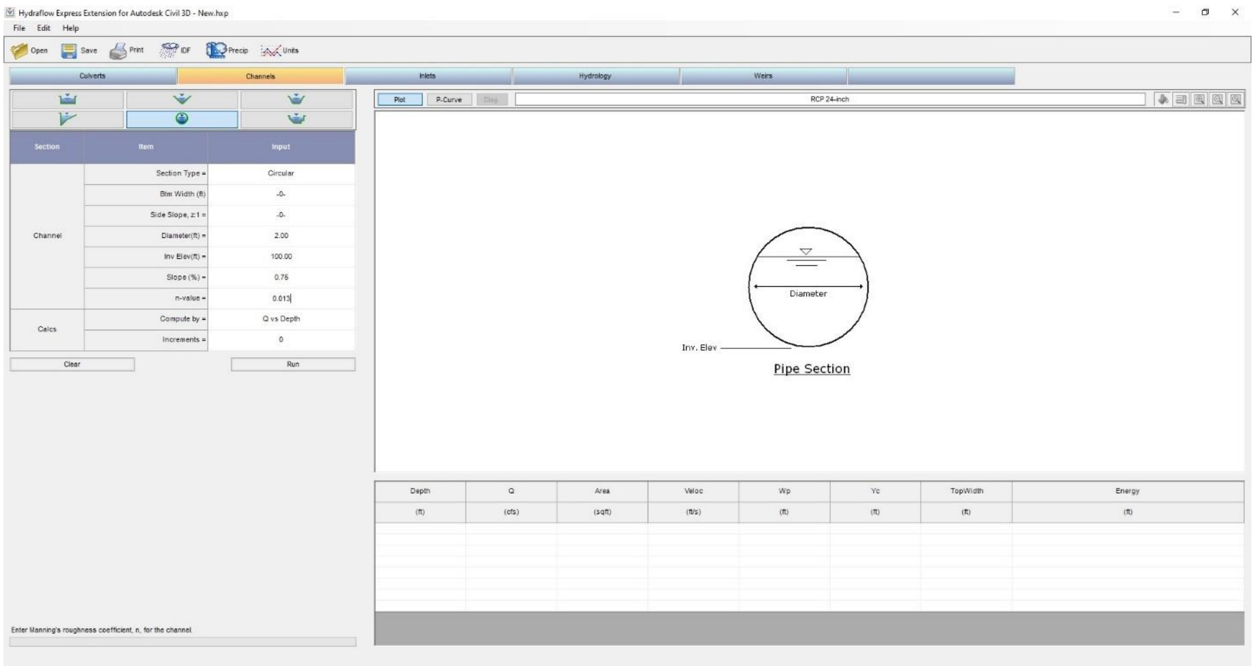

Figure 5-7 HYDRFLOW INPUT (24-inch RCP)

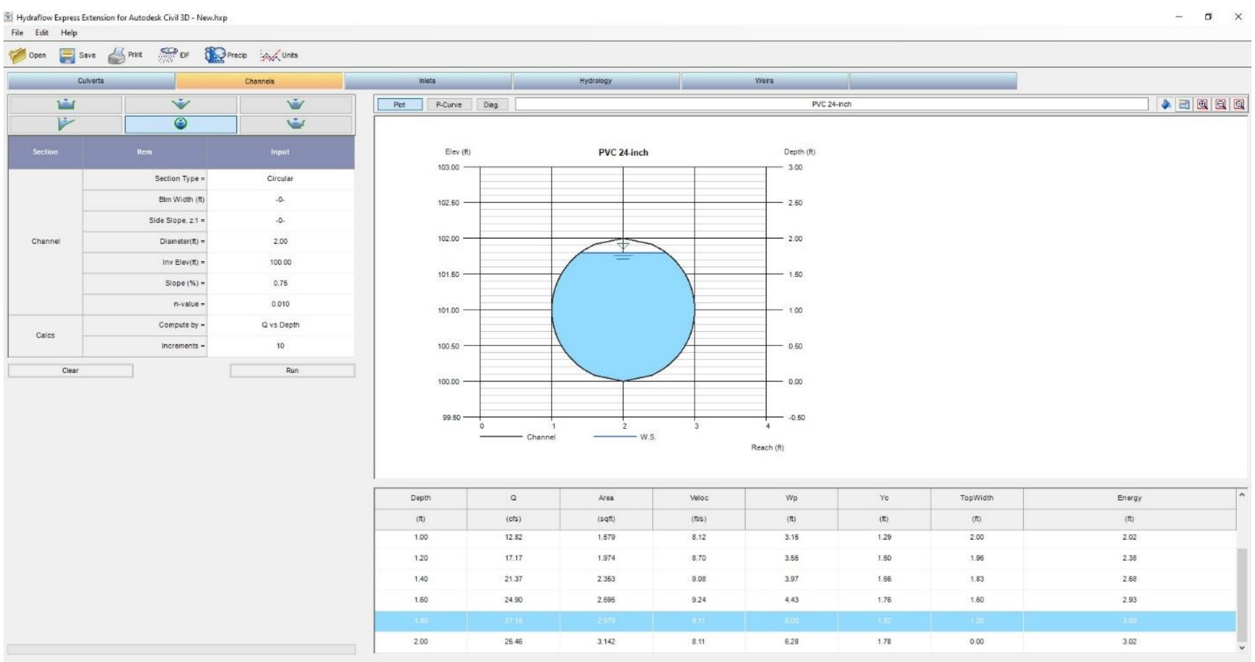

Figure 5-8 HYDRFLOW OUTPUT (24-inch PVC)

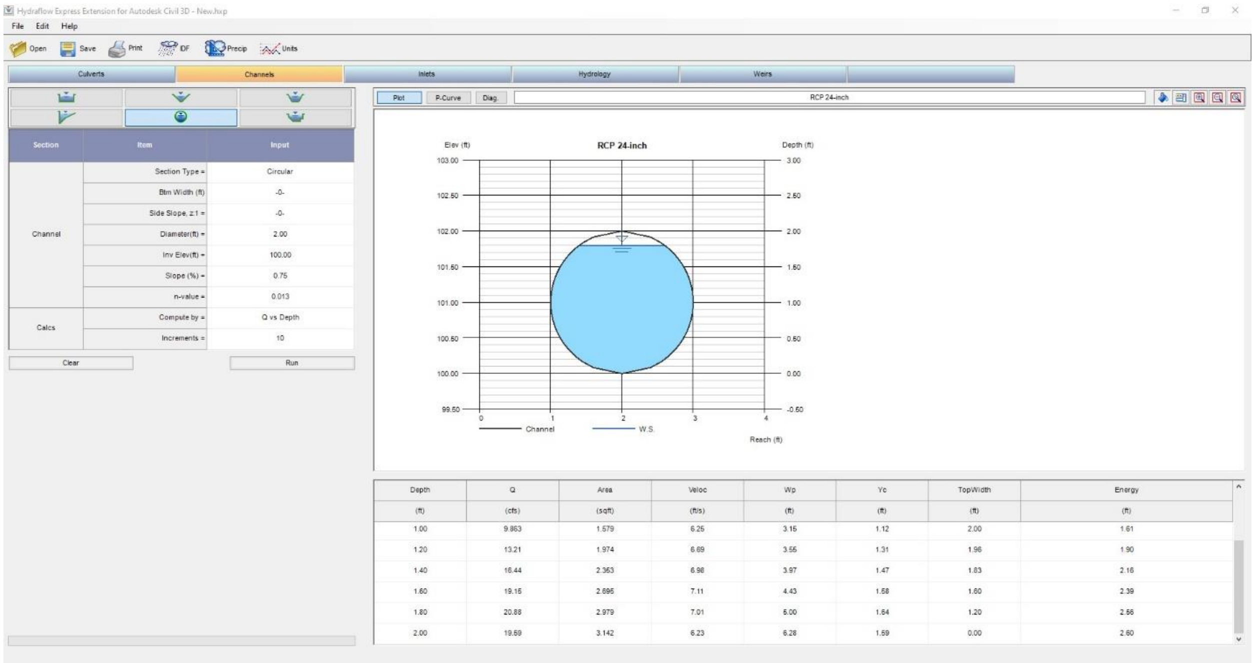

Figure 5-9 HYDRFLOW OUTPUT (24-inch RCP)

5.5.3 Figures

FIGURE 5A-1

DRAINAGE CALCULATIONS FOR ______________________

MADE BY ________ DATE ________ JOB NO ________
CHECKED BY ________ DATE ________ SEC NO ________
SHEET NO ________

PIPE CODE	STRUCTURE			DRAINAGE AREA			RUNOFF COEFFICIENT				TIME		DISCHARGE		PIPE DESIGN							REMARKS
	CODE	LOCATION	TYPE	ΔA Acres	$\Sigma\Delta A$ Acres	ΣA Acres	C	ΔCA	$\Sigma\Delta CA$	Wt.C	Δt (Min.)	Σt (Min.)	i (in/hrs)	Q (cfs)	DIA. (in.)	L (feet)	SLOPE (%)	VEL. (fps)	CAP. (cfs)	INVERT. ELEVATION Upper	Lower	

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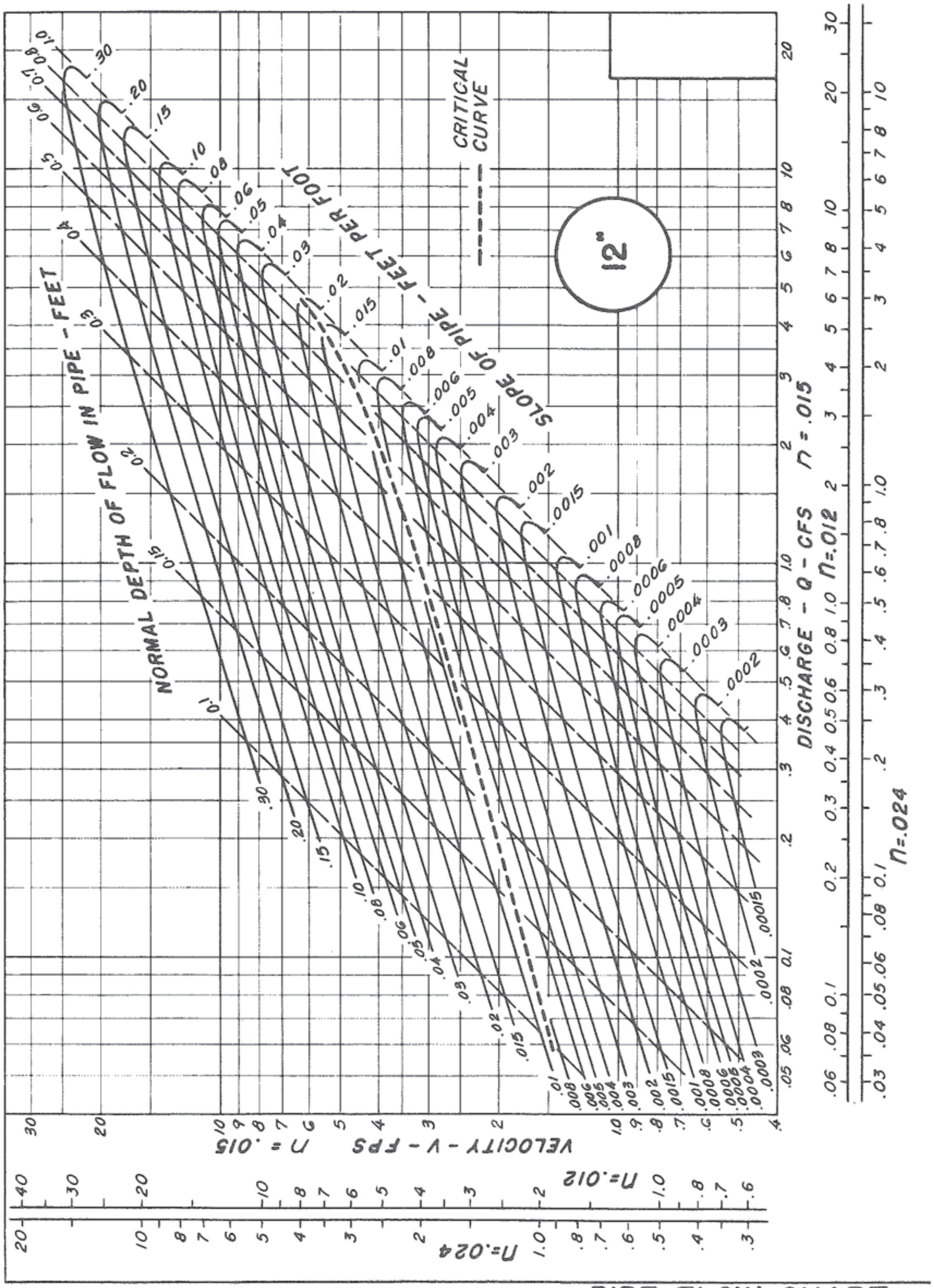
FIGURE 5A-2



PIPE FLOW CHART
12-INCH DIAMETER

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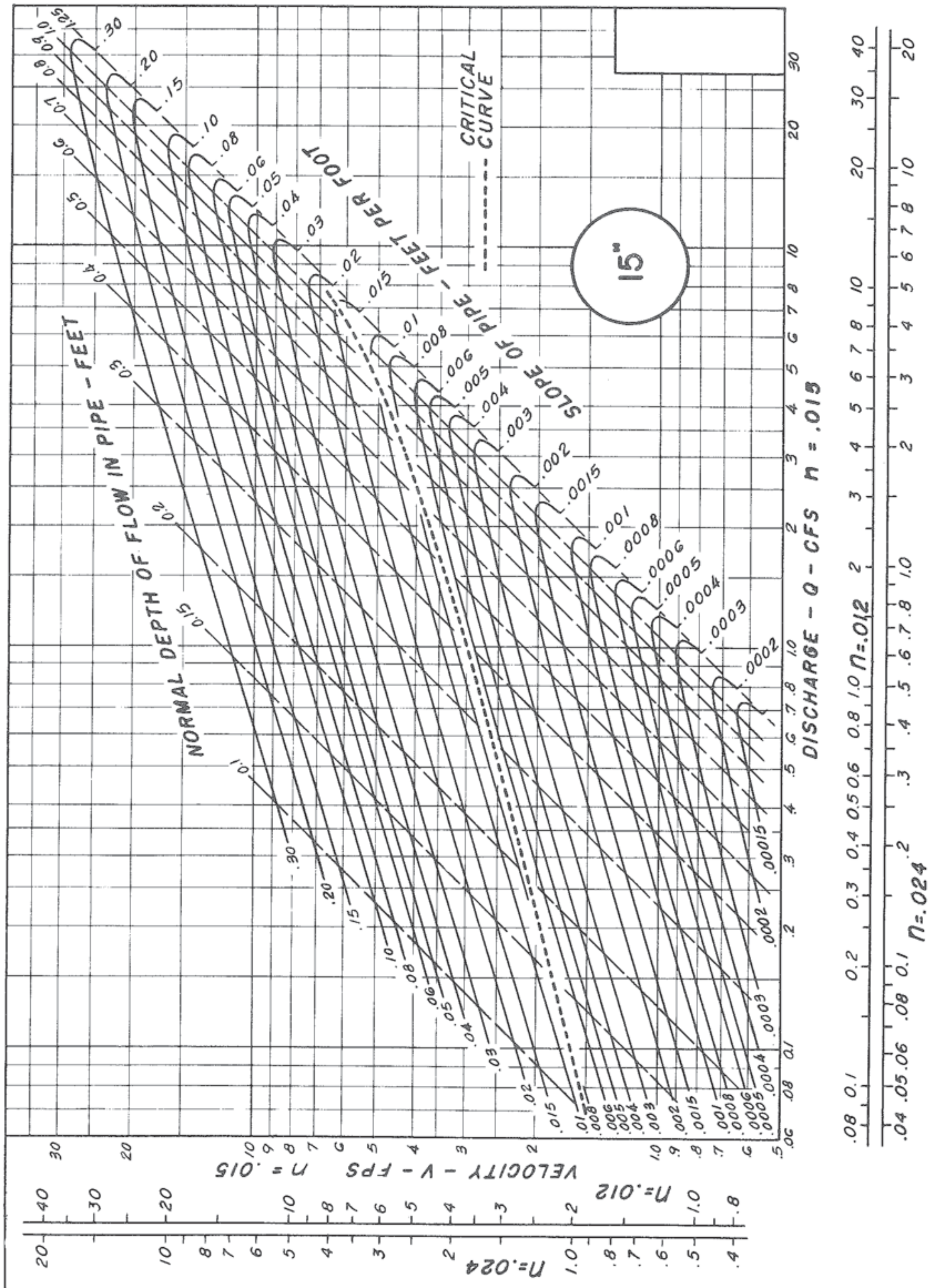
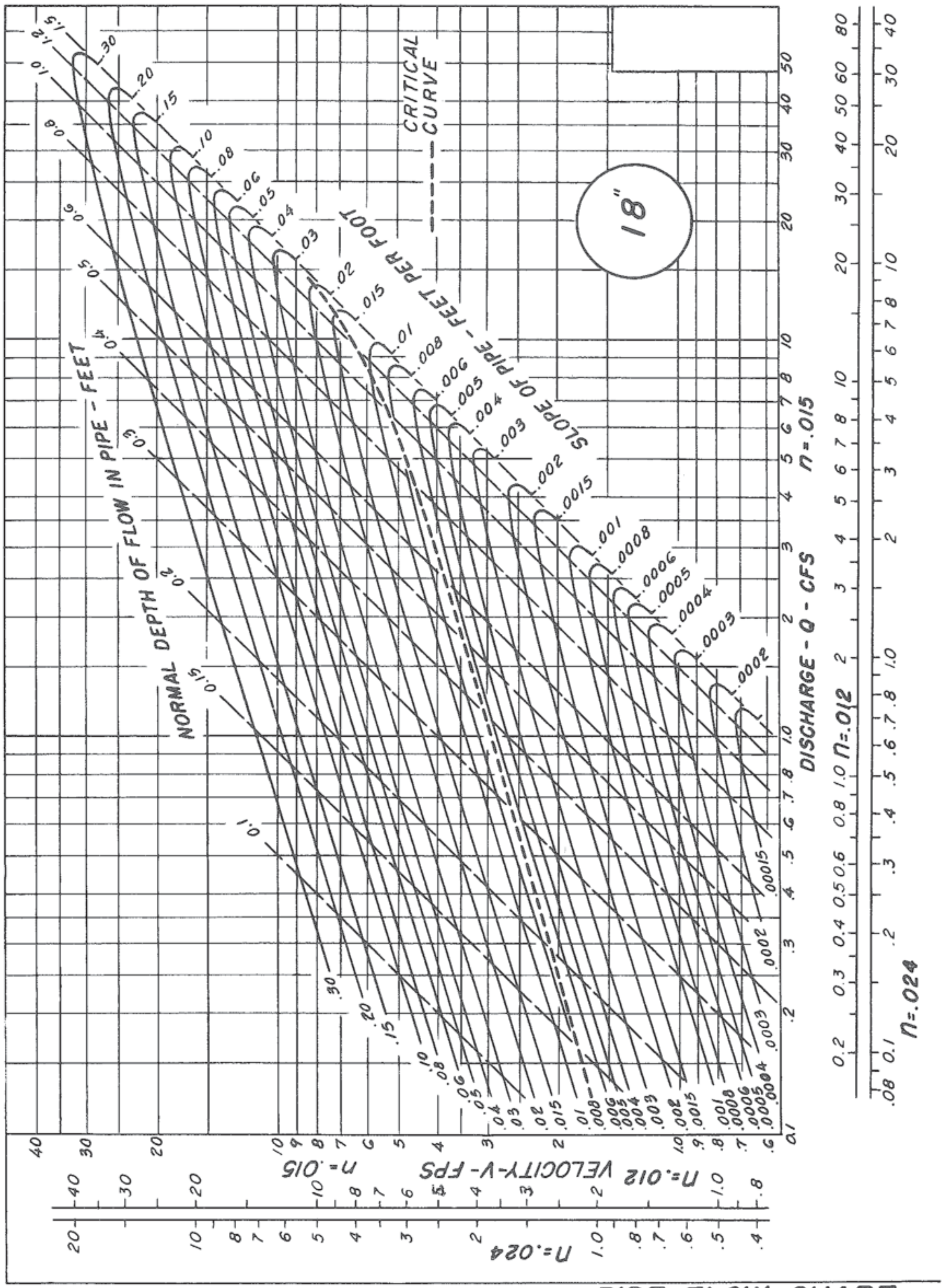
FIGURE 5A-3



PIPE FLOW CHART
15-INCH DIAMETER

FIGURE 5A-4



PIPE FLOW CHART
18-INCH DIAMETER

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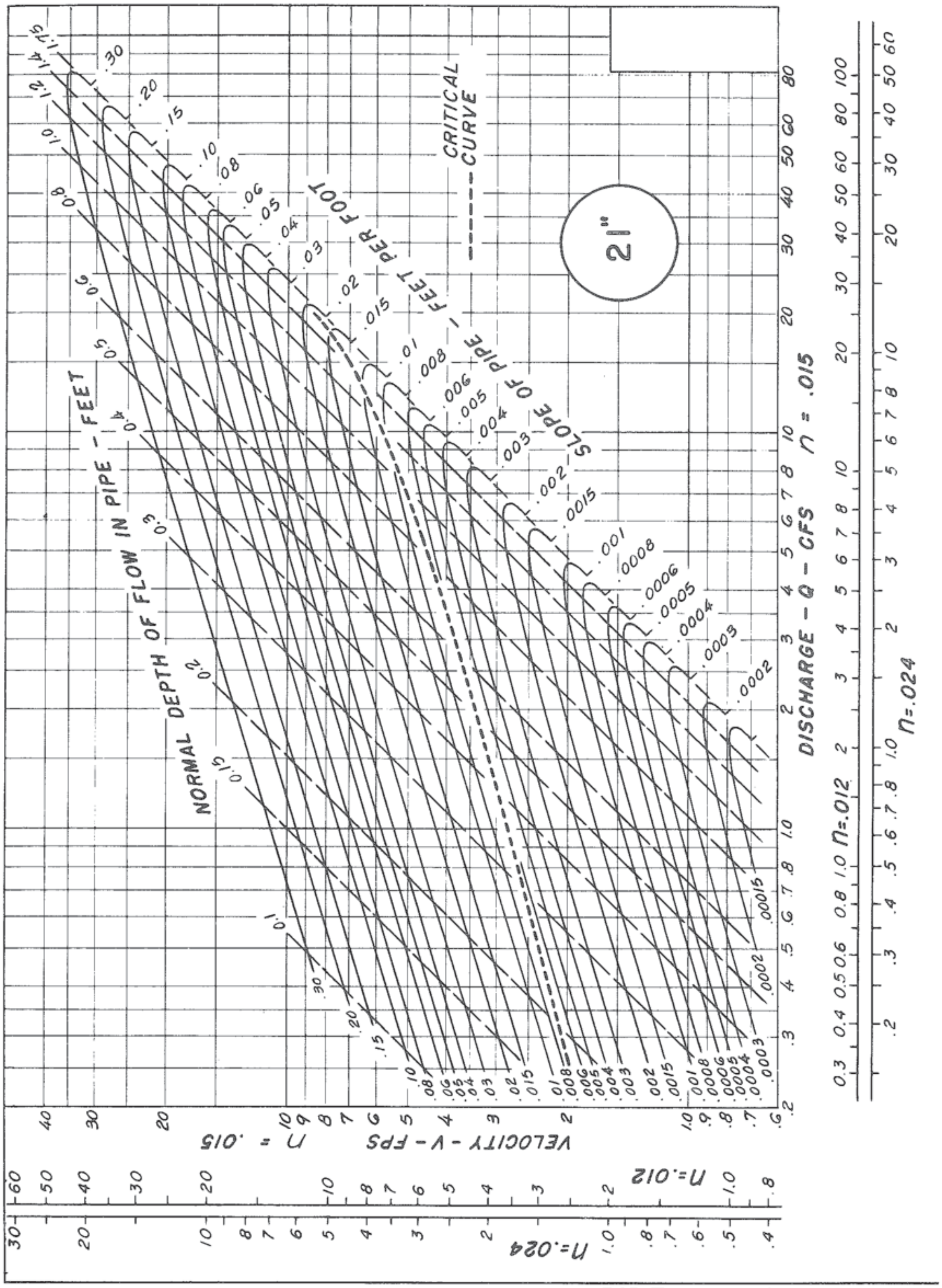
FIGURE 5A-5



PIPE FLOW CHART
21-INCH DIAMETER

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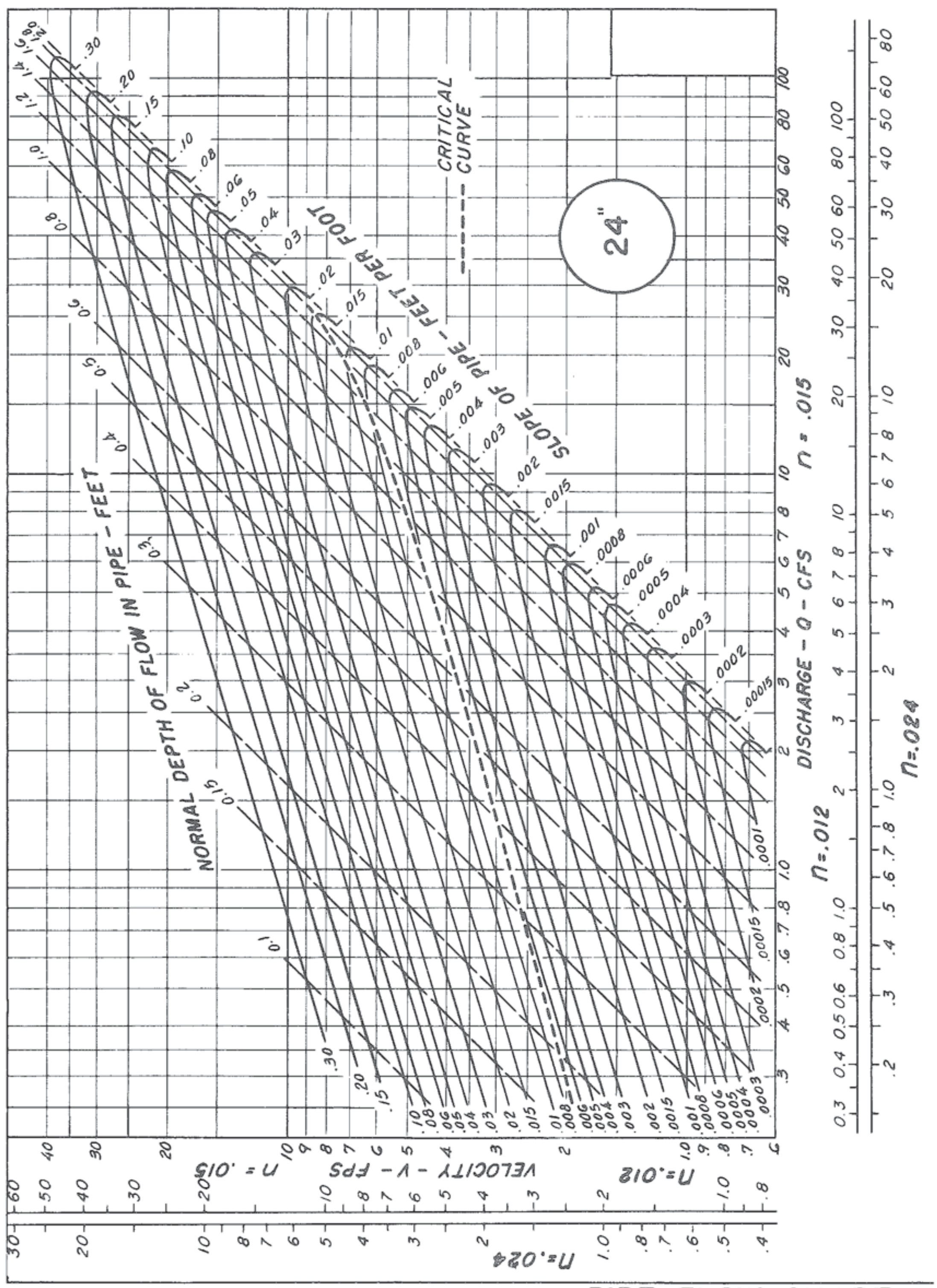
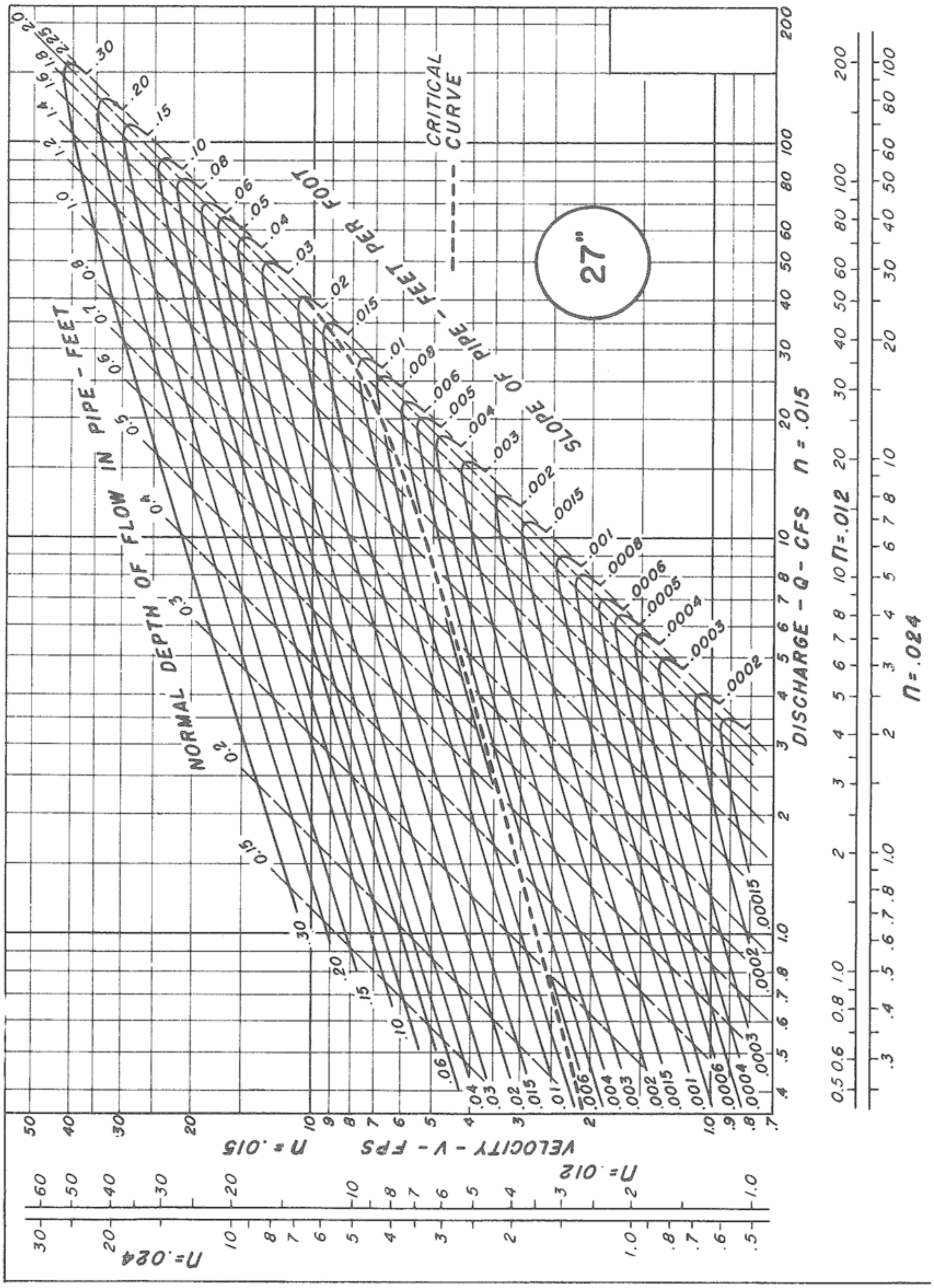
FIGURE 5A-6



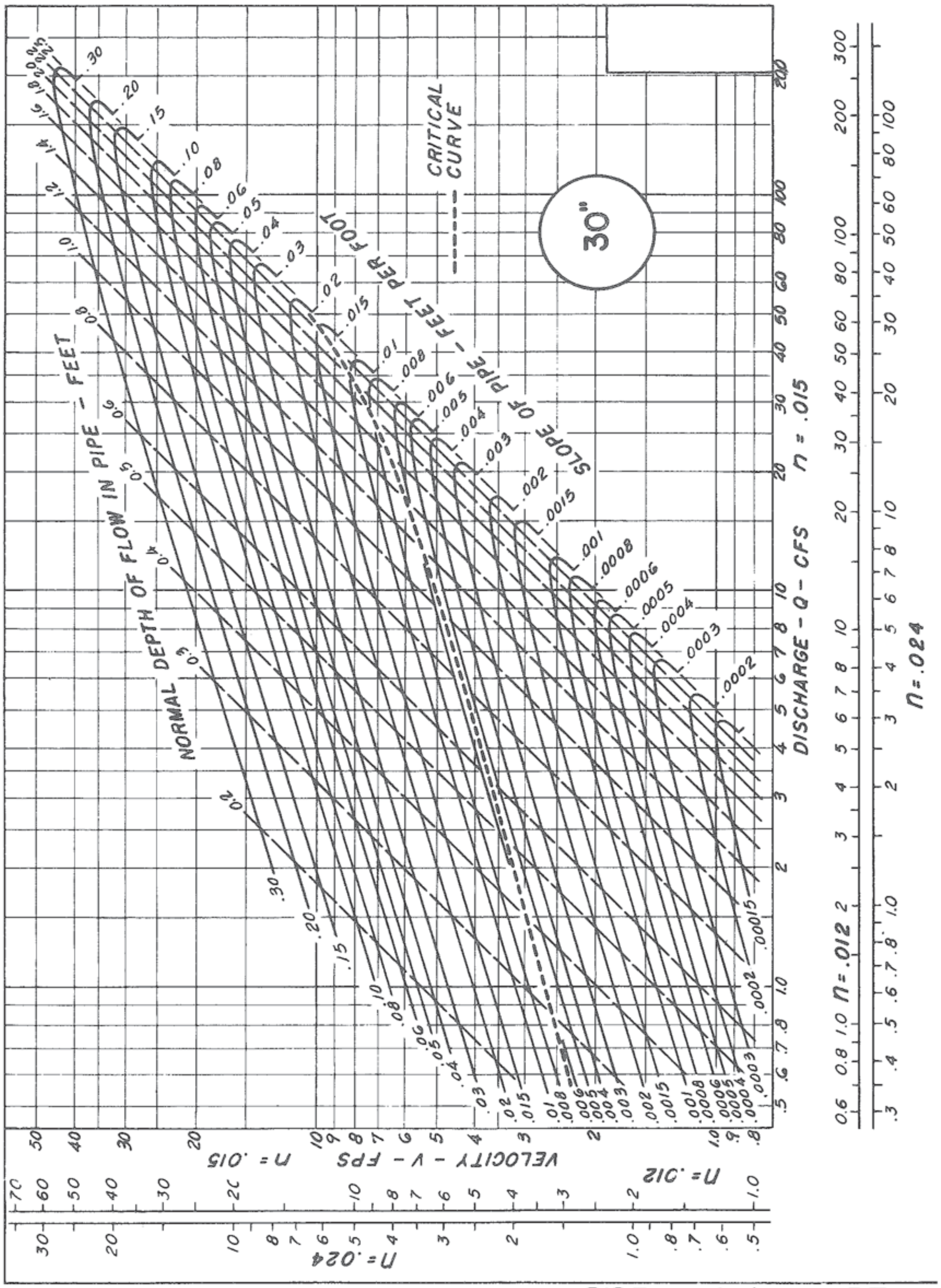
PIPE FLOW CHART
24-INCH DIAMETER

FIGURE 5A-7



PIPE FLOW CHART
27-INCH DIAMETER

FIGURE 5A-8



PIPE FLOW CHART
30-INCH DIAMETER

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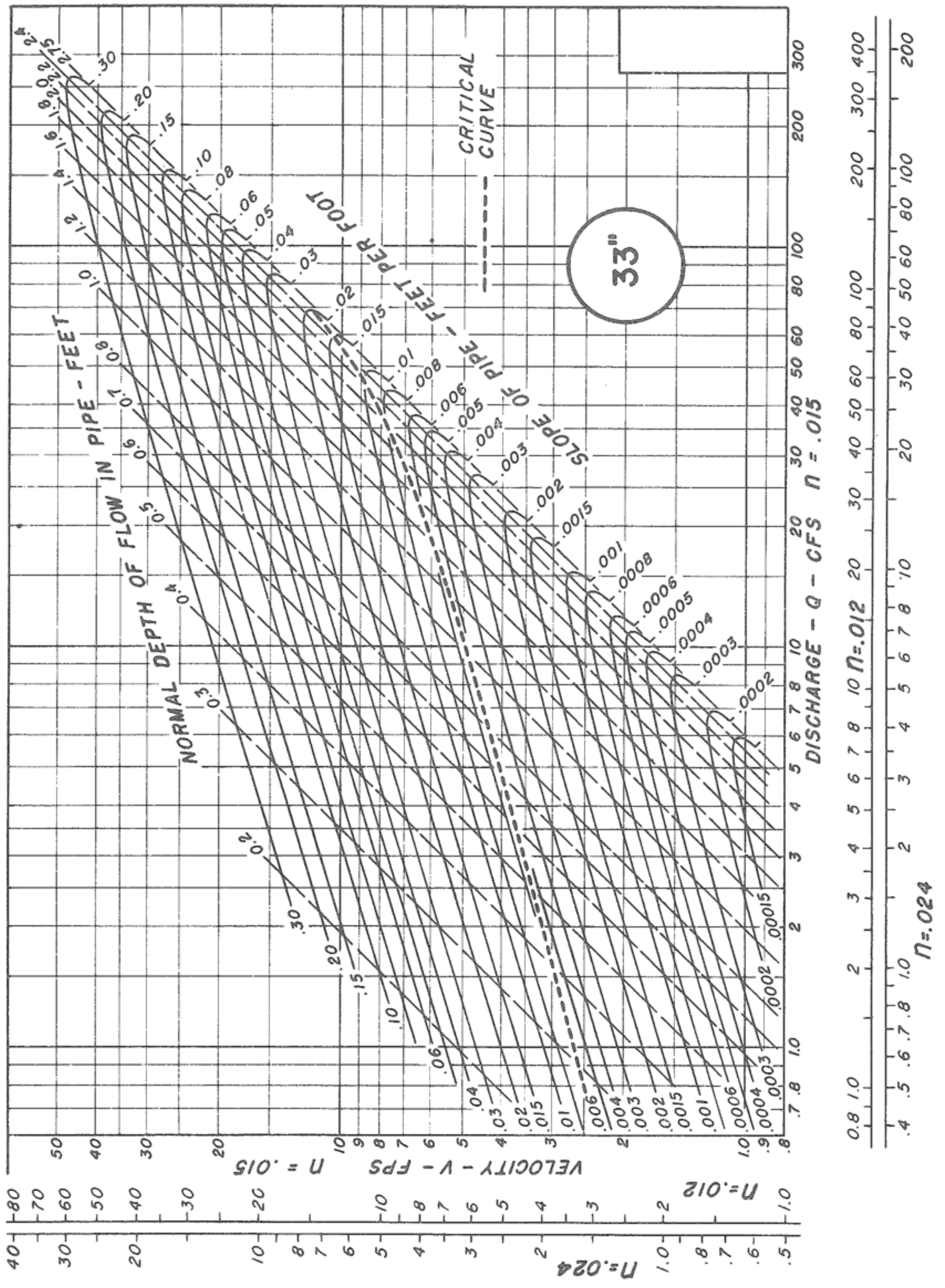
FIGURE 5A-9



PIPE FLOW CHART
33-INCH DIAMETER

CITY OF SHREVEPORT, LOUISIANA

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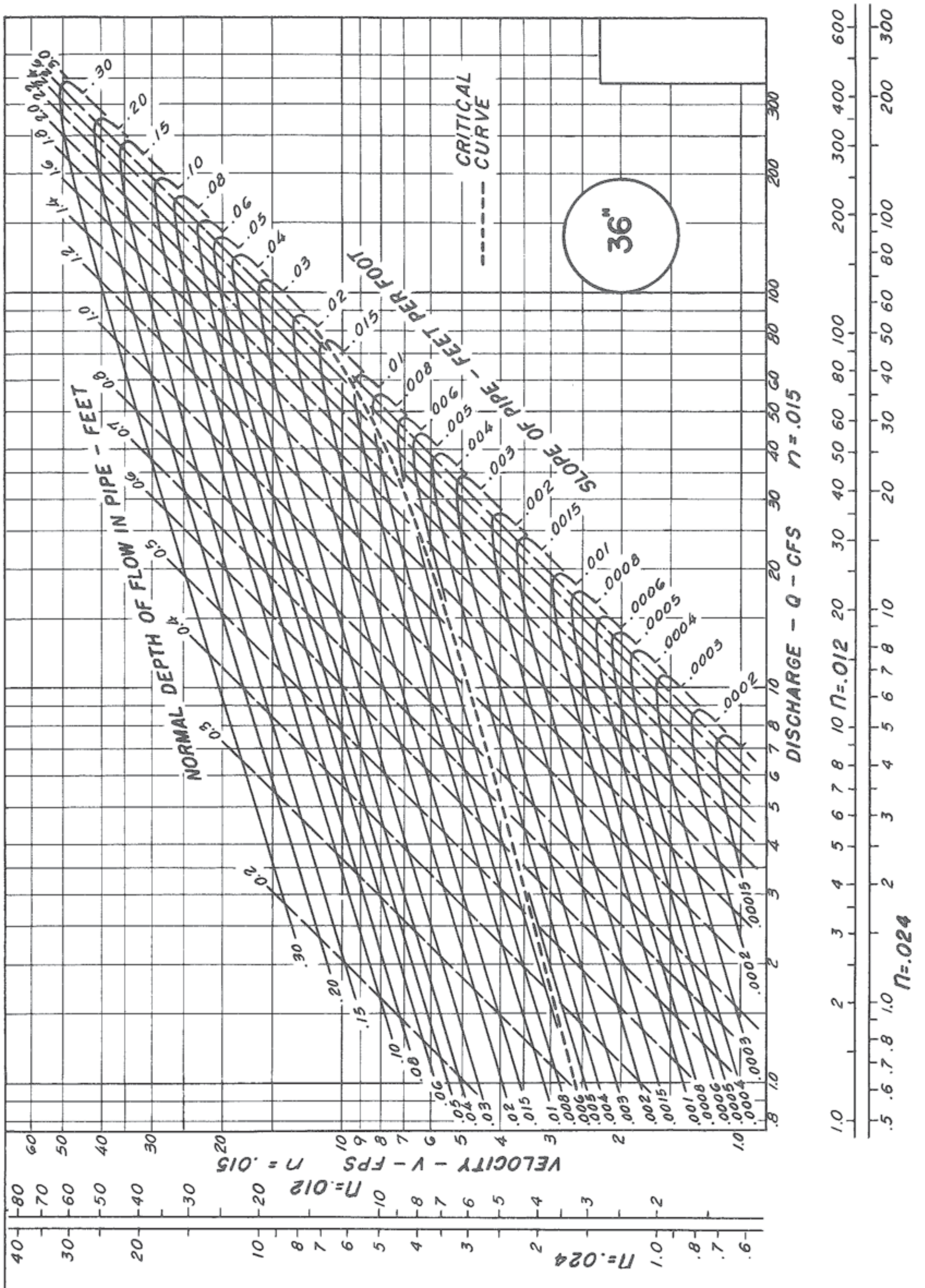
FIGURE 5A-10



PIPE FLOW CHART
36-INCH DIAMETER

CITY OF SHREVEPORT, LOUISIANA

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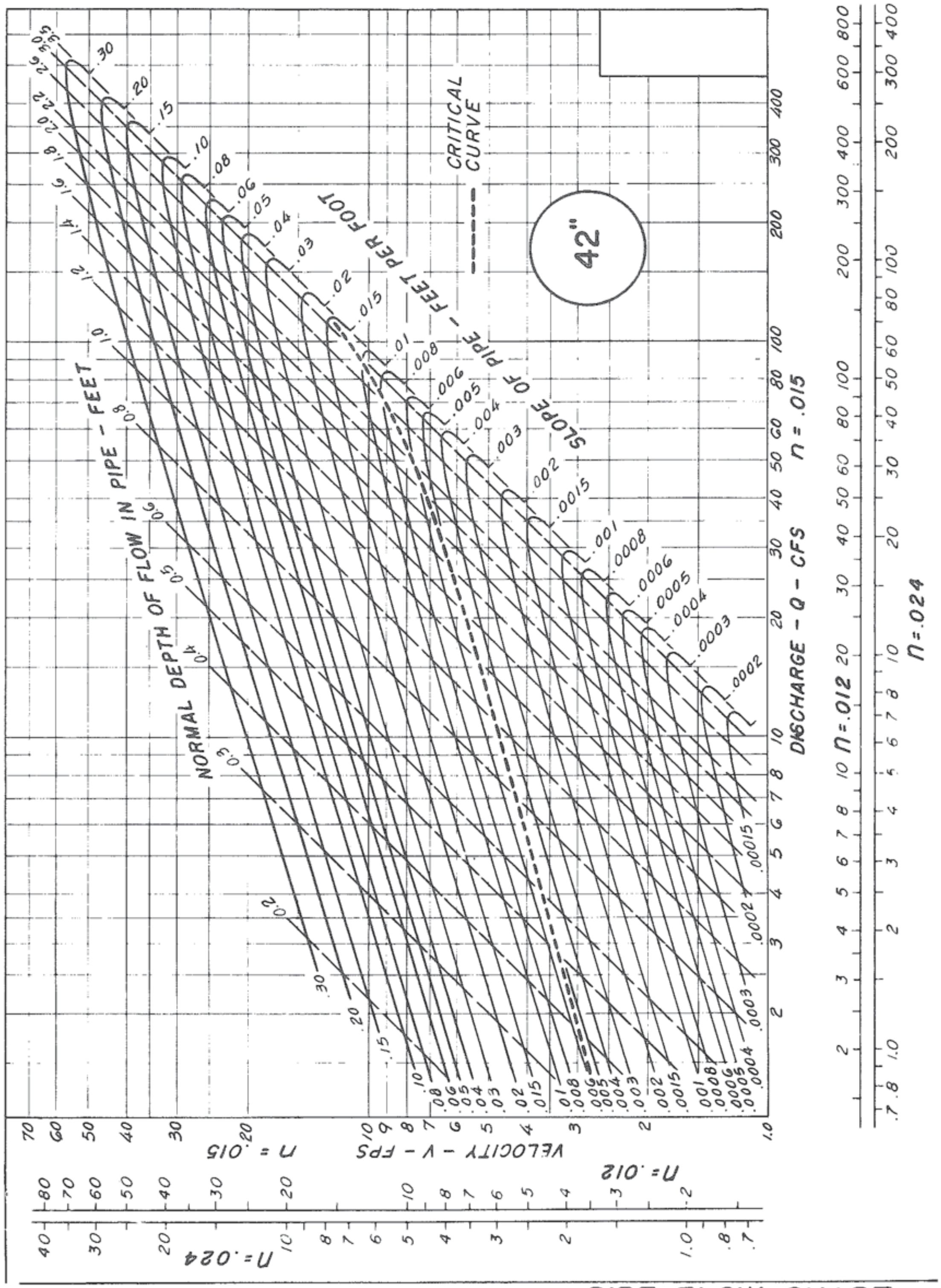
FIGURE 5A-11



PIPE FLOW CHART
42-INCH DIAMETER

CITY OF SHREVEPORT, LOUISIANA

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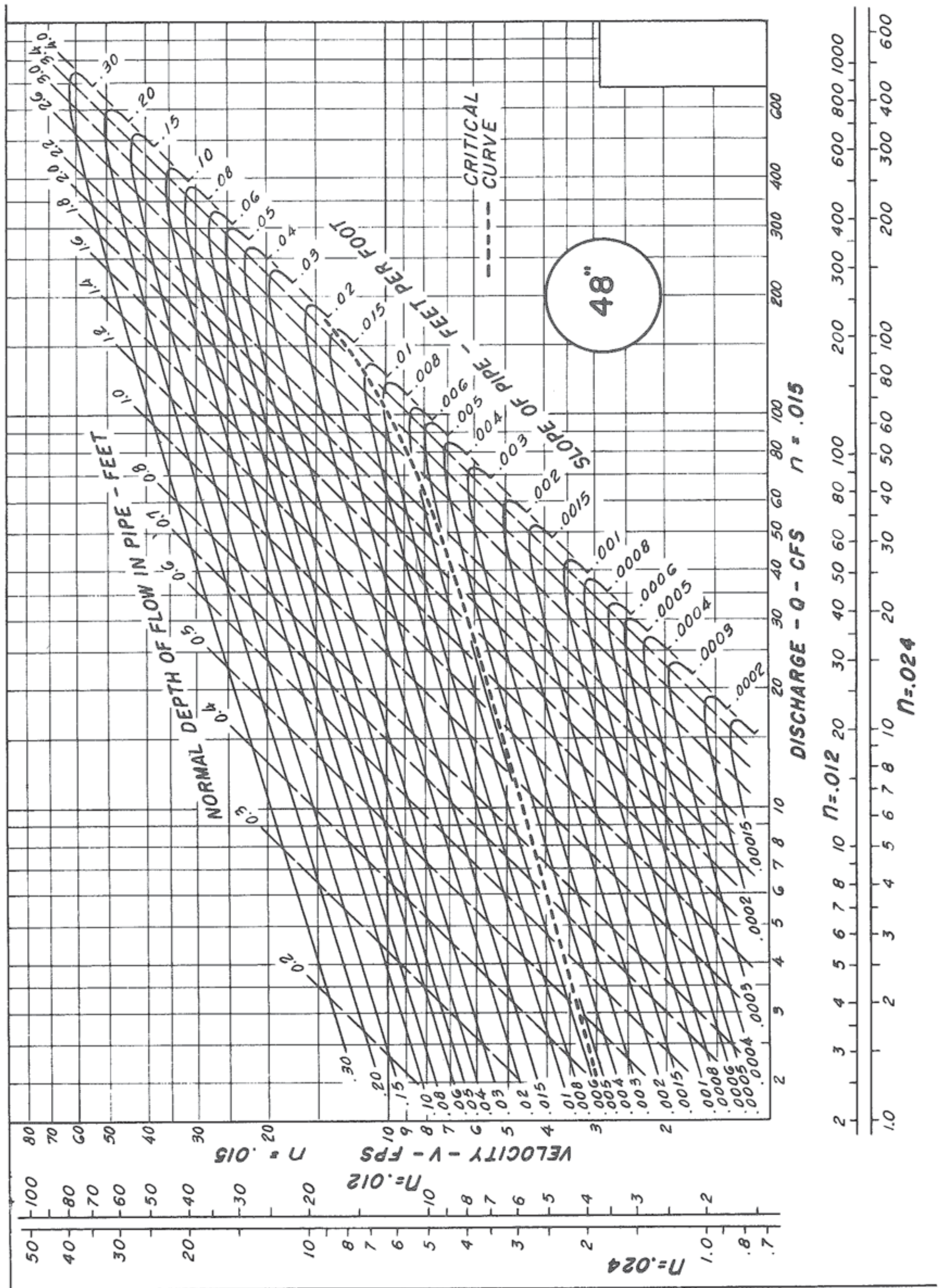
FIGURE 5A-12

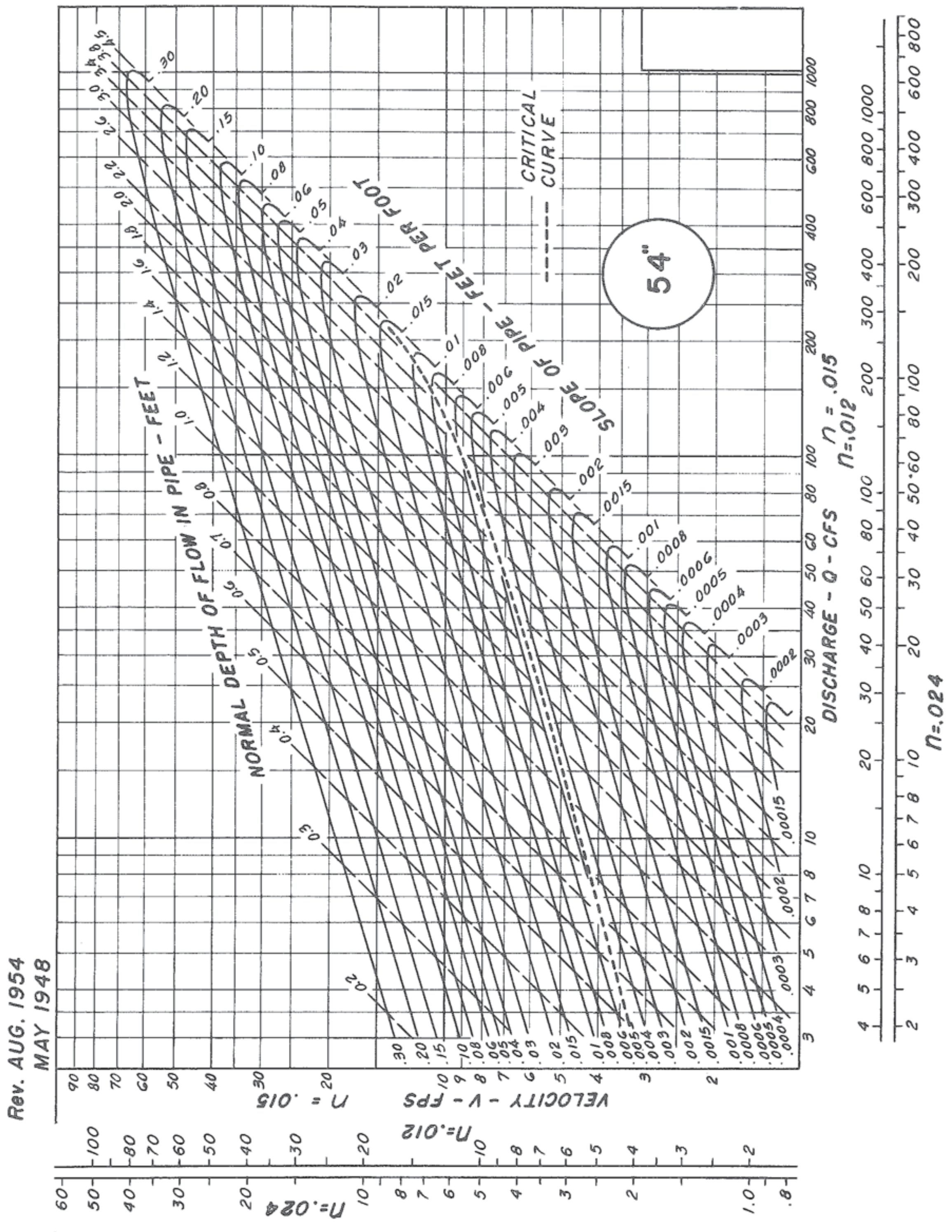


PIPE FLOW CHART
48-INCH DIAMETER

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

FIGURE 5A-13



PIPE FLOW CHART
54-INCH DIAMETER

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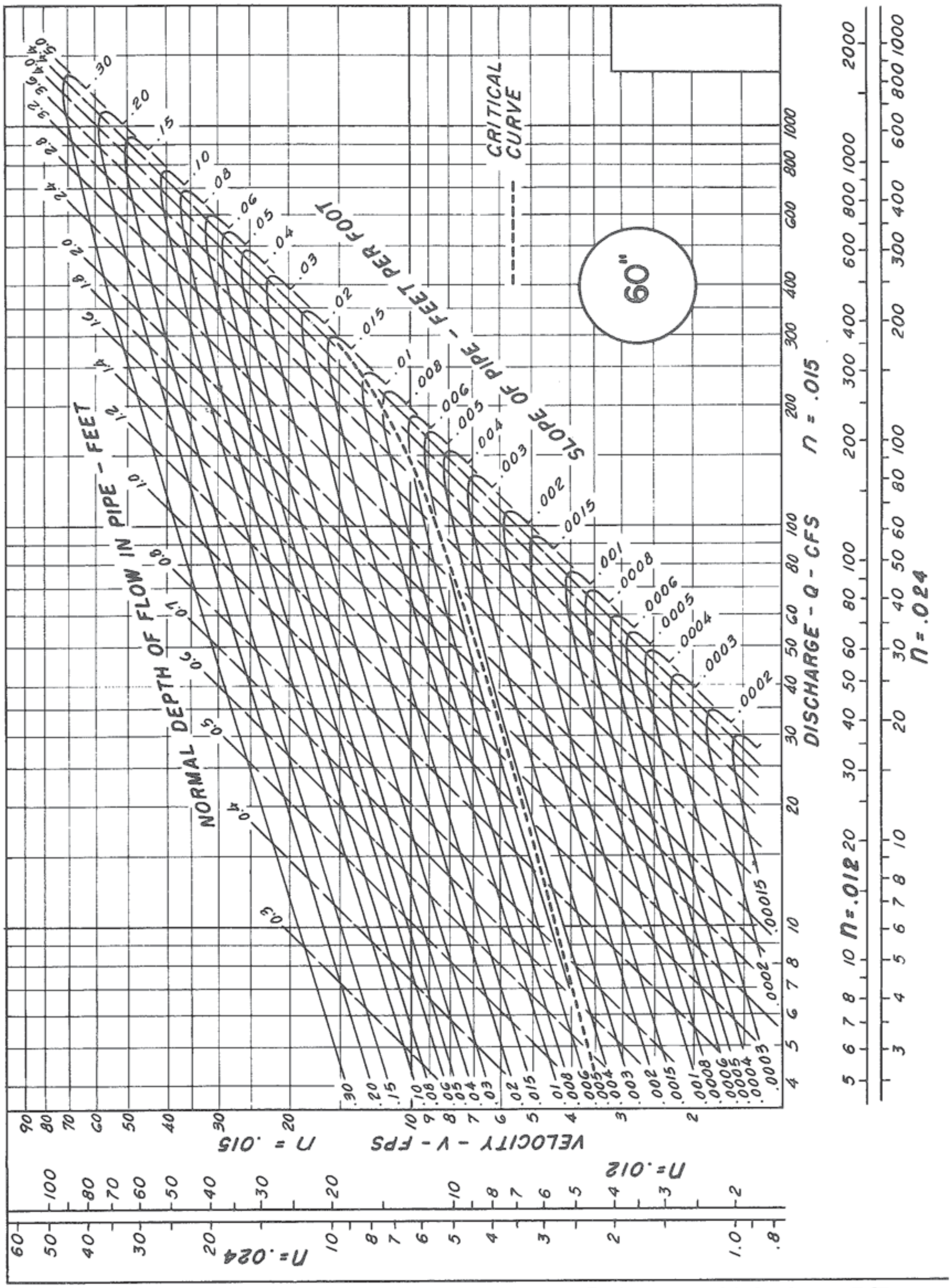
FIGURE 5A-14



PIPE FLOW CHART
60-INCH DIAMETER

CITY OF SHREVEPORT, LOUISIANA

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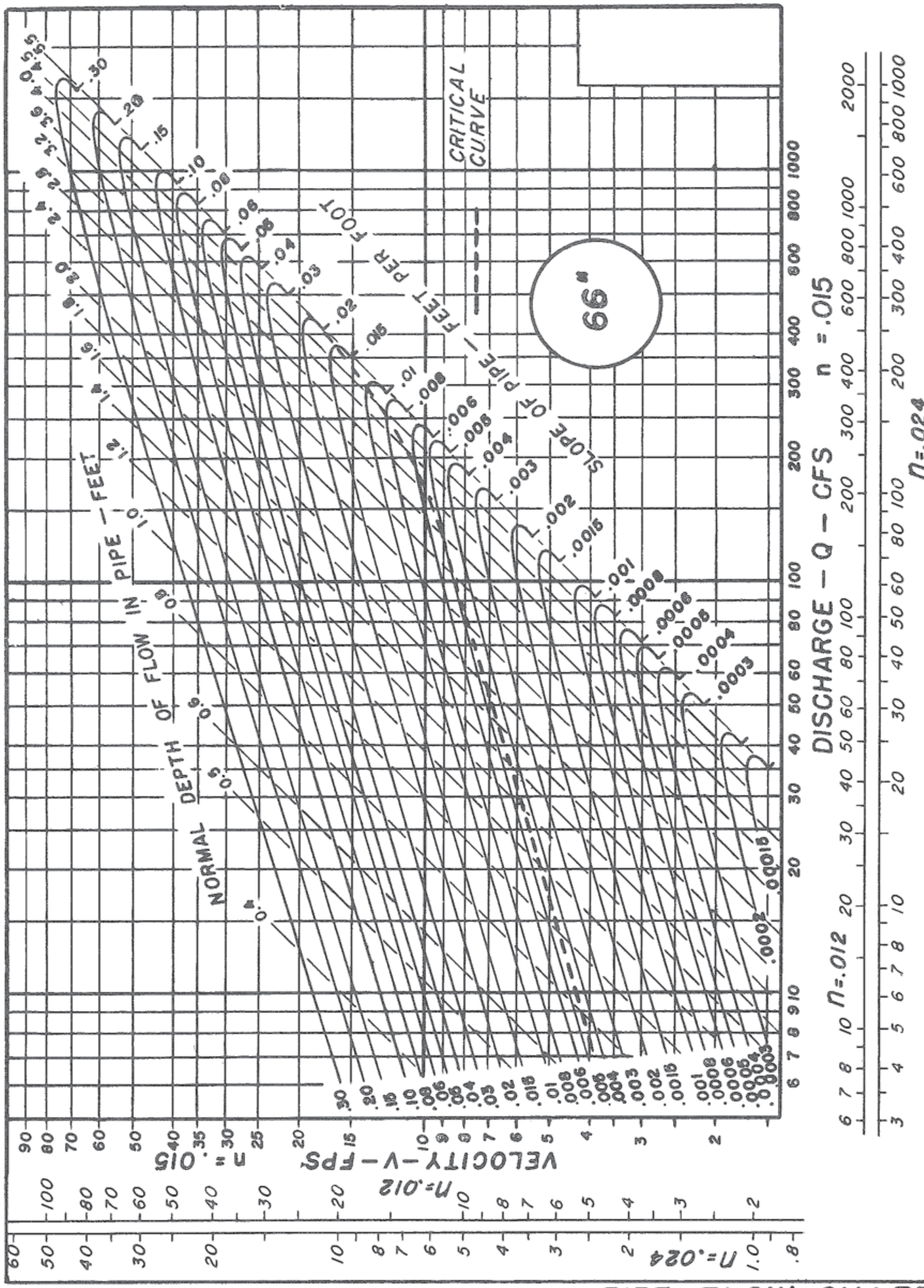

PIPE FLOW CHART
66-INCH DIAMETER

CITY OF SHREVEPORT, LOUISIANA

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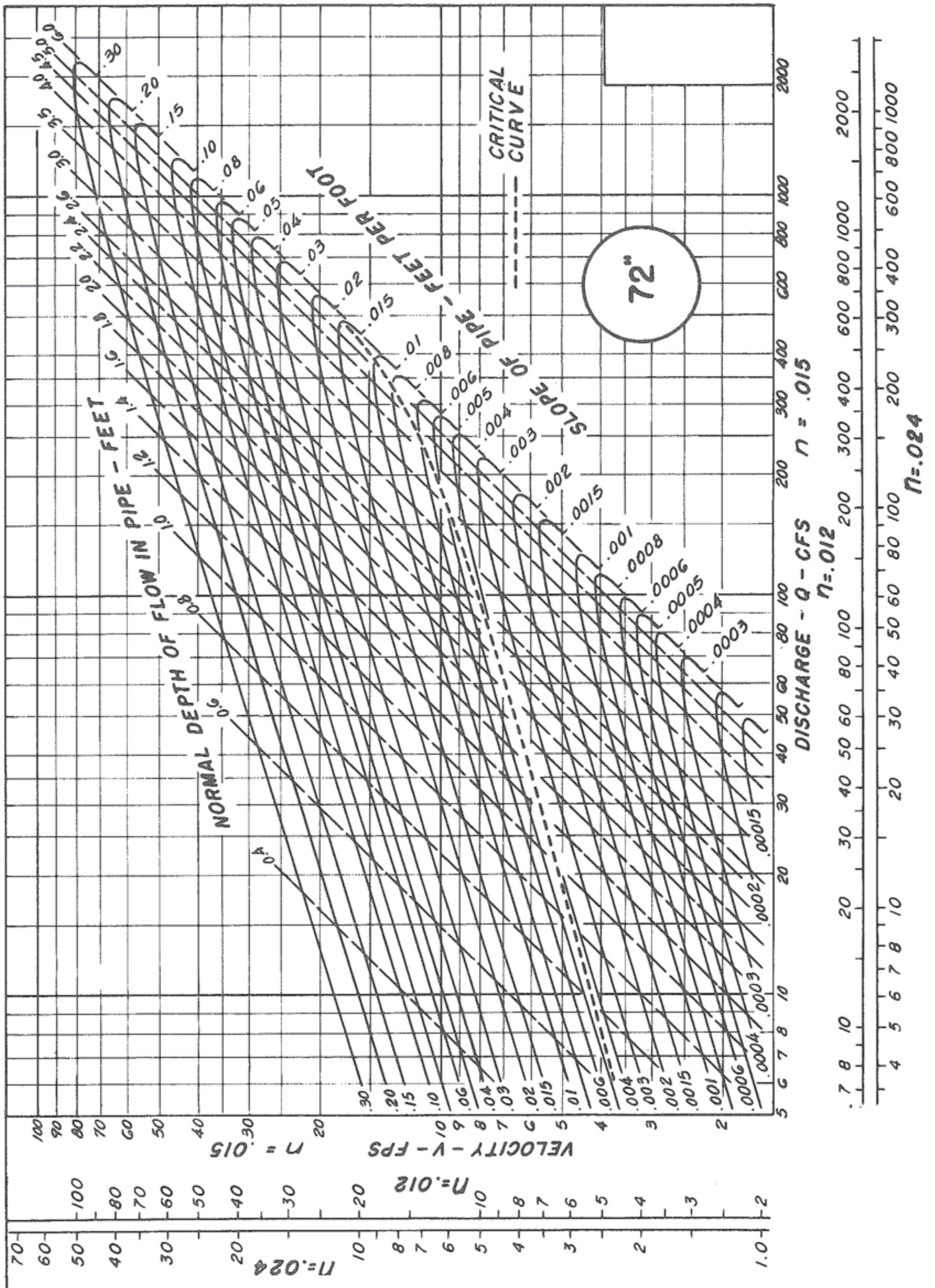
FIGURE 5A-16



PIPE FLOW CHART
72-INCH DIAMETER

CITY OF SHREVEPORT, LOUISIANA
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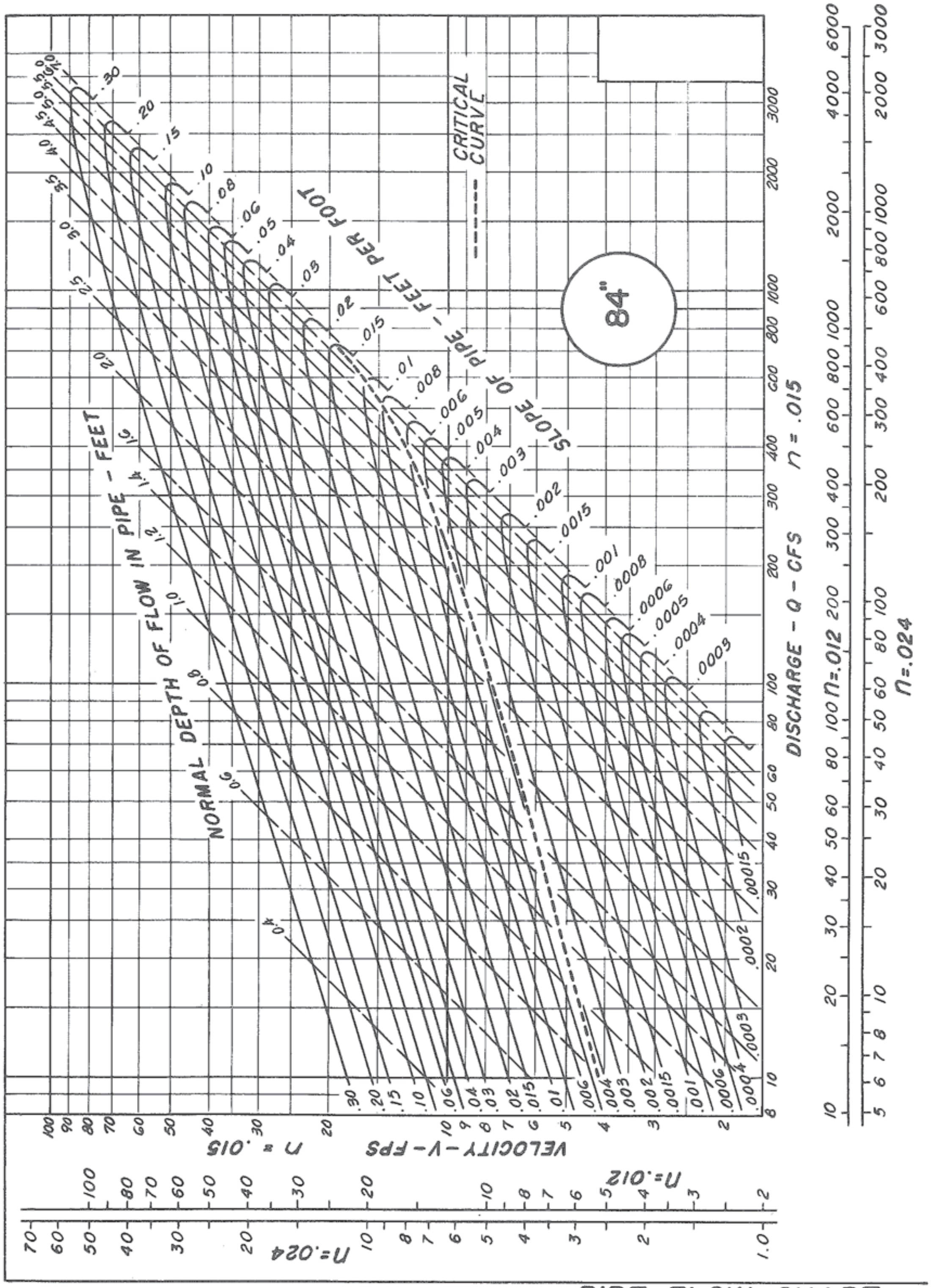
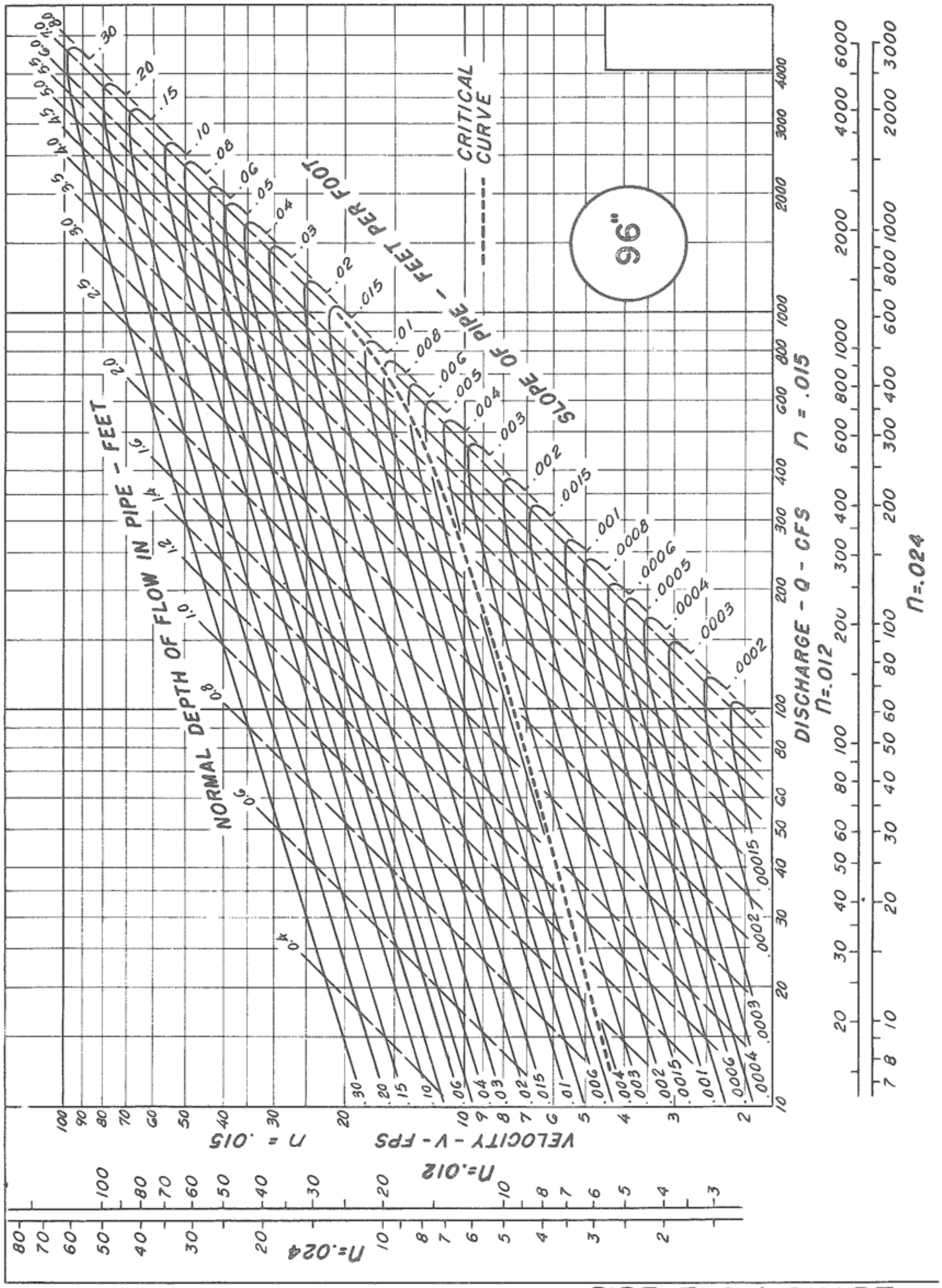
FIGURE 5A-17



PIPE FLOW CHART
84-INCH DIAMETER

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS



PIPE FLOW CHART
96-INCH DIAMETER

Table of Contents

CULVERT DESIGN

6.1 Overview

Culverts convey surface water from storm events under a roadway, railroad, or other embankment. The function of the culvert is to pass the design storm flow without causing excessive backwater or overtopping of the embankment and without creating excessing downstream velocities. In addition to meeting hydraulic functions, culverts must carry overhead loads from vehicles and other functions.

6.2 General Culvert Requirements

6.2.1 Minimum Size and Material

All culverts shall have a minimum size of a 24-inch circular pipe or equivalent for alternate shapes for collector and arterial streets. For local public streets, a minimum 18-inch pipe or equivalent is required. The minimum diameter for a private driveway within the right-of-way shall be 15-inch. Also, see Section 3.5 for culvert size requirements.

1. Structures shall be sized based on their calculated hydraulic capacity as determined by an approved hydraulic analysis procedure. Culverts should be sized to fit the opening of the stream or ditch as much as possible, both vertically and horizontally. Where necessary, multiple lines of pipe may be used, refer to Section 3.

2. All culverts under public roads shall be Reinforced concrete, Ribbed Poly vinyl Chloride Pipe, Polymer Coated Steel Corrugate or Corrugated Polyethylene Double Wall Pipe. Other materials must be approved by the City Engineer. Privately owned culverts may use other materials of choice.

6.2.2 Reinforced Box Culverts

In situations with restrictive vertical clearance where adequate cover for pipe cannot be obtained and in situations requiring multiple openings, reinforced concrete boxes have a geometric advantage where more area of opening can be concentrated in a given width.

1. Box culverts shall be constructed in sizes equal or larger than 4 feet wide by 3 feet high unless approved by the City Engineer. See Section 3.5 for culvert size requirements.

2. Box culverts shall be structurally designed to accommodate earth and live loads to be imposed upon the culvert.

6.2.3 Culvert Slope and Alignment

1. Both minimum and maximum slopes are to be based on flow velocities. A minimum of 3 feet/second when the culvert is flowing partially full is recommended to ensure a self-cleaning condition during partial depth flow. The maximum velocity should not exceed culvert manufacturer recommendations. The maximum velocity should be consistent with channel stability requirements at the culvert outlet. Refer to Section 6.2.5 for maximum discharge velocities for culverts which discharge to an earthen channel.

2. Culverts shall be aligned with natural drainage way in grade and direction whenever practical.

3. Skew: Culverts shall not cross under an embankment at an angle greater than 45 degrees measured to the centerline of the roadway.

4. The flow line, or invert, is the bottom of the lowest point on the interior of a pipe. Flow lines should be set to match the natural stream bed and slope, or to match the design stream bed in cases where channel improvements are being made or new channels are constructed.

6.2.4 End Treatments

The function of the end treatment of a culvert is one or more of the following:

1. Create safer conditions surrounding the culvert without interfering with the hydraulic efficiency of the culvert design.
2. Improve the hydraulic efficiency of the culvert
3. Anchor the culvert to prevent movement caused by hydraulic and soil pressures
4. Control erosion and scour resulting from high velocities and turbulence
5. Preventing the embankment from sloughing into the water channel

There are many types of end treatments available for culverts. Typical end treatments are shown in Figure 6-1.

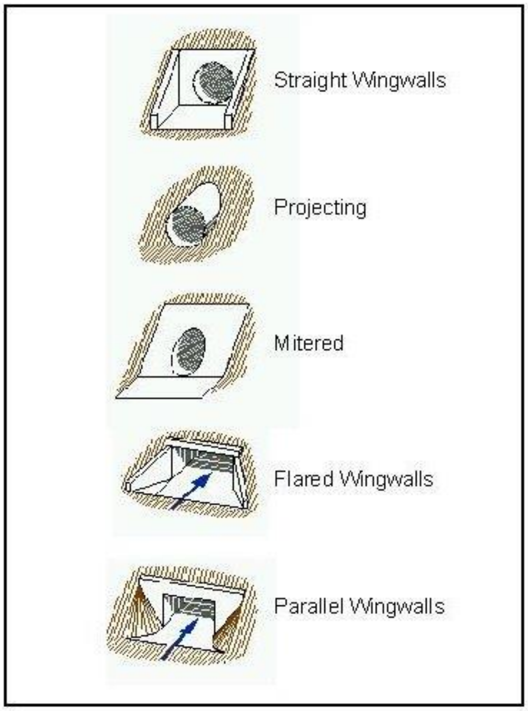


Figure 6-1 Typical End Treatments

6.2.5 Discharge Velocities and Scour Protection

Outlet velocities can influence the performance and reduce the life of a culvert by causing stream scour and bank erosion at the culvert outlet. Culvert outlet scour and erosion can be very damaging during extreme rainfall events. This can lead to damage of the culvert and possibly significant damage to the embankment and roadway. Culvert exit velocities should be minimized to the greatest extent practical. Channel erodibility and local scour potential should be evaluated.

When predicted scour is greater than the limits below, scour protection will be required.

a.	Reinforced Concrete Pipe without Headwalls	3.0 ft
b.	Reinforced Concrete Pipe with Headwalls	4.5 ft
c.	Plastic Pipe with End Joint > 20 ft in length	4.5 ft
d.	Reinforced Concrete Box	6.0 ft

Armored protection of the streambed can include headwalls, toe walls, rip rap, concrete aprons, or a combination of these items. The minimum concrete apron length to provide transition from culvert outlet to an open channel shall be calculated from the following equation:

$$L = 0.2VD \qquad \text{Eq. 6-1}$$

Where: L = Apron Length (ft)
V = culvert discharge velocity (ft/sec)
D = height of box culvert or diameter of culvert (ft)

6.3 Selection of Culvert Size and Flow Classification

6.3.1 Methods and Computer Software Programs

The hydraulic design of culverts shall be based upon the design guidelines set forth by LADOTD, the US Department of Transportation Federal Highway Administration (FHWA), or other suitable method as approved by the City. Computations can be made by using the nomographs in this manual, although it is preferred that these be used for preliminary design. The following computer software programs are acceptable for use in the design of culverts:

a. The LADOTD computer program HYDR1120: "Hydraulic Analysis of Culverts"

b. HYDROFLOW Storm Sewers Extension for Autodesk Civil 3D

b. The FHWA's computer program "HY-8".

6.3.2 Culvert Hydraulics

Culvert flow may be separated into two major types of flow – inlet or outlet control. Under inlet control, the cross-sectional area of the barrel, the shape of the inlet and the amount of ponding (headwater) at the inlet are primary design considerations. Outlet control is dependent upon the depth of water in the outlet channel (tailwater), the slope of the barrel, type of culvert material and length of the barrel.

Terminology:

a. Differential Head (DH or ΔH): The difference between headwater and tailwater.

b. Flow Line (FL): The elevation of the bottom of the inside of a culvert.

c. Headwater (HW): The total depth of upstream water surface measured from the culvert inlet flow line.

d. Tailwater (TW): The flow depth of water downstream of the culvert outfall measured from the flowline of the culvert outlet to the downstream water surface.

6.3.2.1 Manning's Coefficient

Table 6-1 lists the commonly used Manning's roughness coefficients used in the analysis of the hydraulic capacity of culverts.

Table 6-1 Manning's Coefficients

STRUCTURE TYPE	MANNING'S "n"
Concrete Pipe Concrete Box	0.013 0.015
Corrugated Metal Pipe $^{1}/_{2}$" x 2 $^{2}/_{3}$" Corrugations (Annular) $^{1}/_{2}$" x 2 $^{2}/_{3}$" Corrugations (Helical) 1" x 3" Corrugations	 0.025 0.020 0.027
Plastic Pipe Smooth interior Corrugated interior	 0.011 0.015

6.3.2.2 Design Headwater

Design headwater depth is determined by computing headwater depths for both inlet control and outlet control and then using the higher value.

6.3.3 Inlet Control

A culvert operates with inlet control when the culvert barrel is capable of conveying more flow than the inlet will accept. The flow capacity is controlled at the entrance by the depth of headwater and entrance geometry, including the barrel shape, cross-sectional area and the inlet edge. Figure 6-2 shows different examples of inlet control.

In inlet control, roughness and length of the culvert barrel and outlet conditions (including tailwater) are not factors in determining culvert hydraulic performance. An increase in barrel slope reduces the headwater (HW) to a small degree, and any correction for slope may be neglected for conventional or commonly used culverts.

6.3.3.1 Inlet Control Condition

The size of a culvert operating with inlet control is determined by the size and shape of the inlet and the depth of ponding allowable (headwater) between the flow line elevation of a culvert and the elevation of the finished grade surface or surrounding buildings and facilities. Factors not affecting inlet control design are the barrel roughness, slope, length, and the depth of tailwater.

The headwater (HW) depth for a culvert of a given diameter or height (D) for a given discharge can be determined by obtaining the HW/D value from Figure 6A-1 to Figure 6A-7. The desirable maximum headwater for a culvert should not be greater than the diameter or height plus two (2) feet. The elevation of adjacent facilities (i.e., buildings, etc.) must be reviewed to avoid flooding.

Inlet control may occur under two (2) conditions:

a. Unsubmerged: The headwater is not sufficient to submerge the top of the culvert opening and the culvert inlet slope is supercritical. The culvert inlet acts like a weir, see Condition A in Figure 6-2.

b. Submerged: The headwater submerges the top of the culvert but the does not flow full. The culvert inlet acts like and orifice, see Condition B in Figure 6-2.

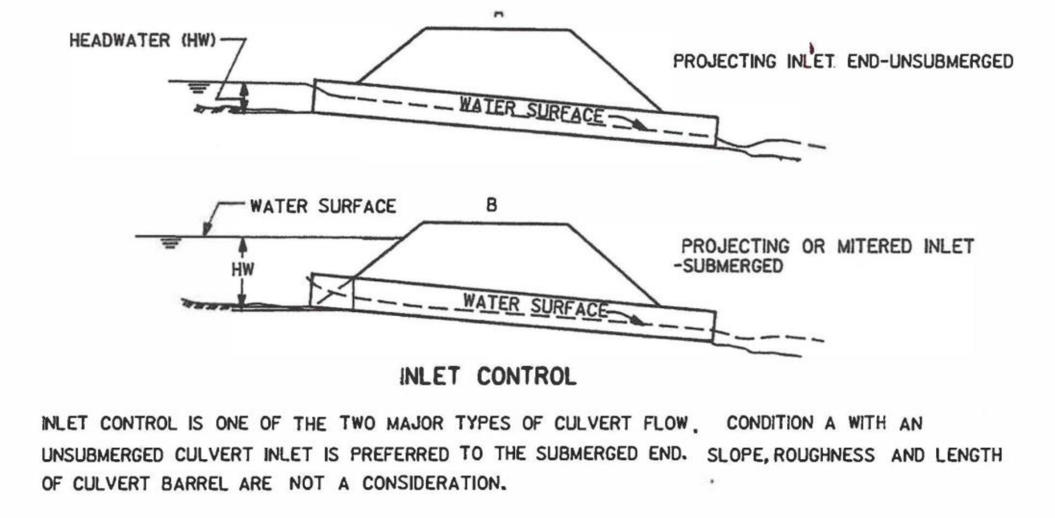


Figure 6-2 – Inlet Control Conditions

6.3.3.2 Headwater Computation for Inlet Control Conditions

For culverts operating with inlet control, headwater (HW) is computed by the following equation:

$$HW = D(J + KX + LX^2 + MX^3 + NX^4 + PX^5) \qquad \text{Eq. 6-2}$$

Where: HW = Headwater (ft)
D = Height of culvert (ft)
J, K, L, M, N, P = Coefficients determined by inlet geometry. (See Table 6-2)

$$X = \frac{Q}{BD^{1.5}} \qquad \text{Eq. 6-3}$$

Where: Q = Discharge (ft^3/s)
B = Width of culvert (ft)

Table 6-2 Inlet Control Headwater Coefficients

CULVERT TYPE	INLET TYPE	J	K	L	M	N	P
REINFORCED CONCRETE PIPE	SOCKET-END PROJECTING	0.108786	0.662381	-0.233801	0.0579585	-0.0055789	0.00020505
	SOCKET-END WITH HEADWALL	0.114099	0.653562	-0.233615	0.0597723	-0.0061634	0.00024283
CORRUGATED METAL PIPE	PROJECTING	0.187321	0.567719	-0.156544	0.0447052	-0.003436	0.00008966
	HEADWALL	0.167433	0.538595	-0.149374	0.0391543	-0.0034397	0.00011588
	MITERED	0.107137	0.757789	-0.361462	0.1233932	-0.0160642	0.00076739
REINFORCED CONCRETE PIPE ARCH	SOCKET-END PROJECTING	0.09618	0.52593	-0.13504	0.03394	-0.00325	0.00013
	SOCKET-END WITH HEADWALL	0.1301	0.43477	-0.07911	0.01764	-0.00114	0.00002
CORRUGATED METAL PIPE ARCH	PROJECTING	0.089053	0.712545	-0.270921	0.0792502	-0.0079805	0.00029321
	HEADWALL	0.111281	0.610579	-0.194937	0.0512893	-0.0048054	0.00016855
	MITERED	0.083301	0.795145	-0.434075	0.163774	-0.0249139	0.00141066
REINFORCED CONCRETE BOX	SQUARE-EDGE HEADWALL	0.122117	0.505435	-0.10856	0.020781	-0.0013676	0.00003456
	BEVEL-EDGE HEADWALL	0.1566086	0.3989353	-0.0640392	0.01120135	-0.0006449	0.000014566

6.3.3.3 Depth of Flow Computation for Inlet Control Conditions

For culverts operating under inlet control, depth of flow at the outlet is the normal depth of flow (dn). Normal depth of flow is obtained by balancing the following equation:

$$\frac{Q.n}{1.49 \cdot S^{\frac{1}{2}}} = \frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}} \quad \text{Eq. 6-4}$$

Where:	Q	=	Discharge (ft^3/s)
	n	=	Manning's roughness coefficient (Table 6-1)
	S	=	Culvert slope (ft/ft)
	A	=	Area of flow at any depth of flow (ft^2)
	P	=	Wetted perimeter of flow at any depth of flow (ft)

6.3.3.4 Outlet Velocity Computation for Inlet Control Condition

Outlet velocity for culverts operating under inlet control is obtained from Manning's equation:

$$V = \frac{1.49 \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}}}{n} \quad \text{Eq. 6-5}$$

Where:	n	=	Manning's roughness coefficient (Table 6-1)
	R	=	Hydraulic radius = A/p (ft)
	A	=	Area of flow at normal depth of flow (ft^2)
	P	=	Wetted perimeter of flow at normal depth of flow (ft)
	S	=	Culvert slope (ft/ft)

6.3.4 Outlet Control

Outlet control flow occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. The control section for outlet control flow in a culvert is located at the barrel exit or further downstream. In outlet control, the culvert hydraulic performance is determined by the following factors: depth of headwater, entrance geometry, including the barrel shape, cross-sectional area and the inlet edge, plus the controlling water surface elevation at the outlet and the slope, length, and roughness of the culvert barrel.

A culvert operating in outlet control may flow full or partly full, depending on various combinations of the above factors. Figure 6-3 shows different examples of outlet control.

6.3.4.1 Outlet Control Condition

A culvert will operate under outlet control when the depth of tailwater, the length, slope, or roughness of the culvert barrel act as the control on the quantity of water able to pass through a given culvert. The energy head required for a culvert to operate under outlet control is comprised of velocity head (H_v), entrance loss (H_e) and friction loss (H_f). This energy head (H) is obtained from Figure 6A-8 to Figure 6A-14 and entrance loss coefficients from Table 6-2.

There are three (3) types of outlet control conditions for culverts:

a. The headwater submerges the culvert opening, and the culvert outlet is submerged by tailwater. The culvert will flow full, see Condition A in Figure 6-3.

b. The headwater submerges the culvert opening but the culvert outlet is not submerged by the tailwater, see Conditions B or C in Figure 6-3.

c. The headwater is insufficient to submerge the top of the culvert opening. The culvert slope is subcritical and the tailwater depth is lower than the critical depth for the culvert, see Condition D in Figure 6-3.

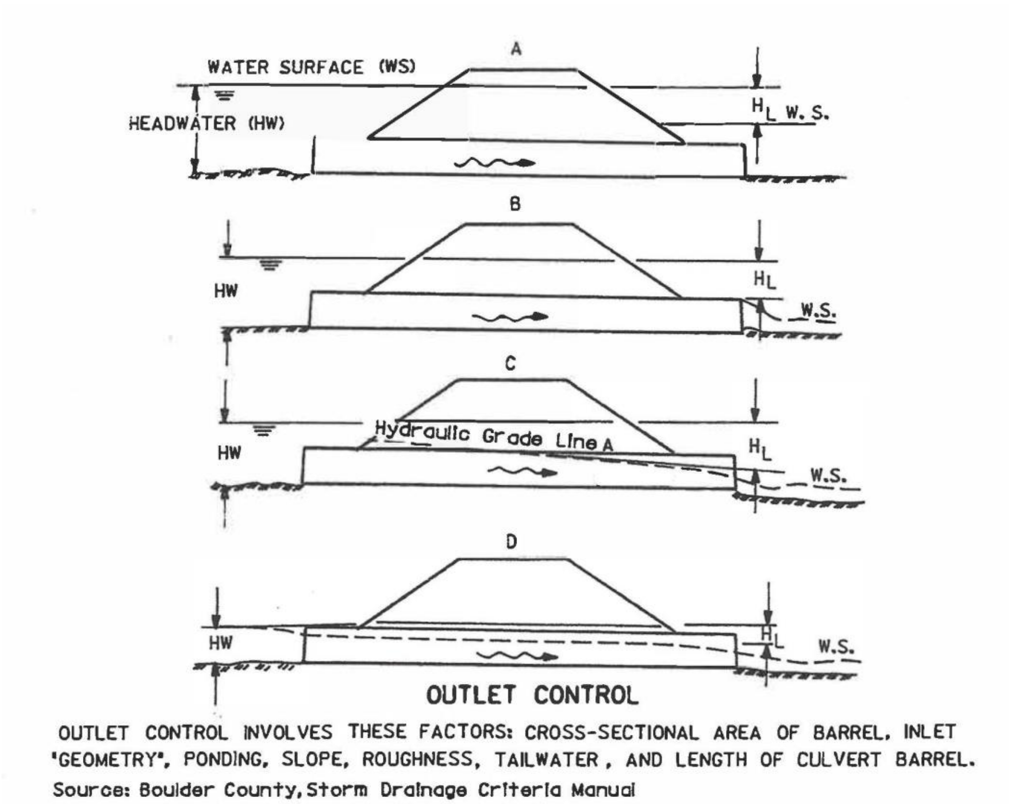


Figure 6-3 – Outlet Control Conditions

The headwater depth (HW) at the culvert entrance is calculated by means of the following formula:

$$HW = H + h_O - (L)(S_O) \qquad \text{Eq. 6-6}$$

Where:
- H = energy head
- L = length of culvert (ft.)
- S_o = slope of barrel (ft. per ft.)
- $H_o = \frac{d_c + D}{2}$ or TW, whichever is greater
- d_c = critical depth of flow in barrel. Critical depth may be determined by using Figures 19 through 24.

D = height of pipe or box
TW = tailwater depth

The maximum desirable headwater depth for culverts operating under outlet control should not be greater than the diameter or height plus two (2) feet. The elevation of adjacent facilities (i.e., buildings, etc.) must be reviewed to avoid flooding.

Table 6-3 Entrance Loss Coefficients

TYPE OF STRUCTURE AND DESIGN OF ENTRANCE	COEFFICIENT Ke
Pipe, Concrete	0.2
Projecting from fill, socket end	0.5
Projecting from fill, sq. cut end	
Headwall or headwall and wingwalls	
Socket end of pipe	0.2
Square-edge	0.5
Rounded (Radius = 1/2D)	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 wingwalls	
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	
Barrel dimension	0.2
Wingwalls at 30° to 75°to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of 1/12	
Barrel dimension	0.2
Wingwalls at 10°to 25°to barrel	
Square-edged at crown	0.5

Wingwalls parallel (extension of sides) Square-edged at crown	0.7

*Standard sections are commonly available from manufacturers

6.3.4.2 Headwater Computation for Outlet Control Conditions

Headwater depth (HW) for culverts operating under outlet control and flowing full can be determined by the following equation:

$$V = H + H_o - (L \cdot X \cdot S) \qquad \text{Eq. 6-7}$$

Where: HW = Headwater depth (ft)
H = Head for full flow (ft) (See Section X)
L = Length of the culvert (ft)
S = Slope of the culvert (ft/ft)
H_0 = Distance to the hydraulic grade line from the outlet invert (ft)
= D when $d_c \geq D$ and D> TW
= $(d_c + D)/2$ when $d_c < D$ and $(d_c + D)/2 > TW$
= TW when TW > D or TW > $(d_c + D)/2$

Where: TW = Tailwater (ft)
D = Height of culvert (ft)
d_c = Critical depth of flow in culvert (ft) (See Section X)

6.3.4.3 Head Computation for Outlet Control Conditions, Full Flow

$$H = \left(\frac{1 + Ke + (29.14n^2 \cdot L \cdot S^{\frac{1}{2}})}{R^{\frac{4}{3}}} \cdot \frac{V^2}{2g}\right) \qquad \text{Eq. 6-8}$$

Where: Ke = Entrance loss coefficient (Table 6-2)
N = Manning's coefficient of roughness (Table 6-1)
L = Length of the culvert (ft)
R = Hydraulic radius = A/p (ft)
A = Cross-sectional area of the culvert (ft^2)
p = Wetted perimeter of the culvert (ft)
V = Full flow velocity = A/A (ft/s)
Q = Discharge (ft^3/s)
g = Acceleration due to gravity (32.2 ft/s^2)

Table 6-4 Entrance Loss Coefficients, Ke

Types of Structure and Entrance Configuration*	Ke
Concrete Pipe (or Pipe Arch)	
projecting from fill, socket end	0.2
projecting from fill, square cut end	0.5
mitered to conform to fill slope	0.7
headwall, socket end of pipe or rounded	0.2
headwall, square-edge	0.5
Corrugated Metal Pipe (or Pipe Arch)	
projecting from fill	0.9
mitered to conform to fill slope	0.7
headwall, square-edge	0.5

*For more information on entrance configurations and entrance loss coefficients refer to Hydraulic Design of Improved Inlets for Culverts, Hydraulic Engineering Circular No. 13, FHWA.

6.3.4.4 Critical Depth of Flow Computation for Outlet Control Conditions

Critical depth of flow (d_c) is obtained by balancing the following equation:

$$\frac{Q^2}{g} = \frac{A^3}{T} \qquad \text{Eq. 6-9}$$

Where:

a = Velocity distribution factor (Table 6-5)
Q = Discharge (ft^3/s)
g = Acceleration due to gravity (32.2 ft/s^2)
A = Cross-sectional area of water at any depth of flow (ft^2)
T = Top surface of water at any depth of flow (ft)

Table 6-5 Values of Velocity Distribution Factor, a, for Various Types of Culverts

Culvert Type	a
Reinforced Concrete Box	1.00
Reinforced Concrete Pipe	1.04
Reinforced Concrete Pipe Arch	1.05
Corrugated Metal Pipe	1.12
Corrugated Metal Pipe Arch	1.16

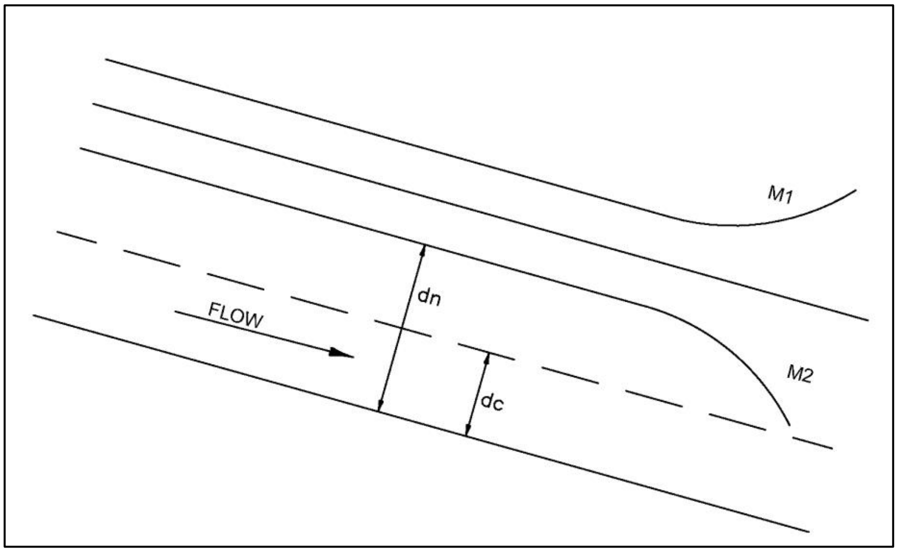


Figure 6-4 M1 and M2 Curves

6.3.4.5 Part-Full Flow in Outlet Control Conditions

Part-full flow condition may occur when critical depth (d_c) falls below the crown of the culvert at the outlet, see Figure 6-4. To accurately determine headwater (HW) for culverts flowing part-full, backwater computations are required to establish a water surface profile. The water surface profile for normal depth (d_n), greater than or equal to d_c, is computed from the following equations:

a. For Tailwater (TW) ≥ d_n (M1 Curve):

$$\Delta L = \frac{(d_1 + \frac{v_1^2}{2g}) - (d_2 + v_2^2)}{S_{culv} - S_w} \qquad \text{Eq. 6-10}$$

b. For Tailwater (TW) < d_n (M2 Curve):

$$\Delta L = \frac{(d_2 + \frac{v_2^2}{2g}) - (d_1 + v_1^2)}{S_w - S_{culv}} \qquad \text{Eq. 6-11}$$

Where: ΔL = Distance between two sections of water (ft)
d_1, d_2 = Depth at Sections 1 and 2, respectively (ft)
V_1, V_2 = Velocities at Sections 1 and 2 (ft/s)
g = Acceleration due to gravity (ft/s^2)
S_{culv} = Slope of the culvert (ft/ft)

$$S_w = \frac{n^2 V^2}{2.21 R^{\frac{4}{3}}} \quad \text{Eq. 6-12}$$

Where: S_W = Slope of the water surface ft/ft)
n = Manning's coefficient of roughness (Table 6-1)
V = Average velocity of the two sections (ft/s)
R = Average hydraulic radius of the two sections (ft)

The backwater profile starts with a depth (d_1) equal to:

a. The tailwater (TW) at the outlet and decreases in depth as the profile extends into the culvert for an M1 curve.

b. The tailwater (TW) or critical depth of flow (d_c), whichever is greater, at the outlet and increases in depth (not to exceed the depth of the culvert) as the profile extends into the culvert for an M2 curve.

The depth (d_1) then approaches normal depth (d_n) in the culvert. If the normal depth (d_n) is not reached before the length of the culvert is exceeded, the depth for the last cross section in the culvert is used to compute the headwater (HW). HW is computed by the following equation:

$$HW = d_2 + \frac{V_2^2}{2g} + (Ke)V_1^2 \quad \text{Eq. 6-13}$$

Where: HW = Headwater depth (ft)
D_2 = Depth at Section 2 (ft)
V_2 = Velocity at Section 2 (ft/s)
V_1 = Velocity at Section 1 (ft/s)
Ke = Entrance loss coefficient (Table 6-2)

6.3.4.6 Outlet Velocity Computation for Outlet Control Conditions

Outlet velocity for culverts operating under outlet control is computed by the following equation:

$$V = \frac{Q}{A} \qquad \text{Eq. 6-14}$$

Where: Q = Discharge (ft^3/s)
V = Outlet velocity (ft/s)
A = Cross-sectional area for the depth of flow at the culvert outlet (ft^2).

Depth of flow at the outlet is the critical depth of flow (d_c), or the tailwater (TW), whichever is greater, with a maximum equal to the height of the culvert.

6.4 Computation Format

Figure 6A-1 was developed by the Federal Highway Administration and can be useful in preliminary sizing of culvert or for culvert design.

6.4.1 Procedure

The procedures to follow in determining culvert size are:

1. List all design data.
2. Select a trial culvert size.
3. Determine the headwater depth for the trial size.
   a. Headwater for inlet control.
   b. Headwater for outlet control.
   c. Compare headwaters and use higher value.
4. Compare this headwater with the allowable limit.
   a. If headwater is within allowable limit, repeat Steps 3 and 4 until allowable limits are reached.
5. Compute outlet velocity to determine need for channel protection. See Section 7.2.6 for additional information on channel protection.

6.5 Appendix

6.5.1 References

(1) Louisiana Department of Transportation and Development, “2011 Hydraulics Manual”, 2011

(2) U.S. Department of Transportation, Federal Highway Administration, “Urban Drainage Design Manual, Hydraulic Engineering Circular No. 22, Third Edition”, August 2013

(3) City of Austin, Texas, “Design Criteria Manual”, Department of Public Works, 2020

(4) City of Ft. Wayne, Indiana, “City Utilities Design Standards Manual, Sept. 2017

6.5.2 Example Problems

6.5.2.1 EXAMPLE PROBLEM #1: Headwater Calculation for Culvert Crossing (HYDR1120)

GIVEN: Road Elevation – 108.0 ft; Shoulder Elevation – 107.5

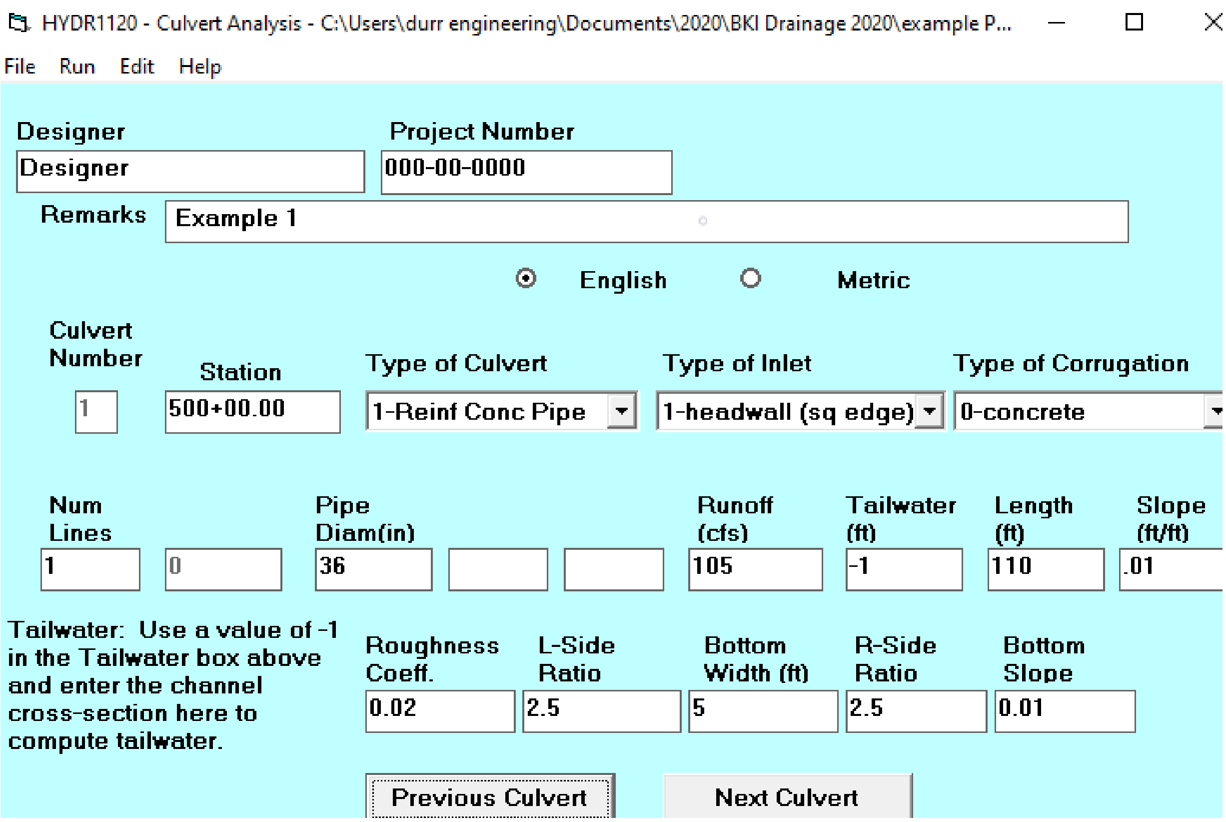
Culvert Elevation – 100.00 ft; Max. Allowable Headwater – 6.5 ft

Stream side slopes – 2.5:1; Stream Bottom – 5 ft

Stream slope – 1%; Design Discharge – 105 cfs

FIND: Determine the minimum size single RCP culvert under road.

SOLUTION: See Figure 6-6 and 6-7 for HYD1120 inputs and outputs.



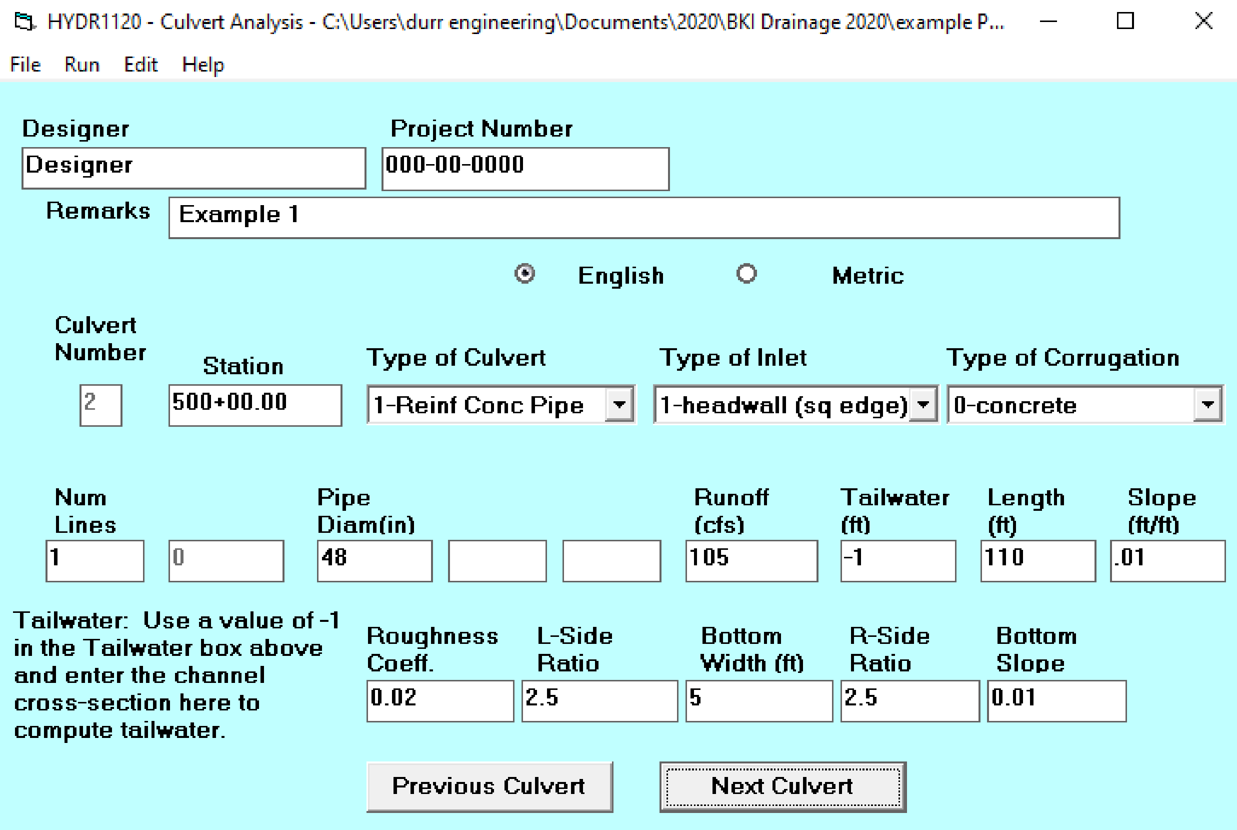


Figure 6-6 HYDR1120 Input

```
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT      HYDR1120-120199
HYDRAULICS SECTION
DESIGNER: Designer                     DATE: 03-05-2020
REMARKS : Example 1

                 STATE PROJECT NUMBER   000-00-0000   .

         REINFORCED CONCRETE PIPE ( INLET TYPE: 1-HEADWALL   )
**********************************************************************
         STATION                                   500+00.00
         NUMBER OF PIPES                                   1
         DIAMETER (IN.)                                   36
         DESIGN DISCHARGE (CFS)                       105.00
         TAILWATER (FT.)                                1.56
         LENGTH (FT.)                                 110.00
         SLOPE (FT./FT.)                              .01000
**********************************************************************

         HEADWATER (INLET)                              8.59  FT.
         OUTLET VELOCITY                               14.85  F.P.S.
         DEPTH OF SCOUR FOR TYPE A SOIL                 4.27  FT.

**********************************************************************


CHANNEL CROSS-SECTION:

    SIDE SLOPE RATIO,  LEFT (FT.:1)                     2.50
    CHANNEL BOTTOM WIDTH (FEET)                         5.00
    SLOPE OF CHANNEL BOTTOM (FT./FT.)                 .01000
    SIDE SLOPE RATIO, RIGHT (FT.:1)                     2.50
    ROUGHNESS COEFFICIENT                               .020

**********************************************************************
```

Figure 6-7 HYDR1120 OUTPUT (Allowable Headwater Exceeded)

```
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT      HYDR1120-120199
HYDRAULICS SECTION
DESIGNER: Designer                    DATE: 03-05-2020
REMARKS : Example 1

                 STATE PROJECT NUMBER   000-00-0000

         REINFORCED CONCRETE PIPE ( INLET TYPE: 1-HEADWALL   )
**********************************************************************
         STATION                                   500+00.00
         NUMBER OF PIPES                                   1
         DIAMETER (IN.)                                   48
         DESIGN DISCHARGE (CFS)                       105.00
         TAILWATER (FT.)                                1.56
         LENGTH (FT.)                                 110.00
         SLOPE (FT./FT.)                              .01000
**********************************************************************

         HEADWATER (INLET)                              4.93  FT.
         OUTLET VELOCITY                               13.27  F.P.S.
         DEPTH OF SCOUR FOR TYPE A SOIL                 3.42  FT.

**********************************************************************


CHANNEL CROSS-SECTION:

    SIDE SLOPE RATIO,  LEFT (FT.:1)                     2.50
    CHANNEL BOTTOM WIDTH (FEET)                         5.00
    SLOPE OF CHANNEL BOTTOM (FT./FT.)                 .01000
    SIDE SLOPE RATIO, RIGHT (FT.:1)                     2.50
    ROUGHNESS COEFFICIENT                               .020

**********************************************************************
```

Figure 6-8 (Allowable Headwater Acceptable)

6.5.2.2 EXAMPLE PROBLEM #2: Culvert Analysis - (HYDROFLOW)

GIVEN:

Culvert Elevation –102.00 ft

Culvert Size – 36" RCP

Culvert Slope – 0.75%

No. of Barrels - 1

Culvert Length – 80 ft

Road Elevation – 106.75 ft

Embankment Width – 50 ft

Crest Width – 62 ft

FIND: Determine the maximum discharge (Q) to not overtop the roadway.

SOLUTION: See Figure 6-9 and 6-11 for HYDROFLOW inputs and outputs.

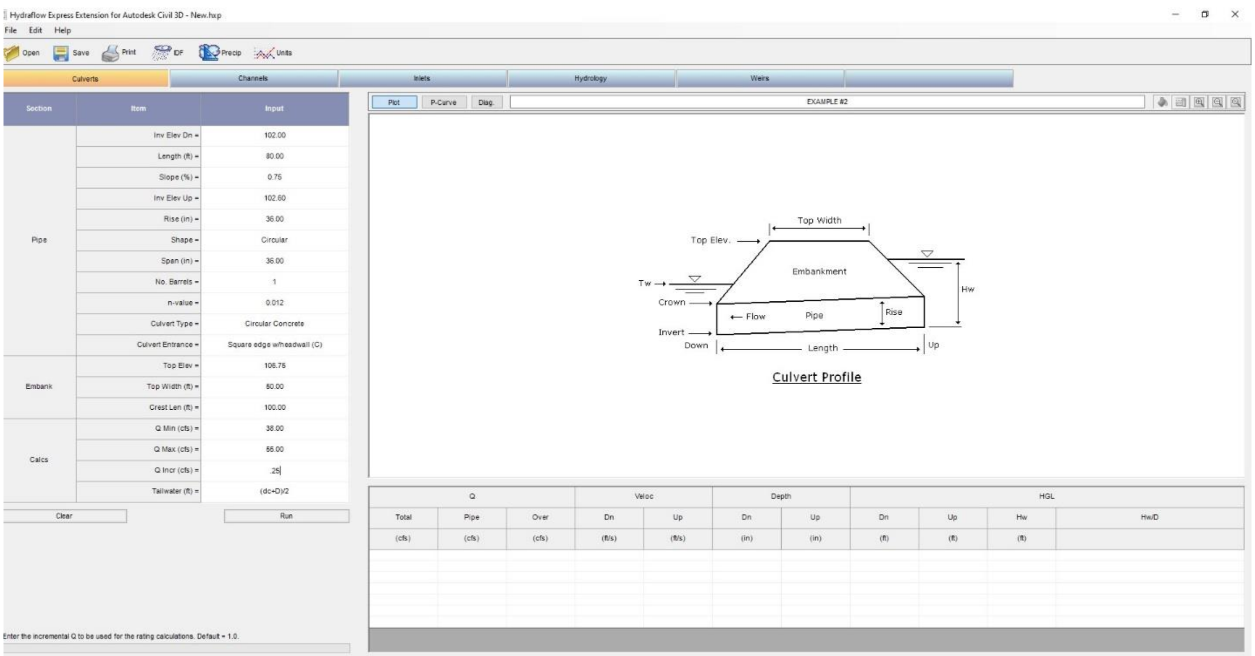


Figure 6-9 HYDROFLOW Input

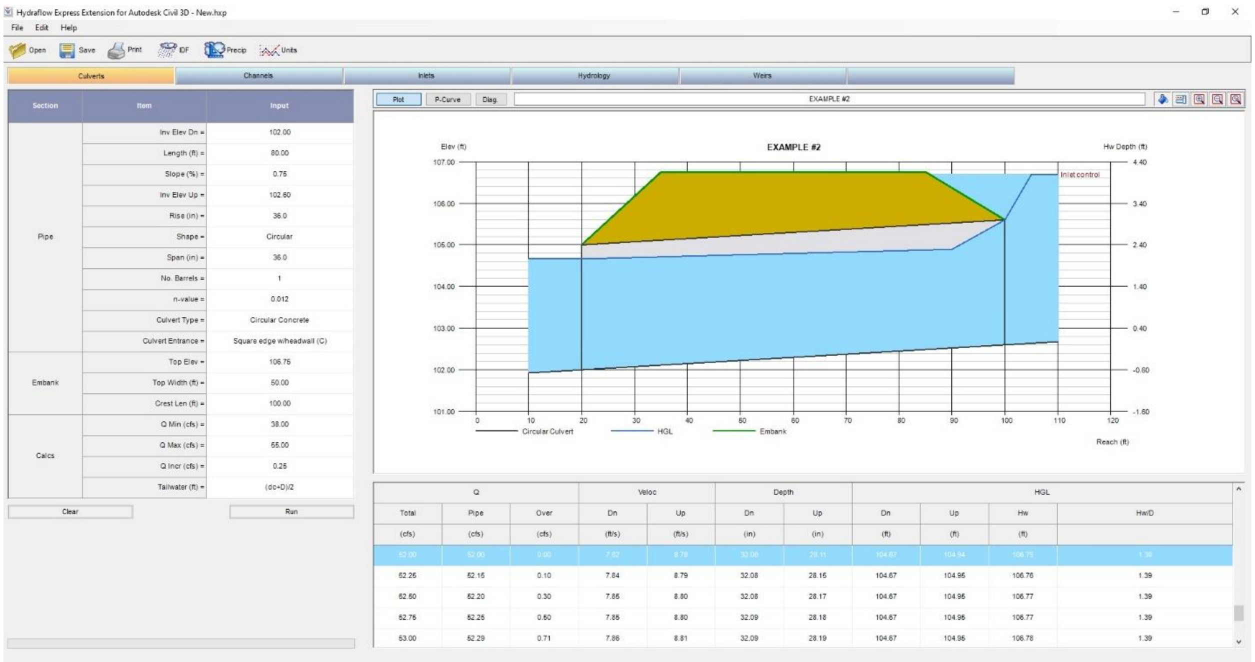


Figure 6-10 HYDROFLOW Output

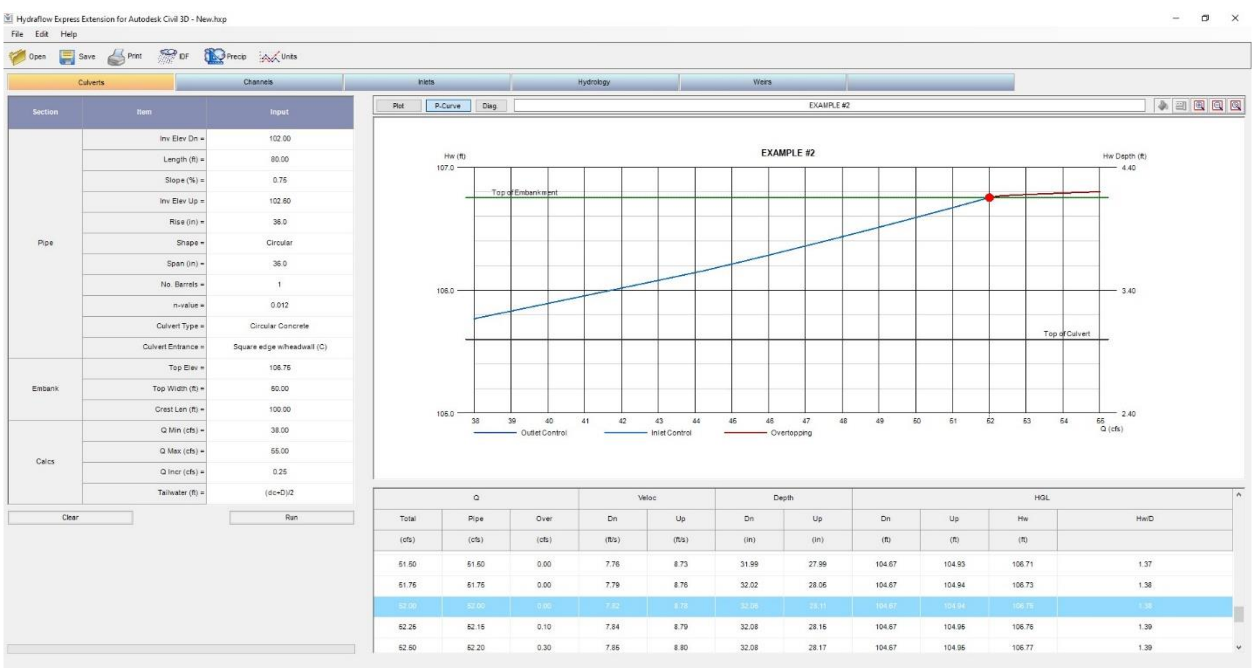


Figure 6-11 HYDROFLOW Output Performance Curve

6.5.2.2 EXAMPLE PROBLEM #3: Culvert Analysis - (HY-8)

GIVEN:

Culvert Elevation –102.00 ft	Road Elevation – 106.75 ft
Culvert Size – 36" RCP	Embankment Width – 50 ft
Culvert Slope – 0.75%	Crest Width – 62 ft
No. of Barrels - 1	
Culvert Length – 80 ft	
Stream Bottom Width – 8 ft	
Stream Slope – 1%	
Stream Shape – Trapezoidal (2.5:1 side slopes)	

FIND: Determine the maximum discharge (Q) to not overtop the roadway and the outlet velocities.

SOLUTION: See Figure 6-12 and 6-15 for HY-8 inputs and outputs.

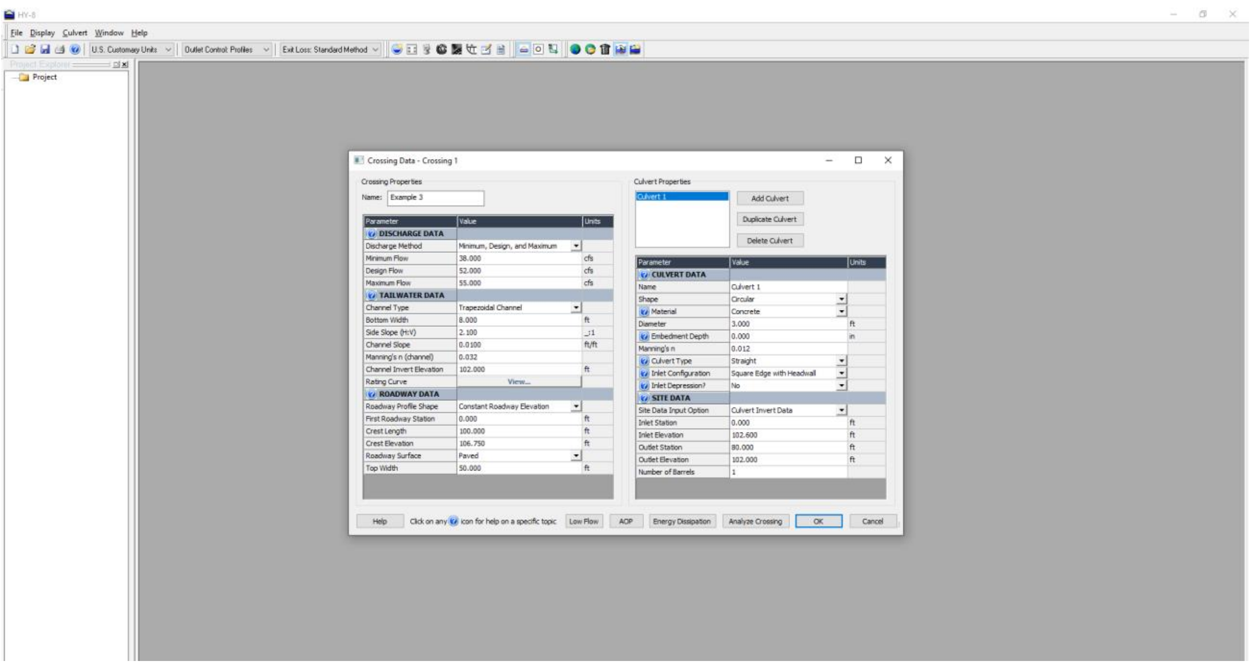


Figure 6-12 HY-8 Input

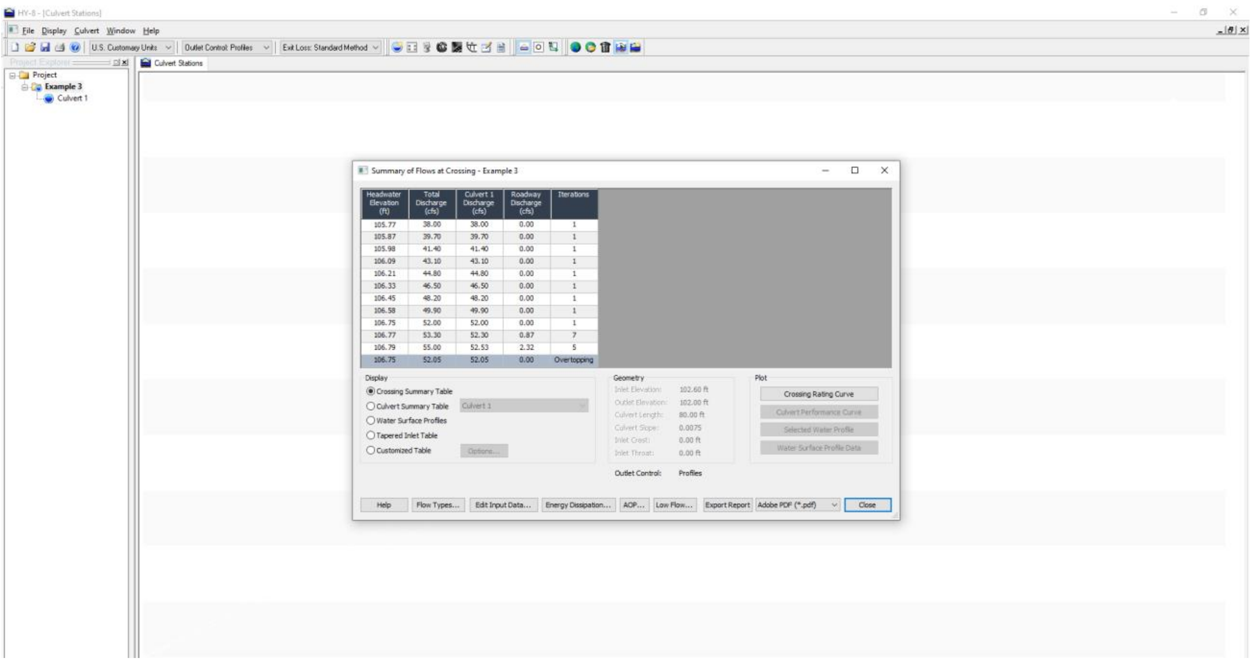


Figure 6-13 HY-8 Summary Table Showing Overtopping

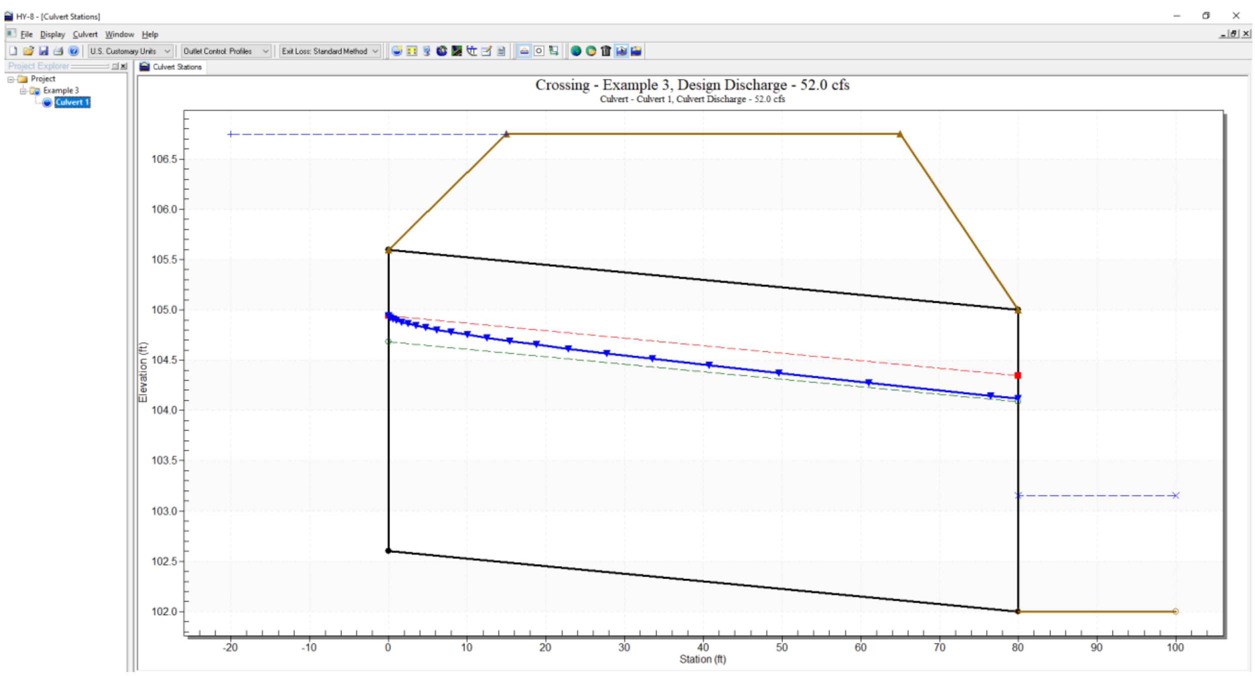


Figure 6-14 HY-8 Output Screen – Water Surface Profile

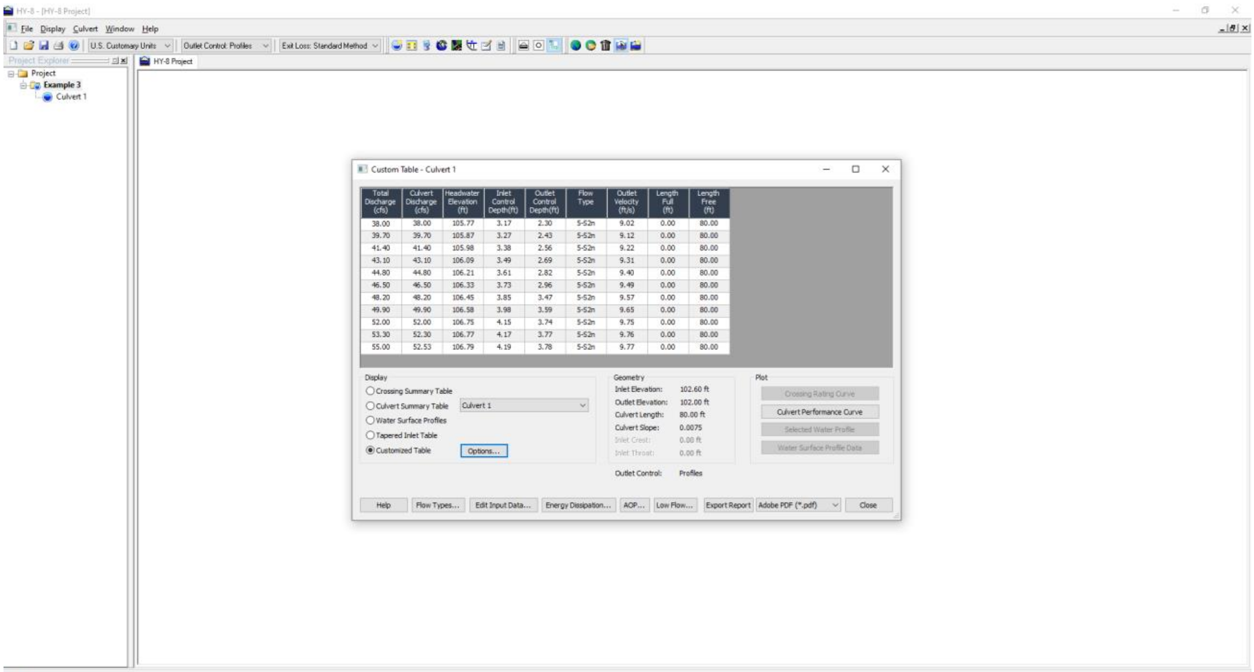


Figure 6-15 HY-8 Output Screen – Summary Table Showing Outlet Velocities

6.5.3 Figures

FIGURE 6A-1

DESIGNER: ______________

PROJECT: ______________

DATE: ______________

HYDROLOGIC AND CHANNEL INFORMATION

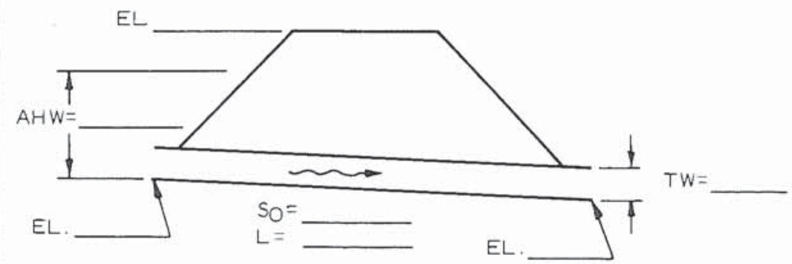
Q_1 = ______________ TW_1 = ______________

Q_2 = ______________ TW_2 = ______________

Q_1 = DESIGN DISCHARGE
Q_2 = CHECK DISCHARGE

SKETCH

STATION: ______________



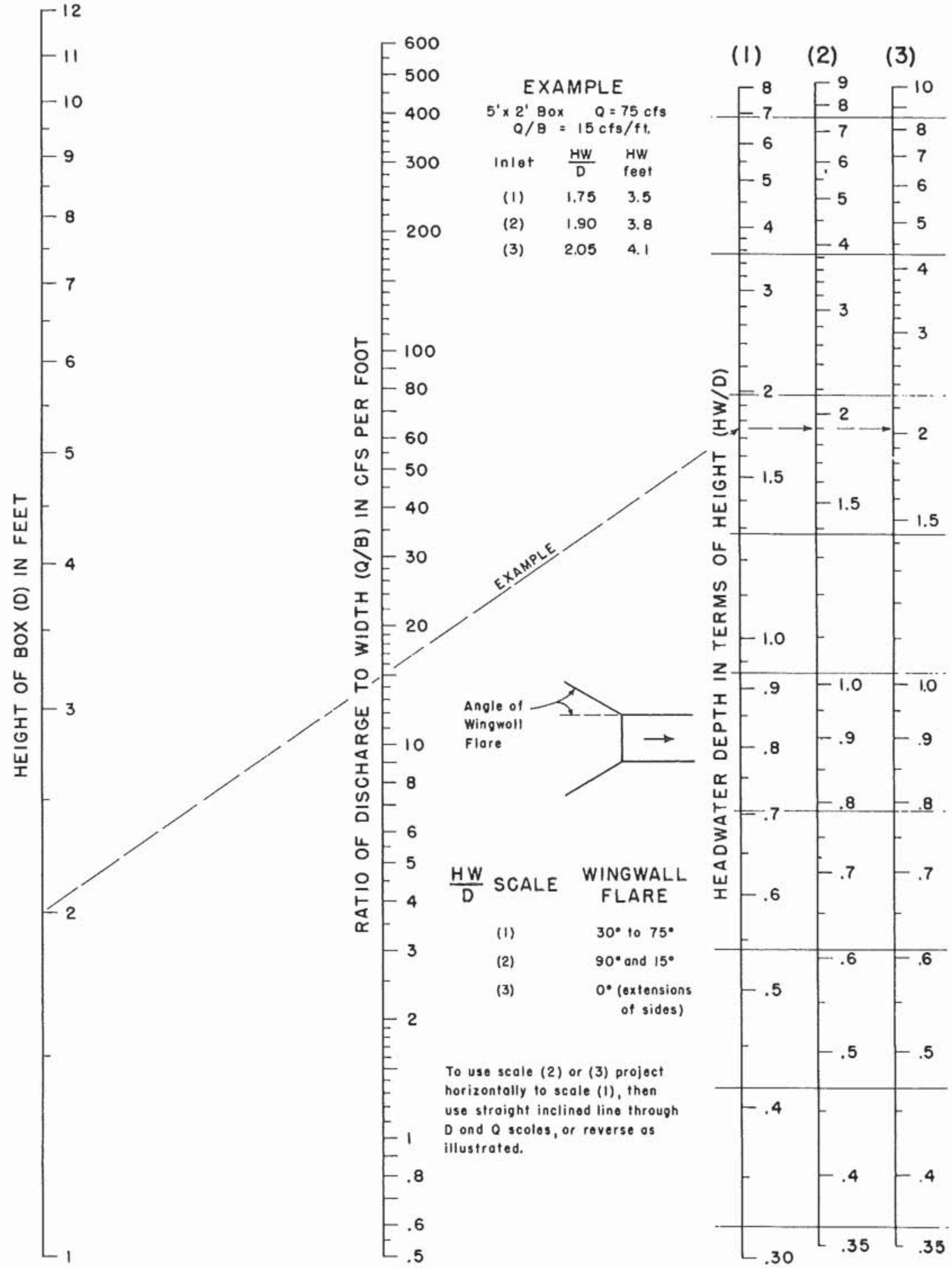
MEAN STREAM VELOCITY= ______________

MAX. STREAM VELOCITY= ______________

CULVERT DESCRIPTION (ENTRANCE TYPE)	Q	SIZE	HEADWATER COMPUTATION										CONTROLLING HW	OUTLET VELOCITY	COMMENTS
			INLET CONT.		OUTLET CONTROL $HW=H+h_o-LS_o$										
			$\frac{HW}{D}$	HW	K_e	H	d_c	$\frac{d_c+D}{2}$	TW	h_o	LS_o	HW			

SUMMARY & RECOMMENDATIONS:

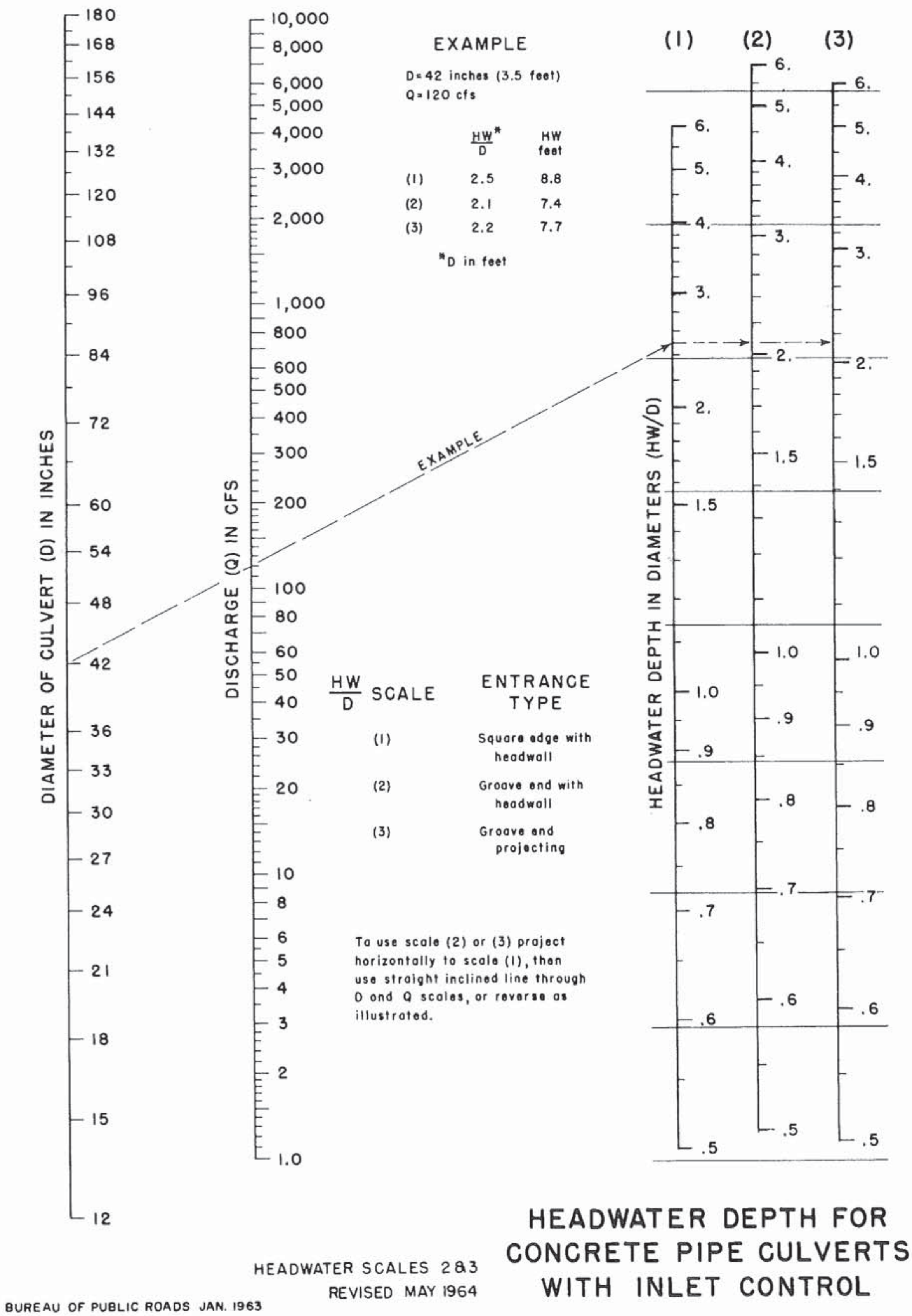
FIGURE 6A-2



HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

FIGURE 6A-3

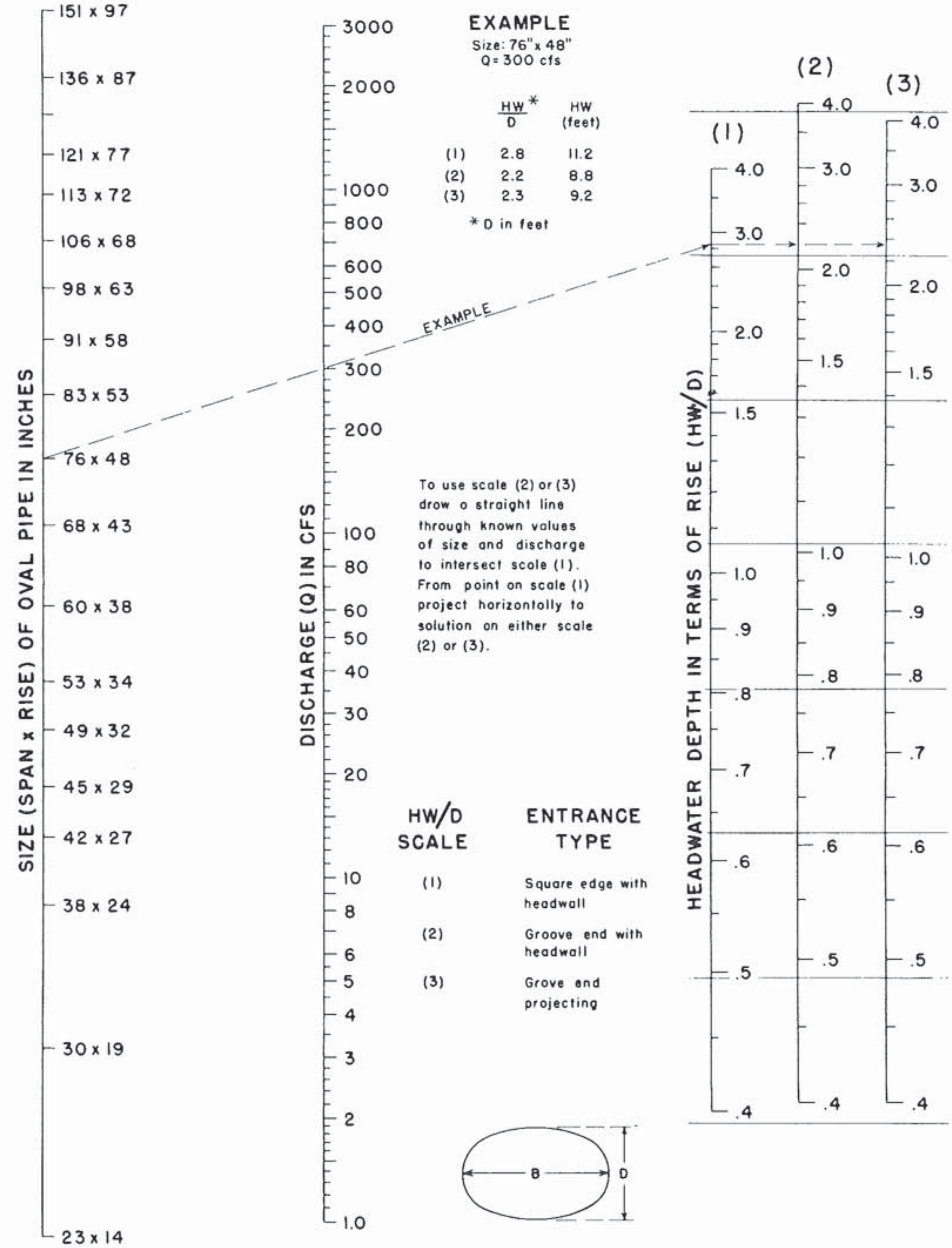


HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

FIGURE 6A-4



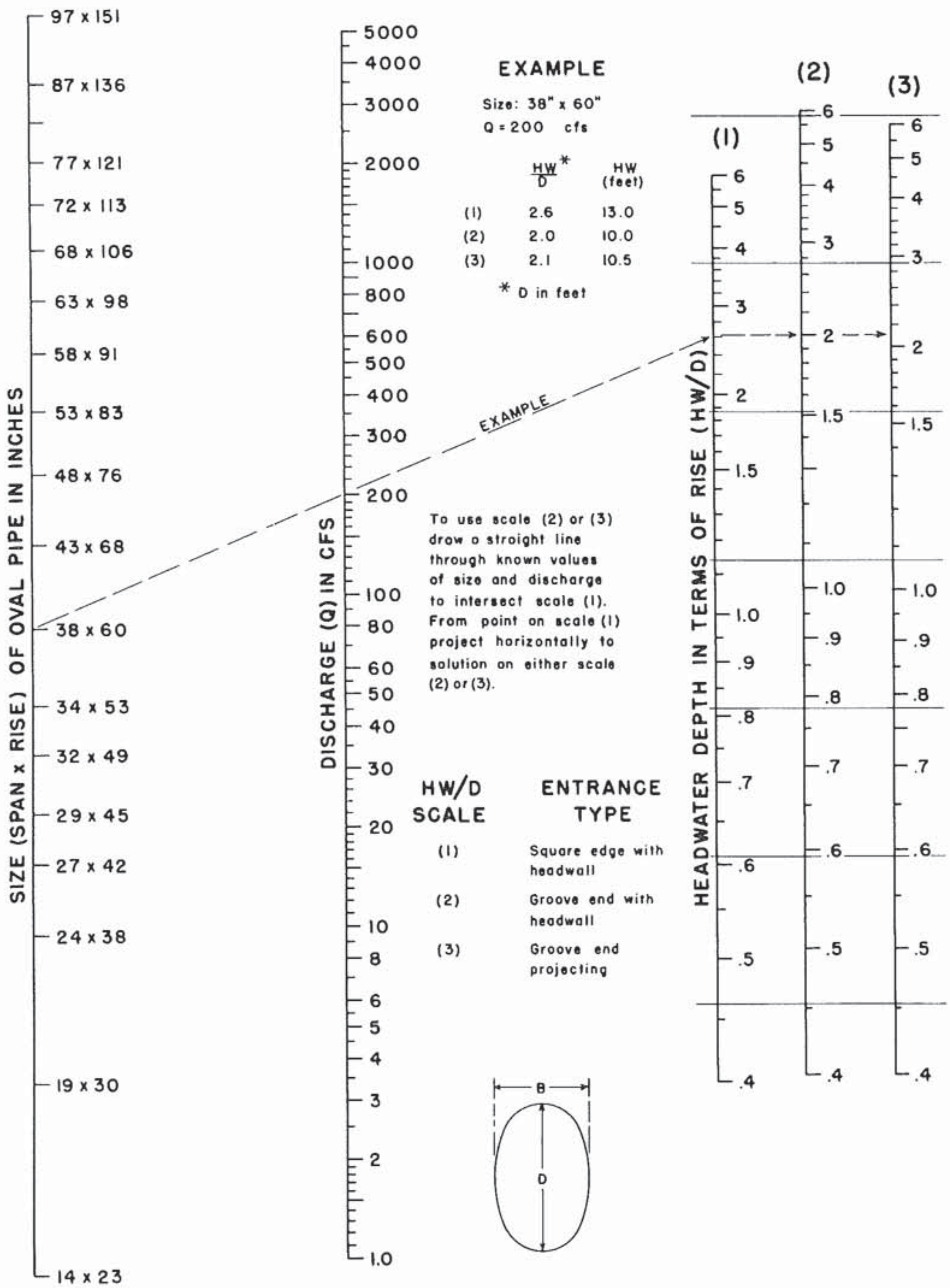
HEADWATER DEPTH FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS HORIZONTAL
WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

FIGURE 6A-5



HEADWATER DEPTH FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS VERTICAL
WITH INLET CONTROL

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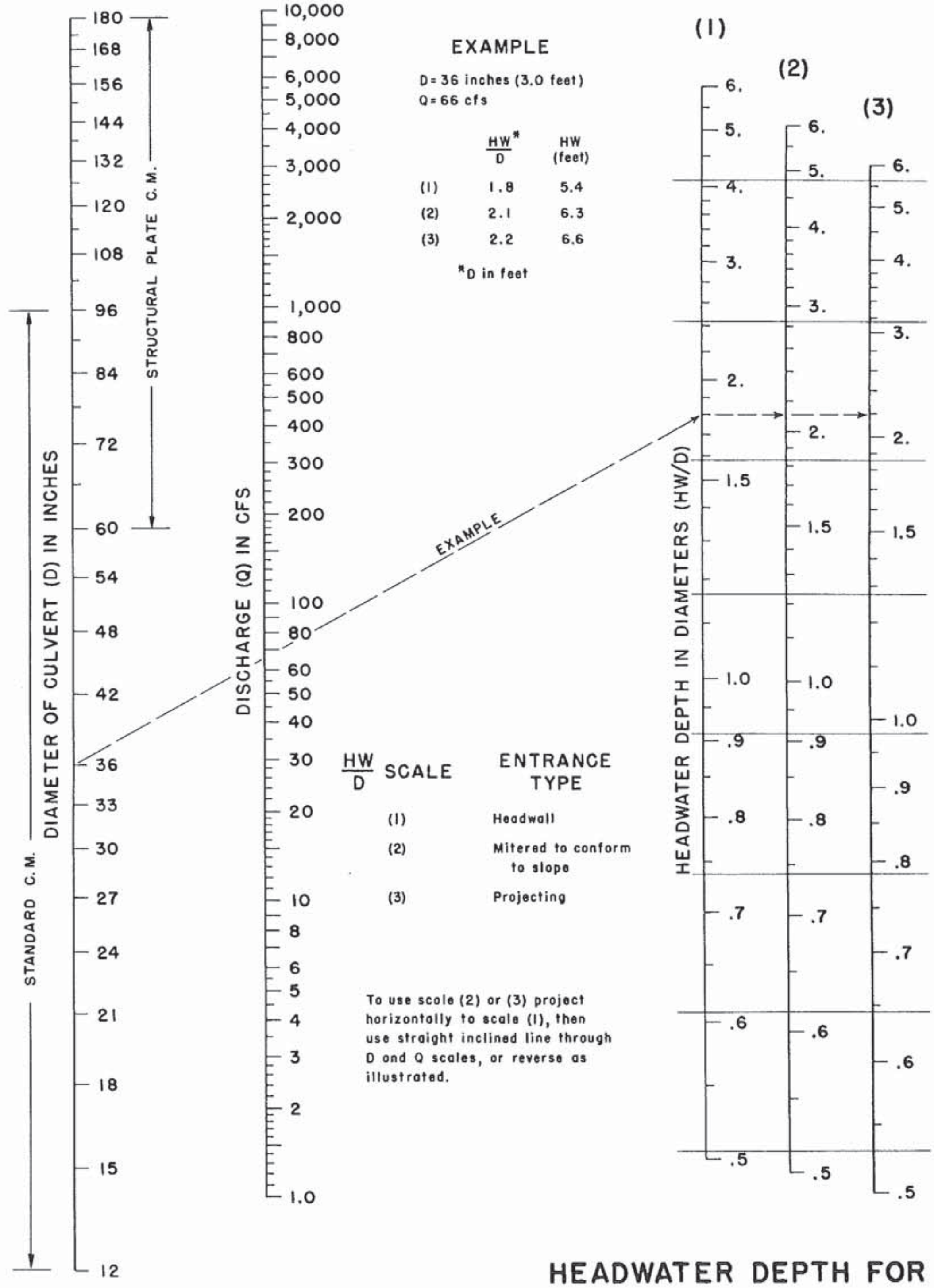
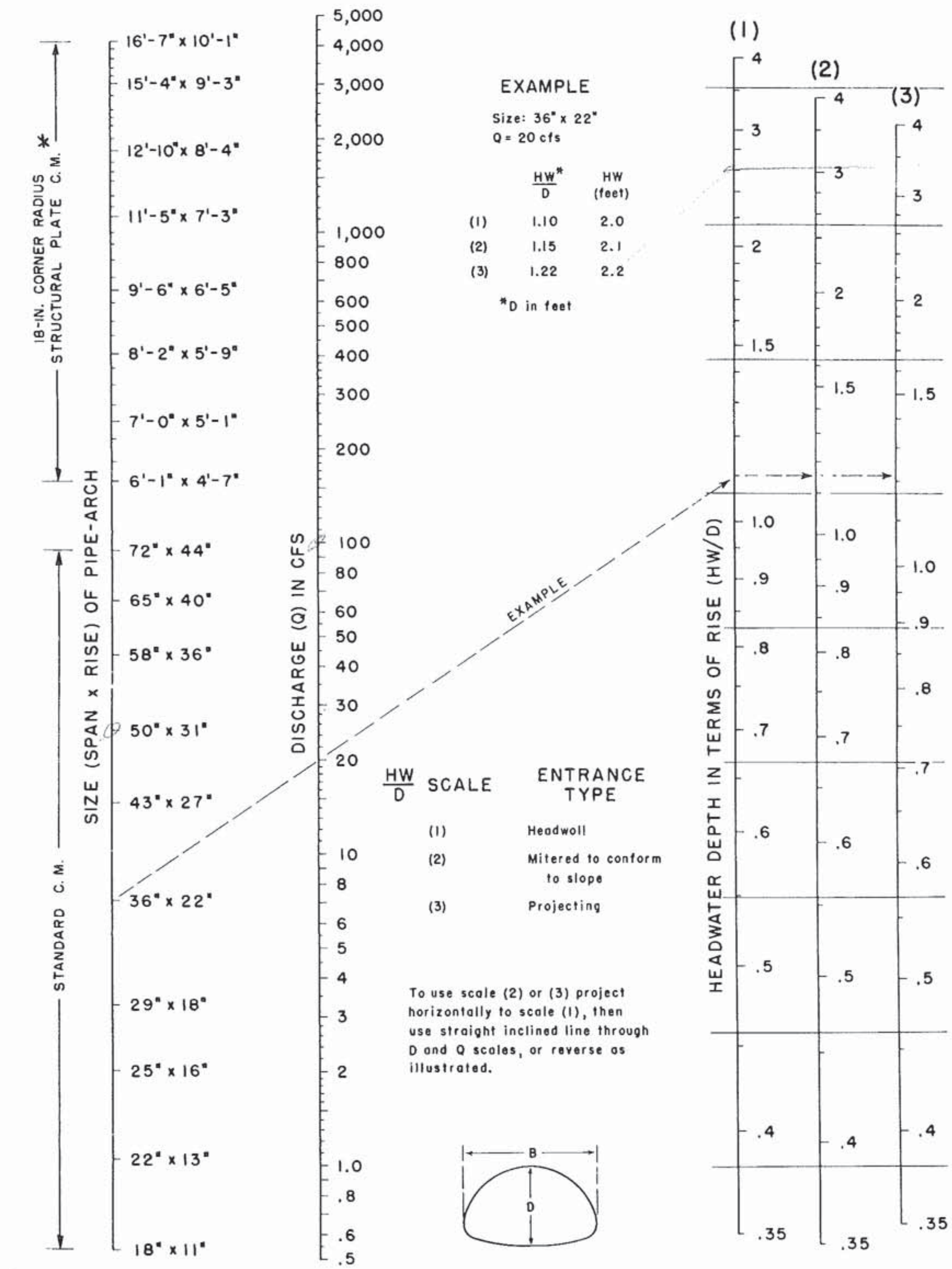
FIGURE 6A-6



HEADWATER DEPTH FOR C. M. PIPE CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

FIGURE 6A-7



*ADDITIONAL SIZES NOT DIMENSIONED ARE LISTED IN FABRICATOR'S CATALOG

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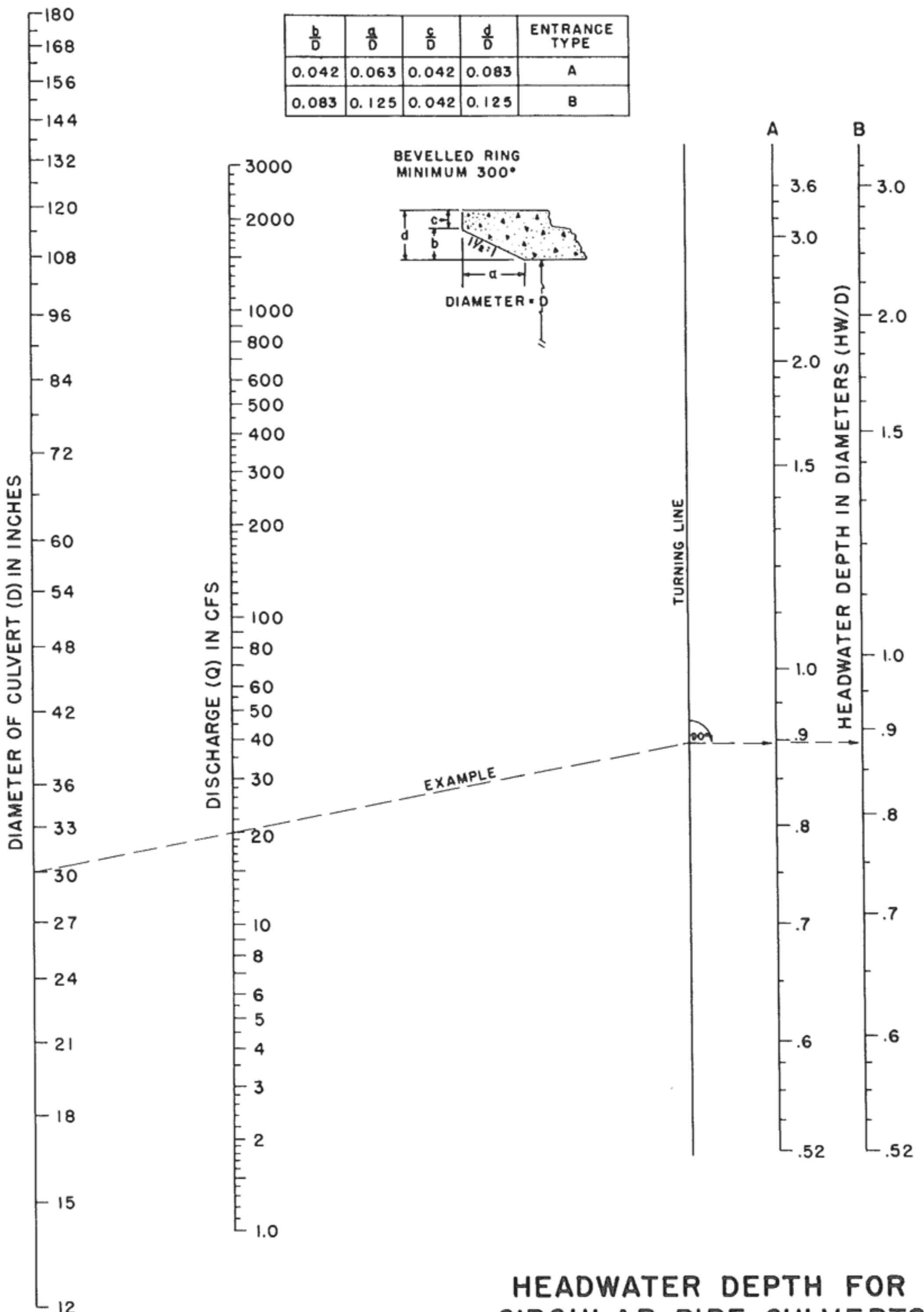
HEADWATER DEPTH FOR C. M. PIPE-ARCH CULVERTS WITH INLET CONTROL

FIGURE 6A-8

b/D	a/D	c/D	d/D	ENTRANCE TYPE
0.042	0.063	0.042	0.083	A
0.083	0.125	0.042	0.125	B



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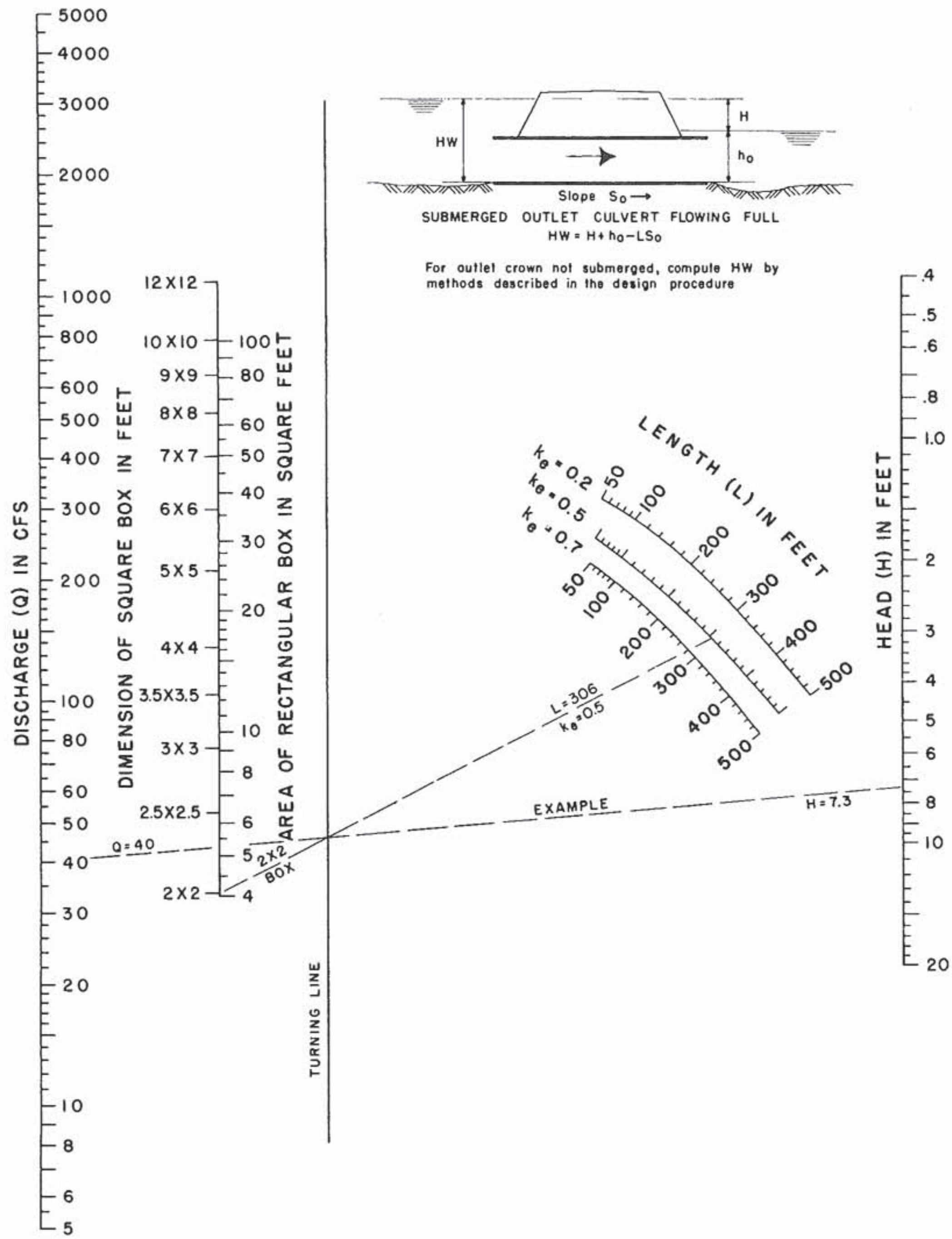
MARCH 1964

HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELLED RING INLET CONTROL

FIGURE 6A-9



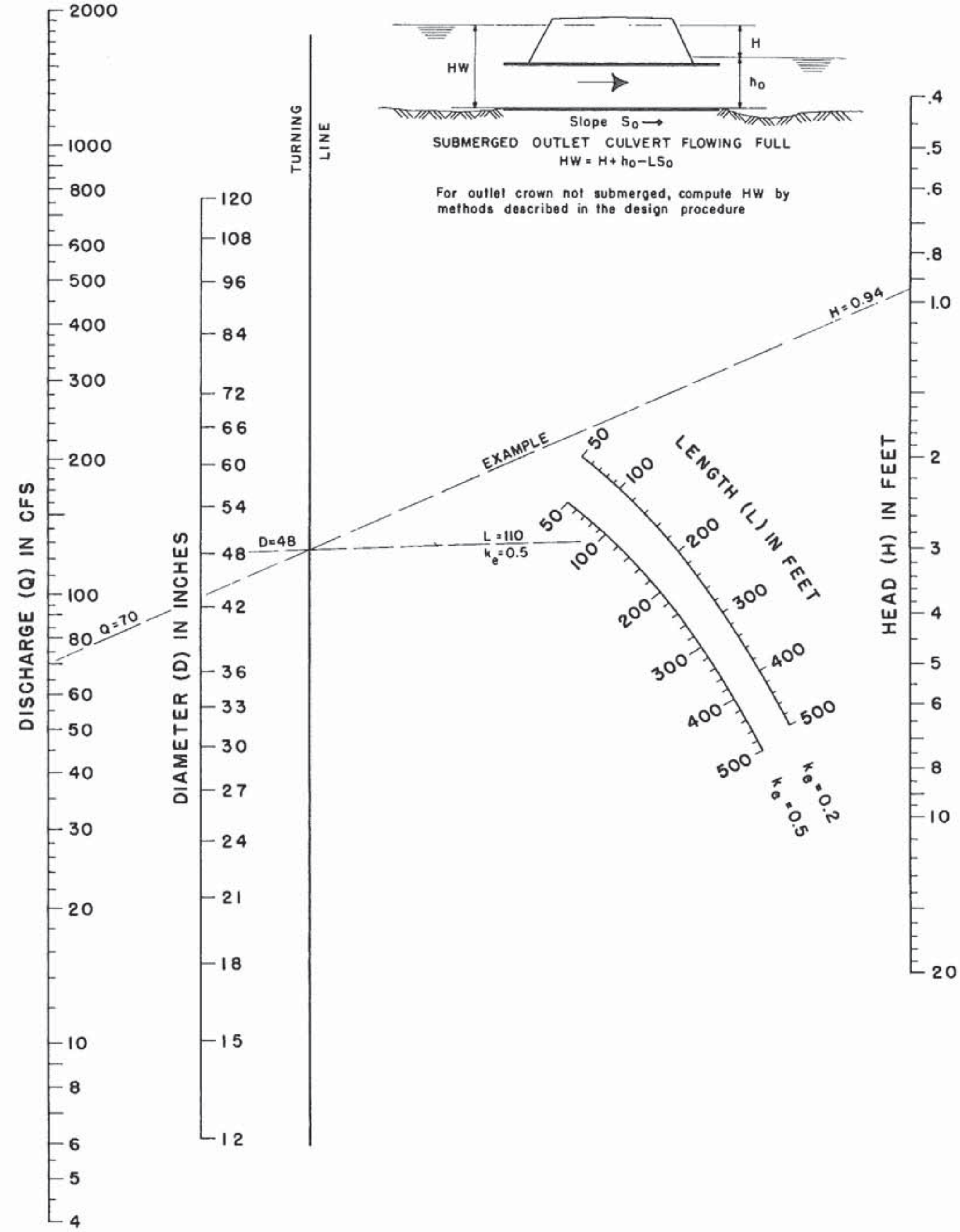
HEAD FOR CONCRETE BOX CULVERTS FLOWING FULL
n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

CITY OF SHREVEPORT, LOUISIANA

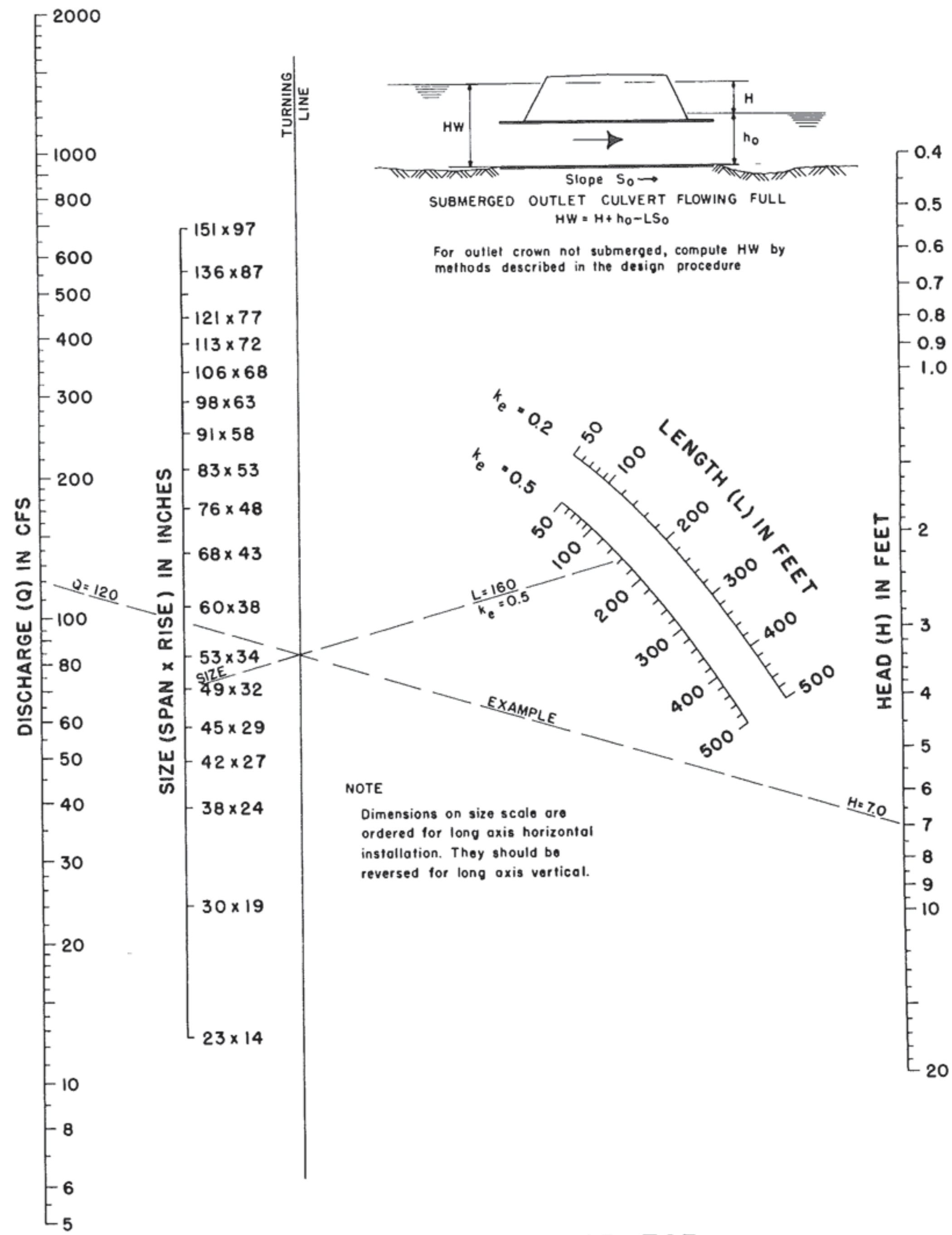
DEPARTMENT OF PUBLIC WORKS

FIGURE 6A-10



BUREAU OF PUBLIC ROADS JAN. 1963

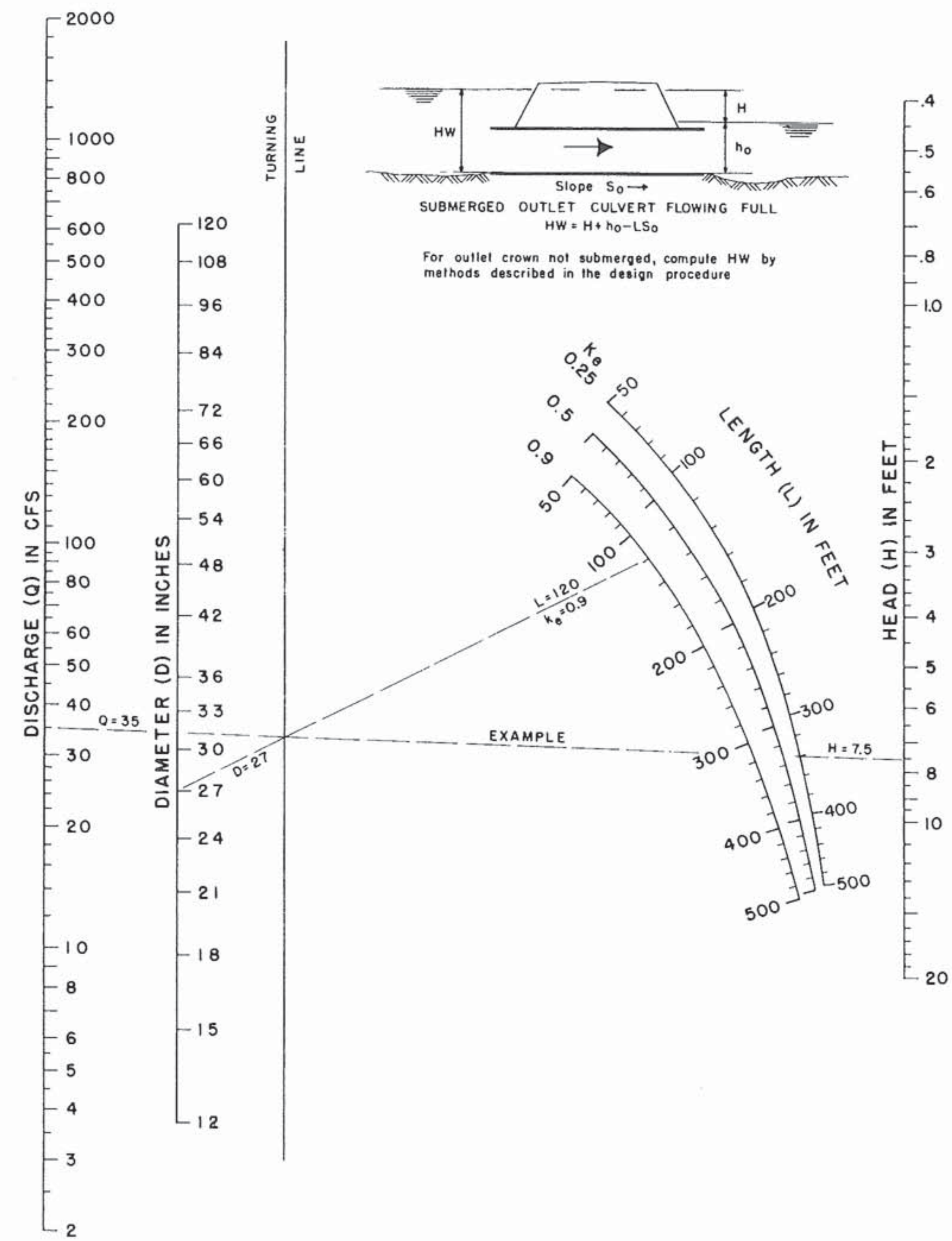
HEAD FOR
CONCRETE PIPE CULVERTS
FLOWING FULL
n = 0.012



HEAD FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS HORIZONTAL OR VERTICAL
FLOWING FULL
$n = 0.012$

BUREAU OF PUBLIC ROADS JAN. 1963

FIGURE 6A-12



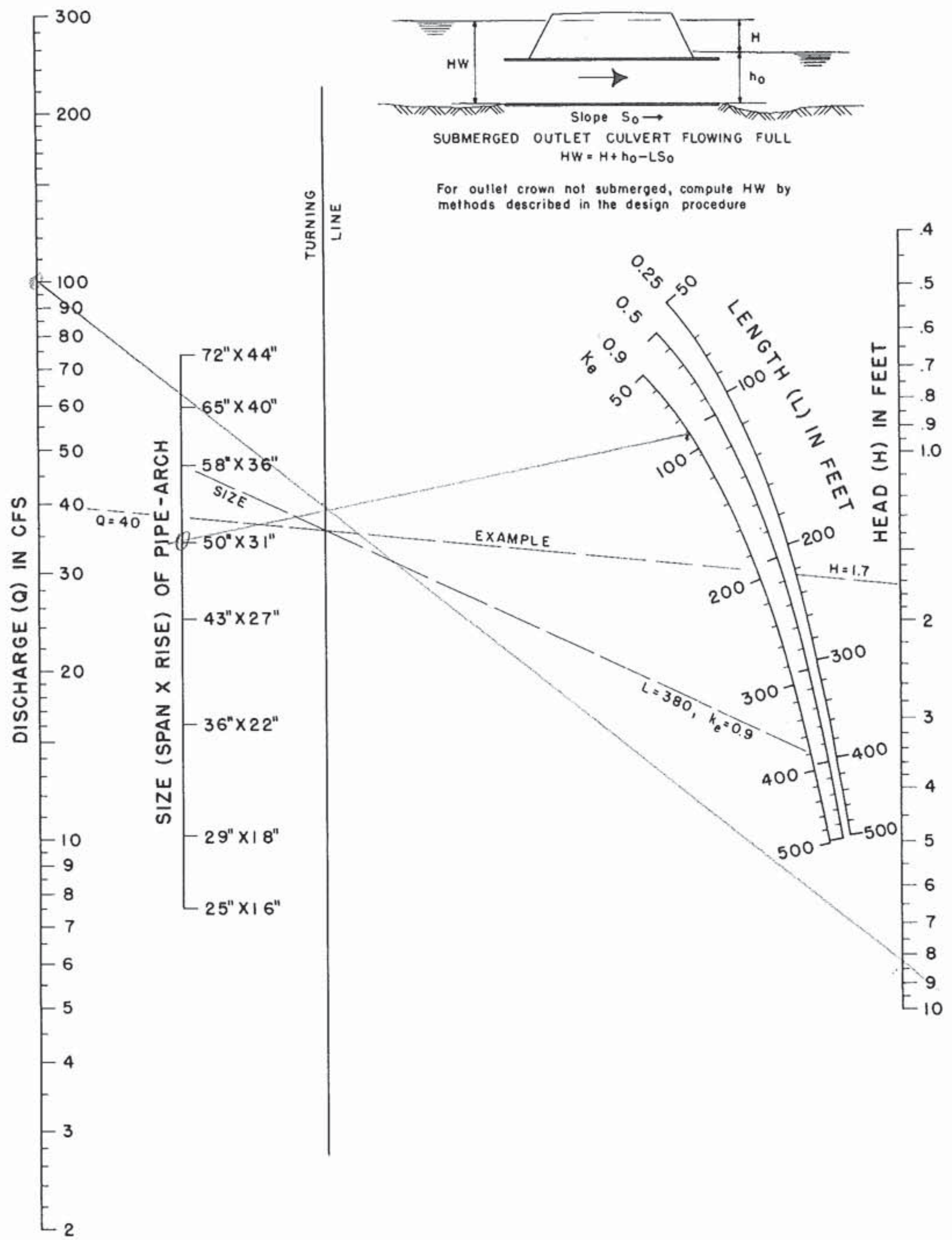
BUREAU OF PUBLIC ROADS JAN. 1963

HEAD FOR STANDARD C. M. PIPE CULVERTS FLOWING FULL $n = 0.024$

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

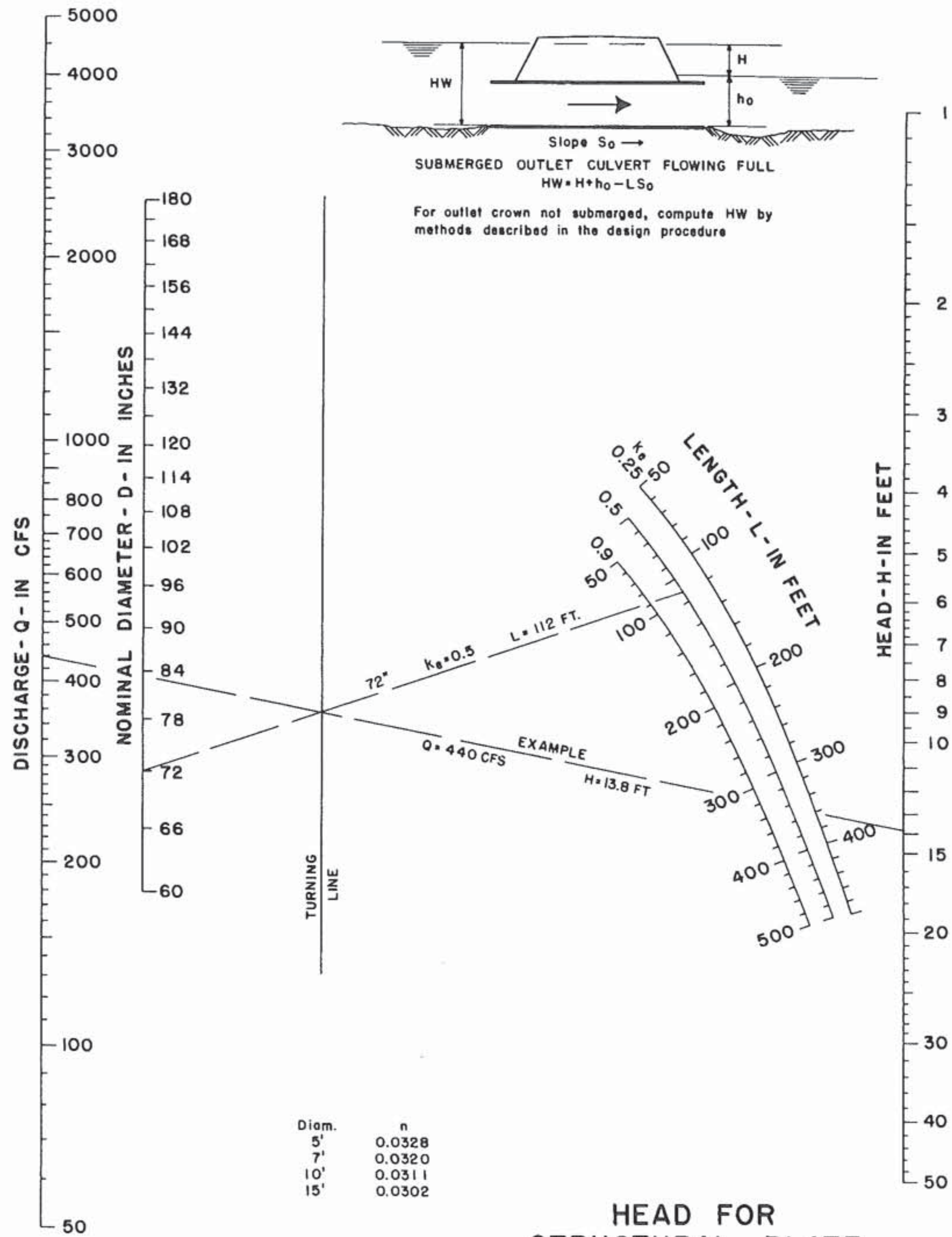
FIGURE 6A-13



HEAD FOR
STANDARD C. M. PIPE-ARCH CULVERTS
FLOWING FULL
n = 0.024

BUREAU OF PUBLIC ROADS JAN. 1963

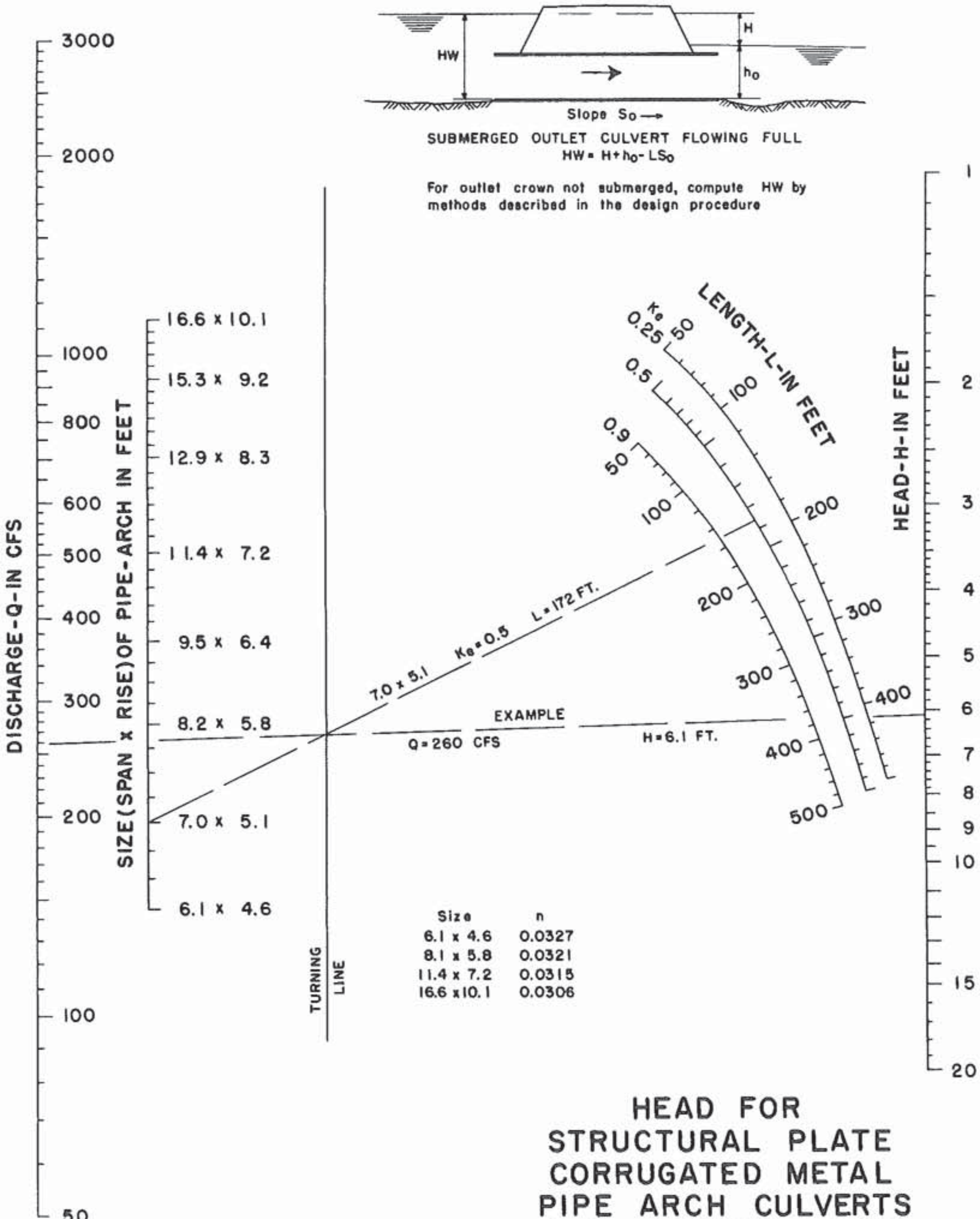
FIGURE 6A-14



HEAD FOR
STRUCTURAL PLATE
CORR. METAL PIPE CULVERTS
FLOWING FULL
n = 0.0328 TO 0.0302

BUREAU OF PUBLIC ROADS JAN. 1963

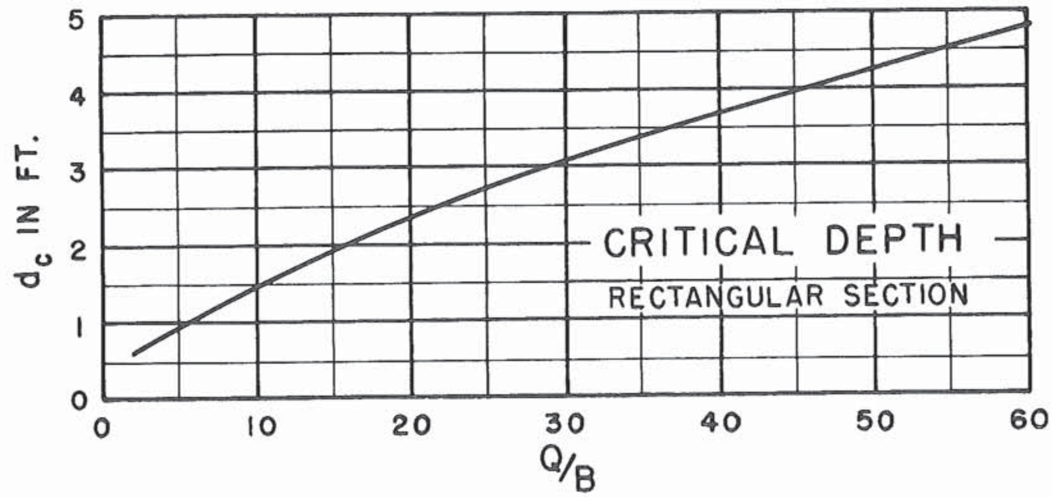
CITY OF SHREVEPORT, LOUISIANA
DEPARTMENT OF PUBLIC WORKS

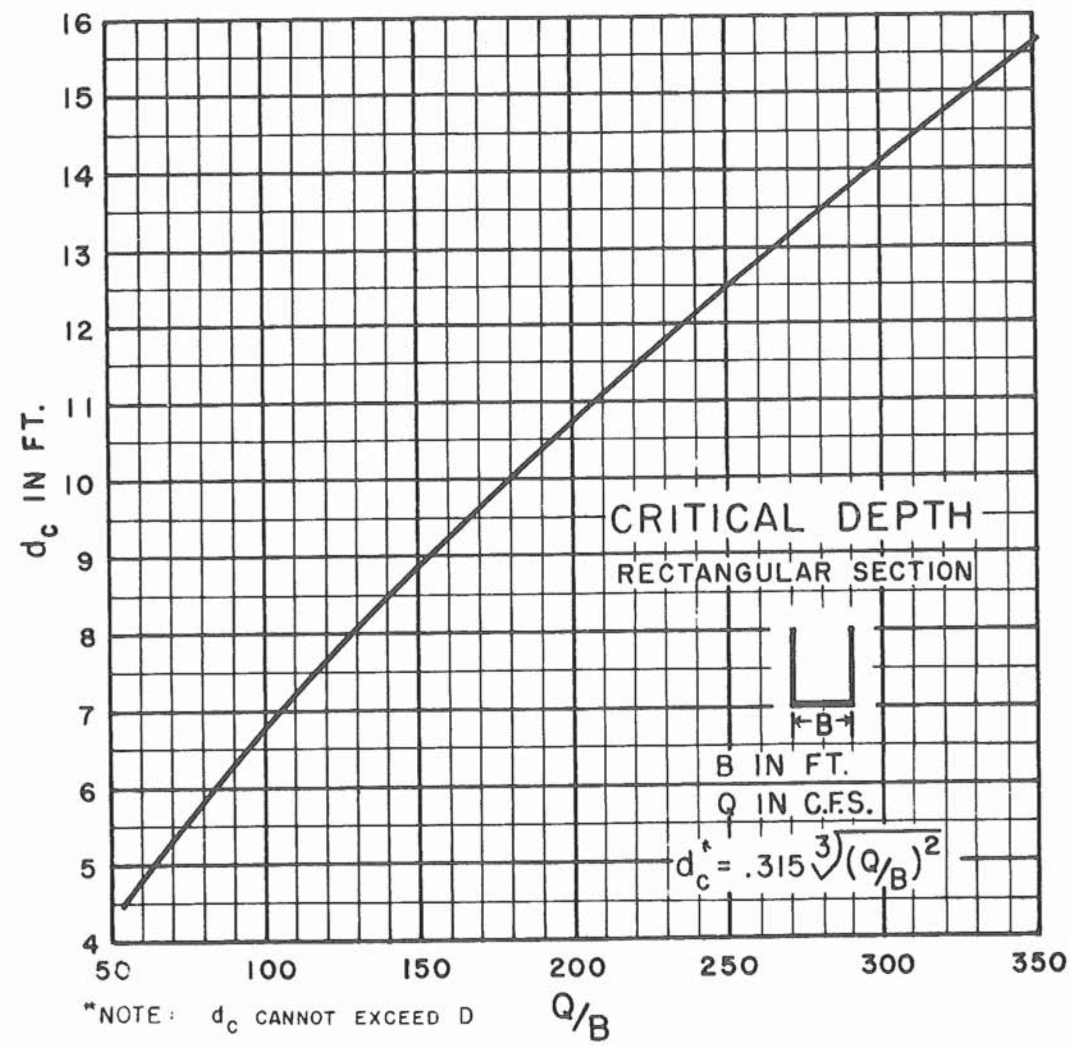


HEAD FOR
STRUCTURAL PLATE
CORRUGATED METAL
PIPE ARCH CULVERTS
18 IN. CORNER RADIUS
FLOWING FULL
n = 0.0327 TO 0.0306

BUREAU OF PUBLIC ROADS JAN. 1963

FIGURE 6A-16





*NOTE: d_c CANNOT EXCEED D

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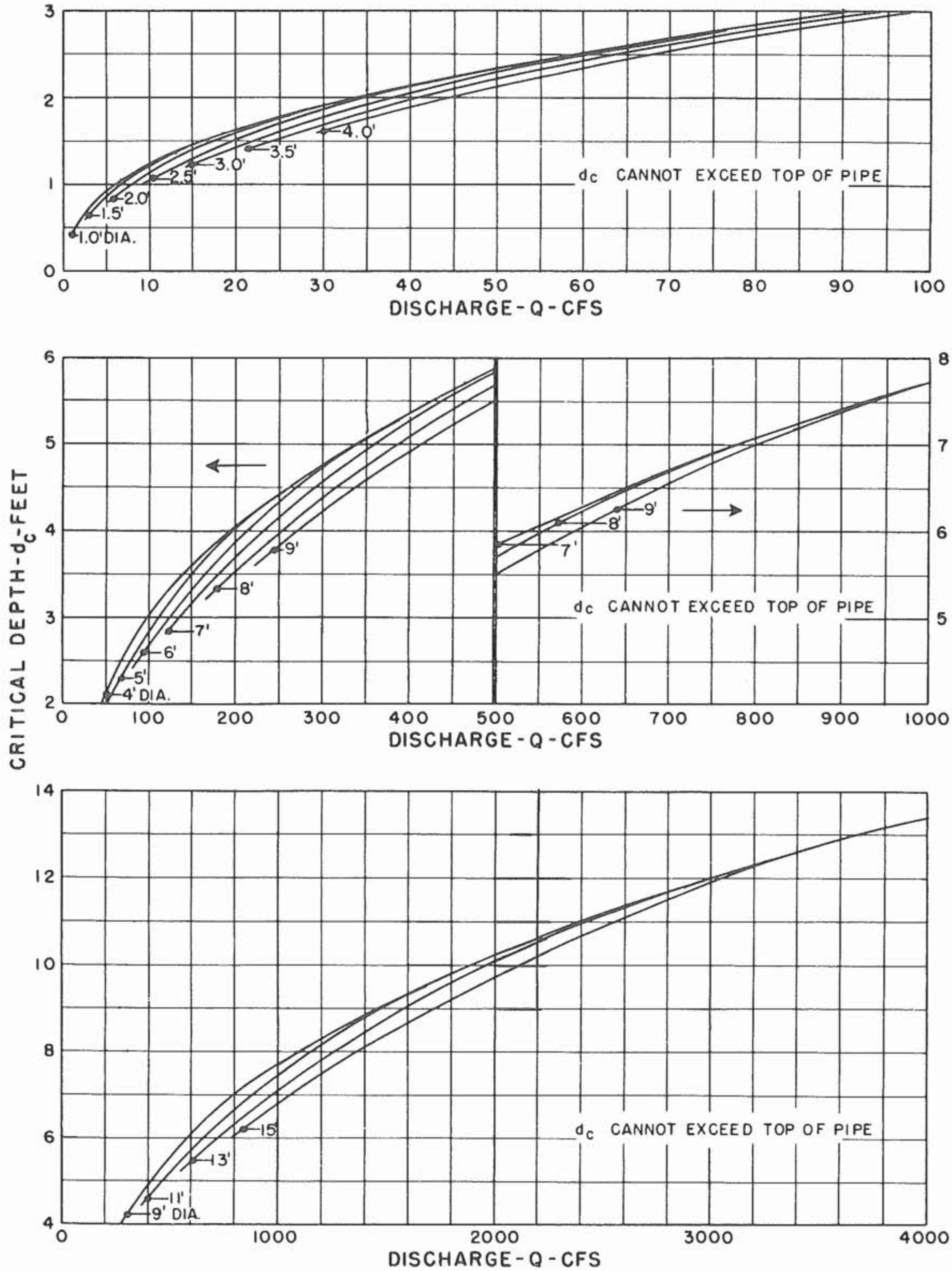
CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

FIGURE 6A-17

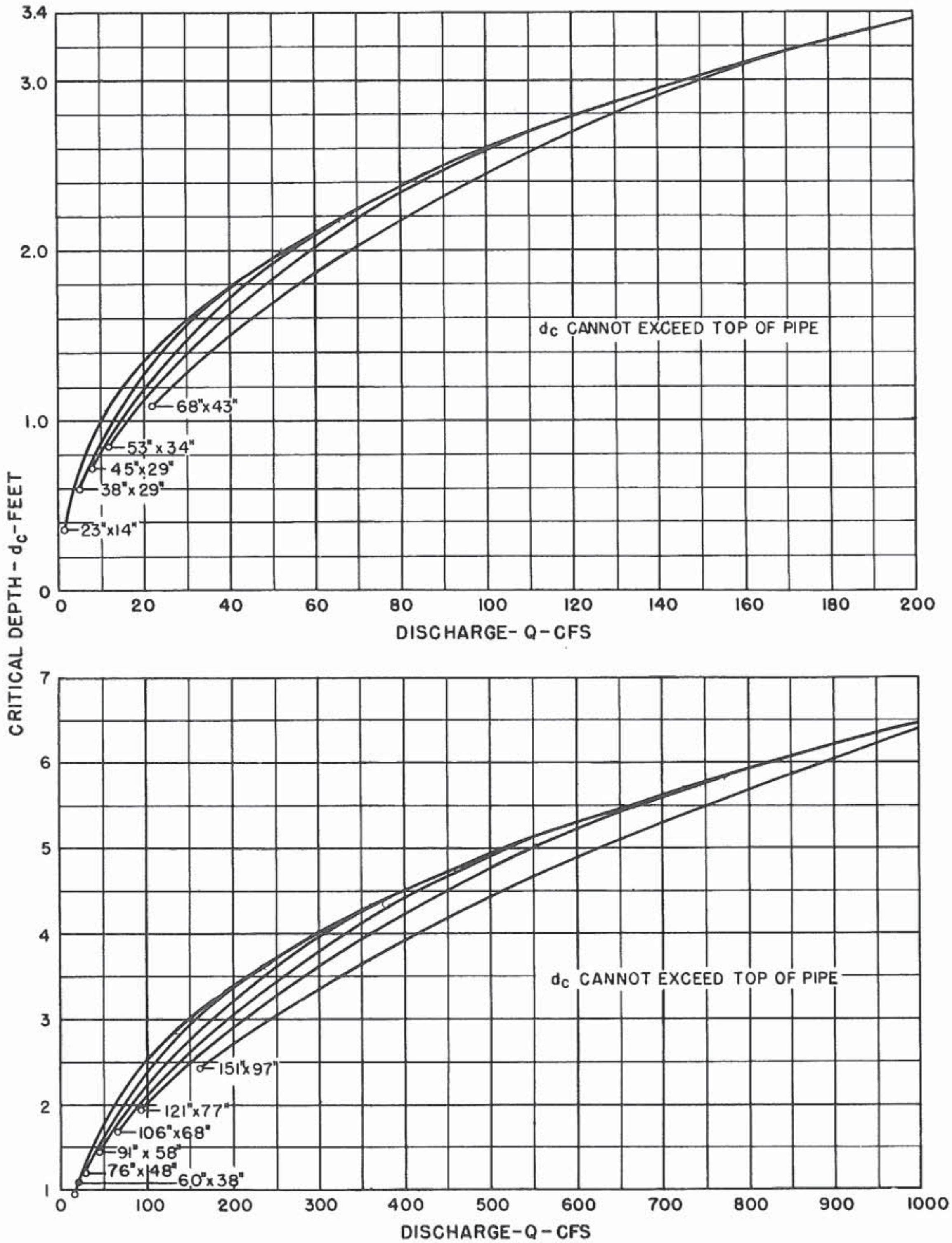


BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
CIRCULAR PIPE

CITY OF SHREVEPORT, LOUISIANA
DEPARTMENT OF PUBLIC WORKS

FIGURE 6A-18



BUREAU OF PUBLIC ROADS

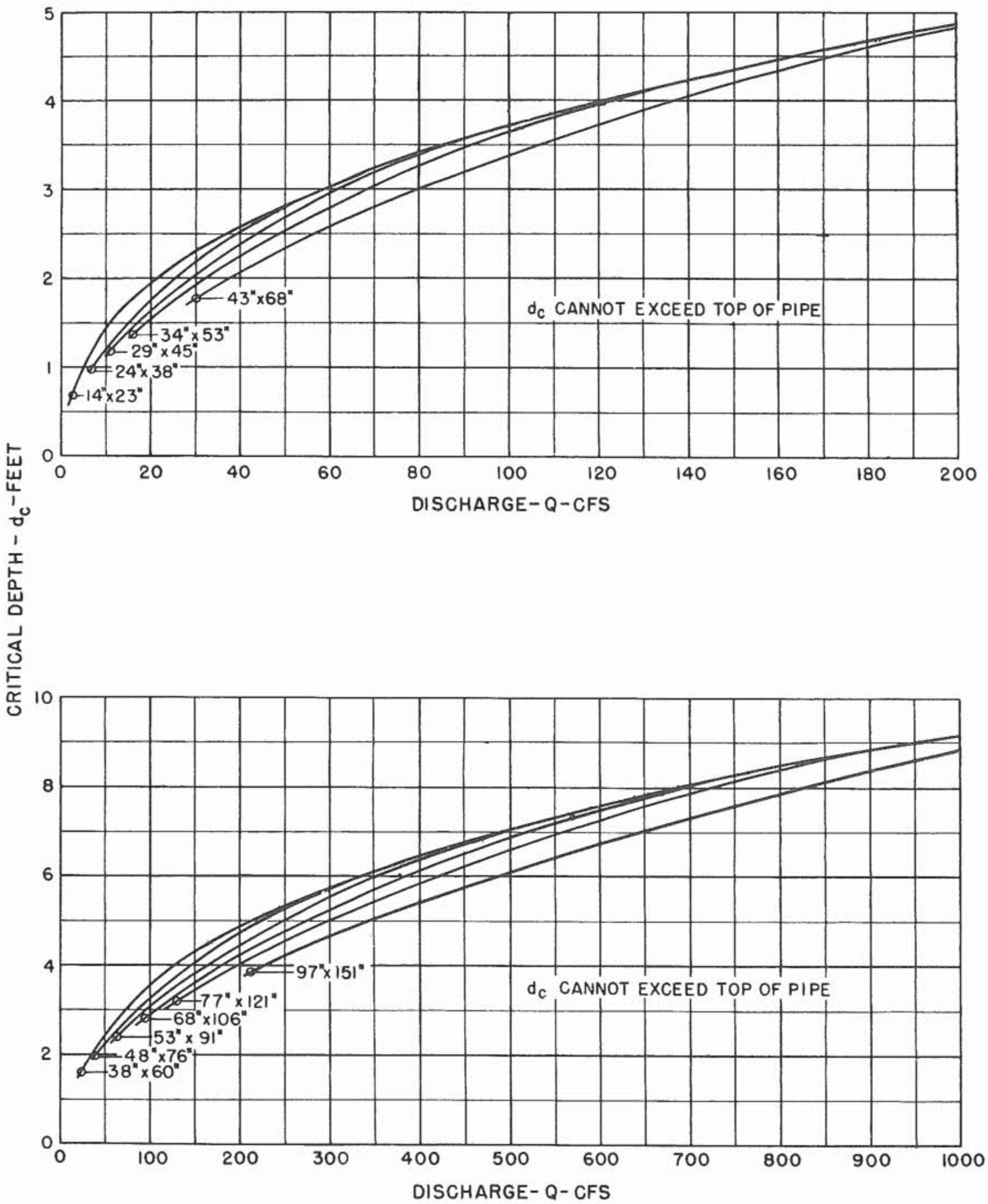
JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS HORIZONTAL

CITY OF SHREVEPORT, LOUISIANA

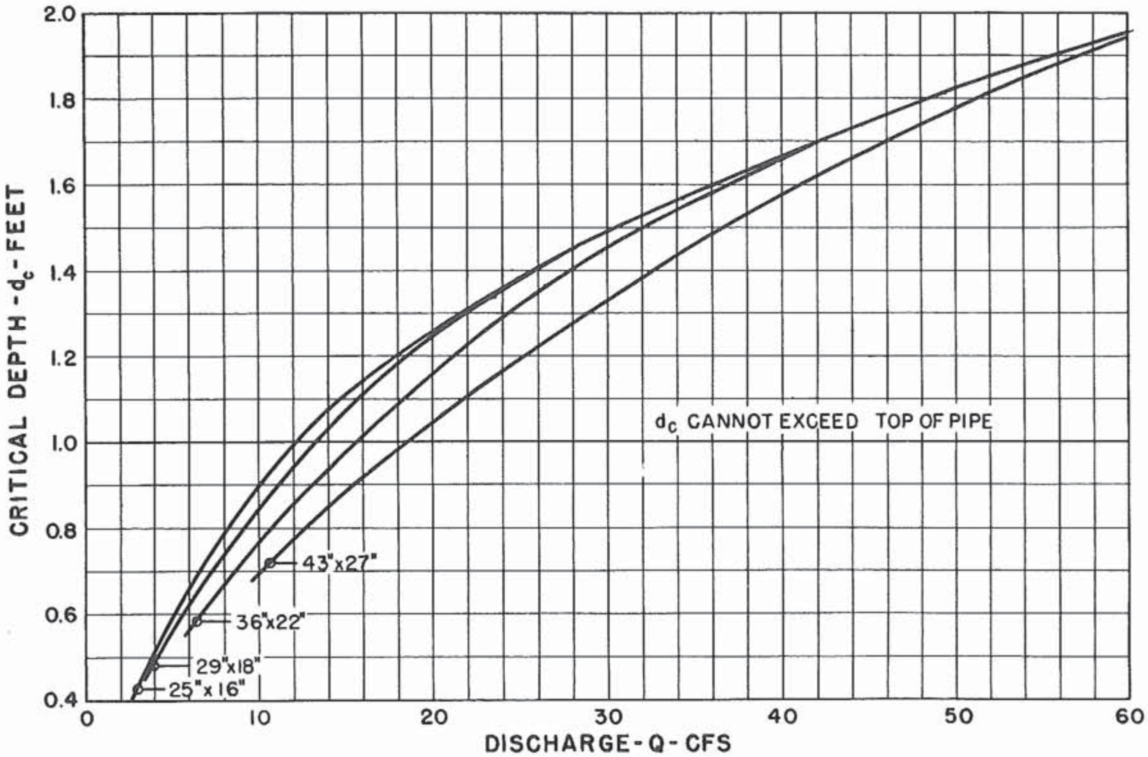
DEPARTMENT OF PUBLIC WORKS

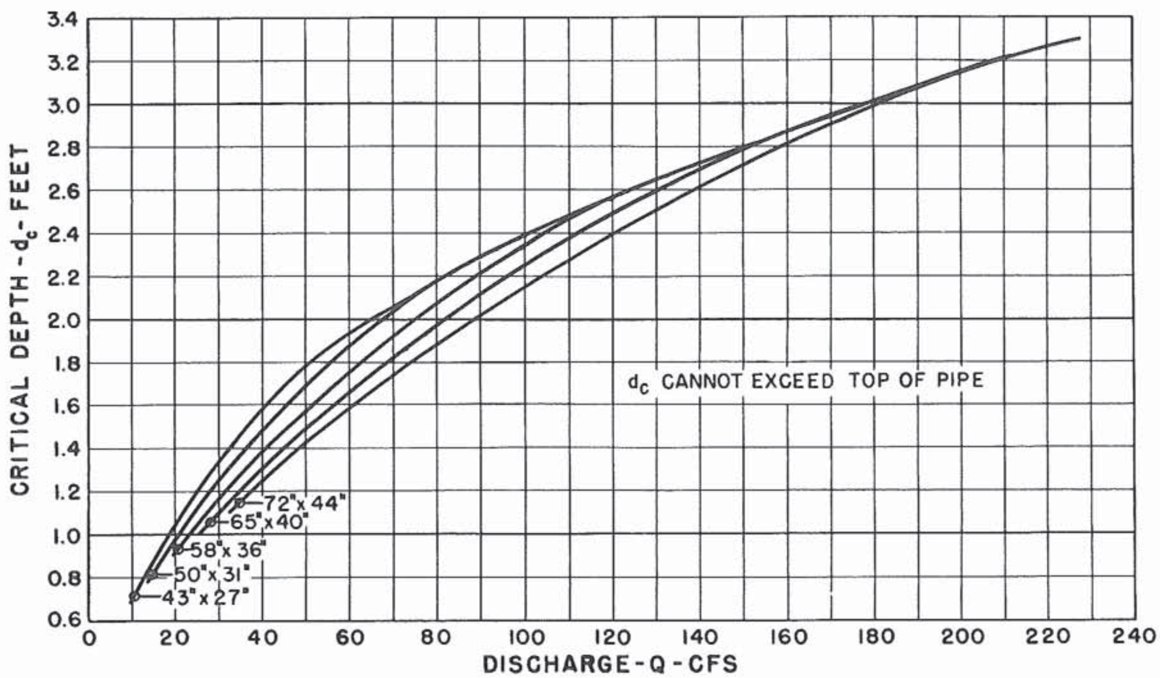
FIGURE 6A-19



BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
OVAL CONCRETE PIPE
LONG AXIS VERTICAL

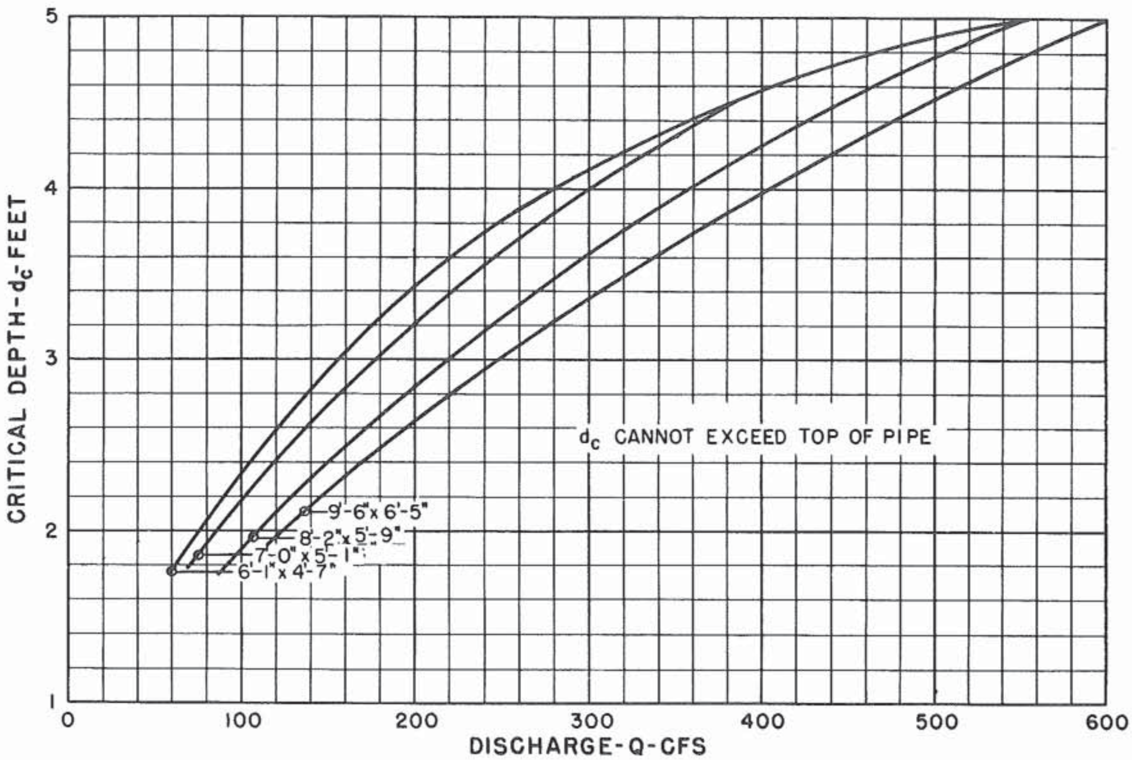


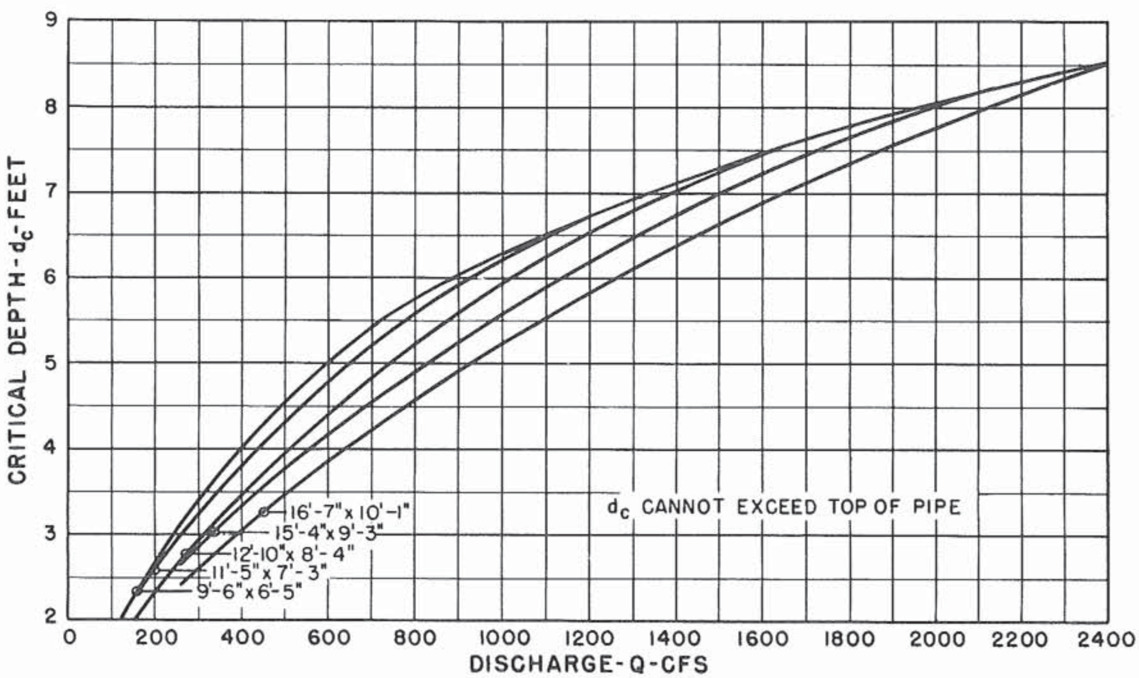


BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
STANDARD C.M. PIPE-ARCH

FIGURE 6A-21





BUREAU OF PUBLIC ROADS

JAN. 1964

CRITICAL DEPTH
STRUCTURAL PLATE
C. M. PIPE-ARCH

18 INCH CORNER RADIUS

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

Table of Contents

Section 7

OPEN CHANNEL

7.1 General

Open channels can be defined as natural streams and rivers, or they can be artificial channels like roadside ditches, canals, flumes, and outfalls. Open channel flow occurs when the flow has a free surface exposed to the atmosphere and a velocity due to gravitational forces.

Intermittent alternating reaches of open and closed systems shall be avoided. Closed systems are preferred due to the inherent hazard of open channels in urban areas and the tendency for trash to collect in open channels.

For safety purposes open channels shall be fenced or graded to reduce potential injury to the public. Sufficient right of way or permanent easements shall be provided adjacent to open channels to allow entry of City maintenance vehicles. Large channels shall include a means of access for maintenance equipment.

Open channels are the preferred method for conveying storm water runoff for the following reasons:

- Velocities are usually lower, resulting in longer concentration times and smaller downstream peak flows.
- Channels provide aesthetically pleasing “green belt” areas if coupled with sufficient right-of-way maintenance.
- Channels are usually more economical.

However, channel should not be used when:

- Right-of-way or drainage easements are difficult to obtain.
- High maintenance costs are associated with the channel.
- Erosive velocities are encountered, and the channel must be stabilized by paving, rip rap, turfing, or other stabilization method.

7.2 Design Criteria

Open channels shall be designed to the following criteria:

7.2.1 Design Storm

The design storm shall be 25-year frequency. The designer should also check 100-year frequency.

7.2.2 Freeboard

The freeboard of a channel is defined as the vertical distance from the water surface to the top of the channel at design condition. At a minimum, the freeboard should be sufficient to prevent the overtopping of the channel by waves or fluctuating water surface. The freeboard shall be minimum of one (1) foot. If flow velocities of eight (8) feet per second or greater are encountered the minimum freeboard shall be increased by the amount of the velocity head.

$$H_v = \frac{V^2}{2g} \qquad \text{Eq. 7-1}$$

Where:	H_v	=	Velocity head (feet)
	V	=	Average velocity (ft/sec)
	g	=	Acceleration due to gravity (32.2 ft/sec^2)

Additional freeboard shall be provided when flooding is caused by the 100-year flood, and as appropriate in other areas.

7.2.3 Bend Radius

The minimum allowable centerline radius for channel curve shall be twenty – five (25) feet or ten (10) times the bottom width, whichever is greater.

7.2.4 Channel Sections

The channel shall have the most efficient flow cross-section where practicable. The half-hexagon has the highest efficiency of all trapezoidal sections for given slope, area and roughness. The recommended types of trapezoidal channels are:

- Fully paved (side slopes determined by slope stability analysis).
- Fully riprap protected with 3:1 or flatter side slopes.
- Earth channel, with 3:1 or flatter side slopes.

The minimum grassed channel bottom width shall be 4 feet to facilitate mowing. Further details of these channels can be found on the City's standard plans.

7.2.5 Velocities

Where velocities in excess of five (5) feet per second are encountered on seeded or sodded ditches, riprap, pavement, or other approved protective measures shall be employed. At the outlet of culverts or storm drain pipes into any open channel, the channel shall be protected by permanent means whenever the exit velocity of the culverts or storm drain pipes equals or exceed eight (8) feet per second.

7.2.6 Channel Protection

Adequate channel protection should be provided where lateral channels or culverts discharge into the channel. Recommended channel protection methods include paved flumes or chutes, riprap, sodding, and energy dissipaters. As a minimum protection, all unlined channels shall be seeded as soon after grading as practical. Temporary erosion control shall be provided until permanent erosion control methods become fully operable. The side slopes of unlined channel shall be no steeper than 3:1. Drop structures, check dams or concrete spillways may be used to control erosion that results from erosive velocities. See Chapter 9 for erosion control criteria.

7.2.7 Connections

Connections at the junction of two or more open channels shall be smooth. Pipe and box culverts or storm drain pipes entering an open channel will not be permitted to project into the normal channel section. Nor will they be permitted to enter an open channel at an angle which would direct flow from the culvert or storm drain pipes upstream in the channel.

Figure 7-1 Example of a Connection Near the Intersection of Willis St. and Audrey Ln.

Figure 7-2 Example of a Connection Between Two Open Channels in Betty Virginia Park.

7.2.8 Channel Linings

Channel lining can be classified into two categories: rigid and flexible. These two types of channel lining are described in the FHWA Hydraulic Engineering Circular No. 15, Third Edition manual and shown below:

7.2.8.1 Rigid Linings

Rigid linings systems are permanent, long-duration installations. Rigid linings are useful in flow zones where high shear stress of non-uniform flow conditions exist. Examples of rigid liners are listed below.

1. Cast-in-place concrete or asphaltic concrete
2. Stone masonry and interlocking modular block
3. Soil cement and roller compacted concrete
4. Fabric for-work systems for concrete
5. Partially grouted riprap

Figure 7-3 Example of a Concrete-Lined Channel Crossing at Beaver Creek Dr.

Figure 7-4 Example of a Concrete-Lined Channel Crossing at Stratmore Dr.

7.2.8.2 Flexible Linings

Flexible linings systems can be either be long-term, transitional, or temporary installation. Flexible channel linings are best suited to conditions of uniform flow and moderate shear stresses. Examples of flexible liners are listed below.

1. Long-term
    a. Vegetative (typically grass species)
    b. Cobbles
    c. Rock Riprap
    d. Wire-enclosed riprap (gabions)
    e. Turf reinforcement (non-degradable)
2. Transitional
    a. Bare soil
    b. Vegetative (annual grasses)
    c. Gravel mulch
    d. Open-weave textile (degradable)
    e. Erosion control blankets (degradable)
    f. Turf reinforcement (non-degradable)
3. Temporary
    a. Bare soil
    b. Vegetative (annual grasses)
    c. Gravel mulch
    d. Open-weave textile (degradable)
    e. Erosion control blankets (degradable)

Figure 7-5 Example of a Natural Vegetative Channel Crossing at Norris Ferry Rd.

Figure 7-6 Example of a Natural Vegetative Channel Crossing at Linear St.

7.2.9 Safety and Maintenance

Open channel with paved side slopes which are deeper than 3.0 feet shall be provided with access structures for maintenance personnel and equipment. Such access structures shall not project into the flow area of the of the channel and shall be provided at intervals no greater than one thousand feet.

7.3 Open Channel Hydraulics

7.3.1 Open Channel Flow

Open channel flow can be classified into three categories:

1. Steady or Unsteady Flow
2. Uniform or Non-Uniform Flow
3. Subcritical or Supercritical Flow

7.3.1.1 Steady or Unsteady Flow

Steady flow occurs when the flow rate and depth are constant over time. Unsteady flow occurs when the flow rate and depth are varied over time.

7.3.1.2 Uniform or Non-Uniform Flow

Uniform flow occurs in a steady state only. Steady flow occurs when the flow rate is constant. In uniform flow, the depth, area of cross-section, velocity of flow, and discharge are the same at every section of a channel. Non-uniform flow results when there are changes in the cross-section areas of the channel.

7.3.1.3 Subcritical or Supercritical Flow

Subcritical flow occurs when the Froude number (Fr) is greater than 1 (Fr > 1) and flow conditions are mild and flow velocities are low. Supercritical flow occurs when the Froude number (Fr) is less than 1 (Fr < 1). During supercritical flow the conditions are steep, flow velocities are high, and surface waves reach the depth of flow.

$$Fr = \frac{V}{\sqrt{gD}} \qquad \text{Eq. 7-2}$$

Where:			
	Fr	=	Froude number, (dimensionless)
	V	=	Mean velocity of flow, (ft/s)
	D	=	Hydraulic depth, (ft) (A/T)
	g	=	Gravity, (32.2 ft/s^2)

7.3.2 Open Channel Equations

7.3.2.1 Continuity Equation

The Continuity equation is used for one – dimensional, steady flow of water and is expressed in the following equation:

$$Q = VA \qquad \text{Eq. 7-3}$$

Where:			
	Q	=	Design capacity of the channel, (ft^3/s)
	V	=	Average velocity, (ft/s)
	A	=	Area of flow, (ft^2)

7.3.2.2 Manning's Equation

Open channel design shall be based on the Manning's equation. The Manning's equation is used to compute the average velocity in an open channel with steady uniform flow, as expressed in the following equation:

$$V = \left(\frac{1.49}{n}\right) \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}} \qquad \text{Eq. 7-4}$$

Where:			
	V	=	Average cross section velocity, (ft/s)
	n	=	Manning's roughness coefficient (See Table 7-1)
	R	=	Hydraulic radius, (ft) (R = A/P)
	A	=	Area of flow, (ft^2)
	P	=	Wetted Perimeter (ft) (cross sectional length that touches water)
	S	=	Channel slope, (ft/ft)

The Continuity equation and Manning's equation can be combined to compute the flow rate of a channel, as expressed in the following equation:

$$Q = \left(\frac{1.49}{n}\right) \cdot A \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}} \qquad \text{Eq. 7-5}$$

Where:

Q	=	Flow rate, (ft^3/s)
n	=	Manning's roughness coefficient (See Table 7-1)
R	=	Hydraulic radius (ft) (R = A/P)
A	=	Area of flow (ft^2)
P	=	Wetted Perimeter (ft) (cross sectional length that touches water)
S	=	Channel slope (ft/ft)

7.3.2.3 Manning's Channel Roughness Coefficients

Table 7-1 Manning's Roughness Coefficient for Open Channels

Type of Channel and Description	Roughness Coefficient "n"		
	Minimum	Normal	Maximum
LINED OR CONSTRUCTED CHANNELS			
1. Concrete			
• Trowel Finish	0.011	0.013	0.015
• Float Finish	0.013	0.015	0.016
• Gunite, Good Section	0.016	0.019	0.023
2. Brick			
• Glazed	0.011	0.013	0.015
• In Cement Mortar	0.012	0.015	0.018
3. Masonry			
• Cemented Rubble	0.017	0.025	0.030
• Dry Rubble	0.023	0.032	0.035
4. Asphalt			
• Smooth	0.013	0.013	-
• Rough	0.016	0.016	-
EXCAVATED OR DREDGED CHANNELS			
1. Earth, Straight and Uniform			
• Clean, recently completed	0.016	0.018	0.020
• Clean, after weathering	0.018	0.022	0.025

Type of Channel and Description	Roughness Coefficient "n"		
	Minimum	Normal	Maximum
• Gravel, uniform section, clean	0.022	0.025	0.030
• With short grass, few weeds	0.022	0.027	0.033
2. Earth, Winding and Sluggish			
• No vegetation	0.023	0.025	0.030
• Grass, some weeds	0.025	0.030	0.033
• Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
• Earth bottom and rubble sides	0.025	0.030	0.035
• Stony bottom and weedy sides	0.025	0.035	0.045
• Cobble bottom and clean sides	0.030	0.040	0.050
3. Dragline Excavated or Dredged			
• No vegetation	0.025	0.028	0.033
• Light brush on banks	0.035	0.050	0.060
4. Rock Cuts			
• Smooth and Uniform	0.025	0.035	0.040
• Jagged and Irregular	0.035	0.040	0.050
5. Channels Not Maintained, Uncut Weeds and Brush			
• Dense weeds as high as flow depth	0.050	0.080	0.120
• Clean bottom, brush on sides	0.040	0.050	0.080
• Same, highest stage of flow	0.045	0.070	0.110
• Dense brush, high stage	0.800	0.100	0.140
NATURAL STREAMS			
Minor streams (top width at flood stage<100 ft)			
1. Streams on Plain			
• Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
• Same as above, but more stones and weeds	0.030	0.035	0.040
• Clean, winding, some pools and shoals	0.033	0.040	0.045
• Same as above, but some weeds and stones	0.035	0.045	0.050

Type of Channel and Description	Roughness Coefficient "n"		
	Minimum	Normal	Maximum
• Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
• Same as 4, but more stones	0.045	0.050	0.060
• Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
• Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
Floodplains			
2. Pasture, no brush			
• Short grass	0.025	0.030	0.035
• High grass	0.030	0.035	0.050
3. Cultivated area			
• No crop	0.020	0.030	0.040
• Mature row crops	0.025	0.035	0.045
• Mature field crops	0.030	0.040	0.050
4. Brush			
• Scattered brush, heavy weeds	0.035	0.050	0.070
• Light brush and trees, in winter	0.035	0.050	0.060
• Light brush and trees, in summer	0.040	0.060	0.080
• Medium to dense brush, in winter	0.045	0.070	0.110
• Medium to dense brush, in summer	0.070	0.100	0.160
5. Trees			
• Dense willows, summer, straight	0.110	0.150	0.200
• Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
• Same as 2, but with heavy growth of sprouts	0.050	0.060	0.080
• Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
• Same as 4, but with flood stage reaching branches	0.100	0.120	0.160
Major Streams (top width at flood stage > 100 ft)			

Type of Channel and Description	Roughness Coefficient “n”		
	Minimum	Normal	Maximum
6. The n-value is less than that for minor streams of similar description, because banks offer less effective resistance.			
• Regular section with no boulders or brush	0.025	-	0.060
• Irregular and rough section	0.035	-	0.100

7.3.3 Channel Design Procedure

The suggested design procedure for open channels is outlined below. The Ditch Design Form in Figure 7A-1 may be used to organize design calculations.

1. Break the design channel reach into separate reaches according to differing flow cross-sections, channel dimensions, or discharges.
2. List all known design data: location, slope of channel, limitation, etc.
3. Calculate the drainage area for each of the separate reaches.
4. Calculate the peak discharge for each reach by adding drainage areas (not discharges). The peak design discharge should be calculated according to methods outlined in Chapter 3.
5. Choose a preferred channel shape, slope, and size. Using Figures 7A-1 to 7A-80 or Manning’s equation, solve for the flow depth and velocity. If the calculated flow depth or velocity is undesirable, choose another channel shape, slope, and/or size.

   Check for other operational and physical characteristics. The flow in open channels should be designed to produce subcritical flow conditions. The flow condition can be determined by calculating the Froude number using Equation 7-2.
6. Determine required freeboard as described in earlier in this chapter.
7. Calculate water surface elevation at road crossing using culvert or bridge backwater analysis methods found in Section 6.
8. Determine the effect of the 100-year storm on the design channel.
9. Show the design storm frequency, design peak discharge, normal flow depth and average velocity on the preliminary and final plans. Where there is a road crossing structure, the storm frequency, discharge, and the headwater or the backwater elevation should be shown. Such headwater or backwater shall be analyzed using the design storm frequency required for the classification of road as stated in Section 2.

7.3.4 Channel Drops

Channel drops are used to check channel erosion and to adjust channel gradients that are to steep for the channel design conditions. While large channel drops may be acceptable in rural areas, the use of several low head drops should be used in urban drainage work. These channel drops may be vertical or sloped. Sloped drops shall have slopes no steeper than 2:1. All channel drops shall be protected against erosion.

7.3.5 Open Channel Shapes

7.3.5.1 Rectangular Channel

The geometric relationships of the cross-section of a rectangular open channel are shown in **Figure 7-7** and in **Table 7-2**.

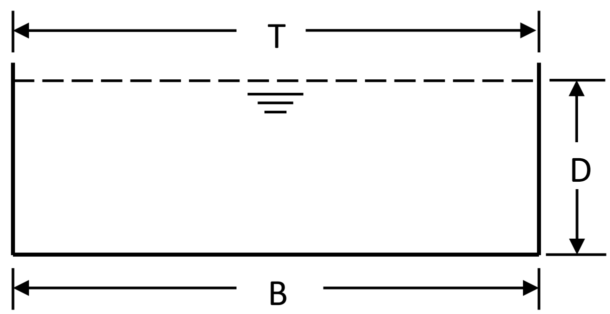


Figure 7-7 Typical Rectangular Cross-Section of an Open Channel

Where:
D = Water depth of the channel
B = Bottom width of the channel
T = Top width of channel

Table 7-2 Geometric Relationships of a Typical Rectangular Open Channel

AREA (A)	WETTED PERIMETER (P)	HYDRAULIC RADIUS (R)	TOP WIDTH (T)	HYDRAULIC DEPTH (D)	CRITICAL DEPTH FACTOR (Z)
$\boldsymbol{BD}$	$B + 2D$	$\frac{BD}{B + 2D}$	B	D	$BD^{1.5}$

The rectangular cross-section channel design charts, **Figures 7A-2** thru **7A-15** in the **Appendix**, are prepared for an n-value (average value for concrete) under uniform flow conditions. A separate chart is provided for each foot of width from 2 feet to 10 feet and for each even foot of width from 10 feet to 20 feet. The design charts may be used to estimate the size and discharge flow rates of rectangular channels under uniform flow conditions, and the design software should be used to check results. The Ditch Design form in **Figure 7A-1** is to be used for open channel design.

7.3.5.2 Trapezoidal Channel

The geometric relationships of the cross-section of a trapezoidal open channel are shown in **Figure 7-8** and in **Table 7-3**.

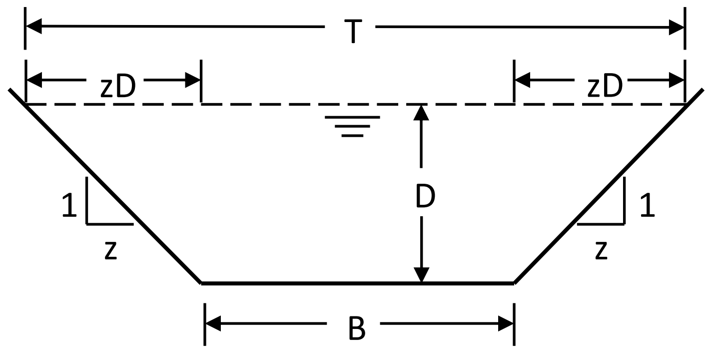


Figure 7-8 Typical Trapezoidal Cross-Section of an Open Channel

Where:

Where:	D	=	Water depth of the channel
	B	=	Bottom width of the channel
	T	=	Top width of channel
	z	=	Side slope for each side

Table 7-3 Geometric Relationships of a Typical Trapezoidal Open Channel

AREA (A)	WETTED PERIMETER (P)	HYDRAULIC RADIUS (R)	TOP WIDTH (T)	HYDRAULIC DEPTH (D)	CRITICAL DEPTH FACTOR (Z)
$\boldsymbol{BD + zD^{1.5}}$	$B + 2D\sqrt{1+z^2}$	$\frac{BD + zD^2}{B + 2D[(\sqrt{1+z^2})]}$	B+2zD	$\frac{(B+zD)D}{B+2zD}$	$\frac{[(B+zD)D]^{1.5}}{\sqrt{B+2zD}}$

Standard trapezoidal channel cross-sections are shown in **Figure 7A-16** of the **Appendix**. Design charts for concrete paved trapezoidal channel cross-sections are shown on **Figures 7A-17** thru **7A-62**. The trapezoidal cross-section channel charts, **Figures 7A-63** thru **7A-80**, are prepared for an n-value of 0.03, side slopes of 2:1 (horizontal to vertical), a specific bottom widths. The design charts may be used to estimate the size and discharge flow rates of trapezoidal channels under uniform flow conditions, and the design software should be used to check results. The Ditch Design form in **Figure 7A-1** is to be used for open channel design.

7.3.5.3 Triangular Channel

The geometric relationships of the cross-section of a triangular open channel are shown in **Figure 7-9** and in **Table 7-4**.

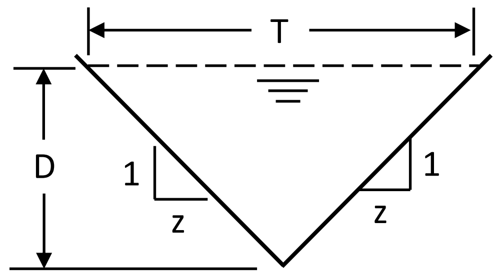


Figure 7-9 Triangular Cross-Section of an Open Channel

Where:

D	=	Water depth of the channel
T	=	Top width of channel
z	=	Side slope for each side

Table 7-4 Geometric Relationships of a Triangular Open Channel

AREA (A)	WETTED PERIMETER (P)	HYDRAULIC RADIUS (R)	TOP WIDTH (T)	HYDRAULIC DEPTH (D)	CRITICAL DEPTH FACTOR (Z)
$\boldsymbol{zD^2}$	$2D\sqrt{1+z^2}$	$\frac{zD}{2\sqrt{1+z^2}}$	$2zD$	$\frac{1}{2}D$	$\frac{\sqrt{2}}{2}BD^{2.5}$

7.3.5.4 Circular Channel

A circular cross section channel is best closed, and a semicircle the best section for channels open at the top. The geometric relationships of the cross-section of a circular open channel are shown in **Figure 7-10** and in **Table 7-5**.

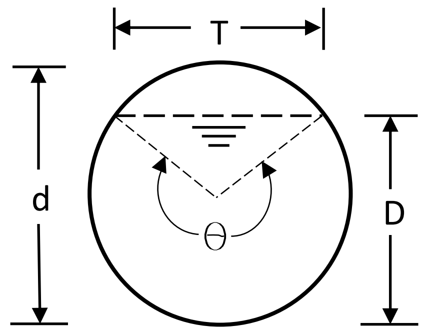


Figure 7-10 Circular Cross-Section of an Open Channel

Where:	D	=	Water depth of the channel
	T	=	Top width of channel
	d_o	=	Diameter of pipe

Table 7-5 Geometric Relationships of a Circular Open Channel

AREA (A)	WETTED PERIMETER (P)	HYDRAULIC RADIUS (R)	TOP WIDTH (T)	HYDRAULIC DEPTH (D)	CRITICAL DEPTH FACTOR (Z)
$\boldsymbol{\frac{d_0^2}{8}(\theta - \sin\theta)}$	$\frac{\theta\, d_0}{2}$	$\frac{1}{4}\left(1 - \frac{\sin\theta}{\theta}\right) d_0$	$\left(\sin\frac{1}{2}\theta\right) d_0$ or $2\sqrt{D(d_0 - D)}$	$\frac{1}{8}\left(\frac{\theta - \sin\theta}{\sin\frac{1}{2}\theta}\right) d_0$	$\frac{\sqrt{2}}{32}\frac{(\theta - \sin\theta)^{1.5}}{\left(\sin\frac{1}{2}\theta\right)^{0.5}} d_0^{2.5}$

7.3.5.5 Irregular Channel

Irregular channel cross sections can sometimes be narrow deep main channels or wide shallow overbank channels.

When determining the flow of an irregular channel, the cross sections must be subdivided into segments so that the flow can be computed separately for the main channel and overbank portions. A depth of flow or tailwater for a particular storm can be calculated with practical accuracy by Manning's formula.

Using a single cross section of the channel, Equation 8-4 can be used to compute discharges for selected water surface elevations. A stage-discharge curve is then plotted.

For an irregular channel, the standard step method is recommended. Hydraulic modeling software like Hydr1110 and HEC-RAS (Chapter 2), can also be used for standard step calculations.

Note that discharges are computed with the assumption that the total discharge of flow is equal to the sum of the discharges of the subdivided areas. Areas with the same coefficient of roughness should be grouped together.

From the stage-discharge curve, the depth of flow or tailwater elevation in the outfall channel can be found for the design discharge.

7.04 Acceptable Software

7.4.1 Hydraflow

Hydraflow Express Extension is an application for solving typical hydraulics and hydrology problems. It addresses a wide variety of tasks, including culverts, open channels, inlets, hydrology and weirs, using a unique user interface. Just select the task you want from a tool bar, fill in the blanks on a simple input grid, and click a button. Hydraflow quickly displays informative graphs, rating curves, on-screen reports, as well as printed reports. This software is available to designers through Autodesk AutoCAD Civil 3D.

7.4.2 Hydr1140

The LADOTD computer program HYDR1140: "Open Channel Flow" is a computer program which computes the normal depth of water, bottom width or design discharge for a given uniform shaped cross-section as outlined in Chapter 7. LADOTD allows the designer to download the software at the following website:
http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Public_Works/Hydraulics/Pages/Hydraulics_Software.aspx

7.4.3 Hydr1110

The LADOTD computer program HYDR1110: "Normal Water Surface" is a computer program which computes the normal water surface elevation, area of opening, and average velocity for a given irregular shape channel cross-section as outlines in Chapter 7. LADOTD allows the designer to download the software at the following website:
http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Public_Works/Hydraulics/Pages/Hydraulics_Software.aspx

7.4.4 Hydraulic Toolbox

The FHWA computer program Hydraulic Toolbox is a computer program which computes and performs routine hydrologic and hydraulic computations. Twelve calculators are available for project development:

1. Channel Analysis
2. Channel Lining Design Analysis
3. Weir Analysis
4. Curb and Gutter Analysis
5. Median/Ditch Drop-Inlet Analysis
6. Rational Method Hydrologic Analysis
7. Detention Basin Analysis
8. Riprap Analysis
9. Rock—Sediment Gradation Analysis
10. Culvert Assessment Analysis
11. Bridge Scour Analysis Calculator
12. Horizontal Grade Inlet Calculator

FHWA allows the designer to download the software at the following website:
https://www.fhwa.dot.gov/engineering/hydraulics/software/toolbox404.cfm

7.5 Appendix

7.5.1 References

(1) Louisiana Department of Transportation and Development, "2011 Hydraulics Manual", 2011. http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Public_Works/Hydraulics/Documents/Hydraulics%20Manual.pdf

(2) U.S. Department of Transportation, Federal Highway Administration, "Urban Drainage Design Manual, Hydraulic Engineering Circular No. 22, Third Edition", August 2013. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/10009/10009.pdf

(3) U.S. Department of Transportation, Federal Highway Administration, "Design of Roadside Channels with Flexible Linings, Hydraulic Engineering Circular No. 15, Third Edition", September 2005. https://www.fhwa.dot.gov/engineering/hydraulics/pubs/05114/05114.pdf

(4) U.S. Army Soil Conservation Service, "Urban Hydrology for Small Water Sheds", Technical Release No. 55, June 1986. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

(5) Chow, V.T., "Open Channel Hydraulics," McGraw-Hill Book Co., Inc., New York, 1959.

(6) Ram S. Gupta, "Hydrology and Hydraulic Systems, Second Edition," 2001.

(7) Tennessee Department of Transportation Design Division, "Drainage Manual," 2012. https://www.tn.gov/tdot/roadway-design/design-standards/drainage-manual.html

(8) Austin, Texas, "Drainage Criteria Manual," 2020. https://library.municode.com/tx/austin/codes/drainage_criteria_manual

(9) Longview, Texas, "Drainage Criteria and Erosion Control Manual," https://www.longviewtexas.gov/DocumentCenter/View/1153/Drainage-Criteria--Erosion-Control-Manual-Long-Form

(10) City of New Braunfels, Texas, "Drainage and Erosion Control Design Manual," 2000 https://www.nbtexas.org/280/Manuals-Forms-and-Maps

(11) City of Griffin, Georgia, "Stormwater Design Manual, Chapter 5: Open Channel Hydraulics," 2007 http://cityofgriffin.com/Portals/1/Documents/Public%20Works/Stormwater/StormwaterUtility/DesignManual/Design_Manual_Section_5.pdf

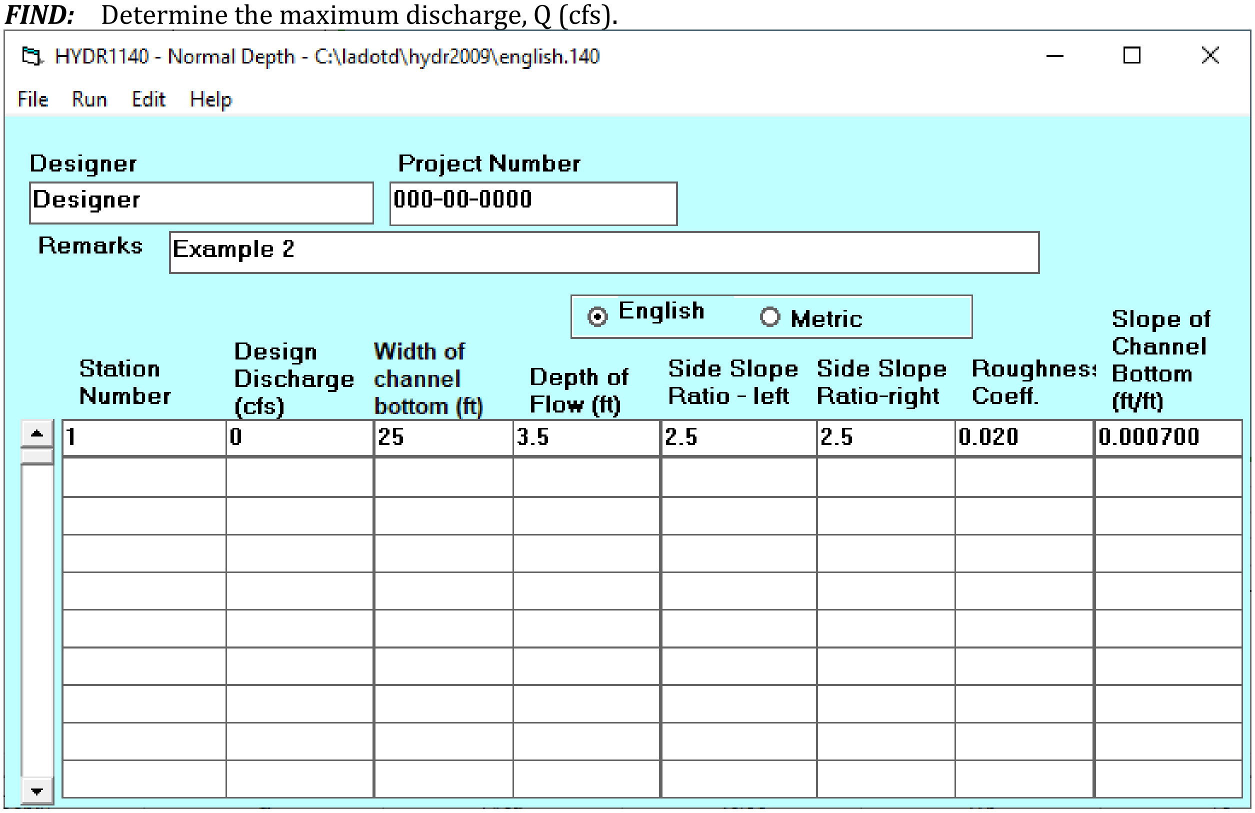
7.5.2 Example Problems

7.5.2.1 Example Problem #1:

Trapezoidal Section (HYDRAFLOW)

GIVEN: Shape:		Trapezoidal (Uniform)
	Width (B):	25.0 ft
	Side Slopes (z):	2.5, 2.5
	Slope:	0.07%
	n-value:	0.020
	Depth of Flow:	0.59 ft

FIND: Determine the maximum discharge, Q (cfs).



SOLUTION: See Figures 7-11 and 7-12 for the HYDRAFLOW inputs and outputs.

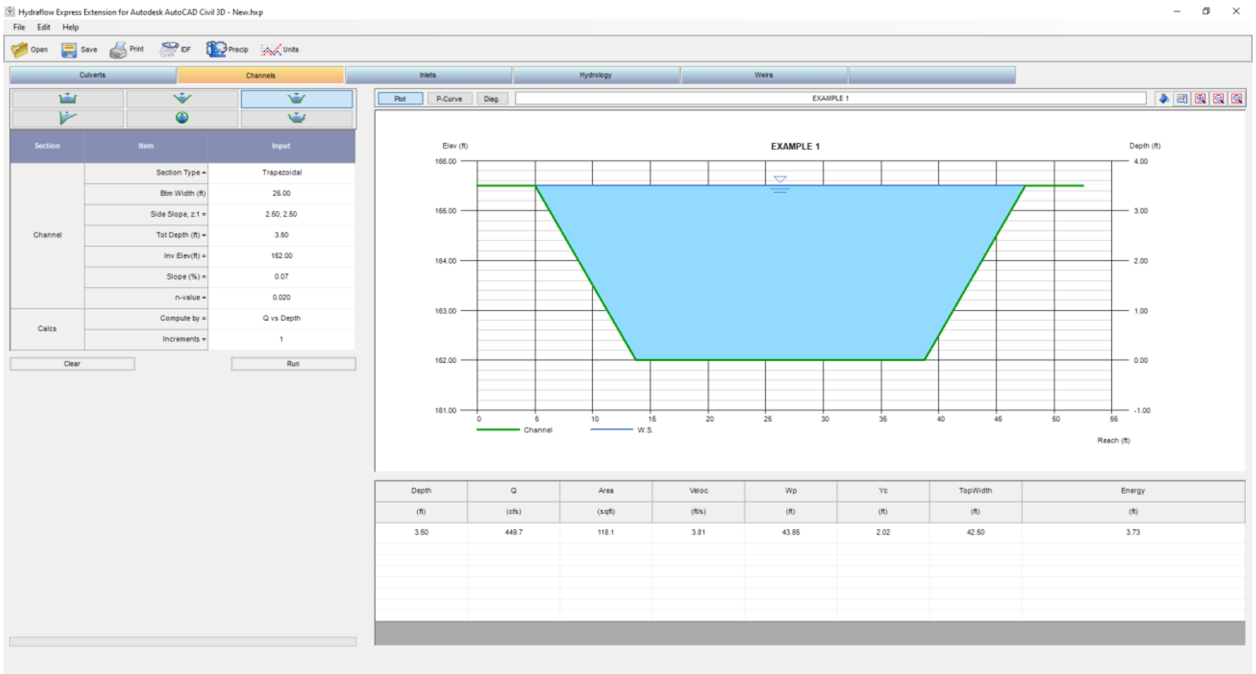


Figure 7-11
Example 1, HYDRAFLOW Input Interface, Open Channel Trapezoidal Section

Channel Report

Hydraflow Express Extension for Autodesk® AutoCAD® Civil 3D® by Autodesk, Inc. Wednesday, Sep 25 2019

EXAMPLE 1

Trapezoidal		**Highlighted**	
Bottom Width (ft)	= 25.00	Depth (ft)	= 3.50
Side Slopes (z:1)	= 2.50, 2.50	Q (cfs)	= 449.73
Total Depth (ft)	= 3.50	Area (sqft)	= 118.13
Invert Elev (ft)	= 162.00	Velocity (ft/s)	= 3.81
Slope (%)	= 0.07	Wetted Perim (ft)	= 43.85
N-Value	= 0.020	Crit Depth, Yc (ft)	= 2.02
		Top Width (ft)	= 42.50
Calculations		EGL (ft)	= 3.73
Compute by:	Q vs Depth		
No. Increments	= 1		

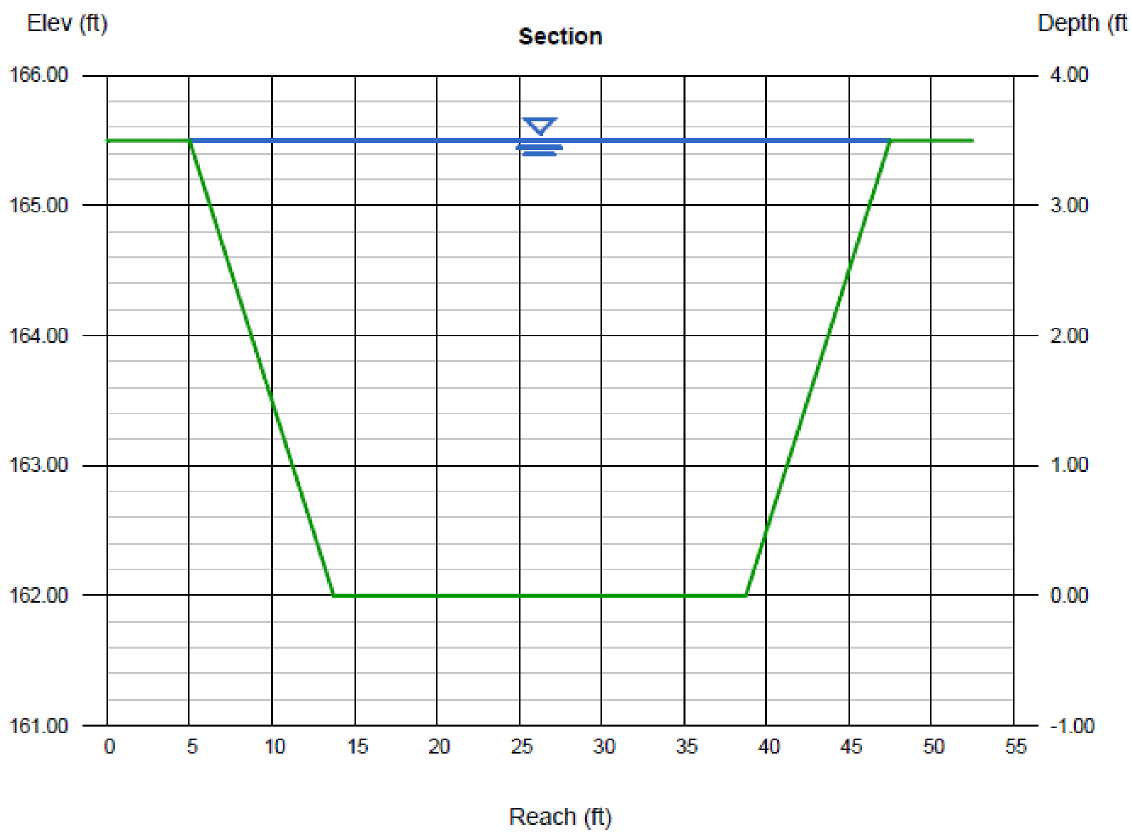


Figure 7-12
Example 1, HYDRAFLOW Output, Open Channel Trapezoidal Section

7.5.2.2 Example Problem #2:

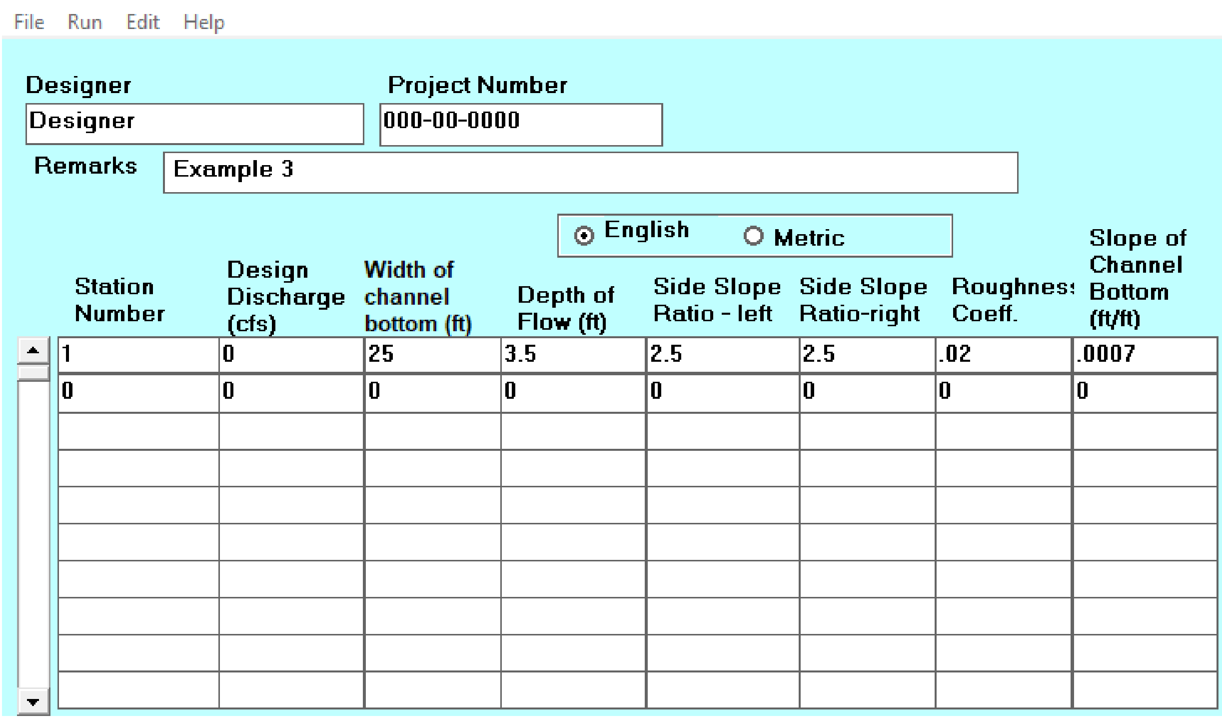
Trapezoidal Section (HYDR1140)

GIVEN: Shape: Trapezoidal (Uniform)

Width (B):	25.0 ft
Side Slopes (z):	2.5, 2.5
Slope:	0.07%
n-value:	0.020
Depth of Flow:	3.5 ft

FIND: Determine the maximum discharge, Q (cfs).

SOLUTION: See Figures 7-13 and 7-14 for the HYDR1140 inputs and outputs.


File Run Edit Help

Designer: Designer

Project Number: 000-00-0000

Remarks: Example 3

English (selected) / Metric

Station Number	Design Discharge (cfs)	Width of channel bottom (ft)	Depth of Flow (ft)	Side Slope Ratio - left	Side Slope Ratio-right	Roughness Coeff.	Slope of Channel Bottom (ft/ft)
1	0	25	3.5	2.5	2.5	.02	.0007
0	0	0	0	0	0	0	0

Figure 7-13
Example 2, HYDR1140 Input, Open Channel Trapezoidal Section

hydrview: C:\ladotd\hydr2009\\HYDR1140.PRT

File Print Edit Help

```
LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT      HYDR1140-071498
HYDRAULICS SECTION

DESIGNER: Designer                     DATE: 09-25-2019
REMARKS: Example 2

                 STATE PROJECT NUMBER  000-00-0000


                        OPEN CHANNEL DESIGN

**********************************************************************

STATION                                                1
DESIGN DISCHARGE (C.F.S.)                                  449.73
WIDTH OF CHANNEL BOTTOM (FT.)                               25.00
DEPTH OF FLOW (FT.)                                          3.50
SIDE SLOPE RATIO, LEFT (FT.:1)                               2.5
SIDE SLOPE RATIO, RIGHT (FT.:1)                              2.5
ROUGHNESS COEFFICIENT                                        .020
SLOPE OF CHANNEL BOTTOM (FT./FT.)                          .00070

**********************************************************************
```

Figure 7-14
Example 2, HYDR1140 Output, Open Channel Trapezoidal Section

7.5.2.3 Example Problem #3:

Irregular Section (HYDR1110)

GIVEN:	Shape:	Irregular Section
	Slope:	0.005 ft/ft
	Manning's coefficient (n):	Varies

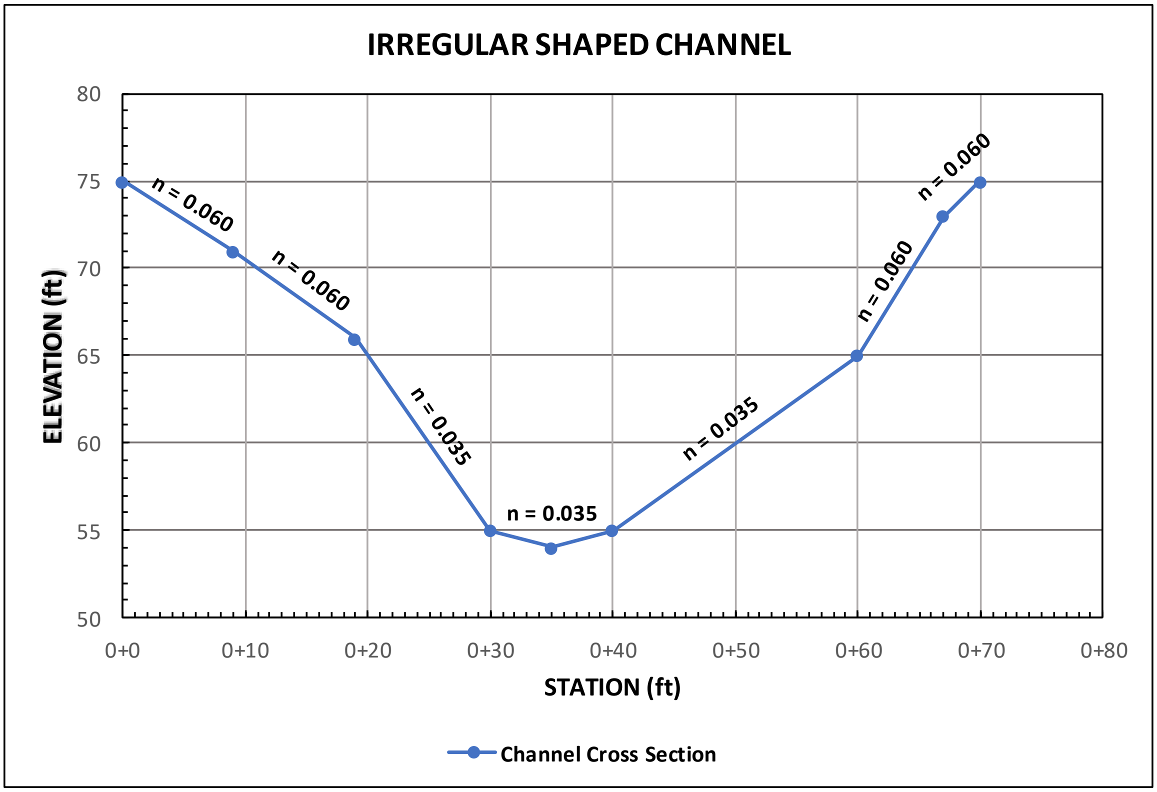


Figure 7-14
Example 3, Irregular Channel Cross Section

FIND: Determine the stage elevation for the channel cross-section shown with a slope of 0.005 ft/ft and a discharge of 2200 cfs.

SOLUTION: See Figures 7-15, and 7-16 for the HYDR1110 inputs and outputs.

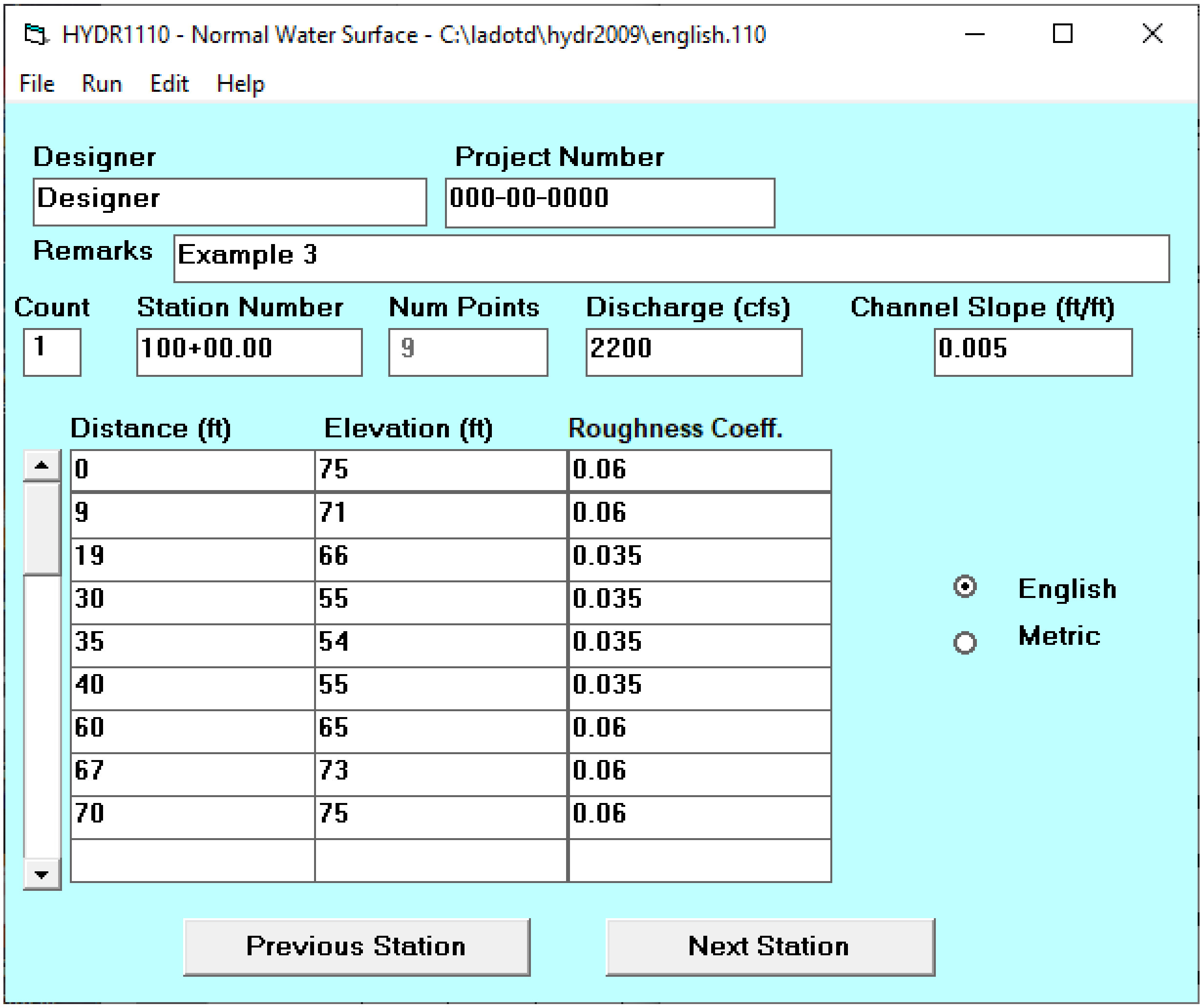


Figure 7-15
Example 3, HYDR1110 Input, Open Channel Irregular Section

hydrview: C:\ladotd\hydr2009\\HYDR1110.PRT

File Print Edit Help

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LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT      HYDR1110-071498
HYDRAULICS SECTION
DESIGNER: Designer                     DATE: 09-26-2019
Remarks: Example 3

                 STATE PROJECT NUMBER   000-00-0000

                    NORMAL WATER SURFACE PROGRAM

**********************************************************************

         STATION                                 100+00.00
         NUMBER OF POINTS                                9
         DESIGN DISCHARGE (CFS)                      2200.
         CHANNEL SLOPE (FT./FT.)                    .00500
OUTPUT:
         NORMAL WATER SURFACE ELEVATION              64.65
         AREA OF OPENING (SQ. FT.)                  241.18
         AVERAGE VELOCITY (FPS)                       9.12

**********************************************************************

CHANNEL CROSS-SECTION:

    DISTANCE (FT.)      ELEVATION     ROUGHNESS COEFFICIENT

            .0           75.00
                                               .060
           9.0           71.00
                                               .060
          19.0           66.00
                                               .035
          30.0           55.00
                                               .035
          35.0           54.00
                                               .035
          40.0           55.00
                                               .035
          60.0           65.00
                                               .060
          67.0           73.00
                                               .060
          70.0           75.00

***************************************************************

 STAGE        Q

 67.00     3698.
 66.00     2976.
 65.00     2374.
 64.00     1908.
 63.00     1502.
 62.00     1152.
 61.00      856.
 60.00      609.
 59.00      410.
 58.00      253.
 57.00      136.
 56.00       56.
 55.00        9.
```

Figure 7-16
Example 3, HYDR1110 Output, Open Channel Irregular Section

7.5.2.4 Example Problem #4:

Trapezoidal Section (Hydraulic Toolbox)

GIVEN: Shape: Trapezoidal (Uniform)

Width (B):	25.0 ft
Side Slopes (z):	2.5, 2.5
Slope:	0.07%
n-value:	0.020
Depth of Flow:	0.59 ft

FIND: Determine the maximum discharge, Q (cfs).

SOLUTION: See Figures 7-17 and 7-18 for the Hydraulic Toolbox inputs and outputs.

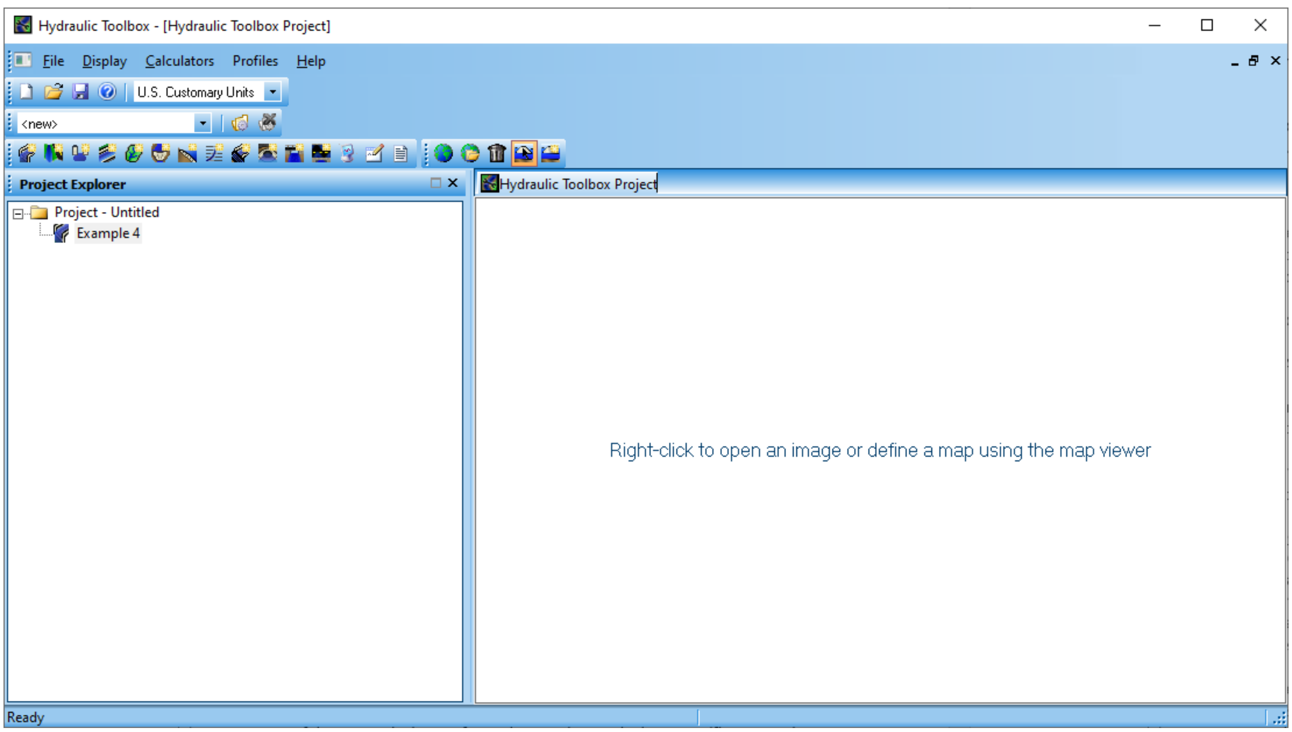


Figure 7-17
Example 4, Hydraulic Toolbox Input Interface, Open Channel Trapezoidal Section

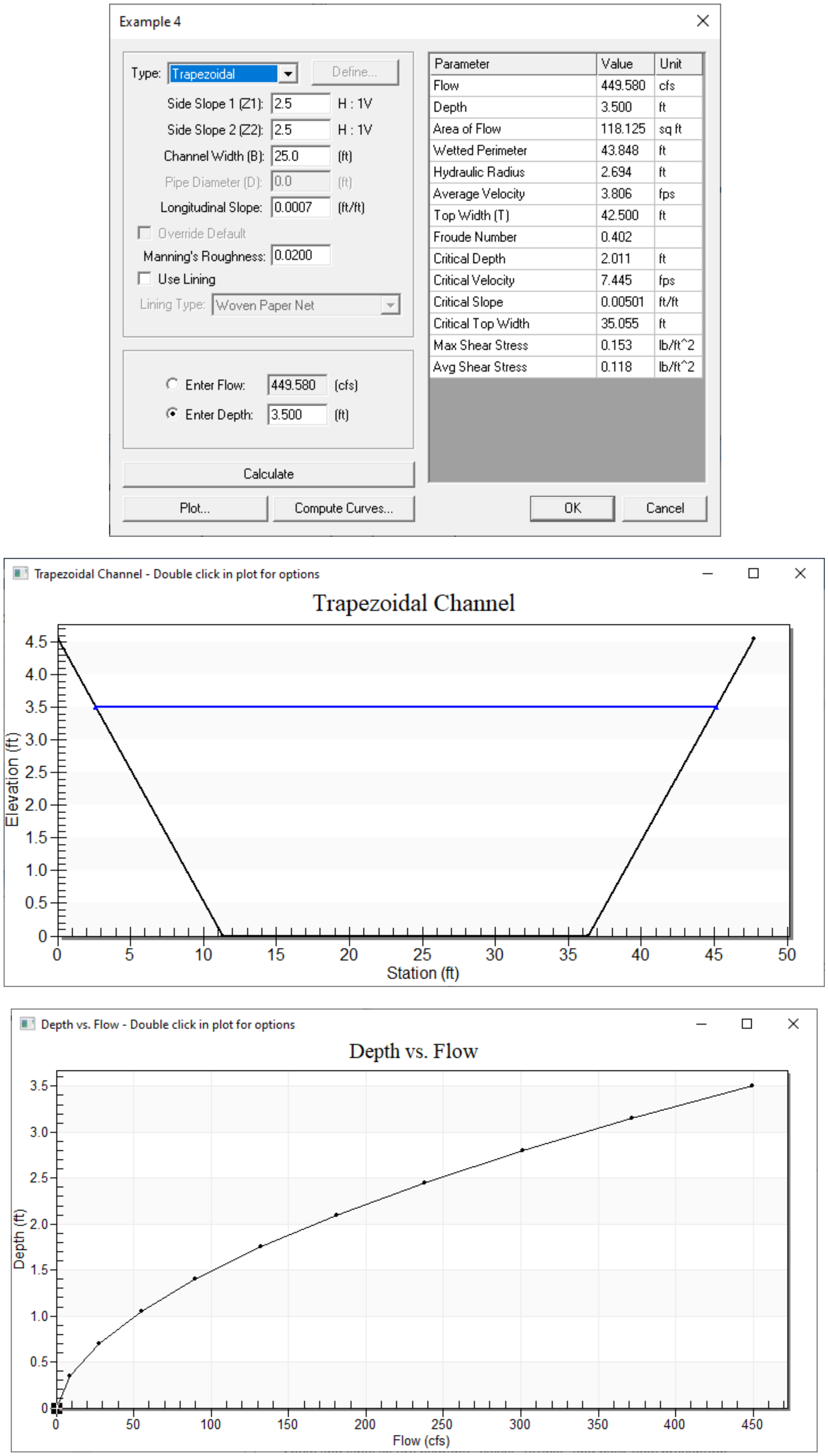


Figure 7-18
Example 4, Hydraulic Toolbox Output Interface, Open Channel Trapezoidal Section

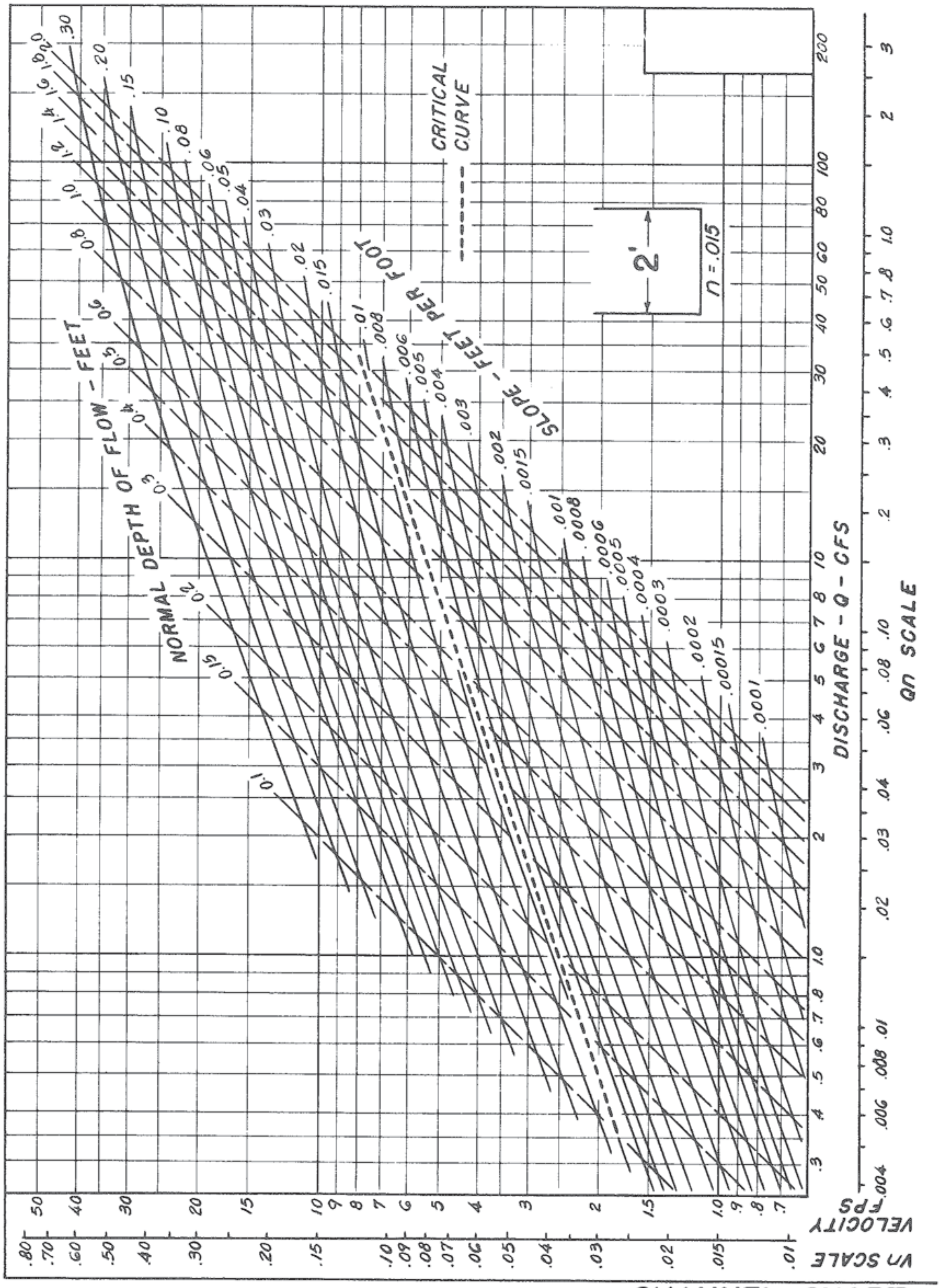
7.5.3 Figures

FIGURE 7A-1

DITCH DESIGN FORM

LOCATION	AREA ACRES	C	A x C	Σ A x C	t_o n	t_d Min	t_c Min	I In/Hrs	Q cfs	TYPICAL SECTION	S_o f/f	"n"	V, CALC Ft Sec	WATER DEPTH	LINING DEPTH	TYPE LINING	REMARKS

FIGURE 7A-2



CHANNEL CHART
VERTICAL b = 2 FT.

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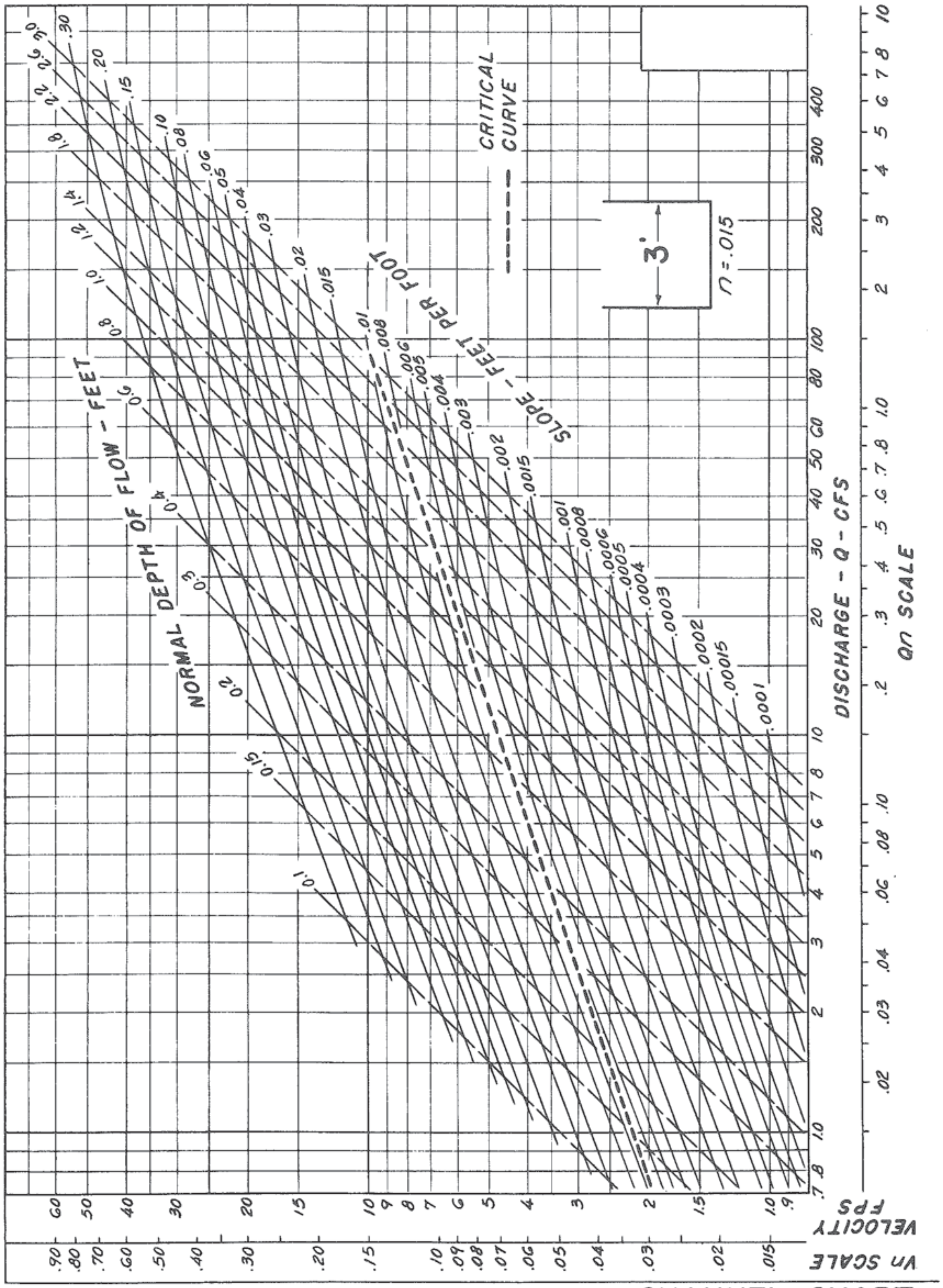

CHANNEL CHART
VERTICAL b = 3 FT.

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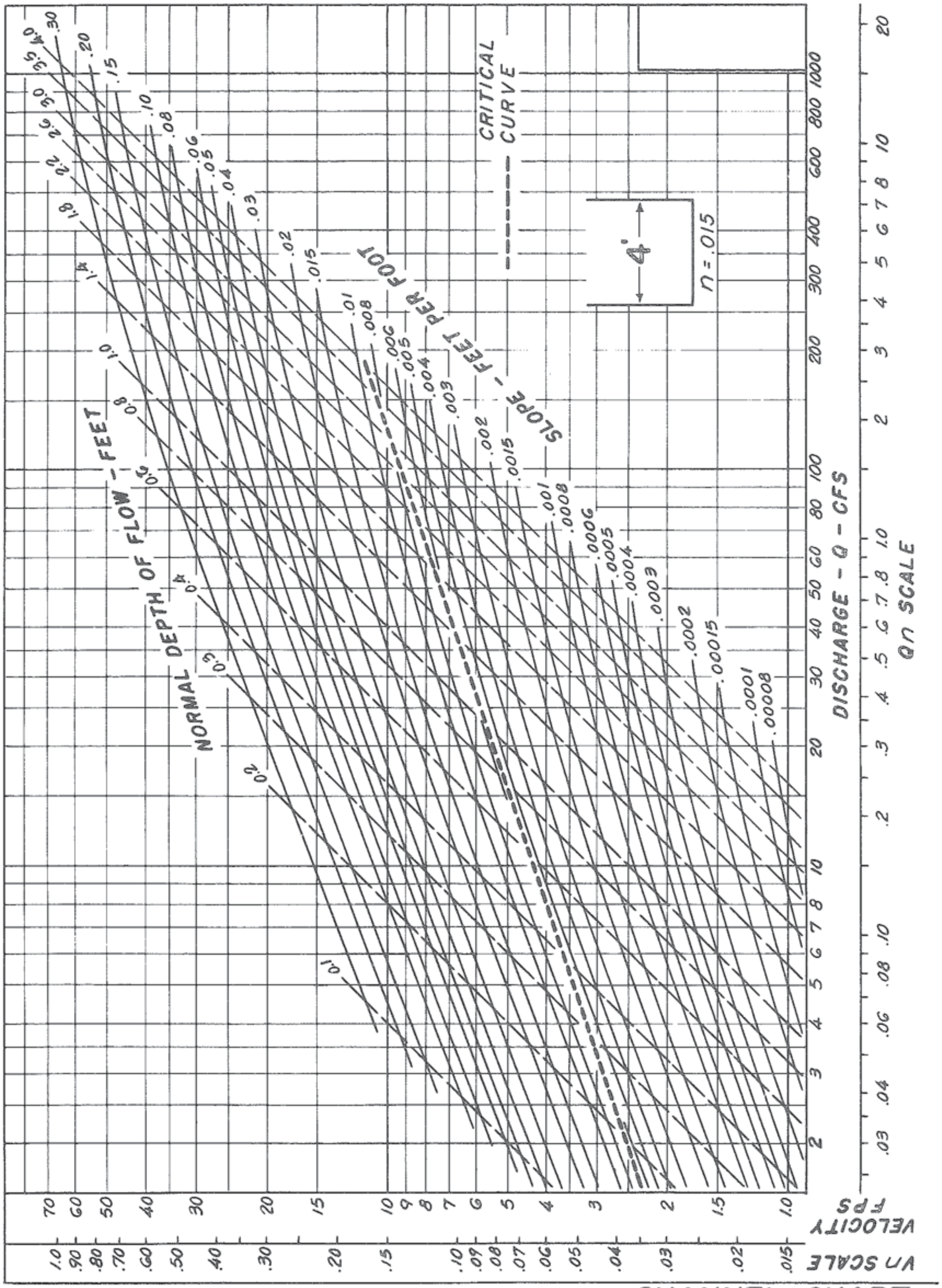
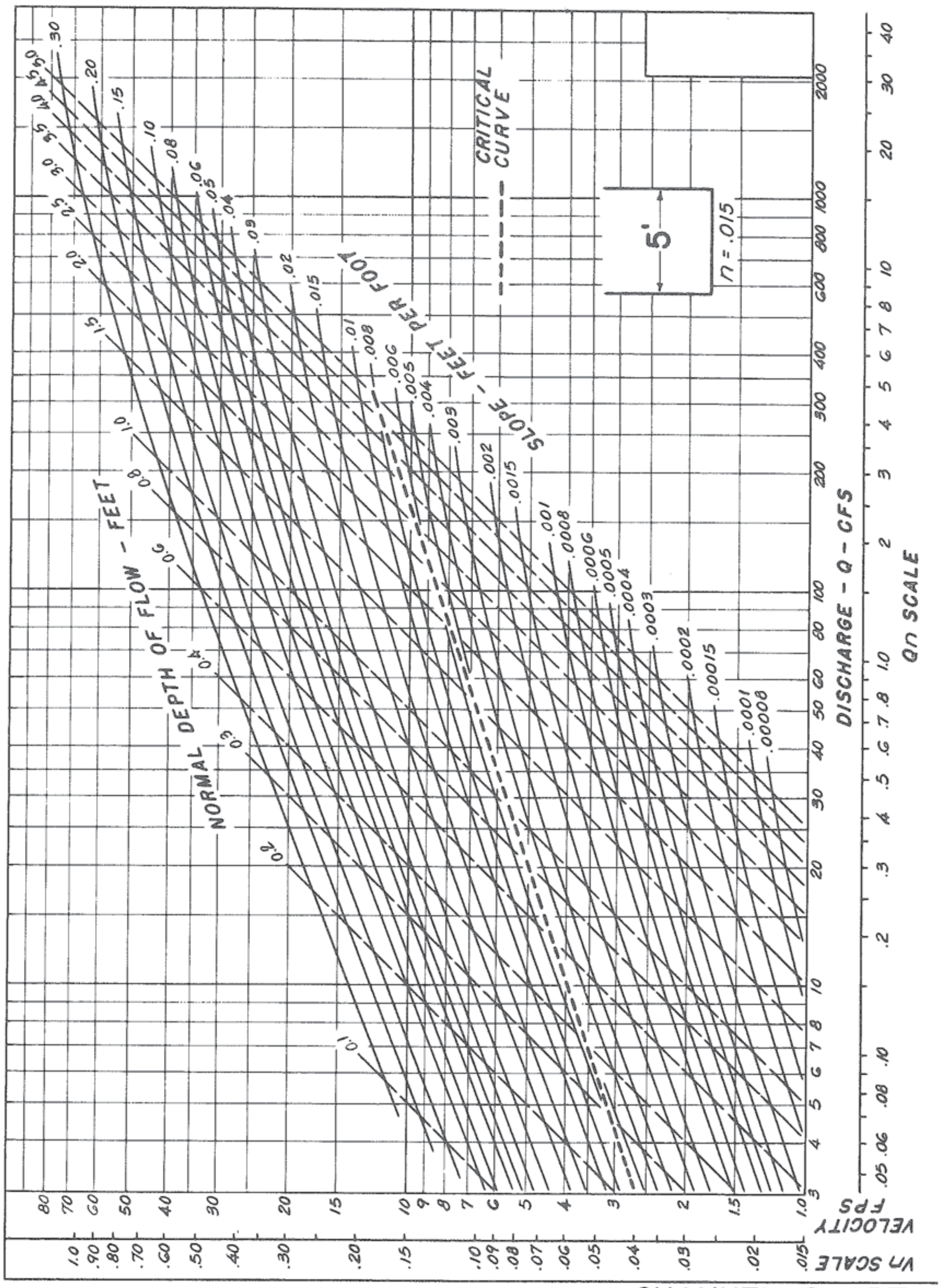
FIGURE 7A-4



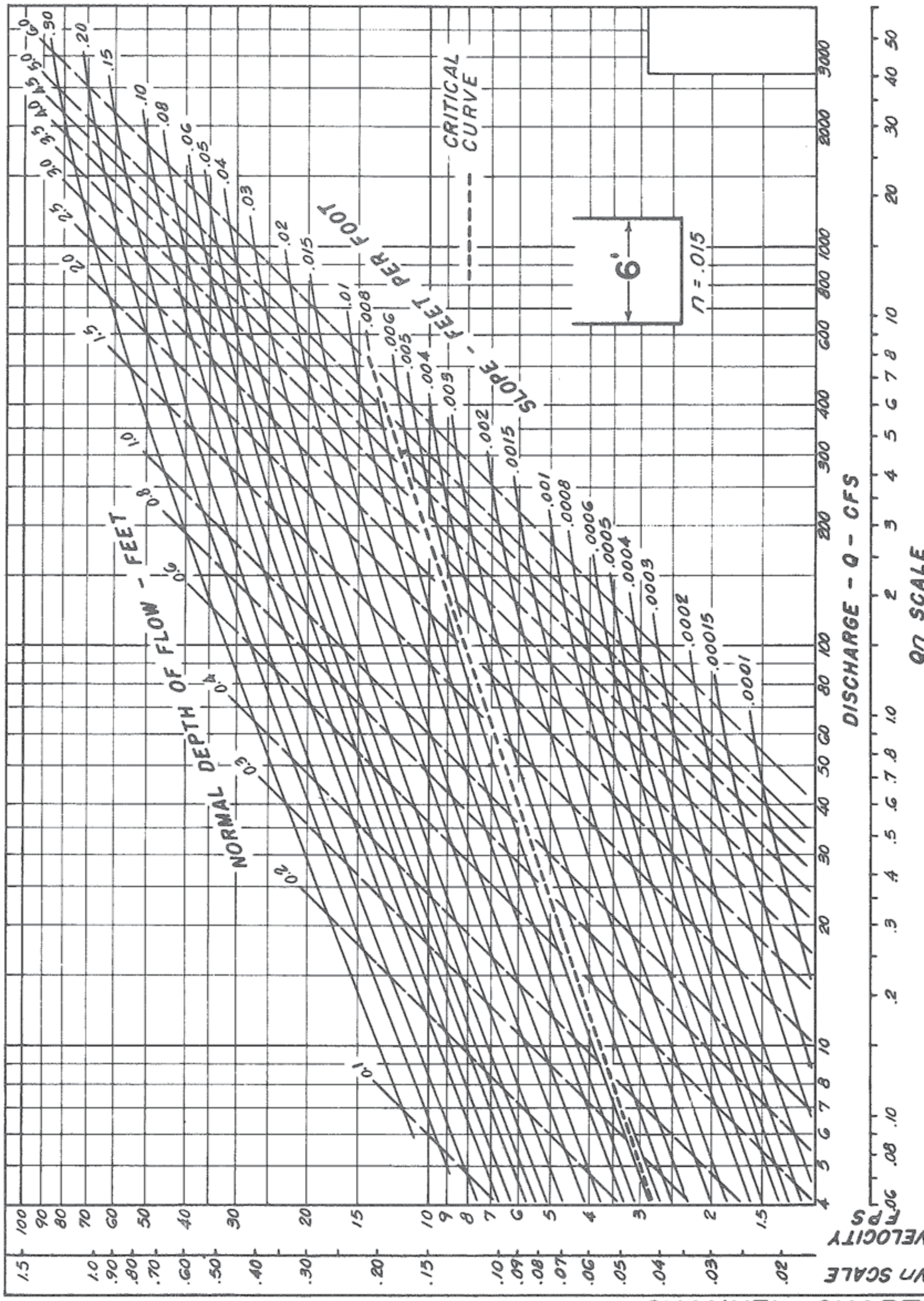
CHANNEL CHART
VERTICAL b = 4 FT.

FIGURE 7A-5



CHANNEL CHART
VERTICAL b = 5 FT.

FIGURE 7A-6



CHANNEL CHART
VERTICAL b = 6 FT.

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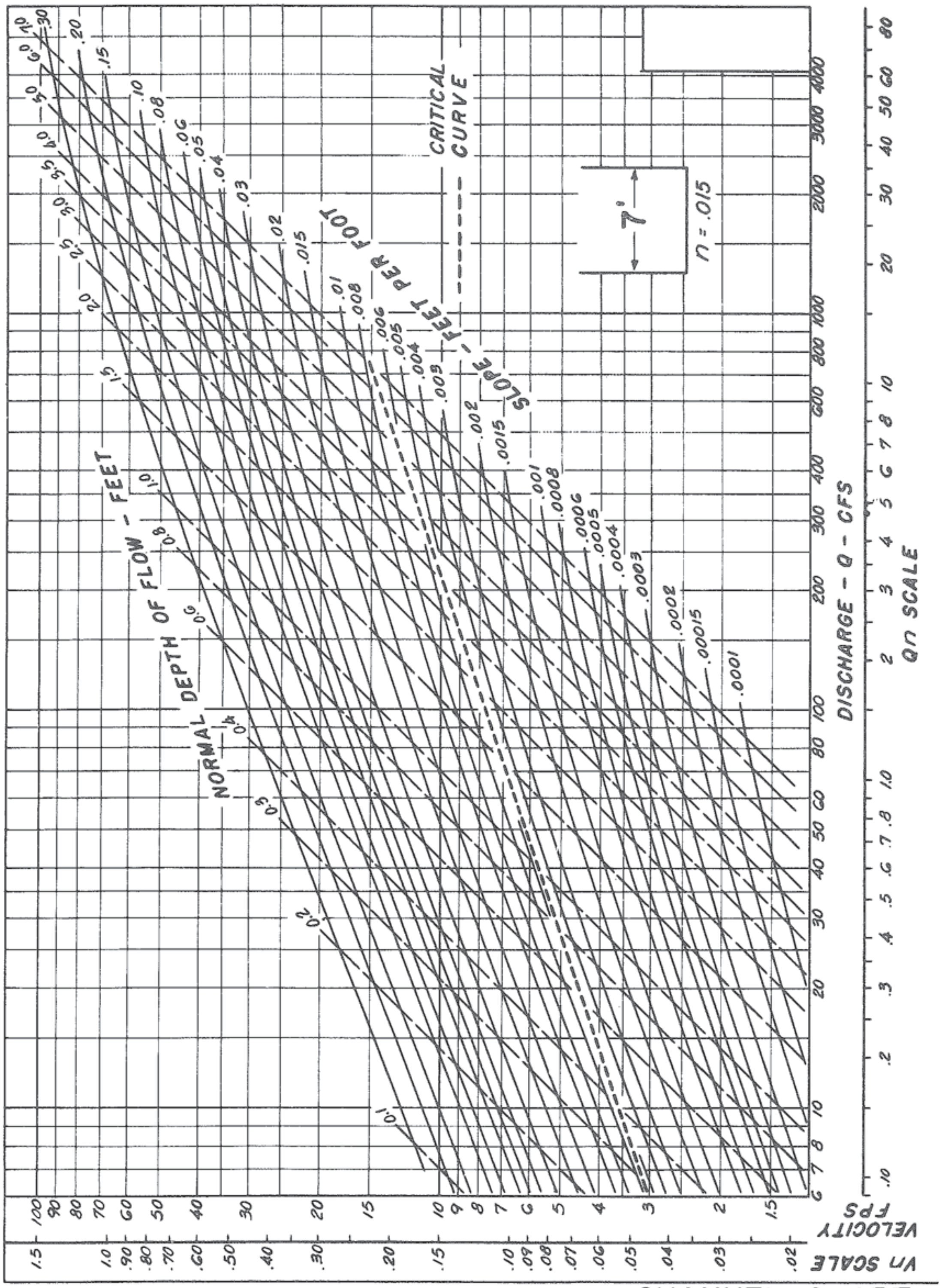
FIGURE 7A-7



CHANNEL CHART
VERTICAL b = 7 FT.

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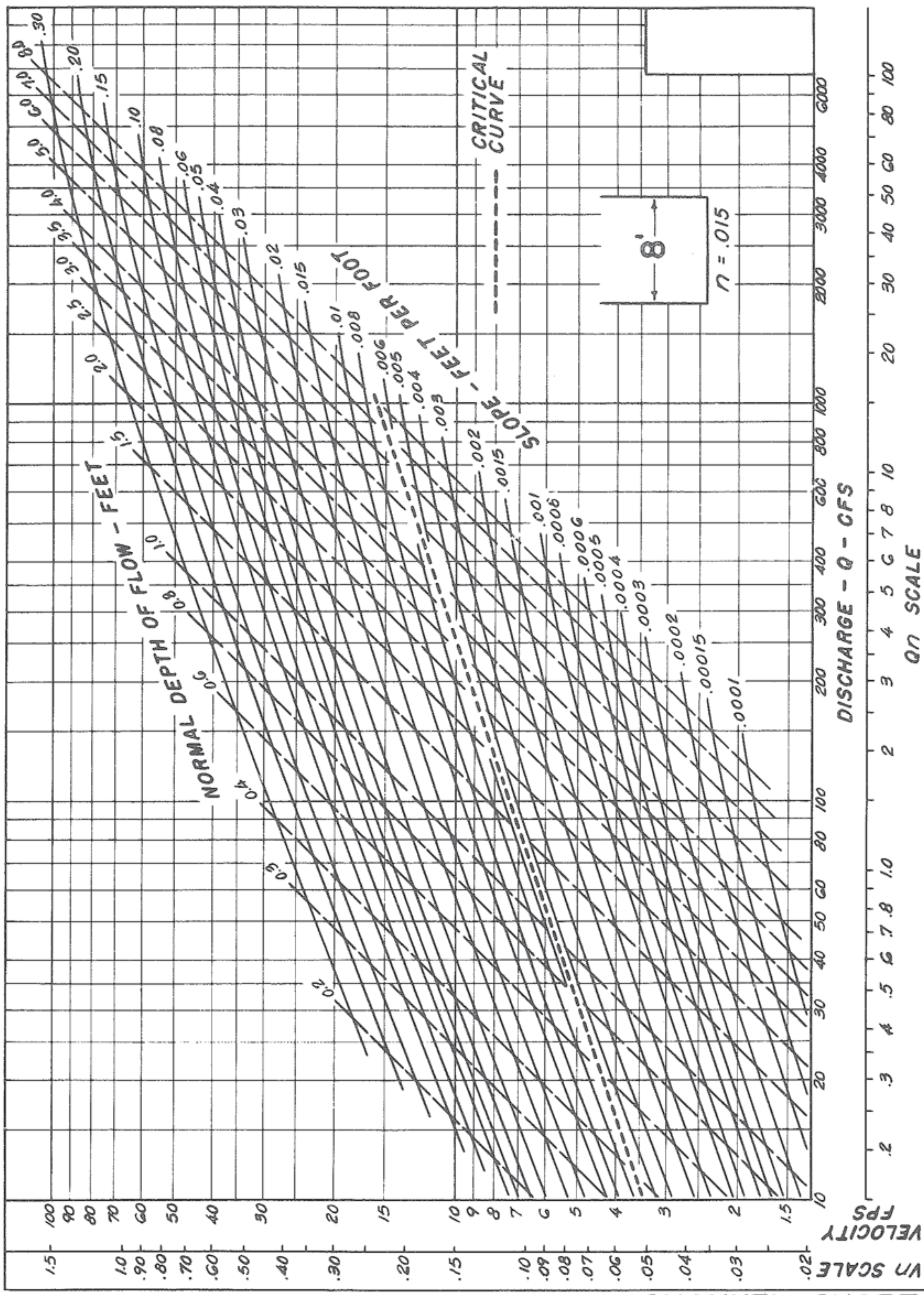
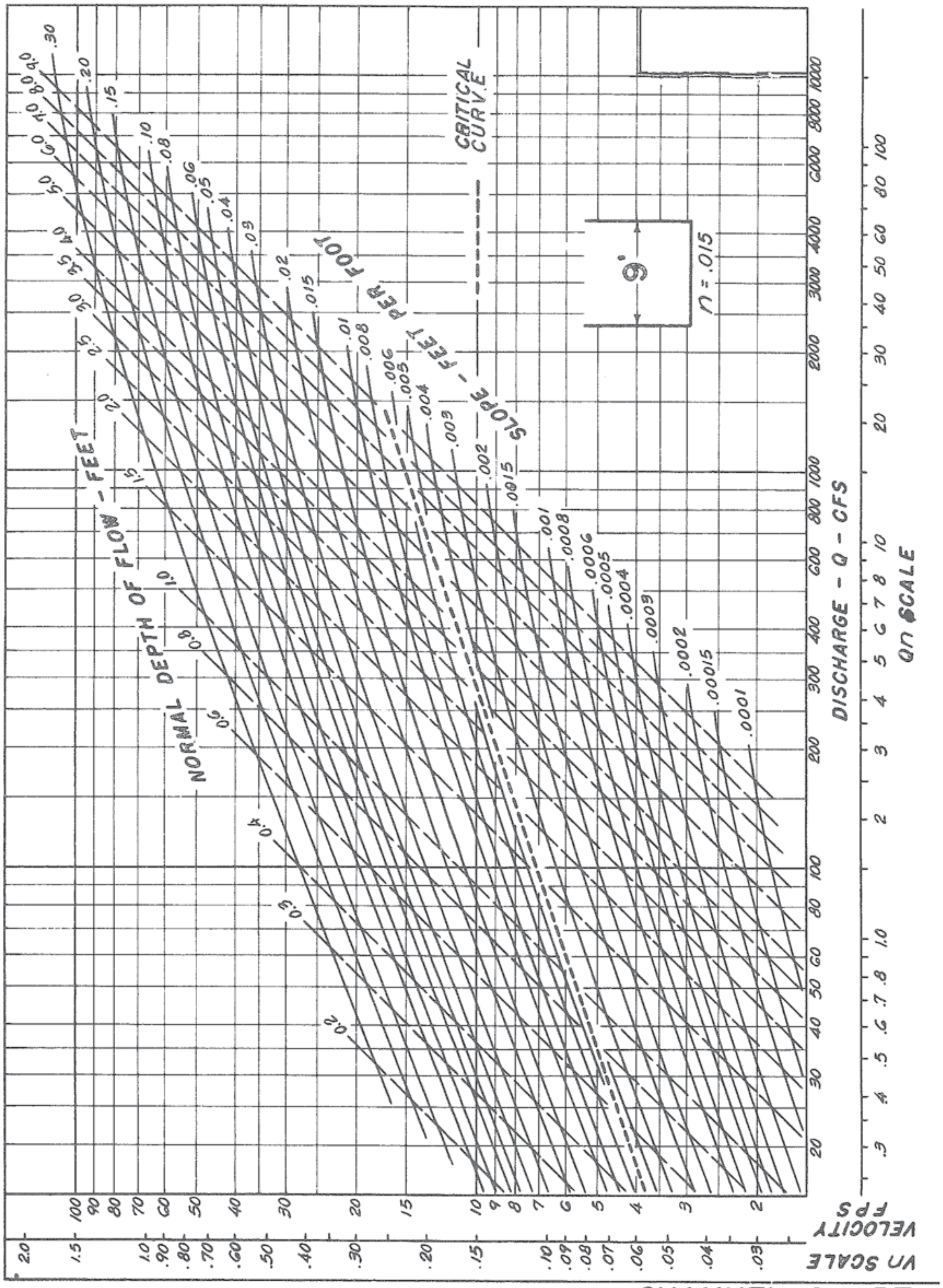


CHANNEL CHART
VERTICAL b = 8 FT.

FIGURE 7A-9



CHANNEL CHART
VERTICAL b = 9 FT.

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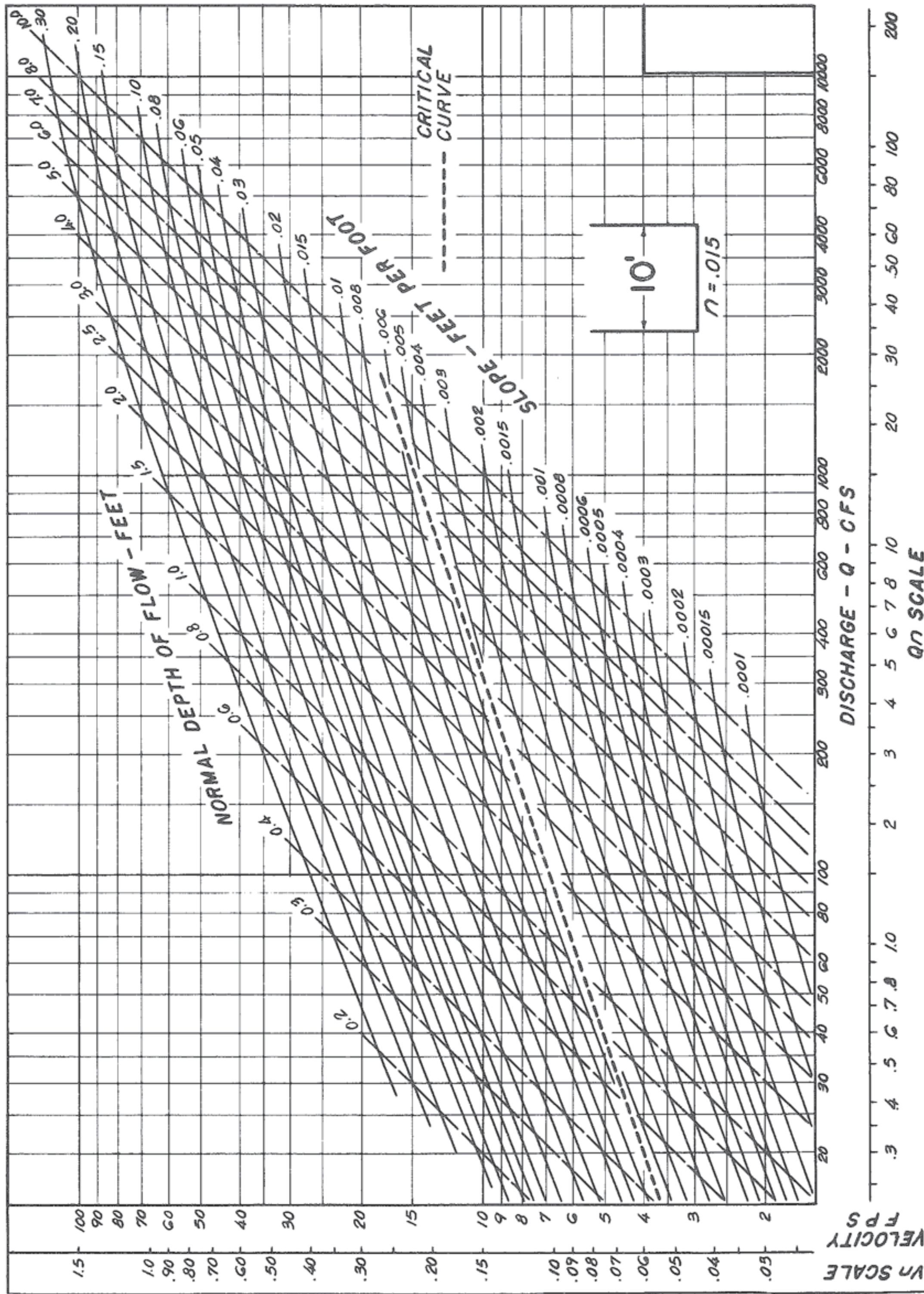
FIGURE 7A-10



CHANNEL CHART
VERTICAL b = 10 FT.

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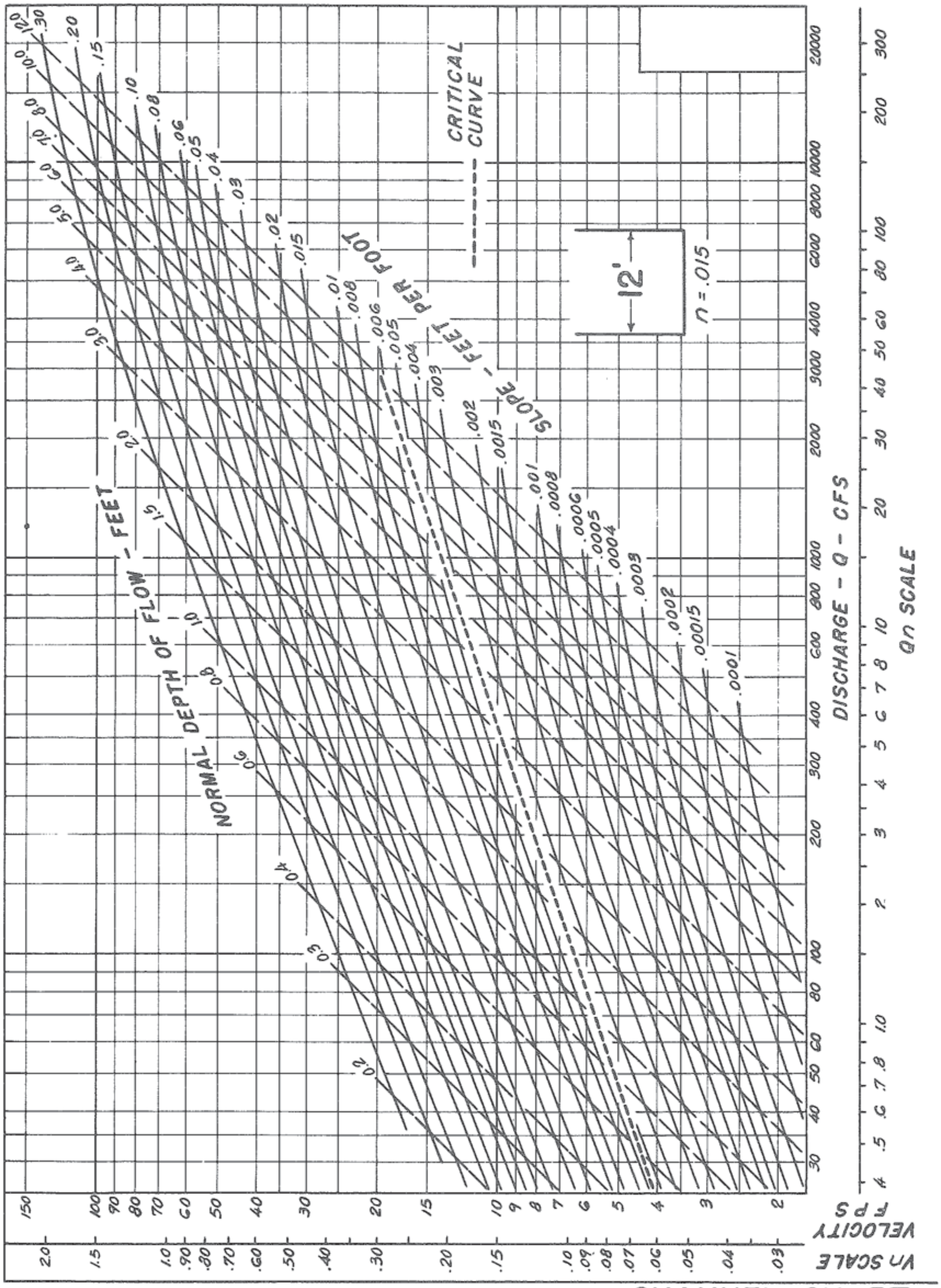
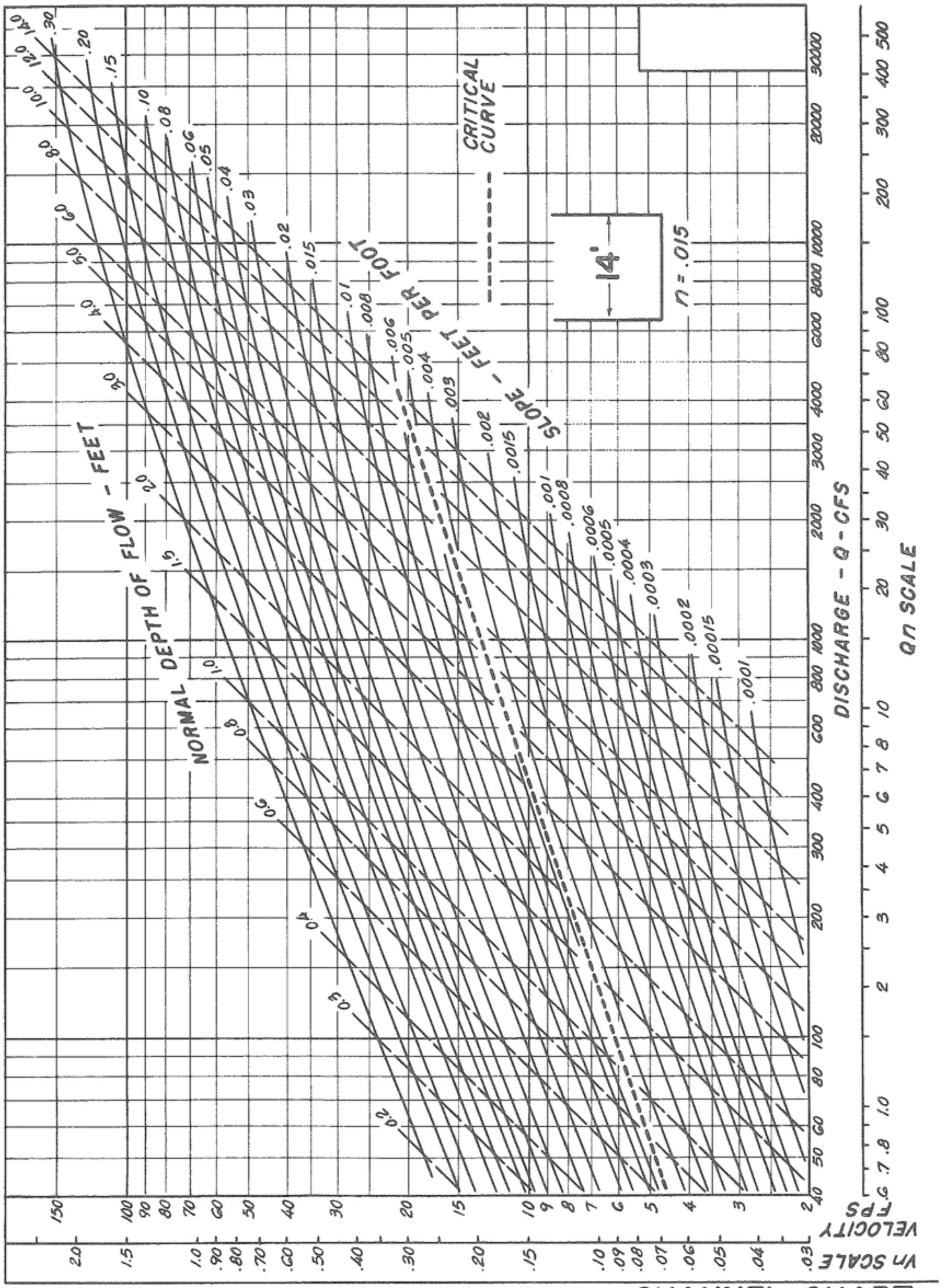
FIGURE 7A-11



CHANNEL CHART
VERTICAL b = 12 FT.

FIGURE 7A-12



CHANNEL CHART
VERTICAL b = 14 FT.

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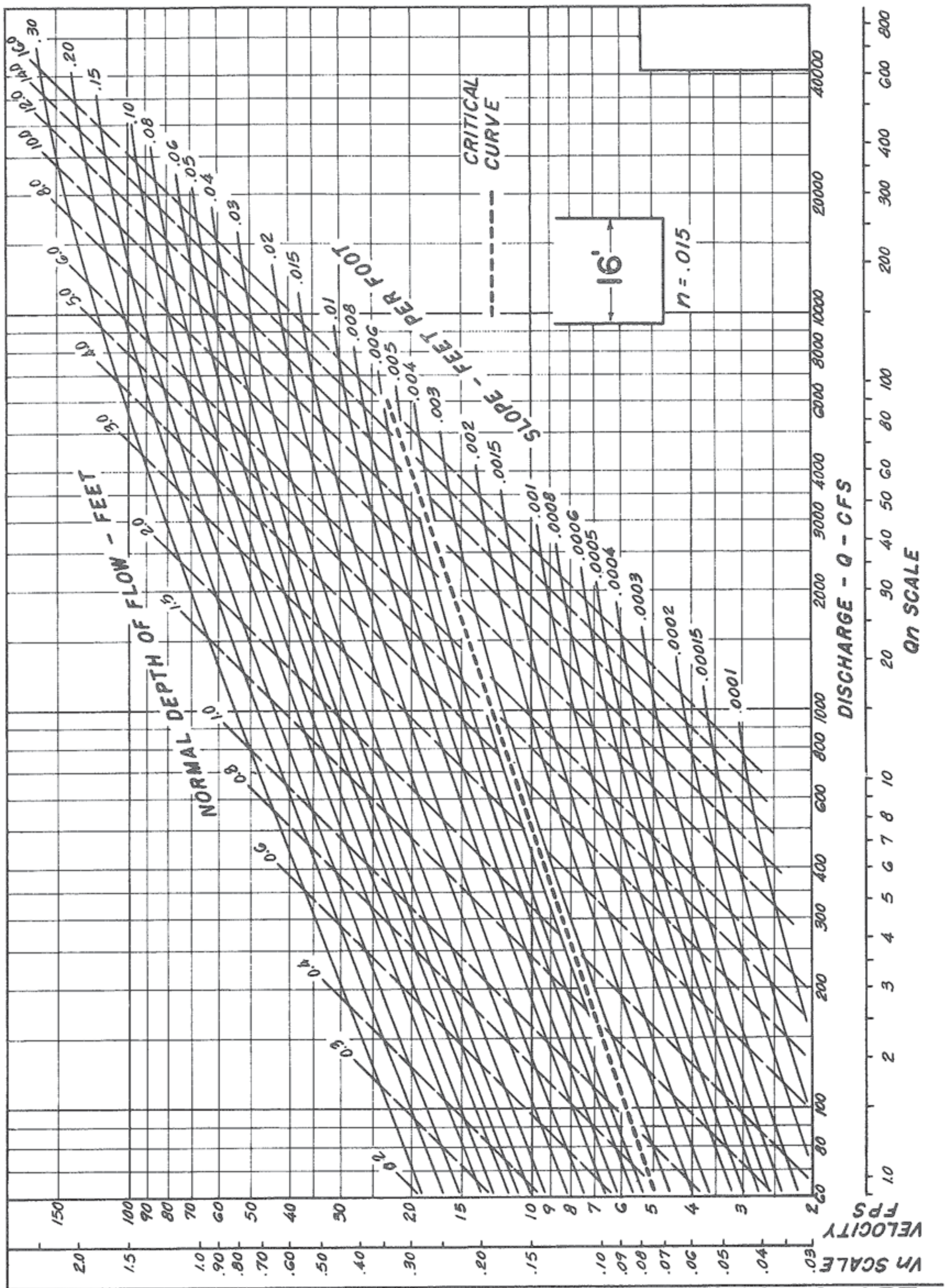
FIGURE 7A-13



CHANNEL CHART
VERTICAL b = 16 FT.

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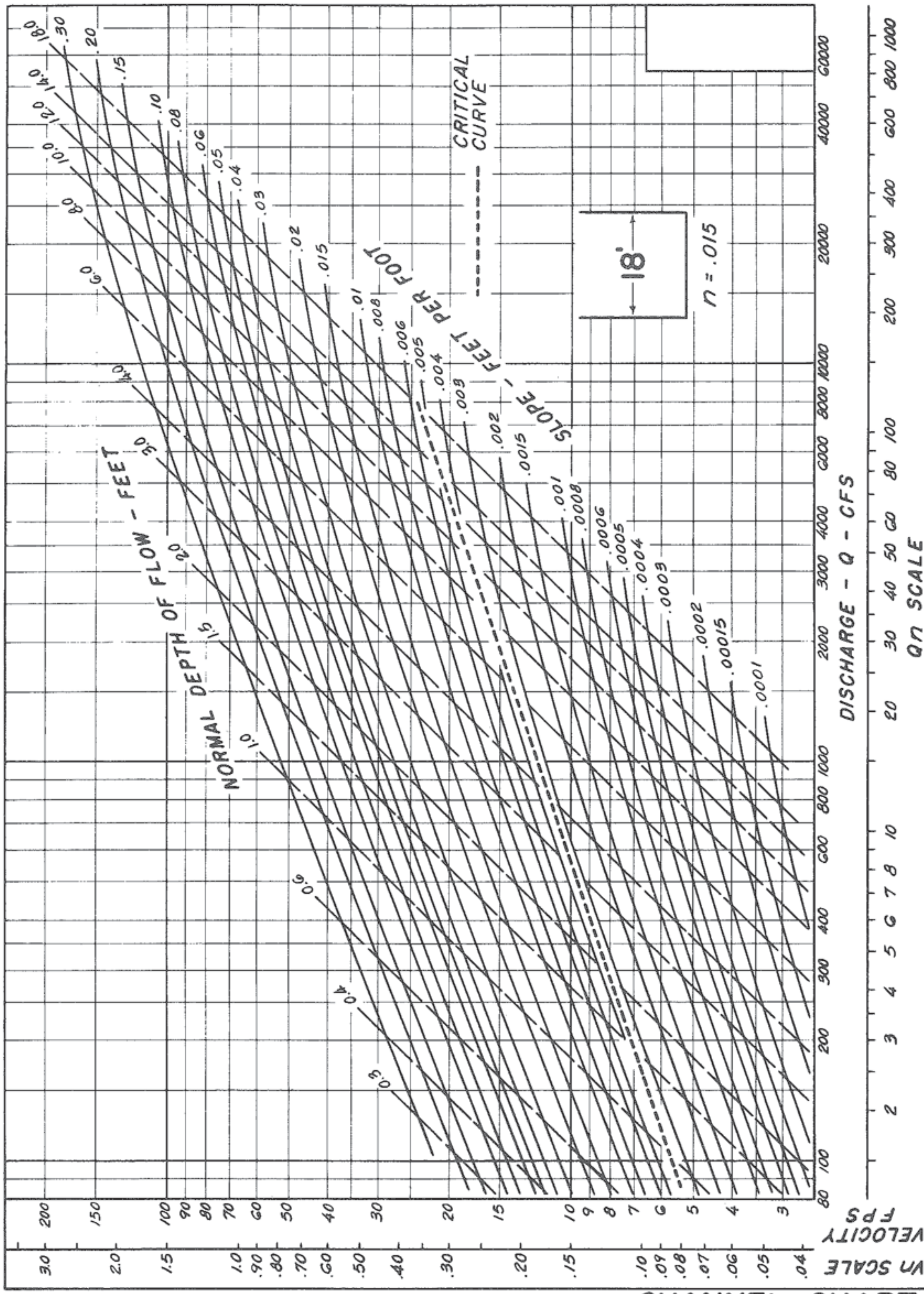
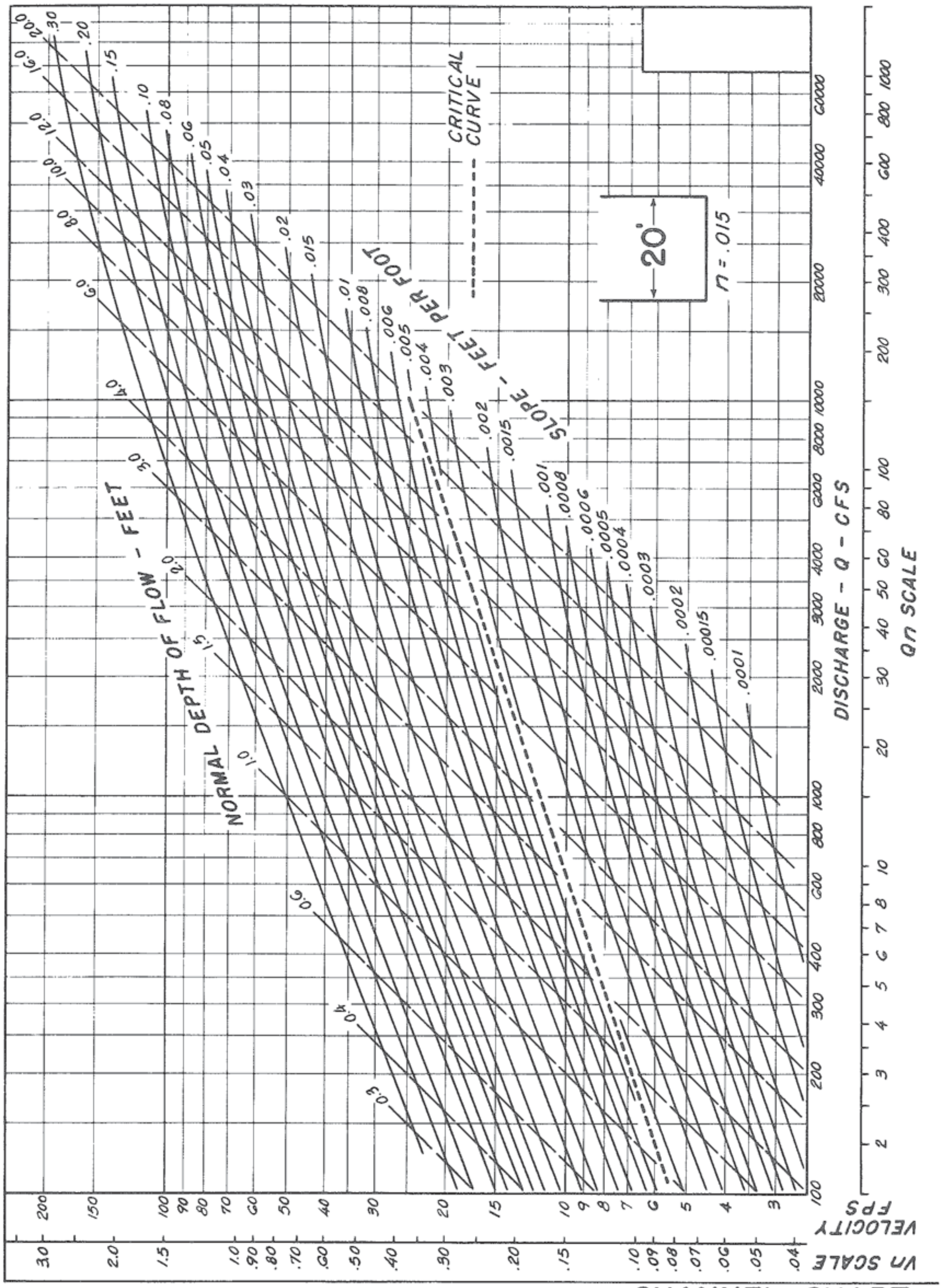
FIGURE 7A-14



CHANNEL CHART
VERTICAL b = 18 FT.

FIGURE 7A-15



CHANNEL CHART
VERTICAL b = 20 FT.

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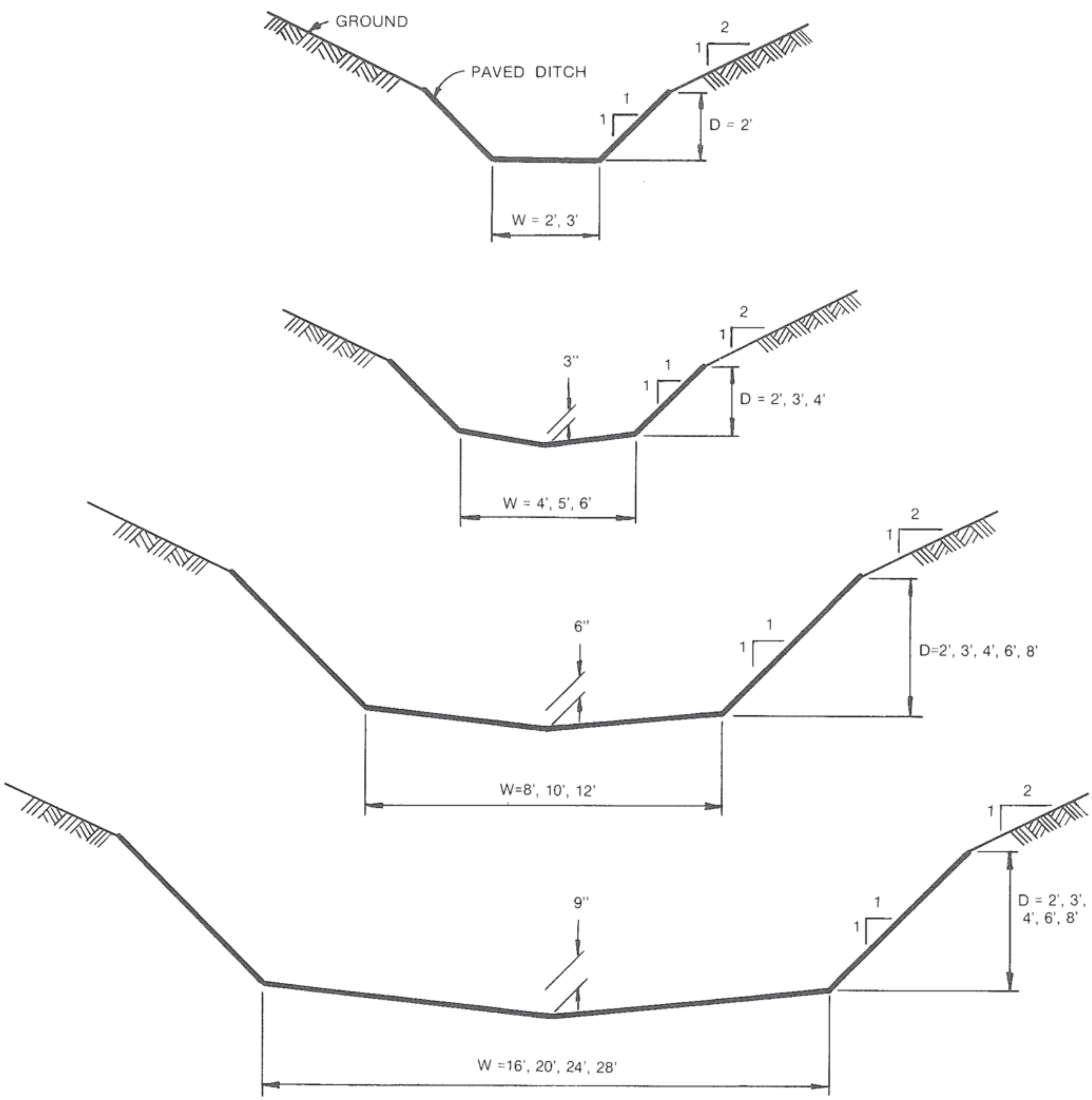
FIGURE 7A-16

STANDARD CHANNEL SECTIONS



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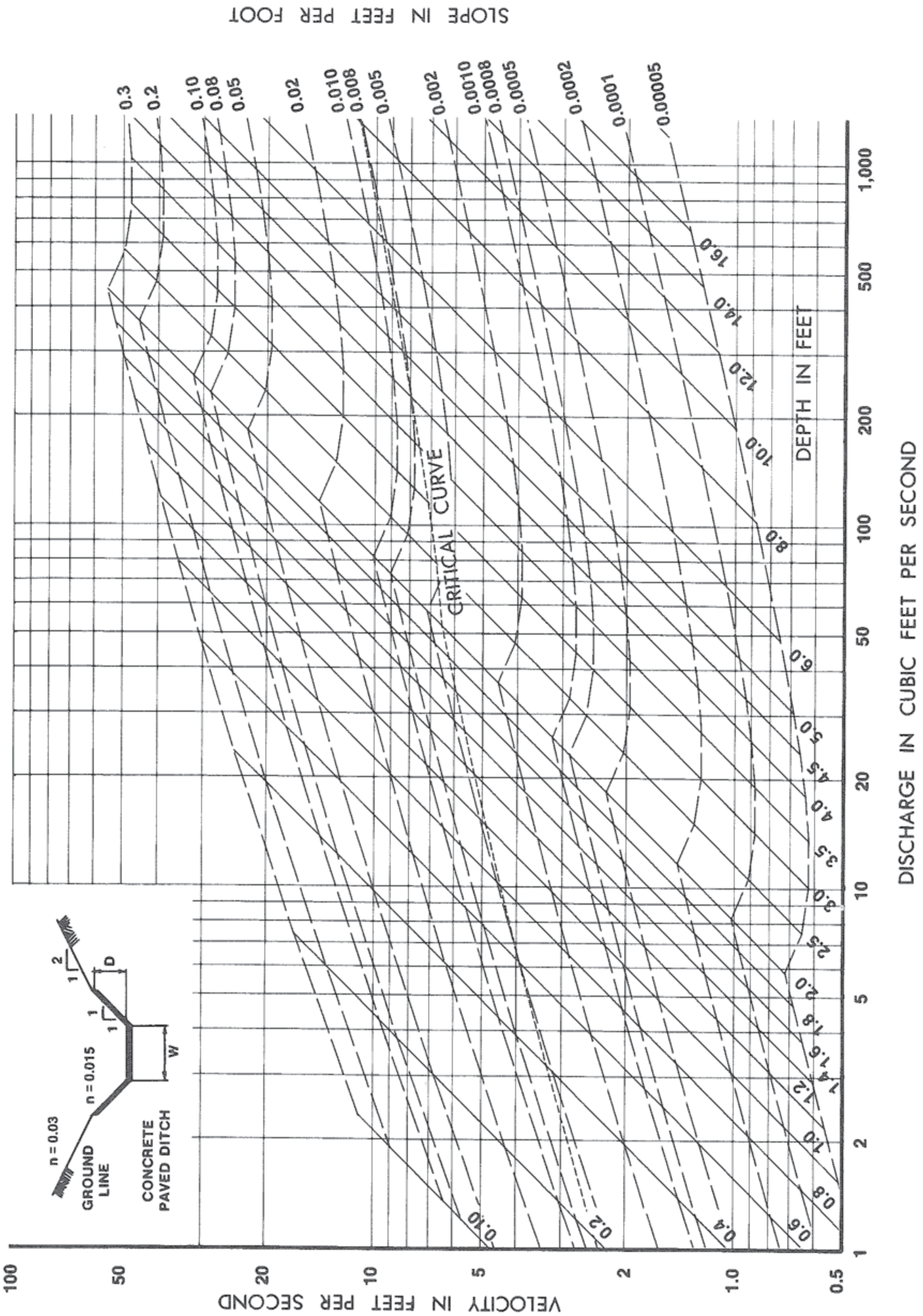
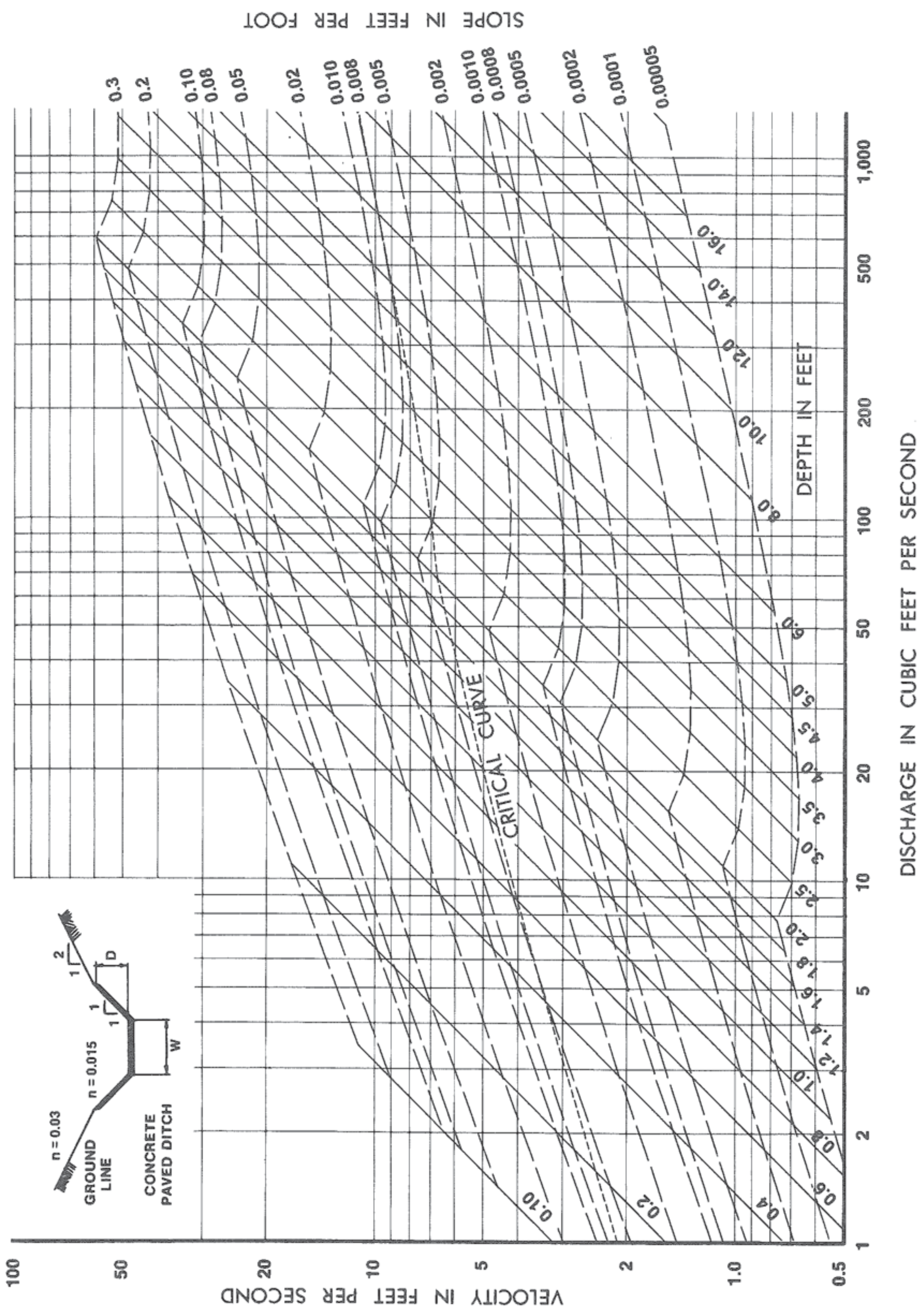


PAVED CHANNEL CHART
W = 2 FT. D = 2 FT.

FIGURE 7A-18



PAVED CHANNEL CHART
W = 3 FT. D = 2 FT.

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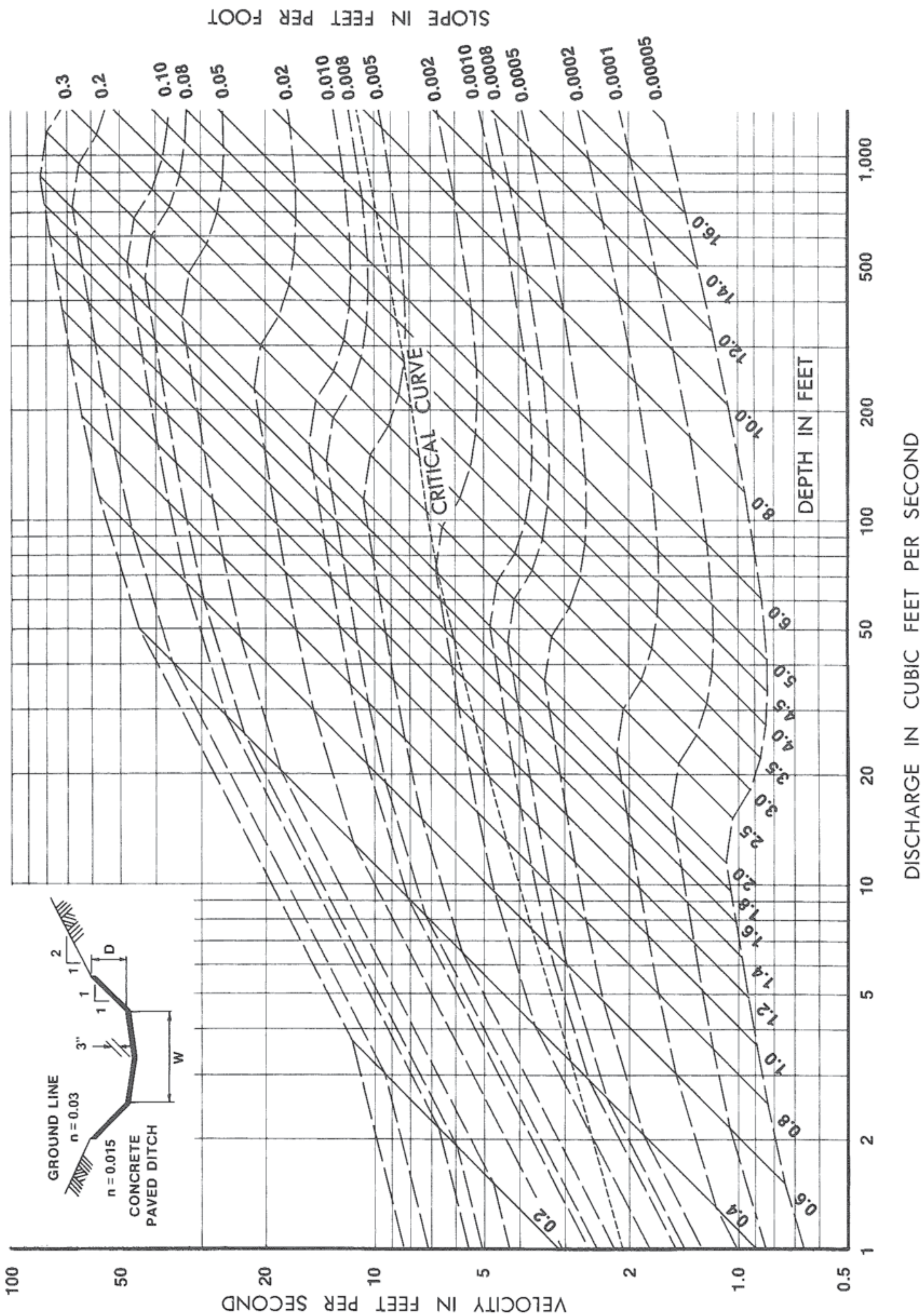
FIGURE 7A-19



PAVED CHANNEL CHART
W = 4 FT. D = 2 FT.

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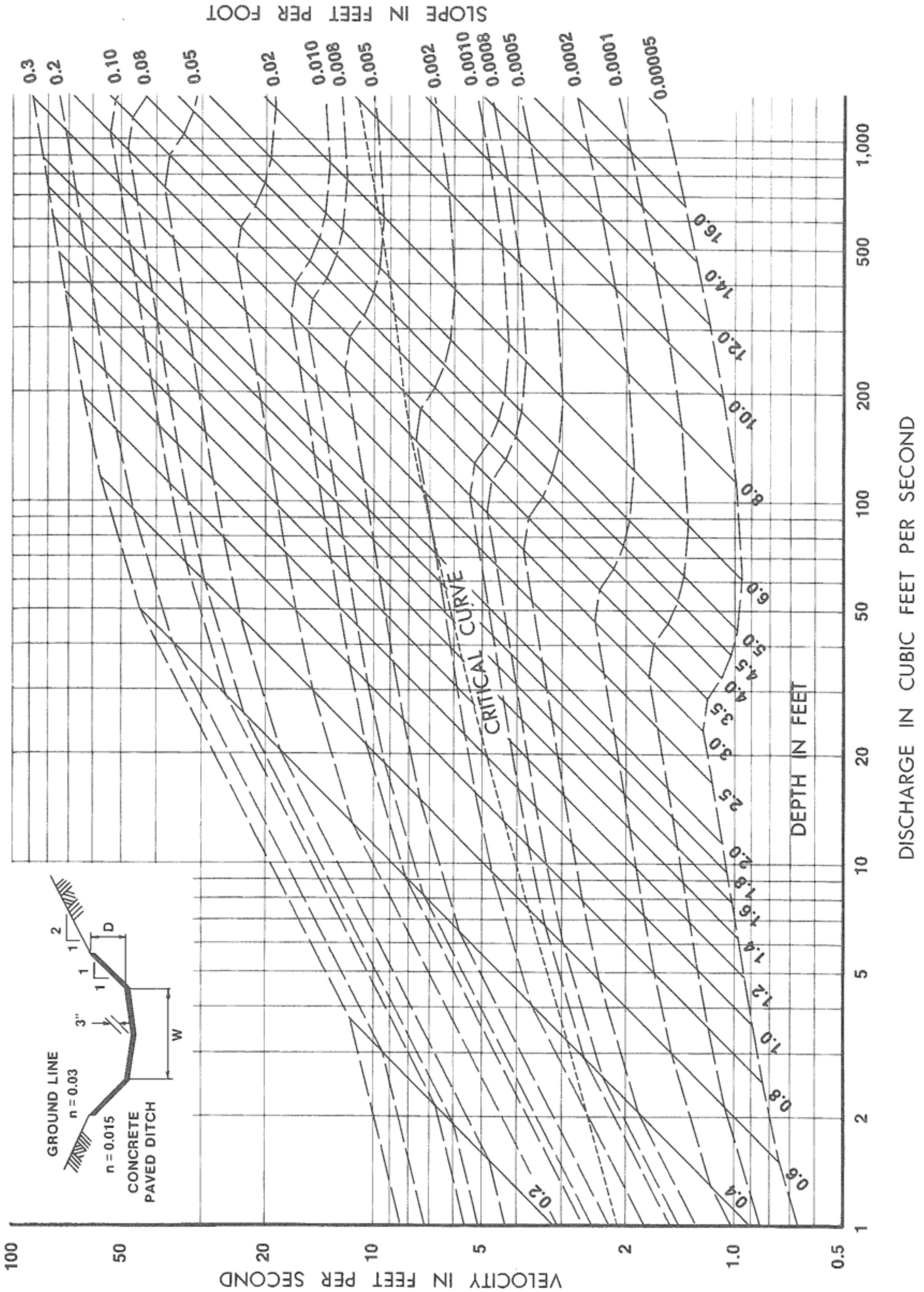

PAVED CHANNEL CHART
W = 4 FT. D = 3 FT.

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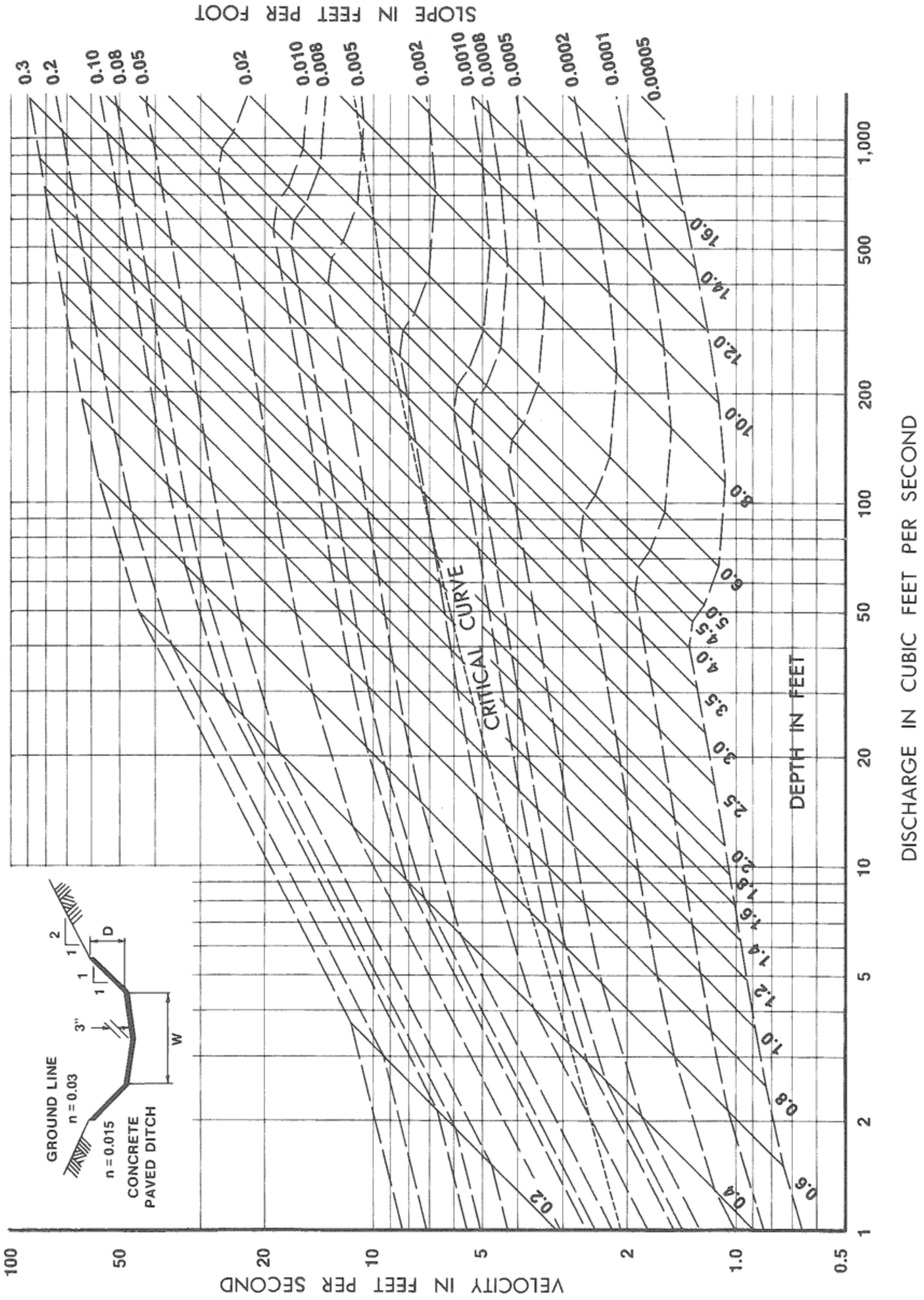
FIGURE 7A-21



PAVED CHANNEL CHART
W = 4 FT. D = 4 FT.

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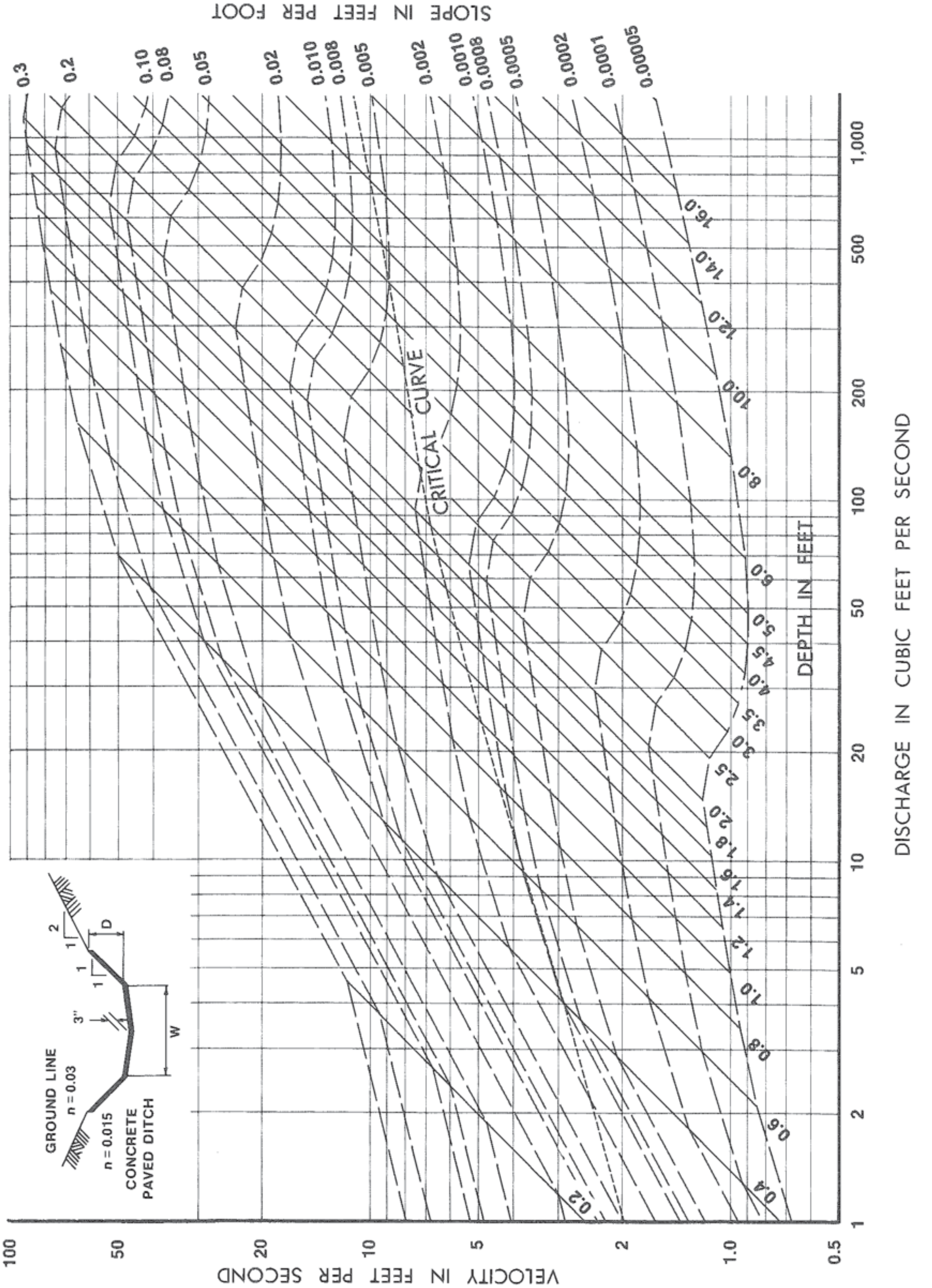
FIGURE 7A-22



PAVED CHANNEL CHART
W = 5 FT. D = 2 FT.

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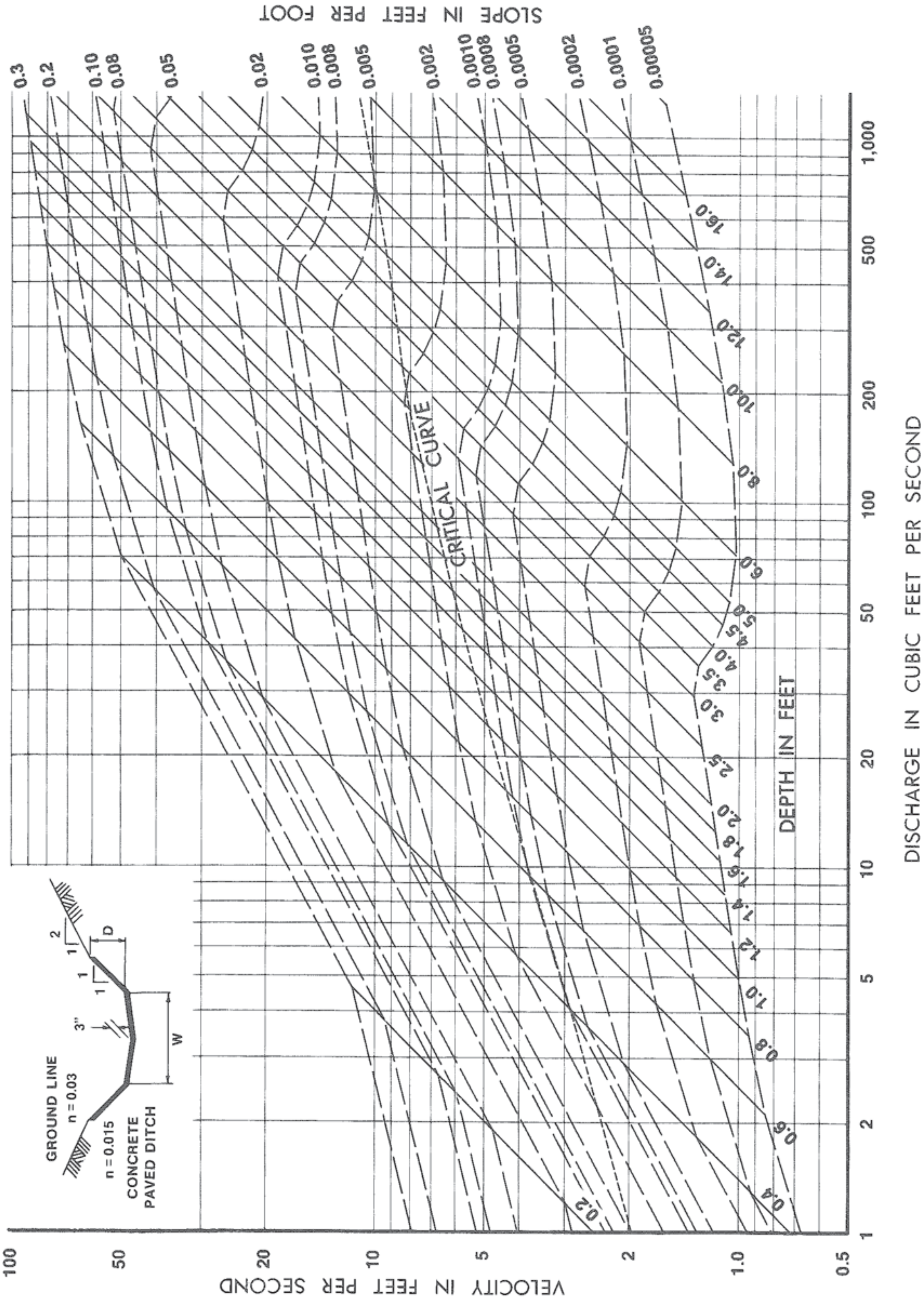
FIGURE 7A-23



PAVED CHANNEL CHART
W = 5 FT. D = 3 FT.

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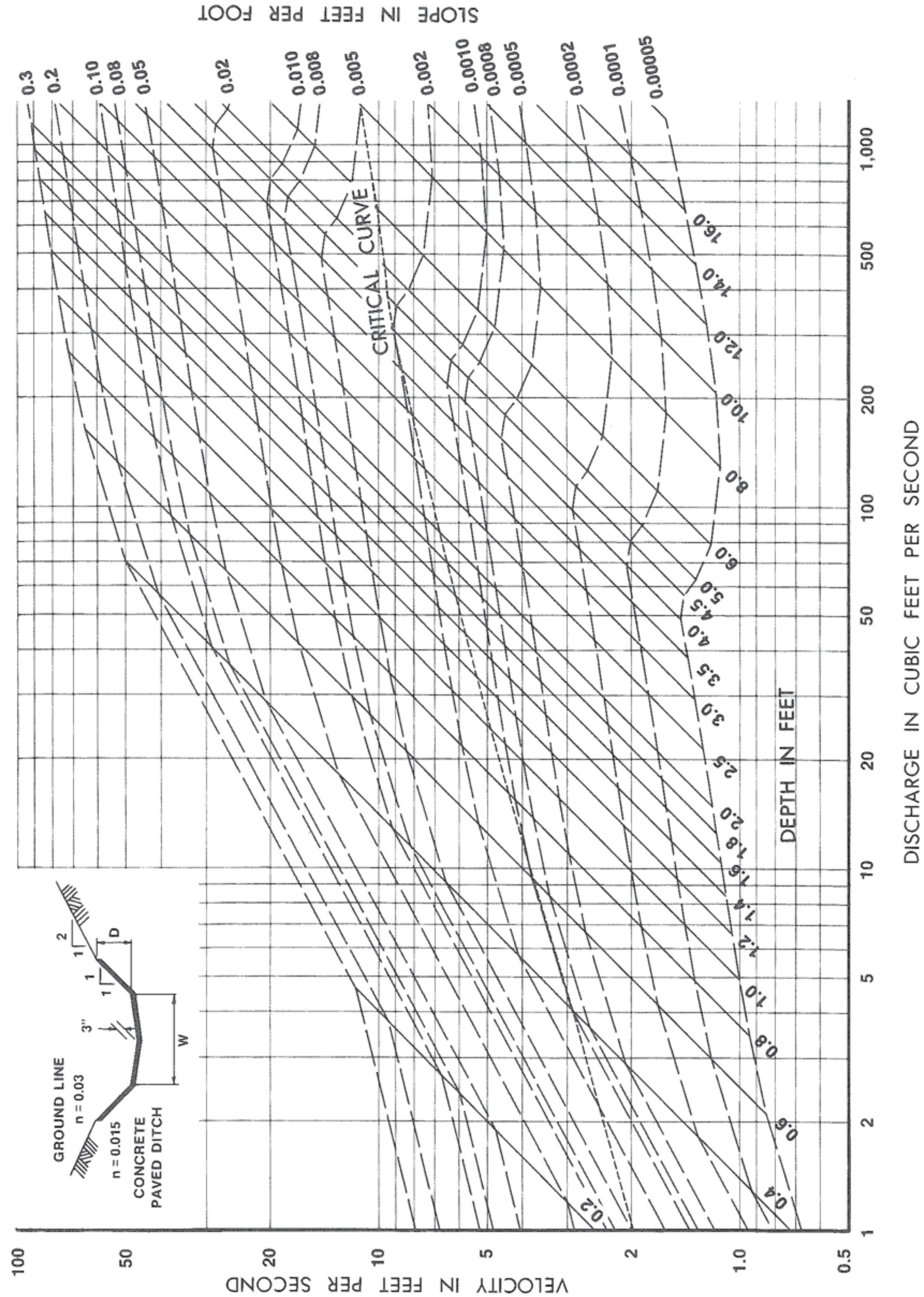
FIGURE 7A-24



PAVED CHANNEL CHART
W = 5 FT. D = 4 FT.

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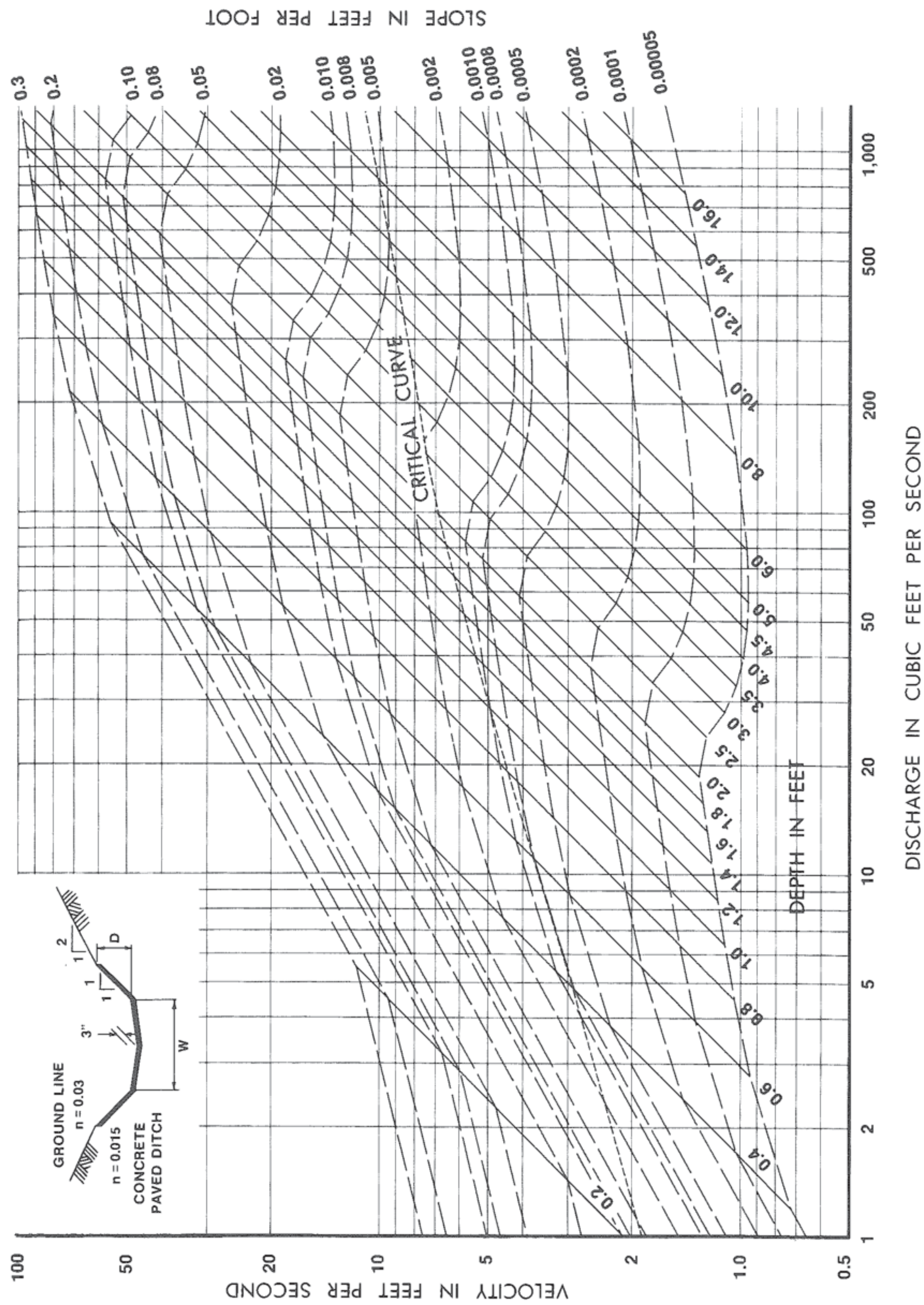
FIGURE 7A-25



PAVED CHANNEL CHART
W = 6 FT. D = 2 FT.

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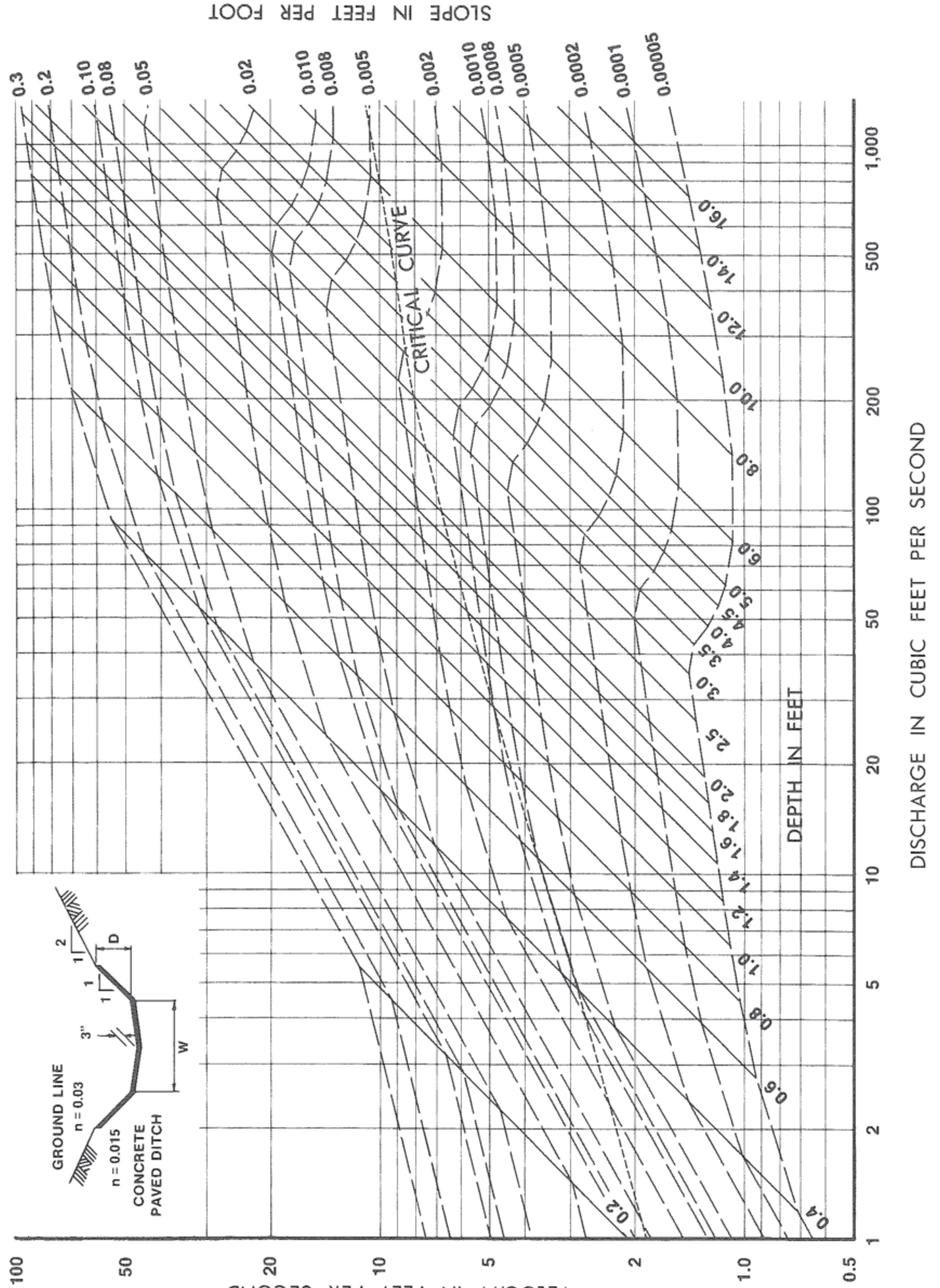
FIGURE 7A-26



PAVED CHANNEL CHART
W = 6 FT. D = 3 FT.

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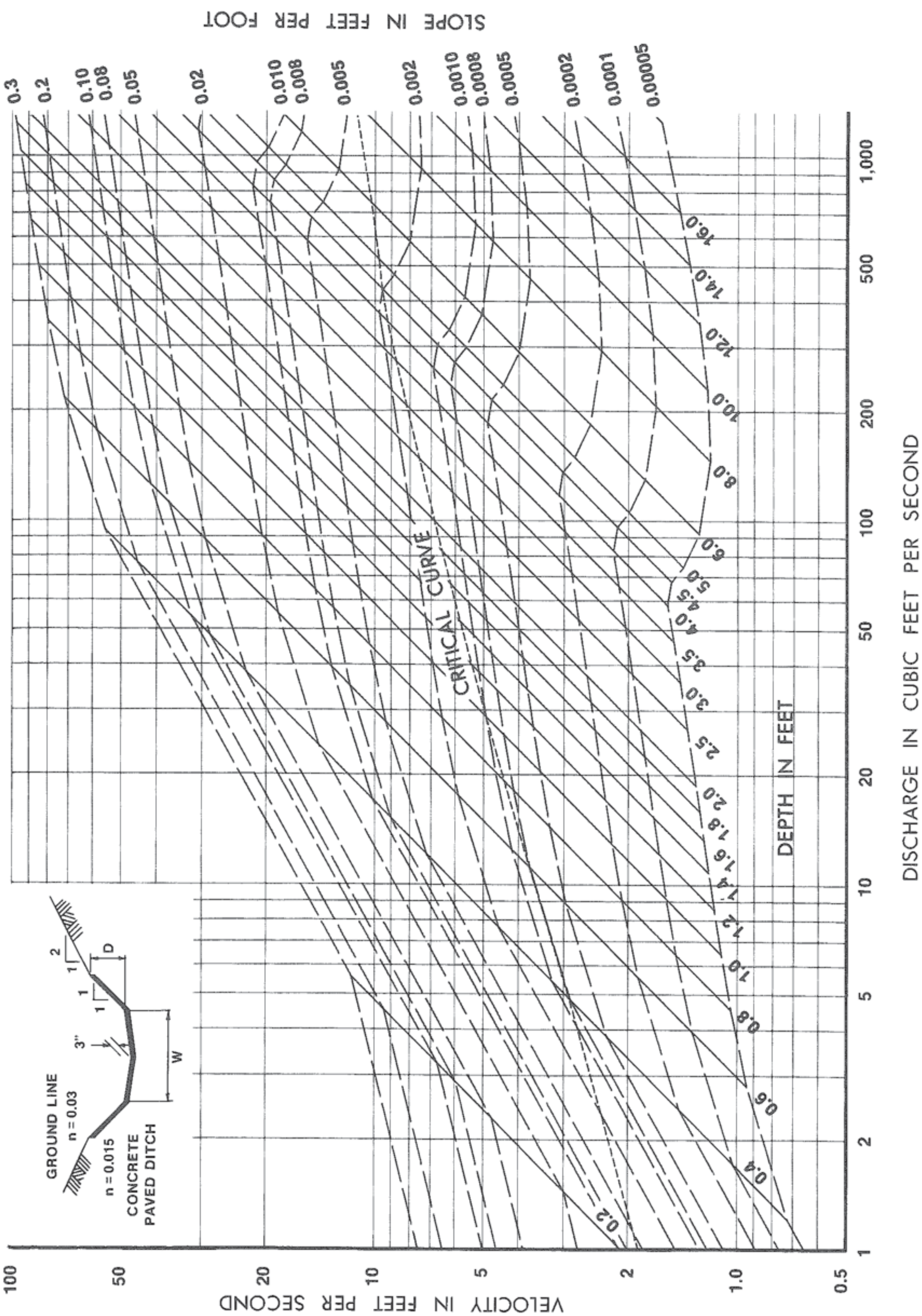
FIGURE 7A-27



PAVED CHANNEL CHART
W = 6 FT. D = 4 FT.

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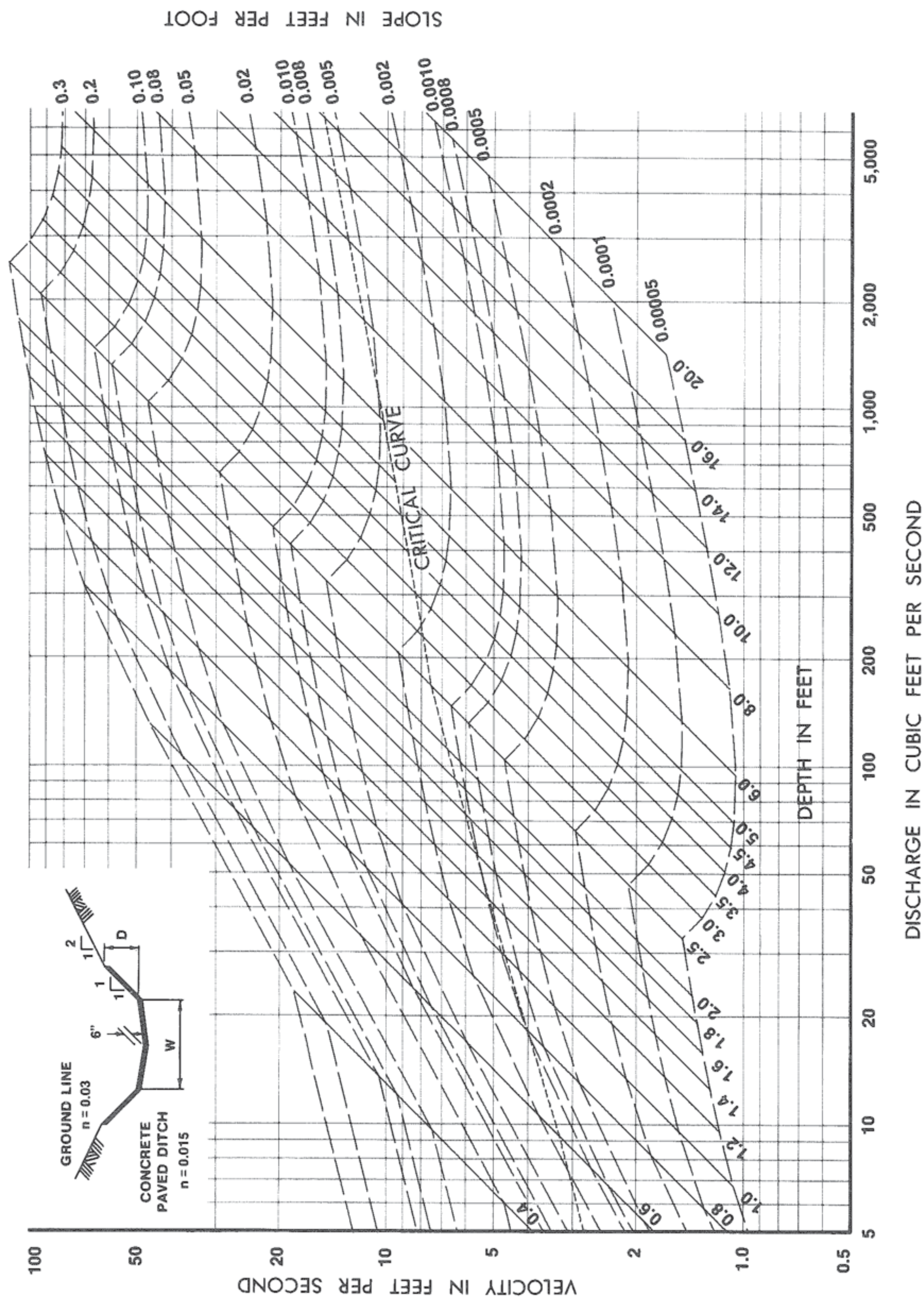
FIGURE 7A-28



PAVED CHANNEL CHART
W = 8 FT. D = 2 FT.

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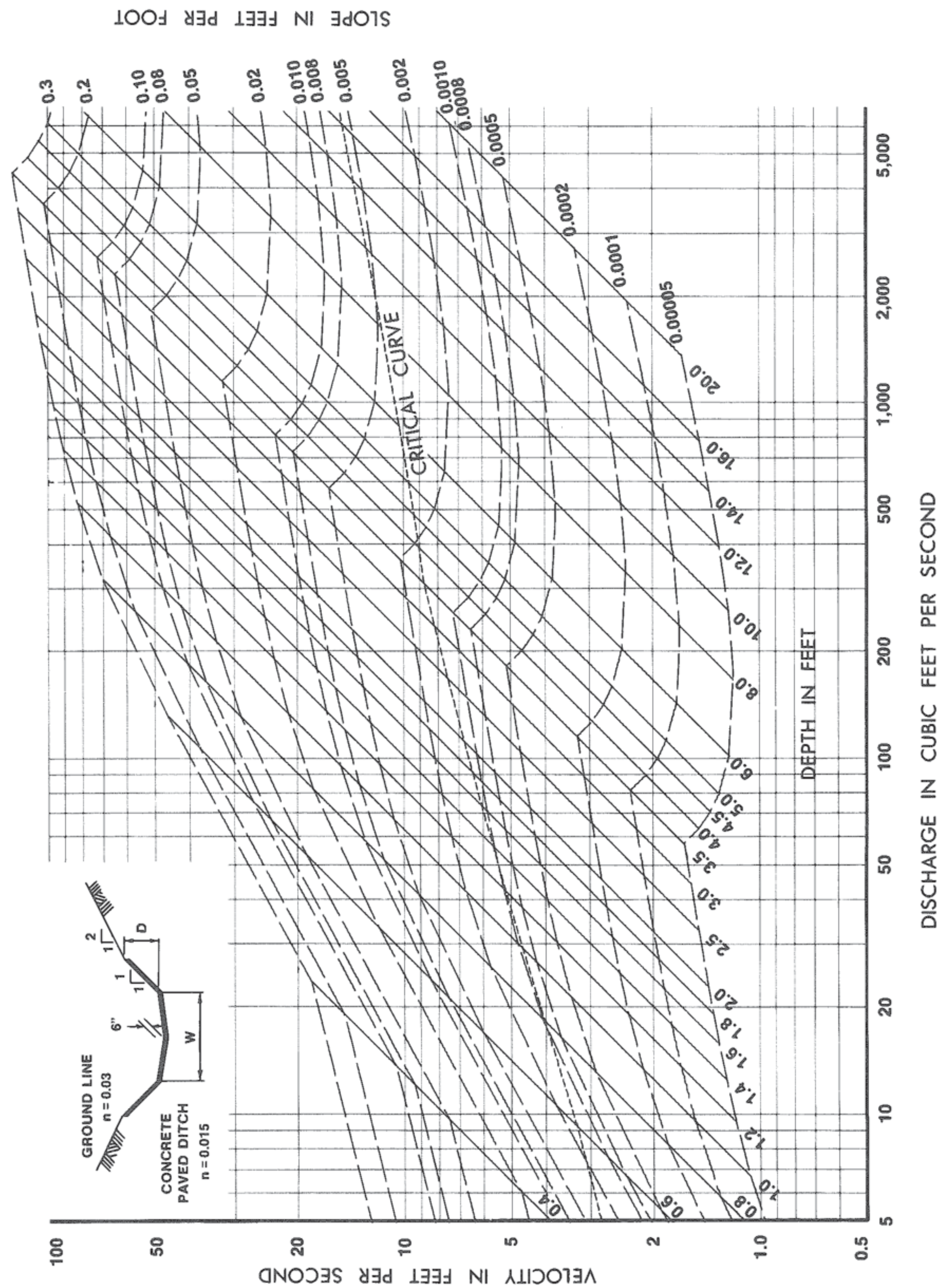
FIGURE 7A-29



PAVED CHANNEL CHART
W = 8 FT. D = 3 FT.

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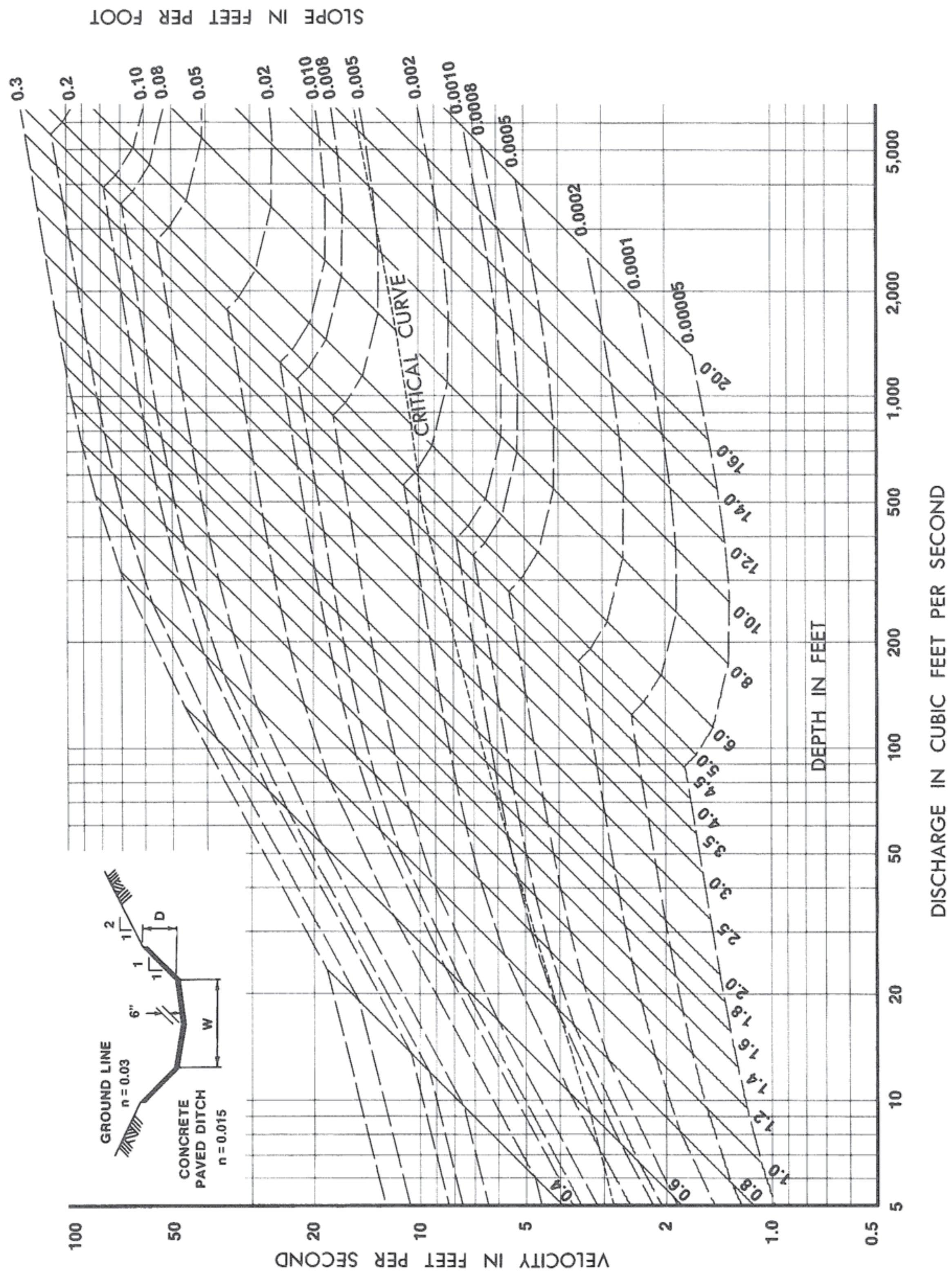
FIGURE 7A-30



PAVED CHANNEL CHART
W = 8 FT. D = 4 FT.

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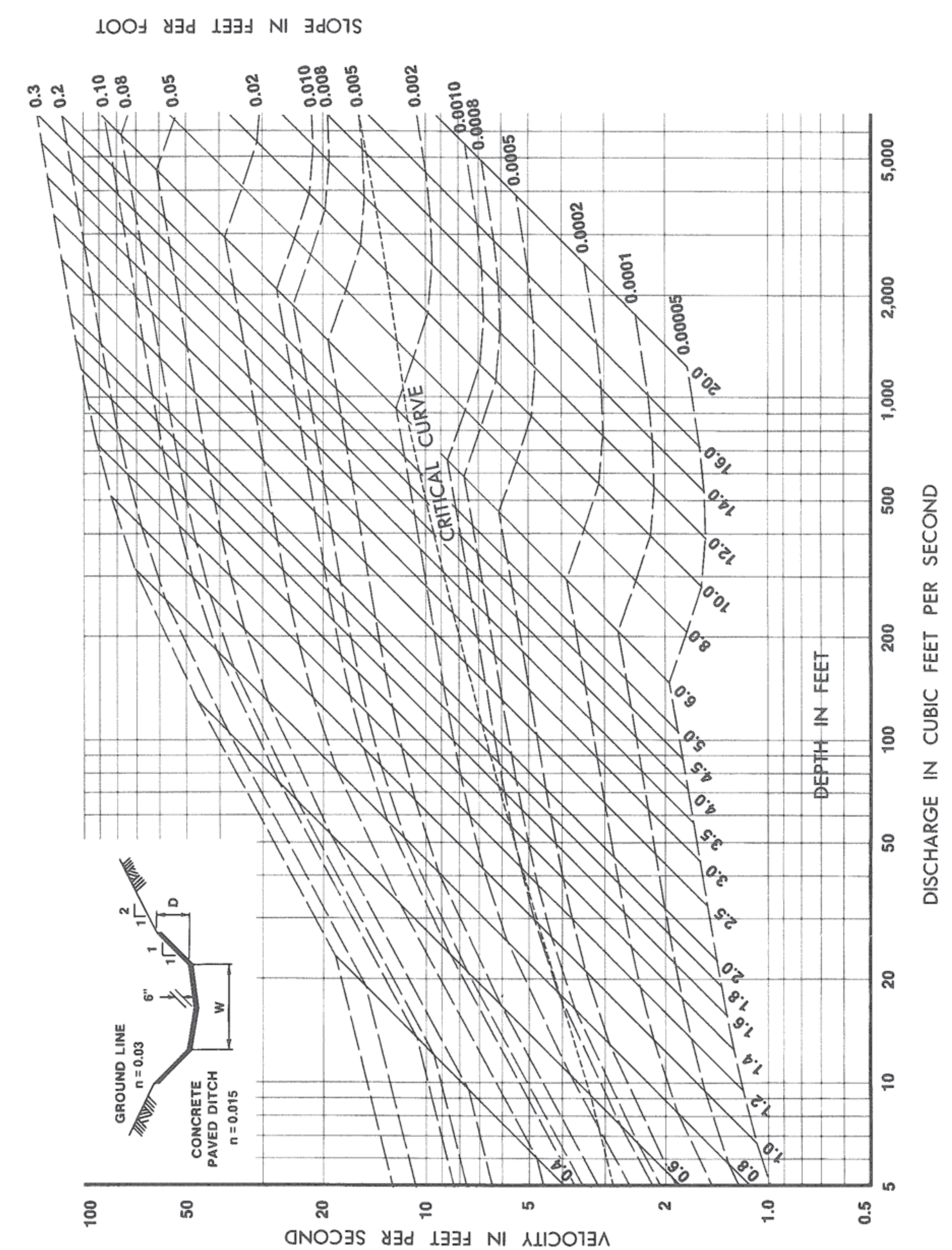
FIGURE 7A-31



PAVED CHANNEL CHART
W = 8 FT. D = 6 FT.

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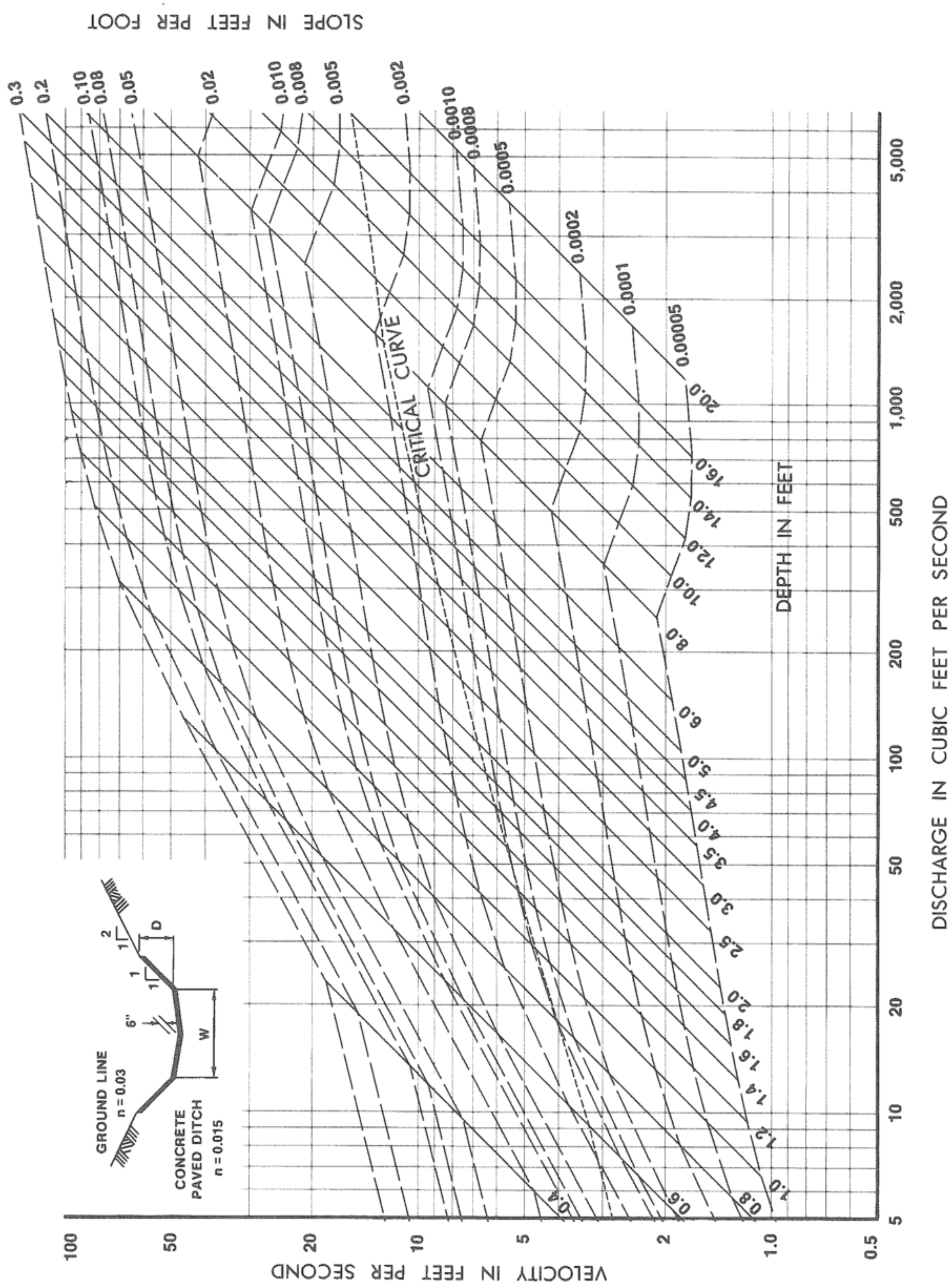

PAVED CHANNEL CHART
W = 8 FT. D = 8 FT.

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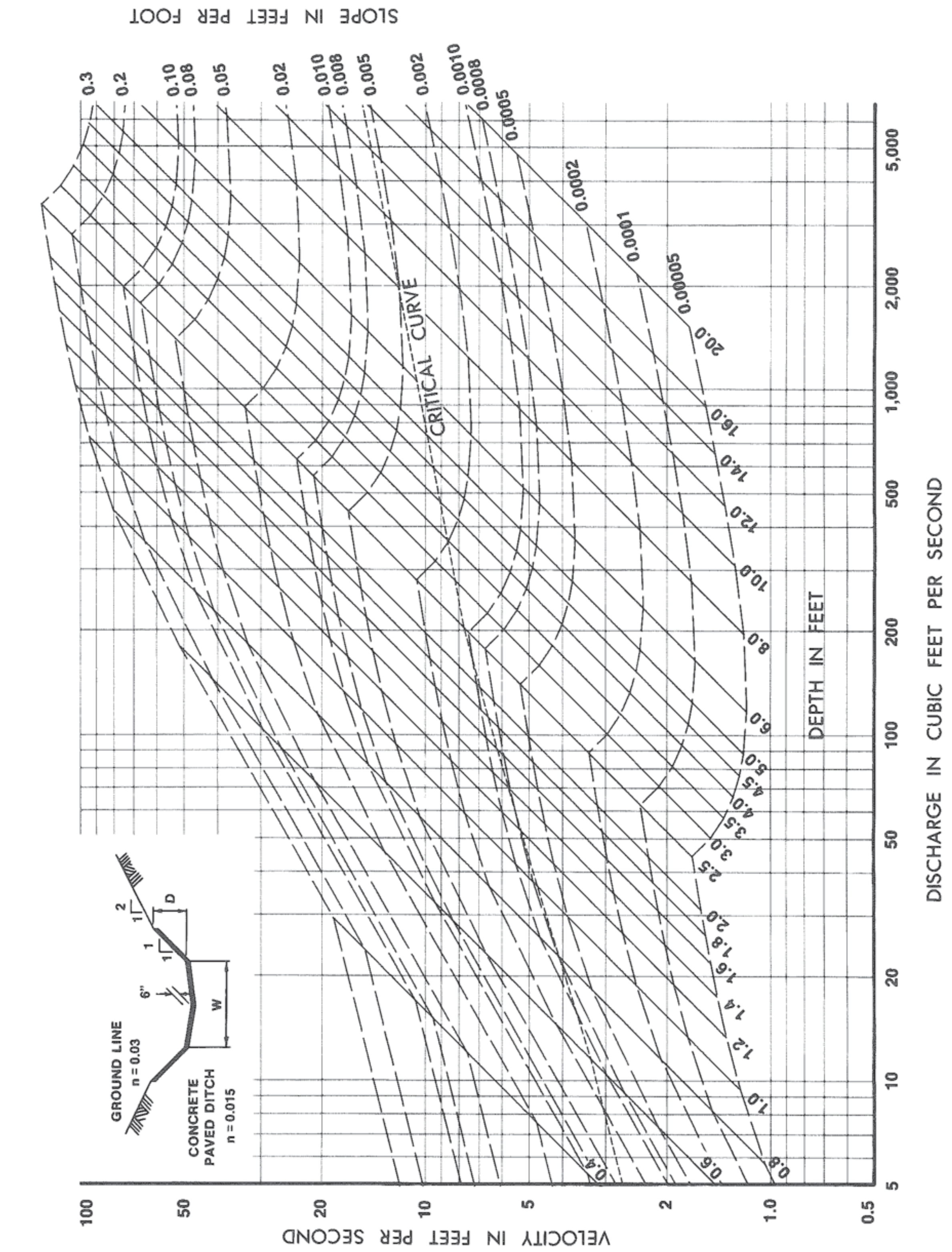
FIGURE 7A-33



PAVED CHANNEL CHART
W = 10 FT. D = 2 FT.

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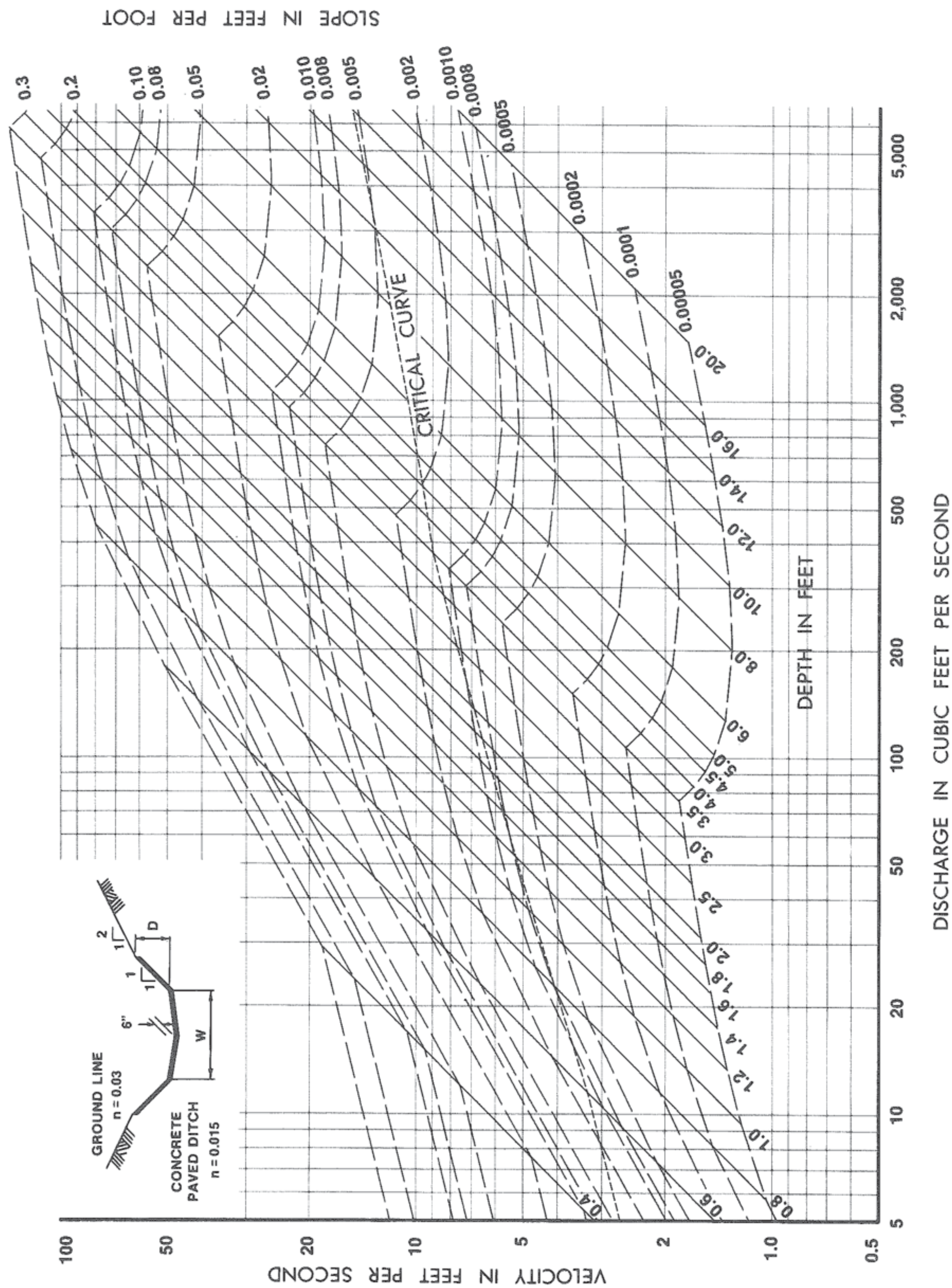
FIGURE 7A-34



PAVED CHANNEL CHART
W = 10 FT. D = 3 FT.

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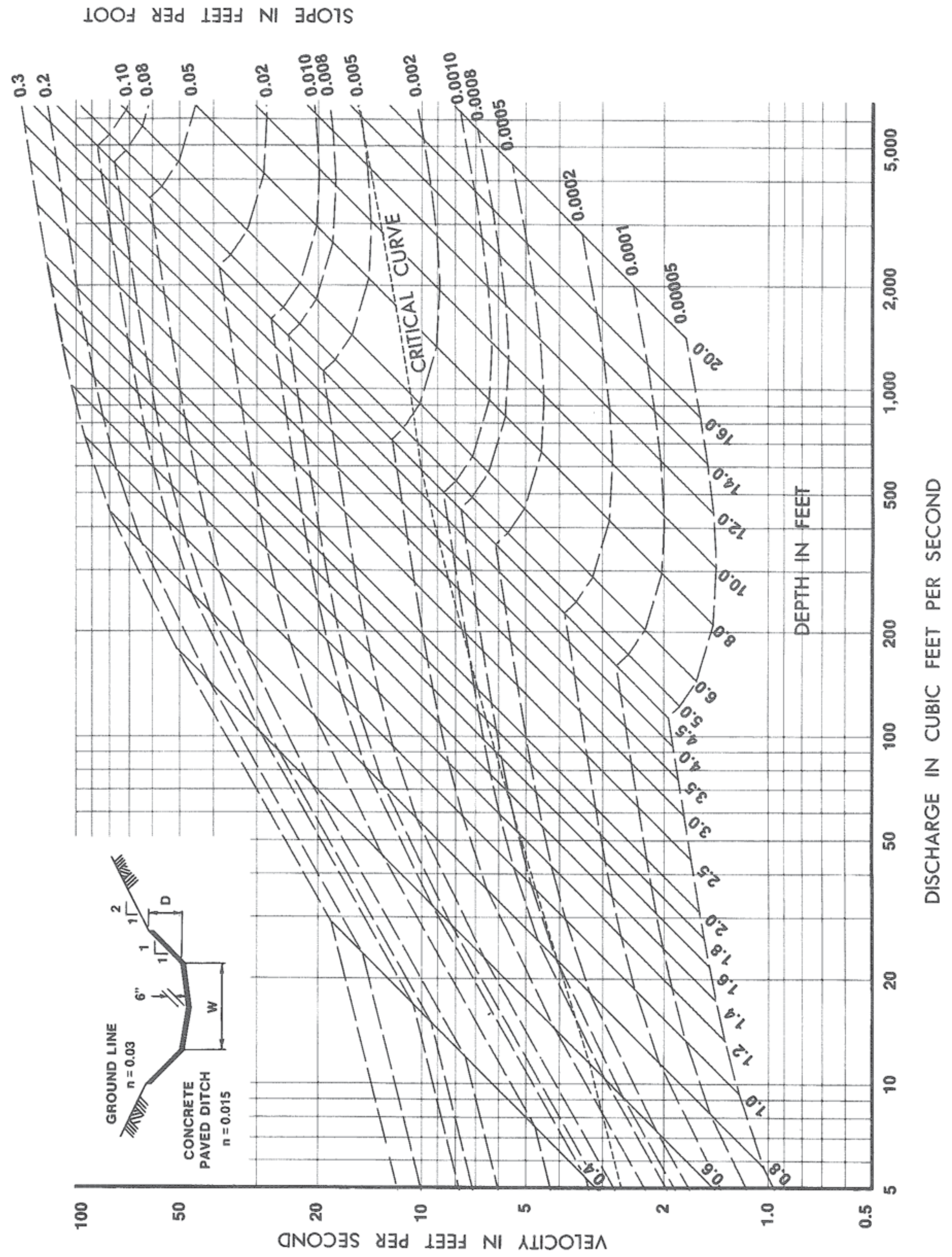

PAVED CHANNEL CHART

W = 10 FT. D = 4 FT.

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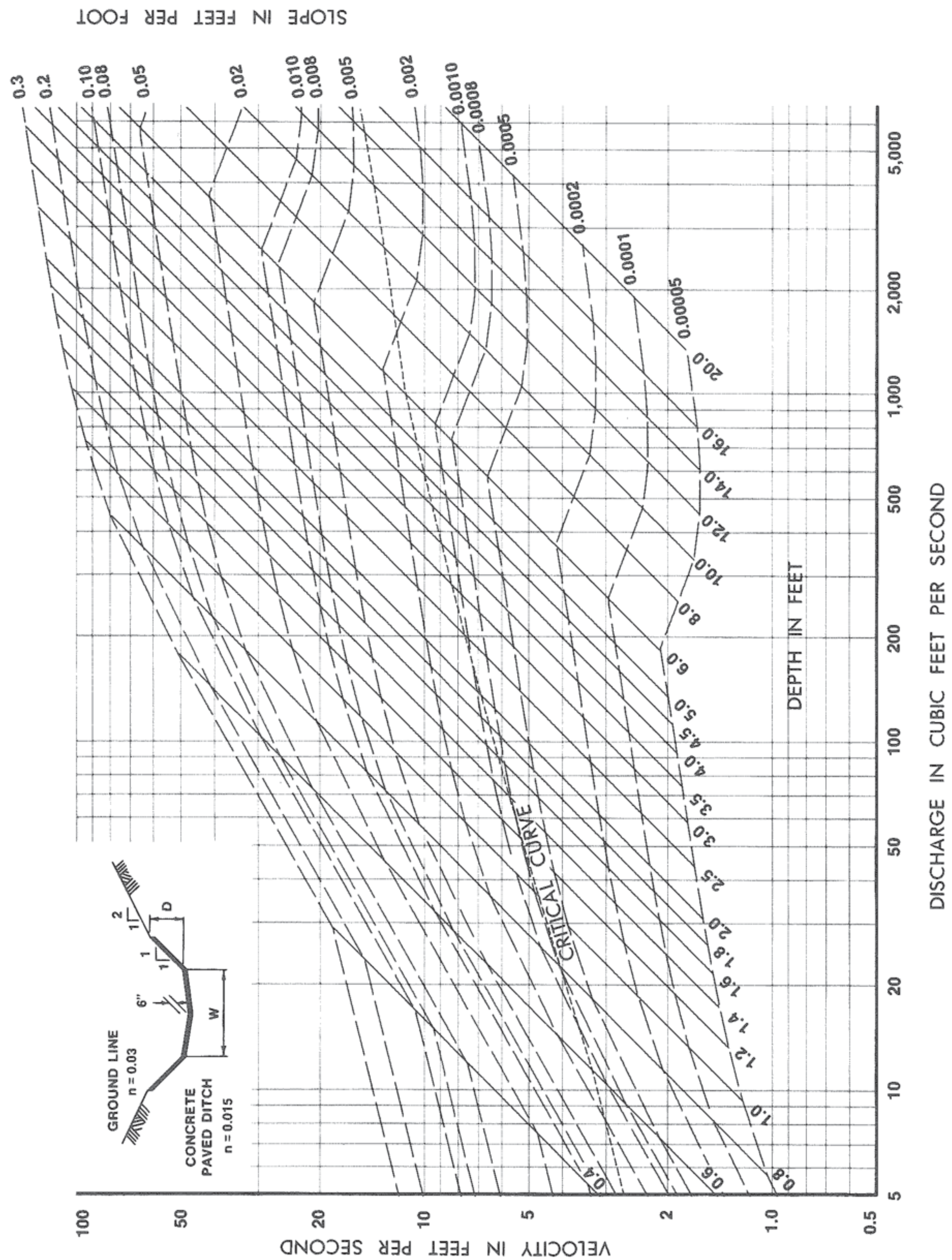
FIGURE 7A-36



PAVED CHANNEL CHART
W = 10 FT. D = 6 FT.

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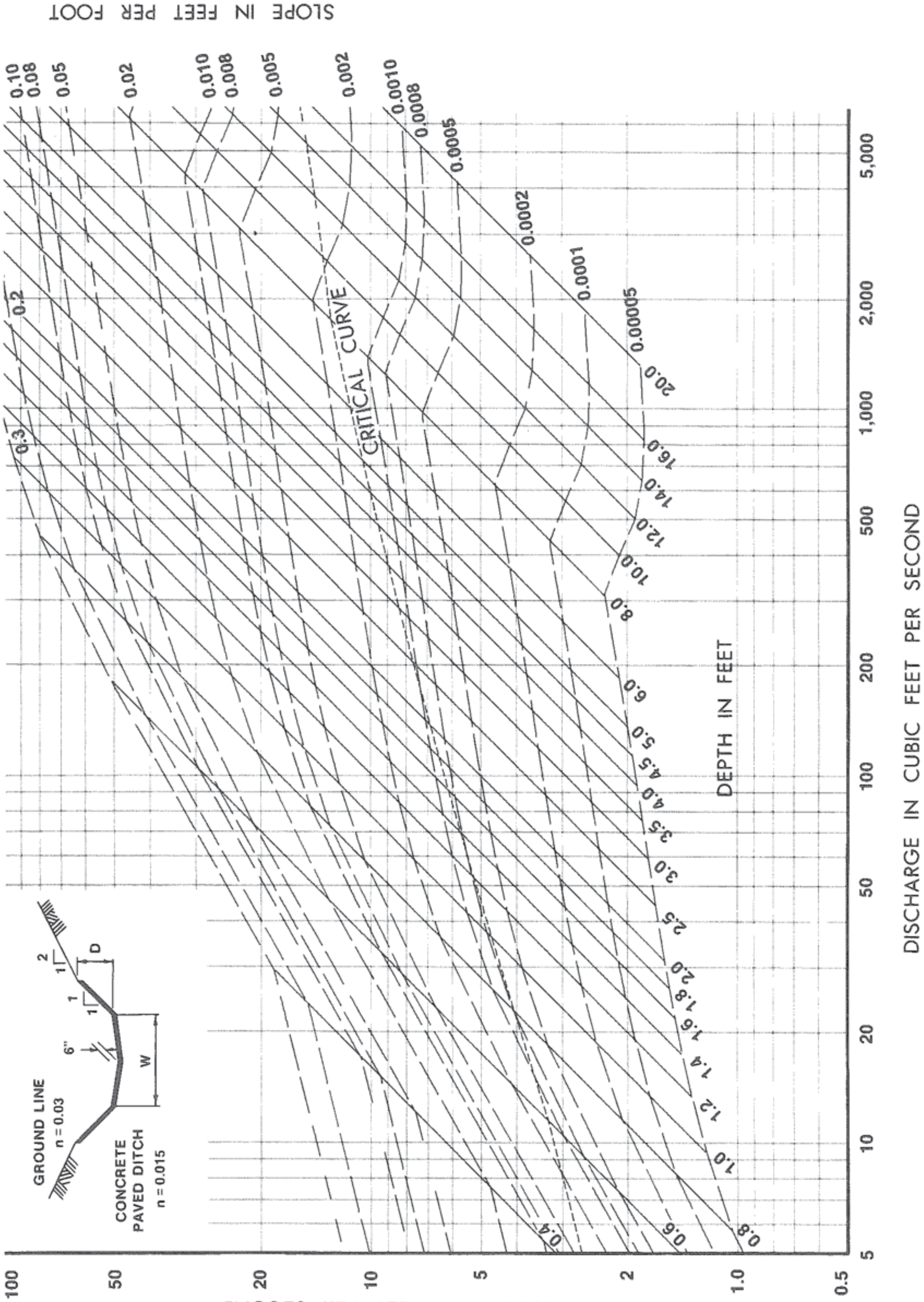
FIGURE 7A-37



PAVED CHANNEL CHART
W = 10 FT. D = 8 FT.

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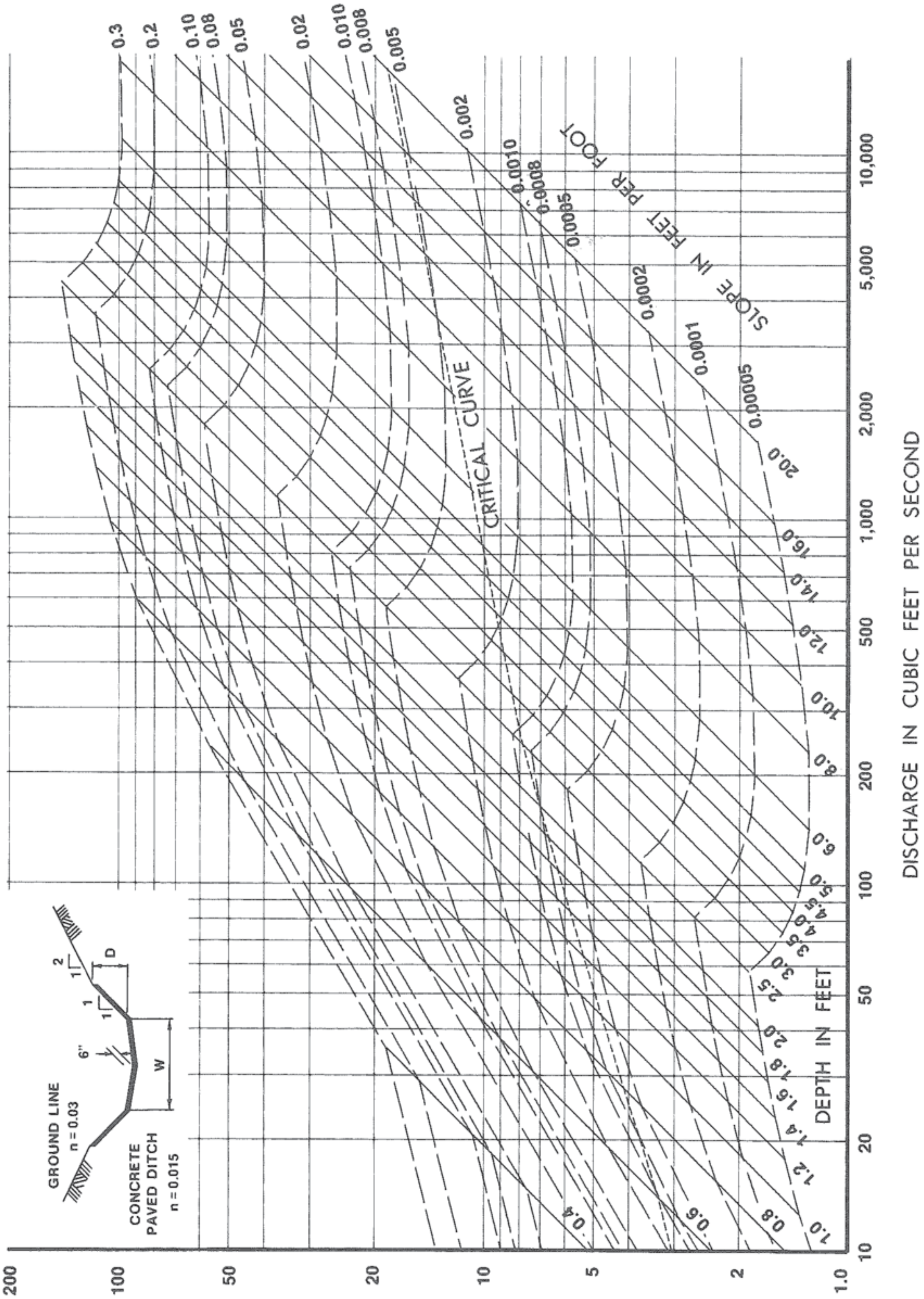

PAVED CHANNEL CHART

W = 12 FT. D = 2 FT.

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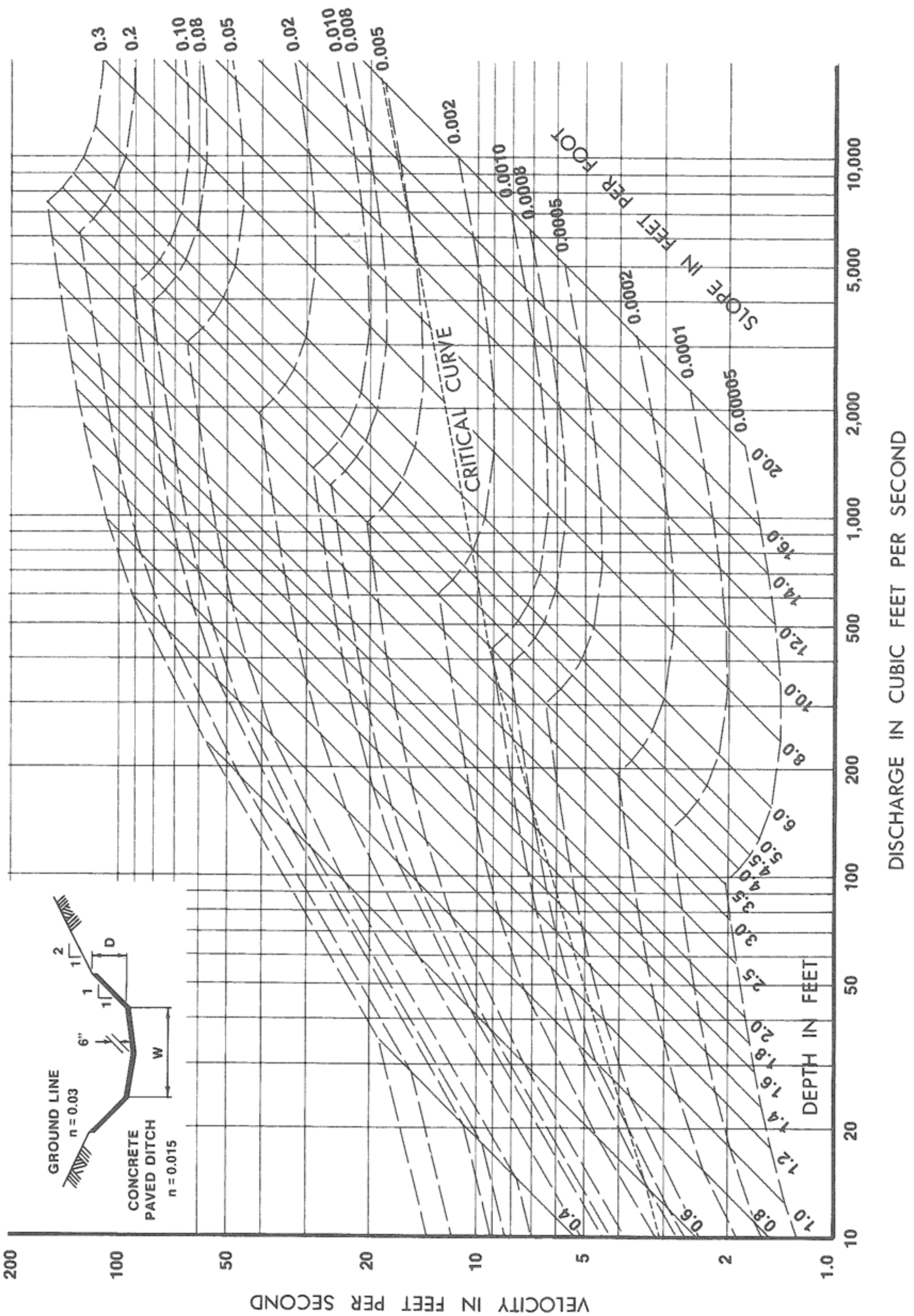
FIGURE 7A-39



PAVED CHANNEL CHART
W = 12 FT. D = 3 FT.

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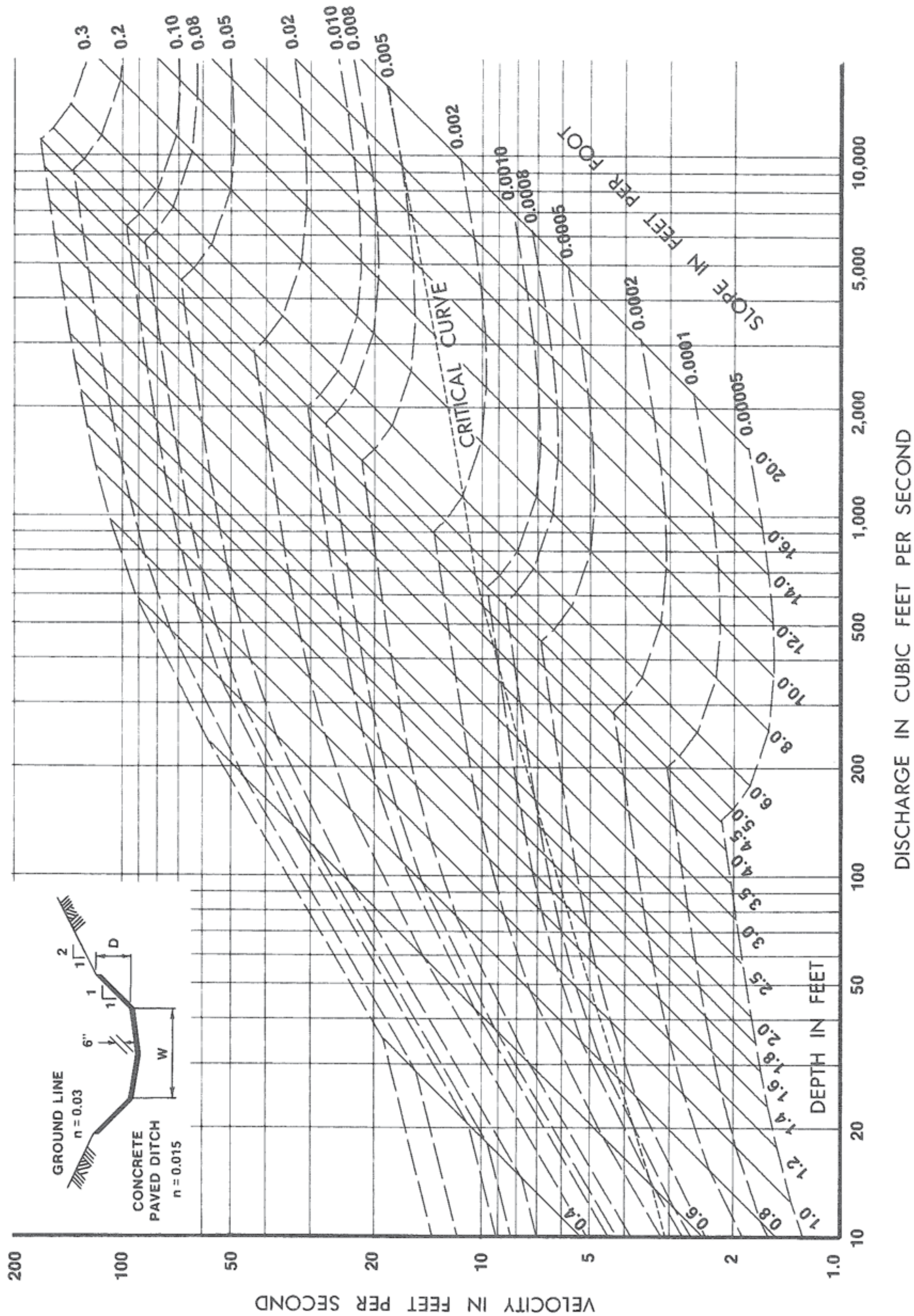
FIGURE 7A-40



PAVED CHANNEL CHART
W = 12 FT. D = 4 FT.

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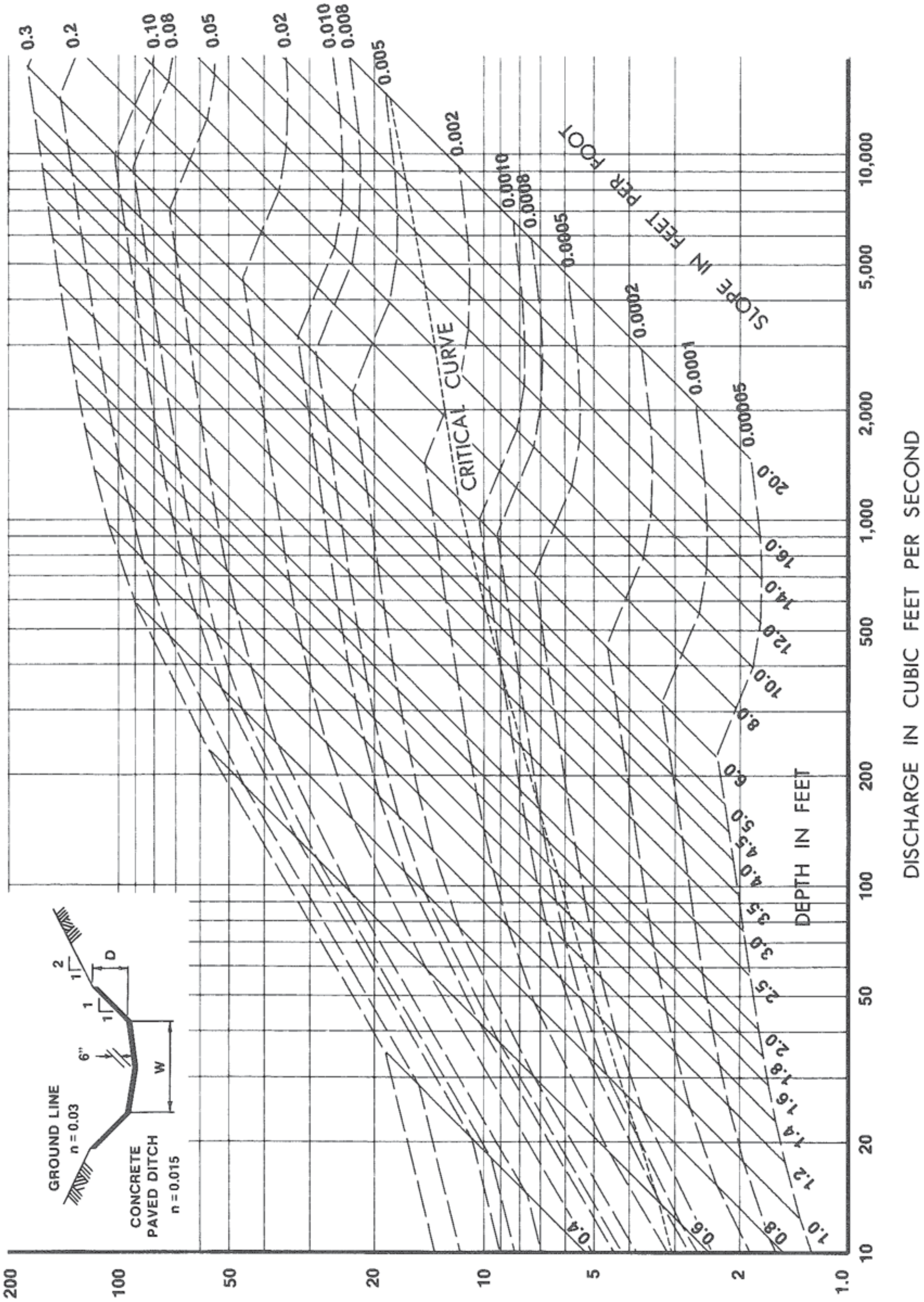
FIGURE 7A-41



PAVED CHANNEL CHART
W = 12 FT. D = 6 FT.

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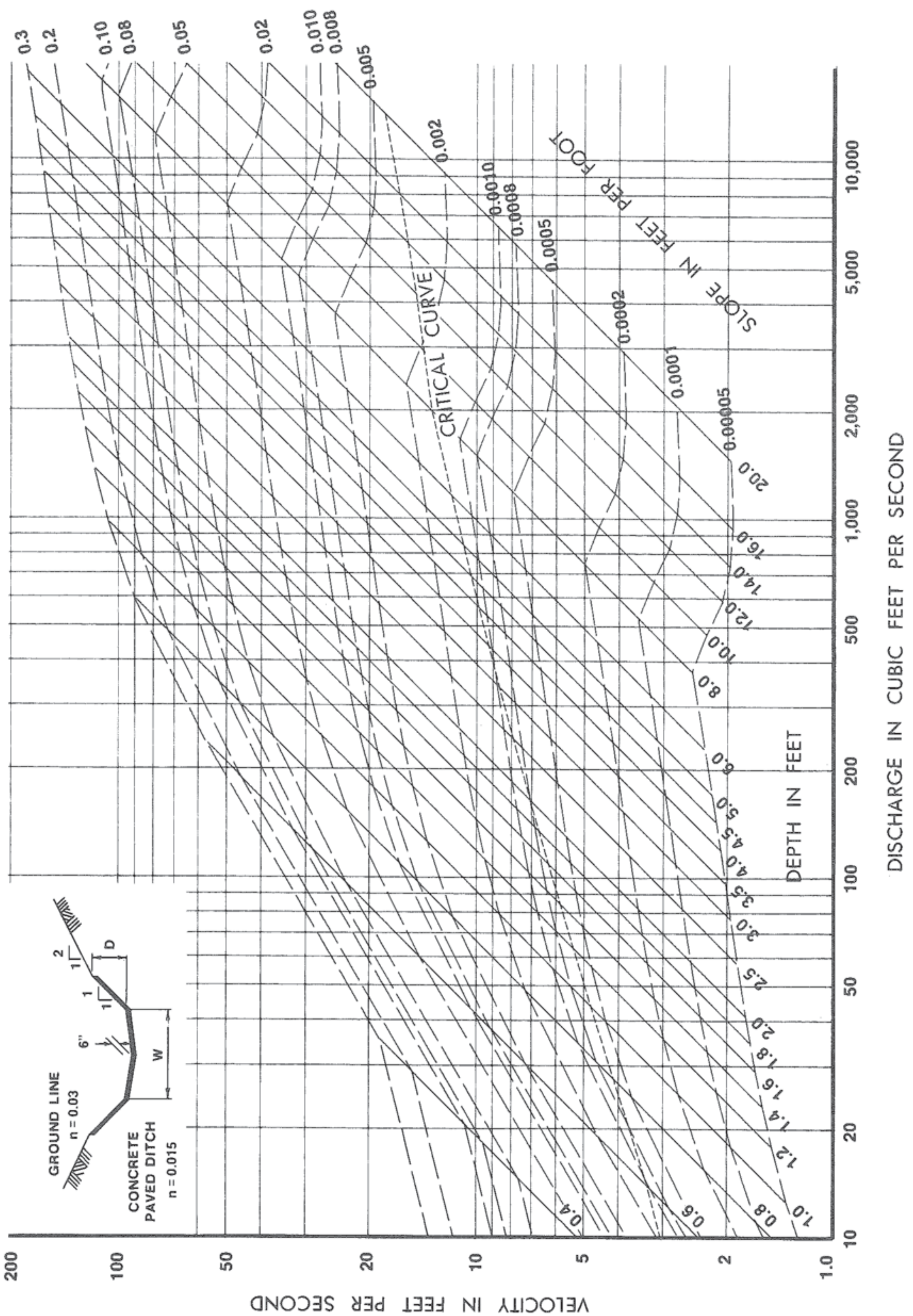
FIGURE 7A-42



PAVED CHANNEL CHART
W = 12 FT. D = 8 FT.

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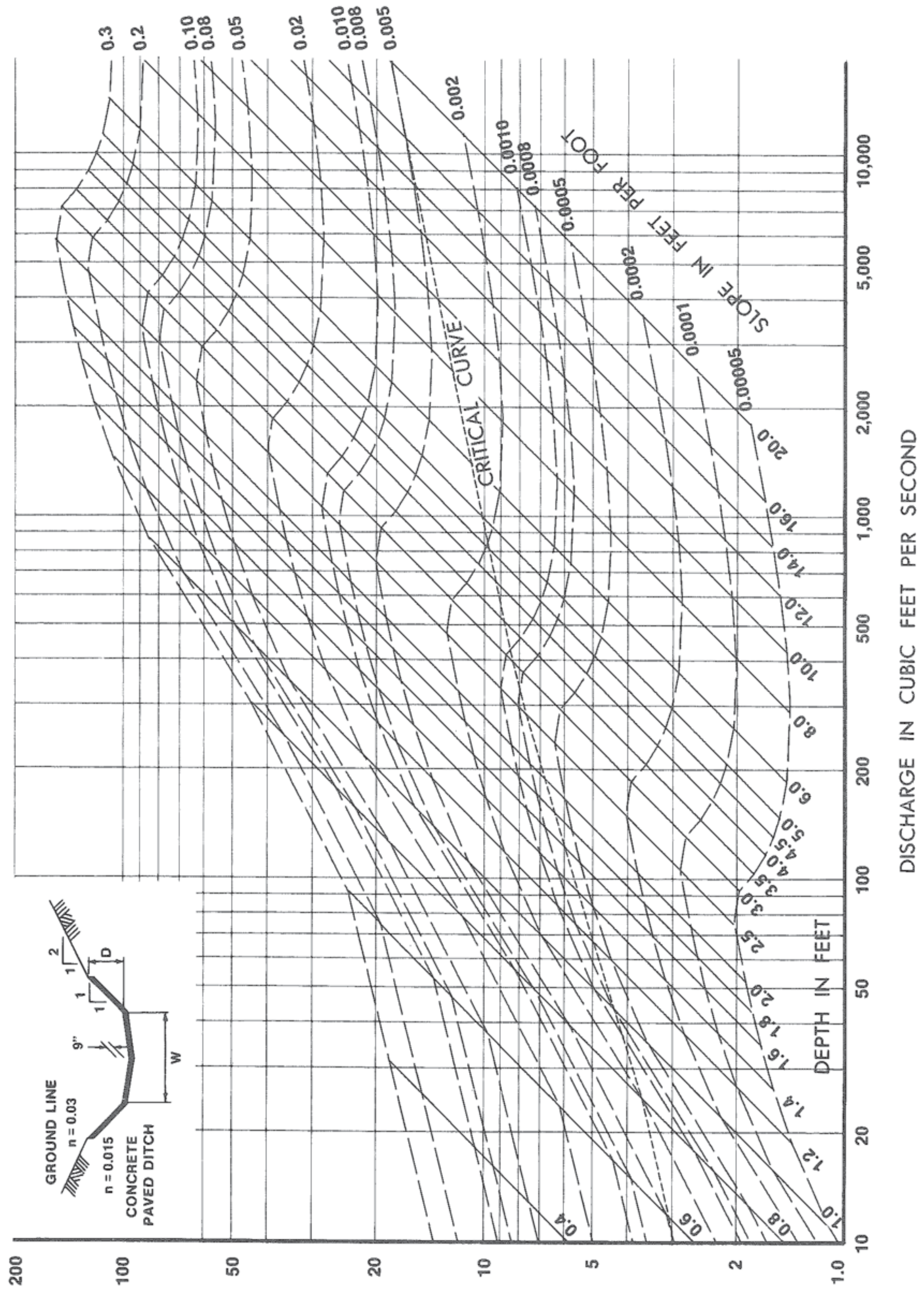
FIGURE 7A-43



PAVED CHANNEL CHART
W = 16 FT. D = 2 FT.

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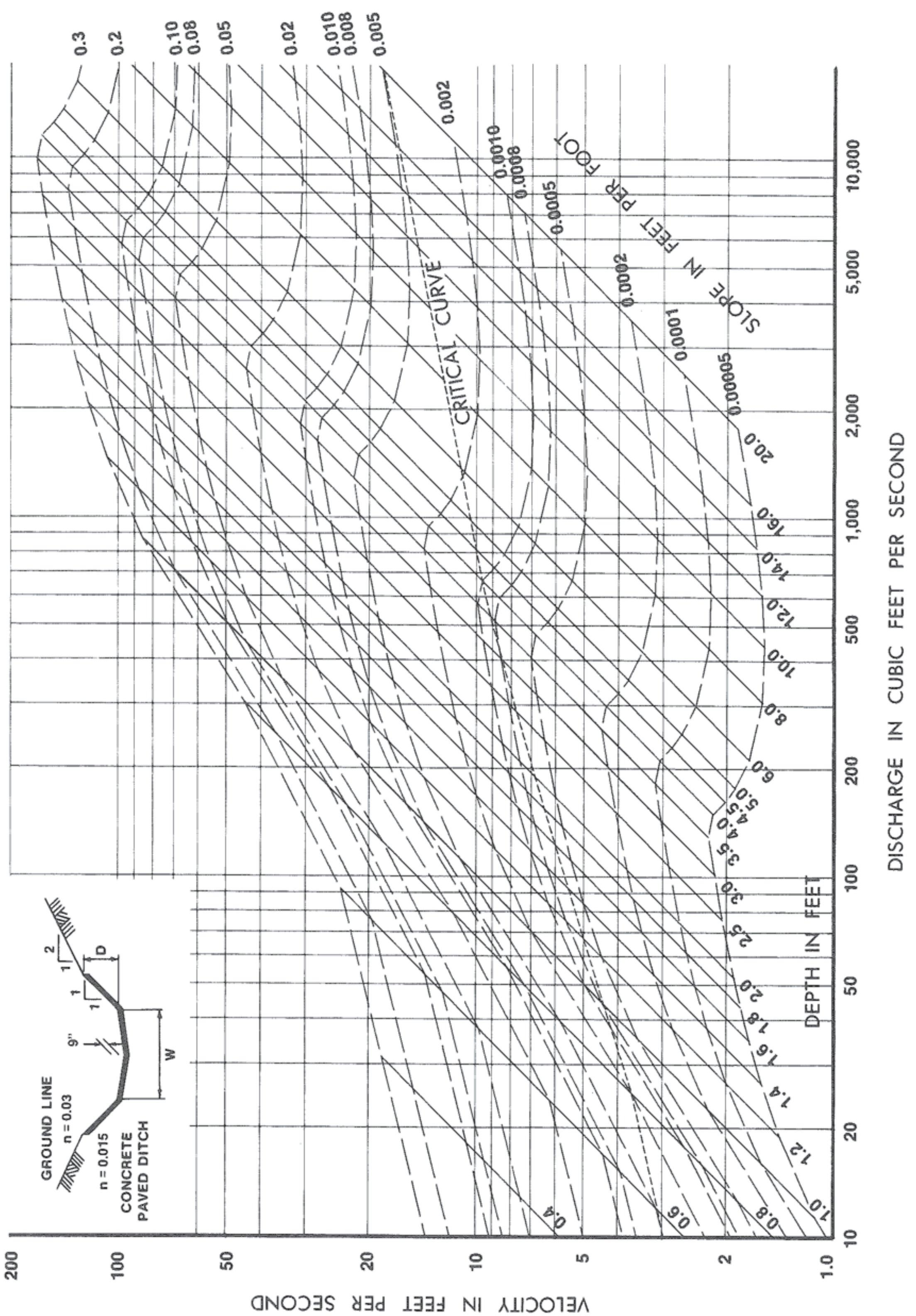
FIGURE 7A-44



PAVED CHANNEL CHART
W = 16 FT. D = 3 FT.

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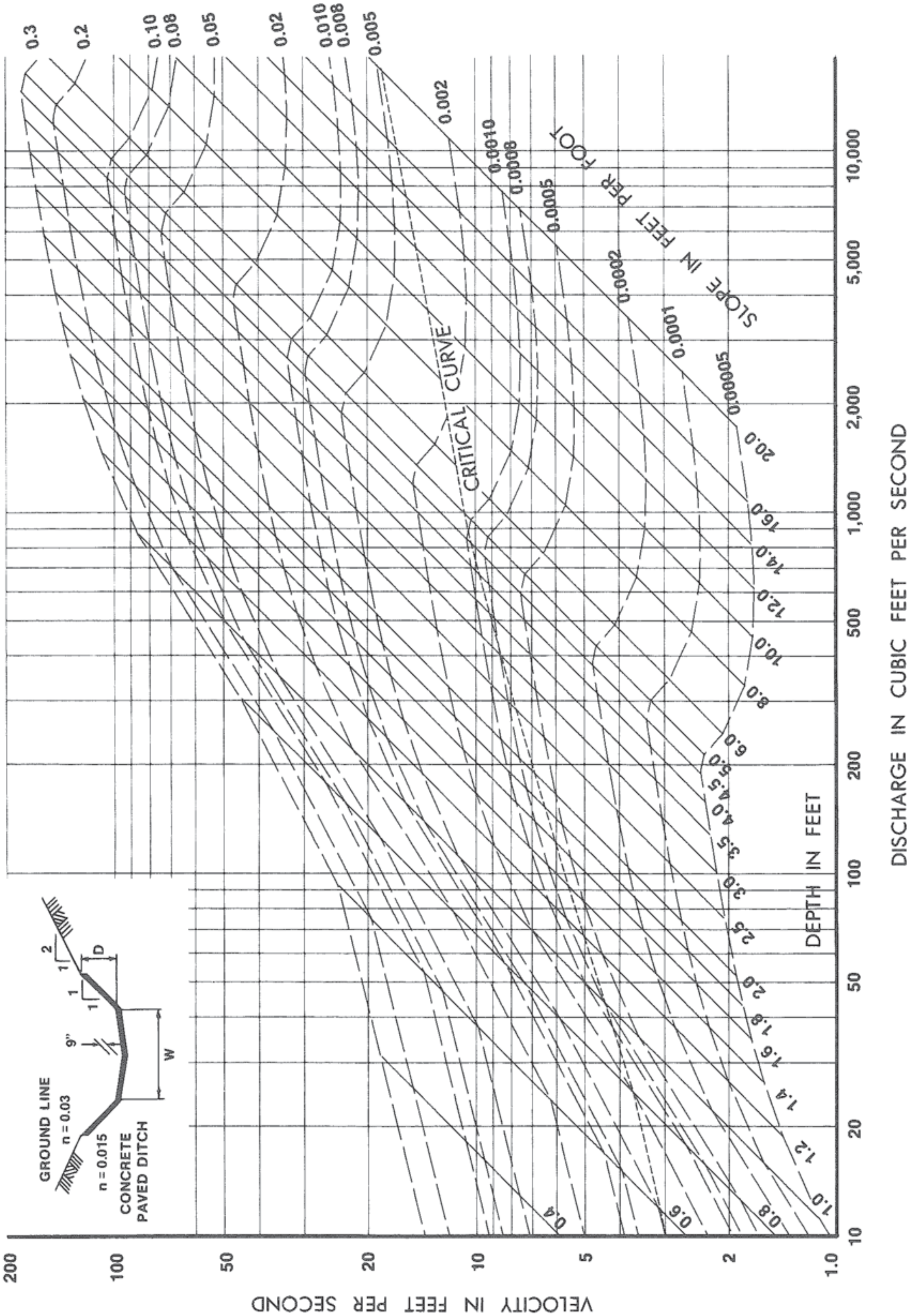

PAVED CHANNEL CHART
W = 16 FT. D = 4 FT.

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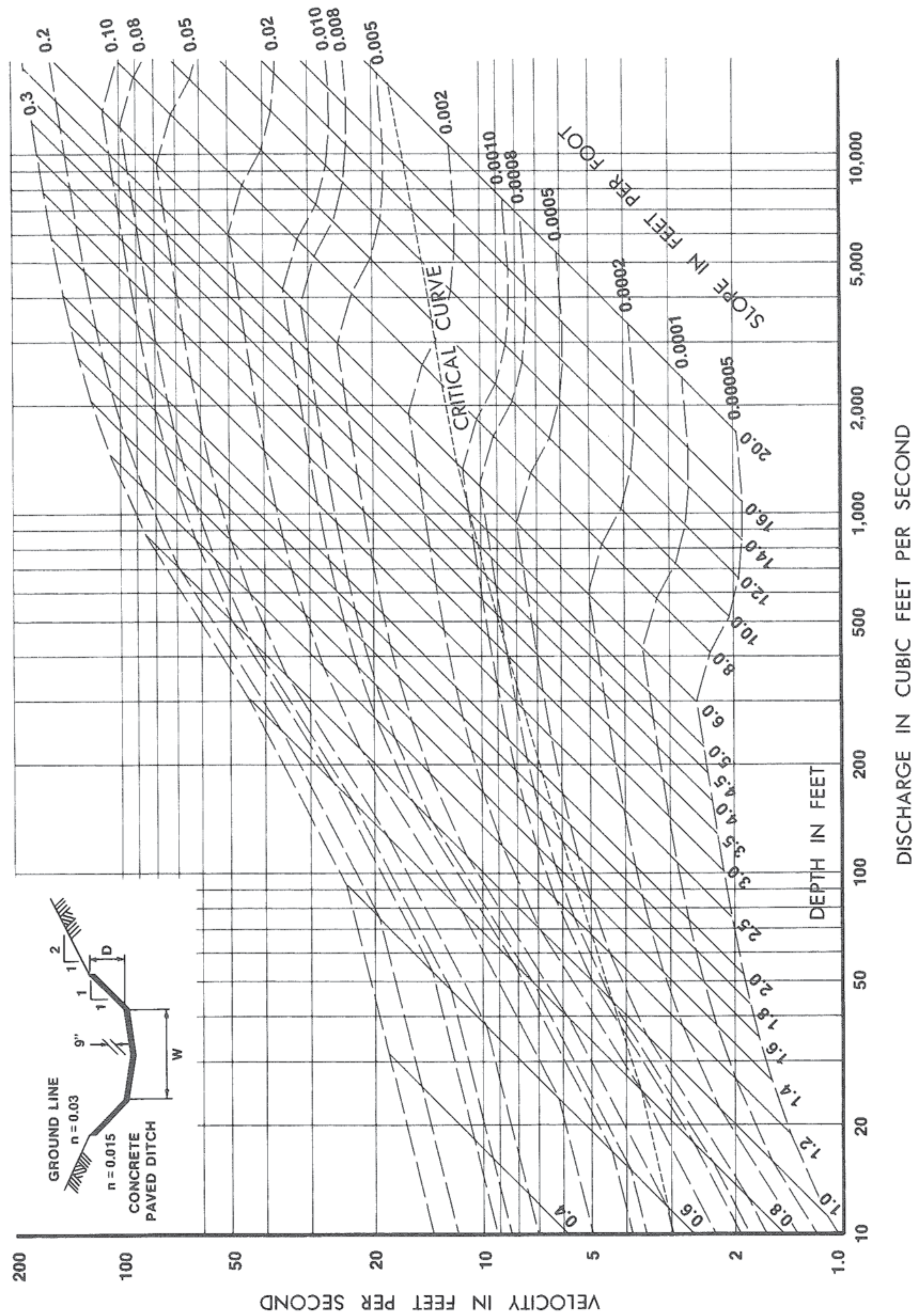

PAVED CHANNEL CHART

W = 16 FT. D = 6 FT.

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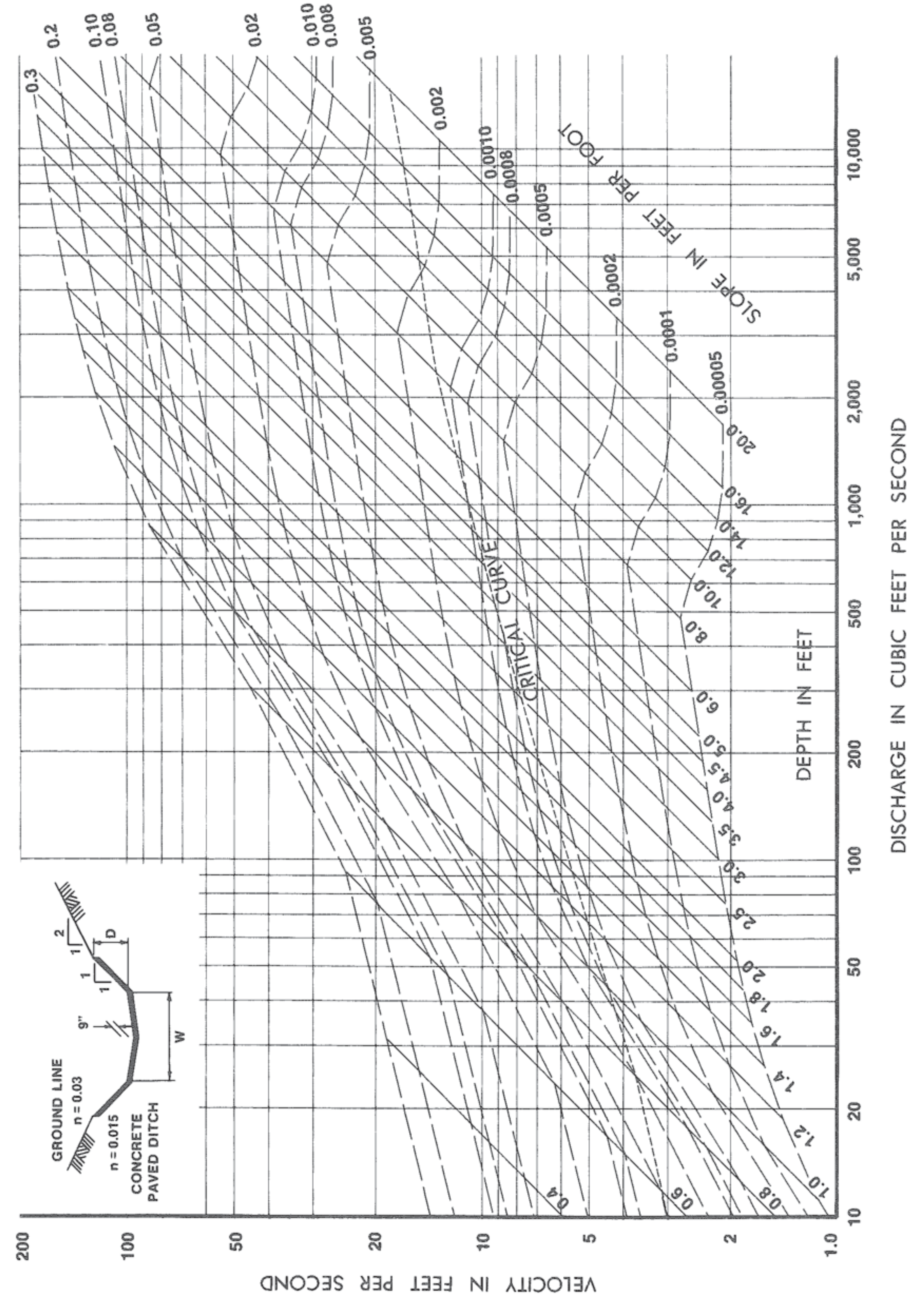
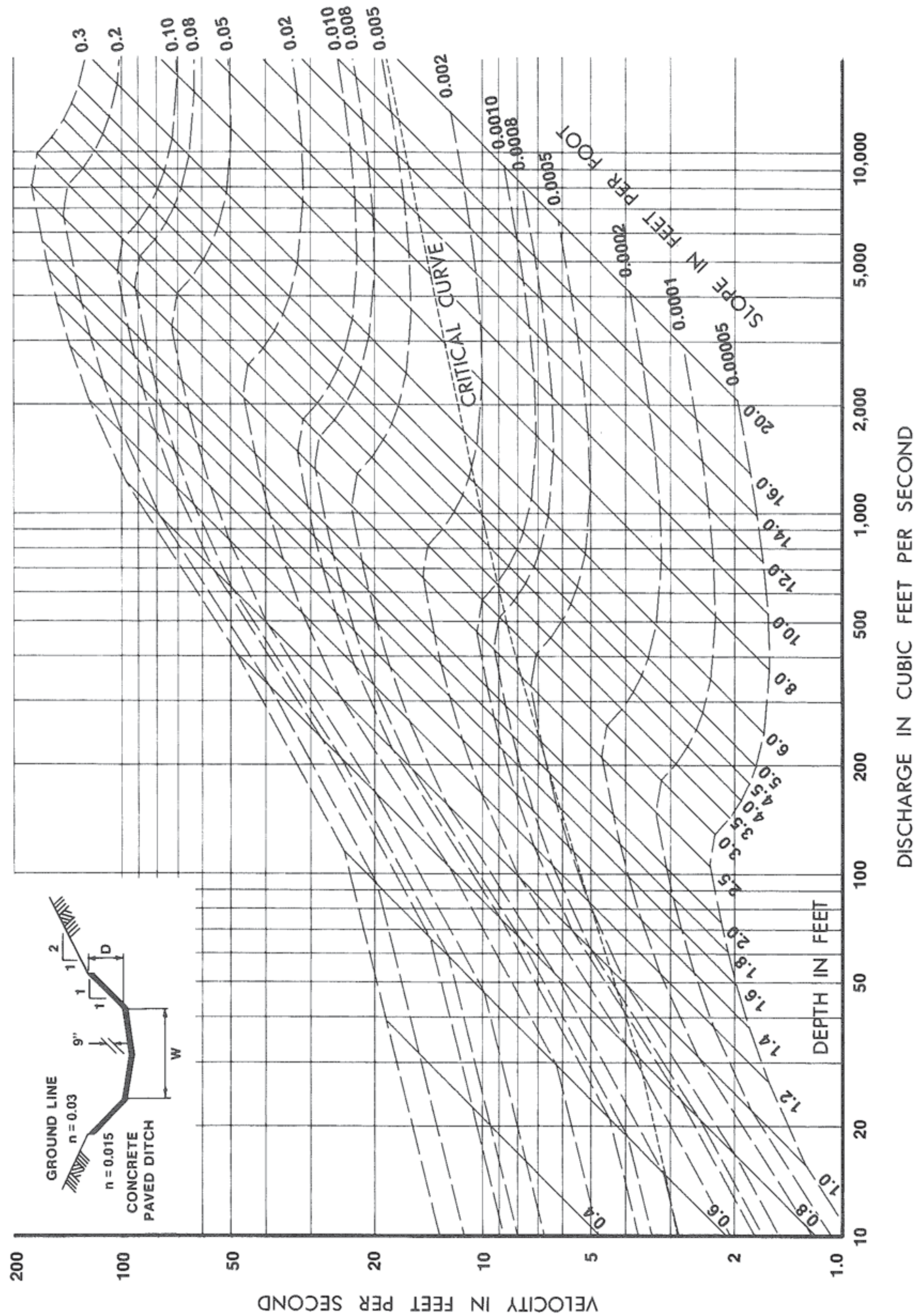
FIGURE 7A-47



PAVED CHANNEL CHART
W = 16 FT. D = 8 FT.

FIGURE 7A-48



PAVED CHANNEL CHART
W = 20 FT. D = 2 FT.

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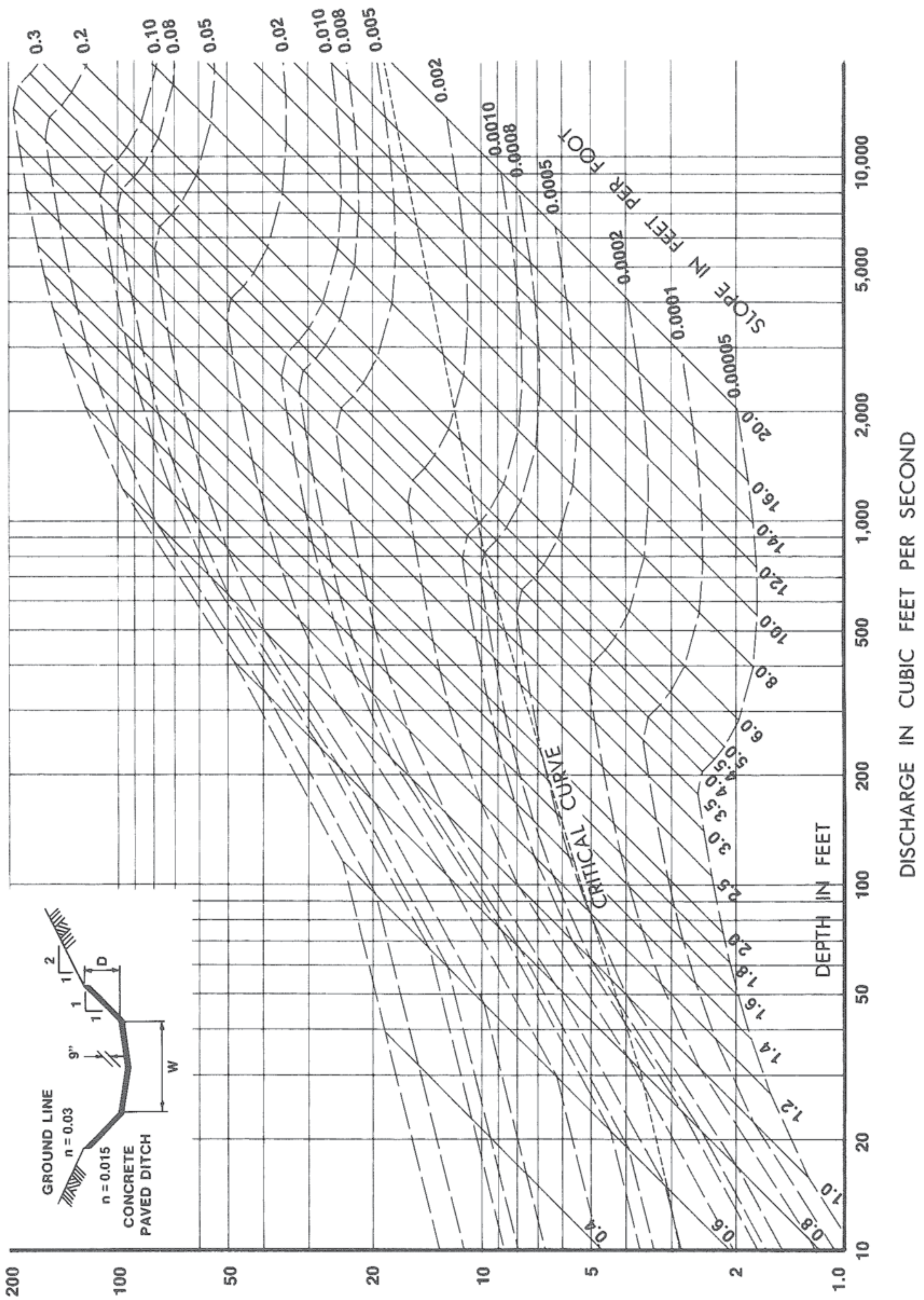
FIGURE 7A-49



PAVED CHANNEL CHART

W = 20 FT. D = 3 FT.

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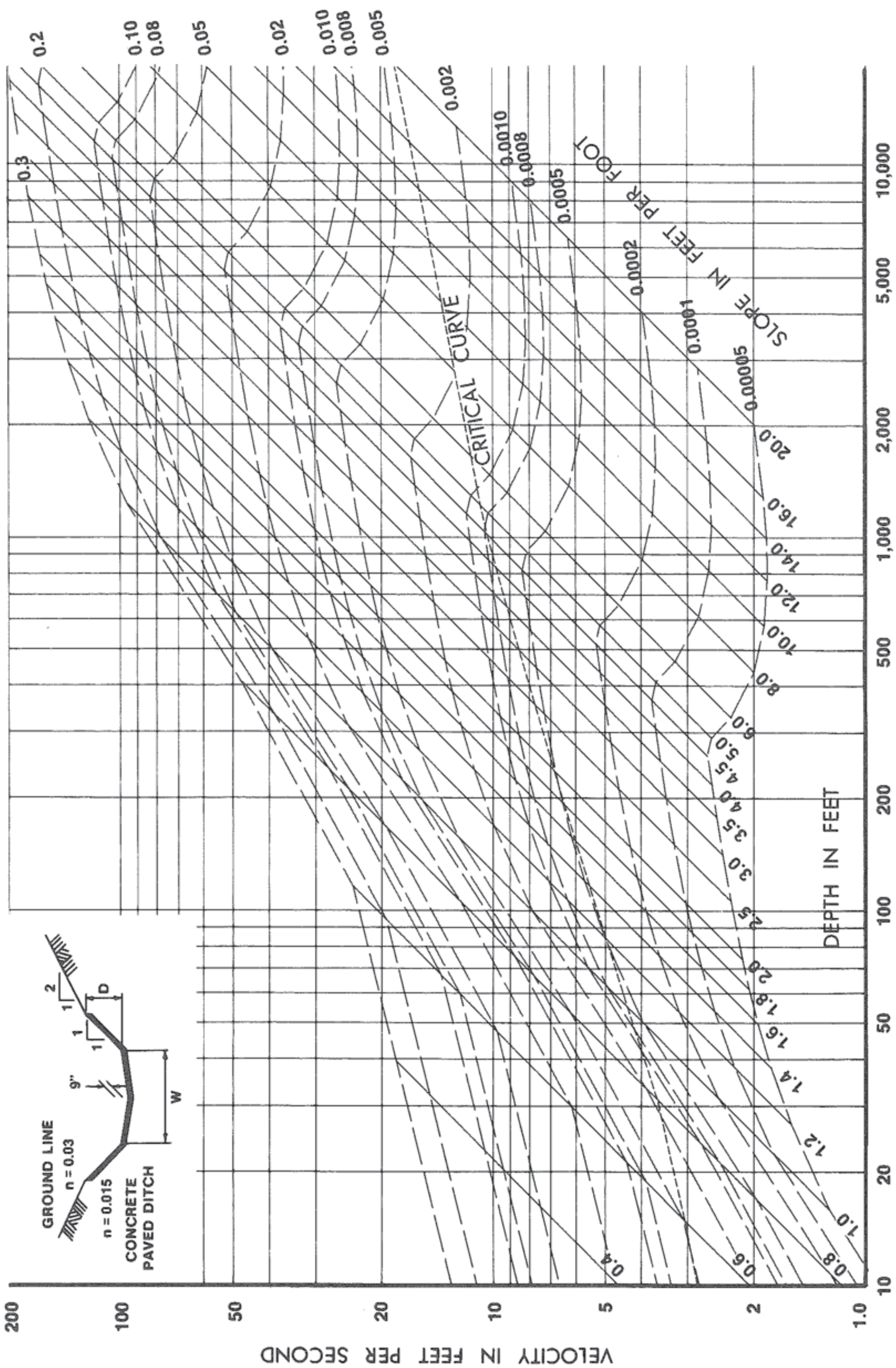
FIGURE 7A-50



PAVED CHANNEL CHART

W = 20 FT. D = 4 FT.

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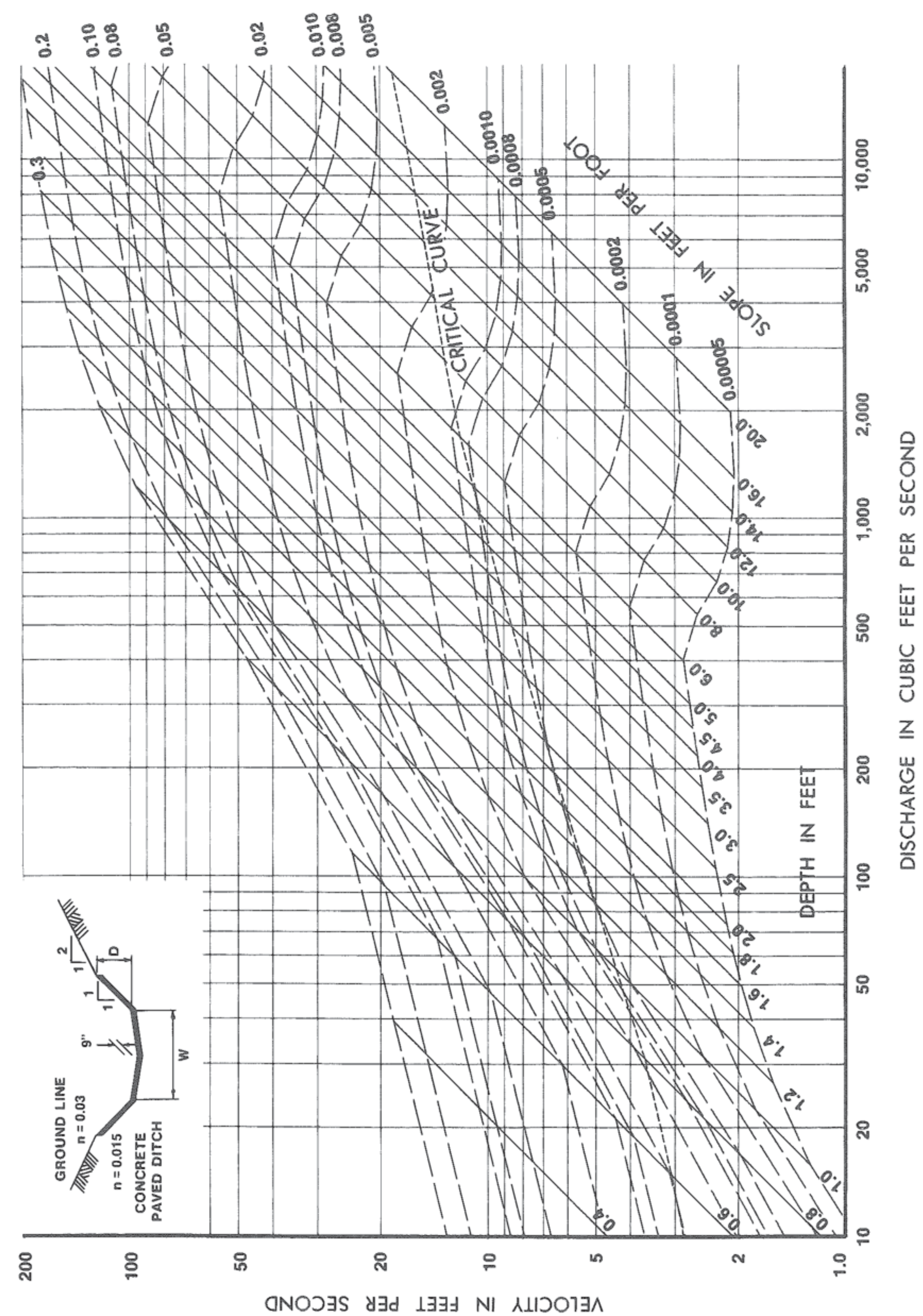
DEPARTMENT OF PUBLIC WORKS

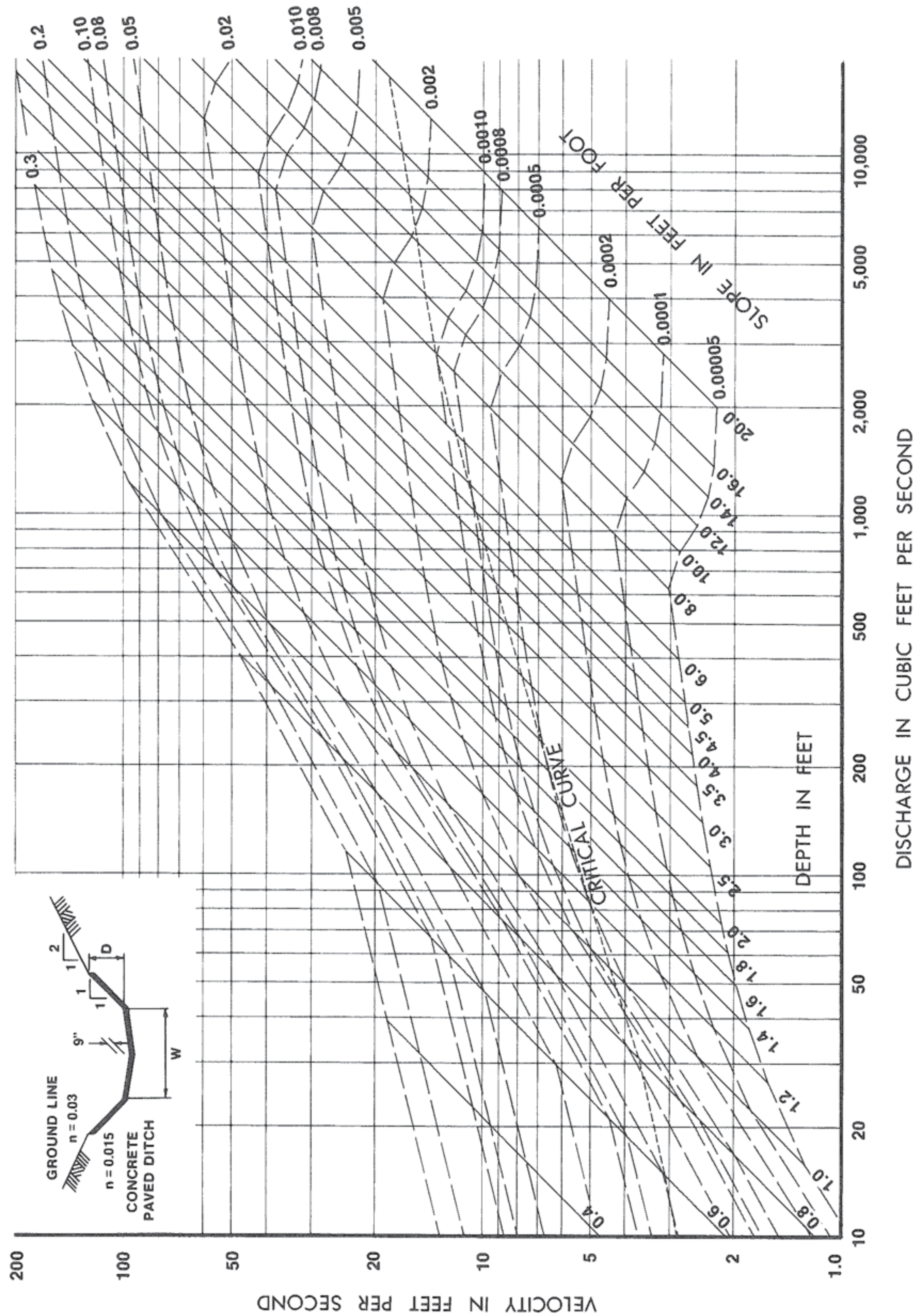
FIGURE 7A-51



PAVED CHANNEL CHART
W = 20 FT. D = 6 FT.

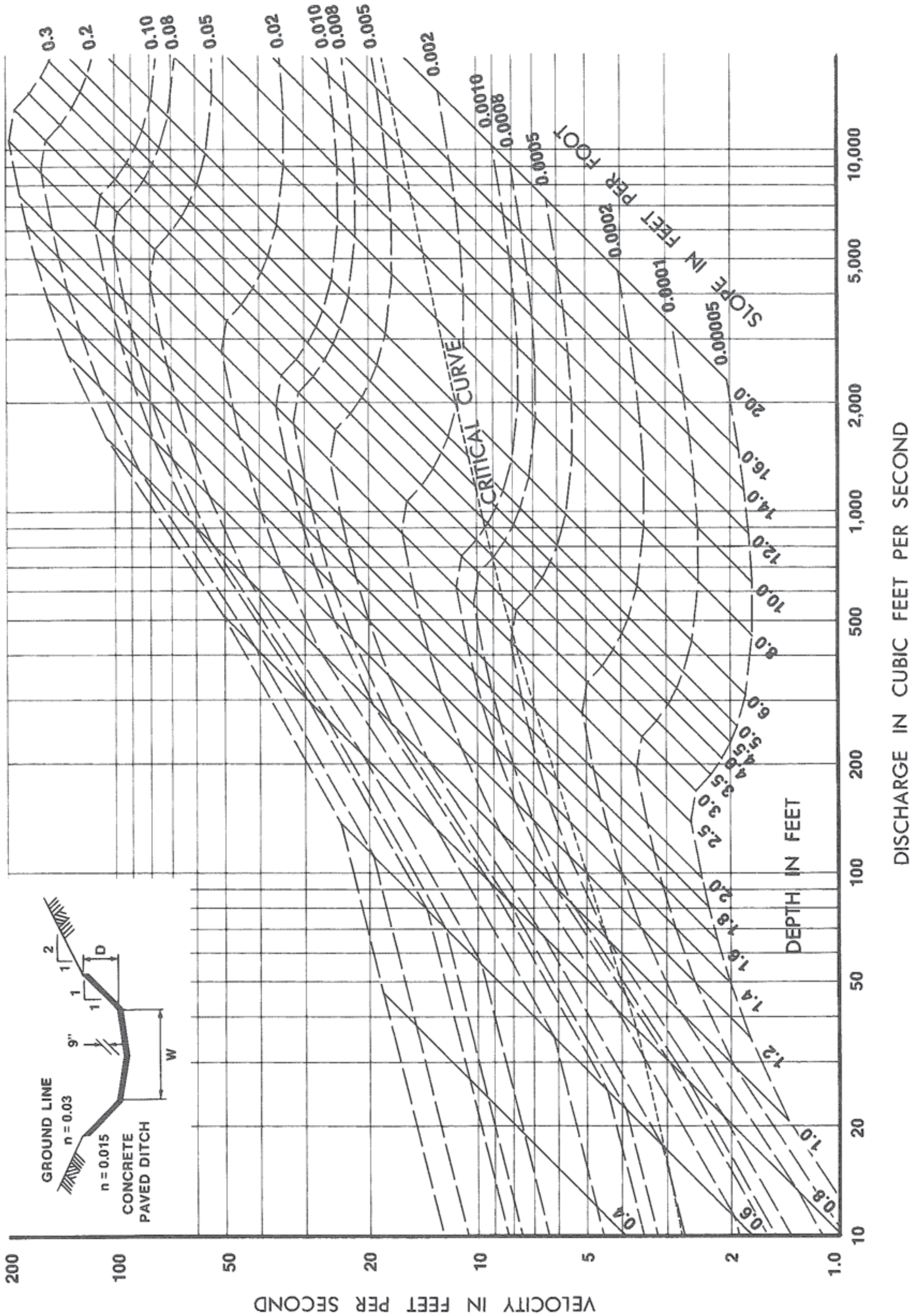
CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS



PAVED CHANNEL CHART

W = 20 FT. D = 8 FT.

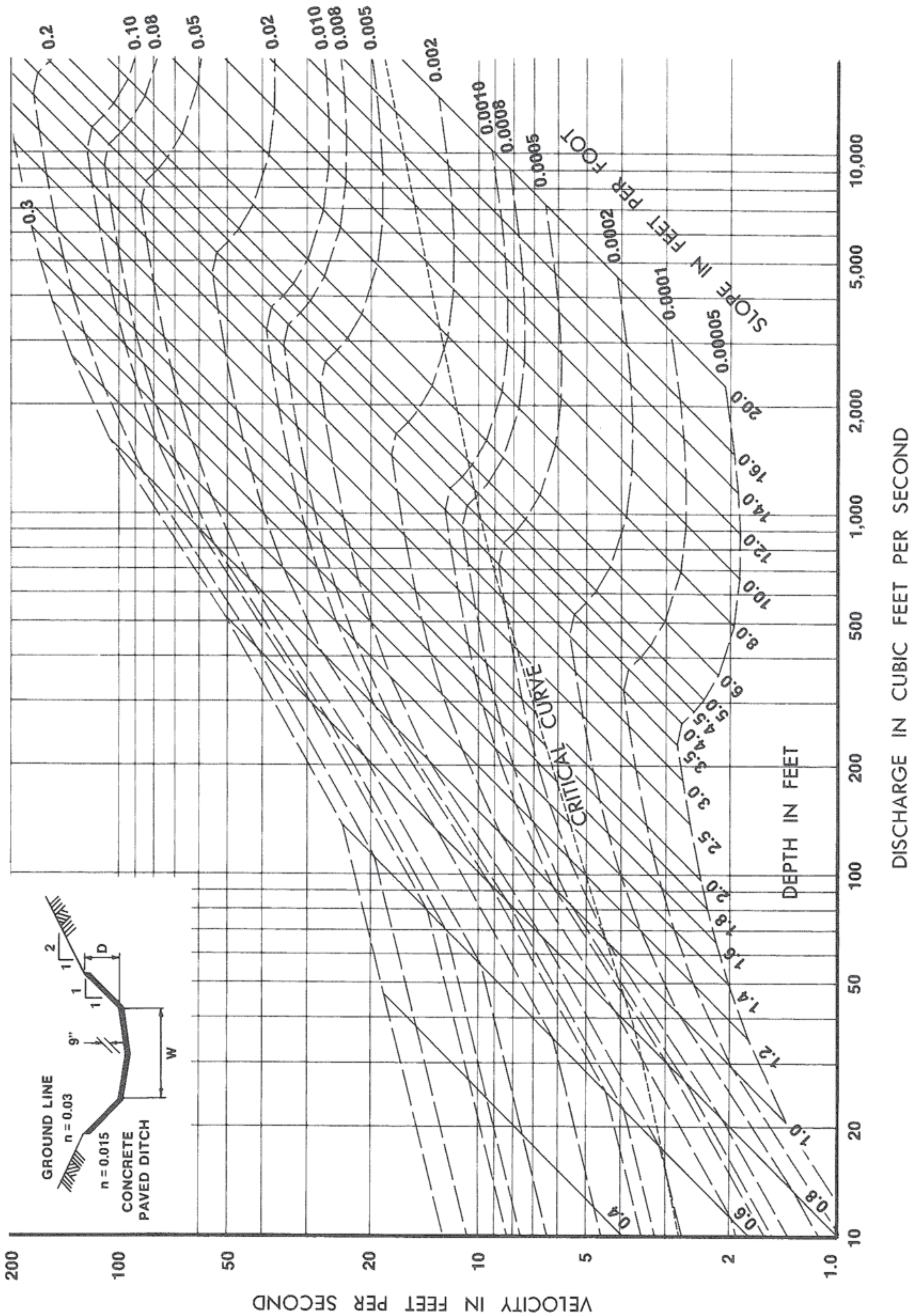


PAVED CHANNEL CHART
W = 24 FT. D = 2 FT.

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

FIGURE 7A-54

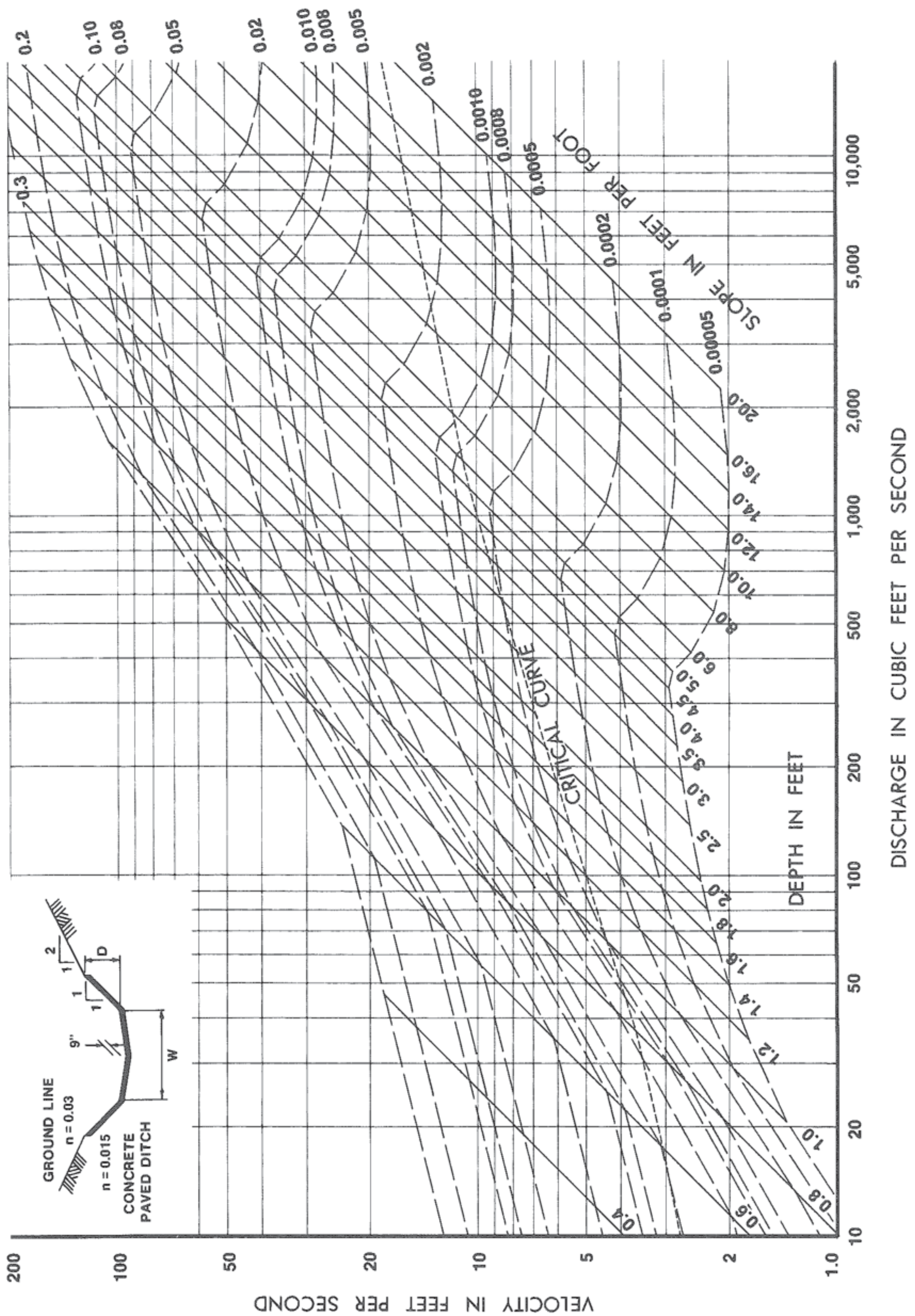


PAVED CHANNEL CHART
W = 24 FT. D = 3 FT.

CITY OF SHREVEPORT, LOUISIANA

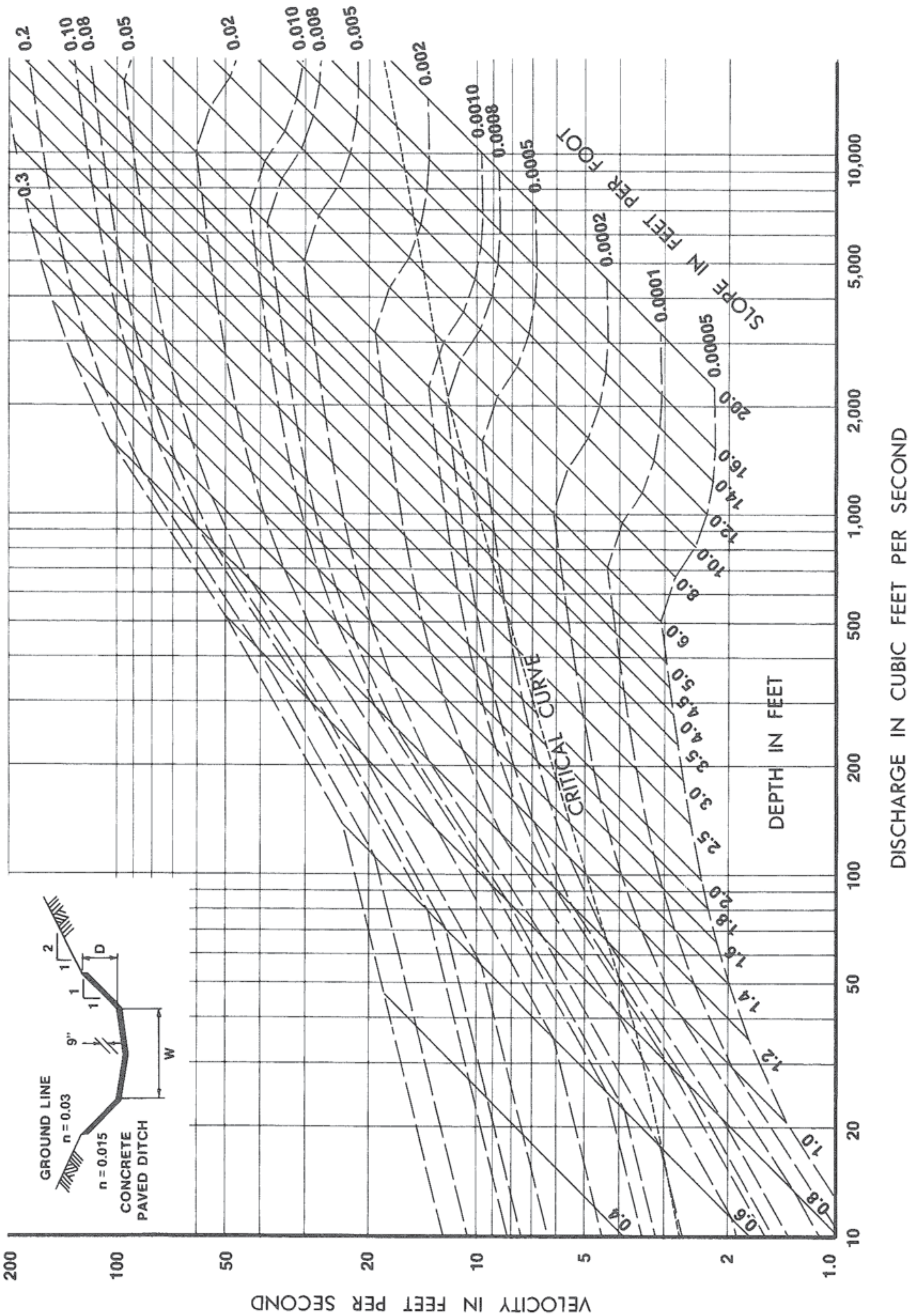
DEPARTMENT OF PUBLIC WORKS

FIGURE 7A-55



PAVED CHANNEL CHART
W = 24 FT. D = 4 FT.

CITY OF SHREVEPORT, LOUISIANA
DEPARTMENT OF PUBLIC WORKS



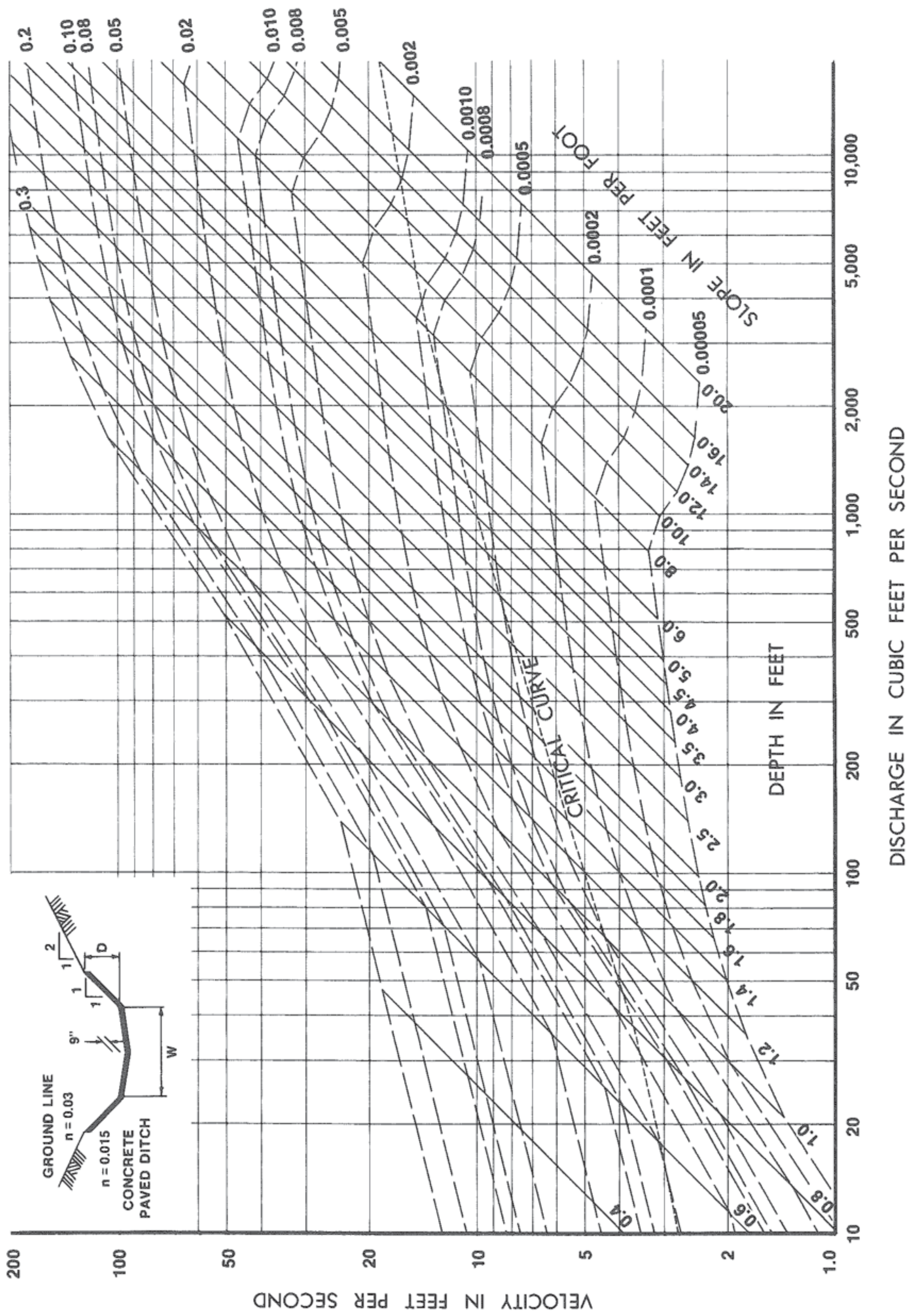
PAVED CHANNEL CHART

W = 24 FT. D = 6 FT.

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

FIGURE 7A-57

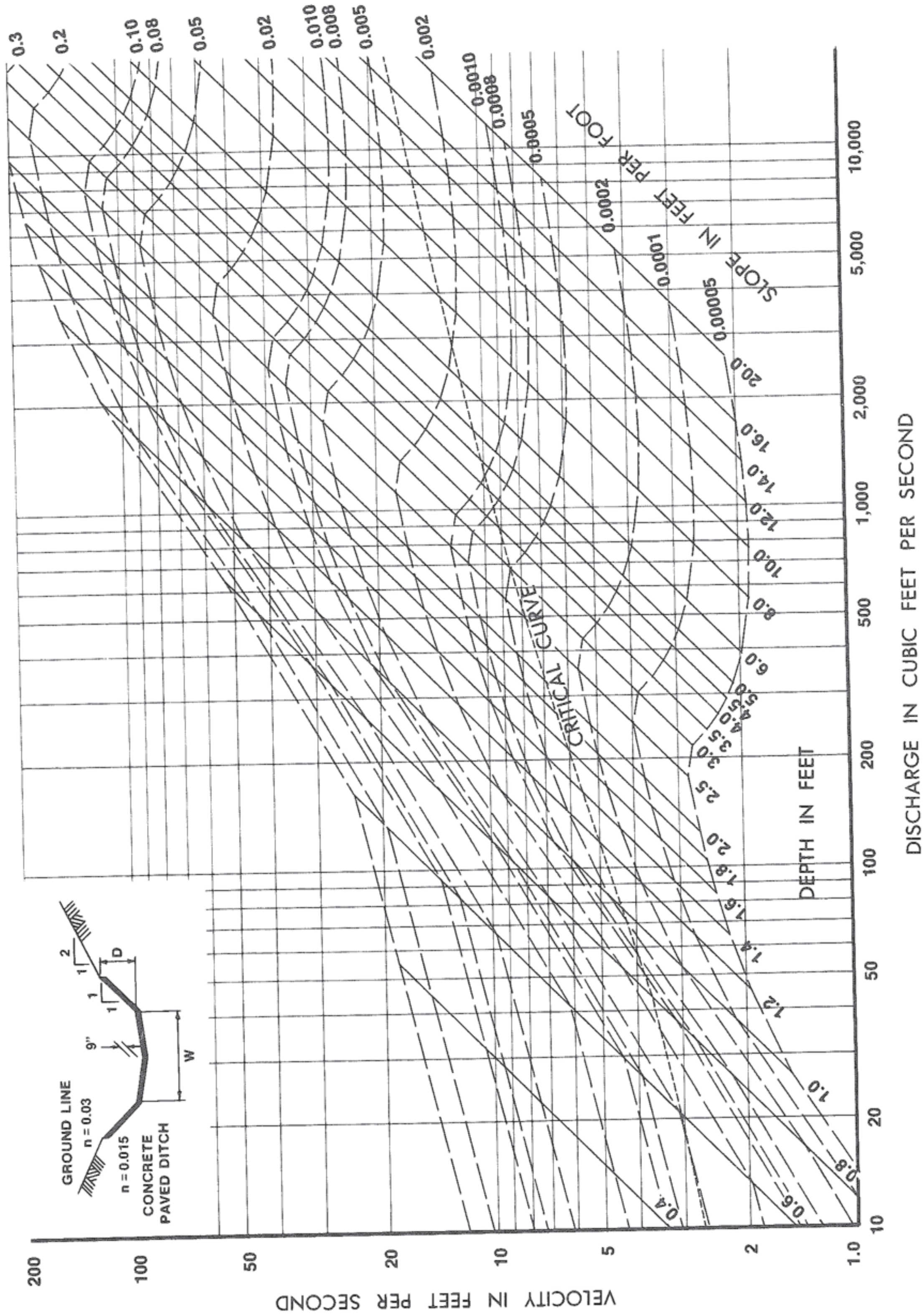


PAVED CHANNEL CHART
W = 24 FT. D = 8 FT.

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

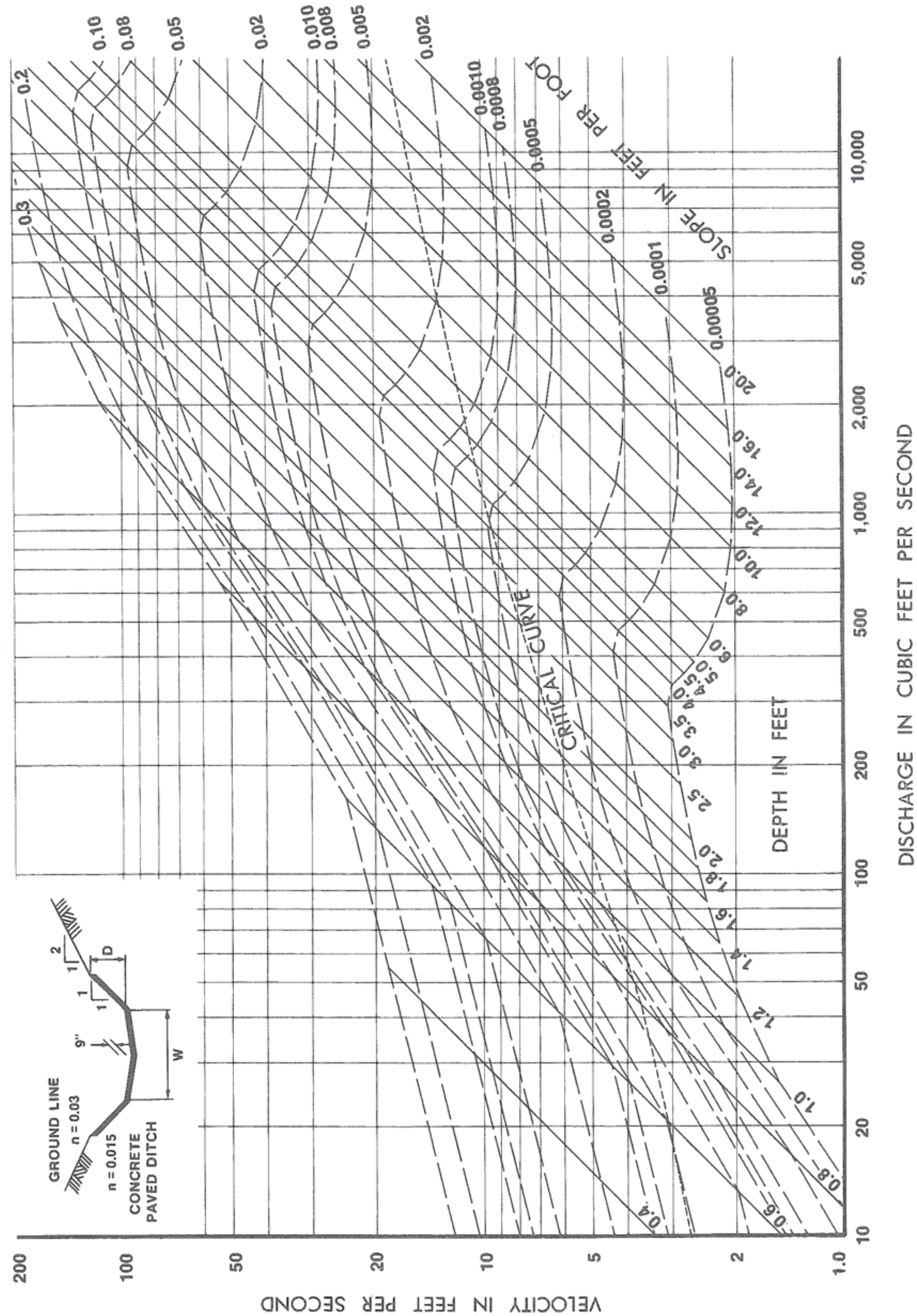
FIGURE 7A-58



PAVED CHANNEL CHART
W = 28 FT. D = 2 FT.

CITY OF SHREVEPORT, LOUISIANA
DEPARTMENT OF PUBLIC WORKS

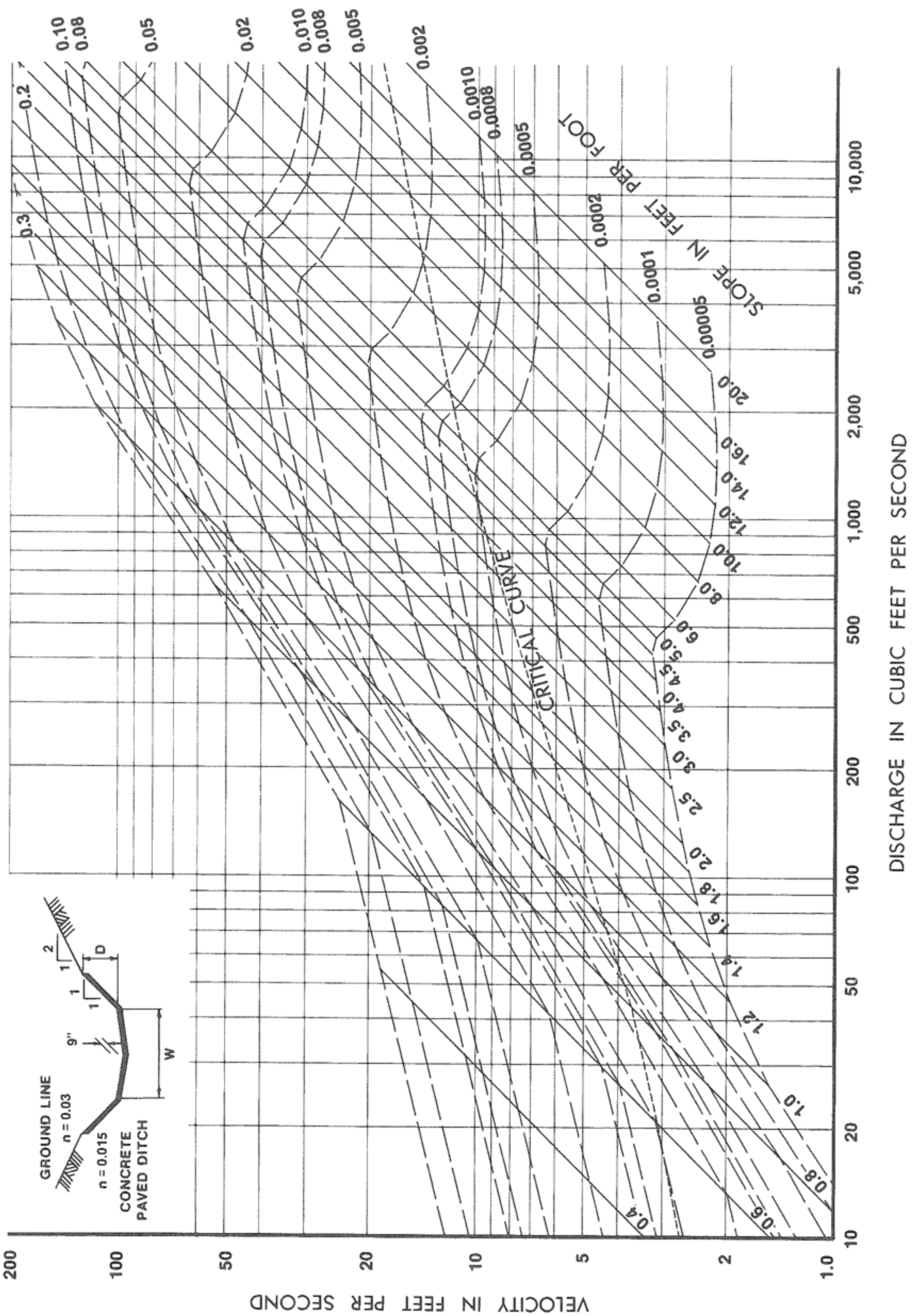
FIGURE 7A-59



PAVED CHANNEL CHART
W = 28 FT. D = 3 FT.

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS



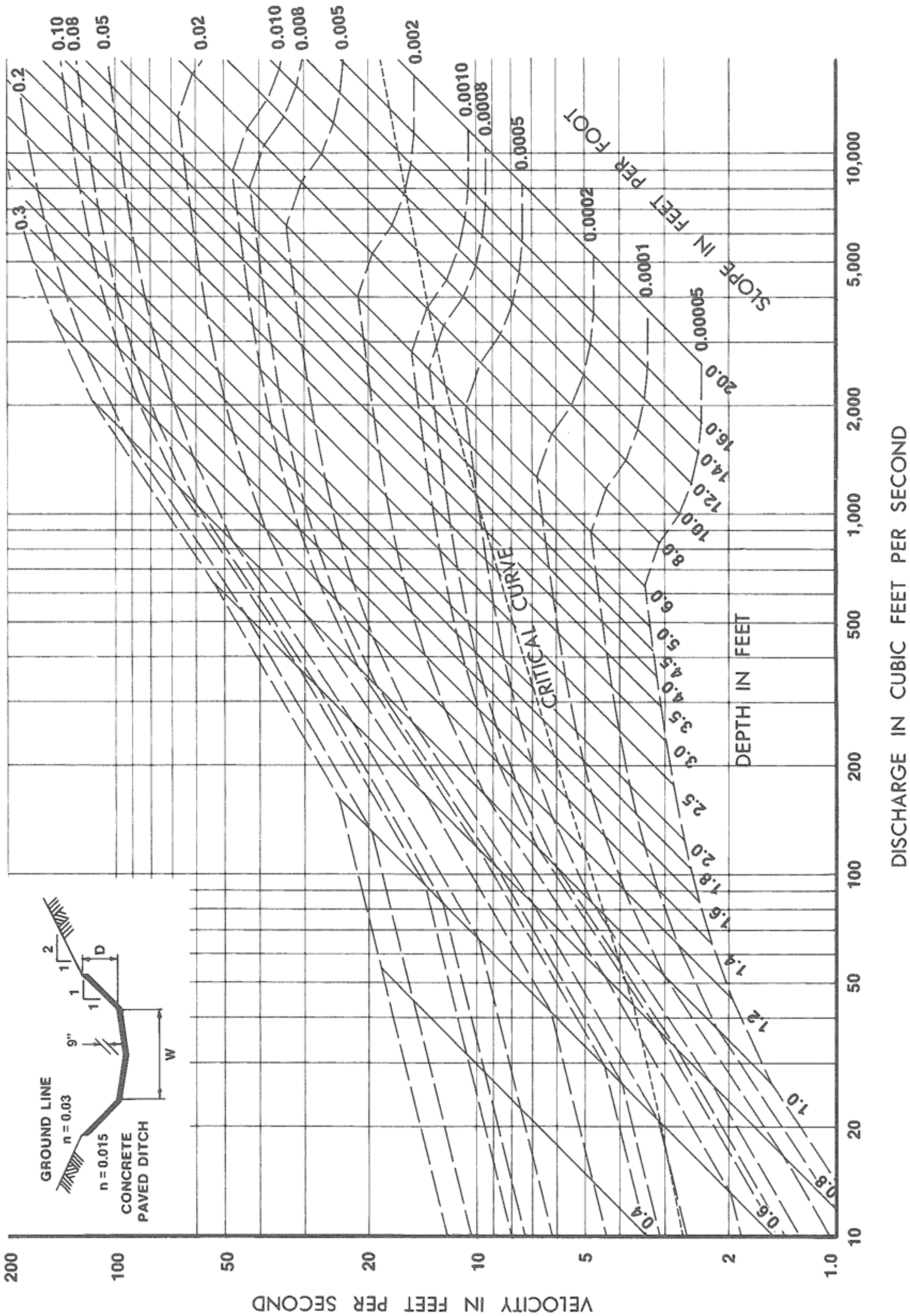
PAVED CHANNEL CHART

W = 28 FT. D = 4 FT.

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

FIGURE 7A-61

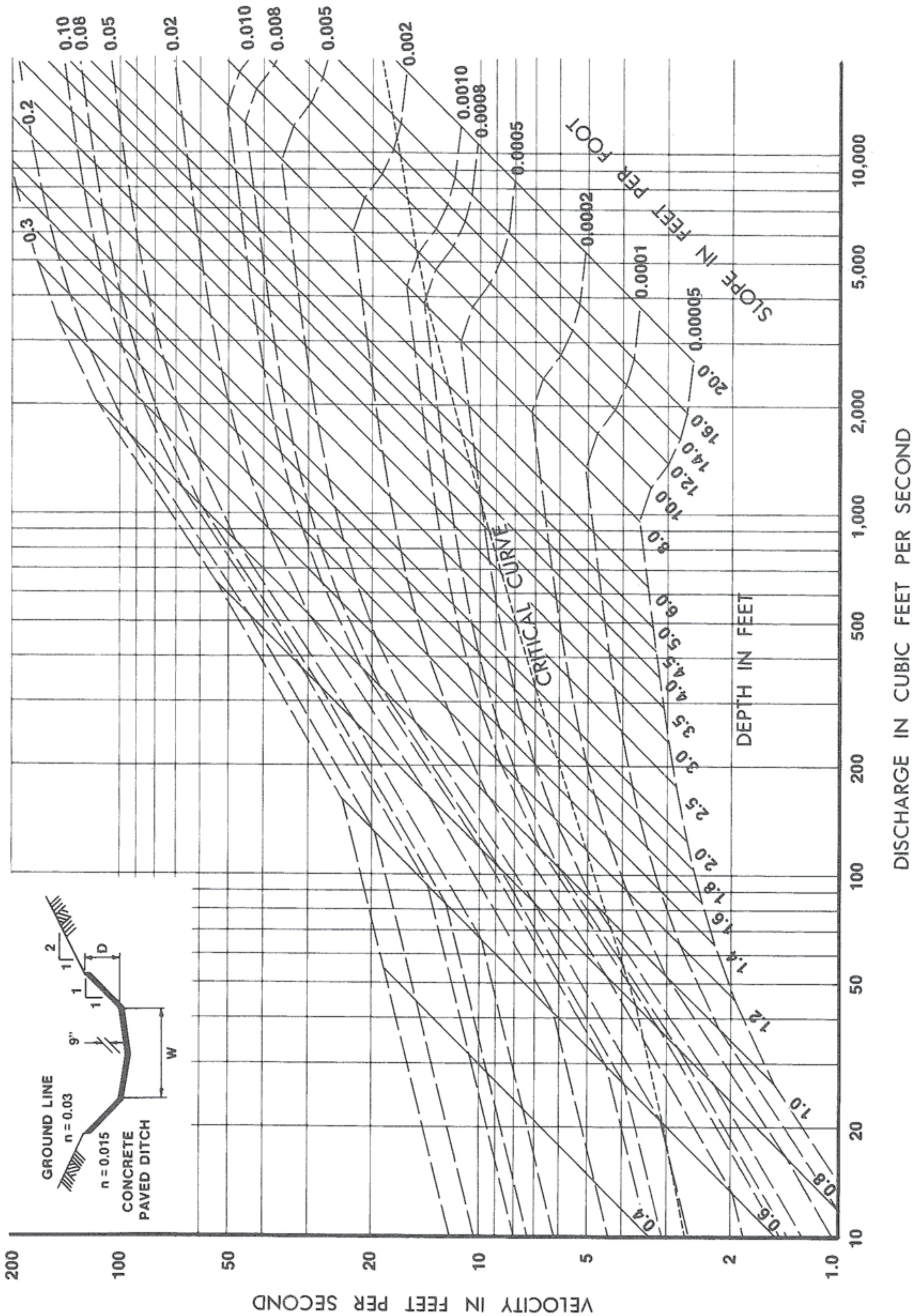


PAVED CHANNEL CHART
W = 28 FT. D = 6 FT.

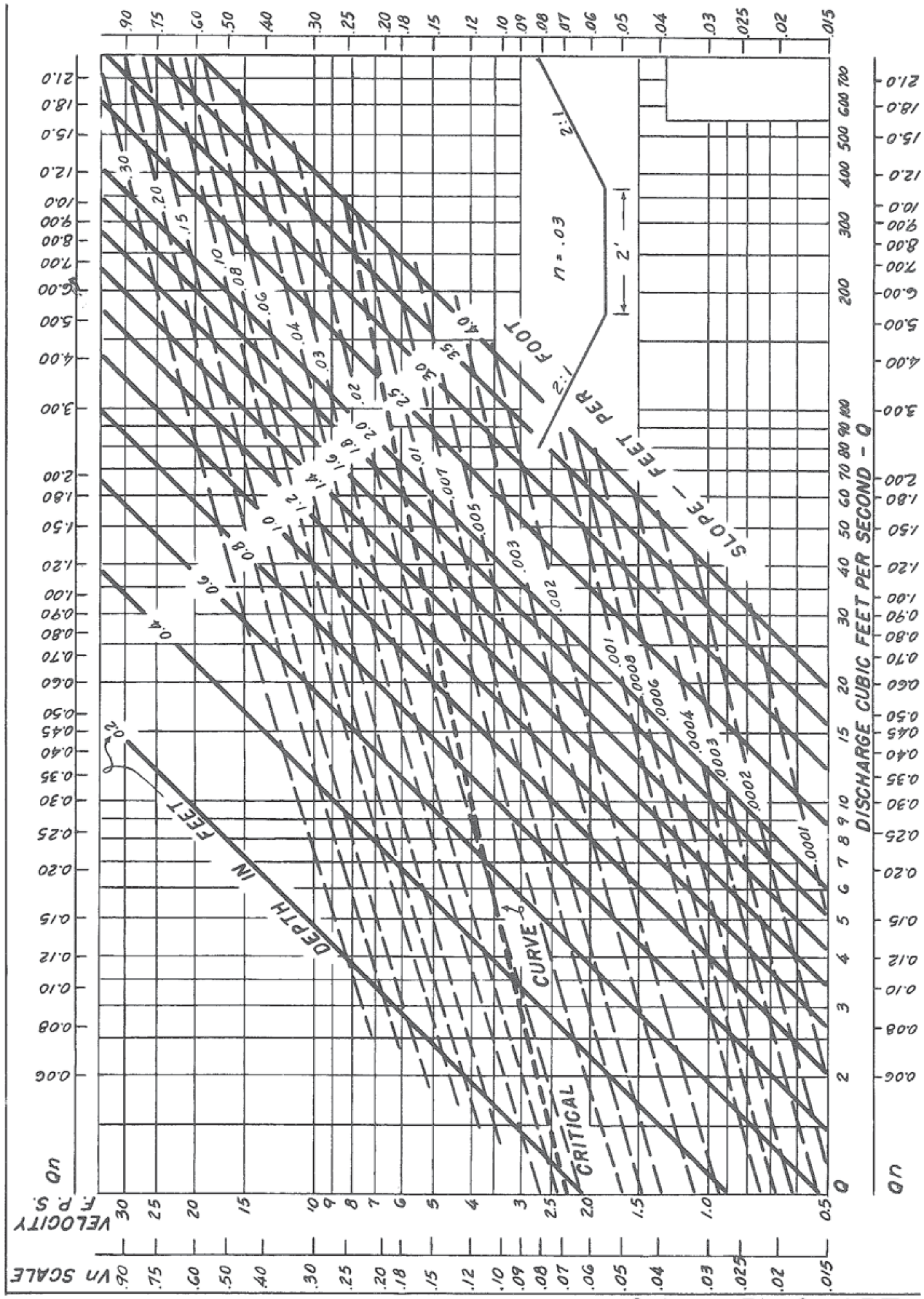
CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

FIGURE 7A-62

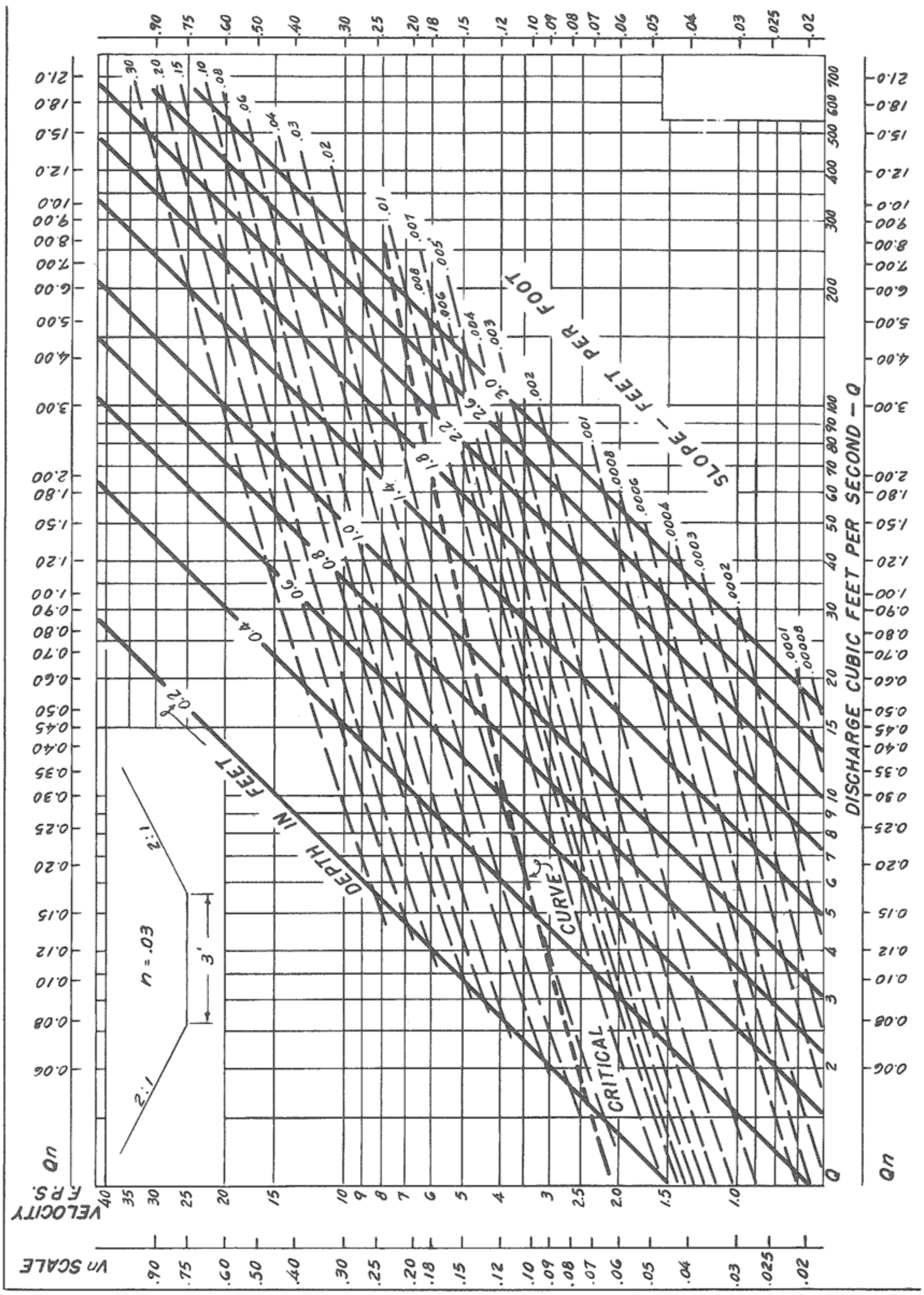


PAVED CHANNEL CHART
W = 28 FT. D = 8 FT.



CHANNEL CHART
2:1 b = 2 FT.

FIGURE 7A-64

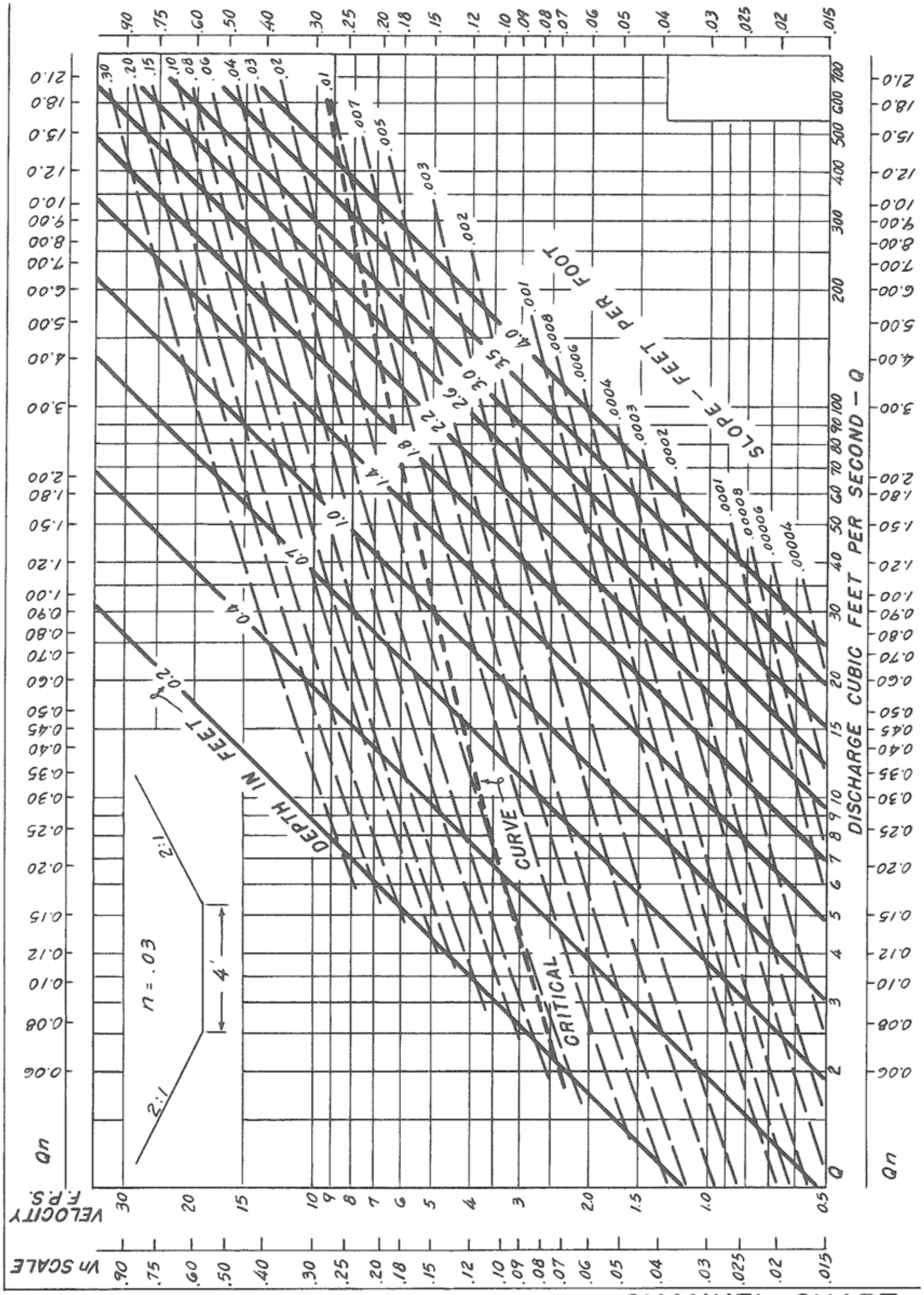


CHANNEL CHART
2:1 b = 3 FT.

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

FIGURE 7A-65

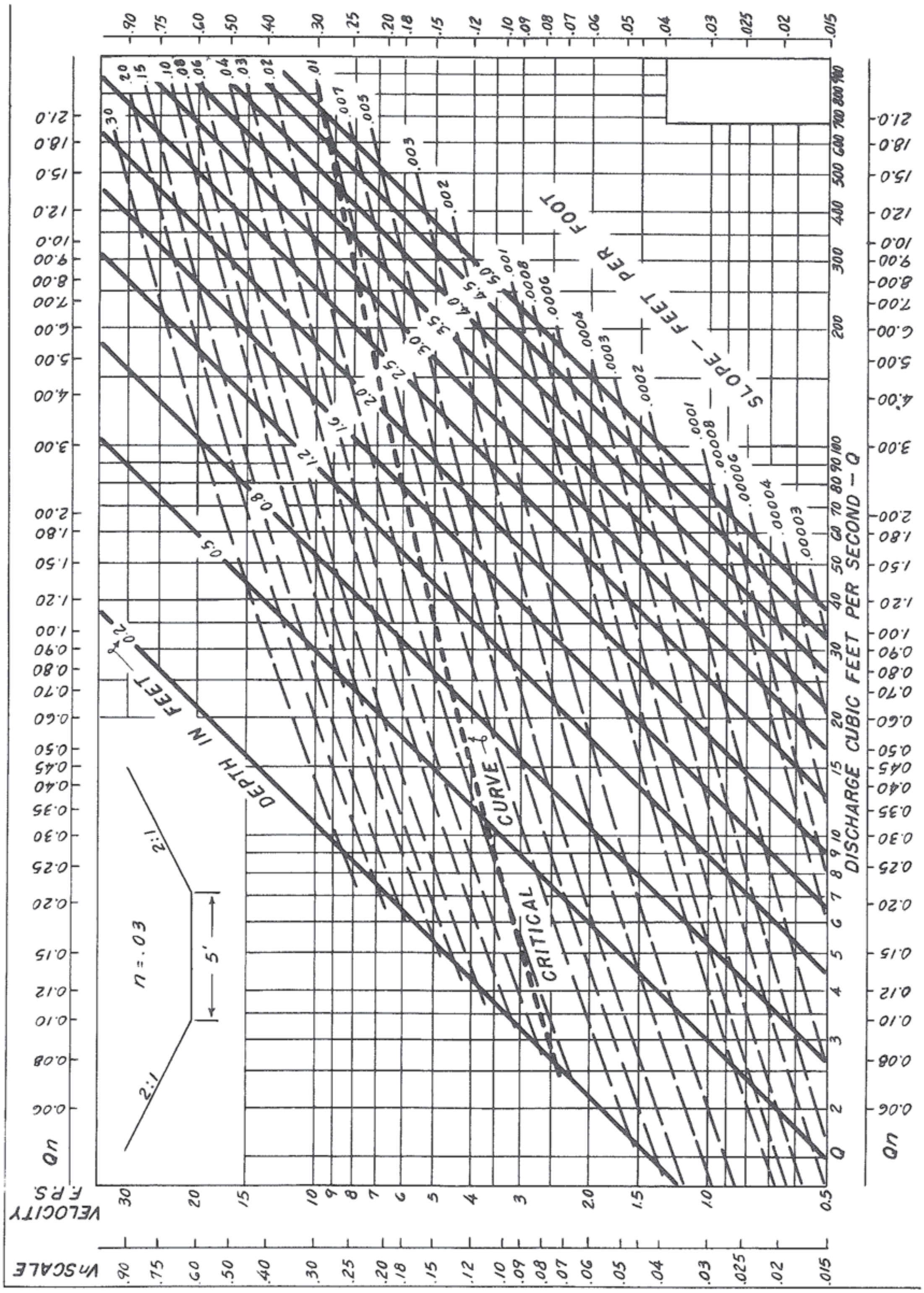


CHANNEL CHART
2:1 b = 4 FT.

CITY OF SHREVEPORT, LOUISIANA

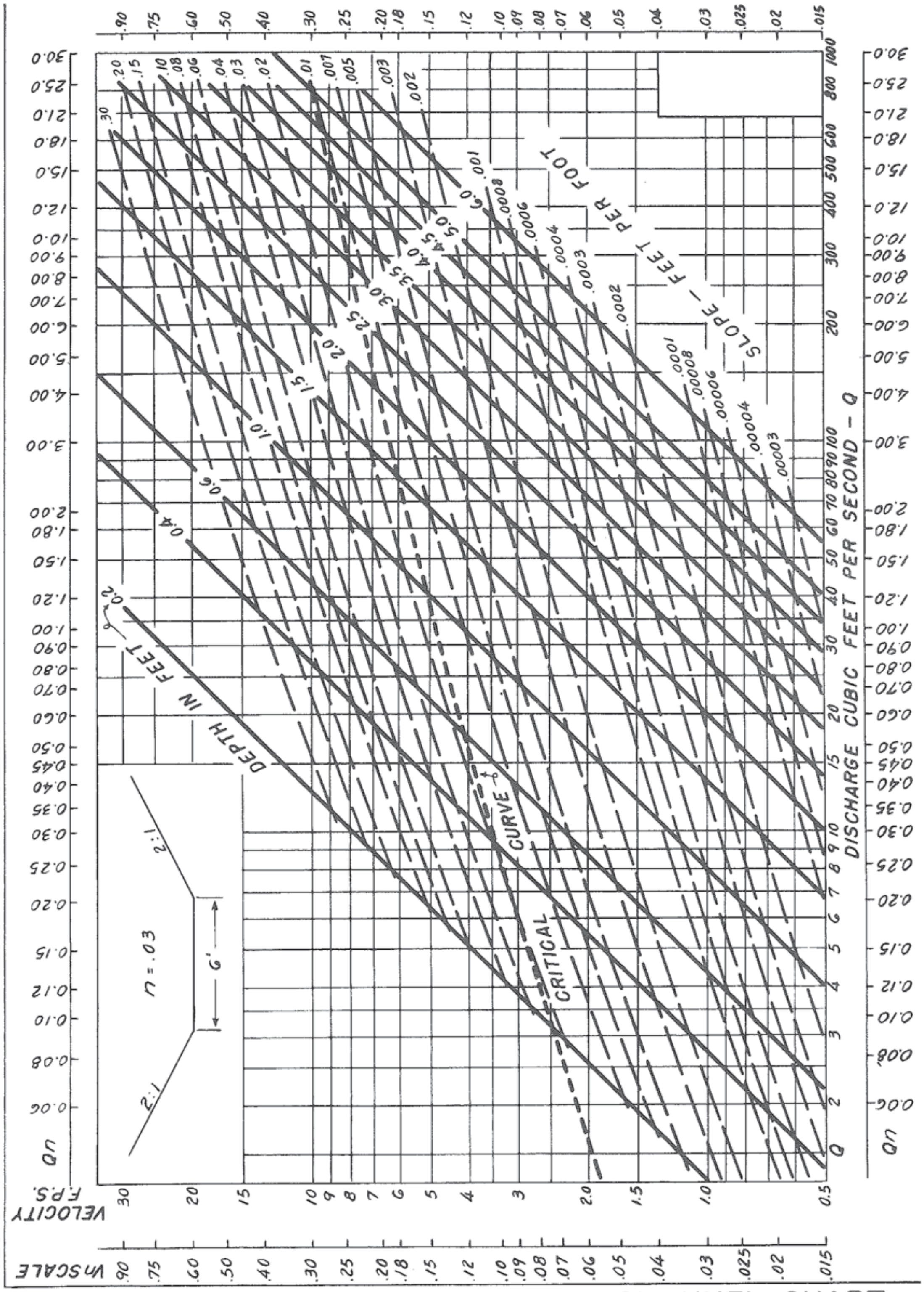
DEPARTMENT OF PUBLIC WORKS

FIGURE 7A-66



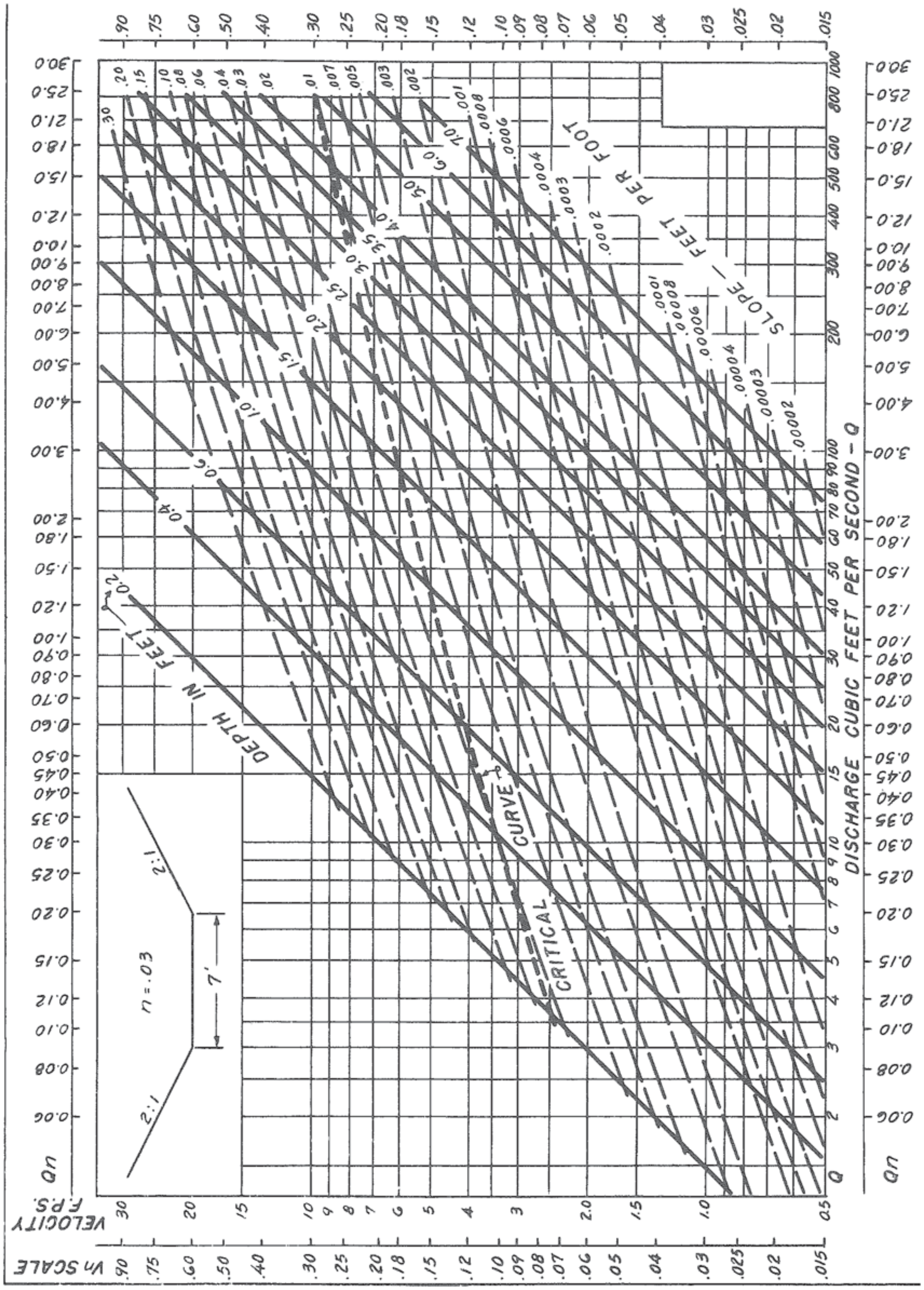
CHANNEL CHART
2:1 b = 5 FT.

FIGURE 7A-67



CHANNEL CHART
2:1 b = 6 FT.

FIGURE 7A-68

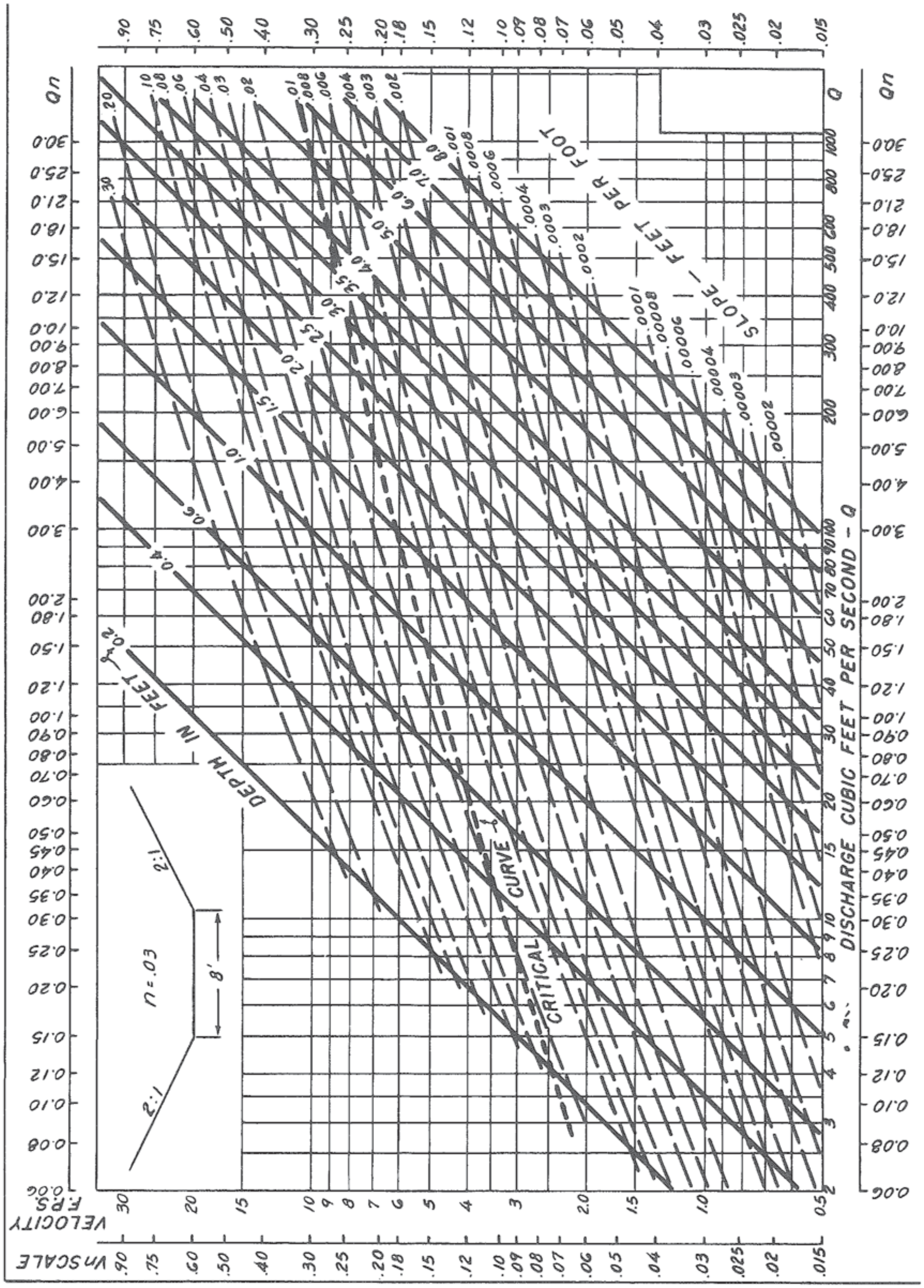


CHANNEL CHART
2:1 b = 7 FT.

CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS

FIGURE 7A-69



CHANNEL CHART
2:1 b = 8 FT.

CITY OF SHREVEPORT, LOUISIANA

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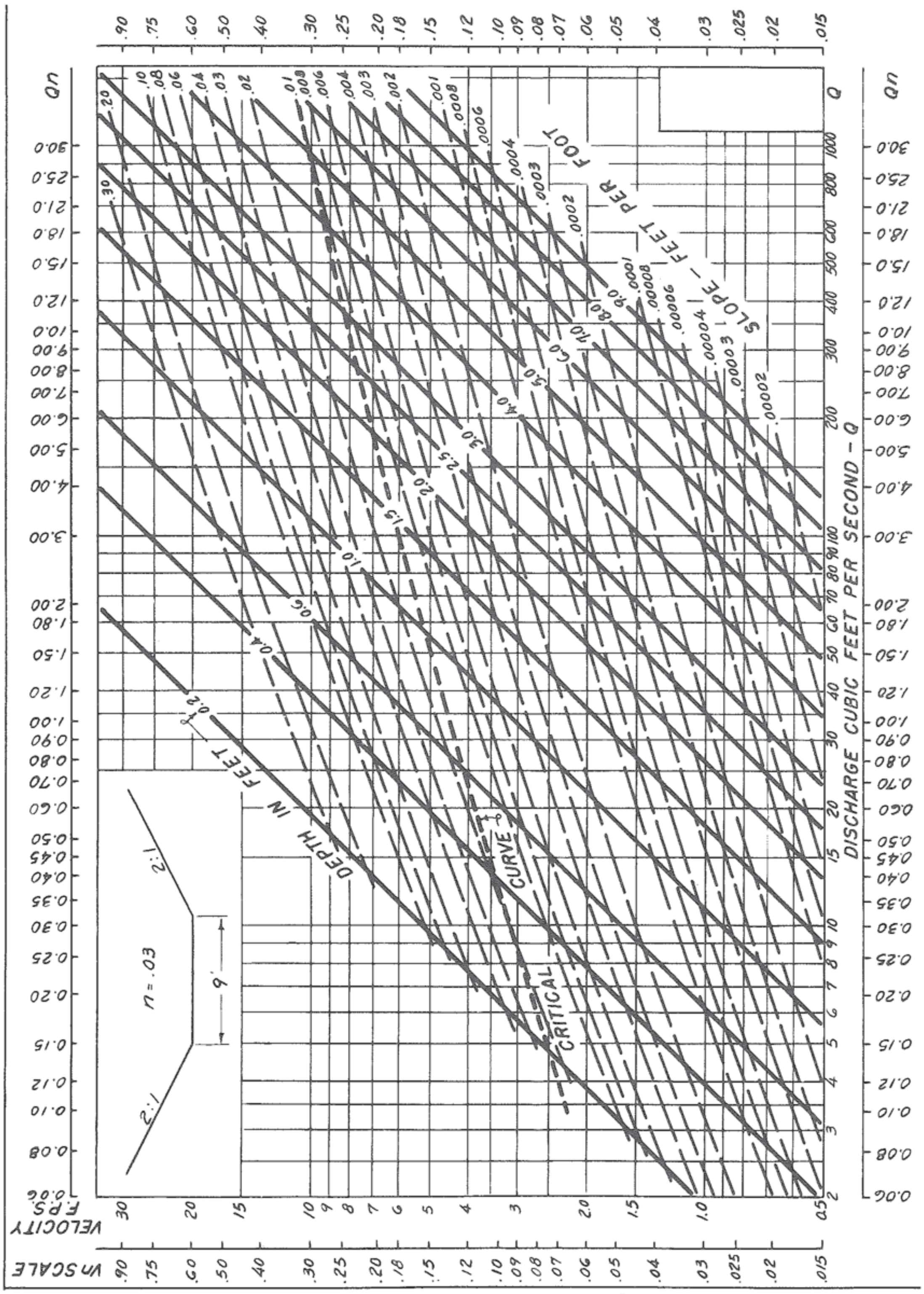
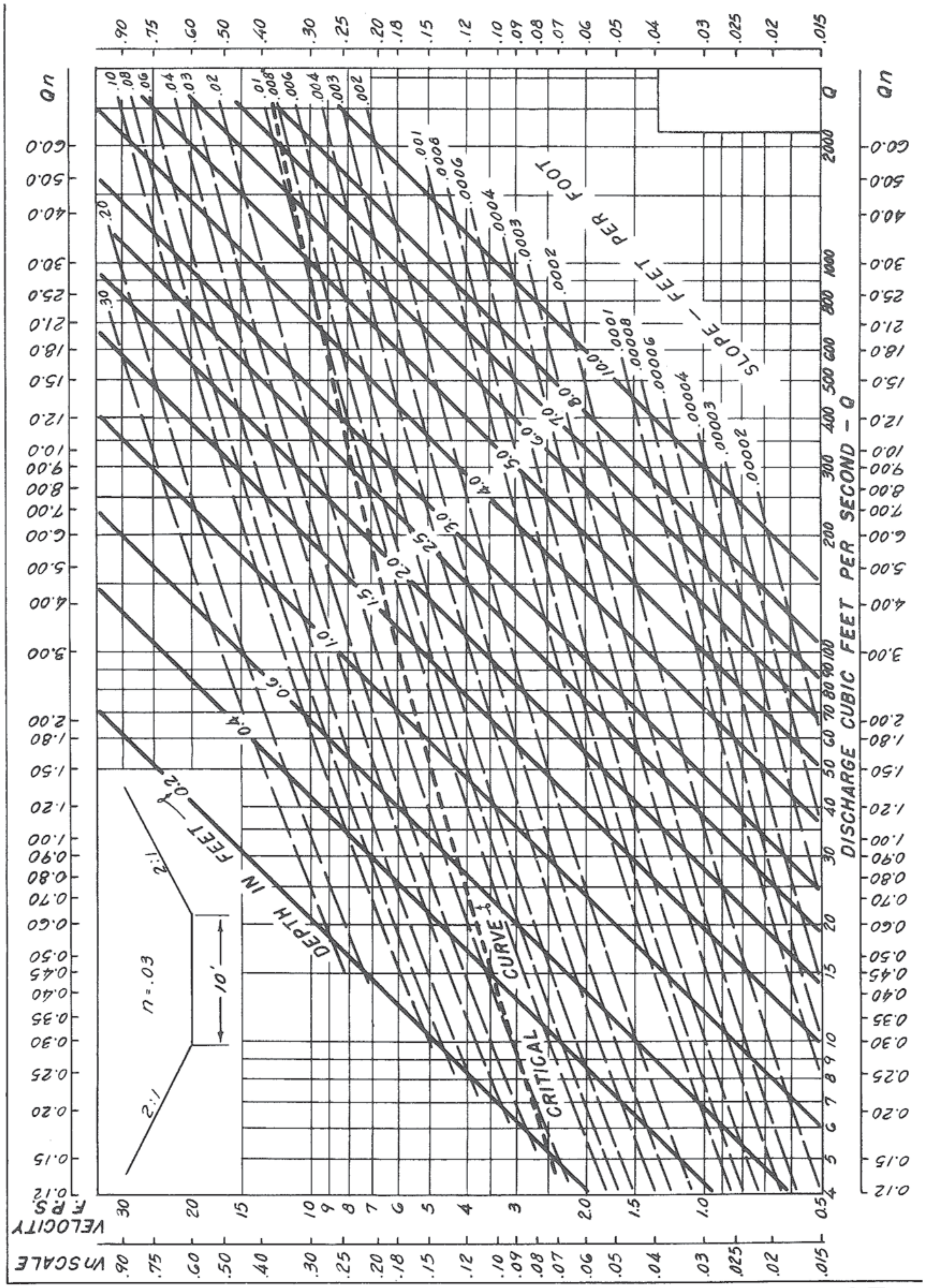
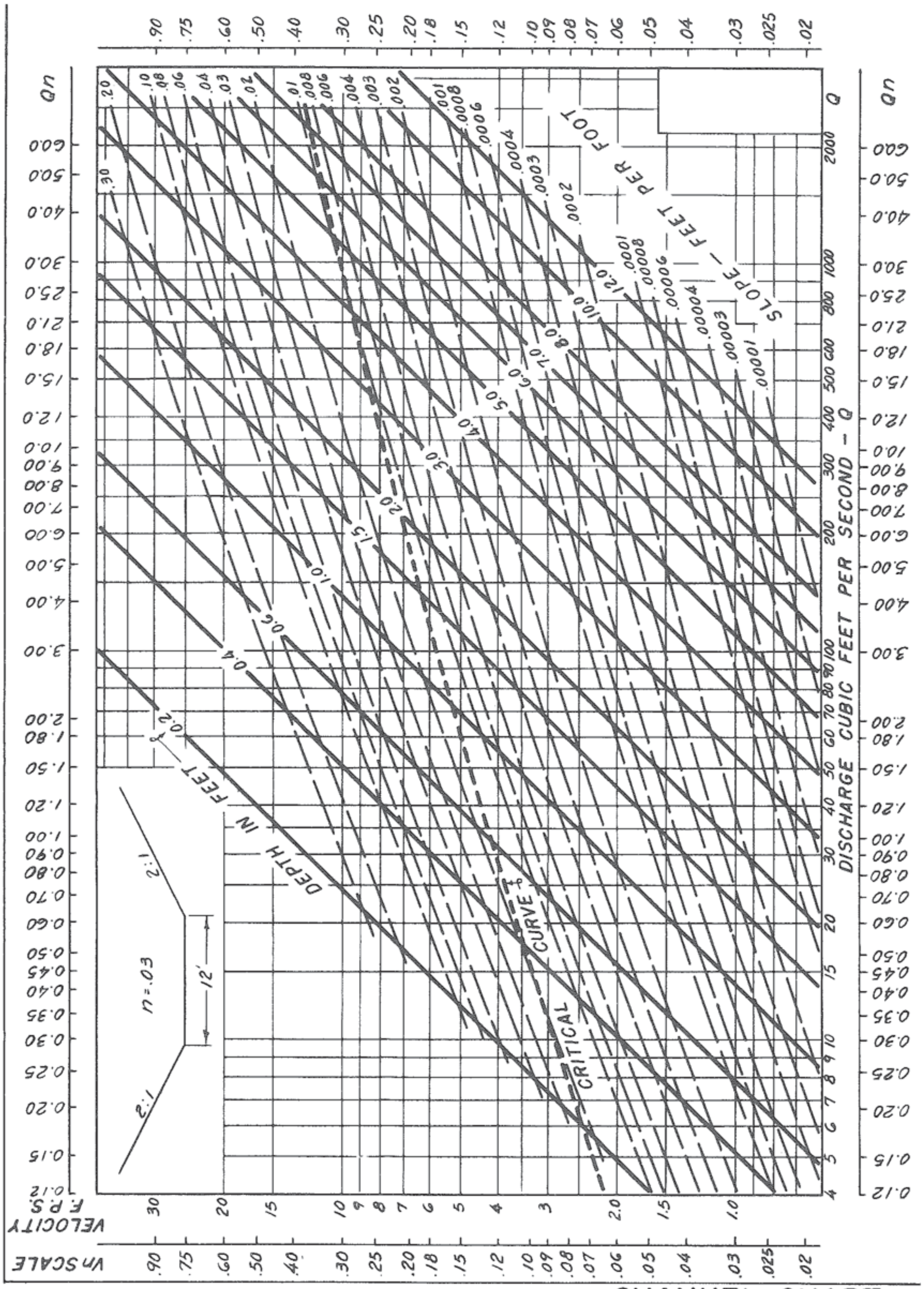


CHANNEL CHART
2:1 b = 9 FT.

FIGURE 7A-71

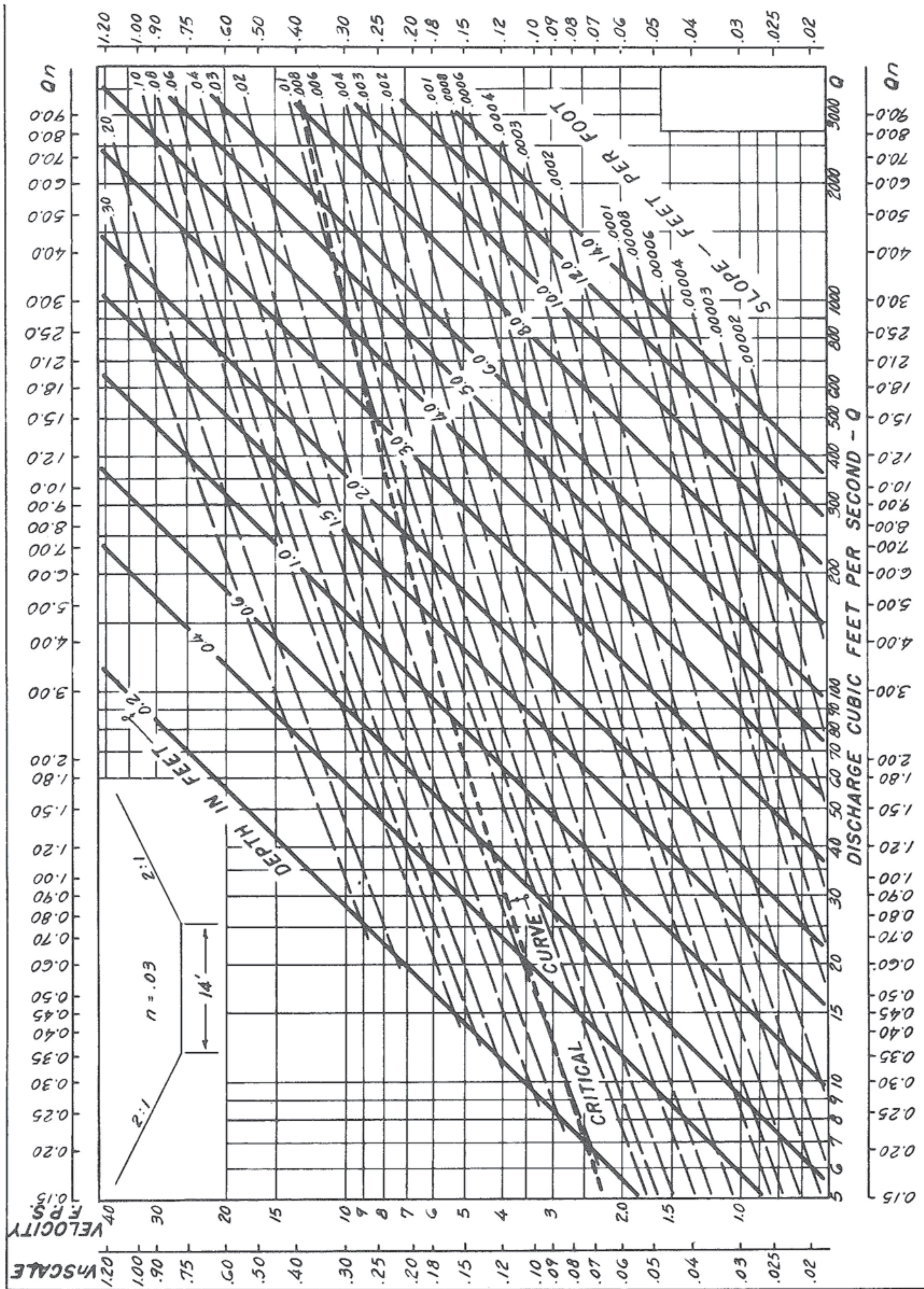


CHANNEL CHART
2:1 b = 10 FT.



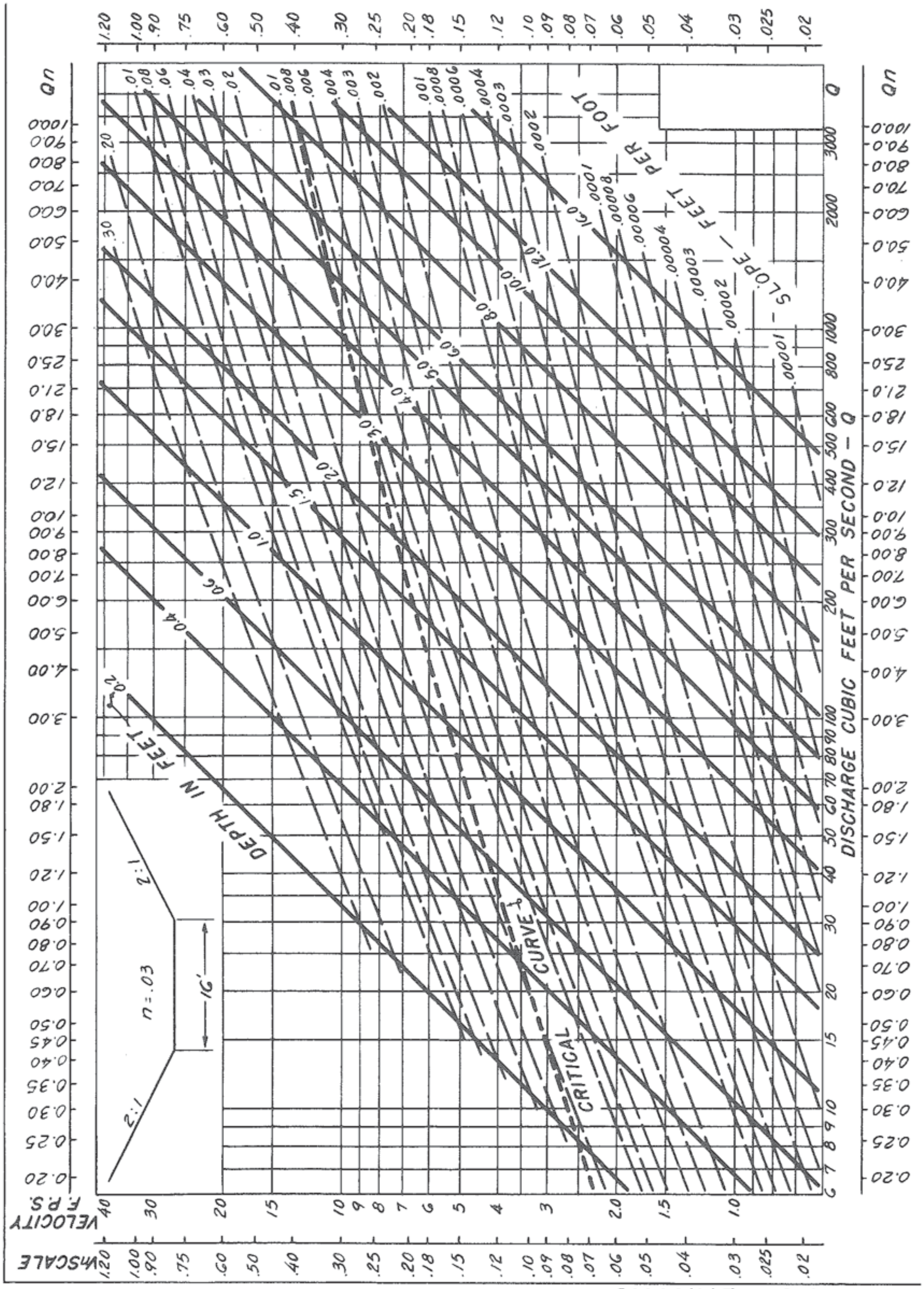
CHANNEL CHART
2:1 b = 12 FT.

FIGURE 7A-73



CHANNEL CHART
2:1 b = 14 FT.

FIGURE 7A-74

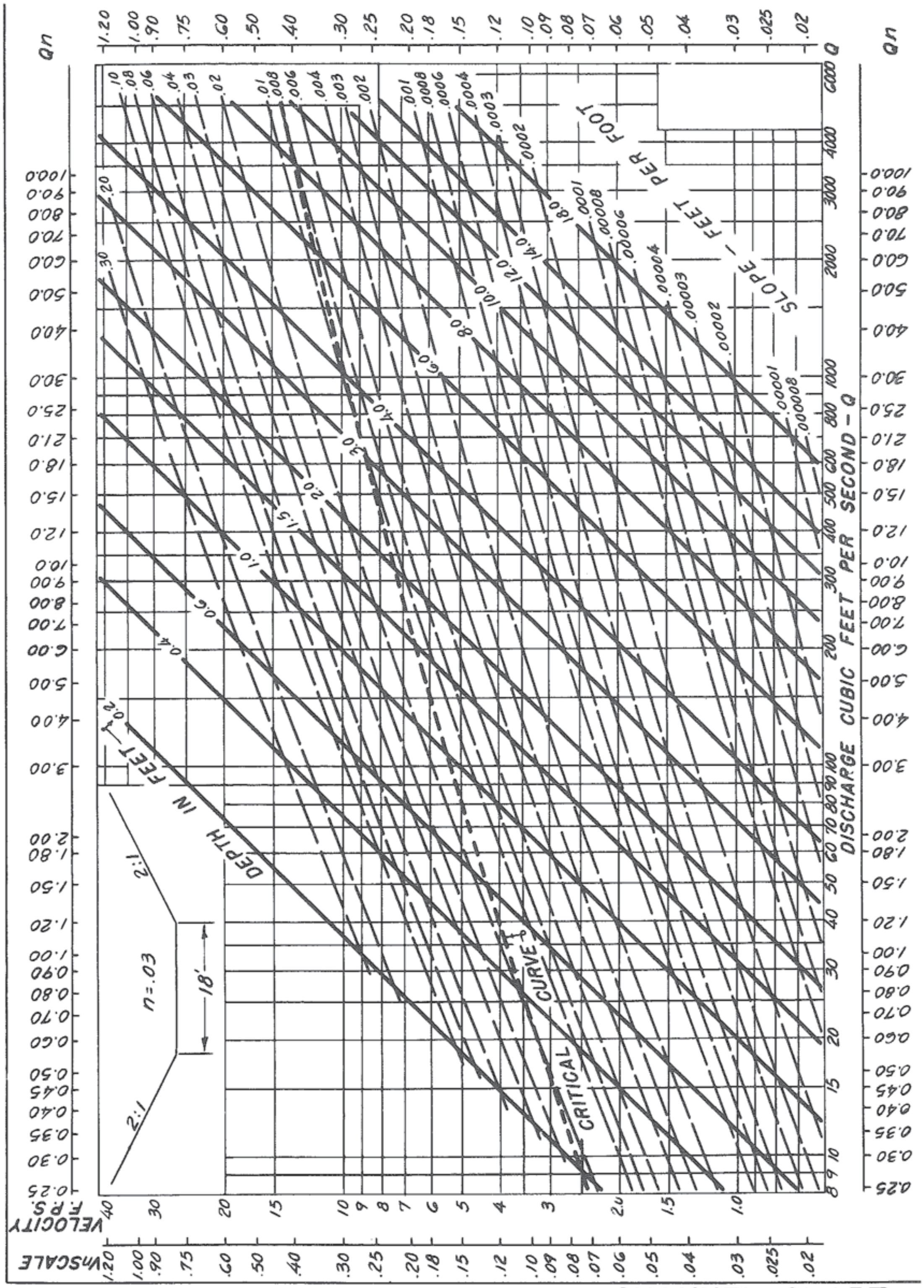


CHANNEL CHART
2:1 b = 16 FT.

CITY OF SHREVEPORT, LOUISIANA

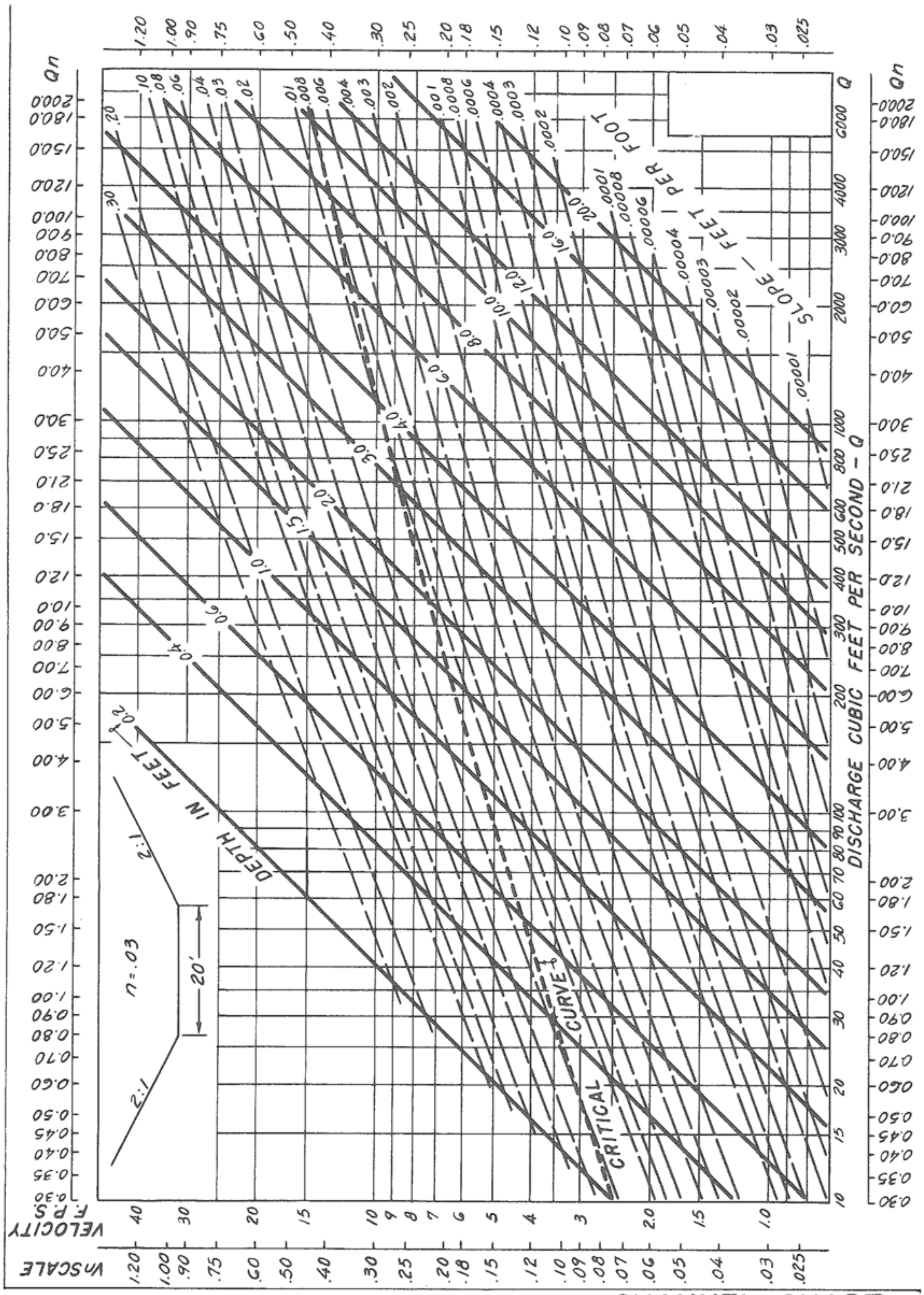
DEPARTMENT OF PUBLIC WORKS

FIGURE 7A-75



CHANNEL CHART
2:1 b = 18 FT.

FIGURE 7A-76

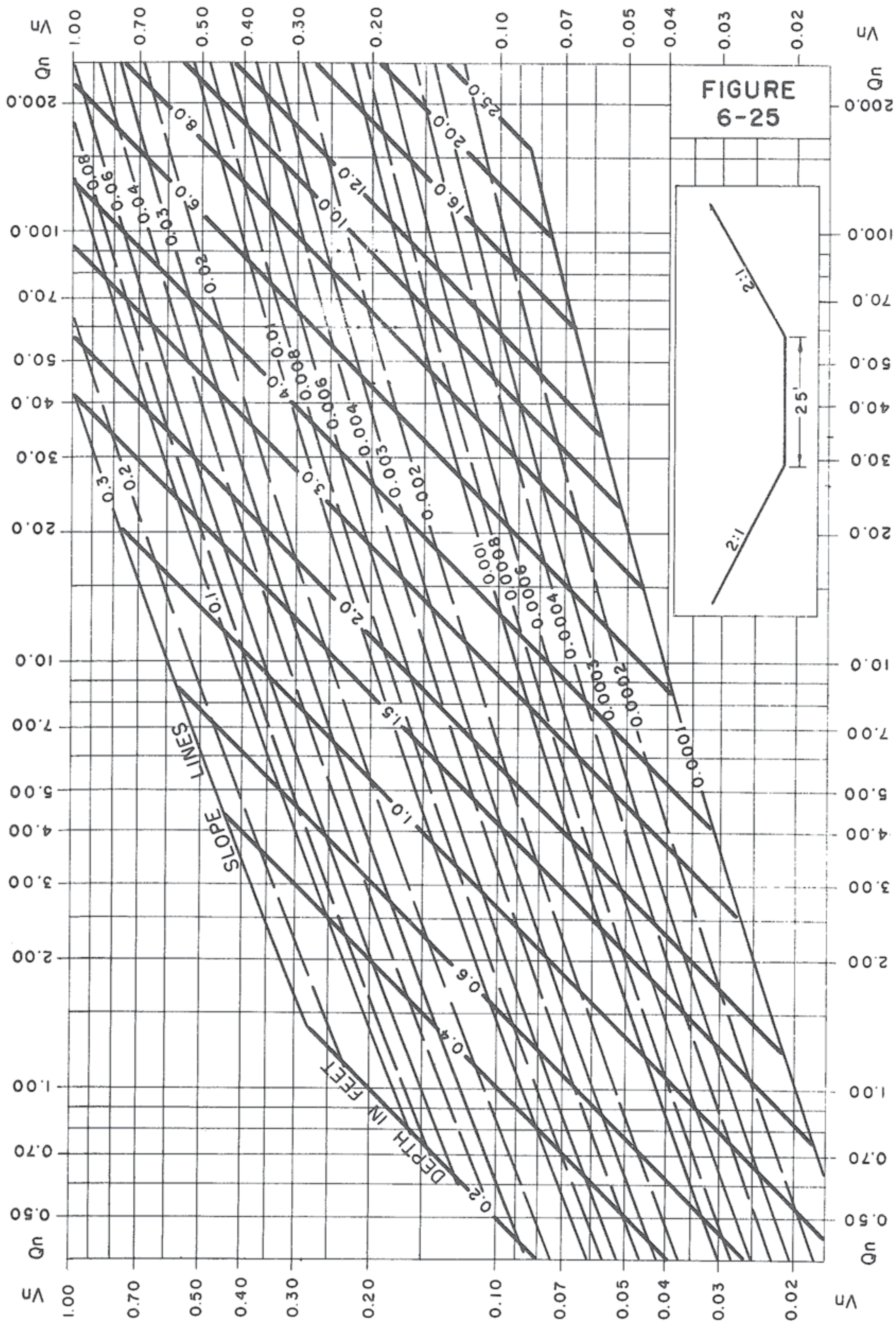


CHANNEL CHART
2:1 b = 20 FT.

CITY OF SHREVEPORT, LOUISIANA

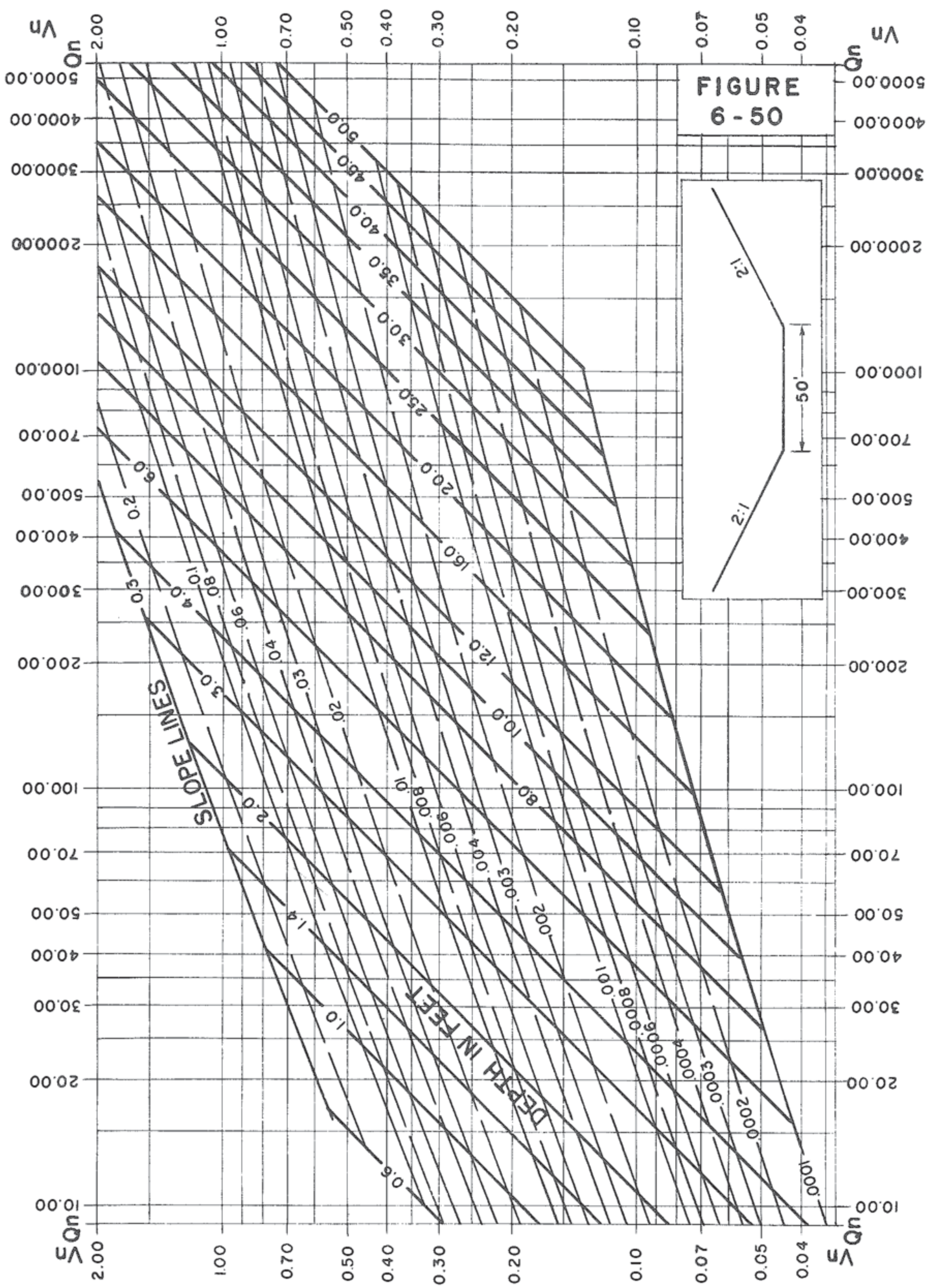
DEPARTMENT OF PUBLIC WORKS

FIGURE 7A-77



CHANNEL CHART
2:1 b=25 FT.

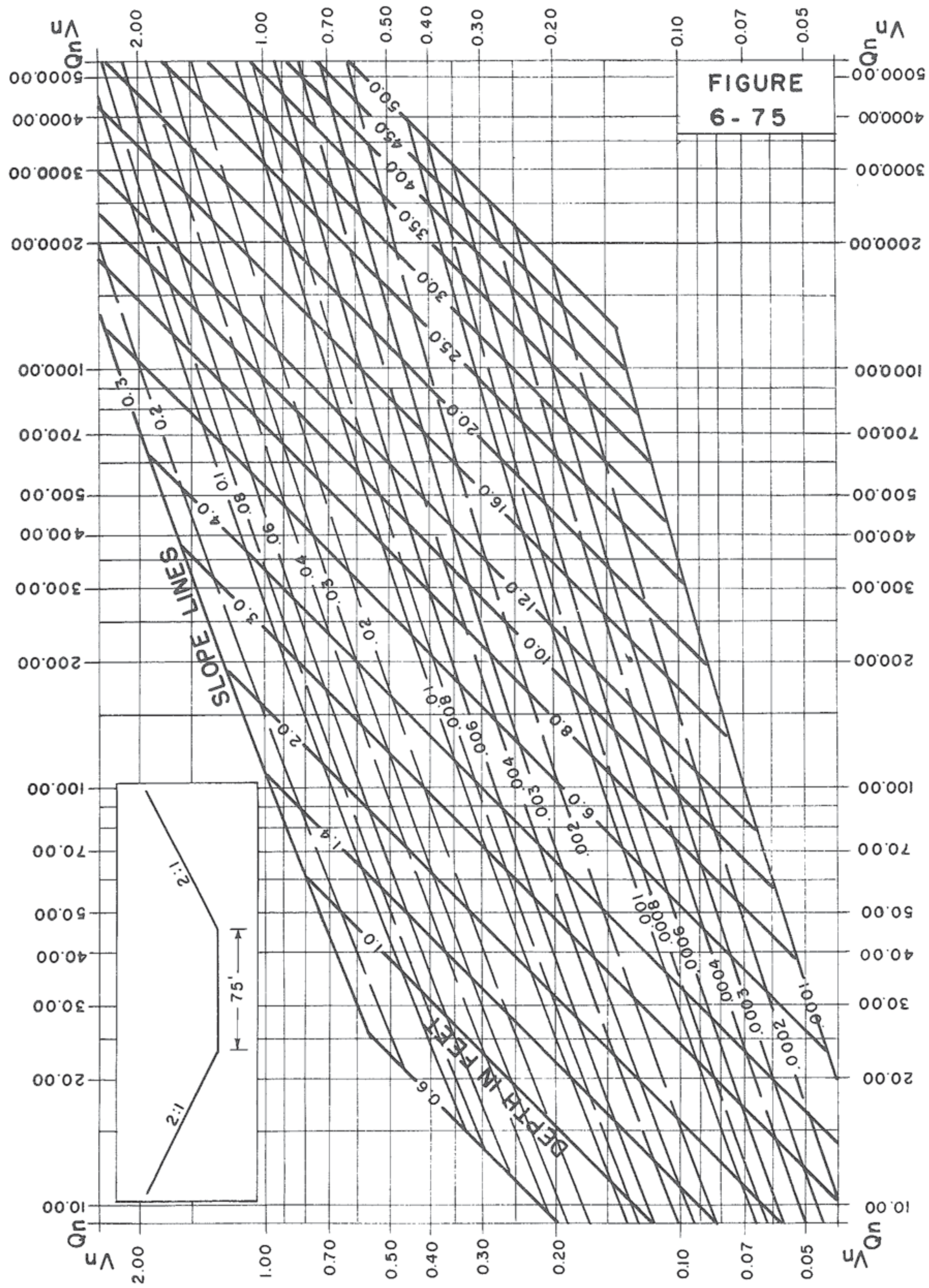
CITY OF SHREVEPORT, LOUISIANA
DEPARTMENT OF PUBLIC WORKS



CHANNEL CHART
2:1 b = 50FT.

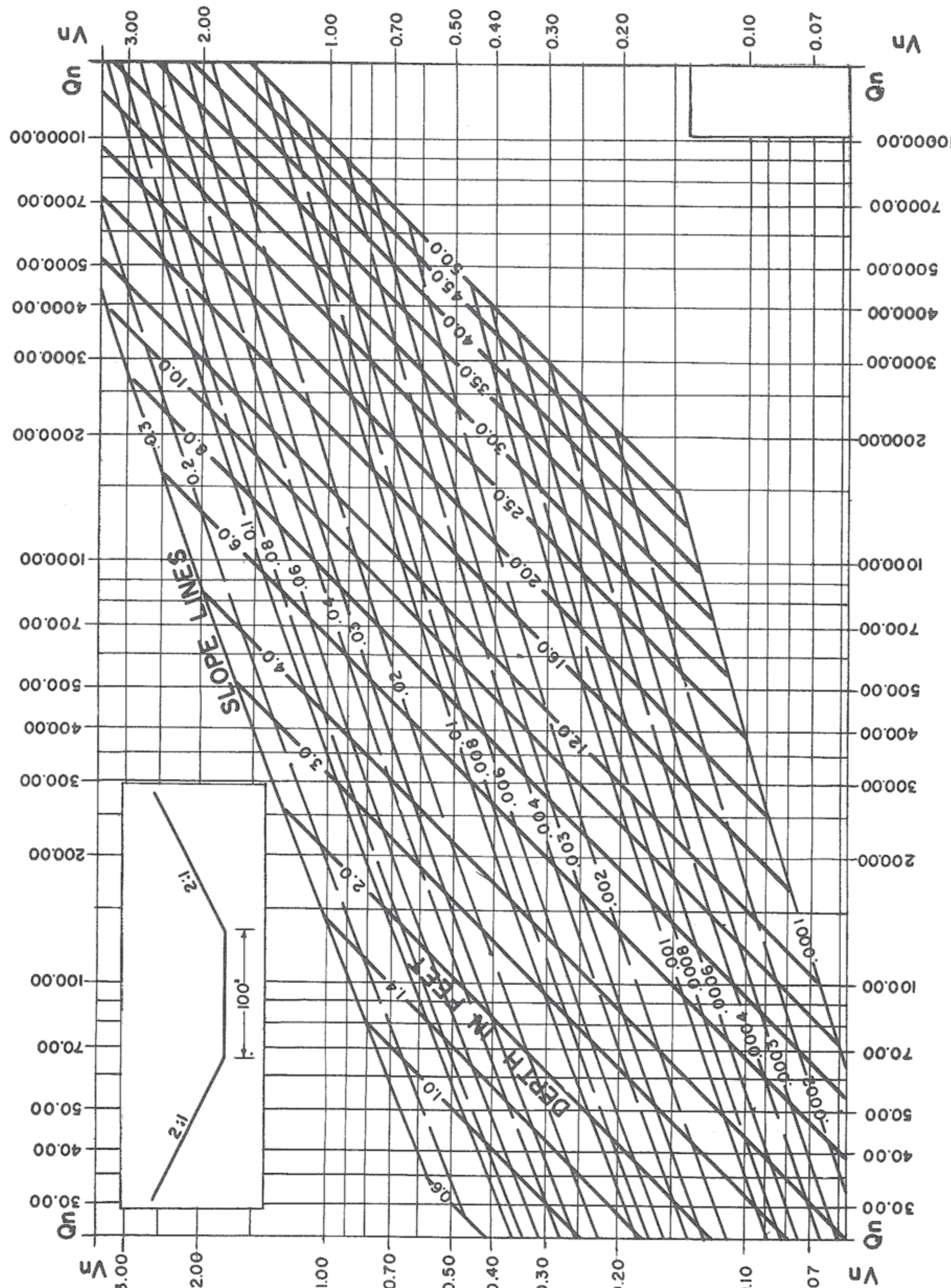
CITY OF SHREVEPORT, LOUISIANA

DEPARTMENT OF PUBLIC WORKS



CHANNEL CHART
2:1 b =75 FT.

FIGURE 7A-80



CHANNEL CHART
2:1 b=100 FT.

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Section 8

EROSION CONTROL

8.1 General

Pollution of streams and bayous by sediment generated from construction sites is becoming an increasingly important factor in design. The intent of this section of criteria is to emphasize that timely application of structural and soil stabilization measures can minimize this effect of construction, aid in alleviating a source of water pollution, and indicate sources of design data to the design engineer.

Chapter 34 Article IV of the Code of Ordinances of the City of Shreveport defines the requirements for erosion and sedimentation control. The ordinance requires a permit be obtained from the Department of Engineering and Environmental Services prior to any land altering activities within the city limits or the Cross Lake watershed. Land altering activities are defined in the ordinance as "*any change to existing land including, but not limited to, clearing, grading, excavating, filling, or other construction activities, such as parking lots, residential and commercial buildings, retaining walls, storm drainage systems, and utility main installations, or repairs thereof, any of which would physically alter the existing conditions and/or vegetative cover of the land*."

Soil erosion is a process of detachment and transportation of soil by wind and water. The process is increased by land development activities. Further information on proper erosion control, including planning, execution of temporary and permanent control measures, and maintenance of those measures can be located in the City of Shreveport standard specifications. The Design Engineer can request the latest version of these documents from the City's Engineering and Environmental Services Department.

"The following URL on the City's website contains additional information and links on this topic which may be helpful for builders and developers: https://www.shreveportla.gov/271/Construction-Activities"

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STORMWATER DETENTION

9.1 Overview

Stormwater detention basins are used to temporarily impound (detain) excess stormwater, thereby reducing peak discharge rates. Detention basins temporarily store a determined quantity of water for a specified period of time with a release rate that is either fixed or variable. The purpose of detention basins is to reduce the peak flow of a post-development site to peak flow the pre-development conditions.

9.2 Water Control Standards

The volume of water to be detained and the rate at which water may be gradually released from detention shall be calculated in a manner consistent with sound engineering practices and shall be based on the characteristics of the drainage basin in which the proposed construction is located.

Drainage facilities shall be designed and constructed so that the rate of runoff from a site post-construction shall be equal to or less than the runoff of a pre-construction site for the 2-year, 10-year, 25-year, and 100-year design storms.

Pre-construction conditions for sites located in the Ockley Basin and special flood hazard areas shall use a runoff coefficient characteristic of the current site conditions with a maximum runoff coefficient of 0.5.

9.3 Minimum Requirements for Detention Basin Design

Documentation on detention facilities structures should include design hydrographs, calculation of stage-storage-discharge tables, drawings of the basin, spillway and outlet size and location, erosion control measures, and detention basin design report. The detention basin design report shall include the pre-construction runoff rates, the post-construction runoff rates, outlet structure selection, and stage - discharge relationship. In all cases the effects of tailwater or other outlet control considerations should be included in the rating table calculations.

The following criteria shall serve as minimum requirements for detention basin design:

1. Detention basins to be excavated shall provide positive drainage through the basin with a minimum slope of 0.5%.

2. When the outflow structure discharges flow into a natural stream or unlined channel, it shall do so at a non-erosive rate in accordance with Section 7 of this manual.

3. Earthen embankments used to impound a required detention volume must have a minimum top-width of 4-feet.

4. Detention basins shall have a minimum of 1-foot of freeboard. Freeboard is the vertical difference between the basin's top of berm and the water surface of the peak 100-year inflow passing over the emergency spillway.

9.3.1 Methods and Computer Software Programs

The hydraulic design of stormwater detention basins requires modeling of storage and outfall structures. The following is a list of acceptable modeling software:

a. Hydroflow Hydrographs
b. Other software as approved by the City Engineer

9.3.2 Outlet Structure Design

Design and construction information for outlet works is contained in the publication "Stormwater Detention Outlet Control Structures (ASCE, 1985). Multi-level outlet structures may be necessary to reduce both the 10-year and 100-year design storm runoff to pre-development levels and provided for an emergency spillway.

There are two basic types of outlet control structures: those incorporating orifice flow and those incorporating weir flow. Rectangular and V-notch weirs are the most common types. The respective weir and orifice flow equations are as follows:

1. Rectangular Weir Flow

$$Q = C \cdot L \cdot H^{\frac{3}{2}} \qquad \text{Eq. 9-1}$$

Where: Q = Weir discharge, (cfs)
C = Weir Coefficient
L = horizontal length, (ft)
H = Head on weir, (ft)

2. V-notch Weir Flow

$$Q = 2.5 \cdot tan(\frac{\theta}{2}) \cdot H^{2.5} \qquad \text{Eq. 9-2}$$

Where: Q = Weir Discharge, (cfs)
Θ = Angle of the weir notch at the apex (degrees)
H = Head on Weir, (ft)

3. Orifice Flow

$$Q = C_o \cdot A \cdot (2gH)^{0.5} \qquad \text{Eq. 9-3}$$

Where: Q = Orifice Flow, (cfs)
C_o= Orifice Coefficient (use 0.6)
A = Orifice Area, (ft^2)
g = Gravitation constant, (32.2 $ft/s^{2)}$
H = Head on orifice measured from centerline, (ft)

4. Culverts Outlet Control

Standard culvert design techniques are appropriate for larger pipes and calculations and nomographs can be found in Section 6.

9.4 Minimum Maintenance for Drainage Facilities

The following criteria shall serve as minimum requirements for drainage facility maintenance:

1. Debris, trash, and sediment must be removed from inlets, outlets and the bottom of the detention basin.

2. Vegetative growth must be limited to less than 6" in height.

3. Standing water is not permitted in dry detention basins. Basin shall be sloped to shallow channels that slope and drain to the outfall.

4. Eroded areas must be repaired. Use of rip-rap at entrance of flow into the basin is recommended.

5. Bare ground must be seeded to prevent soil loss.

9.5 Appendix

9.5.1 References

(1) Ram S. Gupta, “Hydrology and Hydraulic Systems, Second Edition,” 2001.

(2) Austin, Texas, “Drainage Criteria Manual,” 2020.
https://library.municode.com/tx/austin/codes/drainage_criteria_manual

(3) City of New Braunfels, Texas, “Drainage and Erosion Control Design Manual,” 2000
https://www.nbtexas.org/280/Manuals-Forms-and-Maps

(4) HEC No. 22, “Urban Drainage Design Manual,” Third Edition, 2009

(5) Metropolitan Nashville, Tennessee, “Stormwater Management Manual,” 2016

(6) City of San Marcos, Texas, “San Marcos Development Code,” 2017

9.5.2 Forms

(1) Stormwater Detention Facility Information

Stormwater Detention Facility Information

Provide the following information of the owner of the stormwater detention facility that will be responsible for the maintenance and annual fee:

Owner Name (Person and/or Business):

Phone Number:

E-mail address:

Billing address:

Detention facility address, if different from above:

Area of site (acres):

Required detention volume (ft^3):

Provided detention volume (ft^3):

Allowable discharge rate from site (cfs):

Proposed discharge rate from site (cfs):

Description of control structure:

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FLOODPLAIN MANAGEMENT

10.1 General

Floodplain management is a program, created by the Federal Emergency Management Agency (FEMA), that a community or municipality who is participating in the National Flood Insurance Program (NFIP), of which Shreveport participates, uses to take corrective measures in the case of a flood event and uses to help reduce and mitigate the risk of future flooding. The program's corrective measures can be used in zoning, subdivision and commercial developments, building codes and special-purpose floodplain ordinances. For further review into floodplain management please see the following link to the FEMA website: https://www.fema.gov/floodplain-management

Floodplain managers utilize the Flood Insurance Study (FIS), Flood Insurance Rate Maps (FIRMs) and other best available information to regulate the floodplain. Typical FEMA special flood hazard areas (SFHA) in Shreveport are Zone A, Zone AE, Zone AH, Zone AO, Zone X, and Zone X protected by levee. The Shreveport SFHA permit application can be found in the Appendix. In addition, there are several regulatory floodways. An example of FIRM is shown below in Figure 10-1.

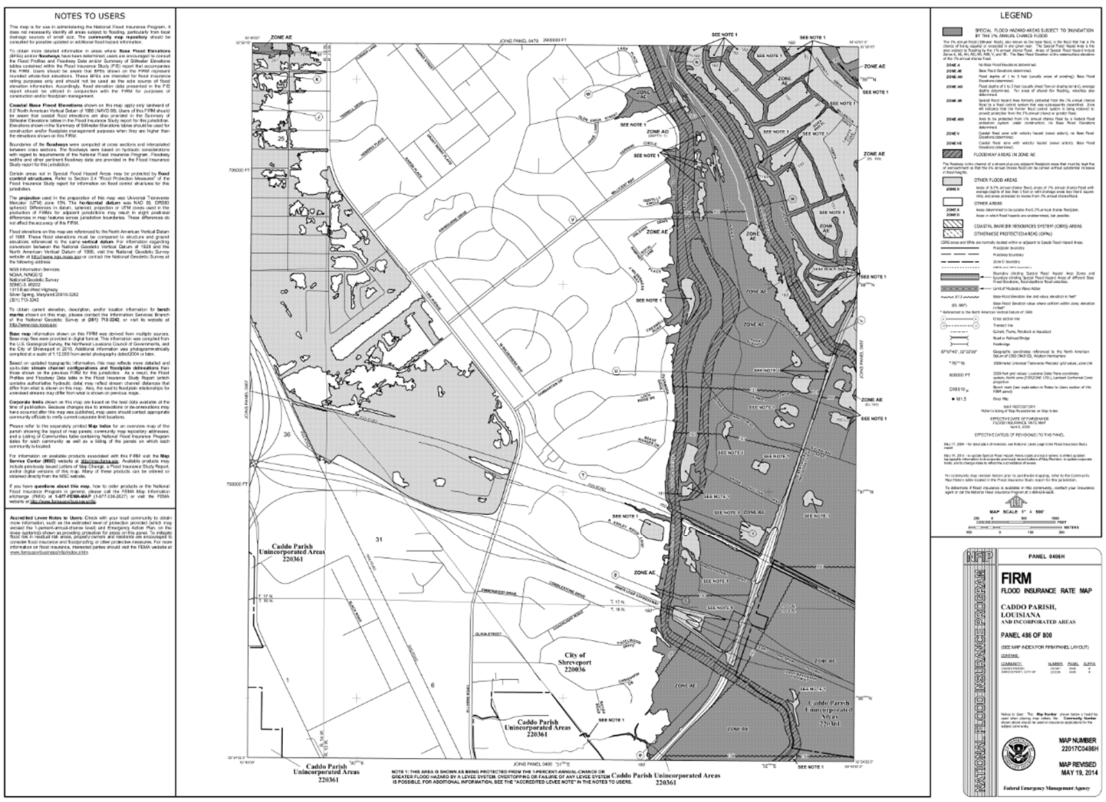

Figure 10-1 Example of a Flood Insurance Rate Maps (FIRM)

10.2 Base Flood Elevation

FEMA defines the Base Flood Elevation (BFE) as the elevation of surface water resulting from a flood that has a 1% chance of equaling or exceeding that level in any given year. The BFE is shown on the FIRM for zones AE, AH, A1–A30, AR, AR/A, AR/AE, AR/A1– A30, AR/AH, AR/AO, V1–V30 and VE. Structures must be protected from the base flood to reduce the risk of flood damage. The relationship between the BFE and a structure's elevation determines the flood insurance premium. Chapter 34 of the City Code of Ordinances discusses flood prevention and protection.

BFEs are shown on FIRMs and on the flood profiles found in the FIS. The FIRMs and FIS can be located by using the FEMA website: https://msc.fema.gov/portal/home

10.3 Approximate Zone A

Zone A identifies an approximately studied SFHA for which no BFEs have been provided. Although there is no BFE determined, the community is responsible for ensuring that new development within Zone A is constructed using methods that will minimize flood damages. This often requires obtaining and calculating BFEs. See FEMA 265 – Managing Floodplain Development in Approximate Zone A Areas for more information.
https://www.fema.gov/sites/default/files/documents/fema_approx-zone-a-guide.pdf

Simplified and detailed methodologies can be used to develop a BFE for various situations and conditions. Simplified methodologies include contour interpolation and data extrapolation. Detailed methodologies require a site-specific engineering analysis that includes flood plain geometry (topography), flood discharge and/or volume (hydrology), and flood height (hydraulics).

Detailed methodologies must be used to develop BFE information needed to obtain a LOMA, LOMR, or LOMR-F from FEMA and to be used to complete an Elevation Certificate for flood insurance rating. If the BFEs developed will be used to revise or amend FIRMs, they must be developed using the detailed methodologies or other methods comparable to those in a FIS.

10.4 Regulatory Floodway

Regulatory floodway means the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height. The National Flood Insurance Program (NFIP) states that a community shall prohibit encroachments, including fill, new construction, substantial improvements, and other development within the adopted regulatory floodway unless it has been demonstrated through hydrologic and hydraulic analyses performed in accordance with standard engineering practice that the proposed encroachment would not result in any increase in flood levels within the community during the occurrence of the base flood discharge.

All projects in a regulatory floodway must be reviewed to determine if the project will increase flood heights. To ensure that the encroachment review is done correctly, the developer must provide a no-rise certification, which certifies that the development project will not affect flood heights. The no-rise certification must be supported by technical data and signed by a registered professional engineer. The supporting technical data should be based on the standard step-backwater computer model utilized to develop the 100-year floodway shown on the community's effective FIRM or Flood Boundary and Floodway Map (FBFM) and the results tabulated in the community's FIS. The Engineering "No Rise" Certification form can be found in the Appendix.

Please refer to Section 10 of the *Louisiana Floodplain Management Desk Reference* for more information.
http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Public_Works/NFIP/Misc%20Documents/2008_Desk_Ref.pdf

10.5 Appendix

10.5.1 References

(1) Floodplain Management, Federal Emergency Management Agency. Retrieved from: https://www.fema.gov/floodplain-management

(2) FEMA 265 – Managing Floodplain Development in Approximate Zone A Areas https://www.fema.gov/sites/default/files/documents/fema_approx-zone-a-guide.pdf

(3) Louisiana Floodplain Management Desk Reference http://wwwsp.dotd.la.gov/Inside_LaDOTD/Divisions/Engineering/Public_Works/NFIP/Misc%20Documents/2008_Desk_Ref.pdf

10.5.2 Forms

(1) Special Flood Hazard Area Permit Application_Fillable 6-29-20

(2) Engineering “No Rise” Certification

Shreveport
Special Flood Hazard Area Permit

Address of Proposed Work: ____

City:________________________ State: __________Zip: ____________

Contact Information

Property Owner's Contact Information

Title: ________ First Name: ______________ Last Name: ____________ Suffix: ______

Business Name: ____

Mailing Address: ____

City:______________ State: ____________ Zip: ________

Email Address: ______________________________________

Cell Phone: ______________ Work Phone: ______________ Home Phone: ______________

Applicant's Contact Information

Title: ________ First Name: ______________ Last Name: ____________ Suffix: ______

Business Name: ____

Mailing Address: ____

City:______________ State: ____________ Zip: ________

Email Address: ______________________________________

Cell Phone: ______________ Work Phone: ______________ Home Phone: ______________

Contractor's Contact Information

Title: __________ First Name: ________________ Last Name: ______________ Suffix: ________

Business Name: ____

Mailing Address: ____

City:__________________ State: ______________ Zip: _________

Email Address: ____

Cell Phone: ________________ Work Phone: ________________ Home Phone: ________________

Application Questionnaire (* denotes required question)

Special Flood Hazard Area Permit

Type of Development Activity (Select One)

- ☐ Other
- ☐ Structural

Structural Activity (Select One)

- ☐ Addition
- ☐ Demolition
- ☐ New Construction
- ☐ Relocation
- ☐ Remodel

Structure Type (Select One)

- ☐ Accessory Structure
- ☐ Manufactured Home
- ☐ Non-Residential
- ☐ Residential (1-4 Family)
- ☐ Residential (more than 4 family)

Other Development Activity (Select One)

- ☐ Alteration of Waterway or Drainage
- ☐ Clearing
- ☐ Drilling
- ☐ Excavation
- ☐ Filling
- ☐ Grading
- ☐ Mining
- ☐ Other
- ☐ Subdivision
- ☐ Utility Work

Other ______________________________

Estimated Cost of Project ______________________________

FIRM Panel Number ______________________________

Effective Date ______________________________

Flood Zone ______________________________

Regulatory Floodway (Select One)

- ☐ No
- ☐ Yes

Base Flood Elevation ______________________________

Floodway Acknowledgement *
No fill will be placed in the regulatory floodway. Please Check Box to Acknowledge

Check Here ☐

Required Permits Acknowledgement *
All necessary Federal. State, and local permits have been obtained. Please Check Box to Acknowledge

Check Here ☐

ESA Acknowledgement *
Compliance with Sections 9 and 10 of the Endangered Species Act (ESA) has been achieved. Please Check Box to Acknowledge

Check Here ☐

SFHA Acknowledgement *
The land and any existing or proposed structures to be removed from the SFHA are or will be reasonably safe from flooding as defined in 44CFR 65.2(c). Please Check Box to Acknowledge

Check Here ☐

Elevation Certificate Acknowledgement *
An Elevation Certificate will be turned into the City of Shreveport, Department of Engineering and Environmental Services prior to issuance of the Certificate of Occupancy. Please Check Box to Acknowledge

Check Here ☐

Floodplain Maps Acknowledgement *
The Applicant agrees that the floodplain maps and other flood data used in evaluating the flood hazards for the proposed development are considered reasonable and accurate for regulatory. Please Check Box to Acknowledge

Check Here ☐

Documents Requested (* denotes required document)

The Jurisdiction requests that the following documents are attached to your application:

Any Additional Supporting Documents

Engineering "No Rise" Certification

This is to certify that I am a duly qualified registered professional engineer licensed to practice in the State of Louisiana.

It is further to certify that the attached technical data supports the fact that proposed

____
(Name of Development)

will not impact (0.000 foot rise) the base (100-year) flood elevations, floodway elevations and floodway widths on

____
(Name of Stream)

at published sections in the Flood Insurance Study for ____________________________
(Name of Community)

dated __________________________ and will not impact (0.000 foot rise) the base (100-year) flood elevations, floodway elevations, and floodway widths at unpublished cross sections in the vicinity of the proposed development.

_____________________________ (Date)

_____________________________________ (Signature)

_____________________________________ (Title)

SEAL:

_____________________________________ (Address)

_____________________________________ (License number)

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Section 11

GREEN INFRASTRUCTURE

11.1 General

Green infrastructure may be utilized in public spaces and is encouraged in private development to reduce runoff and improve stormwater quality. The use of green infrastructure elements in the public right of way needs approval from the City Engineer and Director of Public Works.

The EPA describes Green Infrastructure as the following:

"Section 502 of the Clean Water Act defines green infrastructure as "...the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters."

Green infrastructure is a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits. While single-purpose gray stormwater infrastructure—conventional piped drainage and water treatment systems—is designed to move urban stormwater away from the built environment, green infrastructure reduces and treats stormwater at its source while delivering environmental, social, and economic benefits.

Stormwater runoff is a major cause of water pollution in urban areas. When rain falls on our roofs, streets, and parking lots in cities and their suburbs, the water cannot soak into the ground as it should. Stormwater drains through gutters, storm sewers, and other engineered collection systems and is discharged into nearby water bodies. The stormwater runoff carries trash, bacteria, heavy metals, and other pollutants from the urban landscape. Higher flows resulting from heavy rains also can cause erosion and flooding in urban streams, damaging habitat, property, and infrastructure.

When rain falls in natural, undeveloped areas, the water is absorbed and filtered by soil and plants. Stormwater runoff is cleaner and less of a problem. Green infrastructure uses vegetation, soils, and other elements and practices to restore some of the natural processes required to manage water and create healthier urban environments. At the city or county scale, green infrastructure is a patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the neighborhood or site scale, stormwater management systems that mimic nature soak up and store water."

11.2 Green Infrastructure Types

Green infrastructure activities can improve existing stormwater management infrastructure. Examples of green infrastructure that can be implemented in a community are stream daylighting, permeable pavement, green roofs, bioswales/stormwater parks, green streets and alleys, urban tree canopy, rain gardens/bioretention, cisterns and rainfall harvesting devices, subsurface infiltration, downspout disconnection, planter boxes, green parking and land conservations. Proposals for green infrastructure should be incorporated into community or neighborhood scale projects and include a future maintenance plan.

11.3 Appendix

11.3.1 References

(1) Green Infrastructure. (2019, December). United States Environmental Protection Agency. https://www.epa.gov/green-infrastructure/what-green-infrastructure

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Section 12

GLOSSARY

12.1 Glossary of Terms

Archival – refers to documents, records and data previously published or accepted by a governing agency. Archival information supersedes other information in instances of contradiction.

Backwater (H_1*) – the rise in water surface elevation due to a downstream bridge, culvert, or other construction.

Baseflood – the flood defined by the Federal Emergence Management Agency as the basis for managing flood prone areas. It is a 100-year event.

Bypass – flow which passes an inlet without entering

Conveyance – the carrying capacity of a part of a floodplain, i.e., the amount of discharge a specific portion of the floodplain can carry.

Critical flow – the state of flow for a given discharge at which the specific energy is a minimum with respect to the bottom of the conduit.

Design period – the period of time (years) between storms or floods of a particular magnitude (intensity and deviation). Specified for particular structures or circumstances. Also referred toas design interval, base, or frequency.

Design runoff – the quantity of water flow (usually cubic feet per second), calculated based on the design period, the design criteria, and specific flow equations, to be used to design a particular structure or circumstance. Also referred to as design flow, or quantity.

Designer: Engineer responsible for design process

Detention – temporary storage of storm water runoff for gradual release to equalize runoff discharge to drainage systems.

Differential head (h) – the difference in water surface elevations between upstream and downstream sides of approach embankments.

Drainage area (A) – (catchment, watershed) the area which contributes runoff to a specific point or structure of interest.

Duration – the effective time span of a storm

Floodplain – the land adjacent to a watercourse that is subject to flooding

Floodway – the channel and adjacent to a watercourse that is subject to flooding

Floodway fringe – the part of the floodplain outside the floodplain outside the floodway that may be obstructed without causing more than a 1.0’ increase in water surface elevation for the base flood.

Freeboard – the vertical clearance between the design water surface elevation and the top of the drainage structure or low chord of bridge. Freeboard allows for passage of debris and a safety factor in design.

Gauged Station: Part of a continuous stream monitoring program employed by the USGS.

Headwater (hw) – water upstream of a structure

HEC-HMS: US Army Corps of Engineers Hydrologic Engineering Center – Hydrologic Modeling System

HEC-RAS: US Army Corps of Engineers Hydrologic Engineering Center – River Analysis System

HYDRO CAD: Computer Aided Design stormwater runoff modeling system

Hydraulic length (L) – the effective length of unchannelized overland flow of a drainage area.

Hydraulic radius – r = A/P ft., is a term used in flow calculation which represents the cross-sectional area of flow divided by the wetted perimeter created by the flow on the confining surface.

Hydrograph – plot of discharge verses time used for determining peak rates of discharge and a total volume of flow.

Hydrologic soil group – a group of soils sharing similar infiltration and transmission rates. The four hydrologic group (A, B, C and D) are used in SCS procedure for estimating peak rate of runoff.

Hydrology: The science dealing with the properties, distribution, and circulation of water on and below the earth's surface and in the atmosphere. Specific to this document, the focus is on rainfall.

HYDRWIN: LADOTD hydraulic modeling program

Impervious area – surfaces which runoff will not appreciably penetrate, such as roofs, concrete and asphalt surfaces.

Intensity (I) – the concentration of rainfall; the amount of rainfall within a set time.

Intrado – the interior curve of an arch

LADOTD: Louisiana Department of Transportation and Development

Low chord – the bottom elevation of the span of a bridge which defines the top of the clear opening for flow.

NOAA: National Oceanic and Atmospheric Administration

Non-uniform flow – a condition of flow in which the discharge, or quantity of water flowing per unit of time, and velocity vary.

Normal depth – the depth at which uniform flow occurs for a certain cross-sectional area, slope discharge, and roughness coefficient.

NRCS: Natural Resources Conservation Service (formerly Soil Conservation Service)

NRCS Method: The Natural Resources Conservation Service method is used to estimate peak runoff rates of ungauged watersheds of 200 to 2,000 acres and can be used in rural or urban watersheds.

NSS: National Streamflow Statistics

Peak Discharge: A calculated maximum discharge during a storm event.

Rainfall Intensity: The ratio of the total amount of rain (rainfall depth) falling during a given period to the duration of the period.

Rational Method: The rational method was developed to predict peak flow rates for small, urban watersheds.

Re-expansion – the return of flow to its natural width of spread after passing through a constriction.

Runoff: The portion of precipitation on land that ultimately reaches streams and other water bodies.

Runoff discharge (Q) – the measure of flow from a drainage area resulting from rainfall, after deducting infiltration, retention and transit losses.

Rural drainage area – any watershed that meets both of the following criteria: all parts of the watershed are outside the City Limits of Shreveport, and no drainage system within the watershed collects of conveys runoff using curb-and-gutters.

Scour – the removal of channel bed material by swiftly moving or turbulent flow, associated with the increased transport ability of a stream flowing through a constriction.

Specific energy – the distance between the channel bottom and the energy gradeline. Specific energy is usually expressed as the sum of flow depth and velocity head.

Spillthrough abutments – bridge abutments which slope down to the channel bed rather than having a straight vertical wall.

Spread (W) – the width of flow (transverse to direction of flow) in a roadway or channel.

Spingline – a term used in pipe installation in trenches that denotes the line that is a distance of one half of the diameter of pipe above the bottom of the pipe.

Subcritical flow – flow at depths greater than critical flow.

Submergence – (inundation) occurs when the water surface elevation rises above the clear opening of a bridge. Hydraulic forces then act on the bridge, and flow is either constructed under the low chord or split over and under the bridge structure.

Sump – a low point in a surface drainage system which holds water unless drained by a ssubsurface system.

Supercritical flow – flow characterized by unstable depth, where the Froude number $F > 1$, depth $y=(Q^2/g)^{0.33}$, and velocity head is half of the depth.

Surcharge – an increase in water surface elevation above the “natural” W.S.L. due to encroachments or constrictions in the floodplain.

SWMM: Stormwater Management Model

SWPPP: Stormwater Pollution Prevention Program

Tailwater – water downstream of a structure.

Time of concentration (t_c) – the total travel time of a wave to travel from the hydraulically most distant point of a watershed to a point of interest and marks the time required for the entire upstream catchment to contribute flow to the point of interest.

Turbulence – a characteristic of flow including eddies and mixing action resulting in variable velocity and rough streamlines.

Uniform flow – (steady uniform flow) – a condition of flow in which the discharge, or quantity of water flowing per unit of time, and velocity are constant. Flow is at normal depth and can be computed by the Manning Equation.

Urban drainage area – any watershed that collects and conveys runoff using curb-and-gutters; or any watershed, partially or totally, that is contained within the City Limits of Shreveport.

USACE: The U.S. Army Corps of Engineers.

USDA: United States Department of Agriculture

USGS Regression Method: This method uses an isohyetal line map to represent annual rainfall data.

USGS: The United States Geological Survey.

Waterway – stream channel and adjacent land which carries floodwaters out of the floodplain.

Watershed: An area of land that feeds all the water running under it and draining off it into a body of water.

Watershed slope (S) – the average slope of the watershed land which overland flow covers. (This is not the channel slope.)

Weighted – composite; an average value based on proportions of the total.

Wetted perimeter – (WP) a linear measure of the portion of a drainage structure which is in contact with flow, measured on plan for grate inlets and on cross section for channels.

WIN TR-55: USDA NRCS Modeling System

12.2 Glossary of Abbreviations

A – drainage area (Ch. 2)

A – cross sectional area of flow (Ch. 3 & 4)

a – Inlet depression

A.C.E. – U.S. Army, Corps of Engineers

C – coefficient (various)

CF – reduction coefficient for closing

cfs – cubic feet per second (CFS)

CMP – Corrugated metal pipe

CN – runoff curve number

COS – City of Shreveport

D_b – depth of grate inlet bars

D_f – flow distance in excess of 1000 feet

F – adjustment factor (various)

F – Froude number

FEMA – Federal Emergency Management Agency

FHWA – Federal Highway administration

fps – feet per second

$ft.^2$ – square feet (sq. ft.)

g – gravitational acceleration = 32.2 fps^2

H – depth of water in inlet entrance

h – total height of inlet opening

h – differential head

H_1* – backwater

h_j – juncture or structure loss

HEC – Hydrologic Engineering Center, A.C.E.

I – rainfall intensity

K_j – head loss coefficient

L – length of inlet opening (L_i)

L – hydraulic length of watershed (L_n)

L_{Gcap} – length of roadway to accumulate Q_{Gcap}

L.F. – linear feet

n – Manning's coefficient of roughness

P – precipitation / 24hr (NRCS) or (USGS)

Q – discharge

Q_p – peak rate of runoff

Q_{Gcap} – gutter flow capacity

q_a – unit flow per length; over-the-curb constant

R – runoff

R – hydraulic radius

RF – reduction factor, recession

R_L – urban adjustment ratio

RCP – reinforced concrete pipe

S – longitudinal slope

SCS – Soil Conservation Service

s_x – cross slope

S_f – slope of energy grade line/slop of pipe

NRCS – Natural Resource Conservation Service

T – time of overland travel in excess of time for 1000 ft.

t_c – time of concentration

USGS – United Stated Geological Survey

V - velocity

X – exponent (various)

W – (spread) width of flow

W_p – average width of drainage area (average block, transverse to flow)

Y – depth of flow upstream if inlet depression

y – total depth of flow at curb or sump (H)

z – reciprocal of cross slope ($1/s_x$)