CITY OF LONGMONT
STORM DRAINAGE CRITERIA MANUAL

TABLE OF CONTENTS

Page

SECTION 800 STORM SEWER SYSTEM

801 INTRODUCTION.. 802
802 DESIGN CRITERIA... 802
    802.1 Design Storm Frequency.. 802
    802.2 Construction Materials.. 803
    802.3 Vertical Alignment.. 803
    802.4 Horizontal Alignment.. 803
    802.5 Pipe Size... 803
    802.6 Storm Inlets.. 803
    802.7 Storm Sewer Capacity and Velocity............................. 804
    802.8 Storm Sewer Outlets... 804
803 HYDRAULICS OF STORM SEWERS.. 804
    803.1 Pipe Friction Losses.. 804
    803.2 Pipe Form Losses.. 804
    803.3 Junction and Manhole Losses................................... 806
    803.4 Partially Full Pipe Flow...................................... 806
    803.5 Storm Sewer Outlets... 806
804 HYDRAULICS OF STORM INLETS.. 806
    804.1 Introduction.. 806
    804.2 Continuous Grade Condition.................................... 807
    804.3 Sump Condition.. 808
    804.4 Inlet Spacing... 809
805 STORM SEWER SYSTEM DESIGN... 810
    805.1 Preliminary Design.. 810
        1. Basic Data... 810
        2. Hydrologic Analysis...................................... 811
        3. Preliminary Sizing....................................... 811
        4. Major Storm Routing...................................... 811
        5. Evaluation of Preliminary Design......................... 812
    805.2 Final Design.. 812
    805.3 Rational Method Storm Sewer Sizing............................ 812
        1. Time-of-Concentration.................................... 812
        2. Preliminary Storm Sewer Sizing........................... 812
        3. Preliminary Inlet Sizing................................. 814

LIST OF TABLES

Page

801 STORM SEWER ALIGNMENT AND SIZE CRITERIA.......................... 815

802 STORM SEWER ENGERGY LOSS COEFFICIENT (EXPANSION, CONTRACTION, BENDS)............ 816/817

803 MANHOLE AND JUNCTION LOSSES...................................... 818

LIST OF FIGURES

801 HYDRAULIC PROPERTIES OF CIRCULAR PIPE........................... 819

802 HYDRAULIC PROPERTIES OF ELLIPTICAL PIPE......................... 820

803 HYDRAULIC PROPERTIES OF ARCH PIPE............................... 821

804 ALLOWABLE INLET CAPACITY - TYPE 13 COMBINATION ON CONTINUOUS GRADE.......... 822

805 ALLOWABLE INLET CAPACITY - TYPE R CURB OPENING ON CONTINUOUS GRADE............ 823

806 ALLOWABLE INLET CAPACITY - SUMP CONDITION ALL INLETS.......... 824

CITY OF LONGMONT
STORM DRAINAGE CRITERIA MANUAL

SECTION 800 STORM SEWER SYSTEM

801 INTRODUCTION

The criteria presented herein shall be used in the design and evaluation of the storm sewer systems for City of Longmont. The review of all planning submittals (see Section 200) will be based on the criteria presented in this section.

The phrase "storm sewer system" refers to the system of inlets, pipes, manholes or junctions, outlets and other appurtenant structures designed to collect and convey the minor storm runoff (see Section 304.3) and discharge the runoff into a Major Drainageway System. The storm sewer system is a part of the Minor Drainage System, which may also include curb and gutters, roadside ditches, swales, and channels.

The storm sewer system receives the most attention from the engineer and the public, since the primary function is to collect and convey the regularly recurring storm runoff with minimal inconvenience to the public. If the system does not function accordingly, inconvenience and damage can occur resulting in adverse publicity. The storm sewer system must therefore be designed to minimize the nuisances of regular recurring storms.

In general, the storm sewer system is required when the other parts of the Minor Drainage System (especially the streets) no longer have the capacity for additional runoff. Because of this requirement, the relationship with the Major Drainageway System will effect the need for the storm sewer system. The more extensive the Major Drainageway System (i.e., channels), the less extensive is the need for the storm sewer system, which is generally the more costly part of the Total Drainage System.

Presented in this section, along with the technical criteria, is the general procedure for design and evaluation of storm sewer and storm inlets using the Rational Method (see Section 602).

802 DESIGN CRITERIA

802.1 Design Storm Frequency

The storm sewer system, beginning at the upstream end with inlets, is required when the allowable street capacity (see Section 900) is exceeded for the minor storm. The minor storm frequency is dependent on land use, as presented in the Policy Section 304.3 and is repeated here:

LAND USE	RECURRENCE INTERVAL (YRS) MINOR DRAINAGE SYSTEM
Residential-Urban	2
Residential-Rural	5
Commerical/Business	5
Industrial	5
Open Space	2
School	2

802.2 Construction Materials

Reinforced Concrete Pipe (RCP) of any cross sectional shape in accordance with ASTMC-76, C-506, C-507 is acceptable for use in storm sewer construction. Non- reinforced concrete pipe in accordance with ASTMC-14 is permitted provided it meets the same D-load to produce the ultimate load under the three edge bearing method as specified for RCP. Wall thickness of pipe may be increased as required to meet D-load requirement. Other acceptable materials are corrugated PVC in accordance with ASTM D-3034,and ASTM F-679 (such as "Perma-Loc" by Johns Mansville) corrugated polyethylene pipe in accordance with ASTM D-1248 (such as "Spirolite Pipe by Gulf Plastic Fabricated Products Company), or other plastic pipe manufactured for the purpose of storm drainage and approved by the City Engineer.

802.3 Vertical Alignment

The sewer grade shall be such that a minimum cover is maintained to withstand AASHTO H-20 loading on the pipe. The minimum cover depends upon the pipe size, type and class, and soil bedding condition, but shall be not less than 1-foot at any point along the pipe.

Manholes will be required whenever there is a change in size, direction, elevation, grade or where there is a junction of two or more sewers. In addition, the maximum spacing between manholes for various pipe sizes shall be in accordance with Table-801.

The minimum clearance between storm sewer and water main, either above or below, shall be 12-inches. Concrete encasement of the water line will be required for clearances of 12-inches or less.

The minimum clearance between storm sewer and sanitary sewer, either above or below, shall also be 12-inches. In addition, when a sanitary sewer main lies above a storm sewer, or within 18-inches below, the sanitary sewer shall have an impervious encasement or be constructed of structural sewer pipe for a minimum of 10-feet on each side of where the storm sewer crosses.

802.4 Horizontal Alignment

Storm sewer alignment between manholes shall be straight, except when approved in writing by the City Engineer. Storm sewers may be constructed with curvilinear alignment by the pulled-joint method, pipe bends, or by radius pipe. The limitations on the radius for pulled-joint pipe is dependent on the pipe length and diameter, and amount of opening permitted in the joint. The maximum allowable joint pull shall be 3/4-inches and is subject to prior approval of the City Engineer. The minimum parameters for radius type pipe is shown in Table-801. The radius requirements for pipe bends is dependent upon the manufacturer's specifications.

802.5 Pipe Size

The minimum allowable pipe size for storm sewers is dependent upon a practical diameter from the maintenance standpoint. The length of the sewer also affects the maintenance and, therefore, the minimum diameter. Table-801 presents the minimum pipe size for storm sewers.

802.6 Storm Inlets

The standard inlets permitted for use in City of Longmont streets are:

INLET TYPE	STANDARD DETAIL	PERMITTED USE
Curb Opening Inlet Type R	SD-1	All street types with 6" vertical curb
Grated Inlet Type C	SD-2	All streets with a roadside ditch
Grated Inlet Type 13	SD-3	Alleys or private drives with a valley gutter
Combination Inlet Type 13	SD-4	All street types with 6" vertical curb

Refer to "Policy" Section 304.5 for definition of street types. Note that Type C grated inlet is always operating under a sump condition due to the downstream berm required by Standard Detail SD-2.

802.7 Storm Sewer Capacity and Velocity

Storm sewers shall be designed to convey the initial storm flood peaks without surcharging the sewer. The capacity and velocity shall be based on the Mannings n-values presented in Table-801. The maximum full flow velocity shall be less than 15 fps. The energy grade line (EGL) for the design flow shall be at or below the final grade (± 6 inches) above the pipe at manholes , inlets, or other junctions. To insure this objective is achieved, the hydraulic grade line (HGL) and the EGL shall be calculated by accounting for pipe friction losses and pipe form losses. Total hydraulic losses will include friction, expansion, contraction, bend, and junction losses. The methods for estimating these losses are presented in the following sections.

802.8 Storm Sewer Outlets

All storm sewer outlets into open channels shall be constructed with a headwall and wingwalls or a flared-end-section. Riprap shall be provided at the outlet in accordance with Section 705.6.

803 HYDRAULICS OF STORM SEWERS

Presented in this section are the general procedures for hydraulic design and evaluation of storm sewers. The user is assumed to possess a basic working knowledge of storm sewer hydraulics and is encouraged to review the text books and other technical literature available on the subject (References-3, -6, -7, -9, -10, -12, and -40).

803.1 Pipe Friction Losses

The Mannings n-values to be used in the calculation of storm sewer capacity and velocity are presented in Table-801.

803.2 Pipe Form Losses

Generally, between the inlet and outlet, the flow encounters a variety of configurations in the flow passageway such as changes in pipe size, branches, bends, junctions, expansions, and contractions. These shape variations impose losses in addition to those resulting from pipe friction. Form losses are the result of fully developed turbulence and can be expressed as follows:

$$H_L = K\,(V^2/2g) \qquad (801)$$

where H_L = head loss (feet)

K = loss coefficient

$V^2/2g$ = velocity head (feet)

g = gravitational acceleration (32.2 ft/sec^2)

The following is a discussion of a few of the common types of form losses encountered in sewer system design. The reader is referred to Reference-1 and -6 for additional discussion.

1. Expansion Losses

   Expansion in a storm sewer conduit will result in a shearing action between the incoming high velocity jet and the surrounding sewer boundary. As a result, much of the kinetic energy is dissipated by eddy currents and turbulence. The loss head can be expressed as:

   $$H_L = K_e\,(V_1^{\,2}/2g)(1-(A_1/A_2))^2 \qquad (802)$$

   in which A is the cross section area, V is the average flow velocity, and K-sub e is the loss coefficient. Subscripts 1 and 2 denote the upstream and downstream sections respectively. The value of K-sub e is about 1.0 for a sudden expansion and about 0.2 for a well designed expansion transition. Table-802 presents the expansion loss coefficient for various flow conditions.

2. Contraction Losses

   The form loss due to contraction is:

   $$H_L = K_c\,(V_2^{\,2}/2g)(1-(A_2/A_1)^2)^2 \qquad (803)$$

   where K-sub c is the contraction coefficient. K-sub c is equal to 0.5 for a sudden contraction and about 0.1 for a well designed transtion. Subscripts 1 and 2 denote the upstream and downstream sections respectively. Table-802 presents the contraction loss coefficient for various flow conditions.

3. Bend Losses

   The head losses for bends, in excess of that caused by an equivalent length of straight pipe, may be expressed by the relation

   $$H_L = K_b(V^2/2g) \qquad (804)$$

   in which K-sub b is the bend coefficient. The bend coefficient has been found to be a function of, (a) the ratio of the radius of curvature of the bend to the width of the conduit, (b) deflection angle of the conduit, (c) geometry of the cross section of flow, and (d) the Reynolds Number and relative roughness. A table showing the recommended bend loss coefficients is presented in Table-803.

803.3 Junction and Manhole Losses

A junction occurs where one or more branch sewers enter a main sewer, usually at manholes. The hydraulic design of a junction is in effect the design of two or more transitions, one for each flow path. Allowances should be made for head loss due to the impact at junctions. The head loss at a junction can be calculated from:

$$H_L = (V_2^2/2g) - Kj\ (V_1^2/2g) \qquad (805)$$

where V_2 is the outfall flow velocity, V_1 is the inlet velocity

Because of the difficulty in evaluating hydraulic losses at junctions (Reference-6) due to the many complex conditions of pipe size, geometry of the junction and flow combinations, a simplified table of loss coefficients has been prepared. Table-803 presents the recommended energy loss coefficients for typical manhole or junction conditions that will be encountered in the urban storm sewer system. The coefficients are based on a review of the available data in References-1, -3, -6, and -7.

803.4 Partially Full Pipe Flow

When a storm sewer is not flowing full, the sewer acts like an open channel and the hydraulic properties can be calculated using open channel techniques (Section 700 Open Channels). For convenience, charts for various culvert shapes have been developed by the pipe manufacturers for calculating the hydraulic properties (Figures-801, -802, and -803). The data presented assumes that the friction coefficient, Mannings n-value, does not vary throughout the depth.

803.5 Storm Sewer Outlets

When the storm sewer system discharges into the Major Drainage System (usually an open channel), additional losses occur at the outlet in the form of expansion losses (see Section 803.2). For a headwall and no wingwalls, the loss coefficient K-sub e = 1.0 (see Table-802(a)) and for a flared-end-section the loss coefficient is approximately 0.5 or less.

804 HYDRAULICS OF STORM INLETS

804.1 Introduction

There are three types of inlets: curb opening, grated, and combination grate and curb opening. Other variations, such as deflector inlets, are also available but are not accepted standard inlets for City of Longmont (see Section 802.6). Inlets are further classified as being on a "continuous grade" or in a "sump". The term "continuous grade" refers to an inlet so located that the grade of the street has a continuous slope past the inlet and therefore ponding does not occur at the inlet. The sump condition exists whenever water is restricted to the inlet area because the inlet is located at a low point. A sump condition can occur at a change in grade of the street from positive to negative or at an intersection due to the crown slope of a cross street.

The procedures and basic data used to define the capacities of the standard inlets under various flow conditions were obtained from Reference-1 and -11 for curb opening inlets. The procedure consists of defining the amount and depth of flow in the gutter and determining the theoretical flow interception by the inlet. To account for effects which decrease the capacity of the various types of inlets, such as debris plugging, pavement overlaying and variations in design assumptions, the theoretical capacity calculated for the inlets is reduced by the factors presented below for the standard inlets.

ALLOWABLE INLET CAPACITY

CONDITION	INLET TYPE	PERCENTAGE OF THEORETICAL CAPACITY ALLOWED
Sump or Continuous Grade	CDOH Type R (SD-1)	
	5' length	88
	10' length	92
	15' length	95
Continuous Grade	Combination Type 13 (SD-4)	66
Sump	Grated Type C (SD-2)	50
Sump	Combination Type 13 (SD-4)	65

Allowable inlet capacities for the standard inlets have been developed and are presented in Figures-804 and -805 for "continuous grade" and Figure-806 for sump conditions. The allowable inlet capacity is dependent on the allowable street capacity (Section 900) and the values shown were calculated on the basis of the <u>maximum</u> flow allowed in the street gutter (or roadside ditch for Type C). For the gutter flow amounts less than the maximum, the allowable inlet capacity must be proportionately reduced.

804.2 Continuous Grade Condition

For the "continuous grade" condition (Figures-804 and -805), the capacity of the inlet is dependent upon many factors including gutter slope, depth of flow in the gutter, height and length of curb opening, street cross slope, and the amount of depression at the inlet. In addition, all of the gutter flow will not be intercepted and some flow will continue past the inlet area ("inlet carryover"). The amount of carryover must be included in the drainage facility evaluation as well as in the design of the inlet. Only type R and Type 13 inlets are allowed in a continuous grade condition, since Type C will operate under a sump condition per the Standard Detail SD-2.

The use of Figure-805 is illustrated by the following example:

<u>Example 15: Allowable Capacity for Type R Curb Opening Inlets on Continuous Grade</u>

<u>Given:</u> Street Type - Major Collector - Type C, S = 1.0 percent, maximum flow depth = 0.43 (5-1/8") (see Section 900), maximum allowable street capacity = 7.0 cfs (see Section 900), gutter flow = 6.0 cfs.

<u>Find:</u> Interception and carryover amounts for 15-foot Type R inlet

<u>Solution:</u>

Step 1: From Figure-805 for an allowable depth of 0.43-feet read the value 6.4 cfs. Note that even though the gutter flow is less than maximum allowable, the maximum depth is used for Figure-805. The effect of the lower depth on the inlet capacity will be accounted for in the following steps.

Step 2: Compute the interception ratio R

$$R = \frac{\text{Allowable Inlet Capacity}}{\text{Allowable Street Capacity}} = \frac{6.4}{7.0}$$

$$R = 0.91$$

Step 3: Compute the interception amount Q_I

$$Q_I = R \times Q \text{ street}$$

$$= 0.91 \times 6.0$$

Q_I = 5.5 cfs amount intercepted by inlet

Step 4: Compute the carryover amount Q_{co}

$$Q_{co} = Q \text{ street} - Q_I$$

$$= 6.0 - 5.5$$

$$Q_{co} = 0.5 \text{ cfs}$$

The same procedure above can be used for type 13 inlets using Figure-804.

804.3 Sump Condition

The capacity of the inlet in a sump condition is dependent on the depth of ponding above the inlet. Typically the problem consists of estimating the amount of inlets or depth of flow required to intercept a given flow amount. The use of Figure-806 is illustrated by the following example:

Example 16: Allowable Capacity for Combination Type 13 Inlet in a Sump

Given: Flow in gutter = 6.0 cfs
Maximum allowable street depth = 0.43-feet
Type 13 single inlet

Find: Depth of ponding

Solution:

Step 1: From Figure-806, read the depth of flow (d = 0.43) for the gutter flow of 6.0 cfs.

Step 2: Compare computed to allowable depth. Since the computed depth is less than or equal to the allowable depth, the inlet is acceptable, otherwise the amount of inlets or the type of inlet would be changed and the procedure repeated.

804.4 Inlet Spacing

The optimum spacing of storm inlets is dependent upon several factors, including traffic requirements, contributing land use, street slope, and distance to the nearest outfall system. The suggested sizing and spacing of the inlets is based upon the interception rate of 70 percent to 80 percent. This spacing has been found to be more efficient than a spacing using 100 percent interception rate. Using the suggested spacing, only the most downstream inlet in a development would be designed to intercept 100 percent of the flow. Also considerable improvements in overall inlet system efficiency can be achieved if the inlets are located in the sumps created by street intersections. The following example illustrates how inlet sizing and interception capacity may be analyzed:

Example 17: Inlet Spacing

Given: Maximum allowable street flow depth = 0.48
Street slope = 1.0 percent
Maximum allowable gutter flow = 9.5 cfs
Gutter flow = 9.5 cfs

Find: Size and type of inlet for 75 percent interception

Solution:

Step 1: Compute desired capacity

$$Q = (0.75)(9.5 \text{ cfs}) = 7.1 \text{ cfs}$$

Step 2: Read the allowable inlet capacities from Figures-804 and -805 for various inlets. The following values were obtained:

INLET TYPE	CAPACITY	% INTERCEPTION
Triple Type 13	4.7	51%
Double Type R	6.3	63%
Triple Type R	7.7	79%

Therefore a curb opening inlet type-R, L = 15-feet is required, and will intercept 7.7 cfs. The remaining 1.8 cfs will continue downstream and contribute to the next inlet.

A comparison of the inlet capacity with the allowable street capacity (Section 900) will show that the percent of street flow interception by the inlets varies from less than 50 percent to as much as 95 percent of the allowable street capacity. Therefore, the optimum inlet spacing cannot be achieved in all instances, and the spacing requirements should be analyzed by the design engineer.

805 DESIGN OF STORM SEWER SYSTEM

Presented in this section is the design procedures for a storm sewer system from preliminary design considerations to final design. The use of the Rational Method for sizing the sewer system is also discussed.

A typical drainage system within a subdivision would consist of flow in the storm sewer and allowable flow in the gutter, which combined would carry the flows from the "minor" storm without the effects of detention. These flows would be discharged to a larger sewer system or an open channel with capacity for the "major" flood. As the storm intensity increases (i.e., 10-year storm), the onsite detention would reduce the developed flood peaks to "undeveloped" levels thereby allowing the storm sewer/street upstream to extend its effectiveness to major floods. During calculation of the major storm runoff (i.e., 10- and 100-year) the benefits of upstream onsite detention can be accounted for during the routing of flood peaks through the development (see also Sections 805 and 1202.2).

805.1 Preliminary Design

The preliminary design of the storm sewer system begins after a sketch plan or preliminary development plan has been prepared delineating the general development areas, major drainage paths, and drainage outfall locations. In accordance with Section 302 "Policy" of this MANUAL, allocation of space for drainage, consideration of a multi-purpose resource, and other policy requirements shall be incorporated into the sketch plan or preliminary development plan. The drainage engineer must have input to the development plan to assure proper drainage planning.

1. Basic Data

   The first step in any drainage project is the collection of basic data since all drainage projects are unique. The typical information required is as follows (note: refer to Section 200 for specific requirements):

   a. Topographic maps of the development also delineating road patterns, existing and proposed land uses, and major drainage features.

   b. A topographic map of the basin containing the development area and property boundaries.

   c. Typical street cross sections.

   d. Preliminary grading information, such contours, prepared profiles, and/or control elevations.

   e. Soils information.

   f. Existing or proposed utilities.

   g. Existing irrigation facilities and requirements for maintaining facilities.

   h. Rainfall information (Section 500)

2. Hydrologic Analysis

The next step is to perform the hydrologic evaluation of the basin for both the initial and major storms (see Section 304 Policy and Section 600 Runoff). The basin is divided into smaller sub-basins and the design flood peaks are determined for each hydrologic point of interest. The degree of basin sub-division will be dependent on the detail of information available and experience of the drainage engineer. Some general guidelines are discussed in Section 602.2 for the Rational Method and Section 604.5 for the CUHP. The Rational Method for sizing storm sewers is discussed further in Section 805.3

3. Preliminary Sizing

Preliminary street grades and cross sections must be available to the storm sewer designer so he can calculate the allowable carrying capacity for these streets. Beginning at the upper end of the basin in question, the designer should calculate the quantity of flow in the street until the point is reached at which the allowable carrying capacity of the street matches the design runoff computed by the Rational Method. Initiation of the storm sewer system would start at this point if there is no alternate method of removing runoff from the street surface. Removal of all the street flow by the storm sewer system is not required except at sump areas and may not be economical (see Section 804.4). However, the sum of the flow in the sewer plus the flow in the street must be less than or equal to the allowable capacity of the street and storm sewer.

For preliminary sizing purposes, the diameter, type of pipe, and slope is generally sufficient. Manning's n-values used shoud be consistent with Table-801. In some instances, a profile may be required to check utility conflicts or to assure compatability with the major drainage system. The assumed grade of the sewer should not be steeper than the proposed street grade unless checked by a profile. The designer should also be aware of utility requirements, especially when crossing water, sewer, and sewer service lines.

4. Major Storm Routing

After sizing the storm sewer, the next step is to route the major storm through the system and compare the flows to the allowable capacity (see Section 900). The combined total of the allowable street carrying capacity for the major storm and the storm sewer capacity should equal or exceed the major design runoff. At any given point along the storm sewer system, the capacity of the sewer should be assumed to be the same for the major storm as the initial storm for preliminary design purposes, unless special analysis indicate that the sewer has surcharge capacity. A plan and profile and hydraulic calculations will be required. If the combined allowable capacity is less than the design flows the following options are available:

a. Increase storm sewer size.

b. Increase street grade within acceptable limits or revise classification of street allowing additional capacity.

c. Revise major drainage system such that the runoff is collected further upstream.

d. Provide additional onsite detention within the development to decrease flows (see Section 1200).

5. Evaluation of Preliminary Design

In addition to a cost estimate for the design, the preliminary system can also be evaluated by developing alternatives and comparing the total benefits. The impact of the system outfall on downstream properties must be identified and resolved if problems exist.

805.2 Final Design

Final design consists of the preparation of plan, profiles, and specifications for the storm sewer system in sufficient detail for construction. The first step consists of the review and verification of the basic data, hydrologic analysis, and storm sewer inlet sizing performed for the preliminary design. Plan and profile drawings are prepared containing the basic data. Drainage subbasins are revised as necessary, and the design flood peaks recalculated. The storm sewer and inlets are then sized taking into account actual street and storm sewer grades, locations of existing and proposed utilities, and the design of the major drainage system. The calculations also include the determination of the hydraulic and energy grade line, both which must be below the street grade. The manholes, junction structures, or other appurtenent structures must be evaluated for energy losses. If special transitions are required to reduce losses, the structural design of the facilities must include these requirements when detailing the structures.

805.3 Rational Method Storm Sewer Sizing

The Rational Method procedure presented in this section is recommended for storm sewer sizing. The procedure consists of computing the design runoff peaks at each hydrologic point using the Rational Method (Section 602), sizing the storm sewer and inlets required to carry the runoff, and using the sewer to route the flows to the next design point. A detailed example for the Rational Method procedure can be found in Reference-1. A general discussion of the three steps is presented below:

1. Time-of-Concentration

When using the Rational Method, the first step is the calculation of the time-of-concentration, which is dependent on whether the basin is urbanized or non-urbanized (see Section 602.3). Standard Form SF-8 has been prepared for these calculations and shall be included with the drainage report submitted (Section 200). The form is used to calculate the initial or overland flow time (t-sub i), the travel time (t-sub t), and the time-of-concentration (t-sub c) for each individual sub-basin. For urbanized basins, an additional calculation check for the final t-sub c is required with the lesser of the two values used (see Section 602.3.2).

2. Preliminary Storm Sewer Sizing

The next step in the Rational Method procedure for storm sewer sizing is the calculation of the runoff peaks at the various design points. Standard Form SF-9 has been prepared for these calculations and shall be included with the drainage report submittal. This form, which is based in part on the form in the USDCM (Reference-1) is divided into five parts, Direct Runoff, Total Runoff, Street, Pipe, and Travel Time. Direct Runoff calculates the runoff peak from each individual sub-basin. Total Runoff combines all the sub-basin and computes the total flow at a given design point. The Street and Pipe parts of the table compute the flow proportions, between the street flow and storm sewer flow, within allowable capacity limits. The lines in the table are offset to represent the portion of the drainage system from one design point to the next downstream design point. Finally, the Travel Time part computes the increment in time for the flow to reach the next downstream design point. The description of each column is as follows:

Col. 1: Street: Street name for which a storm sewer is being considered.

Col. 2: Design Point: Designation for specific location at which the flow is being calculated.

Col. 3: Area Designation: Sub-basin(s) for which the Direct Flow is being calculated. After the first line, the Area Designation represents the sub-basin(s) which is being added to the first Design Point.

Col. 4: Area: Area of sub-basin(s) in Column 3.

Col. 5: Runoff Coefficient: Runoff Coefficient for sub-basin(s) in Column 3 obtained from Table-601.

Col. 6: CA: Product of the Runoff Coefficient (Column 5) and the sub-basin Area (Column 3).

Col. 7: t-sub c: Time-of-Concentration for sub-basin(s) in Column 3 obtained from Standard Form SF-8.

Col. 8: I: Rainfall intensity for t-sub c in Column 7 obtained from Figures-502, -503, or -504.

Col. 9: Q: Peak flow in cfs computed by multiplying Column 6 and Column 8.

Col. 10: t-sub c: Time-of-Concentration for Total Runoff calculation. After the first line, t-sub c is the sum of the t-sub c for the prior design point plus the travel time t-sub t from Column 21.

Col. 11: I: Rainfall intensity for t-sub c in Column 10 obtained from Figures-502, -503, or -504.

Col. 12: Σ CA: Summation of CA values in Column 6 for all prior design points of which this calculation is a part.

Col. 13: Q: Peak flow in cfs computed by multiplying Column 11 and Column 12.

Col. 14: Slope: The minimum street slope to the next design point.

Col. 15: Street Flow: Portion of the total runoff of Column 13 which will be allocated to the street gutter. This value must not be greater than the allowable street capacity shown in Figure-902.

Col. 16: Design Flow: The portion of the total runoff in Column 13 required to be conveyed by the storm sewer. The sum of Column 15 plus Column 16 must be equal to or greater than Column 13.

Col. 17: Slope: The assumed pipe slope for which the pipe capacity is calculated.

Col. 18: Pipe Size: The size of pipe required to convey the flow in Column 16 at the slope in Column 17.

Col. 19: Length: The length to the next design point.

Col. 20: Velocity: The larger velocity between the street flow and the pipe flow, usually the pipe flow.

Col. 21: t-sub t: Travel Time in minutes computed by dividing the length in Column 19 by the velocity in Column 20. This time is added to the time of concentration in Column 10 to compute the t-sub c for the next downstream design point.

3. Preliminary Inlet Sizing
The final step in the Rational Method storm sewer sizing procedure is to size the inlets required to intercept the assumed storm sewer flow (Column 16 Standard Form SF-9). At each design point, there must be sufficient inlets accumulated in the system to intercept the assumed pipe flow, including carryover effects. Refer to Section 804 for calculation procedure.

STORM SEWER ALIGNMENT AND SIZE CRITERIA

Vertical Dimension of Pipe (Inches)	Maximum Allowable Distance Between Manholes and/or Cleanouts
15 to 36	400 Feet
42 and Larger	500 Feet

Minimum Radius for Radius Pipe

Diameter of Pipe	Radius of Curvature
24" to 54"	28.50 ft.
57" to 72"	32.00 ft.
78" to 108"	38.00 ft.

Short radius bends shall not be used on sewers 21 inches or less in diameter.

Minimum Pipe Diameter

Type	Minimum Equivalent Pipe Diameter	Minimum Cross-sectional Area
Main Trunk	18 in.	1.77 sq. ft.
*Lateral from inlet	15 in.	1.23 sq. ft.

*Minimum size of lateral shall also be based upon a water surface inside the inlet or a minimum distance of 1 foot below the grate or throat.

Manning's N-Value

Sewer Type	Capacity Calculation	Velocity Calculation
Concrete (newer pipe)	.013	.011
Concrete (older pipe)	.015	.012
Concrete (preliminary sizing)	.015	.012
Plastic smooth	.011	.009

REFERENCE: "Urban Storm Drainage Criteria Manual", DRCOG, 1969

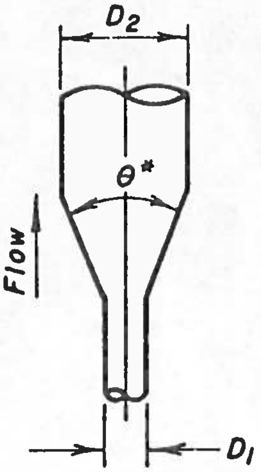
STORM SEWER ENERGY LOSS COEFFICIENT

(EXPANSION, CONTRACTION)

(a) Expansion (K_e)

θ*	$\frac{D_2}{D_1} = 3$	$\frac{D_2}{D_1} = 1.5$
10	0.17	0.17
20	0.40	0.40
45	0.86	1.06
60	1.02	1.21
90	1.06	1.14
120	1.04	1.07
180	1.00	1.00

*The angle θ is the angle in degrees between the sides of the tapering section.



(b) Pipe Entrance from Reservoir

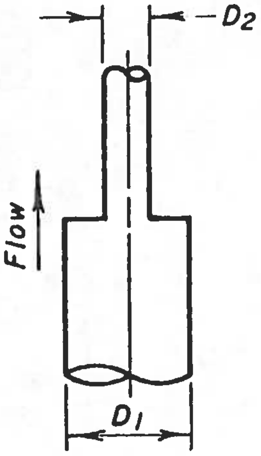
Bell-mouth $H_L = 0.04 \frac{V2}{2g}$

Square-edge $H_L = 0.5 \frac{V2}{2g}$

Groove and U/S For Concrete Pipe $H_L = 0.2 \frac{V^2}{2g}$

(c) Contractions (K_c)

$\frac{D_2}{D_1}$	K_c
0.1	0.5
0.4	0.4
0.6	0.3
0.8	0.1
1.0	0



EQUATIONS:

$$H_L = K_e\left(\frac{V_1^2}{2g}\right)\left[1-\left(\frac{A_1}{A_2}\right)\right]^2$$

$$H_L = K_c\left(\frac{V_2^2}{2g}\right)\left[1-\left(\frac{A_2}{A_1}\right)^2\right]^2$$

REFERENCE: Linsley and Franzini, "Water Resources Engineering", McGraw-Hill, 1964

STORM SEWER ENERGY LOSS COEFFICIENT

(BENDS)

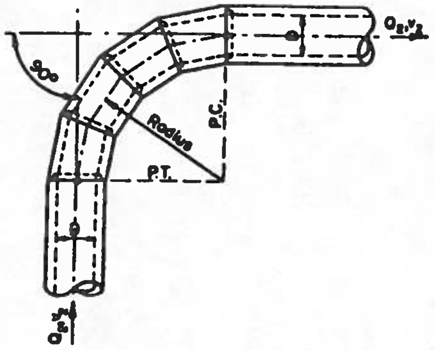
$$H_L=K_j(V^2/2g)$$

CASE I
CONDUIT ON 90° CURVES*

NOTE: Head loss applied at P.C. for length

RADIUS	K_b
1 X D	0.50
(2 to 8) X D	0.25
(8 to 20) X D	0.04
>20 X D	0

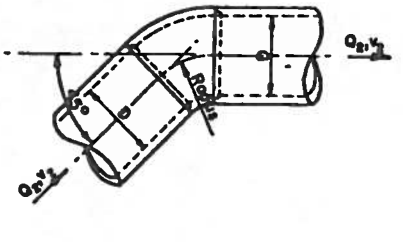
* When curves other than 90° are used, apply the following factors to 90° curves
60° curve 85%
45° curve 70%
22-1/2° curve 40%



CASE II
BENDS WHERE RADIUS IS EQUAL TO DIAMETER OF PIPE

NOTE: Head loss applied at begining of bend

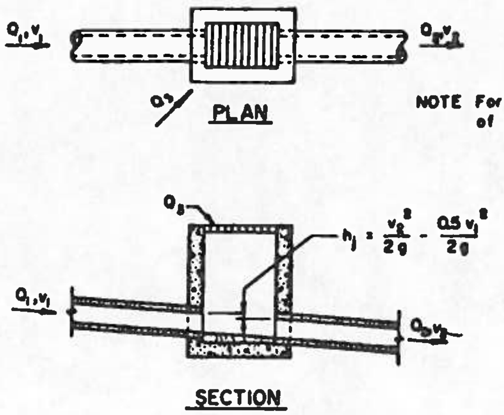
θ° BEND	K_b
90	0.50
60	0.43
45	0.35
22-1/2	0.20



WRC ENG.

REFERENCE:
APWA Special Report No. 49, 1981

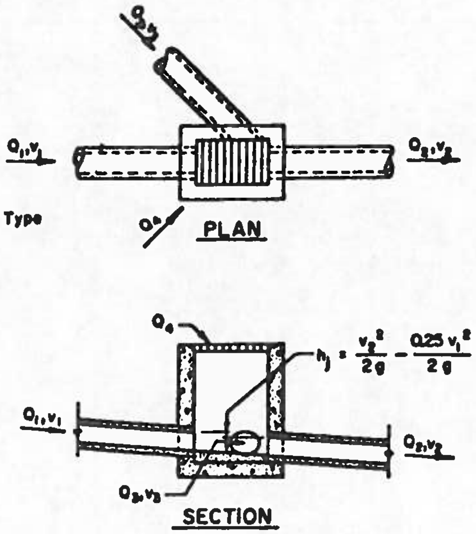
MANHOLE AND JUNCTION LOSSES



NOTE For Any Type of Inlet.

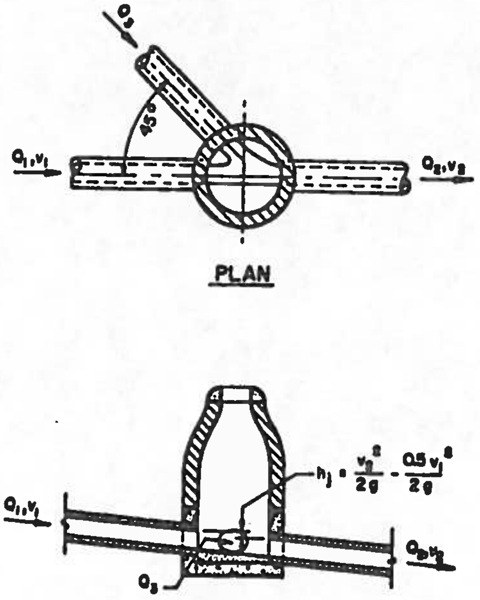
CASE I

INLET ON MAIN LINE



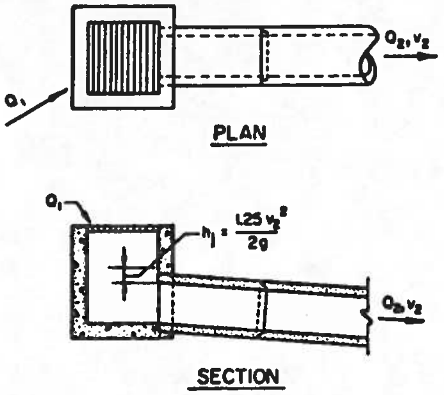
CASE II

INLET ON MAIN LINE WITH BRANCH LATERAL



CASE III

MANHOLE ON MAIN LINE WITH 45° BRANCH LATERAL



CASE IV

INLET OR MANHOLE AT BEGINNING OF LINE

EQUATION:

$$H_L = \left(\frac{V_2^2}{2g}\right) - K_j\left(\frac{V_1^2}{2g}\right)$$

CASE NO.	K_j	CASE III $\theta°$	CASE III K_j
I	0.50	22-1/2	0.75
II	0.25	45	0.50
IV	1.25	60	0.35
		90	0.25
		No Lateral	0.50

WRC ENG.

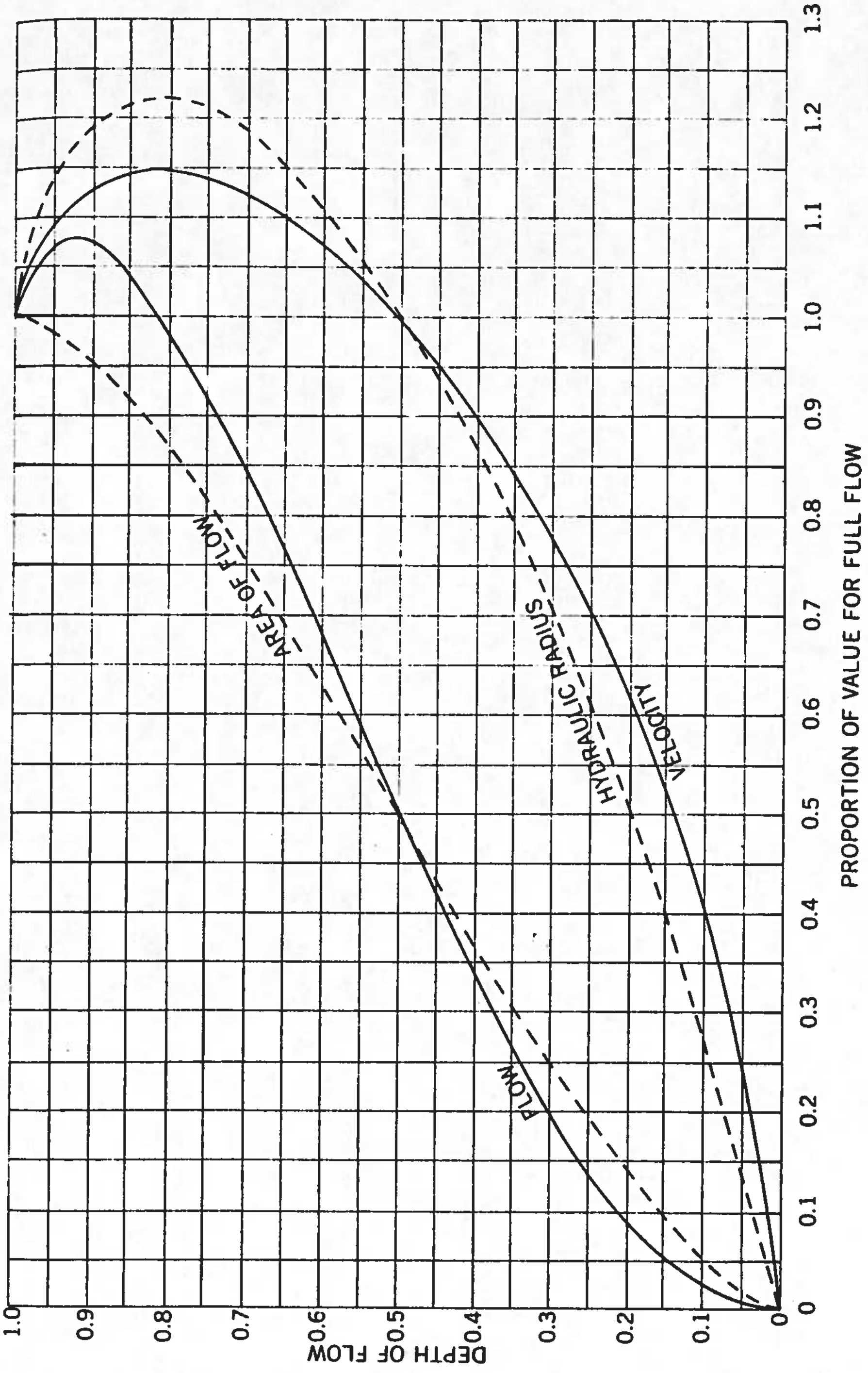
REFERENCE:

APWA Special Report No. 49, 1981

BOULDER COUNTY
STORM DRAINAGE CRITERIA MANUAL

FIGURE 801

HYDRAULIC PROPERTIES CIRCULAR PIPE



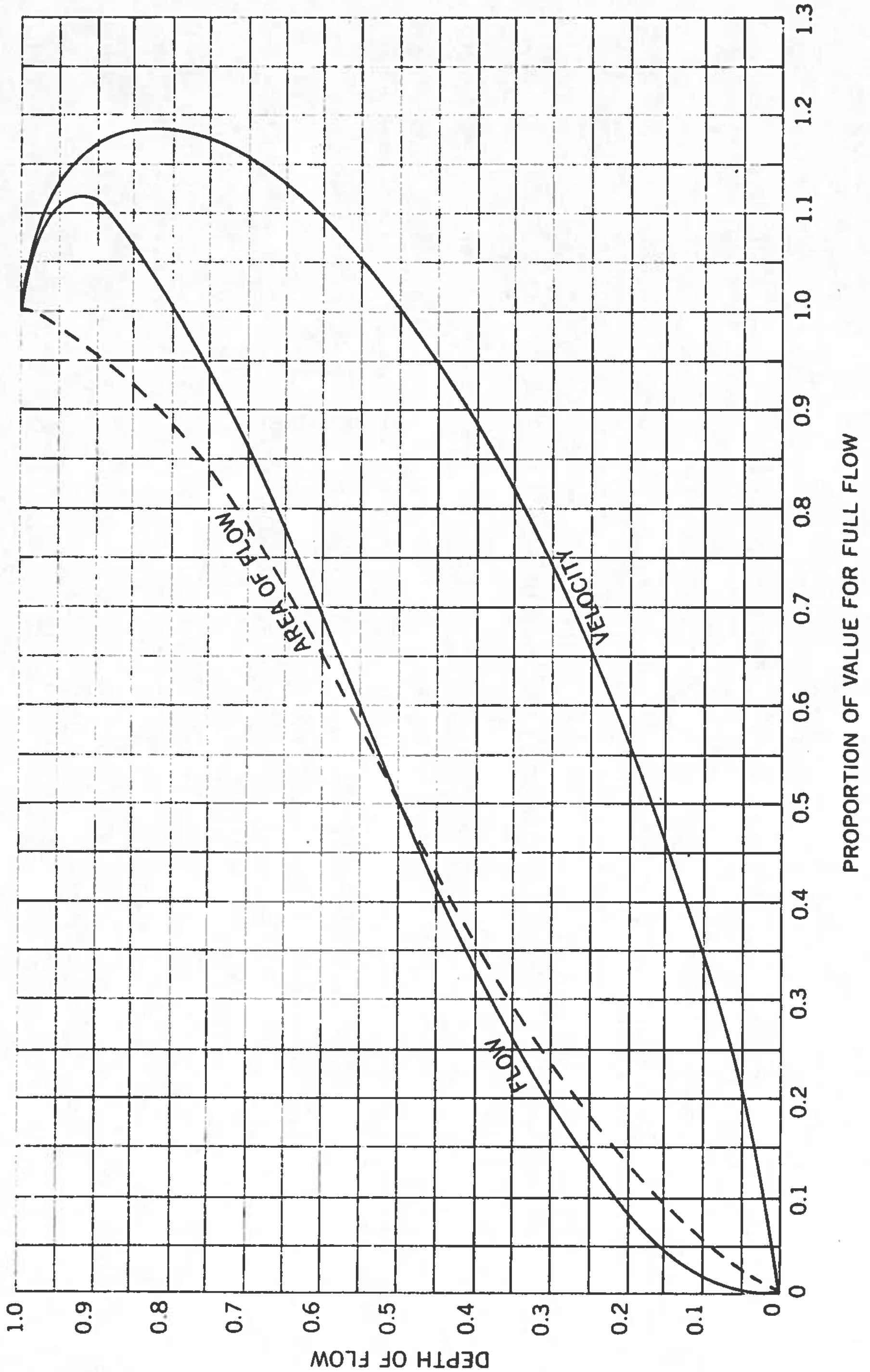
WRC ENG.

REFERENCE: "CONCRETE PIPE DESIGN MANUAL" ACPA, 1970

BOULDER COUNTY STORM DRAINAGE CRITERIA MANUAL

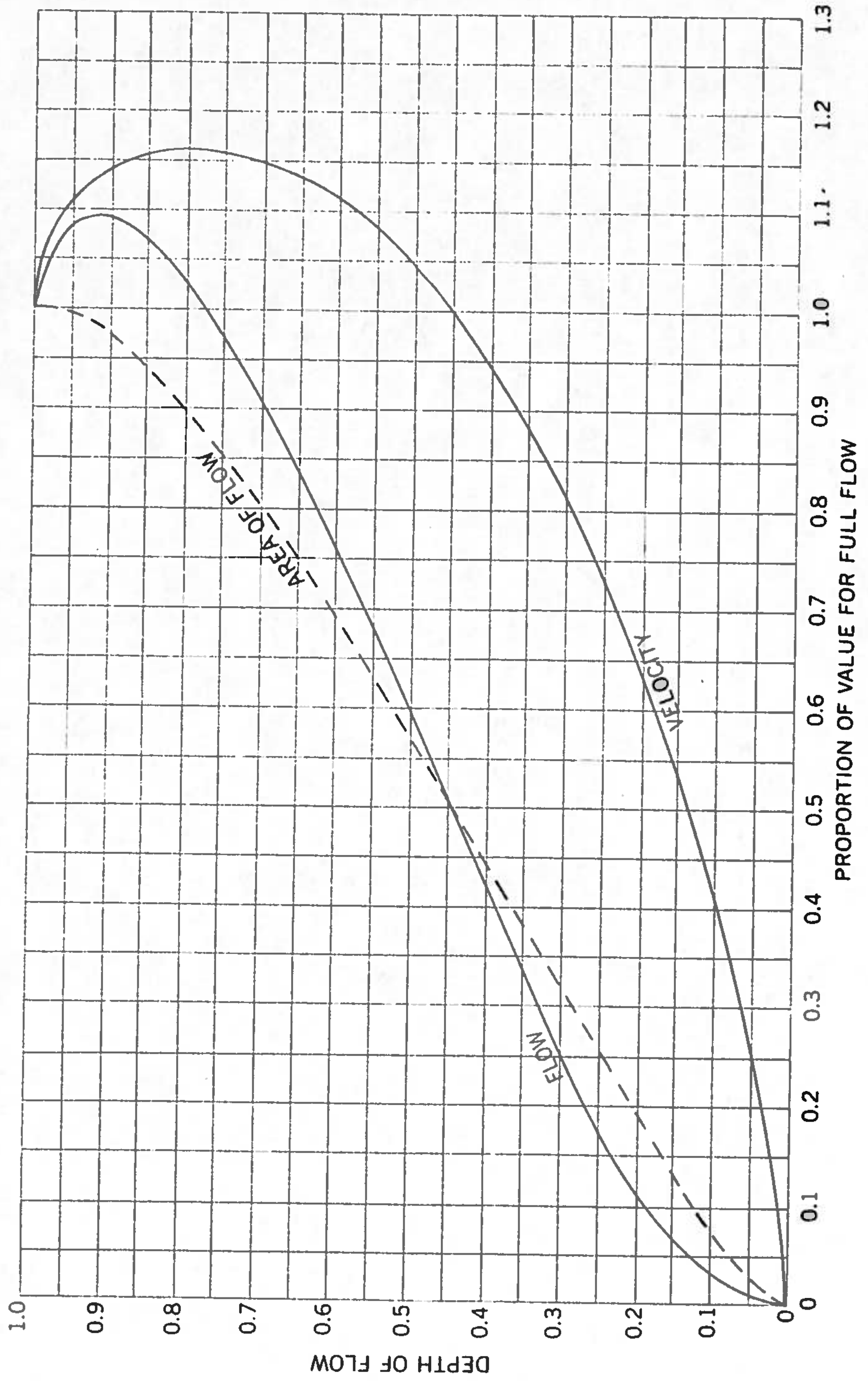
FIGURE 802

HYDRAULIC PROPERTIES HORIZONTAL ELLIPTICAL PIPE



WRC ENG.	**REFERENCE:** "CONCRETE PIPE DESIGN MANUAL" ACPA, 1970

HYDRAULIC PROPERTIES ARCH PIPE



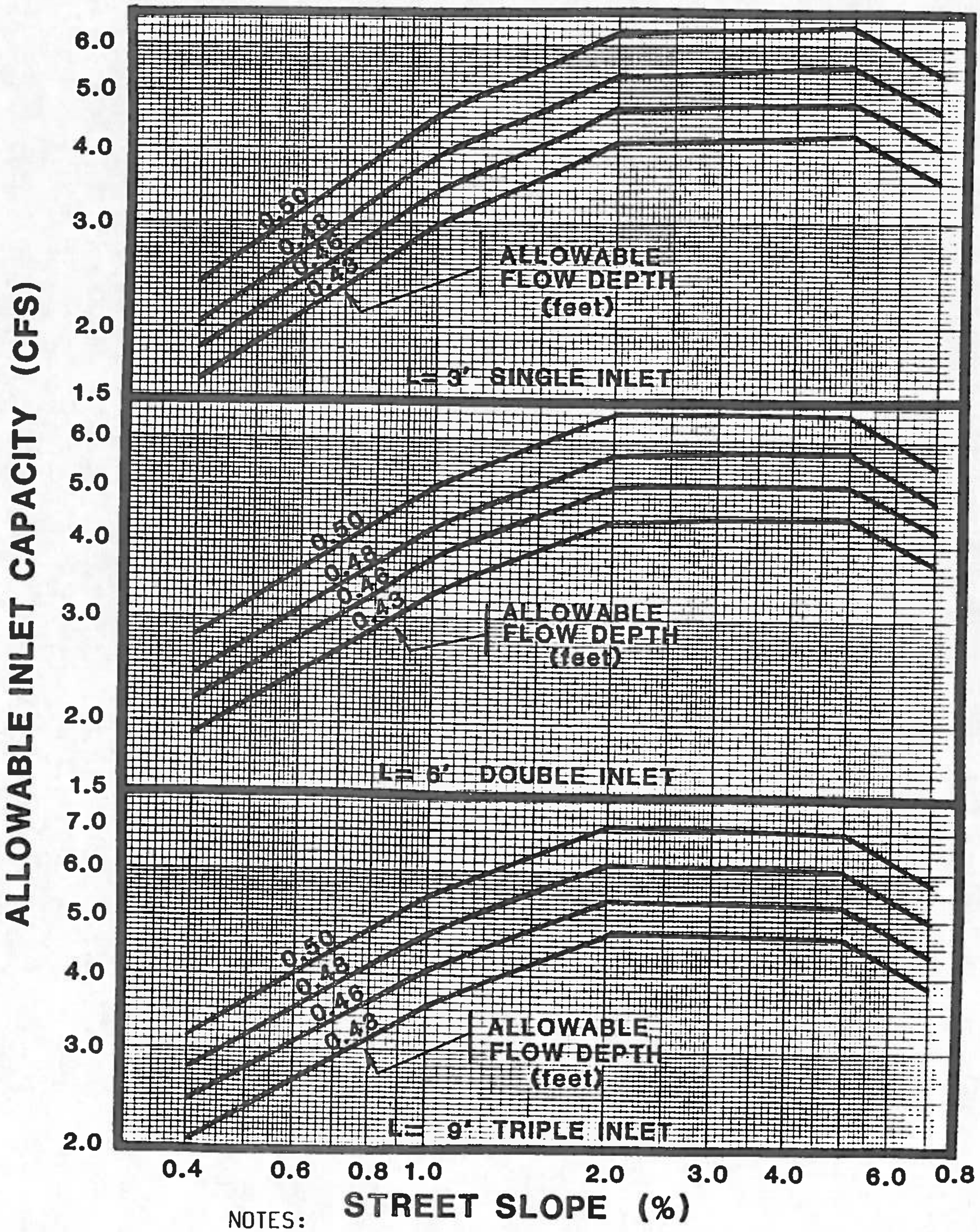
WRC ENG.

REFERENCE:

CONCRETE DESIGN MANUAL, ACPA 1970

ALLOWABLE INLET CAPACITY

TYPE 13 COMBINATION ON CONTINUOUS GRADE



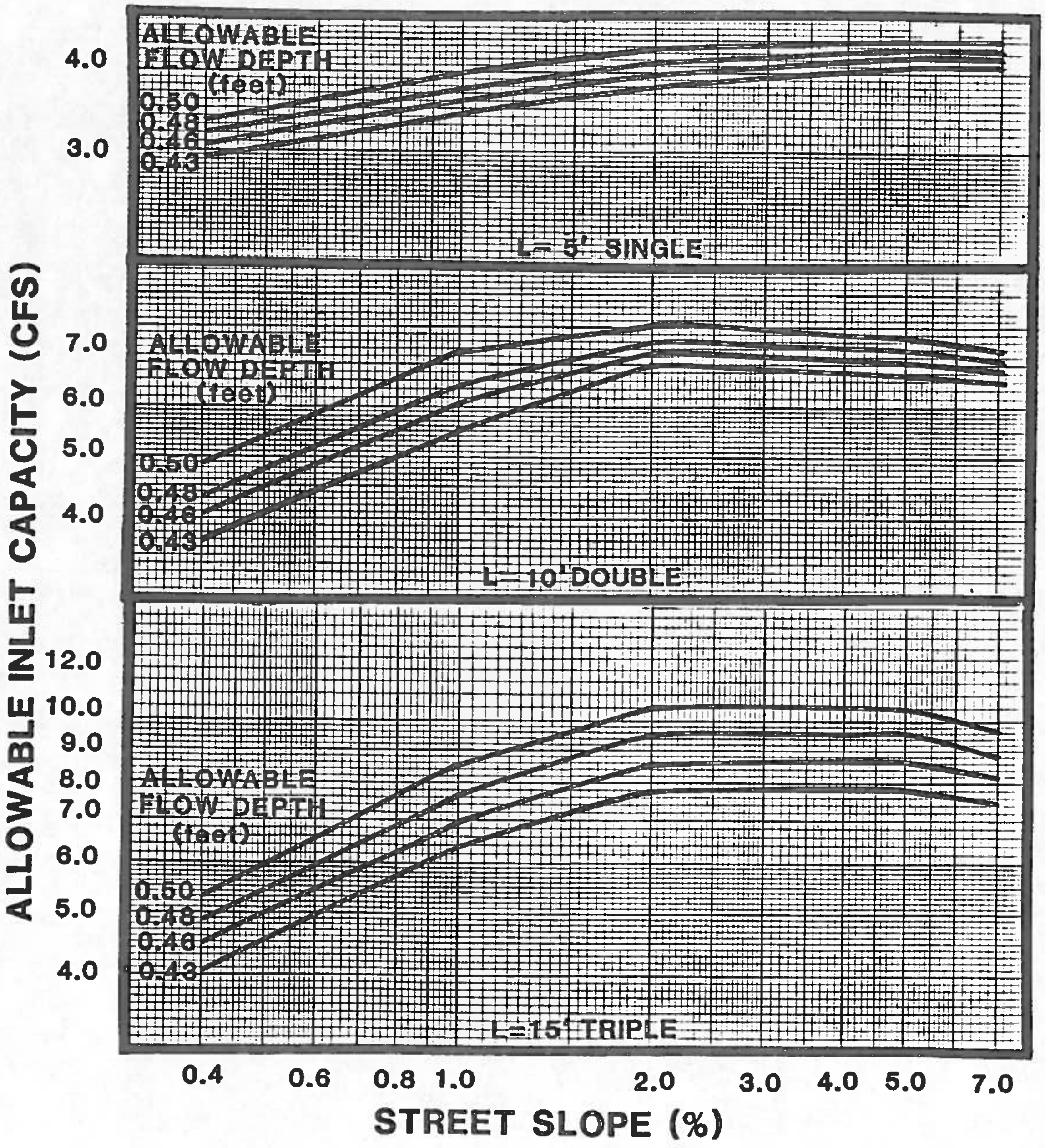
NOTES:

1. Allowable capacity = 66% theoretical
2. Maximum inlet capacity at maximum allowable flow depth. Proportionally reduce for other depths.

WRC ENG.	REFERENCE: WRC ENGINEERING, INC. TM-2 FEB 1984

ALLOWABLE INLET CAPACITY

TYPE - R CURB OPENING ON A CONTINUOUS GRADE



NOTES:

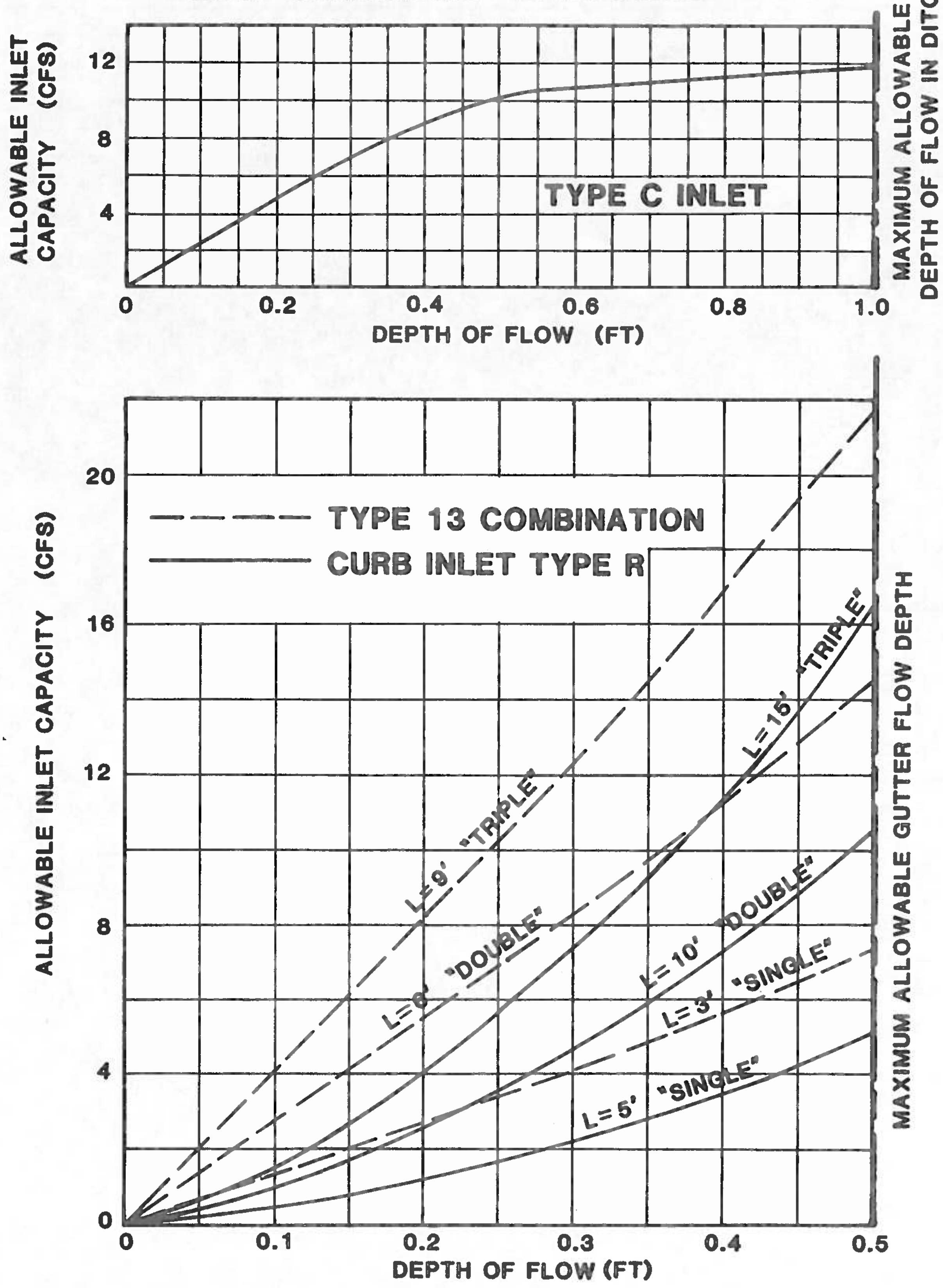
1. Maximum inlet capacity at maximum allowable flow depth. Proportionally reduce for other depths.
2. Allowable capacity =
   88% (L=5')
   92% (L=10')
   95% (L=15')

WRC ENG.	REFERENCE: WRC ENGINEERING, INC. TM-2 FEB 1984

BOULDER COUNTY
STORM DRAINAGE CRITERIA MANUAL

FIGURE 806

ALLOWABLE INLET CAPACITY
SUMP CONDITIONS - ALL INLETS



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REFERENCE:
WRC ENGINEERING, INC., TM-2 FEB 1984