TEXAS HIGHWAY DEPARTMENT

R A T I O N A L   D E S I G N

O F

C U L V E R T S   A N D   B R I D G E S

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F O R E W O R D

A serious attempt has been made herein to simplify the rational design of hydraulic structures. It is our intent to apply these established principles of hydraulics to the design of highway structures in the simplest way possible. Complicated theorems and equations have been eliminated as far as practicable. It is felt that a judicious use of the material will improve the general design of highway structures by reducing the possibility of overflow and the resulting interruption of traffic, reducing the flood damage to adjacent property, and in some cases, a saving of funds due to over-design of highway structures.

Acknowledgement is made for source material obtained from "Design of Culverts and Incidental Hydraulic Structures", by M. R. Mitchell, Senior Designing Engineer, Bridge Division, Austin Office, and from "Design of Culverts, Channels, Ditches and Dykes", by H. P. Carothers, formerly Resident Engineer, District 20, Beaumont, and now of the United States Army. Valuable assistance has also been rendered by H. G. Bossy, Assistant to Engineer Road Design, Austin Office, Arnold Staubach, Senior Designing Engineer, Bridge Division, Austin Office, and James P. Exum, Bridge Engineer.

The Authors

"Note to Second Reprint and Revision, October, 1946.- Because the supply of the Reprint of January 1945 of this manual has been exhausted, and in response to the numerous requests for more copies, this reprint has been prepared. The definition of frictional grade has been changed to neutral grade and some other terms have been clarified. Obvious errors have been corrected. - Bridge Division, Austin, Texas."

C O N T E N T S

RATIONAL DESIGN

OF

CULVERTS AND BRIDGES

Page

Page

VII. TABLES, MAPS AND GRAPHS Page

Page

I. FIELD SURVEYS

Drainage Area

The drainage area may be determined by one of the following methods:

(a) Direct field survey with ordinary surveying instruments.
(b) Use of published contour maps (if available) together with field check as to artificial barriers, ditches, etc.
(c) Use of State Highway Planning Survey Maps for large areas.

Meander of Water Course

Meanders are secured for the purpose of determining the feasibility of channel change in the vicinity of the crossing, and to show in general the flow characteristics of the stream. The meanders are preferably shown by contours and should be very accurate for several hundred feet on each side of the crossing and within the limits of possible channel changes.

Profile of Water Course

The profile of the water course should extend far enough upstream and downstream to determine the average slope of the channel and encompass any channel changes.

Average Slope

The average slope of the water shed should be determined as follows:

(a) Flat (slope 0% - 1%)
(b) Rolling (slope 1% - 3 1/2%)
(c) Hilly (slope 3 1/2% - 5 1/2%)
(d) Mountainous (slope 5 1/2% +)
or (e) Average Percent Grade of slope

Soil Classification

The soil included within the limits of the watershed should be classified as follows:

(a) Sandy loam
(b) Clay loam
(c) Clay
(d) Sand
(e) Gravel
(f) Rock, etc.

Soil Cover Classification

The soil cover should be classified as follows:

(a) Cultivated

(b) Pasture
(c) Timber
(d) Terraced for cultivation
(e) Terraced for erosion control (Pasture)
(f) Possibility of suburban development

Channel Cross Sections

Representative channel sections should be taken above or below the location of the proposed structure if the center line profile section is not representative for the determination of the highwater elevation and the capacity of the present channel.

Data on Existing Structure

The location, size, description, highwater elevation, and channel section of existing structures on the water course should be secured in order to determine their capacity. These data should include span lengths, type piers, and similar data on existing structures and often may be secured from old plans.

Often during the development of the P. S. & E., the Engineer has opportunity to observe the structure under extreme flood conditions. If the head through the structure is measured, a fairly accurate estimate of the discharge can be made. This measurement should be made in still water (backwater) on each side of the road, and if a level is not available, a chalk mark may be made on a stake or wingwall and the diference in elevation secured by field party when convenient.

Highwater Elevations

The highwater elevation should be secured at the site of the proposed structure to check against the computed highwater in the channel for the selected design frequency. The highwater elevation at the proposed structure site is extremely important in the flat coastal area where the flow of water is not confined to the channel but spreads out overland covering a wide area.

Channel Lining

The nature of the channel lining should be noted as clean, sodded, weedy, high grass, brushy, trees with heavy undergrowth, etc.

Drift Classification

For large stream crossings, the probable nature, size, and volume of drift should be noted in order to determine the amount of freeboard that will be required for the proposed structure.

Cross Sections at Structure Site

Sufficient cross sections should be taken at the site of the proposed structure to provide contours in the immediate vicinity and should encompass any probable channel changes provided the regular roadway cross sections are insufficient for this purpose.

Foundation Investigation

For large bridges, the foundation investigation should extend to the depth required to disclose the location of suitable foundation material such as rock, shale, hard clay, etc. Where the use of piling is contemplated, the depth of the investigation should extend below the expected pile tips.

These investigations may be made by the use of a hand auger for shallow explorations and the use of State owned core drilling equipment, or rented core drilling equipment for deeper excavations.

Navigation Requirements

Certain streams have been defined by Congress as navigable when they are not navigable in fact. All streams that have been defined as navigable are under the jurisdiction of the War Department. The navigation requirements deal mainly with the horizontal and vertical clearances. After the approval of the proposed design by all participating agencies, approval for construction must be secured from the War Department before construction is begun. Information concerning navigable streams or other navigation requirements may be secured by request from the District Engineer, U. S. Engineer's Office, U.S. Post Office Bldg., Galveston, Texas. The permit is prepared in accordance with War Department Bulletin "INFORMATION CIRCULAR - Applications for authority to execute work or erect structures in the Navigable Waters of the United States." These permits are handled through the District Office and File D-5.

II. DESIGN STEPS

A. GENERAL

General

An important problem in the design and construction of highways is the disposal of storm water without excessive damage to the highway installation and adjacent property due to highwater and to reduce the inconveniences and interruption to public travel to an economic and practicable minimum.

The usual steps in the design procedure for structures are as follows:

(1) Selection of design frequency, depending upon importance, size, and cost.
(2) Estimation of run-off for design frequency.
(3) Determination of tailwater elevation in unobstructed floodway.

(4) Selection of structure, size, and type.

The Rational Design of structures is based on the principle that the maximum rate of run-off from a given watershed for an assumed intensity of rainfall occurs when all parts of the area are contributing to the flow at the point of discharge. That part of the watershed nearest the structures must still be contributing to the flow when the water from the most remote point of watershed reaches the structure. This condition requires that the rainfall must continue as long as is required for the water to travel from the most remote point of the watershed to the structure. This period of time is called TIME OF CONCENTRATION. The maximum rate of run-off result from a rainfall of maximum intensity continuing for a period of time equal to the time of concentration.

B. DESIGN FREQUENCY

Design Frequency

The design frequencies usually recommended are as follows:

(a)	Sewers	2 - 5 yrs.
(b)	Culverts	10 yrs.
(c)	Small Bridges	25 - 50 yrs.
(d)	Large Bridges	50 - 100 yrs.

In specific cases, depending upon local economic and physical considerations, it may be proper to use a different design frequency for overflow and discharge velocity than that shown above.

C. DETERMINATION OF RUN-OFF

Run-off Formula

The Rational Formula for computing run-off is expressed as follows:

$Q = CIA$

Q = Discharge in cu. ft. per second

C = Run-off coefficient (ratio of the maximum rate of run-off to the average rate of rainfall for the time of concentration)

I = Rainfall intensity in inches per hour (approximately cu. ft. per sec. per acre)

A = Drainage Area in Acres.

Coefficient of Run-off

The run-off coefficient "C" in the above formula is dependent on the slope of the watershed, the land use, and the character of the soil.

Great care should be exercised in the selection of proper run-off coefficient inasmuch as the error in the size of the structure required is in direct proportion to the error in the selection of the proper coefficient of run-off.

The recommended values of the run-off coefficient "C" are shown in Table on Page 31 "VALUES OF C IN FORMULA Q = CIA." In the selection of the coefficient of run-off, consideration should be given to probable future development.

Rainfall Intensity

The rainfall intensity "I" for any given time of concentration may be computed from the Texas State Reclamation Department formula:

$$I = \frac{b}{(t + d)} \quad \text{when,}$$

I = Rainfall intensity in inches per hr.

t = Time of concentration in minutes.

b, d, and e are constants which vary according to the locality.

Table shown on Page 47 gives the values of "b", "d", and "e" for all counties of highway district headquarters in Texas.

Railfall Intensity Duration curves shown on Pages 30 to 30 E, give the values of rainfall intensity "I" for all highway districts in Texas.

Time of Concentration

The time of concentration is based on the average velocity of flow from the fartherest point on the watershed to the proposed structure along the existing channel or water course and is dependent upon the length and slope of the water course.

The average velocities for computing the time of concentration may be secured from observed or measured velocities, estimated from Manning's Formula, or estimated from the graph on Page 33 showing "AVERAGE VELOCITIES FOR TIME OF CONCENTRATION."

The time of concentration is determined by dividing the length of the longest route of the flow of water by the average velocity. In certain cases it may be advisable to divide the watershed into segments of overland flow and channel flow in order to arrive at a more nearly correct time of concentration. In general, a time of concentration of not less than 30 minutes should be used since for small areas the storage capacity is large in comparison to the volume of rainfall and no damage may result from rains of higher intensity for lesser duration.

D. TAILWATER ELEVATION

General

The determination of the tailwater elevation is a very important step in the design of a culvert. The tailwater elevation will indicate whether the culvert will function with a free outlet or a submerged outlet and is used in computing backwater head.

For large structures the tailwater elevation may be determined by use of gauge readings, or backwater measured at existing structures. The tailwater elevation is that which corresponds to the design frequency and not the reported highwater elevation. Single determinations of highwater have little value as a criterion of design. If the period of record is too short, the reported highwater may represent a frequency such that when a design is based upon it, the structure may not be economical or balanced for the service required.

It is, however, desirable to report highwater data since such information obtained over a long period of time forms the statistical data for determination of run-off frequencies. Backwater head at existing structures should be reported so that the mean channel velocity and discharge may be estimated therefrom.

In general the tailwater elevation may be computed by the use of Manning's Formula by assuming various depths of flow in the present or proposed channel, and comparing the computed discharge with the design discharge until the correct depth of flow is obtained corresponding to the design frequency.

Manning's Formula

The equation generally used for computing the mean velocity of flow in open channels is Manning's Formula:

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

V = Mean Velocity in feet per sec.
s = Slope in feet per foot.
r = Hydraulic radius = Area divided by the wetted perimeter.
n = Coefficient of roughness.

Coefficient of Roughness

The mean velocity of flow may be determined by direct solution of the above formula or by use of the diagrams shown on Page 34 "DIAGRAM FOR SOLUTION OF MANNING'S FORMULA."

The recommended values of coefficient "n" for use in Manning's Formula are shown in the Table on Page 32 entitled "VALUES OF 'n' FOR MANNING'S FORMULA."

Experimental data contained in "Flow of Water in Drainage Canals" by C. E. Ramser is recommended for use in the selection of the values for "n". The coefficient "n" used in Manning's and Kutter's Formula are interchangeable.

E. SELECTION OF STRUCTURE

General

The function of a roadway structure is to pass the water from the upstream side of the road to the downstream side without causing excessive backwater head and without creating excessive velocities. The designer should keep the losses of head and velocities within safe limits and select the structure of minimum costs that will perform as required and meet the design requirements as to appearance, strength, etc.

The size and type of structure, selected for any given culvert site will, of course, be influenced by the location of the culvert site, the relation of the grade line to the flow line of the channel, tailwater elevation, velocity of discharge, and losses of head through the structure which determines backwater.

Maximum Discharge Velocity

The maximum permissible design velocity for sodded surfaces is usually assumed to be 8 ft. per sec.

The usual practice in trestles is to limit the average velocity of discharge to 4 ft. to 7 ft. per sec., due to variations in the average velocity.

In culverts, the velocity of discharge may be limited to 10 ft. per sec. The downstream channel should be rip-rapped when the discharge velocity exceeds 8 ft. per sec. Occasional scour will not endanger these structures, due to their monolithic construction.

In general, a small amount of scour at the design flood is not serious because it would be corrected during floods at lesser magnitude.

Maximum Head

The importance of loss of head through structures in flat terrain cannot be over emphasized. In the past, the fact that the required head to handle the estimated amount of water was greater than the total available head was often overlooked. This resulted in water "jumping" the road or causing damage to property upstream.

The permissible head is a matter of Engineering judgment, and probable damage and structure costs should be carefully weighed. If backwater will flood crops or residential property, a head of 0.4' to 0.5' is considered the maximum that should be permitted in the design.

III. HYDRAULICS OF STRUCTURES

A. GENERAL

Critical Depth

Critical depth may be defined as the depth at which, for a given energy content of the water in a channel or structure, maximum discharge occurs; or the depth at which in a given channel or structure a given quantity of water flows with the minimum content of energy. Critical depth of flow will occur only when the tailwater elevation is at or below the elevation of critical depth.

The critical depth for a rectangular box culvert is expressed by the following equation:

$$D_{cr} = \sqrt[3]{\frac{q^2}{32.2}} \quad \text{where}$$

D_{cr} = Critical Depth in ft.
q = Discharge in c.f.s. per ft. of width of structure.

For rectangular box culverts the critical depth may be either computed from the above formula or read directly from Curve shown on Page 37, "Critical Depth vs. Discharge per foot of Box."

For pipe culverts the critical depth of flow may be determined by use of Curves shown on Page 41, "Critical Depth vs. Discharge for Pipe Culverts."

The Critical Depth in the structure is approximately 2/3 the depth of flow in the approach channel for rectangular boxes neglecting friction and entrance losses, and velocity of approach.

Free Outlet

When the tailwater elevation is equal to or lower than the critical depth of flow, the structure will discharge as a free outlet, and any lowering of the tailwater elevation below the critical depth will not affect the discharge of the structure.

Partially Submerged Outlet

For the usual case when the tailwater elevation is above the critical depth of flow in the Culvert, critical depth will not occur. If the tailwater elevation is between the elevation of critical depth and the elevation of the top of the culvert barrel, the culvert will discharge as a partially submerged outlet.

Submerged Outlet

When the tailwater elevation is above the elevation of the top of the culvert, the culvert barrel will discharge as a submerged outlet.

When the critical depth exceeds the depth of the culvert, the culvert will flow full if placed on a grade that is less than the frictional grade.

Uniform Flow

Uniform flow will occur when a culvert is discharging with a submerged outlet or partially submerged outlet, when laid on the exact frictional grade. For slight variation from the exact grade, the flow for all practical purposes may be considered to be uniform, i.e., the culvert will flow with a practically uniform depth throughout its entire length. The velocity of flow will be the same throughout the length of the structure and is represented by the following equation:

$$V = \frac{Q}{W}$$

Where V = Velocity in feet per second.
W = Waterway area in sq. ft.
Q = Discharge in c.f.s.

Critical

The critical velocity, Vcr, is the velocity at the point of critical depth in the culvert.

The critical velocity may be determined by dividing the discharge by the area of the waterway.

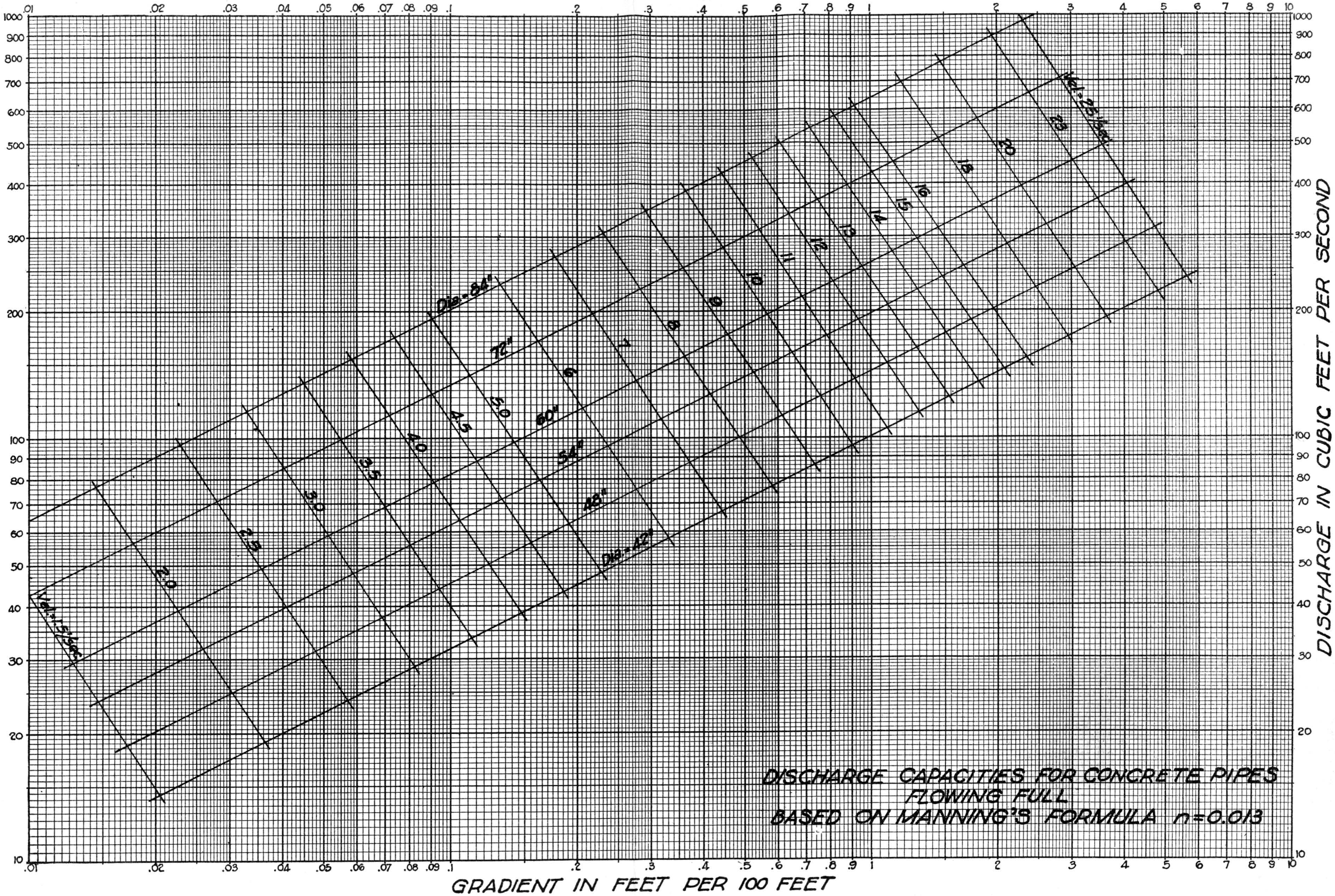
For rectangular culverts the ciritcal velocity may be determined by use of the graph shown on page 38, "Critical Velocity vs. Discharge for Box Culverts."

For pipe culverts the ciritcal velocity may be determined by use of the Curves shown on page 42, "Velocity vs. Discharge - Pipe Culverts."

Critical Slope

The critical slope is the slope required for a given discharge to occur at critical depth.

For pipe culverts, the critical slope may be determined by use of Curves shown on pages 44 and 44A, "Critical Grade vs. Discharge for Pipe Culverts."


DISCHARGE CAPACITIES FOR CONCRETE PIPES
FLOWING FULL
BASED ON MANNING'S FORMULA n=0.013
GRADIENT IN FEET PER 100 FEET
DISCHARGE IN CUBIC FEET PER SECOND
Dia.=84"
72"
60"
54"
48"
Dia.=42"
Vel.=1.5'/sec.
Vel.=25'/sec.
2.0
2.5
3.0
3.5
4.0
4.5
5.0
6
7
8
9
10
11
12
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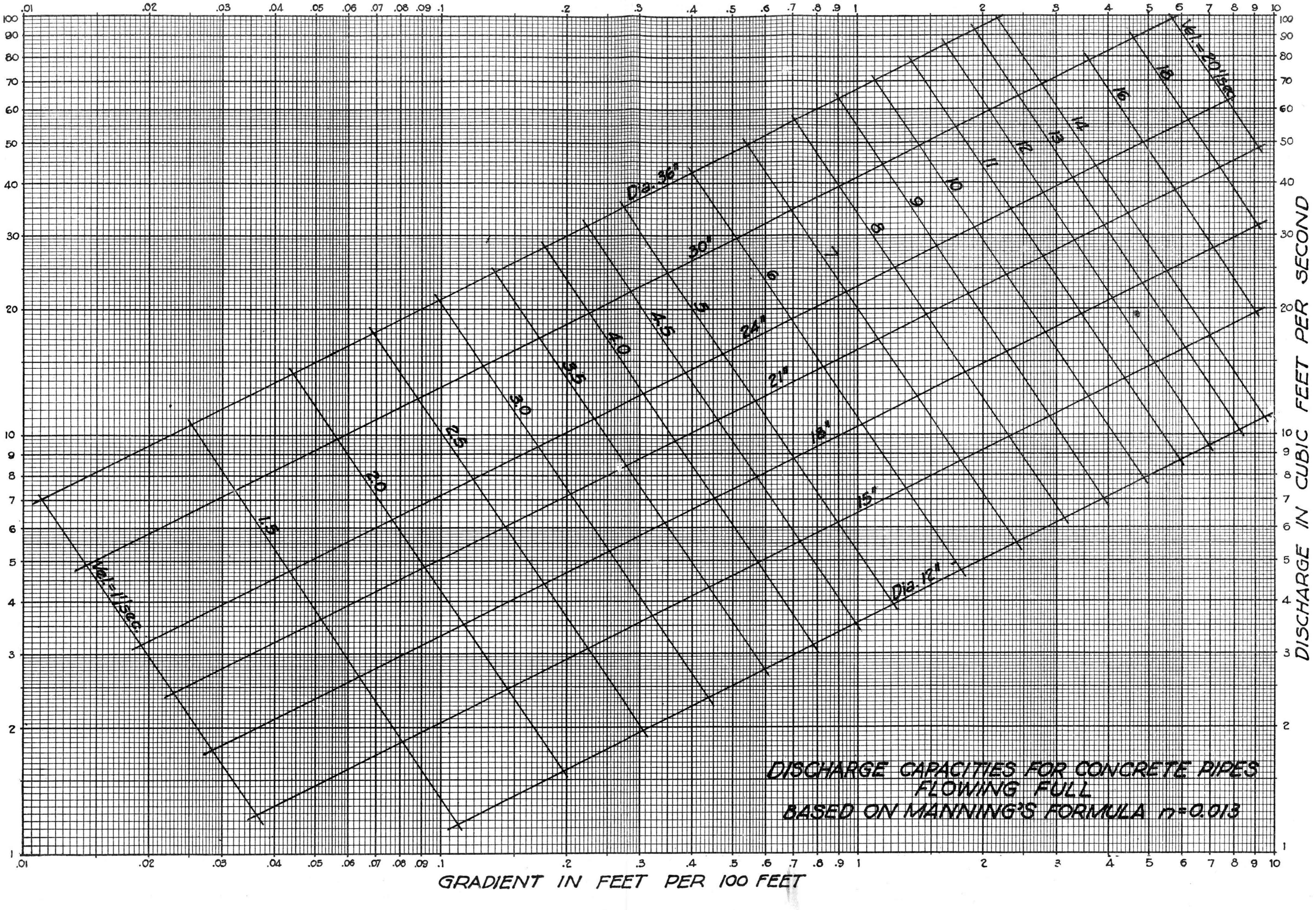

DISCHARGE CAPACITIES FOR CONCRETE PIPES
FLOWING FULL
BASED ON MANNING'S FORMULA n=0.013
GRADIENT IN FEET PER 100 FEET
DISCHARGE IN CUBIC FEET PER SECOND
Dia. 36"
30"
24"
21"
18"
15"
Dia. 12"
Vel. = 1'/sec.
Vel. = 20'/sec.
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5
6
7
8
9
10
11
12
13
14
16
18

B. LOSSES OF HEAD THROUGH STRUCTURES

General

In flat terrain, a very important consideration is the loss of head by the water in passing through the structure. This loss of head may be measured by taking readings with a level, on the water surface above and below the structure. These readings shall be taken far enough above and below the structure so as not to be affected by the velocity head at the structure.

The loss of head has been divided into three parts: namely,

1. Velocity Head
2. Entrance Head
3. Friction Head

Velocity Head

In physics it has been found that an object falling from a height "h" would reach a velocity "V", and this relation may be expressed by the equation $h = \frac{V^2}{2g}$.

A falling object is said to possess kinetic energy, or energy of motion. Neglecting friction, flowing water will reach the same velocity as an object falling through a distance equal to the pressure head on the water; therefore the velocity head may be expressed in terms of the head of water necessary to give the water its velocity.

In the usual culvert installation the energy of motion in the water is dissipated in the form of a combination of inelastic impact and turbulence. Since it is not reconverted to height of flow, the energy of flow is considered lost.

The velocity head is the head required to impart the increase in velocity of flow as the water passes through the culvert barrel. If the channel velocity is the same as the discharge velocity, then there will be no velocity head lost through the structure.

The velocity head lost may be expressed by the following equation:

$$h_V = \frac{V_1^2 - V_2^2}{2g} \text{ in which}$$

h_V = Velocity head in ft.
V_1 = Discharge velocity in ft./sec.
V_2 = Channel velocity or velocity of approach in ft./sec.
g = Acceleration of gravity = 32.2

When the channel velocity is small in relation to the discharge velocity, the channel velocity may be neglected without appreciable error, then the above equation becomes:

$$h_v = \frac{V_1^2}{2g}$$

The curves shown on page 36 have been plotted in terms of $\frac{V^2}{2g}$ and the various losses of head may be determined individually or in groups as desired. For heads less than 0.1 ft. it will be necessary to multiply the factors by 10 and then divide the answer by 10 to obtain the correct result.

The velocity head may be determined by using the Curve 1.0 $V^2/2g$ shown on page 36.

Entrance Head Loss

The entrance head is the loss in energy or head due to the contraction of the channel or waterway at the entrance to the structure. The amount of entrance head depends on the type of wings installed and may be computed from the following equation:

$$h_e = Ce \frac{V^2}{2g}$$

h_e = Entrance head in ft.
V = Average velocity in culvert barrel in ft. per sec.
Ce = 0.10 for parallel wings.
Ce = 0.25 for flared sloping wings.
Ce = 0.50 for flared sloping wings with Weir.

The entrance head may be read directly from curve on page 36 or may be combined with velocity head and read from curve 1.1 $\frac{V^2}{2g}$ for parallel headwalls or 1.25 $\frac{V^2}{2g}$ for flared wings.

Friction Head

The friction head is the loss of energy or head due to friction resulting from the roughness of the culvert barrel and may be expressed by the following equation which is Manning's formula expressed in terms of feet of drop and in terms of $\frac{V^2}{2g}$.

$$h_f = \frac{29.2\, n^2\, L\, V^2}{r^{4/3}\, 2g}$$

h_f = Friction head in ft.
n = Coefficient of roughness usually taken as 0.013 for Concrete.
V = Average velocity in culvert barrel in ft. per sec.

9-44-805

r = Hydraulic radius = Area divided by wetted perimeter.
g = Acceleration of gravity = 32.2

The values for above mentioned losses of head may be determined by use of the constants listed in table on page 35 which when multiplied by culvert length gives the head in terms of $\frac{V^2}{2g}$. The friction head is then read directly from curve on page 36 or combined with velocity head and entrance head and the combinations expressed as a factor of $\frac{V^2}{2g}$ which may be read from curve as described above.

Backwater Head

In cases of submerged or partially submerged outlets, backwater head is the difference between the tailwater elevation and the elevation of the water on the upstream side of the structure. In cases of submerged or partially submerged outlets the backwater head is the sum of velocity head plus entrance head plus friction head and may be found as described above.

Neutral Grade

The neutral grade may be defined as the slope which will produce enough energy of flow to exactly offset the energy lost due to the friction in the culvert barrel.

Except where culverts are flowing as free outlets, and where the backwater elevation is of some consequence, the neutral grade is of small importance. In the usual culvert installation, the head lost due to friction is less than 0.1 foot, and may be disregarded as to its effect on the function of the culvert. It may be desirable to drop the culvert several times the neutral grade in order that the culvert will drain out and keep the barrel clean. In flat terrain, however, the culvert will probably stand in water due to the condition of the ditch below and a slope in the culvert barrel will be of little practical value.

IV. TYPICAL CULVERT DESIGN

A. DETERMINATION OF RUNOFF

Design Conditions

The drainage area shown on Page 27 is located in Harris County in the vicinity of Houston. The proposed highway is to have a 40' roadway crown with 24' 9"-6"-9" concrete pavement with a crown of 1 1/2".

Time of Concentration

The length of the water course is 4200 feet. (Scaled from drainage area map.). The average slope is

$(82.2 - 67.5) \div 4200 = 0.0035'/\text{ft.}$ or 0.35%

Referring to Graph shown on page 33 "Velocities for Time of Concentration" we find an estimated velocity of run-off to be 1.5 ft./sec. The time of Concentration.

$$t = \frac{4200}{1.5 \times 60} = 47 \text{ min.}$$

Rainfall Intensity "I"

The design frequency is assumed to be 10 yrs. for culverts of this classification and by reference to the Railfall Intensity Chart shown on page 30C we find that for a time of concentration of 47 min. the Rainfall Intensity to be 4.0 in./hr.

Coefficient "C"

The soil contained in this drainage area is sandy loam with a clay subsoil. The average slope of 0.35% is considered to be flat. The cover of the drainage area is approximately as follows, 40% cultivated, 30% pasture with heavy grass and 30% timber. By reference to Table shown on page 31 we find the usual Coefficient "C" to be

$$C = (0.40 \times 0.35) + (0.30 \times 0.25) + (0.30 \times 0.20) = 0.275$$

but this area is subject to suburban development in the near future; and we may expect a higher percentage of run-off; therefore, instead of using the coefficient calculated above, we use, say, "C" = 0.30.

Discharge "Q"

From the formula Q = CIA we compute the discharge as follows:

$$Q = 0.30 \times 4.0 \times 230 = 276 \text{ c.f.s.}$$

Outfall Channel

It has been determined that the cross section of the channel as represented by the center line profile is a representative average channel section. If this section is not representative of the average channel, than additional cross sections should be taken above and below the culvert site and the average of all sections determined.

B. TRIAL DESIGN WITHOUT OUTFALL CHANNEL

Design Contitions

If it is practicable to discharge the water from the proposed culvert into the wide flat downstream channel without damage to adjacent property, then a low height structure may be installed without the necessity of excavating an outfall channel.

Depth of Flow in Channel

By the application of the "Trail and Error" method to Manning's Formula we may compute the capacity of the present downstream channel for various depths of flow in order to determine the depth of flow corresponding to the computed discharge of 276 c.f.s.

The coefficient "n" = 0.050 is then selected from Table shown on page 32 "Values of 'n' for Manning's Formula" which corresponds to the condition of the present channel.

The present channel slope is (67.5 - 60.0) ÷ 2000 = 0.00375'/ft.

By assuming various depth of flow in the proximity of the anticipated depth and computing the area, wetted perimeter, hydraulic radius, velocity and discharge, we find a depth corresponding to the given discharge of 276 c.f.s. The Table and Graph shown on page 28 shows the various depths selected and the corresponding discharge. For this present channel it will be noted that a depth of 0.63' will give the required discharge of 276 c.f.s.

Tailwater Elevation

The tailwater elevation will be 0.63' above the flow line of the downstream channel.

Selection Structure Size

From an inspection of the proposed profile grade, under the conditions listed above, it appears desirable to use a direct traffic culvert of two foot height with the flow line of the culvert placed at or near the flow line of the present channel. This will necessitate a slight raise in the profile grade.

Since a direct traffic structure has been proposed it also appears desirable to limit the backwater head to approximately 1.0 ft. and the discharge velocity to approximately 8 ft./sec.

Try 5 - 5' x 2' x 40' MBC-11-40 then

$$q = \frac{276}{25} = 11.0 \text{ c.f.s./ft. of width}$$

Critical Depth

From the Graph shown on page 37 we find that the critical depth, corresponding to the required discharge, is 1.55 ft.

Since the tailwater elevation is only 0.63' above the elevation of the bottom of the downstream channel, the culvert will discharge with a free outlet and at critical depth.

Critical Velocity

From the Graph shown on page 39 the velocity corresponding to a critical depth of 1.55' is 7.12 ft./sec.

Head

From the Table shown on page 35 and the Graph shown on page 36 we compute the following loss of head:

$$h_v = 1.0 \frac{V^2}{2g} = 0.78 \text{ ft.}$$

$$h_e = 0.1 \frac{V^2}{2g} = 0.08 \text{ ft.}$$

$$h_f = .0053 \times 40 \frac{V^2}{2g} = 0.17 \text{ ft.}$$

Total Head Lost = 1.03 ft.

The elevation of the water in the upstream channel would be 67.50 + 1.03 + 1.55 = 70.08. The finished grade elevation would be 67.50 + 2.00 + 0.71 (thickness of top slab) + 0.18 (crown of finished roadway) = 70.39. The backwater head equals backwater elevation minus the tailwater elevation; i.e., 70.08 - 68.13 = 1.95 ft. With this installation the backwater would be only 0.31 ft. below the surface of the pavement.

Frictional Grade

In cases where a direct traffic structure is required, placing on frictional grade will necessitate a special design, which is impracticable in most cases.

Addition of Barrel

The backwater elevation may be lowered by the addition of another barrel to this structure, then

$$q = \frac{276}{30} = 9.2 \text{ c.f.s.}$$

$$D_{cr} = 1.38 \text{ ft.}$$

$$V_{cr} = 6.7 \text{ ft./sec.}$$

$$h_v = 0.70 \text{ ft.}$$

$h_e = 0.07$ ft.

$h_f = 0.16$ ft.

$H = 0.93$ ft.

The backwater elevation would be

$$67.50 + 1.38 + 0.93 = 69.81$$

The backwater head would be

$$69.81 - 68.13 = 1.68 \text{ ft.}$$

It will be noted that the head through the structure was reduced only 0.10 ft., while the backwater elevation was lowered 0.27 ft. by the addition of another barrel to this culvert; therefore the cost of the structure has increased considerably without materially reducing the elevation of the backwater.

The backwater elevation may be lowered also by lowering the flow line of the structure and excavating a shallow outfall channel a short distance below the proposed structure.

C. TRIAL DESIGN WITH OUTFALL CHANNEL

Design Conditions

If it had been determined that, due to the possibility of suburban development or for other reasons, it would be impracticable to allow the flood waters to spread out downstream from the proposed structure then it would be necessary to excavate an outfall channel from the culvert site to Cypress Creek. The design of the structure will include the design of an outfall channel with sufficient capacity to properly discharge the flood waters from the proposed structure into Cypress Creek.

By the application of a "Trial and Error" method to Manning's Formula we can compute the size, depth, and slope of an outfall channel for the calculated discharge of the proposed structure.

Coefficient "n"

In order to determine the proper coefficient "n" in Manning's Formula, it is necessary to take into account the future maintenance of the outfall channel that may be expected. If the channel will be allowed to grow up in weeds and brush and the side slopes allowed to erode, then it is necessary to take this condition into account in computing the probable discharge capacity of the channel.

If the above condition of maintenance is expected, we may select a coefficient "n" of say 0.045 from Table shown on page 32, "Values of 'n' for Manning's Formula."

Channel

The slope of the bottom of the channel should approximate the average ground slope if the water is to be completely contained in the channel.

The channel slope would be

$$(67.5 - 60.0) \div 2000 = 0.00375'/ft.$$

We may now assume the bottom width of the channel to be 10 feet and the side slopes to be 2:1. If it is found that the capacity of the channel is too large or too small with a 10 foot bottom, then the bottom width may be adjusted accordingly.

In order to determine the depth of flow in a given channel it is necessary to use the "Trial and Error" method by assuming various depths, above and below the anticipated depth of flow, until a depth is found that will produce the required discharge. The area, wetted perimeter, and hydraulic radius is then computed for the various depths chosen. Then the velocity is determined by use of the diagram shown on page 34, "Diagram for Solution of Manning's Formula." With the velocity and area known we can compute the discharge capacity of the channel from the formula Q = AV.

A graph may then be plotted using the various depths selected as ordinates and the corresponding discharge as abscissas. The depth of flow corresponding to the given discharge of the culvert may then be read directly from the graph.

The table and Graph shown on page 28 was computed for the channel described above and indicates that the depth of flow in the channel will be 4.0 ft. for a discharge of 276 c.f.s.

Tailwater Elevation

The depth of flow in the downstream channel has been established as 4.0 ft.; therefore, the tailwater elevation will be 4.0 ft. above the flow line of the channel at the downstream end of the proposed culvert.

If there is an existing channel at the culvert site, and no change is proposed in the existing channel, then the depth of flow should be based on the characteristics of the existing channel.

Selection of Structure Size

From an inspection of the proposed profile grade it appears desirable to use a culvert height of 4.0 ft. with a flow line elevation of 63.5. Since the area adjacent to the culvert site is subject to suburban development in the near future, it also appears desirable to limit the backwater head to less than 3/4 ft. (In flat area a maximum of 0.4 or 0.5 should be used).

Try 2 - 6 x 4 x 44 - 13-44-F MBC Culvert

$$V = \frac{Q}{A} = \frac{276}{2 \times 24} = 5.8 \text{ ft./sec.}$$

With the downstream flow line of the culvert placed at an elevation of 63.5 and a depth of flow of 4 ft., the tailwater elevation will be an elevation of 67.5, which is the same elevation as the top of the culvert barrel, and the culvert will discharge with a "Submerged Outlet" and the flow will be uniform.

Head

Since this culvert is flowing full with submerged outlet, we are not concerned about the individual loss of head, critical depth, etc. The heads are computed as follows:

Entrance head	$0.1 \frac{V^2}{2g}$	= 0.05'
Velocity head	$1.0 \frac{V^2}{2g}$	= 0.52'
Friction head .0039 * x 44 =	$0.17 \frac{V^2}{2g}$	= 0.09'
Total Head	$1.27 \frac{V^2}{2g}$	= 0.66'

From the Graph shown on page 36 we find that, for a velocity of 5.8 ft./sec. and for $1.27 \frac{V^2}{2g}$, the total head is 0.66 ft. The above does not take into account the velocity of approach, which is approximately 1 ft./sec., since this velocity is considered small in comparison to the velocity of 5.8 ft./sec. through the structure.

Comparison of Trial Designs

D. SUMMARY

The cross sections through culverts page 29 show three possible installations. Design (1) using 5-5 x 2'x40 indicates a head of 1.95' which in the usual case would

*Values taken from the Table shown on page 35.

cause extensive damage upstream. This head may be reduced as follows:

(1) By lowering the culvert flow line sightly below natural ground.
(2) By adding additional culvert barrels.

The resulting culvert design (2) with flow line lowered 0.3' has a backwater head of 1.38 feet which is excessive, but may be permissible in pasture areas considered unlikely to be developed.

Design (3) requires an outfall ditch but limits the backwater head to 0.66'. The actual increase in the elevation of backwater above the original water is .03 feet, since the use of the outfall channel lowers the tailwater .63 feet. Whether or not design (3) should be selected depends on whether the backwater heads indicated in designs (1) and (2) are excessive. In general, the excavation and maintenance of the channel should be avoided where practicable. In the example used special treatment will be required of the entrance channel by (1) extension of channel for some distance upstream, or (2) a special design of drop inlet or bowl inlet.

V. PRELIMINARY PLANS - BRIDGES

A. GENERAL

Bridges

The construction of bridges usually requires the approval of the P. S. & E. by Agencies outside the State Highway Department; therefore it appears desirable to submit preliminary plans and supporting data showing the general features of the proposed work for approval prior to the preparation of Contract plans. The Public Roads Administration advised on April 23, 1943, that "In order to avoid delay in the ultimate approval of P. S. & E., we call your attention to the desirability and necessity of submitting to this office preliminary layouts, for all structures of the bridge classification, for our approval as to type, roadway width, etc., so that we may be in agreement on these features before the state consumes time and expense in preparing the final set of plans."

Preliminary plans may consist of the first pencil draft of the following:

1. Title Sheet.
2. Drainage Area Map.
3. Plan-Profile sheets.
4. Bridge Layout sheets.

Upon receipt of concurrence by all agencies involved, these sheets may be completed and inked for inclusion in the contract plans.

The preliminary submission of structural detail sheets for standard trestles, and layout and structural detail sheets for multiple box culverts of standard design is usually not necessary, as the plan-profile sheets show all structural data usually required for review and concurrence in layout.

Culverts

The submission of preliminary plans for structures of the culvert classification is usually not necessary.

B. DESIGN STUDY SHEETS

For large bridges and bridges containing special units, preliminary design study sheets may be prepared at reduced scale and submitted in lieu of the Title Sheet, Drainage Area Map, Plan-Profile Sheet, and Bridge Layout Sheet.

In general the design study sheets should include the following:

1. Vicinity Map.
2. Drainage Area Map.
3. Layout of Proposed Structure.
4. Run-off Calculations.
5. Plan-Profile Sketch.
6. Data on Existing Structures.
7. Typical Channel Sections.

This design study may be prepared in pencil on continuous roll plan-profile paper at reduced scale.

Vicinity Map

The vicinity map may be prepared to any convenient scale to show the general location of the structure and the relationship of the proposed structure to the meander of the stream. The purpose of the vicinity map is to assist in the proper location of the proposed structure. In cases where there is some question as to the proper location, contours should be shown in the vicinity of the proposed structure. The relationship of the proposed structure to existing topography, such as other highways, county roads, bridges, towns, etc., in the immediate vicinity should be shown.

Highway Planning Survey Maps may be used in the preparation of this map, but should be supplemented by checks on the ground to verify their accuracy.

Drainage Area Map

The Drainage Area Map may be prepared to any convenient scale to show the limits of the watershed and the area in acres and square miles. The average slope and characteristics of the watershed should also be shown. In the case of large streams, when run-off records are available, the drainage area map may be omitted, and the run-off data shown.

Layout of Proposed Structure

The layout of the proposed structure may be prepared on a reduced scale, usually 1" = 20' both horizontally and vertically for large structures. This layout should include a plan and profile of the proposed structure and should show essentially the same information required for contract plans, except not in such great detail but merely to show the proposed design. It is usually not necessary to show the railing detail throughout the entire length of the structure, which may be partially detailed or merely a statement made as to the proposed type.

Run-off Calculations

The table showing the computation of run-off should contain the following information:

A. Name of Stream.
B. Drainage Area in square miles.
C. Discharge by Slope Area Method (Manning's Formula)

1. Record Highwater Elevation.
2. Area under highwater elevation.
3. Hydraulic radius.
4. Slope of water surface at highwater.
5. Coefficient of roughness "n".
6. Average velocity in Unobstructed Channel.
7. Discharge
8. Velocity through structure.

D. Discharge by Rational Method

1. Soil - Kind of soil contained in watershed.
2. Soil cover and use.
3. Slope - Average slope of watershed in percent.
4. Estimated velocity of flow.
5. Length of water course.
6. Time of Concentration.
7. Design Frequency.
8. Coefficient of run-off - "C".
9. Railfall intensity.
10. Drainage Area in Acres.
11. Discharge
12. Velocity through structure.
13. Head lost through structure.

In the case of large streams, when run-off records are available, the actual run-off data should be shown in lieu of the information shown above.

Plan-Profile Sketch

A Plan-Profile sketch, usual scales 1" - 100' horizontal and 1" = 10' vertical, should be prepared to show the relation of the approach grades to the grade across the proposed structure. This sketch may be modified or omitted if the grade across the proposed structure is tangent to the approach grade or other conditions warrant its modification or omission.

Existing Structures

The data on existing structures, which should be shown, should include an accurate cross section of the stream channel at the existing structure, the elevation of low clearances and of the roadway at the center and ends of the bridge, referred to the highway datum, the waterway opening, the size, location and type of piers or bents and other obstructions to the stream flow within the limits of the bridge, highwater elevations both upstream and downstream a sufficient distance to show the head lost through the structure, the area under highwater elevation and the computed discharge.

Typical Channel Section

A typical channel section should be shown, to a convenient scale, for the determination of the highwater elevation and the capacity of the present or proposed channel.

VI. CONTRACT PLANS

General

It is not the intent of this article to explain in detail the procedure for preparation of Plans for hydraulic structure but to point out certain variations from the present plan procedure.

In general the plans for culverts and incidental hydraulic structures are included in the roadway plans. The plans for structures of the bridge classification may be prepared separtely or combined with the roadway plans. The contract plans for bridges should not be completed until concurrence in the preliminary plans have been received.

The Contract Plans for highway structures include the following:

1. Title Sheet.
2. Estimate and Quartity Sheet.
3. Plan-Profile Sheets.
4. Drainage Area Map.
5. Structure Layout Sheets.
6. Structural Detail Sheets.
7. Cross Sections at Culvert Sites.

Title Sheet

The title sheet should show the general location of the project and the relationship of the bridges in the project when bridge plans are prepared separately, but when combined with the roadway plans the usual title sheet will suffice for both the bridge and roadway plans as previously required. The estimate and quantity sheet may be combined with the title sheet or the drainage area map for a small project.

Drainage Area Map

The Drainage Area Map should show the following information:

1. Topography including natural channels, existing ditches and tributaries.
2. Existing Structures.
3. Outline of Drainage Area.
4. Proposed Structures
   a. Station number at structure.
   b. Size and type of structure.
5. Type of Soil.
6. Type of Soil Cover.
7. Average slope - Contours if available from published maps.
8. Area of watershed computed in acres.
9. Discharge in c.f.s. suffixed to indicate design frequency (e.g. Q_{10}).

The above information may be shown for each drainage area or tabulated in a convenient location on the map. Separate maps at different scales may be used for culverts and bridges if more convenient.

Plan—Profile Sheets

The plan of the plan-profile sheets should include the following data:

1. Existing structures.
2. Meander of stream.
3. Thread of overflow waters for larger streams.
4. Culture in vicinity of proposed structure.
5. Contours when necessary to support location or design features of culverts, flumes, etc. If necessary, a separate layout should be prepared to a larger scale.
6. Plan of proposed channels.
7. Other data necessary to support assumed roughness coefficient, distribution of openings, or skew of structure.

The profile of the plan-profile sheets should include the following data:

1. Typical ravine section when the center line profile is not representative.
2. Calculated highwater elevation in unobstructed floodway (Tailwater Elevation) for design frequency and observed H. W. Elevations with date if any.
3. Profile of natural and proposed channels for at least 300 feet both upstream and downstream.
4. Data on Proposal Structure.

    a. Station number.
    b. Size and type.
    c. Discharge velocity for design frequency.
    d. Backwater head; i.e., the difference in elevation between backwater and tailwater.

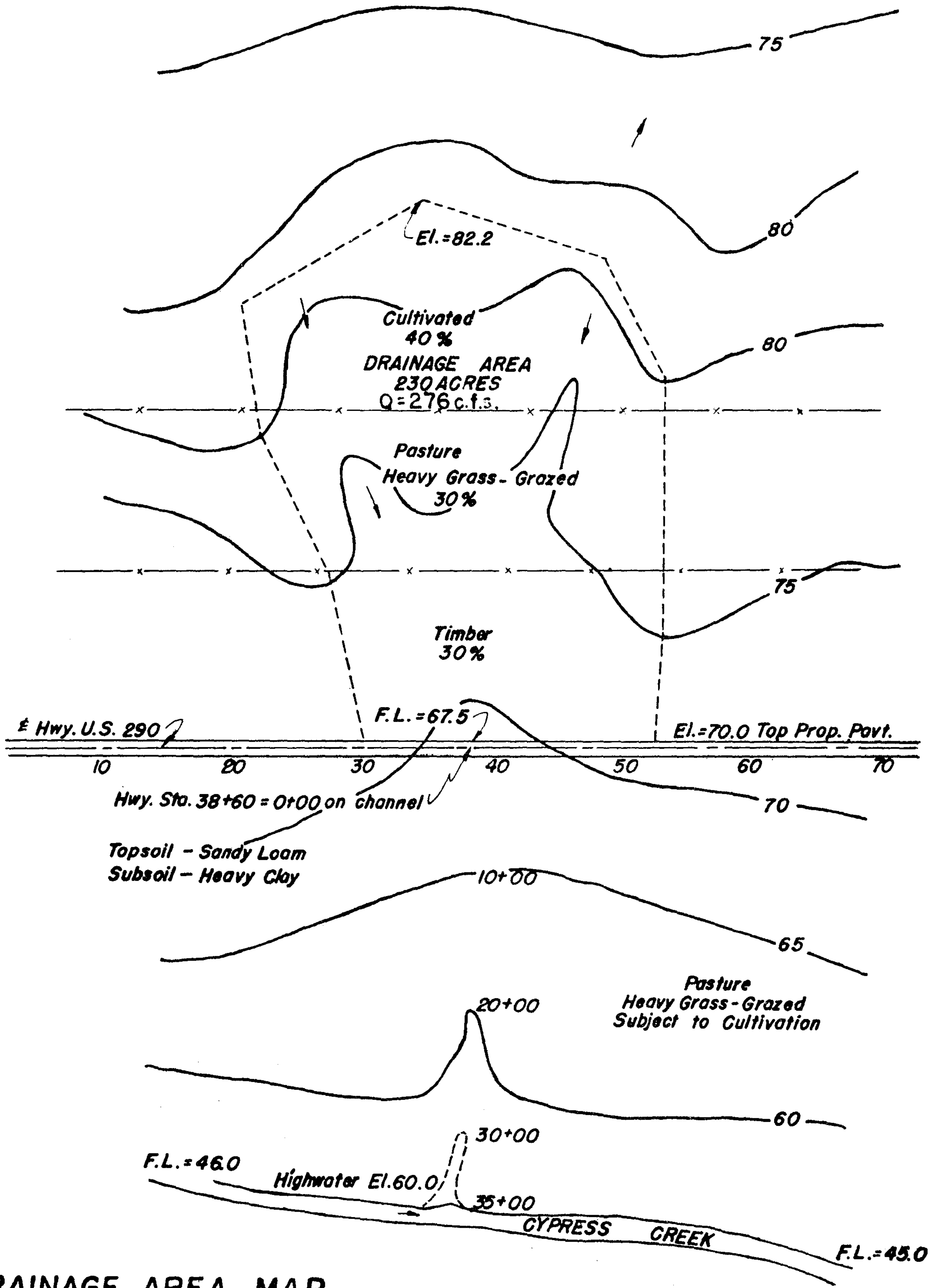
When necessary due to the size or nature of the stream crossing, a full plan size vicinity map may be prepared at a convenient scale; and the required data shown thereon instead of the plan-profile sheet. For large bridges, a condensed plan-profile at location map scale may be used to show the correct relationship of the various structures in the crossing, and the flow characteristics placed thereon instead of the standard plan-profile sheets.

Computation Sheets

The sample computation sheets shown on pages 49 and 50 are for use in calculating the hydraulic data to be shown on the plan-profile sheets and to support the proposed design. These sheets have been prepared for calculating the run-off for overland flow, channel flow, or any combination of these types of flow. The reverse side of these sheets contain the formulas and a description of the symbols used.

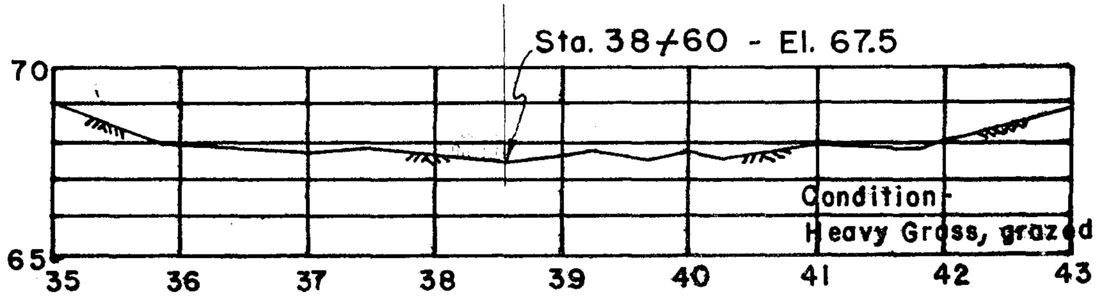
Three copies of these computation sheets should be submitted to the District Office with the P.S. & E.

Notes:



DRAINAGE AREA MAP

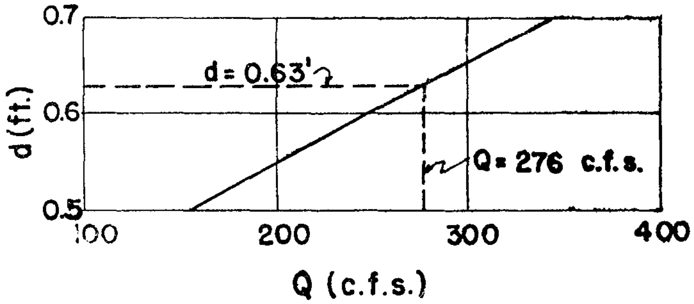
Scale 1"=1000'



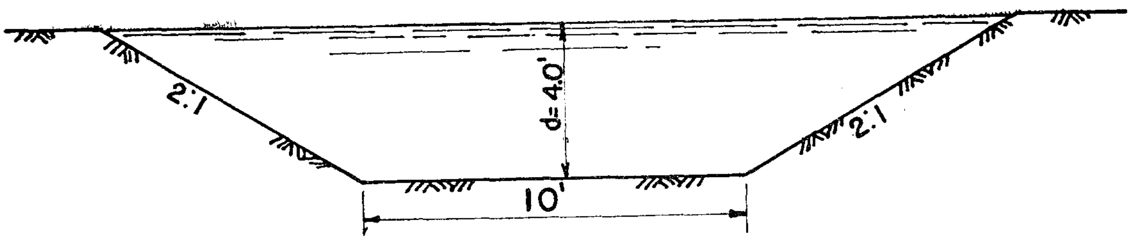
Scales: 1" = 5' Vert.
1" = 150' Horiz.

PROFILE ON HWY. ℄

D	A	p	r	V	Q
0.5	187.2	601.	0.31	0.84	157.
0.6	249.2	640	0.39	0.97	242
0.7	314.7	676	0.46	1.09	344

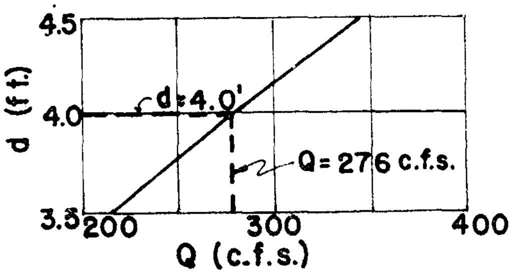


DESIGN WITHOUT OUTFALL CHANNEL

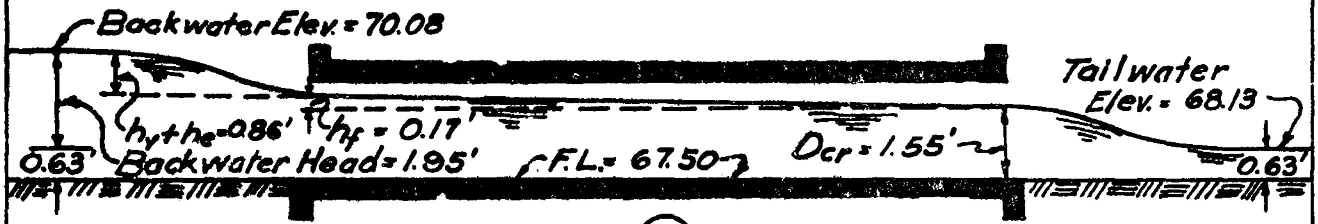


TYPICAL SECTION - OUTFALL CHANNEL

D	A	p	r	V	Q
3.5	59.5	25.6	2.32	3.54	211.
4.0	72.0	27.9	2.58	3.80	274.
4.5	85.5	30.1	2.84	4.06	347.



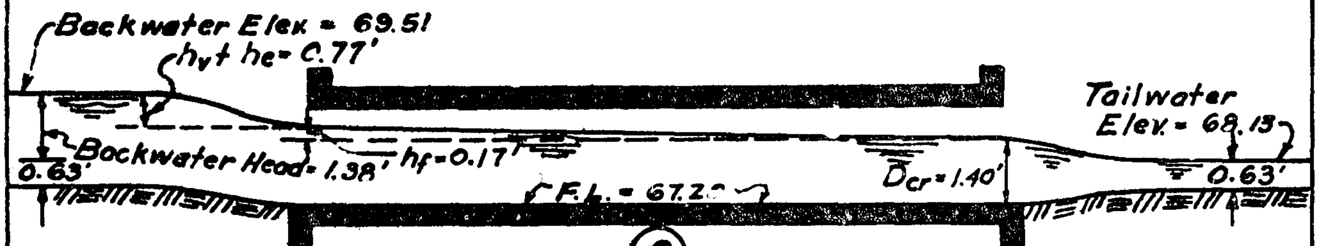
DESIGN WITH OUTFALL CHANNEL



(1)

5-5x2x40 MBC-11-40

DESIGN WITHOUT OUTFALL CHANNEL

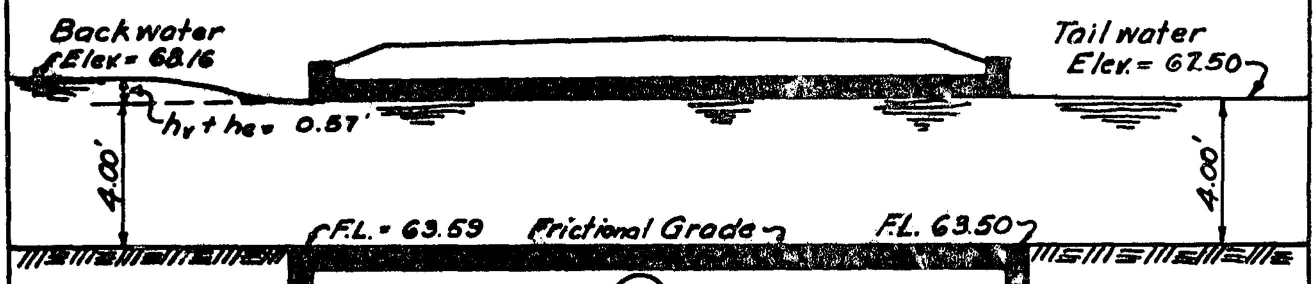


(2)

6-5x2x40 MBC-11-40

DESIGN WITHOUT OUTFALL CHANNEL

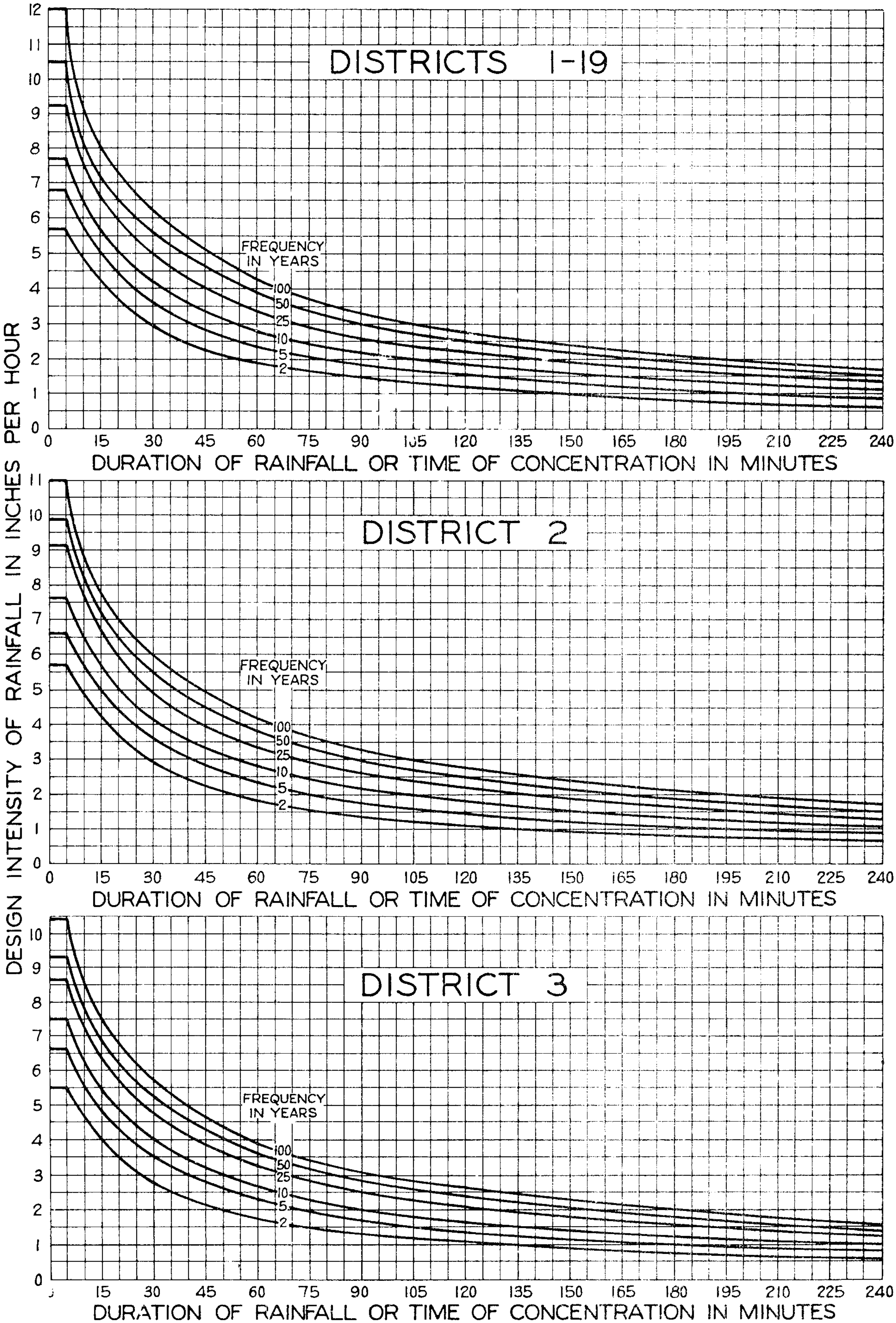
(Flowline Buried 0.30 ft.)

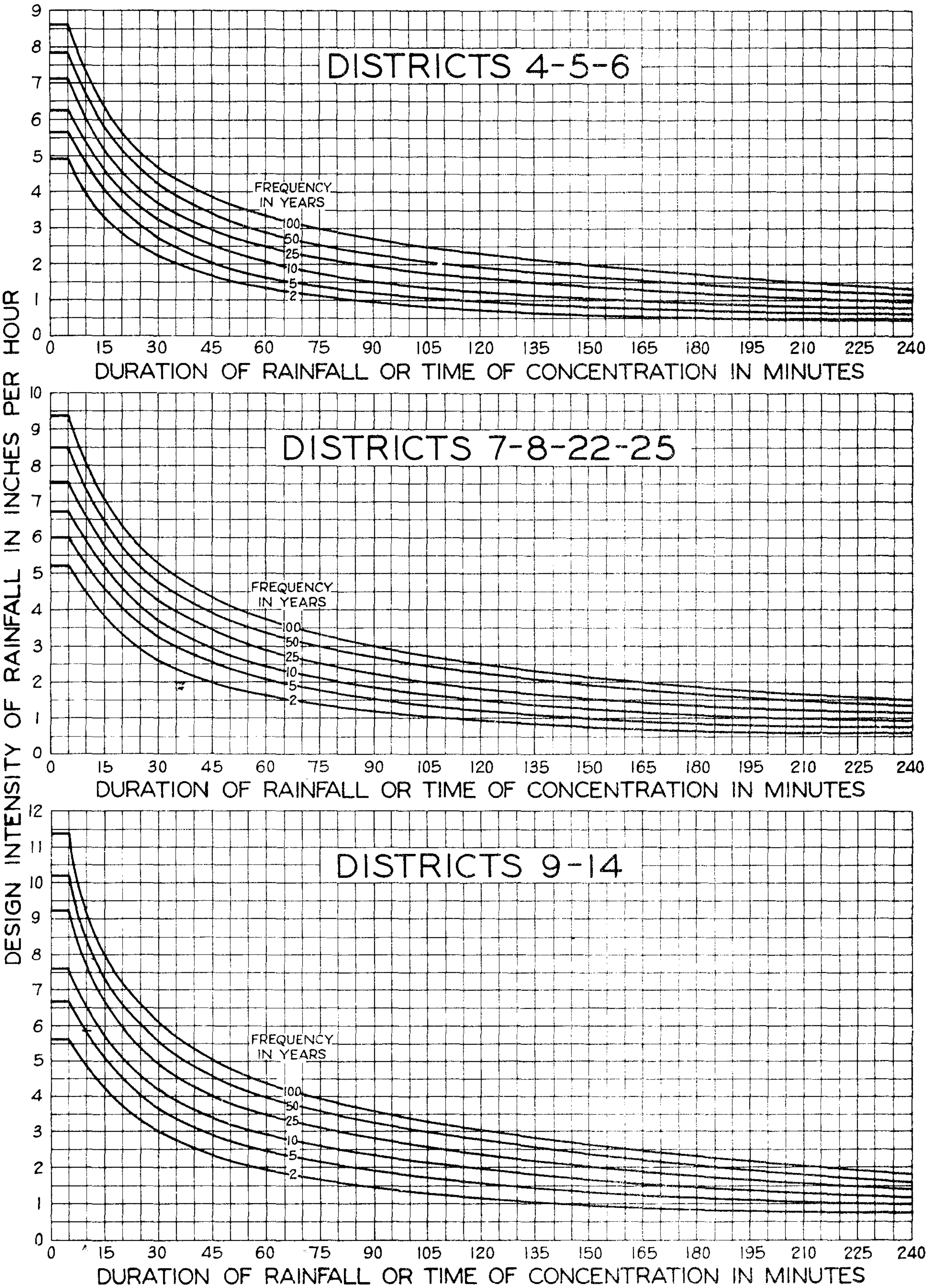


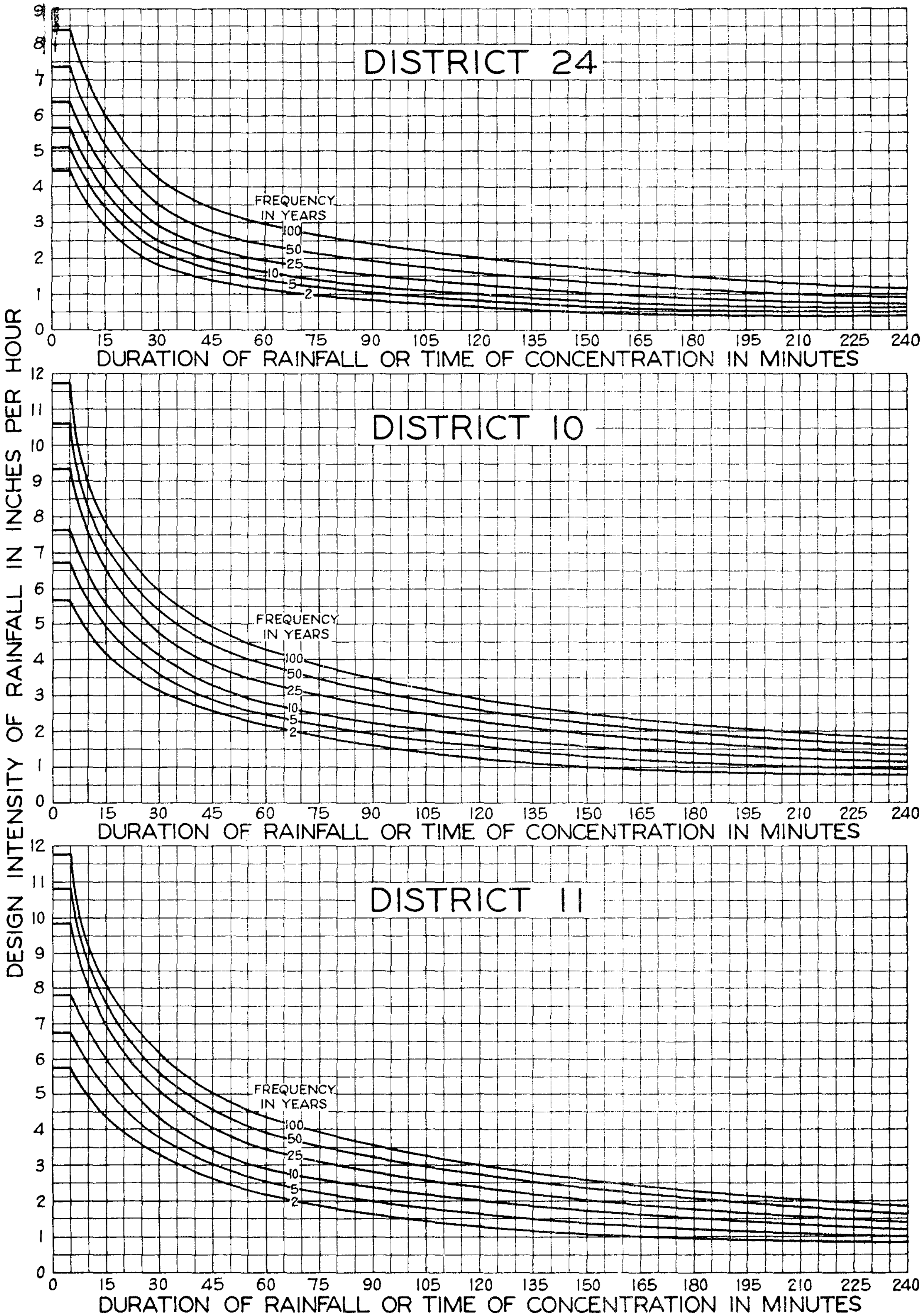
(3)

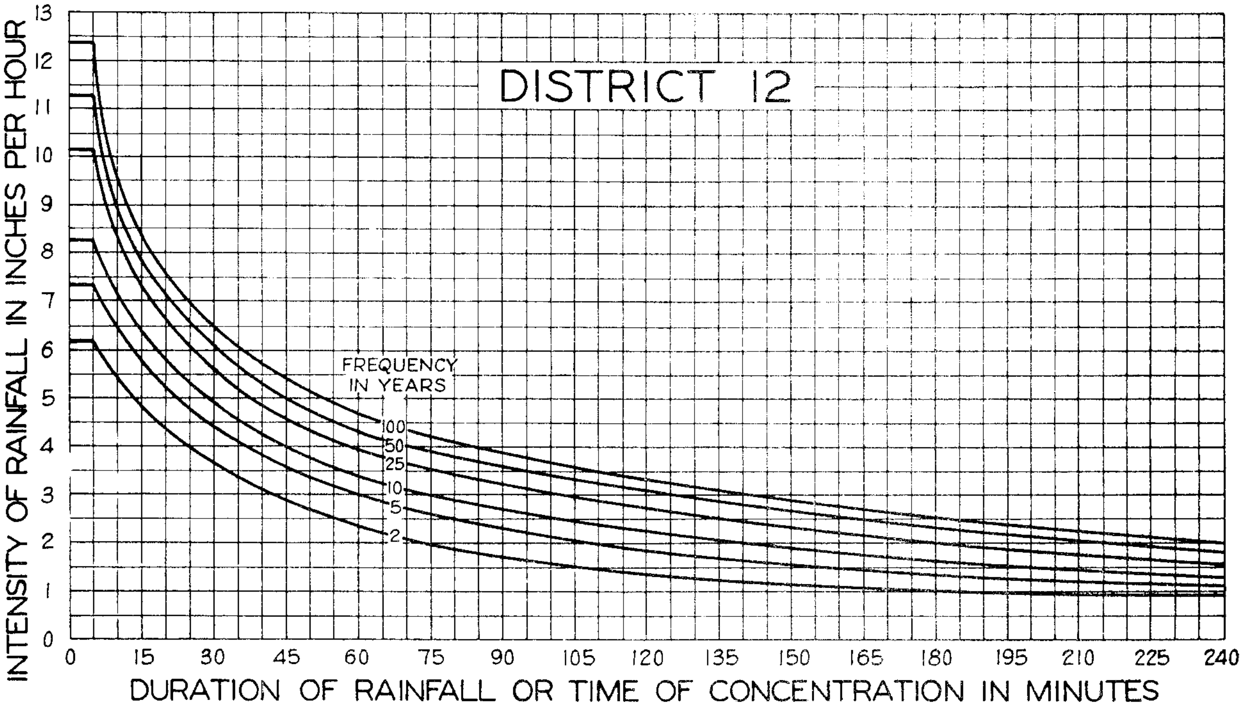
2-6x4x44 MBC-13-44F

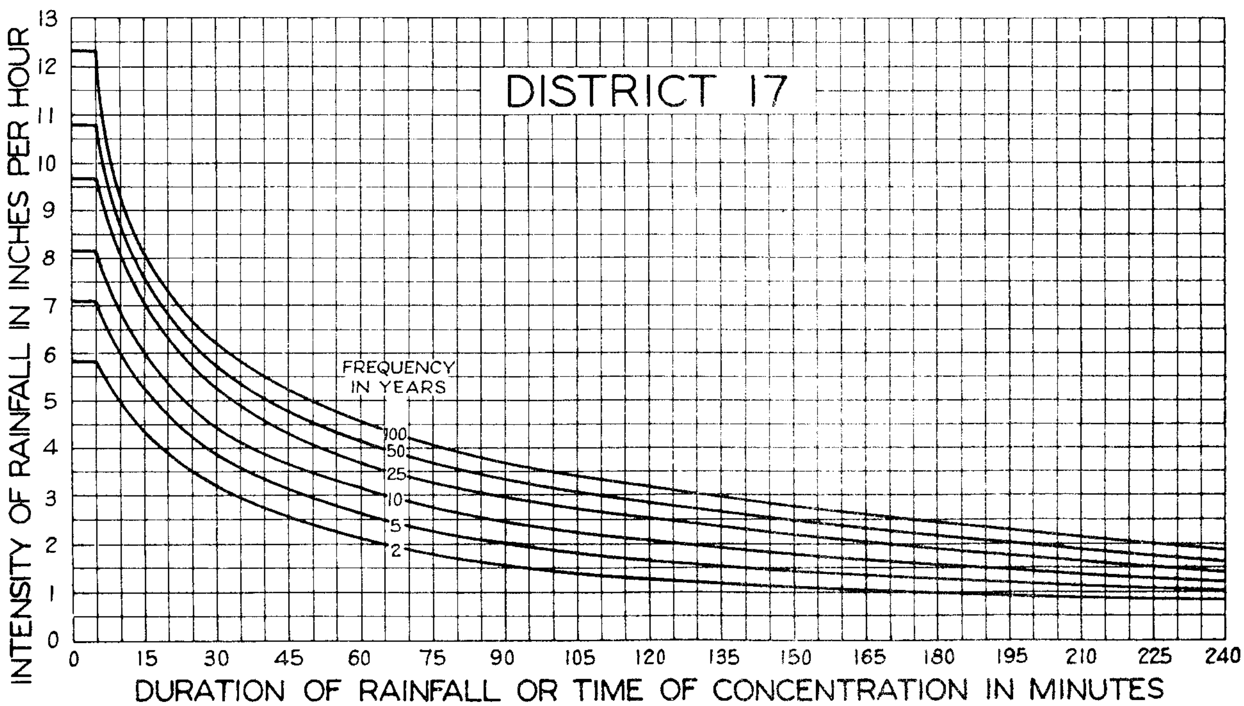
DESIGN WITH OUTFALL CHANNEL

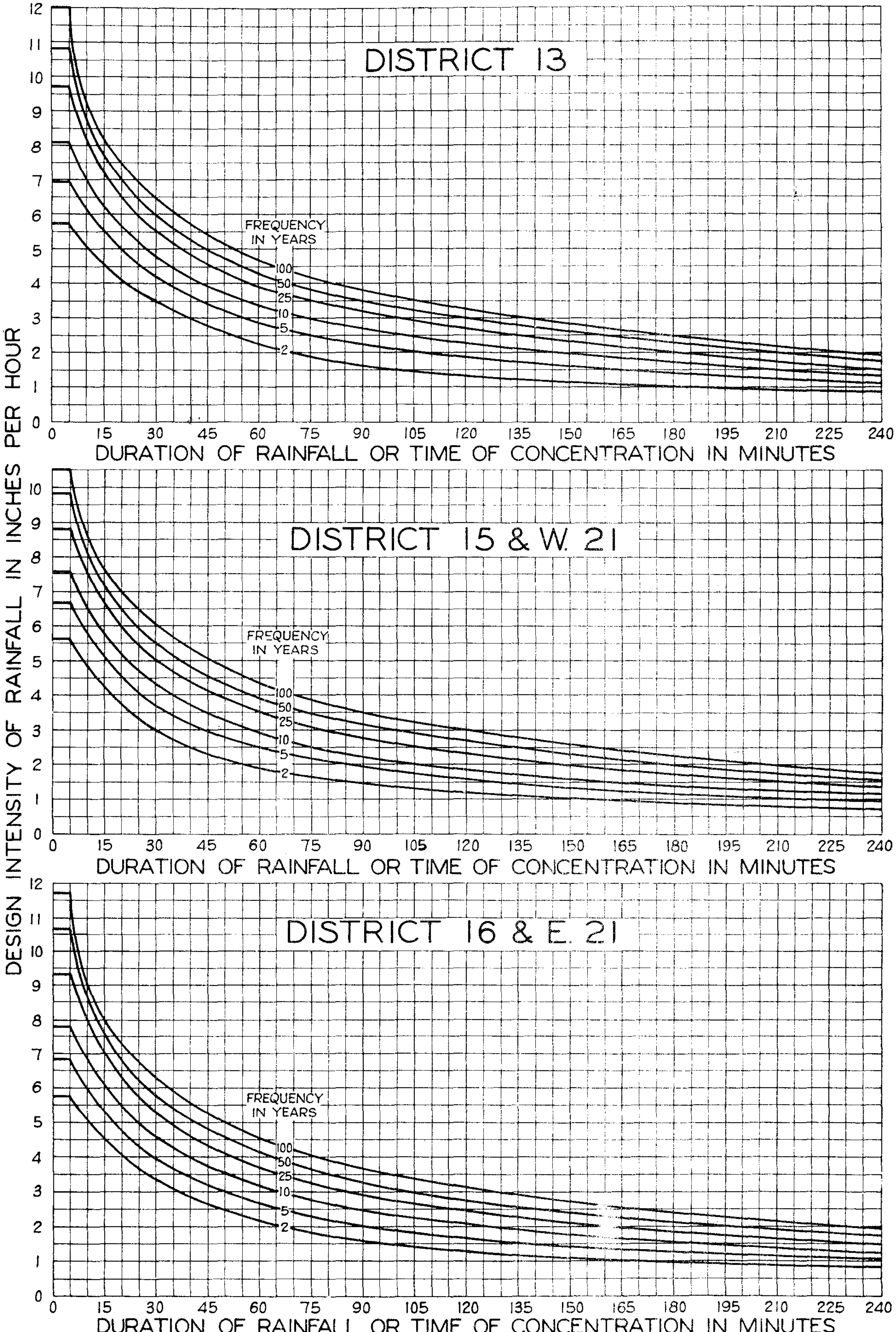

DISTRICTS 1-19
DISTRICT 2
DISTRICT 3
FREQUENCY IN YEARS
100
50
25
10
5
2
DESIGN INTENSITY OF RAINFALL IN INCHES PER HOUR
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240

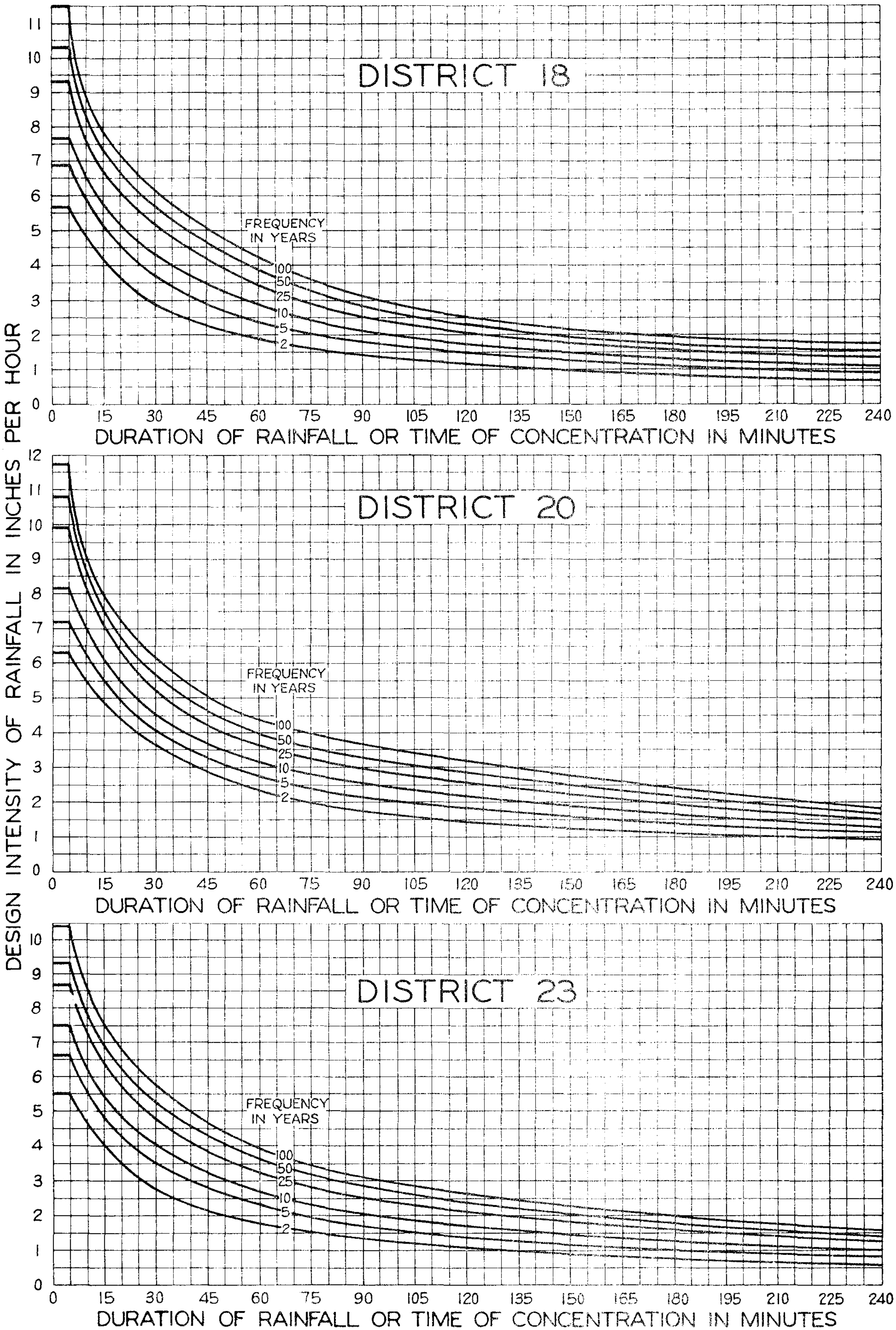

DISTRICTS 4-5-6
DISTRICTS 7-8-22-25
DISTRICTS 9-14
FREQUENCY IN YEARS
100
50
25
10
5
2
DESIGN INTENSITY OF RAINFALL IN INCHES PER HOUR
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240


DESIGN INTENSITY OF RAINFALL IN INCHES PER HOUR
DISTRICT 24
FREQUENCY IN YEARS
100
50
25
10
5
2
0 1 2 3 4 5 6 7 8 9
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES
DISTRICT 10
FREQUENCY IN YEARS
100
50
25
10
5
2
0 1 2 3 4 5 6 7 8 9 10 11 12
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES
DISTRICT 11
FREQUENCY IN YEARS
100
50
25
10
5
2
0 1 2 3 4 5 6 7 8 9 10 11 12
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES


DISTRICT 12
FREQUENCY IN YEARS
100
50
25
10
5
2
INTENSITY OF RAINFALL IN INCHES PER HOUR
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240


DISTRICT 17
FREQUENCY IN YEARS
100
50
25
10
5
2
INTENSITY OF RAINFALL IN INCHES PER HOUR
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240


DESIGN INTENSITY OF RAINFALL IN INCHES PER HOUR
DISTRICT 13
FREQUENCY IN YEARS
100
50
25
10
5
2
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES
DISTRICT 15 & W. 21
FREQUENCY IN YEARS
100
50
25
10
5
2
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES
DISTRICT 16 & E. 21
FREQUENCY IN YEARS
100
50
25
10
5
2
0 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES


DESIGN INTENSITY OF RAINFALL IN INCHES PER HOUR
DISTRICT 18
FREQUENCY IN YEARS
100
50
25
10
5
2
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES
DISTRICT 20
FREQUENCY IN YEARS
100
50
25
10
5
2
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES
DISTRICT 23
FREQUENCY IN YEARS
100
50
25
10
5
2
DURATION OF RAINFALL OR TIME OF CONCENTRATION IN MINUTES

VALUES OF C (RUN-OFF COEFFICIENT) IN FORMULA Q = CIA

SLOPE — LAND USE — CLASSIFICATION OF SOIL

SLOPE	LAND USE	Rolling Plains Min.	Rolling Plains Max.	Sand or Sandy Loam Soils (Pervious) Min.	Sand or Sandy Loam Soils (Pervious) Max.	Black or Loessial Soils (Impervious) Min.	Black or Loessial Soils (Impervious) Max.
Flat (0% - 1%)	Timber			0.15	0.20	0.15	0.20
	Pasture			0.20	0.25	0.25	0.30
	Cultivated			0.25	0.35	0.30	0.40
Rolling (1% - 3.5%)	Timber			0.15	0.20	0.18	0.25
	Pastures	0.25	0.30	0.30	0.40	0.35	0.45
	Cultivated	0.40	0.45	0.45	0.65	0.50	0.70
Hilly (3.5% - 5.5%)	Timber			0.20	0.25	0.25	0.30
	Pasture			0.35	0.45	0.45	0.55
	Cultivated			0.60	0.75	0.70	0.85
Mountainous (5.5% +)	Timber					0.70	0.80
	Bare					0.80	0.90

VALUES OF "n" FOR MANNING'S FORMULA

	Value of "n" for Manning's Formula		
	Good	Fair	Bad
Type of Structure:			
Vitrified Sewer Pipe	0.013	0.015	0.017
Common Clay Drainage Tile	0.012	0.014	0.016
Concrete Culverts	0.012	0.013	0.015
Concrete Pipe	0.012	0.013	0.015
C. G. M. Pipe	0.019	0.021	0.023
Canals and Ditches:			
Earth - Straight and Uniform	0.020	0.022	0.025
Earth - Fairly Rough	0.025	0.030	0.035
Earth - Sodded - No Rank Growth	0.035	0.040	0.045
Earth - Rank Growth	0.040	0.045	0.050
Earth - Dredged Channels	0.027	0.030	0.033
Rock Cuts - Smooth and Uniform	0.030	0.033	0.035
Rock Cuts - Jagged and Irregular	0.035	0.040	0.045
Natural Streams:			
Clean, straight banks, full stage, no deep pools	0.027	0.030	0.033
Clean, straight banks, full stage, some weeds and pools	0.033	0.035	0.040
Clean, Straight banks, full stage winding, some pools	0.035	0.040	0.045
Some weeds and stones, lower stages winding, some pools.	0.040	0.045	0.050
Sluggish River Reaches, weedy or with Deep Pools.	0.060	0.070	0.080
Sluggish Channels, winding, very weedy with Rank Growth	0.100	0.125	0.150

Approximate Average Velocities of Runoff Flow for Calculating Time of Concentration

(Adapted from "Rainfall and Runoff" - Region 2)

Description of Course of Runoff Water	Slope in Per Cent			
	0 - 3	4 - 7	8 - 11	12 - 15
	Ft/Sec.	Ft/Sec.	Ft/Sec.	Ft/Sec.
Unconcentrated*				
Woodlands	1.0	2.0	3.0	3.5
Pastures	1.5	3.0	4.0	4.5
Cultivated Land (Row Crops)	2.0	4.0	5.0	6.0
Pavements	5.0	12.0	15.5	18.0
Concentrated**				
Vegetative Outlet Channel	Use designed velocities			
Outlet Channel Containing Drop Structures	4.0	5.0	6.0	7.0
Natural Channel Not Well Defined	1.0	3.0	5.0	8.0
Natural Channel Well Defined	Calculate velocities by Manning's Formula			

Note: - Average velocity of flow in variable grade terrace channels may be considered as 1.0 ft. per sec.

* This condition occurs in upper extremity of watershed only.

** These values vary with the channel size and other conditions so that the ones given are the averages of a wide range. Where possible more accurate determinations should be made for particular conditions by the Manning Channel Formula for velocity.

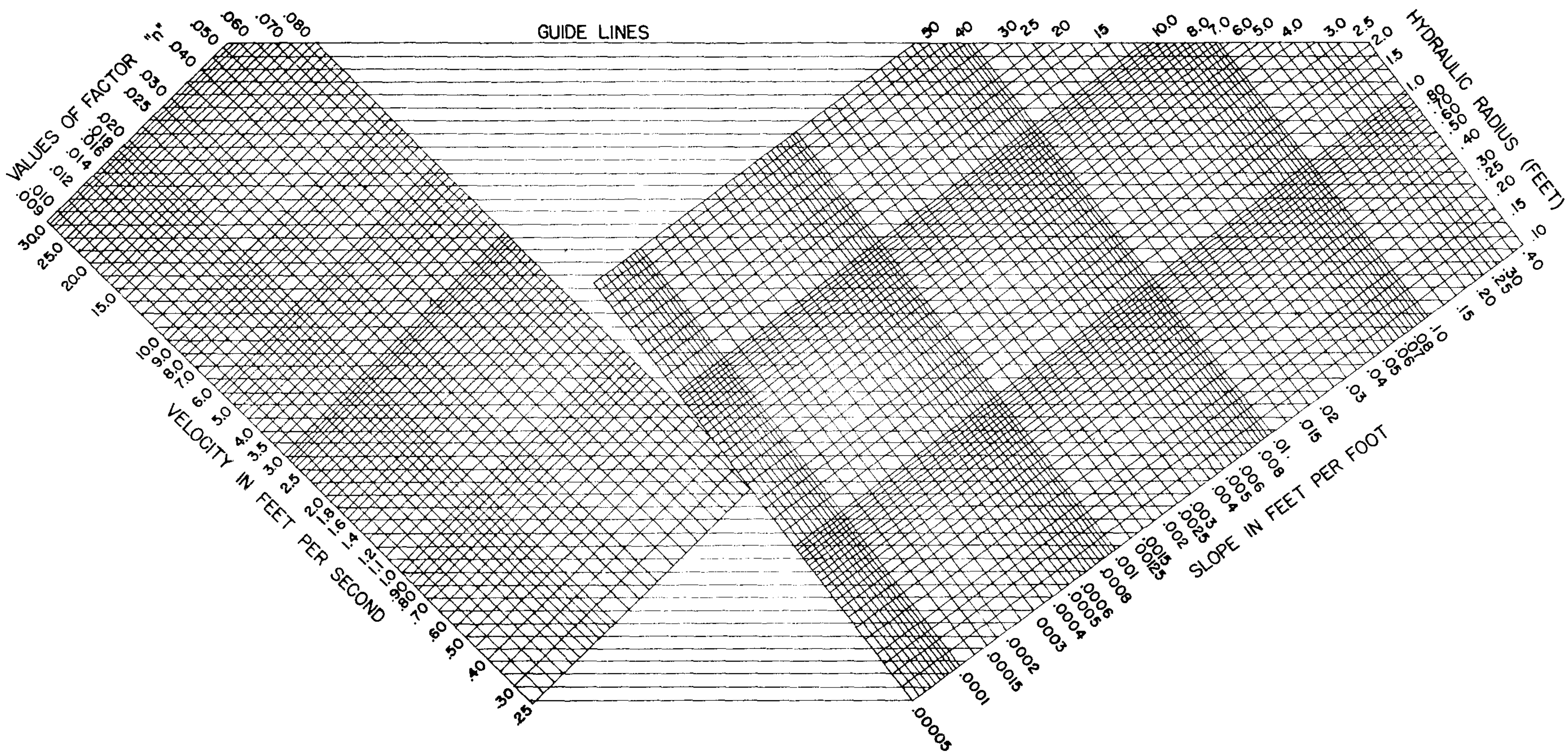


DIAGRAM
FOR SOLUTION OF
MANNING'S FORMULA

VALUES OF K & K'

FOR USE IN COMPUTING FRICTION LOSSES IN CONCRETE CULVERTS

FORMULAS USED:

$$h_f = K L \frac{V^2}{2g} \quad \text{for culverts flowing full}$$

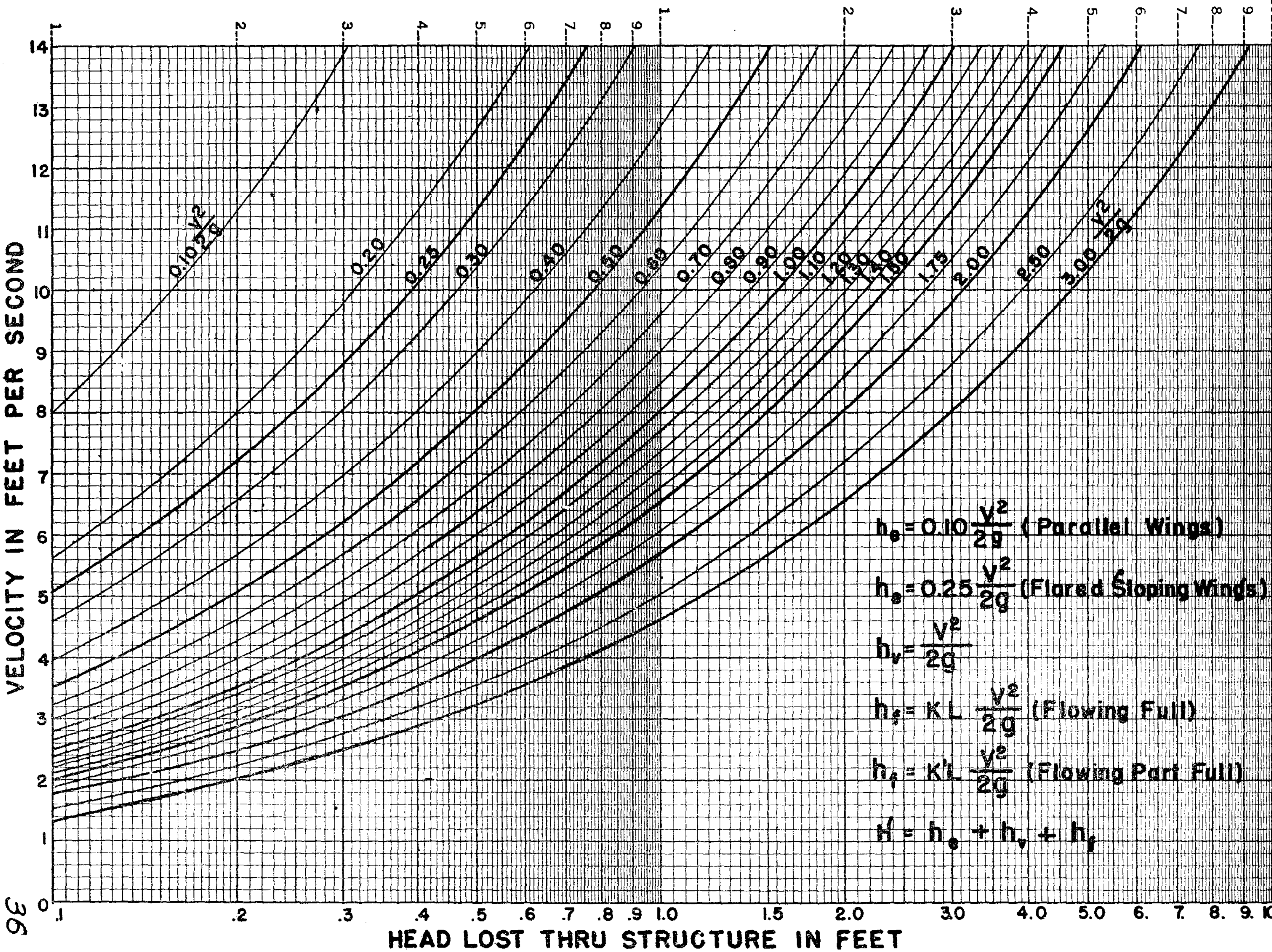
$$h_f = K' L \frac{V^2}{2g} \quad \text{for culverts flowing part full}$$

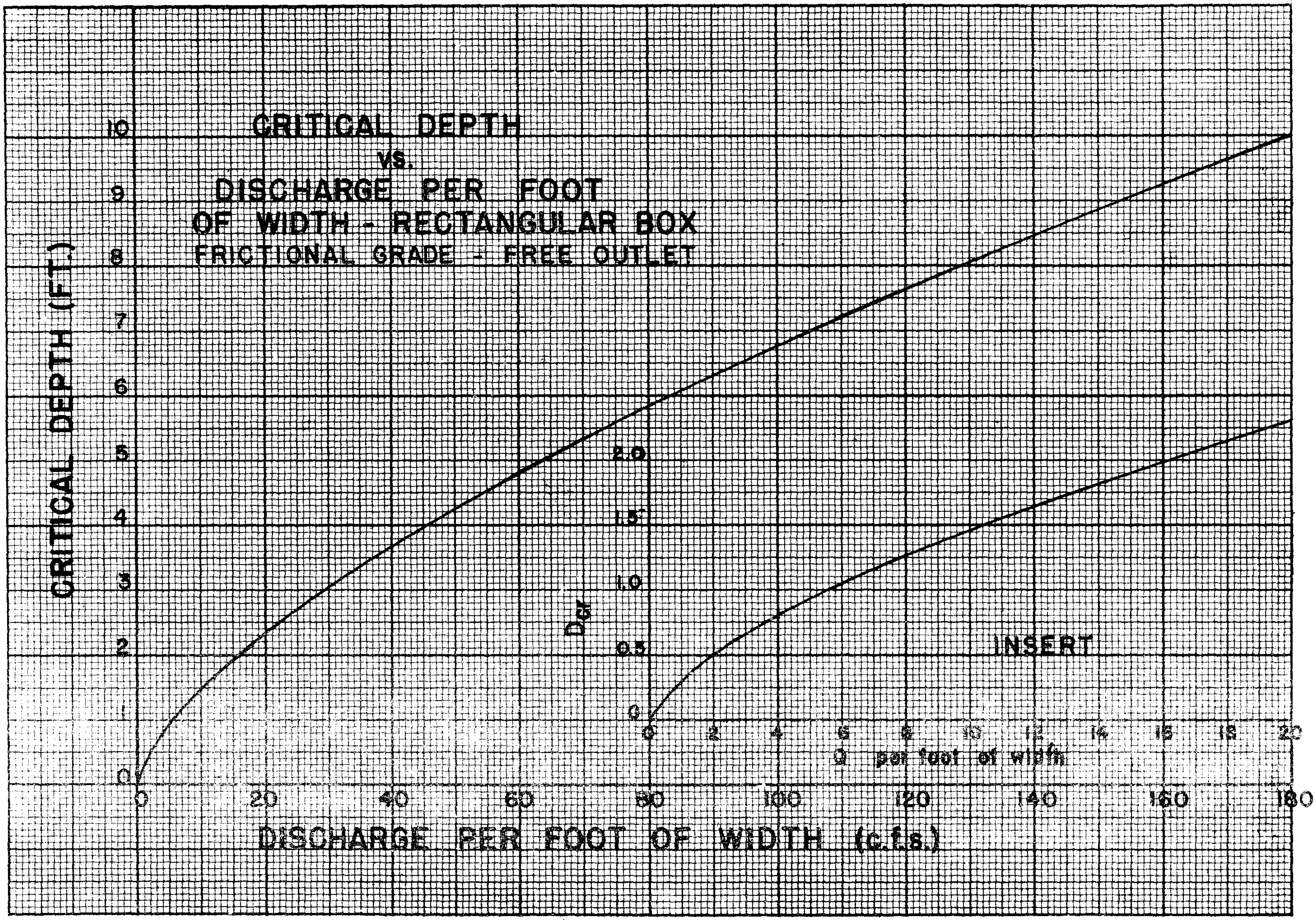
h_f = Head lost in feet due to friction in culvert and does not include entrance head or velocity head.
K = Constant for culvert flowing full.
K' = Constant for culvert flowing part full.
L = Length of culvert in feet.
g = Acceleration of gravity = 32.2

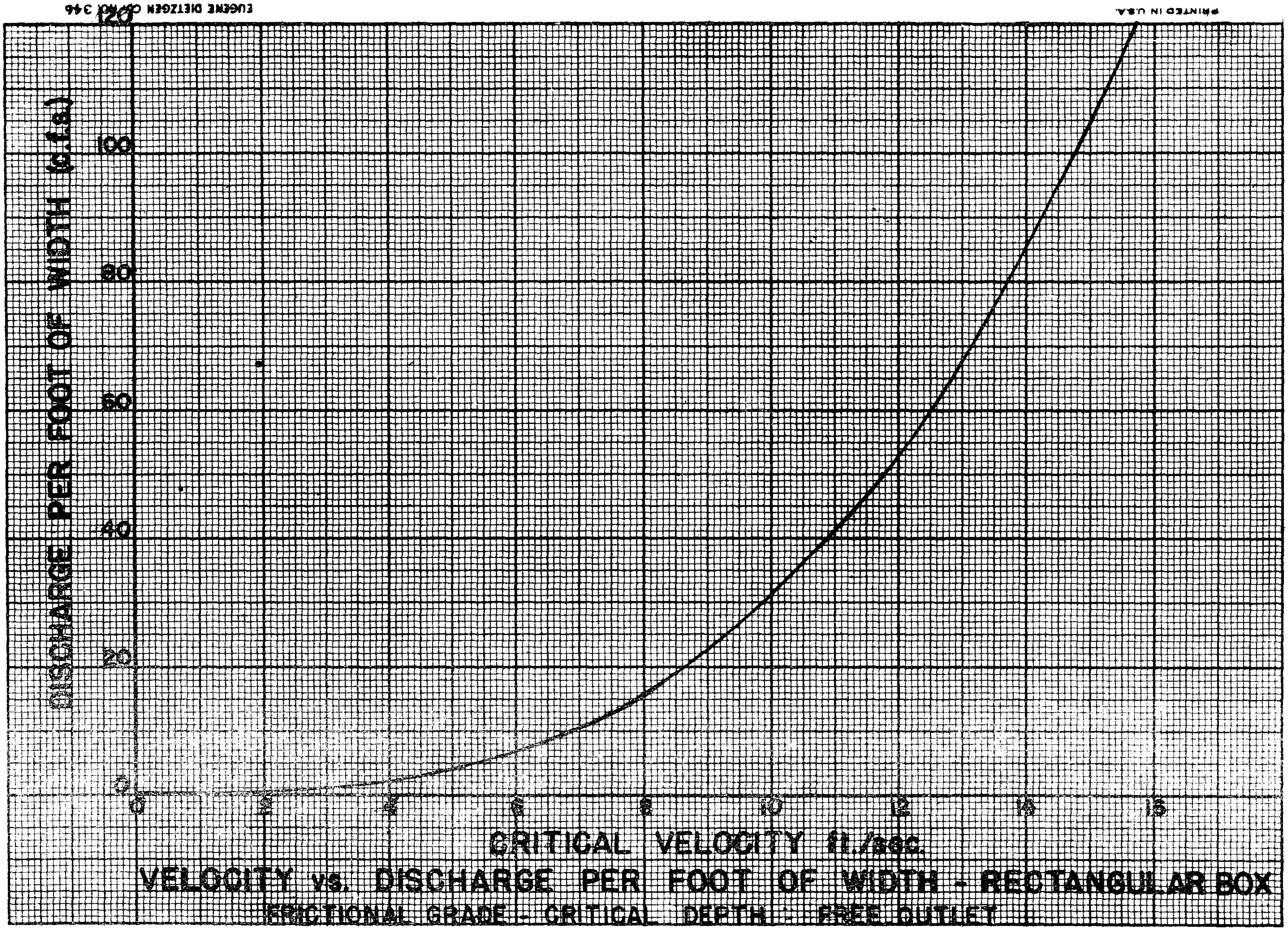
Note: For culverts flowing part full, use the depth of flow instead of depth of culvert.

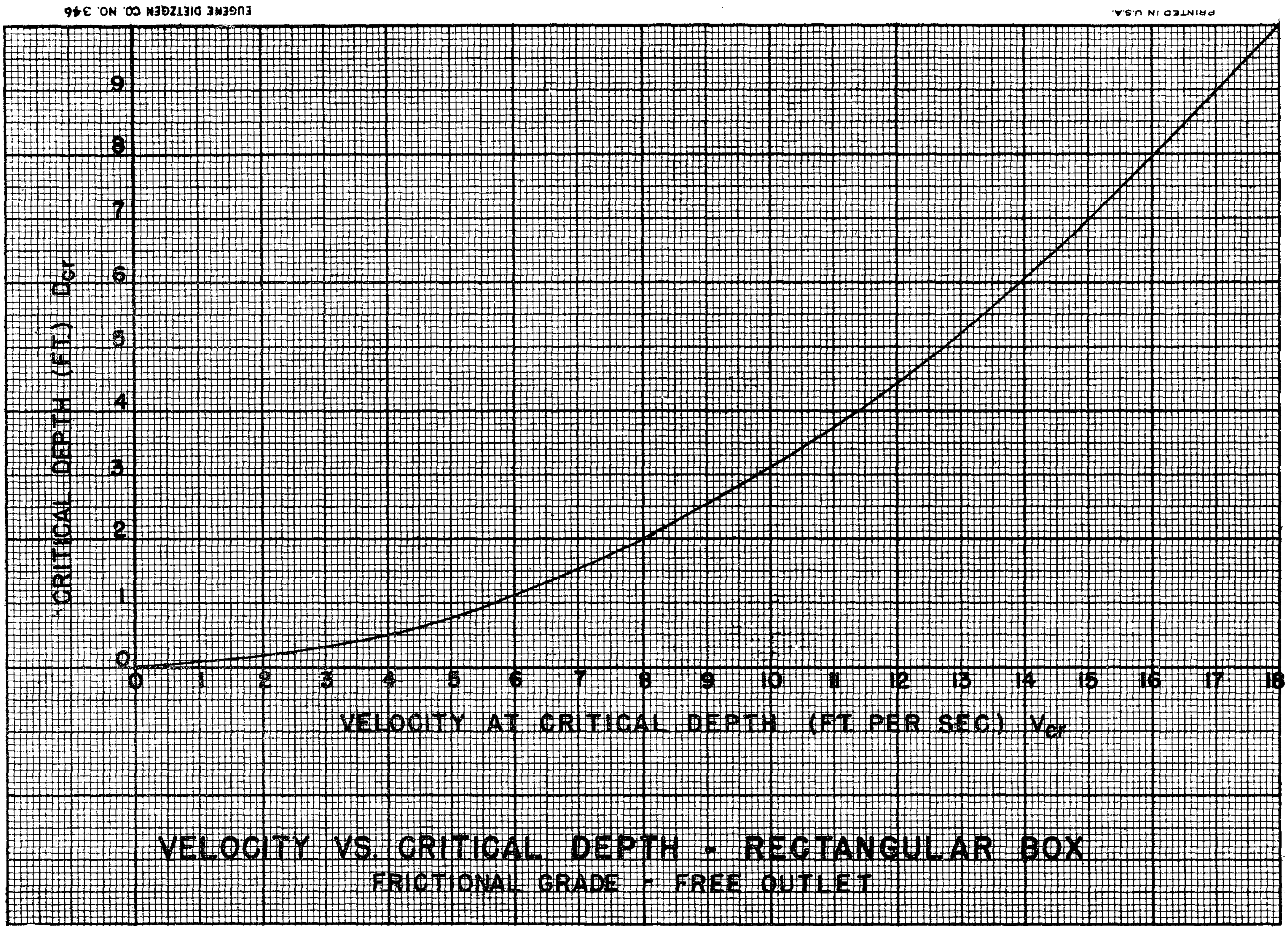
Culvert Size	K	K'	Culvert Size	K	K'
(Pipes) 12"	.0312		7 x 2	.0070	.0036
18"	.0182		7 x 2	.0046	.0026
24"	.0124		7 x 4	.0036	.0021
36"	.0072		7 x 5	.0030	.0019
42"	.0059		7 x 6	.0026	.0017
48"	.0049		7 x 7	.0023	.0016
54"	.0042		8 x 3	.0044	.0024
60"	.0036		8 x 4	.0036	.0020
(Box Culverts)			8 x 5	.0028	.0017
2 x 1.5	.0157	.0098	8 x 6	.0024	.0015
2 x 2	.0124	.0084	8 x 7	.0022	.0014
3 x 1.5	.0124	.0073	8 x 8	.0020	.0013
3 x 2	.0098	.0060	9 x 3	.0042	.0023
3 x 2.5	.0083	.0054	9 x 4	.0032	.0018
3 x 3	.0073	.0049	9 x 5	.0026	.0016
4 x 1.5	.0112	.0060	9 x 6	.0023	.0014
4 x 2	.0086	.0049	9 x 7	.0020	.0013
4 x 2.5	.0071	.0043	9 x 8	.0018	.0012
4 x 3	.0061	.0039	9 x 9	.0017	.0011
4 x 4	.0049	.0034	10 x 3	.0041	.0021
5 x 1.5	.0105	.0054	10 x 4	.0031	.0017
5 x 2	.0078	.0043	10 x 5	.0025	.0015
5 x 3	.0054	.0033	10 x 6	.0021	.0013
5 x 4	.0043	.0028	10 x 7	.0019	.0012
5 x 5	.0038	.0025	10 x 8	.0017	.0011
6 x 2	.0073	.0039	10 x 9	.0016	.0010
6 x 3	.0049	.0029	10 x 10	.0015	.0010
6 x 4	.0039	.0024	10 x 11	.0014	.0010
6 x 5	.0033	.0021	10 x 12	.0013	.0009
6 x 6	.0029	.0020			

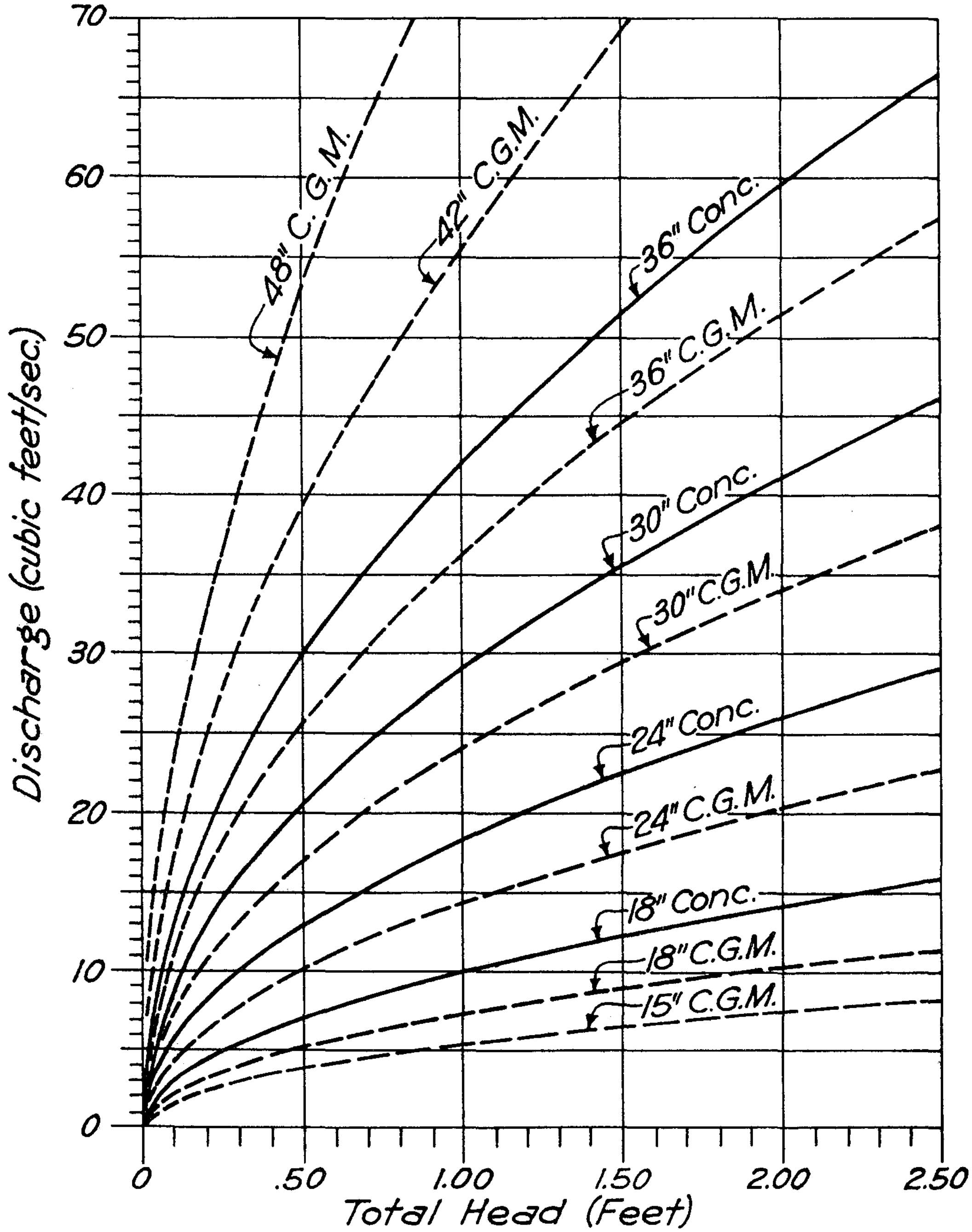
Based on Manning's Formula $V = \frac{1.486\, r^{2/3}\, s^{1/2}}{n}$ where "n" = 0.013 and h_f = S L.


VELOCITY IN FEET PER SECOND
HEAD LOST THRU STRUCTURE IN FEET
0.10 V²/2g
0.20
0.25
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
1.10
1.20
1.30
1.40
1.50
1.75
2.00
2.50
3.00 V²/2g
hₑ = 0.10 V²/2g (Parallel Wings)
hₑ = 0.25 V²/2g (Flared Sloping Wings)
hᵥ = V²/2g
h_f = KL V²/2g (Flowing Full)
h_f = K'L V²/2g (Flowing Part Full)
H' = hₑ + hᵥ + h_f


CRITICAL DEPTH
vs.
DISCHARGE PER FOOT
OF WIDTH - RECTANGULAR BOX
FRICTIONAL GRADE - FREE OUTLET
CRITICAL DEPTH (FT.)
0
1
2
3
4
5
6
7
8
9
10
0
20
40
60
80
100
120
140
160
180
DISCHARGE PER FOOT OF WIDTH (c.f.s.)
Dcr
0
0.5
1.0
1.5
2.0
0
2
4
6
8
10
12
14
16
18
20
Q per foot of width
INSERT


EUGENE DIETZGEN CO. NO. 346
PRINTED IN U.S.A.
DISCHARGE PER FOOT OF WIDTH (c.f.s.)
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
CRITICAL VELOCITY ft./sec.
VELOCITY vs. DISCHARGE PER FOOT OF WIDTH - RECTANGULAR BOX
FRICTIONAL GRADE - CRITICAL DEPTH - FREE OUTLET

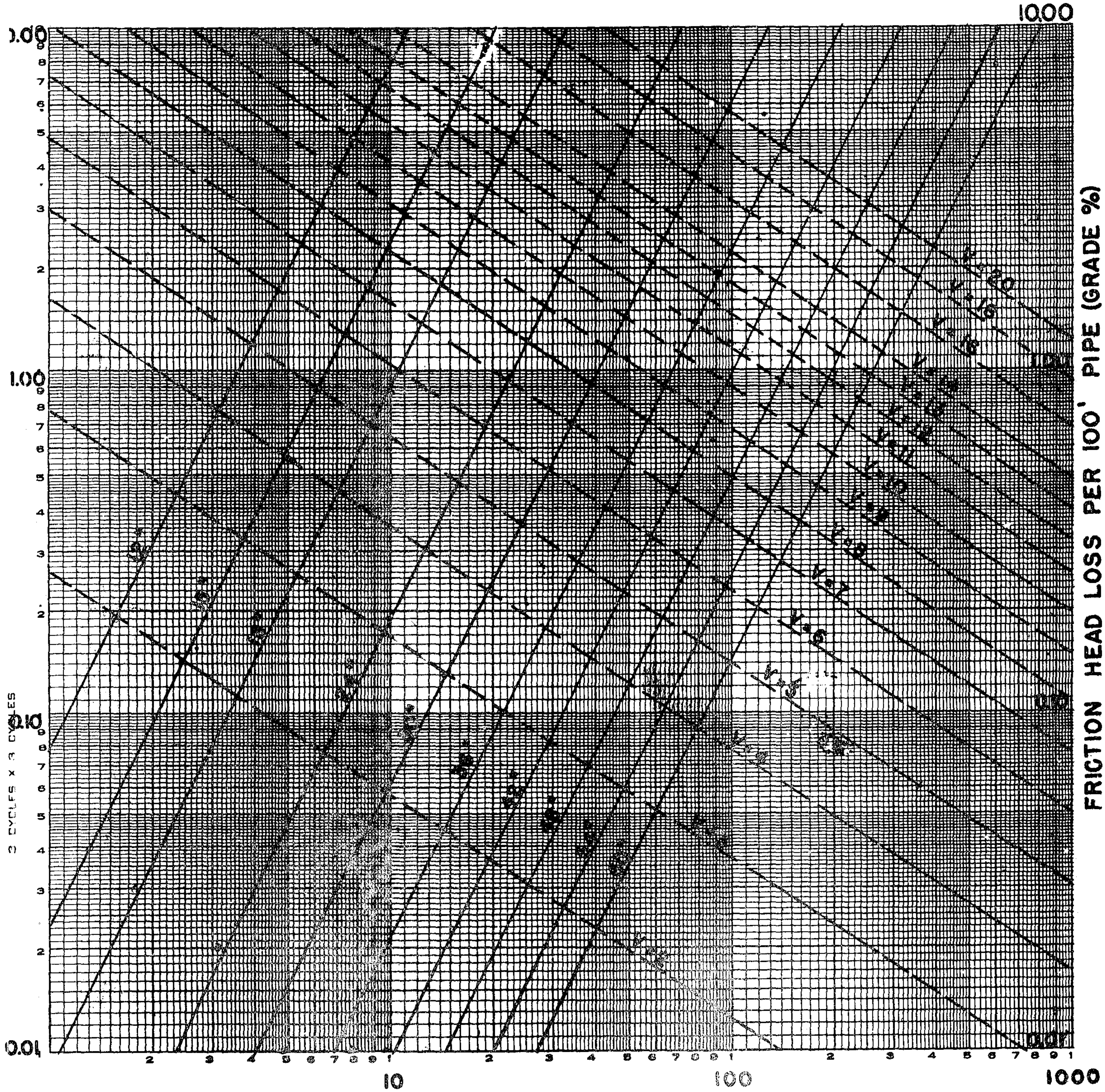

EUGENE DIETZGEN CO. NO. 346
PRINTED IN U.S.A.
CRITICAL DEPTH (FT.) Dcr
0
1
2
3
4
5
6
7
8
9
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
VELOCITY AT CRITICAL DEPTH (FT. PER SEC.) Vcr
VELOCITY VS. CRITICAL DEPTH - RECTANGULAR BOX
FRICTIONAL GRADE - FREE OUTLET



Length = 40', Downstream end Submerged

DISCHARGE CAPACITY OF CONCRETE AND CORRUGATED METAL PIPE
(Submerged Outlet)

DISCHARGE VS. SLOPE
CONCRETE PIPE CULVERTS
PIPE FLOWING FULL
Manning's "n" = 0.013

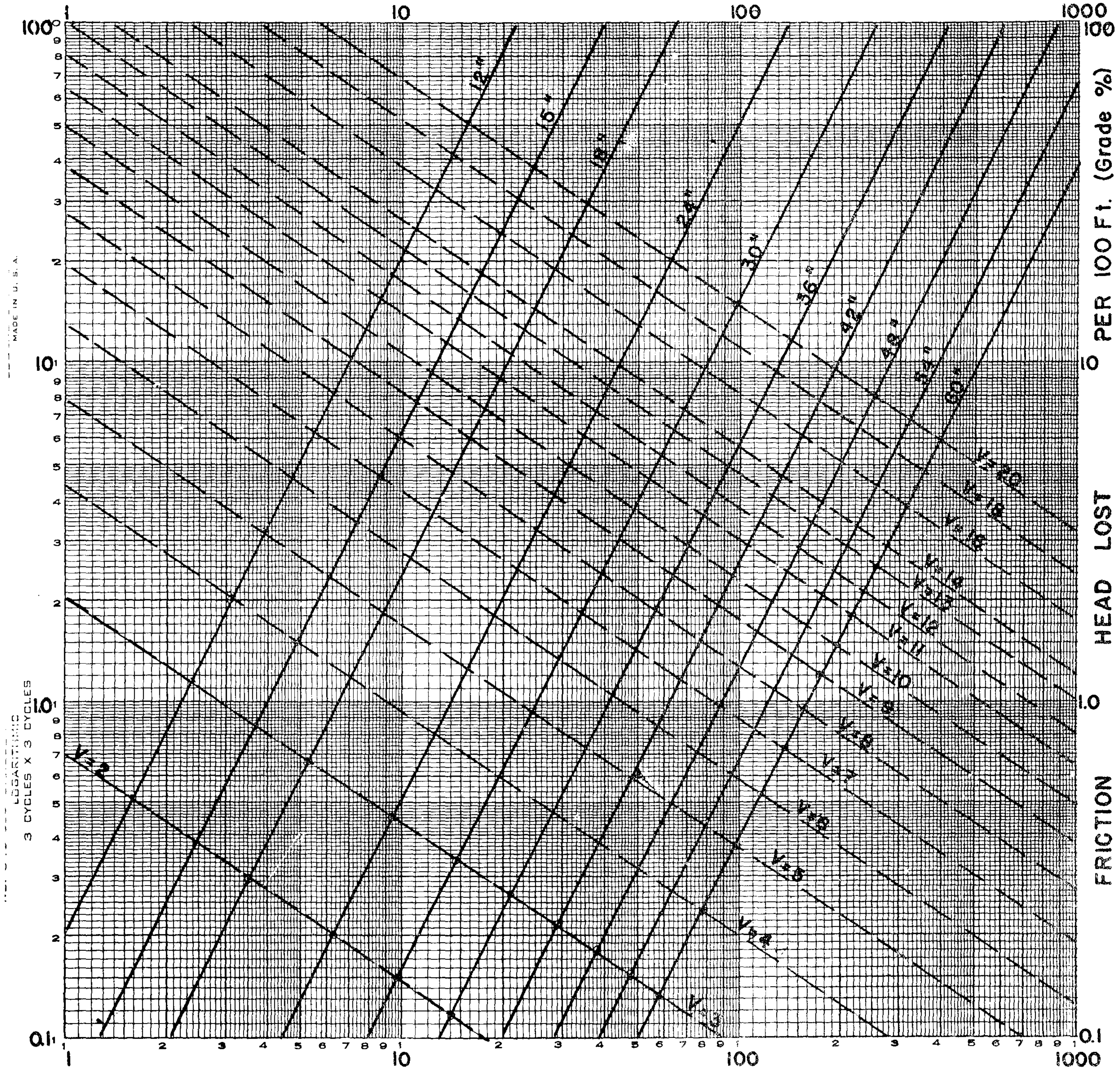


DISCHARGE (c.f.s.)

40-A

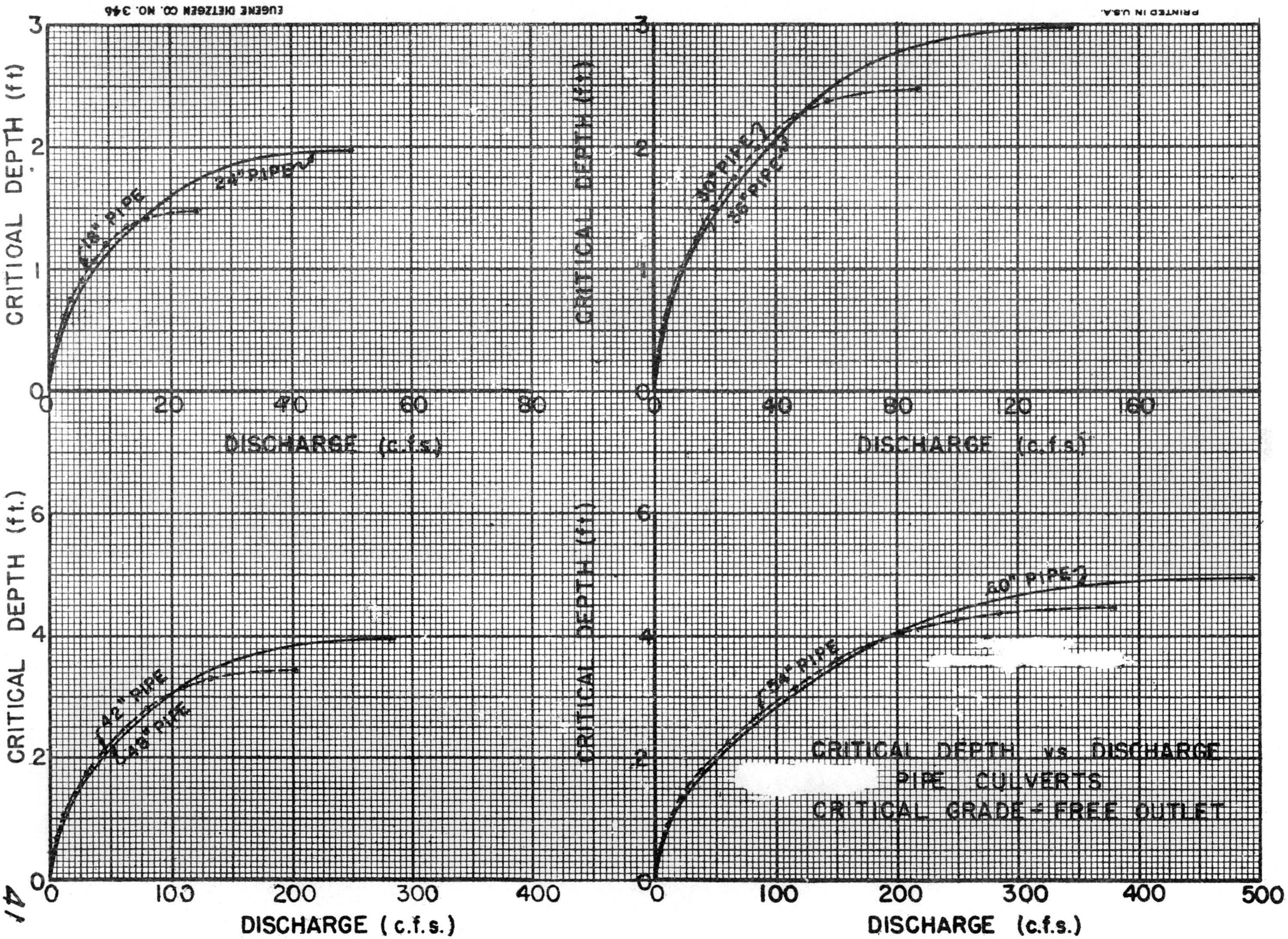
$$h_f = \frac{29.2\ n^2\ LV^2}{r^{4/3}\ 2g} \quad Q = AV$$

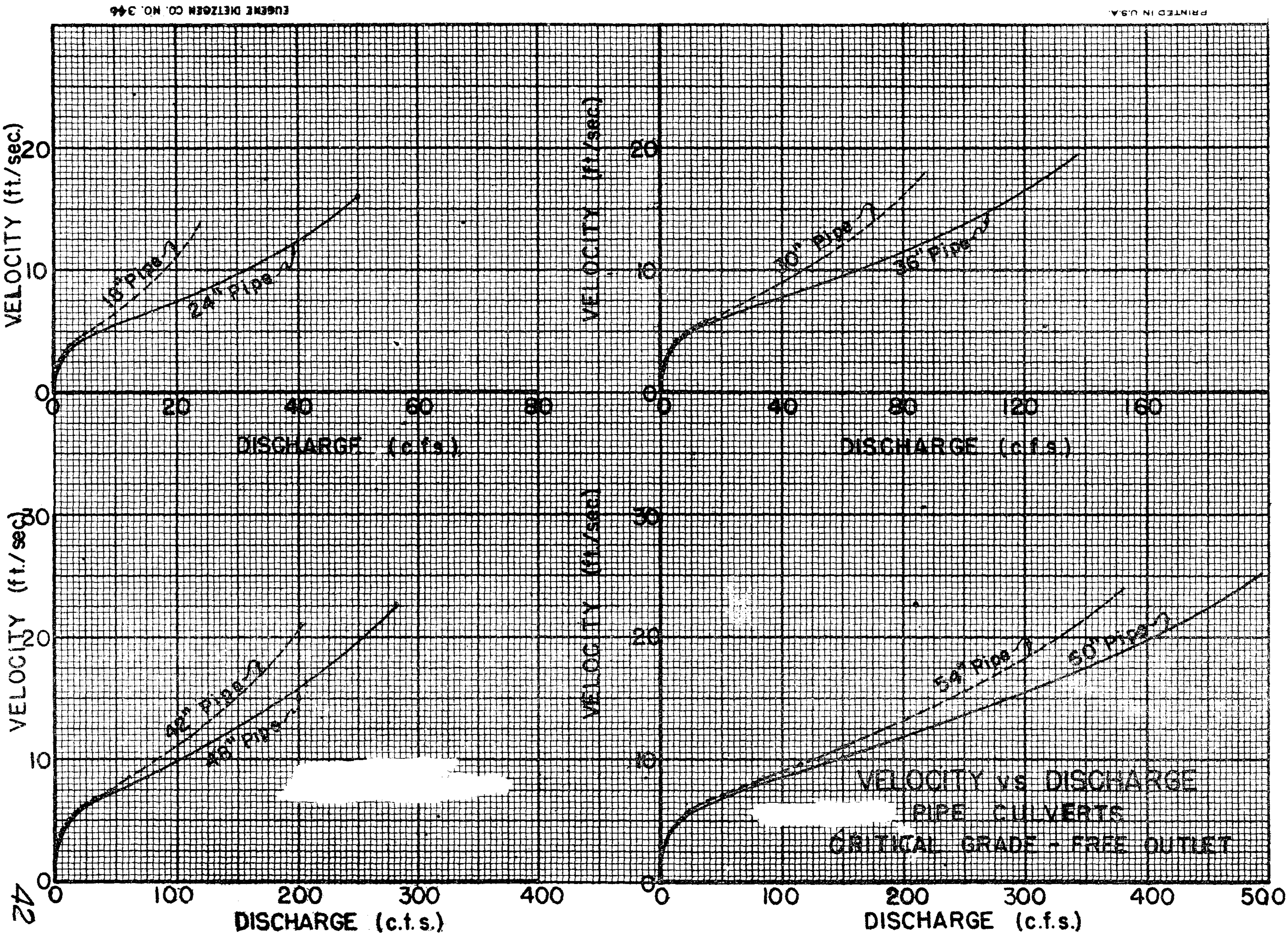
DISCHARGE VS. SLOPE
C.G.M. PIPE CULVERTS
PIPE FLOWING FULL
Manning's "n" = 0.021

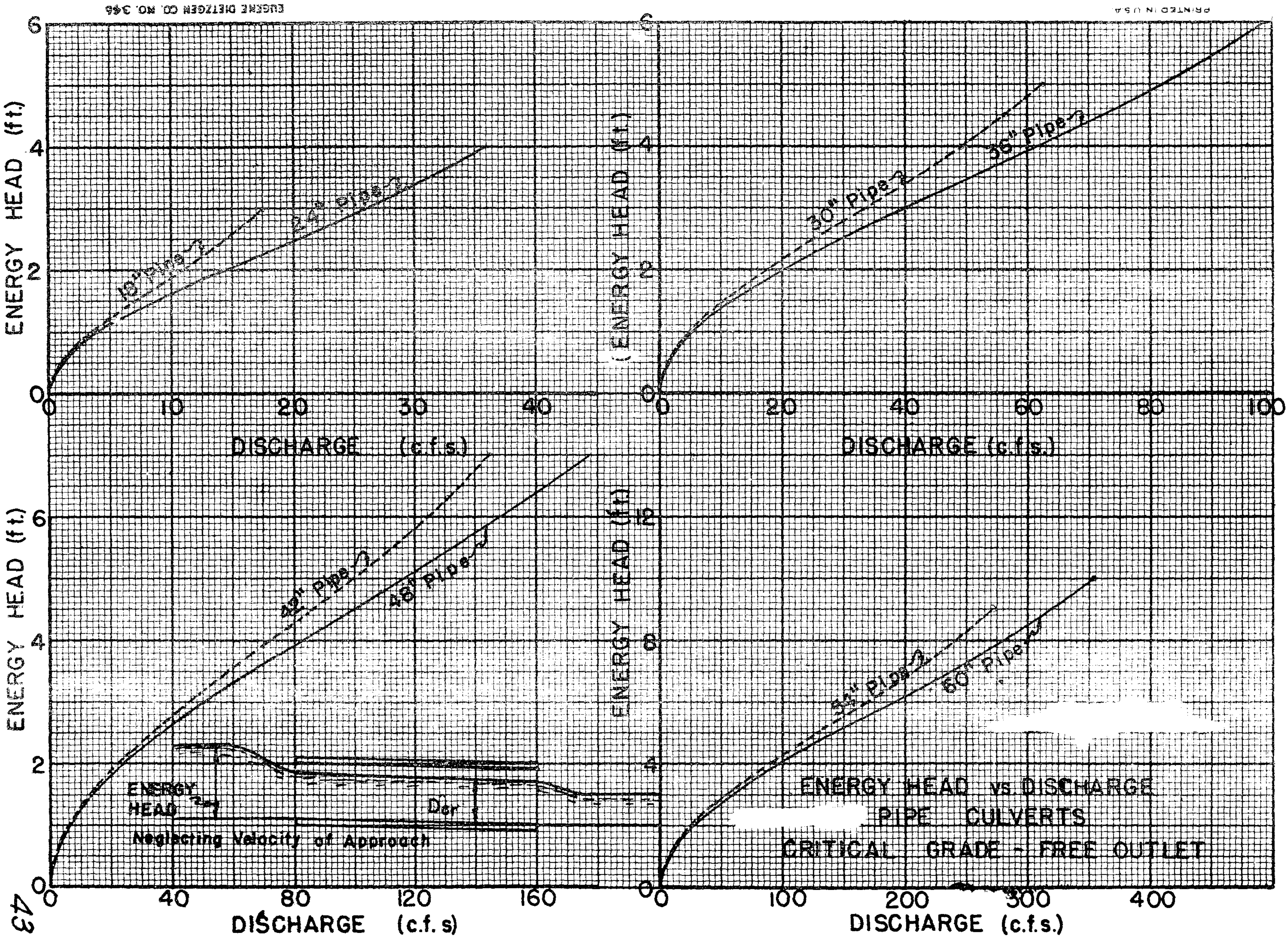


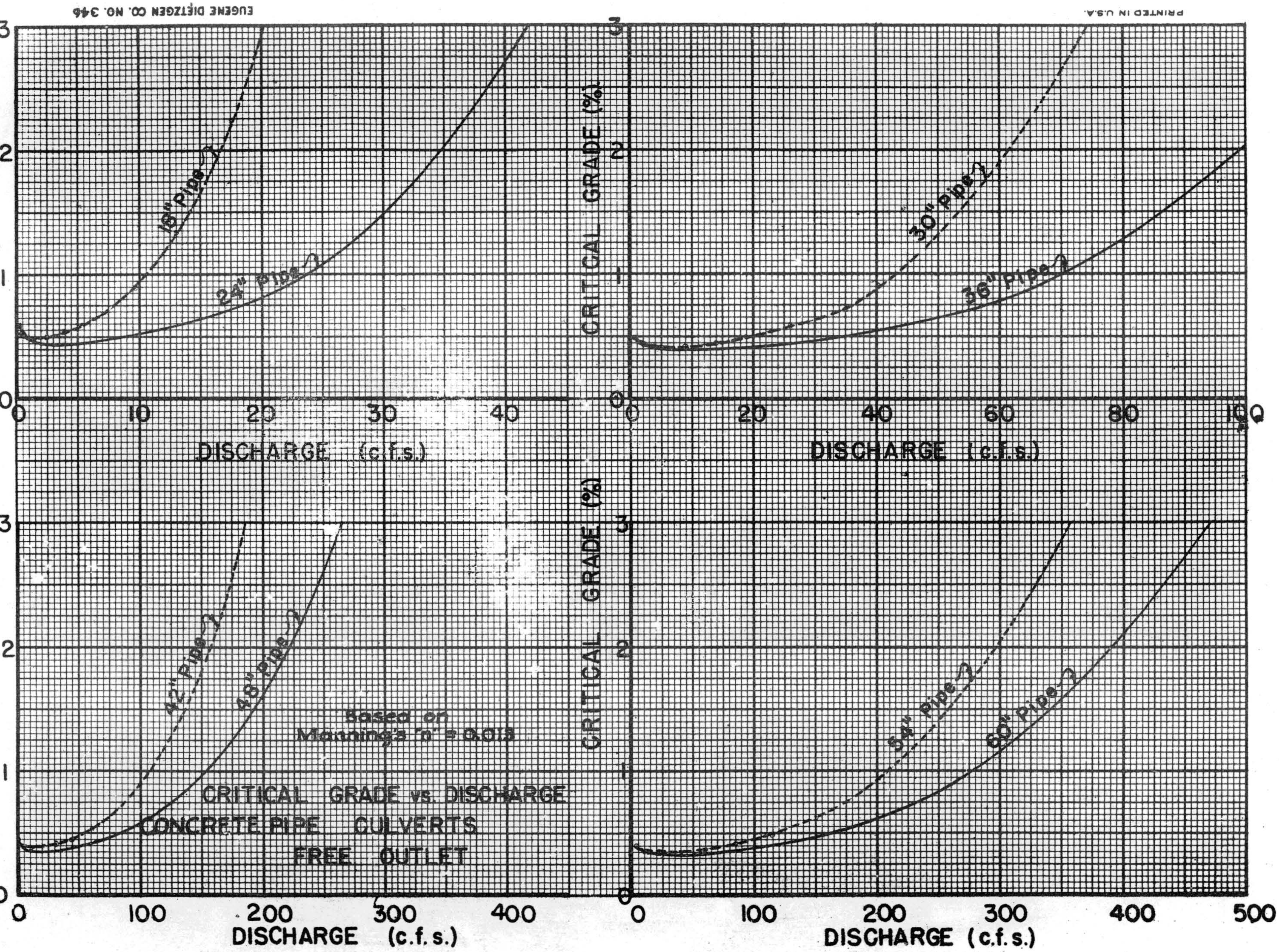
DISCHARGE (c.f.s.)

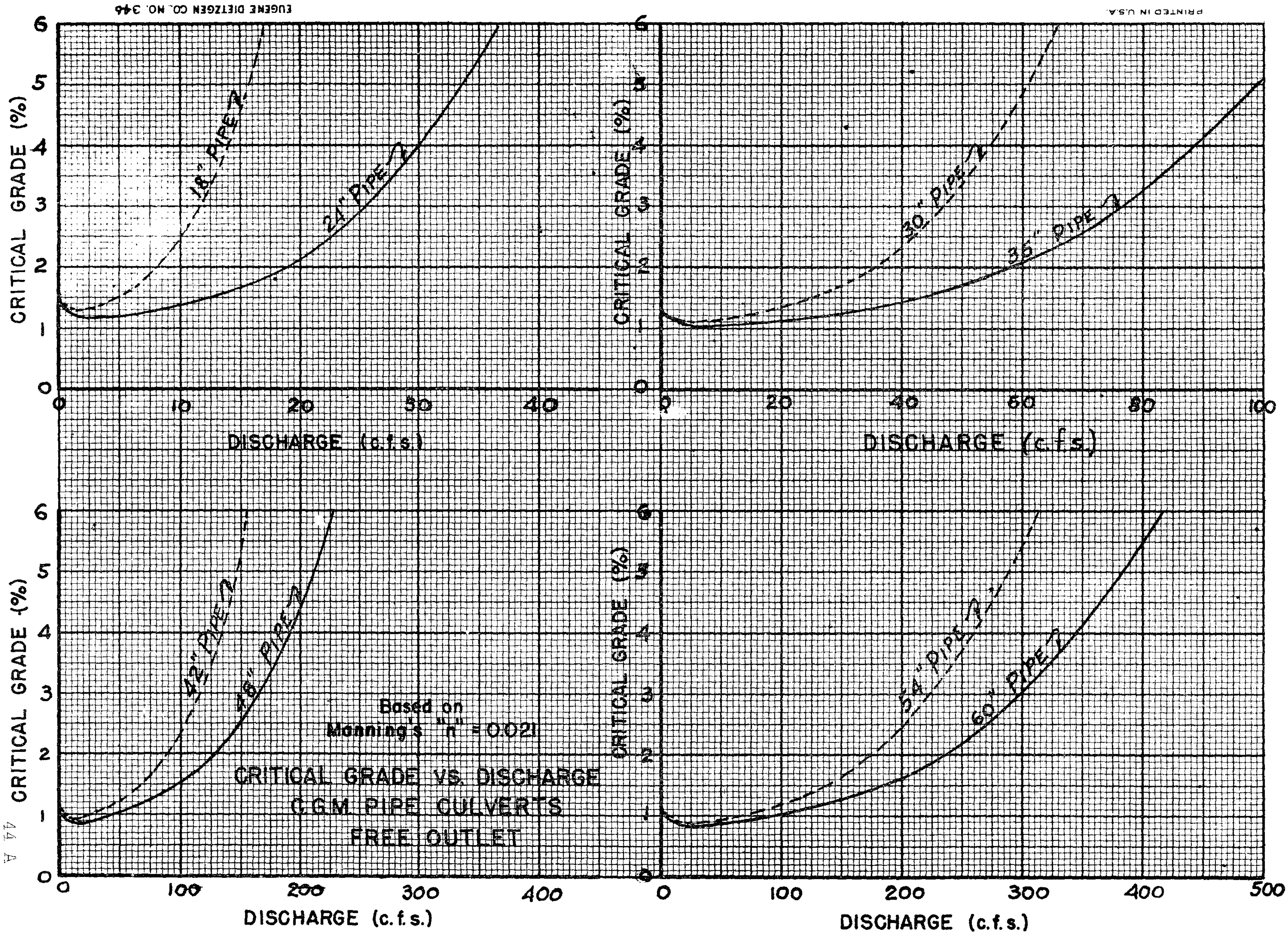
$$h_f = \frac{29.2\ n^2\ LV^2}{r^{4/3}\ 2g} \quad Q = AV$$


EUGENE DIETZGEN CO. NO. 346
PRINTED IN U.S.A.
CRITICAL DEPTH (ft)
DISCHARGE (c.f.s.)
18" PIPE
24" PIPE
30" PIPE
36" PIPE
CRITICAL DEPTH (ft.)
DISCHARGE (c.f.s.)
42" PIPE
48" PIPE
54" PIPE
60" PIPE
CRITICAL DEPTH vs DISCHARGE
PIPE CULVERTS
CRITICAL GRADE - FREE OUTLET


VELOCITY (ft./sec.)
DISCHARGE (c.f.s.)
18" Pipe
24" Pipe
30" Pipe
36" Pipe
42" Pipe
48" Pipe
54" Pipe
60" Pipe
VELOCITY vs DISCHARGE
PIPE CULVERTS
CRITICAL GRADE - FREE OUTLET


EUGENE DIETZGEN CO. NO. 346
PRINTED IN U.S.A.
ENERGY HEAD (ft.)
DISCHARGE (c.f.s.)
18" Pipe
24" Pipe
30" Pipe
36" Pipe
42" Pipe
48" Pipe
54" Pipe
60" Pipe
ENERGY HEAD
Dcr
Neglecting Velocity of Approach
ENERGY HEAD vs. DISCHARGE
PIPE CULVERTS
CRITICAL GRADE - FREE OUTLET

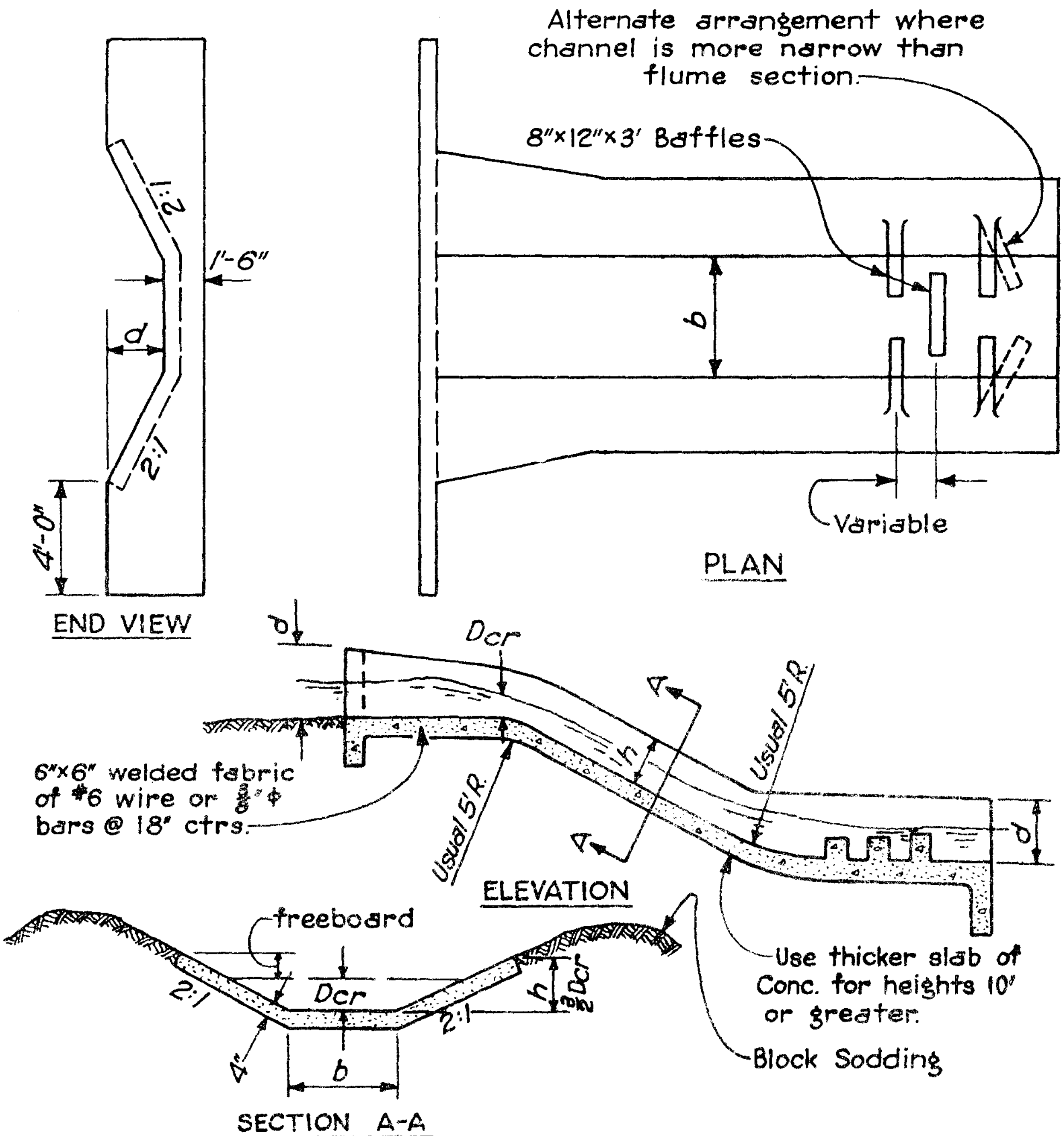

CRITICAL GRADE vs. DISCHARGE
CONCRETE PIPE CULVERTS
FREE OUTLET
Based on
Manning's "n" = 0.013
CRITICAL GRADE (%)
DISCHARGE (c.f.s.)
18" Pipe
24" Pipe
30" Pipe
36" Pipe
42" Pipe
48" Pipe
54" Pipe
60" Pipe
EUGENE DIETZGEN CO. NO. 346
PRINTED IN U.S.A.


EUGENE DIETZGEN CO. NO. 346
PRINTED IN U.S.A.
CRITICAL GRADE (%)
18" PIPE
24" PIPE
DISCHARGE (c.f.s.)
30" PIPE
36" PIPE
42" PIPE
48" PIPE
54" PIPE
60" PIPE
Based on
Manning's "n" = 0.021
CRITICAL GRADE VS. DISCHARGE
C.G.M. PIPE CULVERTS
FREE OUTLET

FLUMES

Capacity cu. ft. per sec.	b	Critical Depth D_{cr}	Usual h	Usual d
17.8	4'	9"	1'-1½"	1'-6"
29.5	4'	1'-0"	1'-6"	2'-0"
40.6	6'	1'-0"	1'-6"	2'-0"
61.0	4'	1'-6"	2'-3"	3'-0"
81.3	6'	1'-6"	2'-3"	3'-0"
135.0	6'	2'-0"	3'-0"	4'-0"

Note: This design on flumes is intended for use as a guide in erosion control of side road ditches and outfalls. The exact dimensions of upstream and downstream aprons will depend on slope and other conditions that affect the design. The number and arrangement of baffles, sodding, and additional riprap is determined by the Engineer to fit the particular location. Plans should show calculated discharge for each flume.



EROSION VELOCITIES FOR VARIOUS SOILS

Material	Maximum Mean Velocity (ft./sec.) Safe against Erosion
Very Light Pure Sand	1.00 - 1.50
Coarse Sand - Light Sandy Soil	1.50 - 2.00
Average Sandy Soil	2.00 - 2.50
Sandy Loam	2.50 - 2.75
Average Loam	2.75 - 3.00
Firm Loam, Clay Loam	3.00 - 3.75
Stiff Clay, Ordinary Gravel Soil	4.00 - 5.00
Coarse Gravel	5.00 - 6.00
Sodded Soil, Conglomerates, Cemented Gravel, Soft Slate, Tough Hardpan, Soft Sedimentary Rock	6.00 - 8.00
Hard Rock	10.00 -15.00
Concrete	15.00 -20.00

- -

Note: It is not the intent of the above to limit the discharge in culverts to the values shown. A small amount of scour at the design frequency is not serious because siltation will probably take place by rains of lesser intensity. In general, box culverts may be designed with velocities up to 10 feet per second but it is recommended that velocities be reduced to a maximum of 8 feet per second unless special protection is provided downstream.

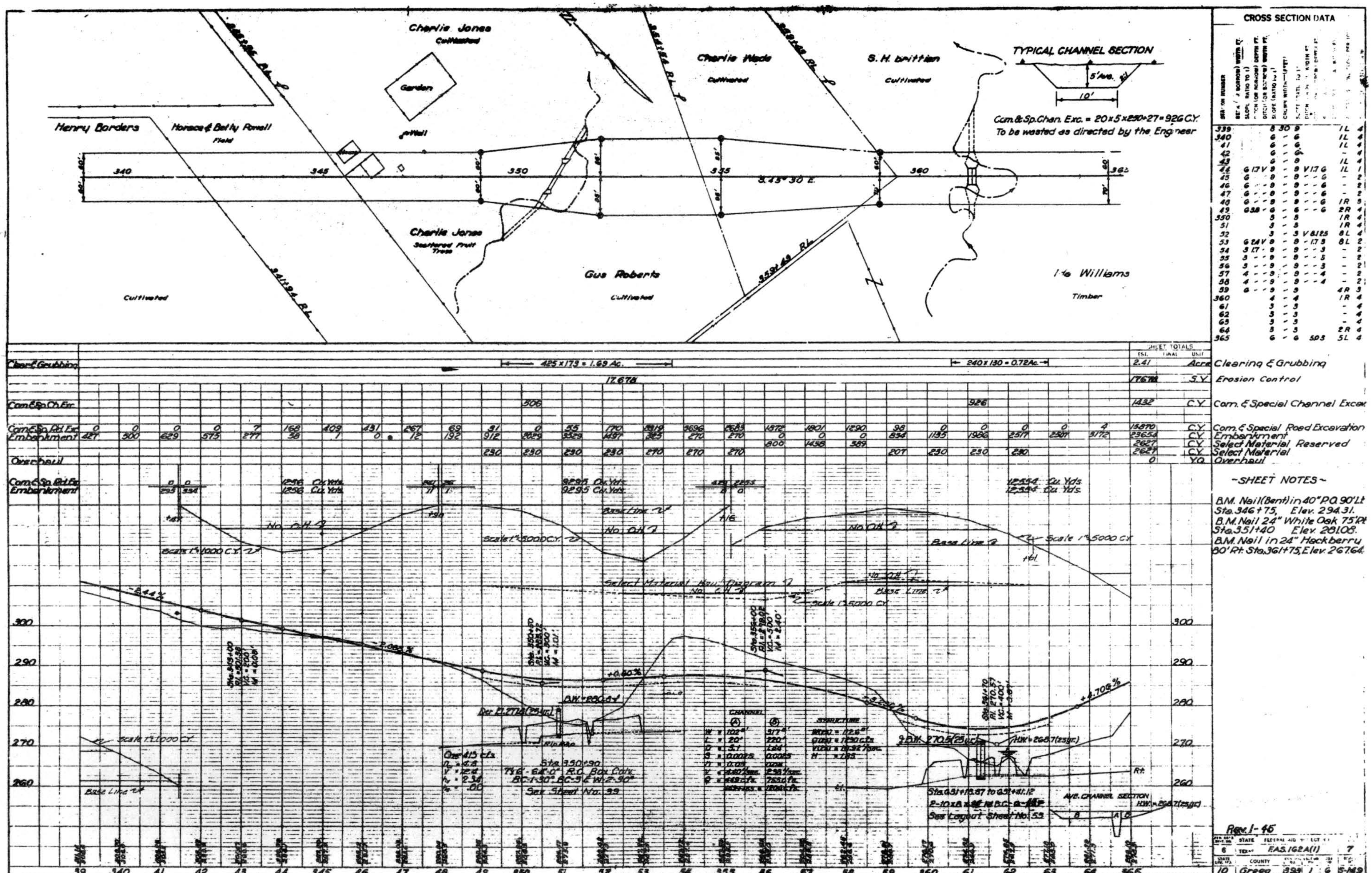
RAINFALL INTENSITY

Constants for Use in Formula $I = \frac{b}{(t+d)^e}$

Based on Texas Reclamation Dept. Publication

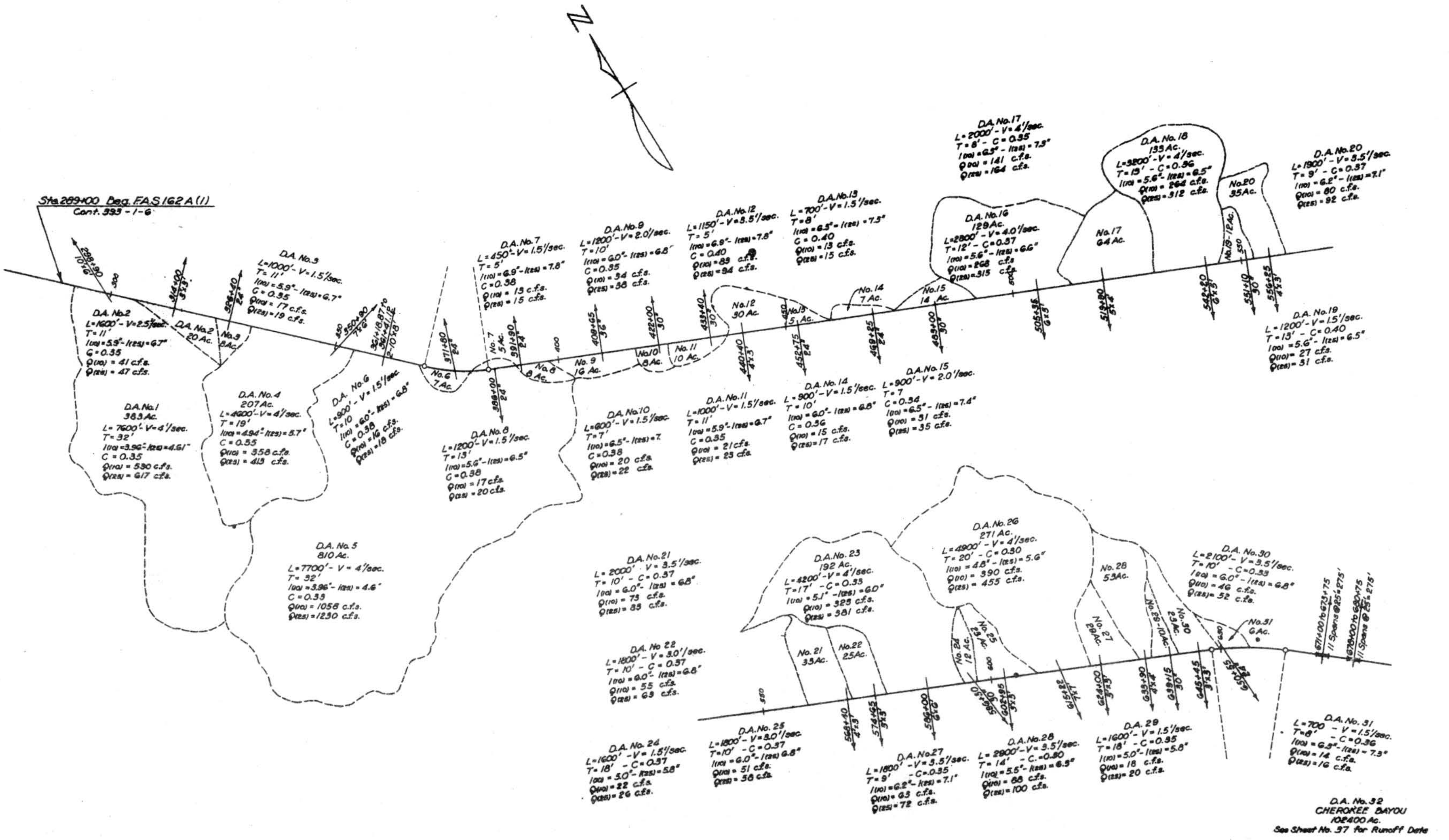
"EXCESSIVE RAINFALL IN TEXAS"

County	e	5 year		10 year		25 year		50 year	
		b	d	b	d	b	d	b	d
Angelina	0.848	115	23.0	140	27.0	175	31.0	200	36.0
Bexar	0.880	110	21.5	140	23.5	170	27.5	190	30.0
Brazos	0.880	135	24.0	160	28.0	195	32.0	235	36.0
Brown	0.882	110	19.0	130	22.0	155	22.0	170	26.0
Cass	0.836	90	19.5	110	22.0	130	25.0	150	27.0
Childress	0.840	70	13.0	80	14.0	100	14.0	110	16.0
Dallas	0.865	110	21.0	133	24.0	150	28.0	180	33.0
DeWitt	0.885	135	26.0	170	30.0	210	35.0	265	45.0
El Paso	0.910	67	16.0	80	18.0	96	21.0	120	26.0
Harris	0.865	140	25.0	165	27.0	210	34.0	235	34.0
Hidalgo	0.980	255	36.0	300	40.0	370	41.0	430	42.0
Jefferson	0.840	135	28.0	170	33.0	205	38.5	250	42.0
Lamar	0.830	87	18.0	105	22.0	120	25.0	135	28.0
Lubbock	0.850	72	12.0	92	14.5	105	16.0	127	17.0
McLennan	0.880	130	26.0	170	31.0	195	36.0	270	46.0
Nueces	0.890	140	29.0	167	33.0	207	38.0	255	43.0
Potter	0.870	77	16.0	90	19.0	105	16.0	125	20.0
Reeves	0.900	85	17.0	105	19.0	135	22.0	160	26.5
Smith	0.848	97	19.5	110	22.0	135	26.0	165	28.0
Tarrant	0.870	110	22.0	135	27.0	160	28.0	180	33.0
Taylor	0.875	95	18.5	120	20.5	145	22.0	162	24.0
Tom Green	0.875	105	19.0	130	22.0	150	26.0	175	30.0
Travis	0.890	155	25.0	200	31.0	250	35.0	300	44.0
Val Verde	0.885	100	19.0	120	22.0	145	24.0	165	26.0
Wichita	0.840	90	17.0	105	19.0	120	20.5	140	23.0



CROSS SECTION DATA
Charlie Jones
Cultivated
Garden
Charlie Wade
Cultivated
S. H. brittian
Cultivated
TYPICAL CHANNEL SECTION
5' Ave.
10'
Com.&Sp.Chan. Exc. = 20x5x250÷27=926 C.Y.
To be wasted as directed by the Engineer
Henry Borders
Horace & Betty Powell
Field
Well
340
345
350
355
360
S. 43° 30' E.
Charlie Jones
Scattered Fruit Trees
Gus Roberts
Cultivated
Cultivated
Timber
SHEET TOTALS
Clear. & Grubbing
425 x 173 = 1.69 Ac.
240 x 130 = 0.72 Ac.
2.41
Acre
Clearing & Grubbing
17,678
S.Y.
Erosion Control
Com.& Sp. Ch. Exc.
506
926
1432
C.Y.
Com. & Special Channel Excav.
Com. & Sp. Rd. Exc.
Embankment
C.Y.
Com. & Special Road Excavation
Embankment
Select Material Reserved
Select Material
Overhaul
0
YD.
Overhaul
-SHEET NOTES-
B.M. Nail (Bent) in 40" P.O. 90' Lt. Sta. 346+75, Elev. 294.31.
B.M. Nail 24" White Oak 75' Rt. Sta. 351+40 Elev. 281.08.
B.M. Nail in 24" Hackberry 80' Rt. Sta. 361+75, Elev. 267.64.
Com.& Sp. Rd. Exc.
Embankment
1256 Cu. Yds.
1256 Cu. Yds.
9295 Cu. Yds.
9295 Cu. Yds.
12554 Cu. Yds.
12554 Cu. Yds.
No O.H.
Base Line
Scale 1"=1000 C.Y.
Scale 1"=5000 C.Y.
Select Material Haul Diagram
No O.H.
300
290
280
270
260
+0.60%
+2.70%
H.W.=280.4'
Rip Rap
Sta. 350+90
7 1/6' - 6'-0" R.C. Box Culv.
See Sheet No. 39
CHANNEL
STRUCTURE
Sta. 361+13.87 to 361+41.12
See Layout Sheet No. 53
AVE. CHANNEL SECTION
39
340
41
42
43
44
345
46
47
48
49
350
51
52
53
54
355
56
57
58
59
360
61
62
63
64
365
Rev. 1-46
STATE
TEX.
FEDERAL AID PROJECT
F.A.S. 162A(1)
7
COUNTY
10
Gregg

48



MAP OF DRAINAGE AREAS (i)

Scale 1" = 1000'

6	TEXAS	F.A.S. 162 A(1) & B(1)			35
10	GREGG	333	1	6	3-369
	RUSK	333	2	1	

4R-A

RATIONAL DESIGN OF STRUCTURES

COMPUTATION SHEET No. 1

STATION	TIME OF CONCENTRATION											DISCHARGE				
	SHEET FLOW OR COMBINED SHEET AND CHANNEL FLOW*				CHANNEL FLOW						TOTAL t	C	DESIGN FRE-QUENCY	I	A	Q
	L	s	v	t	L	s	r	n	v	t						

See reverse side for Formulas, Symbols, etc.

* To be used with Graph shown on Page 33.

L = Length of water course in ft.
s = Slope of channel or watershed in feet per foot.
v = Velocity in ft./sec.
t = Time of Concentration in min.
n = Coefficient of roughness in Manning's Formula:

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

C = Coefficient of run-off (Q = CIA).
I = Rainfall Intensity in inches per hr.
A = Drainage Area in Acres.
Q = Discharge in cu. ft./sec.

RATIONAL DESIGN OF STRUCTURES

COMPUTATION SHEET No. 2

Station No.	HIGHWATER COMPUTATIONS							SELECTION OF STRUCTURE							
	Q	A_c	r	s	n	V_c	Depth of Flow	Description	Area Below H.W.	V_d	h_e	h_v	h_f	H_t	H_b

See reverse side for formulas, symbols, etc.

Q = Discharge in cu. ft./sec.

A_c = Area of channel waterway in sq. ft.

r = Hydraulic radius = $\frac{\text{area}}{\text{wetted perimeter}}$

s = Slope of channel or watershed in feet per foot

n = Coefficient of roughness in Manning's Formula:

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

V_c = Channel Velocity in ft./sec.

V_d = Discharge Velocity in ft./sec.

h_e = Entrance head in feet.

h_v = Velocity head in feet.

h_f = Friction head in feet.

H_t = Total head lost in feet.

H_b = Backwater head in ft. = Backwater Elev. minus Tailwater Elev.

POST WAR PROJECT

F.A.S. DIST. NO.	STATE	FEDERAL AID PROJECT NO.	SHEET NO.
4	TEXAS	SPW-FAS 919	1
STATE DIST. NO.	COUNTY	CONTROL NO.	HIGHWAY NO.
10	Van Zandt	522-2-	S-243

STATE OF TEXAS
STATE HIGHWAY DEPARTMENT

PLANS OF PROPOSED STATE HIGHWAY IMPROVEMENT

FEDERAL AID PROJECT
F.A.S. 919

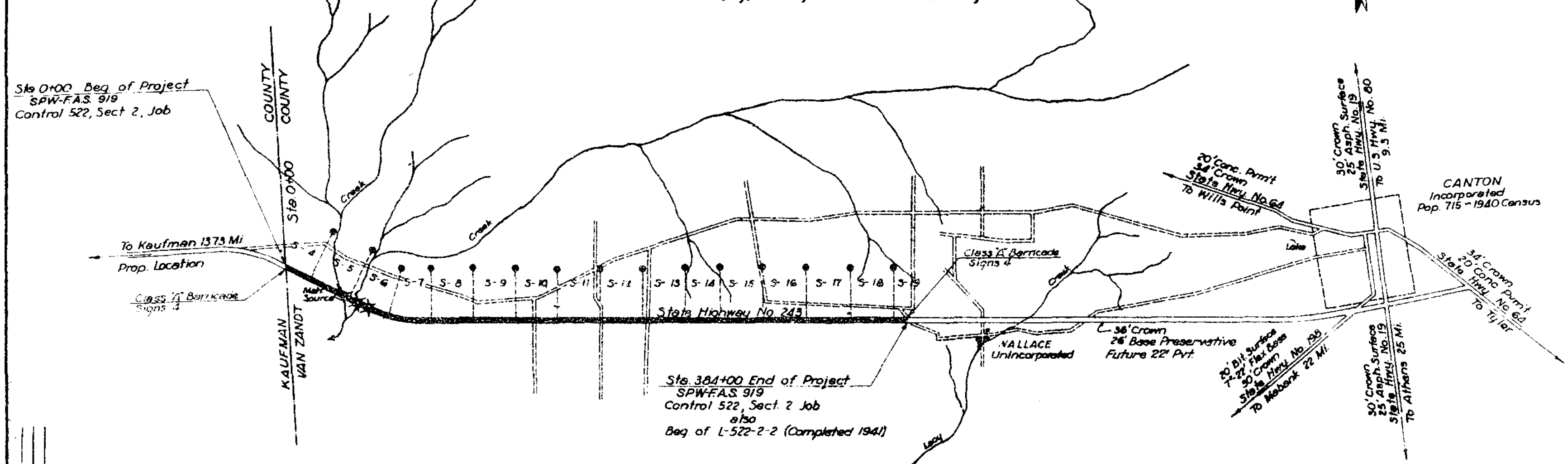
NET LENGTH OF PROJECT = 38,400.0 FT. = 7.273 MI.
Roadway = 37,625.0 Ft. = 7.126 Mi.
Bridges = 775.0 Ft. = 0.147 Mi.

VAN ZANDT COUNTY
STATE HIGHWAY NO. 243
FROM KAUFMAN COUNTY LINE
TO 5.1 MI. WEST OF CANTON
Grading, Drainage Structures & Surfacing

INDEX OF SHEETS

SHEET NO.	DESCRIPTION
	Title Sheet
	Typical Cross Sections
	Estimate & Quantity Sheet
	Plan-Profile Sheets
	Bridge Layout Sheets
	Structural Details

Class "C" Highway
Design Speed 60 M.P.H.
34' Crown
22' Pavement
H-20 Loading (A.A.S.H.O.)(1944)(Bridges)
26' Roadway (Bridges)



DELIVERY POINTS FOR MATERIALS

R.R. Del. Point	Railroad	Dist. From Proj.	Car Capacity
Wills Point	T. & P.		Ample

NOTE—
Special Provisions, Detours, Barricades, Warning Signs, Sequence of Work Etc., shall govern on this Project.

SPECIFICATIONS ADOPTED BY THE STATE HIGHWAY DEPARTMENT OF TEXAS, JANUARY 17, 1938, AND APPROVED BY THE PUBLIC ROADS ADMINISTRATION, FEBRUARY 18, 1939, AND SPECIFICATION ITEMS LISTED AND DATED AS FOLLOWS, SHALL GOVERN ON THIS PROJECT.

NO EXCEPTIONS
NO EQUATIONS

NO RAILROAD CROSSINGS ELIMINATED

Note: Federal Project Markers of Approved Design Erected at Each End of Project Prior to Completion.

LAYOUT SCALE: 1 IN. = 3000 FT.

CONVENTIONAL SIGNS

STATE HIGHWAY DEPARTMENT

CORRECT:

RECOMMENDED FOR APPROVAL [redacted]

RECOMMENDED FOR APPROVAL [redacted]

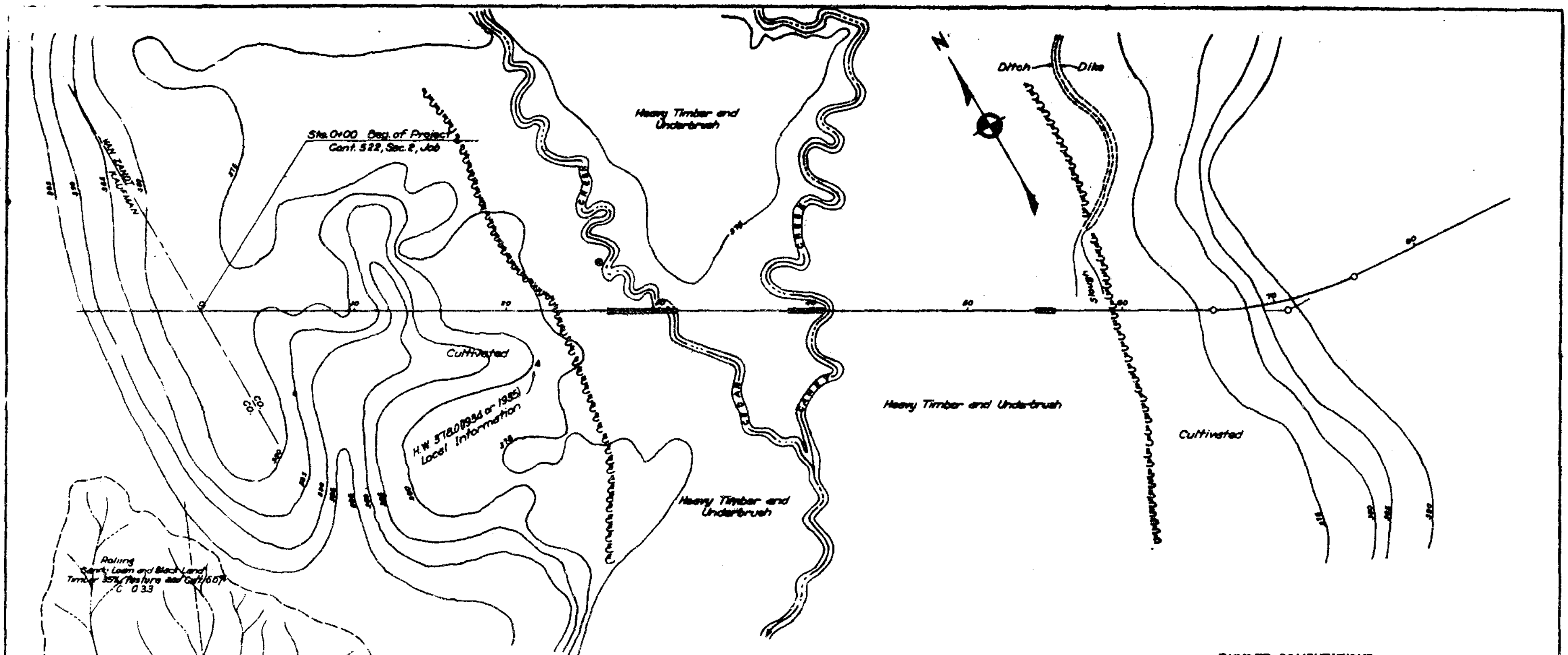
APPROVED [redacted]

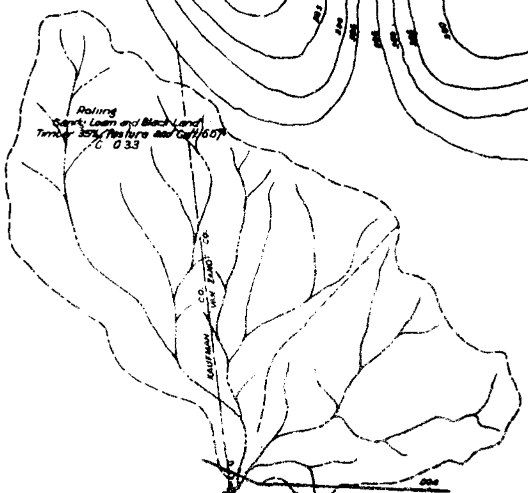
DISTRICT ENGINEER

RECOMMENDED FOR APPROVAL [redacted]

APPROVED [redacted]

COUNTY Van Zandt PROJ. NO. ___
HWY. NO. S-243 LETTING DATE ___
DATE ACCEPTED ___





DRAINAGE AREAS OF CEDAR & CANEY CREEKS
Scale 1" = 2 Mi.
Area = 175.2 Sq. Mi. = 112,100 Acres

CHANNEL FLOW

Elevation		W	L	D	S	$S^{1/2}$	$D^{2/3}$	n	V	Q sec/ft	Tot Q sec/ft
378.0	A	650	52	12.50	0.0012	0.035	5.39	0.05	5.61	3647	
378.0	B	596	57	10.44	0.0012	0.035	4.78	0.05	4.97	2957	34937
378.0	C	20877	4896	4.26	0.0012	0.035	2.63	0.10	1.36	28398	
3779 (50yr)										33600	
3772 (25yr)										27000	
377.0	A	598	52	11.50	0.0012	0.035	5.10	0.05	5.31	3175	
377.0	B	538	57	9.44	0.0012	0.035	4.47	0.05	4.65.	2502	24472
377.0	C	16064	4753	3.38	0.0012	0.035	2.25	0.10	1.17	18795	
3769 (10yr)										23680	
376.0	A	546	52	10.50	0.0012	0.035	4.80	0.05	4.99	2725	
376.0	B	481	57	8.44	0.0012	0.035	4.15	0.05	4.32	2078	16074
376.0	C	11601	4448	2.59	0.0012	0.035	1.89	0.10	0.98	11271	

See Profile for Channel Sections.

RUNOFF COMPUTATIONS

Rational Method (Tex. Road Dept., Van Zandt Co.)
A = 112100 Ac.
L = 105600'
V = 4'/sec. = 240 Min.
T = 440 Min.
C = 0.33
I(10) = 0.64"/hr. - Q(10) = 23680 sec. ft.
I(25) = 0.73"/hr. - Q(25) = 27000 sec. ft.
I(50) = 0.91"/hr. - Q(50) = 33660 sec. ft.

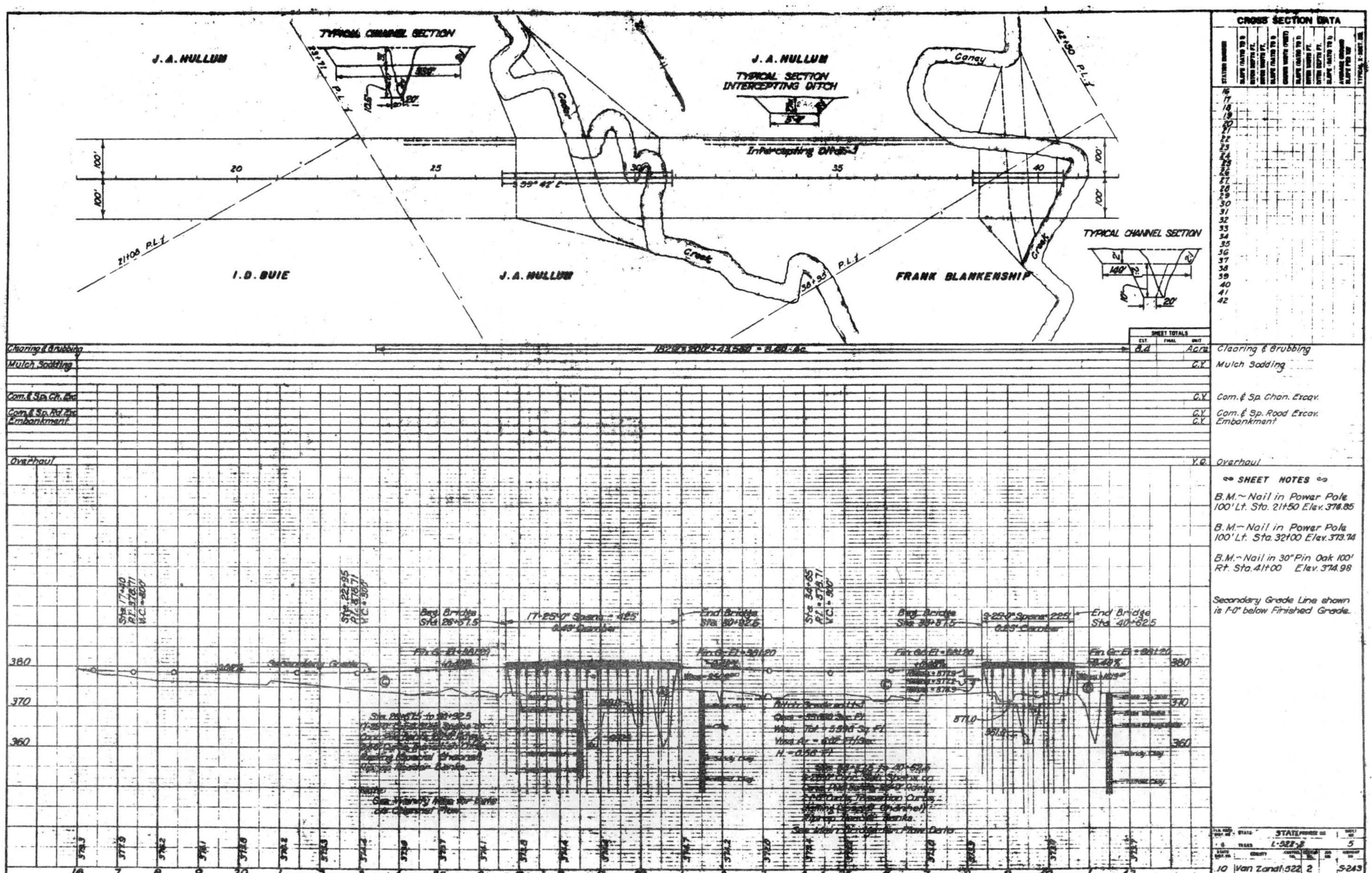
Tex. Board of Water Engineers.

Q(10) = 15974 sec. ft.
Q(25) = 25578 sec. ft.
Q(50) = 36652 sec. ft.

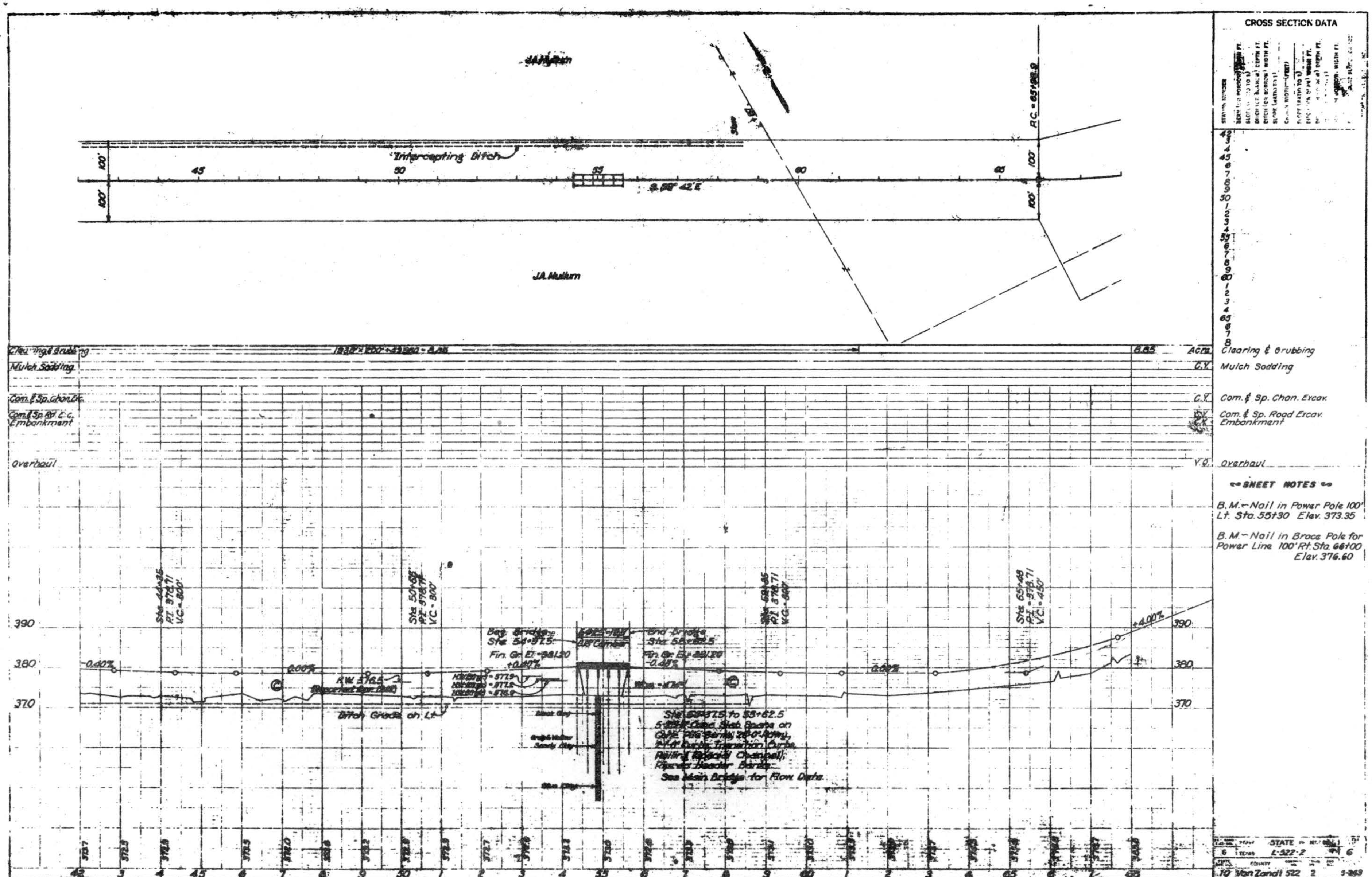
MAP OF DRAINAGE AREAS & VICINITY MAP

Scale 1" = 300 Ft.

10	Van Zandt	522	2


CROSS SECTION DATA
J. A. HULLUM
TYPICAL CHANNEL SECTION
TYPICAL SECTION INTERCEPTING DITCH
Intercepting Ditch
I. D. BUIE
J. A. HULLUM
FRANK BLANKENSHIP
Coney Creek
21+08 P.L.
38+95 P.L.
42+90 P.L.
TYPICAL CHANNEL SECTION
Clearing & Grubbing
Mulch Sodding
Com. & Sp. Chan. Excav.
Com. & Sp. Road Excav.
Embankment
Overhaul
SHEET NOTES
B.M.~Nail in Power Pole 100' Lt. Sta. 21+50 Elev. 376.85
B.M.~Nail in Power Pole 100' Lt. Sta. 32+00 Elev. 373.74
B.M.~Nail in 30" Pin Oak 100' Rt. Sta. 41+00 Elev. 374.98
Secondary Grade Line shown is 1-0" below Finished Grade.
Beg. Bridge Sta. 26+57.5
End Bridge Sta. 30+82.5
Beg. Bridge Sta. 38+37.5
End Bridge Sta. 40+62.5
Secondary Grade
Van Zandt 522 2 S-243
L-522-2 5

53


CROSS SECTION DATA
J.A. Mullum
Intercepting Ditch
45
50
55
60
65
100'
P.C. = 65+98.9
J.A. Mullum
Clearing & Grubbing
Mulch Sodding
Com. & Sp. Chan. Excav.
Com. & Sp. Road Excav. Embankment
Overhaul
Acre
C.Y.
V.C.
SHEET NOTES
B.M.-Nail in Power Pole 100' Lt. Sta. 55+30 Elev. 373.35
B.M.-Nail in Brace Pole for Power Line 100' Rt. Sta. 66+00 Elev. 376.60
Sta. 44+35
P.I. 378.71
V.C. = 800'
Sta. 50+58
P.I. 378.71
V.C. = 800'
Sta. 65+48
V.C. = 450'
Beg. Bridge Sta. 54+37.5
End Bridge Sta. 55+62.5
Fin. Gr. El. = 381.20
-0.40%
0.00%
+4.00%
Ditch Grade on Lt.
Sta. 54+37.5 to 55+62.5
See Main Bridge for Flow Data
390
380
370
42
3
4
45
6
7
8
9
50
1
2
3
4
55
6
7
8
9
60
1
2
3
4
65
6
7
68
STATE
10 Van Zandt 522 2