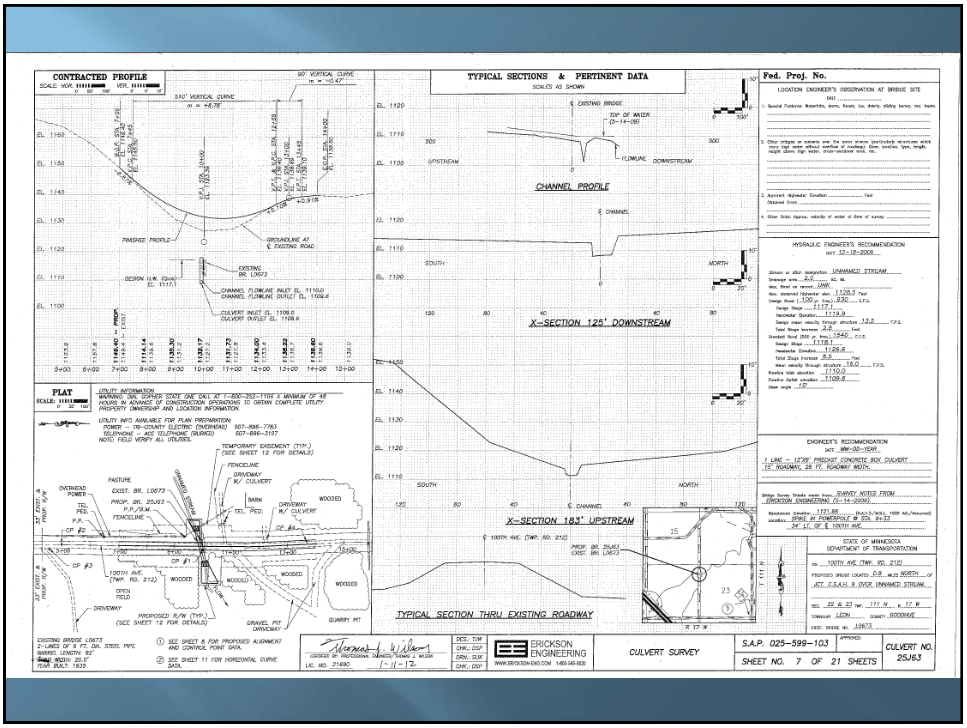
CULVERTS

Criteria

- Don’t want to increase stages
- Velocities shouldn’t exceed 15 fps
- Higher velocities will require energy dissipators
- HY8 is available for free from FHWA


CONTRACTED PROFILE
TYPICAL SECTIONS & PERTINENT DATA
Fed. Proj. No.
CHANNEL PROFILE
X-SECTION 125' DOWNSTREAM
X-SECTION 183' UPSTREAM
TYPICAL SECTION THRU EXISTING ROADWAY
PLAT
ERICKSON ENGINEERING
CULVERT SURVEY
S.A.P. 025-599-103
SHEET NO. 7 OF 21 SHEETS
CULVERT NO. 25J63

ERICKSON ENGINEERING
Consulting Engineers • Designers • Construction Inspectors

January 26, 2012

Greg Isakson, P.E.
Goodhue County Engineer
2140 Pioneer Road
P.O. Box 404
Red Wing, MN 55066

RE: SAP 025-599-103
Replace Bridge L0673 with new Bridge 25J63

Dear Greg:

MnDOT District 6 has requested justification for choosing a 100-year design flood for this project, instead of a lower design flood due to the low ADT of the township road.

Design Flood Justification

The existing structure, consisting of 2-lines of 6 ft diameter CMP culverts, produces an overtopping flood in excess of the 100 year event. Since the overtopping flood is greater than the 100 year flood, this situation is commonly referred to as a 100 year design flood, per MnDOT Bridge Office recommendations. The proposed replacement structure consists of 1-line of 12 ft span box culvert and also will not overtop the road during the 100 year flood. The larger culvert size (compared to existing) was necessary in order to keep outlet velocities at acceptable levels.

In addition, the existing culvert is located at the bottom of a steep vertical curve. In order to meet the minimum design speed requirements of 30 mph, a grade raise of 4.5 ft is required above the existing road profile.

Since the existing culverts and road profile produces a 100 year design flood, and also the requirement that the proposed road profile meet a minimum 30 mph design speed, a 100 year design flood is the only feasible scenario for the proposed structure.

Sincerely,

ERICKSON ENGINEERING COMPANY

Thomas J. Wilson

Thomas J. Wilson, P.E.
Vice President

Phone: (952) 929-6791 or (800) 545-8020 • 9330 James Ave. S., Bloomington, MN 55431 • Fax: (952) 929-2909
www.erickson-eng.com

ERICKSON ENGINEERING
Consulting Engineers • Designers • Construction Inspectors

WATERWAY STUDY
FOR
LEON TOWNSHIP, GOODHUE COUNTY

INPLACE BRIDGE #L0673

Sec. 23 T 111 N R 17 W

CULVERT ALTERNATE FOR THE REPLACEMENT OF THE INPLACE BRIDGE

1. 1 – line of 12 ft. x 9 ft. Concrete Box Culvert
(The culvert will be buried 1 ft. below channel flowline.)

The culvert will have the following hydraulic characteristics:

Stream	unnamed stream.
Drainage Area	2.0 sq. mi.
Flood of Record	unknown
Maximum Observed Highwater Elevation	1128.5
Design Flood (100 Year Frequency)	930 cfs
*Design Stage	1117.1
Total Stage Increase	2.8 ft.
Headwater Elevation	1119.9
Stage Increase of the Inplace Condition	10.1 ft.
Mean Outlet Velocity	13.5 fps
Main Channel Velocity	6.0 fps
Greatest Flood (500 Year Frequency)	1540 cfs
*Stage	1118.1
Total State Increase	8.5 ft.
Headwater Elevation	1126.6
Stage Increase of the Inplace Condition	11.9 ft.
Mean Outlet Velocity	16.0 fps
Main Channel Velocity	6.1 fps
Approximate Channel Flowline Elevation	1110.0(Inlet)
	1109.6(Outlet)
Culvert Invert Elevation	1109.0(Inlet)
	1108.6(Outlet)
Estimated Skew Angle	15°

* Represents unconstricted flood elevation at upstream end of proposed culvert.

Navigational clearance is not required at this site.

Phone: (952) 929-6791 or (800) 545-8020 • 9330 James Ave. S., Bloomington, MN 55431 • Fax: (952) 929-2909
www.erickson-eng.com

Even though, to our knowledge, this site is not on a designated trout stream, the culvert shall be buried 1 foot below the natural channel bottom in order to help preserve the natural habitat and facilitate the migration of fish. This should be verified by the Department of Natural Resources.

The proposed structure should provide adequate waterway to pass the basic flood with minimal risks of flood damage. The upstream floodplain occurs within a mixture of cropland, brushland and woodland. We are not aware of any manmade structures within the upstream floodplain that would present any flood damage potential (this should be verified).

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly licensed professional engineer under the laws of the State of Minnesota.

Daniel Krocheski, P.E.

Date: 12-18-09 Lic. No.: 45779

RISK ASSESSMENT FOR ENCROACHMENT DESIGN

Date 11-13-09
District 6
County Goodhue (Leon Township)
Vicinity of 0.8 mi. N of Jct. CSAH 9
Sec. 23 T 111 N R 17 W

DATA REQUIREMENTS

1. Location of Crossing: Roadway TWP 212 (100th Ave.) C.S. ______ M.P. ______
2. Name of Stream: unnamed stream Bridge No. Old: L0673 New: ______
3. Current ADT 102(2010); Projected ADT 164(2030)
4. Type of Traffic:
   a. Practicable detour available No ______ Yes X

   If no is checked, please explain: ______

   If there is no practicable detour available, then the use of the road must be analyzed. Considerations such as emergency vehicle access, emergency supply and evacuation route, and the need for school bus, milk and mail routes should be studied. Factors to consider for this analysis include design frequency, depth, duration, and frequency of inundation if appropriate, and available funding.
5. Hydraulic Data: (Fill in as appropriate)

   Approximate Flowline Elevation 1110.0(Inlet), 1109.6(Outlet)

Q_2 =		TW_2 Elevation	
Q_5 =		TW_5 Elevation	
Q_{10} =		TW_{10} Elevation	
Q_{25} =		TW_{25} Elevation	
Q_{50} =		TW_{50} Elevation	
Q_{100} (circled) =	930 cfs	TW_{100} Elevation	1117.1

   Circle Design Frequency

   Reasons for selecting Design Frequency: Roadway will not overtop during 100 year flood.
6. Magnitude and Frequency of smaller of "Overtopping" or "500 year" flood:

   1540 cfs 500 year frequency
7. Low member elevation NA
8. Minimum roadway overflow elevation if appropriate 1131.6
9. Elevation of high risk property, i.e. residences None apparent in floodplain

   Other buildings None apparent in floodplain
10. Horizontal location of overflow:

    At structure X (See 12); Not at structure ______
11. Type of proposed structure:

    Bridge ______ (See 12); Culvert(s) X
12. If the proposed structure is a bridge with the sag point located on the bridge and there is ice and debris potential, strong consideration should be given to using Q_{50} as design discharge with 3' of clearance between the 50 year tailwater stage and low member.

MINN. PROJ. NO.

MINNESOTA DEPARTMENT OF TRANSPORTATION

LEON TOWNSHIP, GOODHUE COUNTY

CONSTRUCTION PLAN FOR CULVERT NO. 25J63 AND APPROACH GRADING

LOCATED 0.8 MILES NORTH OF JCT C.S.A.H. 9 ON 100TH AVE. (TWP. RD. 212) OVER UNNAMED STREAM, 7.6 MILES NORTHWEST OF WANAMINGO, MN (Geographical Description).

APPROXIMATELY 951 FT. SOUTH OF THE N.W. CORNER OF SEC. 23, TWP. 111 N, RANGE 17 W.

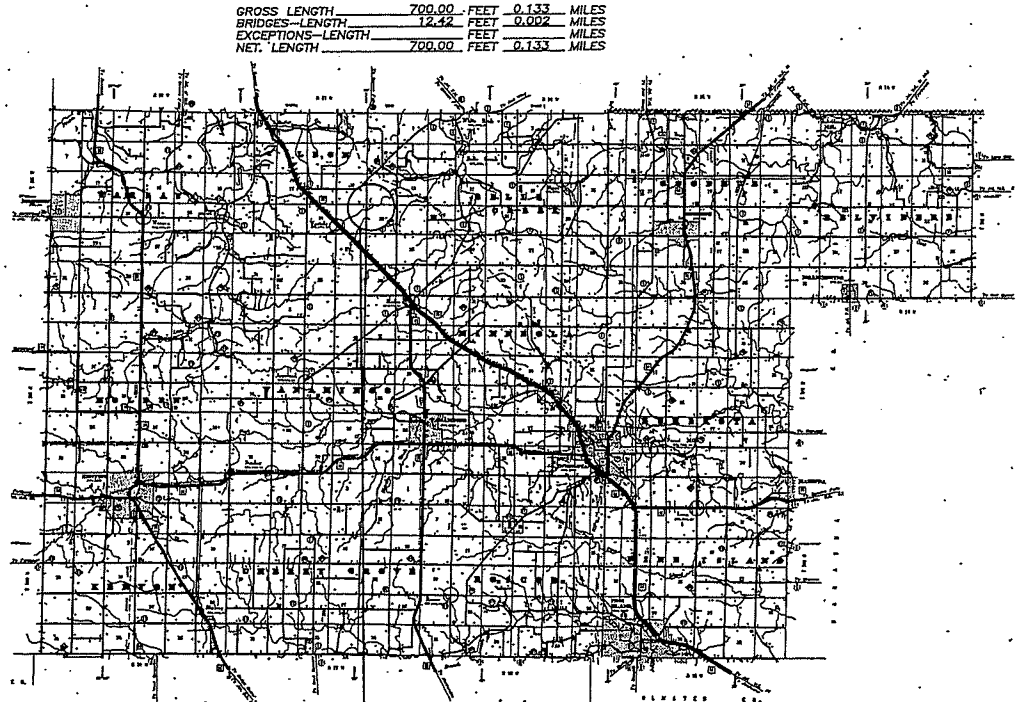
SEC. 22 & 23 TWP. 111 N R 17 W (Legal Description)

STATE AID PROJ. NO. 25-599-103

GROSS LENGTH	700.00	FEET	0.133	MILES
BRIDGES—LENGTH	12.42	FEET	0.002	MILES
EXCEPTIONS—LENGTH		FEET		MILES
NET LENGTH	700.00	FEET	0.133	MILES

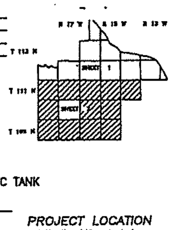
PLAN SYMBOLS

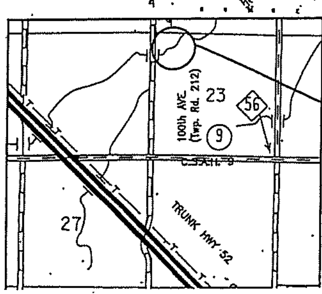
COUNTY LINE
TOWNSHIP OR RANGE LINE
SECTION LINE
QUARTER LINE
SIXTEENTH LINE
EXISTING R/W
NEW R/W
TEMP EASE
RAILROAD R/W
UNSURFACED RD. OR SHLD.
EDGE OF LAKE
SWAMP BOUNDARY
MISCELLANEOUS BOUNDARY
CORPORATE OR CITY LIMITS
VACATED PLATTED PROPERTY
RECREATIONAL TRAIL
ALIGNMENT STATIONS
ALIGNMENT POINTS
RIVER OR CREEK
DRAINAGE DITCH
BRIDGE
RAILROAD (SINGLE TRACK)
RR CROSSING PAVEMENT MARKING
RR CROSSING GATE
RR CROSSBUCK SIGN
RR CROSSBUCK SIGN W/LIGHTS
BARBED WIRE FENCE
CHAIN LINK FENCE
WOVEN WIRE, COMBINATION WOVEN AND BARB
WOOD FENCE
BILLBOARD
RETAINING WALL
GUARDRAIL (CABLE)
GUARDRAIL (PLATE BEAM)
DRAIN TILE
CULVERT
CULVERT WITH APRONS
WOODS OR BRUSH, NURSERY
DECIDUOUS TREES
CONIFER (EVERGREEN) TREES
HEDGE
BUSH OR SHRUB
STUMP
SWAMP OR MARSH
MONUMENT (CI,ACT,ACP,BCP...)
CONCRETE OR STONE MONUMENT
IRON PIPE
IRON PIN OR REBAR
IRON PIN WITH BRASS DISK
NAIL, PK NAIL, SPIKE, SFP, T-BAR, ...
VERTICAL CONTROL — B.M.
HORIZONTAL CONTROL
POWER POLE
LIGHT POLE
LIGHT AND TELEPHONE POLE
LIGHT, TELEPHONE AND POWER POLE
GUY POLE — GP
POLE ANCHOR
TELEPHONE POLE
TELEPHONE AND POWER POLE
UNDERGROUND CABLE PEDESTAL — PED
TELEPHONE MANHOLE (VAULT) — MH
ELECTRIC CABLE IN CONDUIT
TELEPHONE CABLE IN CONDUIT
BURIED ELECTRIC CABLE
BURIED TELEPHONE CABLE
GAS LINE
WATER LINE
VALVE
FIRE HYDRANT
WATER MANHOLE
WELL — WELL
LAWN SPRINKLER HEAD
MANHOLE — MH
CATCH BASIN — CB
SEPTIC TANK — SEPTIC TANK
FORCE MAIN LIFT STA. — LIFT
SEWER LINE
PERMANENT BARRICADE
TRAFFIC SIGNAL LIGHT
HAND HOLE
ENTRANCE
BUILDING — NUMBER 1-S-F
SATELLITE DISH
STEEL TOWER — TOWER



PROJECT LOCATION

GOODHUE COUNTY





PROP. CULVERT NO. 25J63
S.A.P. 025-599-103
B.O.P. STA. 7+00
E.O.P. STA. 14+00
EXIST. BRIDGE NO. L0673
6 FT. DIA. STEEL PIPE
BARREL LENGTH 92.0'
ROAD WIDTH 20.0'
YEAR BUILT 1935

GOVERNING SPECIFICATIONS

THE 2005 EDITION OF THE MINNESOTA DEPARTMENT OF TRANSPORTATION "STANDARD SPECIFICATIONS FOR CONSTRUCTION" SHALL GOVERN.

LIST OF SHEETS

NO.	TITLE
1	TITLE SHEET
2-3	GENERAL PLAN & ELEVATION
4-6	PRECAST CONCRETE CULVERT DETAILS
7	CULVERT SURVEY
8-9	CULVERT SURVEY ~ PLAN & PROFILE
10-15	APPROACH GRADING
16-20	SWPPP
21	TRAFFIC CONTROL

THIS PLAN CONTAINS 21 SHEETS.

DESIGN DESIGNATION

ΣN18 $_{20}$
R VALUE
ADT (2012) 97
PROJ. ADT (2032) 145
SOIL FACTOR
TON DESIGN:

Design Speed 30 MPH
Based on 200' Stopping Sight Distance
Height of eye 3.5'
Height of object 2.0'

Design Speed not achieved at:

STA.	TO STA.		MPH
STA.	TO STA.		MPH
STA.	TO STA.		MPH

THOMAS J. WILSON

DESIGN ENGINEER: I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

DATE 1-11-12 LICENSE NUMBER 21690

APPROVED: COUNTY ENGINEER DATE

DISTRICT STATE AID ENGINEER: REVIEWED FOR COMPLIANCE WITH STATE-AID RULES/POLICY DATE

APPROVED FOR STATE-AID FUNDING: STATE-AID ENGINEER DATE

ERICKSON ENGINEERING

STATE AID PROJECT NO. 025-599-103

CULVERT NO. 25J63

CONSTRUCTION NOTES

RIPRAP CONSTRUCTION AT OUTLET SHALL BE AS SHOWN IN THE PLANS AND STANDARD PLATE 3133. RIPRAP CONSTRUCTION AT INLET SHALL BE AS SHOWN IN THE PLANS. EXACT PLACEMENT SHALL BE DETERMINED BY THE ENGINEER IN THE FIELD.

GEOTEXTILE FABRIC WILL BE CONSIDERED INCIDENTAL TO RIPRAP CONSTRUCTION FOR WHICH NO DIRECT COMPENSATION WILL BE MADE.

RIPRAP INCLUDES ALL EXCAVATION AND REMOVAL. GRANULAR FILTER IS NOT ALLOWED.

EXCAVATION MATERIAL MAY BE USED FOR BACKFILLING APRONS IF APPROVED BY ENGINEER IN THE FIELD.

CLEARING AND GRUBBING ARE CONSIDERED INCIDENTAL TO BRIDGE REMOVAL AND WHICH NO DIRECT COMPENSATION WILL BE MADE.

THE SURVEY USED IN THE DEVELOPING THIS CULVERT PLAN MUST BE VERIFIED WITH THE ACTUAL STREAM LOCATION AT THE TIME OF CONSTRUCTION STAKING. IF THE CULVERT POSITIONING IS NOT COMPATIBLE WITH THE STREAM WHEN STAKING IS COMPLETE THE SEALING ENGINEER SHALL BE NOTIFIED.

THE SUBSURFACE UTILITY INFORMATION IN THIS PLAN IS UTILITY QUALITY LEVEL D. THIS UTILITY QUALITY LEVEL WAS DETERMINED ACCORDING TO THE GUIDELINES OF CI/ASCE 38-02, ENTITLED "STANDARD GUIDELINES FOR THE COLLECTION AND DEPICTION OF EXISTING SUBSURFACE UTILITY DATA." SEE SHEET 7 FOR LOCATION.

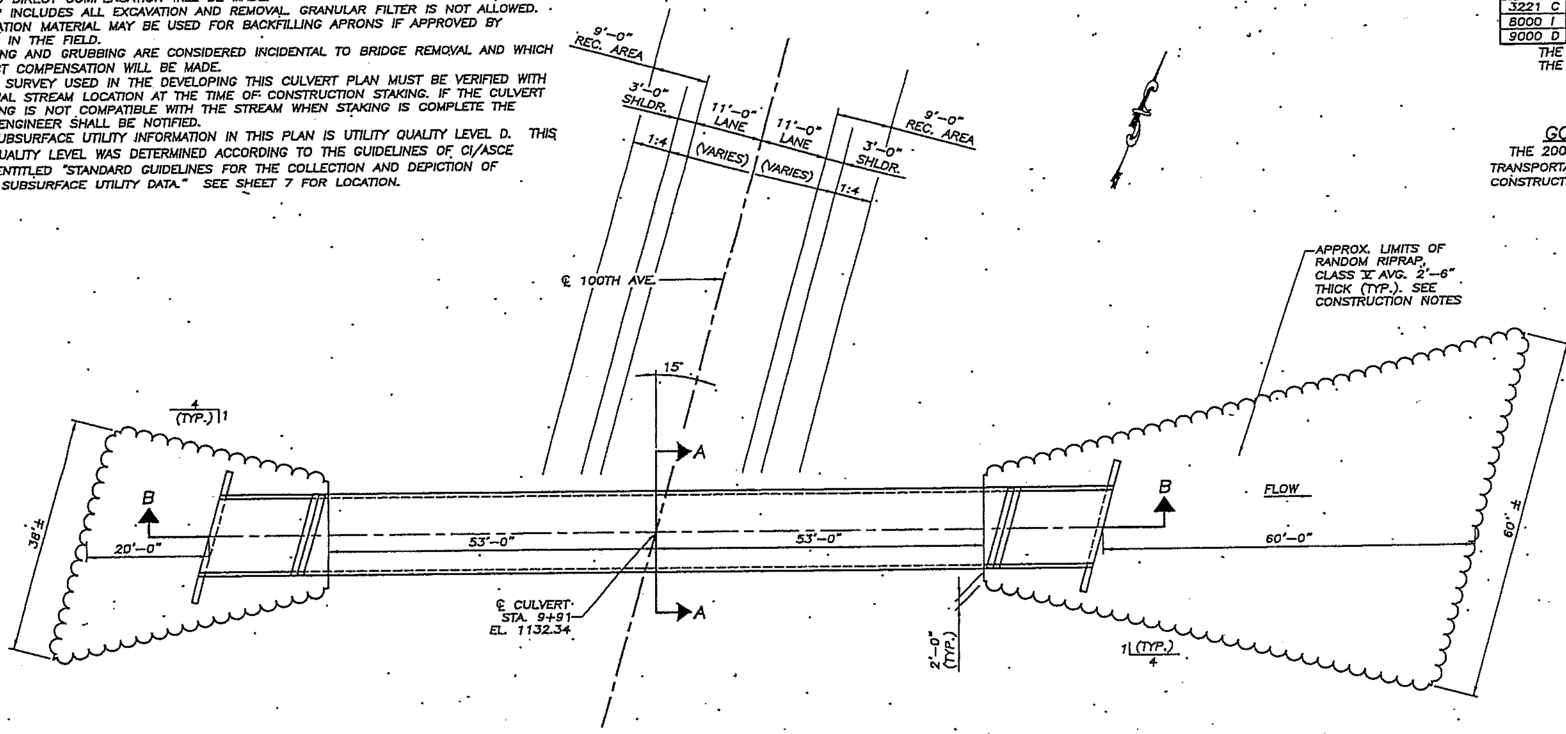
LIST OF STANDARD PLATES

PLATE NO.	DESCRIPTION
3040 F	CORRUGATED METAL PIPE CULVERT
3123 J	METAL APRON FOR C.S. PIPE
3124 B	METAL APRON CONNECTION
3133 C	RIPRAP AT R.C.P. OUTLET
3145 F	CONCRETE PIPE TIES
3221 C	CORRUGATED STEEL PIPE COUPLING BAND
8000 I	STANDARD BARRICADES
9000 D	APPROACHES AND ENTRANCES

THE ABOVE STANDARD PLATES, AS APPROVED BY THE F.H.W.A., SHALL APPLY ON THIS PROJECT.

GOVERNING SPECIFICATIONS

THE 2005 EDITION OF THE MINNESOTA DEPARTMENT OF TRANSPORTATION "STANDARD SPECIFICATIONS FOR CONSTRUCTION" SHALL GOVERN.



PLAN
SCALE: 0 5' 10'

STATEMENT OF ESTIMATED QUANTITIES

	ITEM NO.	ITEM	UNIT	PARTICIPATING	NON-PARTICIPATING	TOTAL
	2021.501	MOBILIZATION	LUMP SUM	1		1
	2101.511	CLEARING AND GRUBBING	LUMP SUM		1	1
	2104.501	REMOVE PIPE CULVERTS	LIN. FT.		40	40
	2105.601	APPROACH GRADING	LUMP SUM		1	1
③	2412.511	12 X 9 PRECAST CONC. BOX CULVERT (CLASS 2)	LIN. FT.	36		36
③	2412.511	12 X 9 PRECAST CONC. BOX CULVERT (CLASS 3)	LIN. FT.	70		70
	2412.512	12 X 9 PC CONC. BOX CULVERT END SECTION	EACH	2		2
①②	2442.501	REMOVE EXISTING BRIDGE	LUMP SUM		1	1
	2451.503	GRANULAR BACKFILL (CV)	CU. YD.	334	345	679
④	2451.509	AGGREGATE BEDDING (CV)	CU. YD.	207		207
⑥	2501.511	12" C.S. PIPE CULVERT	LIN. FT.		30	30
⑥	2501.511	24" C.S. PIPE CULVERT	LIN. FT.		55	55
⑥	2501.515	12" G.S. PIPE APRON	EACH		2	2
⑥	2501.515	24" G.S. PIPE APRON	EACH		2	2
②	2511.501	RANDOM RIPRAP, CL. V	CU. YD.	326		326
	2563.601	TRAFFIC CONTROL	LUMP SUM	1		1
⑦	2573.502	SILT FENCE, TYPE MACHINE SLICED	LIN. FT.		1684	1684
⑧	2573.602	TEMPORARY SEDIMENT TRAP	EACH		1	1

① EXIST. BRIDGE AT STA. 10+00.

② SEE CONSTRUCTION NOTES.

③ STRUCTURE EXCAVATION SHALL BE INCLUDED IN PRICE BID FOR "12X9 PRECAST CONCRETE BOX CULVERT".

④ EXCAVATE TO 2' BELOW BOTTOM OF CULVERT OR BOTTOM OF UNSUITABLE SOIL, WHICHEVER IS GREATER. BACKFILL WITH AGGREGATE BEDDING.

⑤ SEE SECTION A-A & SECTION B-B ON SHEET 3.

⑥ SPIRAL PIPE AND APRONS ARE NOT PERMITTED.

⑦ SEE SHEET 10 FOR DETAILS.

⑧ SEE SHEET 20 FOR DETAILS.

BENCHMARK EL. 1121.68
LOCATION: SPIKE IN POWERPOLE @ STA. 9+33 34' LT. OF ℄ 100TH AVE.

APPROVED: ____________ GOODHUE COUNTY ENGINEER

DATE: ____________

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

Thomas J. Wilson
THOMAS J. WILSON

DATE: 1-11-12 LIC. NO. 21690

ERICKSON ENGINEERING
9330 JAMES AVENUE SOUTH
BLOOMINGTON, MN 55431

100TH AVE (TWP. RD. 212) GOODHUE COUNTY
MINNESOTA DEPARTMENT OF TRANSPORTATION

CULVERT NO. 25J63

LOCATED 0.8 MILES NORTH OF JCT. C.S.A.H. 9 ON 100TH AVE. OVER UNNAMED STREAM

1-12'X9' PRECAST CONCRETE BOX CULVERT
28 FT. ROADWAY ~ 15° SKEW
SPAN IDENTIFICATION NO. 113

GENERAL PLAN & ELEVATION

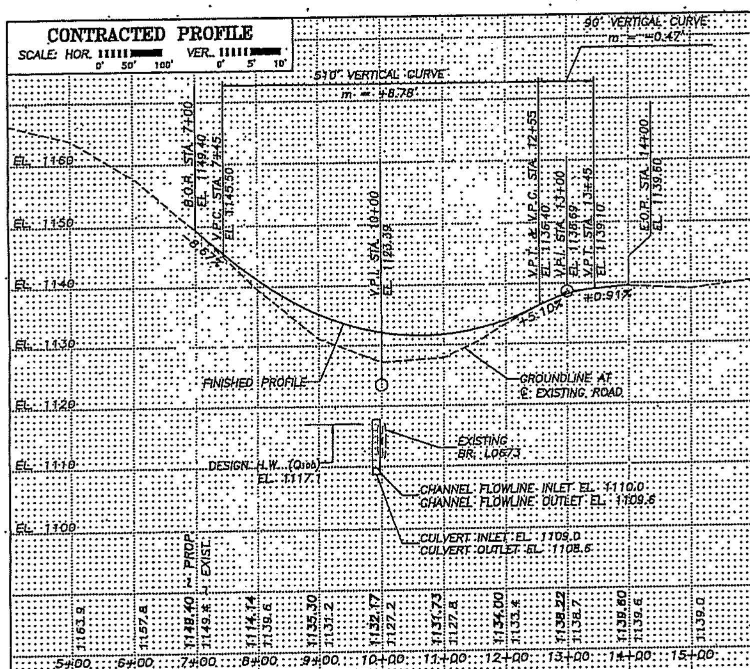
SEC. 22 & 23 TWP. 111 N R 17 W

TOWNSHIP: LEON
COUNTY: GOODHUE

DES.:	TJW	DRN.:	SUK	CULVERT NO.
CHK.:	DSP	CHK.:	DSP	25J63
S.A.P. 025-599-103				

CONTRACTED PROFILE

SCALE: HOR. 0' 50' 100' VER. 0' 5' 10'



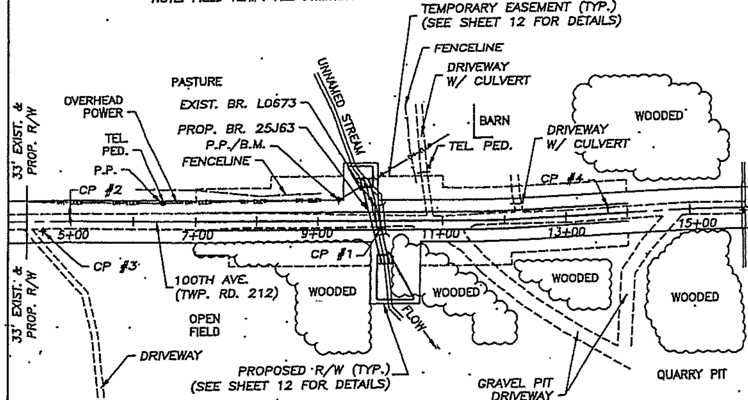
PLAT

SCALE: 0' 50' 100'

UTILITY INFORMATION

WARNING: DIAL GOPHER STATE ONE CALL AT 1-800-252-1166 A MINIMUM OF 48 HOURS IN ADVANCE OF CONSTRUCTION OPERATIONS TO OBTAIN COMPLETE UTILITY PROPERTY OWNERSHIP AND LOCATION INFORMATION.

UTILITY INFO AVAILABLE FOR PLAN PREPARATION:
POWER – TRI-COUNTY ELECTRIC (OVERHEAD) 507-896-7783
TELEPHONE – ACE TELEPHONE (BURIED) 507-896-3107
NOTE: FIELD VERIFY ALL UTILITIES.

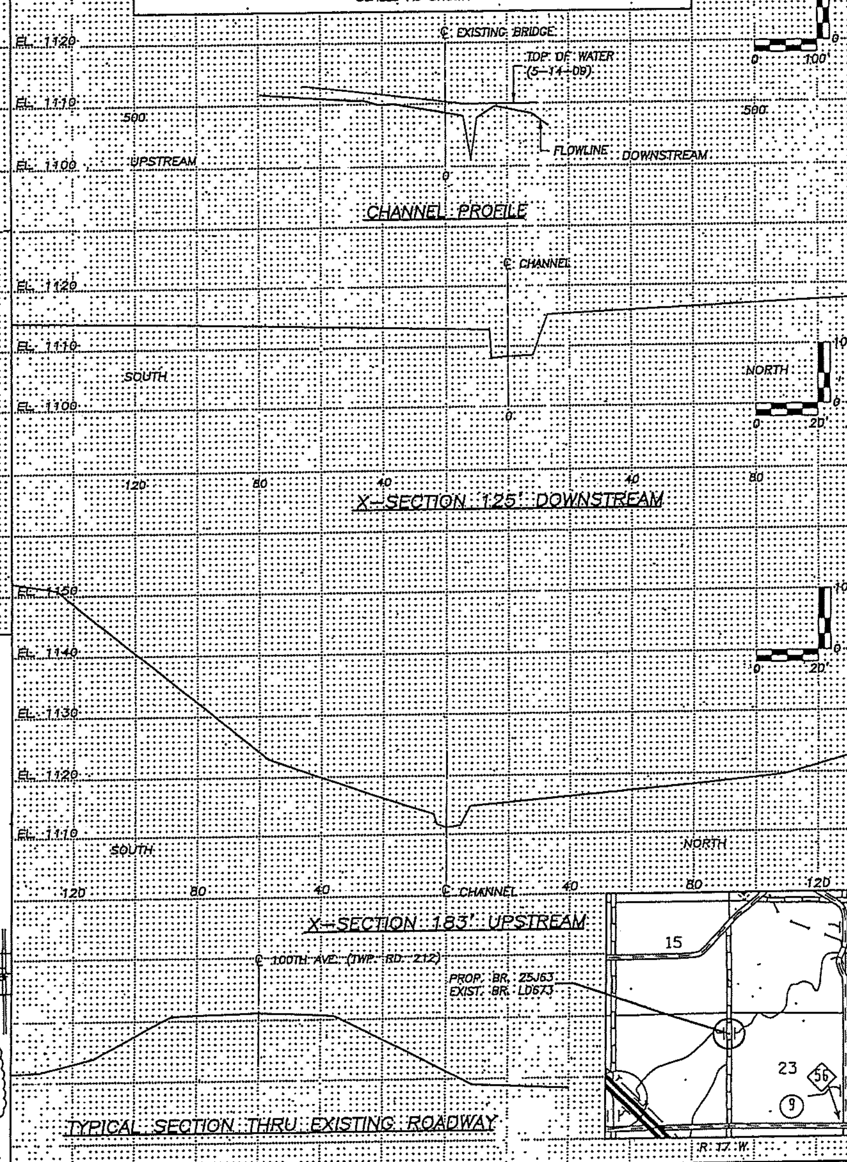


EXISTING BRIDGE L0673
2-LINES OF 6 FT. DIA. STEEL PIPE
BARREL LENGTH: 92'
ROAD WIDTH: 20.0'

① SEE SHEET 8 FOR PROPOSED ALIGNMENT AND CONTROL POINT DATA.
② SEE SHEET 11 FOR HORIZONTAL CURVE

TYPICAL SECTIONS & PERTINENT DATA

SCALES AS SHOWN



Fed. Proj. No.

LOCATION ENGINEER'S OBSERVATION AT BRIDGE SITE

DATE

1. Special Features: Waterfalls, dams, floods, ice, debris, sliding banks, rec. boats.
2. Other bridges or culverts over the same stream (particularly structures which carry high-water without overflow of roadway): Given location, type, length, height above high water, cross-sectional area, etc.
3. Apparent Highwater Elevation ______ Feet
   Obtained From ______
4. Other Data: Approx. velocity of water at time of survey ______

HYDRAULIC ENGINEER'S RECOMMENDATION

DATE 12-18-2009

Stream or ditch designation UNNAMED STREAM
Drainage area 2.0 SQ. MI.
Max. flood on record UNK
Max. observed highwater elev. 1128.5 Feet
Design flood (100 yr. freq.) 930 C.F.S.
Design Stage 1117.1
Headwater Elevation 1119.9
Design mean velocity through structure 13.5 F.P.S.
Total Stage Increase 2.8 Feet
Greatest flood (500 yr. freq.) 1540 C.F.S.
Design Stage 1118.1
Headwater Elevation 1126.6
Total Stage Increase 8.5 Feet
Mean velocity through structure 16.0 F.P.S.
Flowline Inlet elevation 1110.0
Flowline Outlet elevation 1109.6
Skew angle 15°

ENGINEER'S RECOMMENDATION

DATE MM-DD-YEAR

1 LINE – 12'X9' PRECAST CONCRETE BOX CULVERT
15' ROADWAY, 28 FT. ROADWAY WIDTH.

Bridge Survey Sheets made from: SURVEY NOTES FROM ERICKSON ENGINEERING (5-14-2009).

Benchmark Elevation 1121.68 (N.A.V.D./M.S.L. 1929 Adj./Assumed)
Location: SPIKE IN POWERPOLE @ STA. 9+33 34' LT. OF ℄ 100TH AVE.

STATE OF MINNESOTA
DEPARTMENT OF TRANSPORTATION

ON 100TH AVE (TWP. RD. 212)
PROPOSED BRIDGE LOCATED 0.8 MILES NORTH OF
JCT. C.S.A.H. 9 OVER UNNAMED STREAM.
SEC. 22 & 23 TWP. 111 N R. 17 W
TOWNSHIP LEON COUNTY GOODHUE
EXIST. BRIDGE NO. L0673

CERTIFIED BY: PROFESSIONAL ENGINEER/THOMAS J. WILSON

DES.: TJW
CHK.: DSP
DRN.: SUK

ERICKSON ENGINEERING

CULVERT SURVEY

S.A.P. 025-599-103

APPROVED:

SHEET NO. 7 OF 21 SHEETS

CULVERT NO. 25J63

CULVERT

INTRODUCTION

This chapter provides design procedures for the hydraulic design of highway culverts which are based on the Federal Highway Administration (FHWA) Hydraulic Design Series No. 5 (HDS-5), *Hydraulic Design of Highway Culverts* (FHWA, 1985).

Definition

A culvert is defined as a structure sized hydraulically to convey surface water runoff under a highway, railroad, or other embankment.
Culverts are:

- structures distinguished from bridges by being covered with an embankment and generally composed of a structural material around the entire perimeter with some exceptions such as a MN/DOT Arch which may utilize the natural streambed and appropriate erosion protection as the bottom.
- classified as a bridge when horizontal opening width is 10 feet or greater measured perpendicular to the roadway centerline, however, the structure is analyzed using procedures defined in this chapter.

Concept Definitions

The following are discussions of concepts which are important in culvert design.

Barrel Area	Barrel area is measured perpendicular to the flow and refers to the water area in the barrel.
Barrel Length	Barrel length is the total culvert length from the entrance to the exit of the culvert. Because the height of the barrel, barrel slope, and barrel skew influence the actual length, an approximation of barrel length is usually necessary to begin the design process.
Barrel Roughness	Barrel Roughness is a function of the material used to fabricate the barrel. Typical materials include concrete, corrugated metal and plastic. The roughness is represented by a hydraulic resistance coefficient such as the Mannings "n" value.
Barrel Slope	Barrel slope is the actual slope of the culvert barrel, and is often the same as the natural stream slope.
Critical Depth	Critical depth is the depth at which the specific energy of a given flow rate is at a minimum. For a given discharge and cross-section geometry there is only one critical depth.
Crown	The crown is the inside top of the culvert.
Flowline	The flowline is the bottom invert of a conduit. An exception is when the invert is buried and riprap or other fill material is placed in the culvert, the flowline is then the top of the fill material.
Free Outlet	A free outlet has a tailwater equal to or lower than critical depth. For culverts having free outlets, lowering of the tailwater has no effect on the backwater profile upstream of the tailwater.
Headwater,	That depth of water impounded upstream of a culvert due to the influence of the culvert

HW	constriction, friction, and configuration.
Improved Inlet	An improved inlet has an entrance geometry which decreases the flow constriction at the inlet and thus increases the capacity of culverts. These inlets are referred to as either side- or slope-tapered (walls or bottom tapered).
Invert	The invert is the inside bottom of the culvert.
Normal Flow	Normal flow occurs in a channel reach when the discharge, velocity and depth of flow do not change throughout the reach. The water surface profile and channel bottom slope will be parallel. This type of flow will exist in a culvert operating on a uniform slope provided the culvert is sufficiently long.
Slope	There are two classifications of slope, steep and mild. · Steep slope occurs where the critical depth is greater than the normal depth. · Mild slope occurs where critical depth is less than normal depth.
Stage Increase	The difference between headwater and the unconstricted water surface just upstream of the culvert.
Submerged	Submergence can occur at either the inlet and/or the outlet. · A submerged outlet occurs where the tailwater elevation is higher than the crown of the culvert. · A submerged inlet occurs where the headwater is greater than 1.2 times the culvert diameter.
Tailwater (TW)	The depth of water at the outlet of a culvert.

DESIGN CRITERIA

Design criteria are the standards by which a policy is carried out or placed into action. They form the basis for the selection of the final design configuration. There are a number of different culvert sizes, shapes and materials from which a designer can choose. The design selected should be the one that best integrates hydraulic efficiency, serviceability, structural stability, economics, environmental considerations, traffic safety and land use requirements.

Culverts are used in the following conditions:

- where they are more economical than a bridge,
- where bridges are not hydraulically required,
- where higher velocities can be tolerated,
- where greater stage increases can be tolerated, and
- where debris and ice are tolerable.

Policy

Policy is a set of goals that establish a definite course or method of action. These goals are selected to guide and determine present and future decisions. Policy is implemented through design criteria established as standards for making decisions. The policies specific to culverts are listed below.

- All culverts should be hydraulically designed, however the minimum pipe size specified in Section 5.2.4 will sometimes dictate the ultimate design.

- Use 50 year design frequency criteria for minor culverts 48" or less in diameter. The overtopping flood need not be computed. A greater design frequency may be required if there is significant flood damage potential upstream, there are special traffic considerations, or to accommodate FEMA mapped floodplains.
- A risk assessment shall be completed for all major culverts 54" or larger. The 500-year flood or overtopping flood (if less than Q_{500}) shall be computed.
- Culvert location in both plan and profile should be investigated and designed to avoid sediment build-up in culvert barrels.
- The potential for culverts plugging with debris or ice shall be considered in the design.
- Material selection is based on determining the material type which best fulfills all of the engineering requirements for a specific installation. Factors to be considered are hydraulic performance, structural stability, serviceability, and economics. Abrasion and corrosion should be considered when determining serviceability requirements.
- Culverts shall be located and designed to present a minimum hazard to traffic and people.
- The detail of documentation for each culvert site shall be commensurate with the risk and importance of the structure. Design data and calculations should be assembled in an orderly fashion and retained for future reference.
- Culverts should be regularly inspected and maintained.

Site Criteria

Design criteria that are dependant on site factors include: structure type, length, location in plan, location in profile, overfill, debris and ice.

- The length of a culvert should be based on roadway clear zone and embankment geometry.
- Severe or abrupt changes in channel alignment upstream or downstream of culverts are not recommended.
- Small culverts with no defined channel are placed normal to centerline.
- Large culverts perpetuating drainage in defined channels should be skewed as necessary to minimize channel relocation and erosion.
- Culvert location in both plan and profile should be investigated and designed to avoid sediment build-up in culvert barrels. Consider having the invert of one barrel lower than the others in multiple barrel crossings.
- At most locations, the culvert profile will approximate the natural stream profile. Exceptions can be considered to: arrest stream degradation by utilizing a drop inlet or broken back culvert; or improve hydraulic performance by utilizing a slope tapered inlet.
- Culverts shall be located and designed to present a minimum hazard to traffic and people. Full recovery distance is desirable without guardrail. When safety grates are required, the potential for flood damage caused by the grate plugged with debris or ice shall be assessed.
- Minimum and Maximum Overfill
  - Minimum overfill at the shoulder P.I. for reinforced concrete pipe (RCP) and corrugated steel pipe (CSP) on centerline culverts is 1.25 feet to the top of rigid pavement and 1.75 feet to the top of flexible pavement.
  - For precast box culverts fill heights of less than 2.0 feet require a distribution slab.
  - Maximum overfill is controlled by the load tables.

- Survey information used in culvert design shall include topographic features, channel characteristics, fish migration needs, highwater information if available, existing structures, and other related site specific information.
- Debris and Ice
  The potential for plugging with debris or ice shall be considered. The source of the debris or ice and the potential flood damage resulting from plugged culverts are important. Options available to the designer include: attempt to pass the debris or ice through the culvert usually by increasing the culvert height or the placement of relief openings (preferred alternative); retain the debris or ice upstream of the culvert (may require frequent maintenance); non flared sloped end sections allow the ice and debris to ride up the sloped end; use a bridge.
- Where experience or physical evidence indicates the watercourse will transport a heavy volume of controllable debris, the following information should be considered prior to a decision whether to attempt to pass or retain the debris:
  - determine the type and quantity of debris;
  - experience of upstream or downstream culverts in passing or retaining the debris;
  - experience of the subject roadway passing debris at the sag point;
  - large floatable debris will usually ride up the culvert end sections;
  - available access for maintenance to remove debris from the culvert entrance or the debris barrier;
  - assessment of damage due to debris clogging, if protection is not provided;
  - feasibility of relief opening, either in the form of a vertical riser or a relief culvert placed higher in the embankment.
  - review the HEC-9, *Debris Control Structures* (FHWA, 1971).

Design Limitations

There are several criteria that place limitations on the design of a culvert: allowable headwater, channel tailwater relationship, confluence tailwater relationship, outlet velocity, minimum velocity, temporary upstream ponding and flood frequency.

- Allowable headwater is the depth of water that can be ponded at the upstream end of the culvert which will be limited by one or more of the following: be non-damaging to upstream property, be non-damaging to the roadway, meet stage increase criteria set forth by regulatory agencies, and should not cause disruption to traffic flow.
- Channel tailwater relationship requires the evaluation of the hydraulic conditions of the downstream channel to determine a tailwater depth for a range of discharges which include the design and review discharges.
  - Usually a single section analysis is adequate for culvert design. Backwater curves can be calculated to transfer the tailwater elevation from the cross section to the culvert site.
  - Utilize a step backwater method such as provided in computer applications to determine tailwater elevations at sensitive locations.
  - Use the critical depth and equivalent hydraulic grade line if the culvert outlet is operating with a free outfall. $(d_c + D)/2$ where d_c is the critical depth of flow in feet and D is the culvert diameter in feet.
  - Use the headwater elevation of any nearby, downstream culvert or other control structure if it is greater than the channel depth.
- Consider the confluence tailwater relationship.
  - Evaluate the high water elevation that has the same frequency as the design flood if events are known to occur concurrently and are statistically dependent.
  - If statistically independent, evaluate the joint probability of flood magnitudes and use a likely combination resulting in the greater tailwater depth.
- The maximum velocity at the culvert exit shall be consistent with the velocity in the natural channel or

shall be mitigated with: channel stabilization (Channel Chapter), energy dissipation (Energy Dissipator Chapter). In general, outlet velocities less than 6 feet per second will not require energy dissipation or protection.

- The culvert should be designed to maintain a minimum self cleaning velocity. Use 2.5 feet per second for mean annual flood, (2 year frequency) when streambed material size is not known.
- If storage is being contemplated upstream of the culvert in order to reduce the peak outflow through the culvert, consideration shall be given to:
  - limiting ponding in urban areas to non-sensitive locations;
  - limiting ponding in rural areas to non-crop producing locations;
  - limiting the total area of flooding;
  - maintaining storage volume by removing sediment as required; and
- ensuring that the storage area will remain available for the life of the culvert through the purchase of right-of-way or easement.

- Design recommendations for flood frequency, See Hydrology Chapter for Additional Information.
  - Use 50 year design frequency for minor culverts 48" or less in diameter. The overtopping flood need not be computed. A more conservative design frequency (I.E. 100 year flood event) may be required if there is significant flood damage potential upstream.
  - Minimum overtopping flood frequency for risk assessment is based on projected average daily traffic (ADT)

Projected ADT	Minimum Overtopping Flood Frequency
0 - 10	2 year
11 - 49	5 year
50 - 399	10 year
400 - 1499	25 year
1500 and up	50 year

  - Risk assessment shall be completed for all major culverts greater then 48". The 500-year flood or overtopping flood shall be computed, whichever is less.

Road Classification	Size	Design Frequency
All Centerline	> 48 inches	Need Risk Assessment
All Centerline	≤ 48 inches	50 year
Median Drain	15 inch minimum	50 year
Entrance	15 inch minimum	10 year

Design Features

Basic design features and considerations which must be considered include: culvert size and shape, number of barrels, material selection, end treatment for both inlet and outlet, improved inlets, safety and performance curves.

- The culvert size and shape selected shall be based on engineering and economic criteria related to site conditions. All culverts should be designed to provide adequate hydraulic capacity. However land use requirements and debris or ice potential may dictate a larger or different barrel geometry than required for hydraulic design alone. The following minimum sizes shall be used to avoid maintenance problems and clogging:

Type of Road	Minimum Size
Trunk Highway Centerline	24 inches
CSAH Centerline	18 inches
Local Roads Centerline	18 inches
Ramps, Loops, Rest Area	18 inches
Side Culverts	15 inches
Median Drains	15 inches
Entrances	15 inches

- Multiple barrel culverts shall fit within the natural dominant channel, or with minor widening of the channel. Widening the channel at a culvert to allow multiple barrels typically leads to conveyance loss through sediment deposition in some of the barrels. Multiple barrels are to be avoided where the approach flow is high velocity, particularly if supercritical flow is expected. These sites require either a single barrel or special inlet treatment to avoid adverse hydraulic jump effects.
- Where fish passage is required, special treatment is necessary to insure adequate low flows. Commonly when there are multiple barrels one barrel is lowered.
- Barrel material selection is based on the material type that best fulfills all of the engineering requirements for a specific installation. The following factors shall be considered: hydraulic performance, structural stability, serviceability, economics based on design life of structure, and replacement cost and difficulty of construction.
- Abrasion and corrosion are also considered when determining serviceability requirements. The culvert design sheet shall provide documentation for each centerline pipe installation indicating the engineering considerations that dictate the selection of the specific type of pipe.

- An apron end section is a concrete or metal structure attached to the end of a culvert for purposes of appearance, anchorage, and stabilization of the embankment near the waterway. The culvert inlet type and associated entrance coefficient, k_e values are given in Table 1.

Table 1 Inlet and Outlet End Treatments

Standard Plate	Entrance Coefficient, k_e
3022	0.7
3100	0.5
3110	0.5
3114	0.5
3122	0.5
3123	0.5
3125	0.2
3126	0.7
3127	0.7
3128	0.7
3129	0.5
3148	0.7
Bridge Details Manual	0.5

- When the potential for vehicle impact exists at the culvert ends consider vehicle safety during end treatment design, since some end treatments can be hazardous to errant vehicles.
  - Culvert ends located outside the clear zone do not need safety aprons or grates.
  - Culvert ends located within the clear zone should be treated in accordance with Mn/DOT Road Design Manual Guidelines.
  - If a safety apron is installed on the downstream end of a culvert, a safety apron, grate or trash rack should also be installed at the upstream end of the culvert.
- Improved inlets are an option for long culverts which will operate under inlet control. While improved inlets can increase the hydraulic performance of the culvert, they may also add to the total culvert cost. Therefore, these inlets should only be used when necessary. Three types of improved inlets are available: apron inlet with reducer, side tapered inlet, and slope tapered inlet.
- Performance curves are developed for culverts > 48" to evaluate the hydraulic capacity and outlet velocity of a culvert for various headwater depths. These curves display the consequence of high flow rates at the site and provide a basis for evaluating flood hazard.

Related Designs

There are additional criteria for designs related to culverts.

Buoyancy Protection
Inlet protection is usually necessary to anchor the inlet end of the culvert and provide buoyancy protection for all flexible culverts. Buoyancy is affected by steepness of the culvert slope, depth of the potential headwater (debris blockage may increase), flatness of the upstream fill slope, height of the fill, large culvert skews, or mitered ends. The standard apron end section is considered adequate protection for corrugated metal culverts 12" through 84". Standard Plates 3128 and 3148 include anchorage that provide some buoyancy protection. Concrete headwalls such as shown in Standard Plates 3125, 3126, and 3127 shall be specified as inlet protection for structural plate culverts 60" or greater in diameter.

Multiple Use Culverts
Consideration may be given to combining drainage culverts with other land use requirements necessitating passage under a highway such as animal passes, boat traffic or pedestrian underpasses:

- during the selected design flood the land use is temporarily forfeited, but available during lesser floods,
- two or more barrels are required with one situated so as to be dry during floods less than the selected design flood,
- shall be sized so as to insure it can serve its intended land use function up to and including a 2-year flood, and
- the height and width constraints shall satisfy the hydraulic or land use requirements, whichever is the larger.

Outlet Protection
Protection against scour at culvert outlets ranges from riprap placement to complex and expensive energy dissipation devices. The most common energy dissipation devices used by Mn/DOT is the riprap apron. Other outlet protection alternatives are listed below, for more details see HEC-14 (FHWA, 1983).

- A ring dissipator is used where right of way area is limited, debris is not a problem, Fr is >1, a riprap apron is not adequate, and moderate velocity reduction is needed.
- A drop box inlet was initially a grade control structure developed by SCS. It can be used at the culvert inlet to flatten the grade of culvert and thereby reduce the velocity.
- A riprap basin is used where adequate right-of-way is available, the Froude Number (Fr) is less than 3.0, only a moderate amount of debris is present, adequate riprap is available, and other methods are not appropriate or are more expensive.
- An impact basin is used when little debris potential exists, design discharge is less than 150 cfs, no tailwater is required for successful operation, and is economically feasible.
- A stilling basin (SAF Basin) utilizes a hydraulic jump to dissipate energy. This option is an economical mean of dissipating large amounts of energy, but a tailwater is required and the Froude number must be between 1.7 and 17.
- For outlet velocities less then or equal to 6 fps, check shear stress to determine if vegetation will be adequate. If vegetation is used consider temporary erosion control during and immediately following construction until vegetation becomes established.
- Riprap Apron for minor culverts (equivalent diameter ≤ 48"), the riprap apron detailed in Std. Plates 3133 and 3134 will generally be adequate. Geotextile fabric may be substituted for granular filter. Use the following guidelines:

Outlet Velocity, V_o	Riprap Specifications	Filter Specifications
$0 < V_o \leq 6$ fps	Riprap or stable vegetation	

$6 < V_o \le 8$ fps	12" Class II riprap	6" granular or geotextile filter
$8 < V_o \le 10$ fps	18" Class III riprap	9" granular or geotextile filter
$10 < V_o \le 12$ fps	24" Class IV riprap	12" granular or geotextile filter
$V_o > 12$ fps	Consider other energy dissipator	

<u>Improved Inlets</u>
Culverts operating under inlet control generally flow part full. In many cases it is possible to use a smaller pipe having about the same cross sectional area as the area of flow by using special inlets such as the side tapered or slope tapered inlets. These types of inlets work well for box culverts and round culverts but do require special design and fabrication. Another method which utilizes suppliers' standard materials is also available and has been used successfully by Mn/DOT for many years. This method sizes the inlet by conventional means utilizing the inlet control nomographs. Then the size and location of the reducer is calculated in order to minimize the size of the culvert for the balance of the length. Two significant factors then need to be considered: the amount of reduction, and the location of the reducer.

The allowable amount of diameter reduction is determined by comparing critical depth of the smaller pipe with its diameter. Too much constriction of the flow area can cause a choking effect, creating orifice flow at the reducer throat, by sealing off the throat entrance to the smaller pipe with standing waves and other losses in the reducer.

The longitudinal location of the reducer is based on the assumption that the velocity of flow entering the reducer should be equal or greater than the critical velocity in the smaller pipe. Starting with the critical depth, the standard incremental energy equation is used in determining the length of the larger pipe and its associated velocity. The velocity used to determine the total length of the pipe, should be 10% greater than the critical velocity of the smaller pipe to help overcome any other losses that are developed by the flow contraction. Since the depth of flow crosses critical depth in the larger pipe at an approximate distance of 0.5 times the diameter from the inlet of the larger pipe, this length should be added to the total length of the pipe.

Design Methods
The designer has several computational methods to choose from when designing a culvert. These methods include: nomographs, hand calculations or computer applications. Computer applications are most commonly used and have the advantage of being
able to rapidly perform iterations and compare different designs. Computer applications solve equations and give answers, but it does not mean the answers are correct. The designer still needs to understand culvert design and be able to assess the reasonableness of the solution. Occasional hand or nomograph computations are a good way to perform a quick check of computer results.

Culverts are designed by assuming either a constant discharge (peak flow) or routing a hydrograph. Constant discharge is utilized for most culvert designs. The analysis is performed using the peak discharge, however a range of discharges and a performance curve is recommended for the major culverts (diameter > 48"). Using a constant discharge will yield a conservatively sized structure where temporary storage is available, but is not considered in the design. Acceptable methods are detailed in the Hydrology Chapter and include: Regression Equations developed by USGS for ungaged streams, Log Pearson III analysis for gaged streams, SCS Method, and Rational Method for drainage areas less than 200 acres.

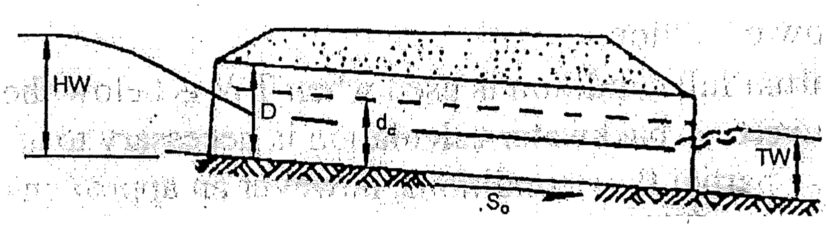
Flood routing through a culvert is a practice that evaluates the effect of temporary upstream ponding caused by the culvert's backwater. Flood routing requires synthesis of a hydrograph and should be used when significant storage upstream will reduce the required culvert size, or storage capacity behind a highway embankment attenuates a flood hydrograph and reduces the peak discharge. When a culvert is initially down sized to take advantage of potential storage the designer is placing an obstruction in the drainage way. This should only be considered in locations that will not damage crops or other property. Control of the upstream right of way by purchase or easement may be necessary.

CULVERT

- The culvert design methodology provided is based on the concepts of minimum performance and control sections. Minimum performance is assumed by analyzing both inlet and outlet control and using the highest headwater.
  The control section is the location where there is a unique relationship between the flow rate and the upstream depth of water.
  Culverts are typically designed by assuming a constant discharge (peak flow) or in rarer cases routing a hydrograph.

Inlet Control

- For inlet control, the control section is at the upstream end of the barrel (the inlet).
- The flow passes through critical depth near the inlet and becomes shallow, high velocity (supercritical) flow in the culvert barrel.
- Inlet control is governed by the inlet geometry that includes the barrel shape, cross-sectional area, and inlet edge.
- Headwater depth is measured from the inlet invert to the surface of the upstream pool.
- Inlet edge configuration describes the entrance type. Some typical inlet edge configurations are apron inlet, beveled edge, mitered to conform to slope, socket end, square edge in a headwall, and thin edge projecting
- Typical shapes are rectangular, circular, elliptical and arch.
- A culvert under inlet control may be in one of three flow regimes: unsubmerged, transition and submerged.



Outlet Control

Outlet control is governed by a combination of the culvert inlet geometry, the barrel characteristics (barrel roughness, barrel area, barrel length and barrel slope), and the tailwater.

- Outlet control has depths and velocity which are subcritical.
- The control of the flow is at the downstream end of the culvert (the outlet).
- Tailwater (TW) is based on the downstream water surface elevation and is assumed to be critical depth near the culvert outlet or the downstream channel depth, whichever is higher.

Backwater calculations from a downstream control, a normal depth approximation, or field observations are used to define the tailwater elevation.

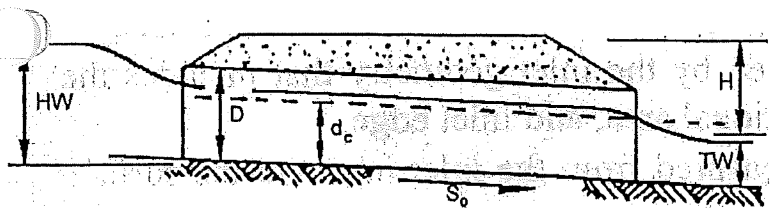


Figure 2 Partly full flow in outlet control

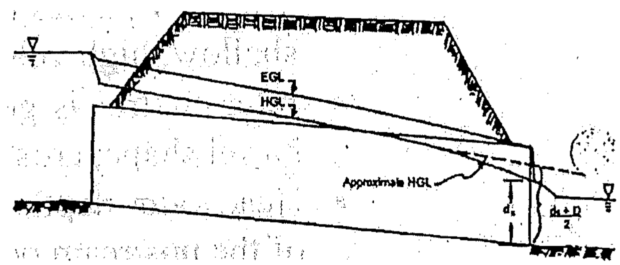


Figure 1 Effectively full flow in outlet

Outlet control flow conditions can be calculated based on an energy balance from the tailwater pool to the headwater pool.

- In the analysis of outlet control hydraulics, full flow condition is assumed when TW depth is above the crown of the culvert. The outlet control nomographs are accurate for the analysis of full flow condition.
- Partial full condition is used when TW is below the crown of the culvert. A backwater calculation is necessary to accurately analyze partial flow conditions, however an approximate method utilizing $TW = (d_c+D)/2$ yields reasonable results, especially with pipes less than 48" diameter.

Outlet Velocity

Culvert outlet velocities shall be calculated to determine the need for erosion protection at the culvert exit. Since the culvert outlet velocity is usually higher than the natural stream velocity, energy dissipation may be necessary to prevent downstream erosion.

Inlet Control

If water surface profile calculations are necessary, begin at d_c at the entrance and proceed downstream to the exit. Determine at the exit the depth and flow area. While water surface profiles can be computed by hand, typically when water surface profile calculations are necessary a computer application will be selected to perform the iterative computations.

- Use normal depth and velocity. This approximation may be used since the water surface profile converges towards normal depth if the culvert is of adequate length. The normal depth velocity may be higher than the actual velocity at the outlet determined from running a water surface profile.

Outlet Control

The cross sectional area of the flow is defined by the geometry of the outlet and either critical depth, tailwater depth, or the height of the conduit.

Critical depth is used when the tailwater is less than critical depth.

Tailwater depth is used when tailwater is greater than critical depth, but below the top of the barrel.

The total barrel area is used when the tailwater exceeds the top of the barrel.

Roadway Overtopping

Roadway overtopping will begin when the headwater rises to the elevation of the roadway. The overtopping will usually occur at the low point of a sag vertical curve on the roadway. The flow will be similar to flow over a broad crested weir.

Step 1 **Select Design Discharge Q_d**

Prorate Q to each barrel if more than one

Summarize known data

Step 2 **Compute Tailwater Elevation**

Minimum data are cross section, "n" values, and slope of channel to compute the rating curve for channel.

Step 3 **Select Design Alternative**

Choose trial culvert material, shape, size, and entrance type.

Step 4 **Determine Inlet Control Headwater Depth (HW_i)**

Use the inlet control nomograph select nomographs for the correct material type and shape.

Calculate headwater depth (HW_i).

- Multiply HW/D by D to obtain HW to energy grade-line.
- For minor culverts neglect the approach velocity, HW_i = HW.
- For major culverts include the approach velocity, HW_i = HW - approach velocity head.

Step 5 **Determine Outlet Control Headwater Depth At Inlet (HW_{oi})**

Compare tailwater depth calculated in Step 2 with the rise of the culvert. If TW < D, a computer backwater analysis is recommended for an exact solution for major culverts; nomographs will give approximate solution for minor culverts.

Calculate critical depth (d_c) using appropriate chart, note that d_c cannot exceed D.

Calculate $(d_c + D)/2$.

Determine (h_o). h_o = the larger of TW or $(d_c + D)/2$.

Determine (k_e). k_e = entrance loss coefficient

Determine losses through the culvert barrel (H) with nomograph or equation.

Calculate outlet control headwater depth (HW_{oi}).

Use following equation, if the approach velocity (V_u) and the downstream velocity (V_d) are neglected:

$$Hwoi = H + ho - SoL$$

Use energy grade line Equation and head loss equations to include V_u and V_d.

If HW_{oi} is less than 1.2D and control is outlet control: the barrel may flow partly full, the approximate method of using the greater of tailwater or $(d_c + D)/2$ may not be applicable, backwater profile calculations should be used to check the result, if the headwater depth falls below 0.75D, don't use the nomograph method for major culverts.

Step 6 **Determine Controlling Headwater (H_{wc})**

Compare HW_i and HW_{oi}, use the higher.

Compare HW_c with allowable HW and adjust culvert size if necessary.

Step 7 **Compute Discharge Over The Roadway (Q_r) (Major Culverts when Appropriate)**

A. Assume the upstream depth over the roadway (HW_r), calculate length of roadway crest (L), and calculate the overtopping flowrate (Q_r).

B. Calculate the flow in the culvert, solving for V and then Q.

Step 8 **Compute Total Discharge (Q_t)**

Sum the flow over the road (Q_r) and the flow in the culvert (Q_c). This sum should equal the total flow (Q_t). If not, assume a new HW_r and make another iteration.

Step 9 **Calculate Outlet Velocity (V_o) And Depth (d_n)**

If inlet control is the controlling headwater:

A. Calculate flow depth at culvert exit, use normal depth

(d_n) or use water surface profile

B. Calculate flow area (A).

C. Calculate exit velocity (V_o) = Q/A.

If outlet control is the controlling headwater:

A Calculate flow depth at culvert exit.

- use (d_c) if $d_c > TW$ for minor culverts
- use ($d_c + TW/2$) if $d_c > TW$ for major culverts
- use (TW) if $d_c < TW < D$
- use (D) if $D < TW$

where: TW = tailwater $\quad$ d_c = critical depth

D = Pipe diameter (height)

B. Calculate flow area (A).

C. Calculate exit velocity (V_o) = Q/A.

Step 10 **Review Results**

Compare alternative design with constraints and assumptions. If any of the following are exceeded, select alternative culvert and repeat.

- the barrel must have adequate cover,
- the length shall be reasonably accurate,
- the proper end treatment is used,
- the allowable headwater shall not be exceeded, and
- the allowable overtopping flood frequency shall not be exceeded.

TABLE 12 - ENTRANCE LOSS COEFFICIENTS

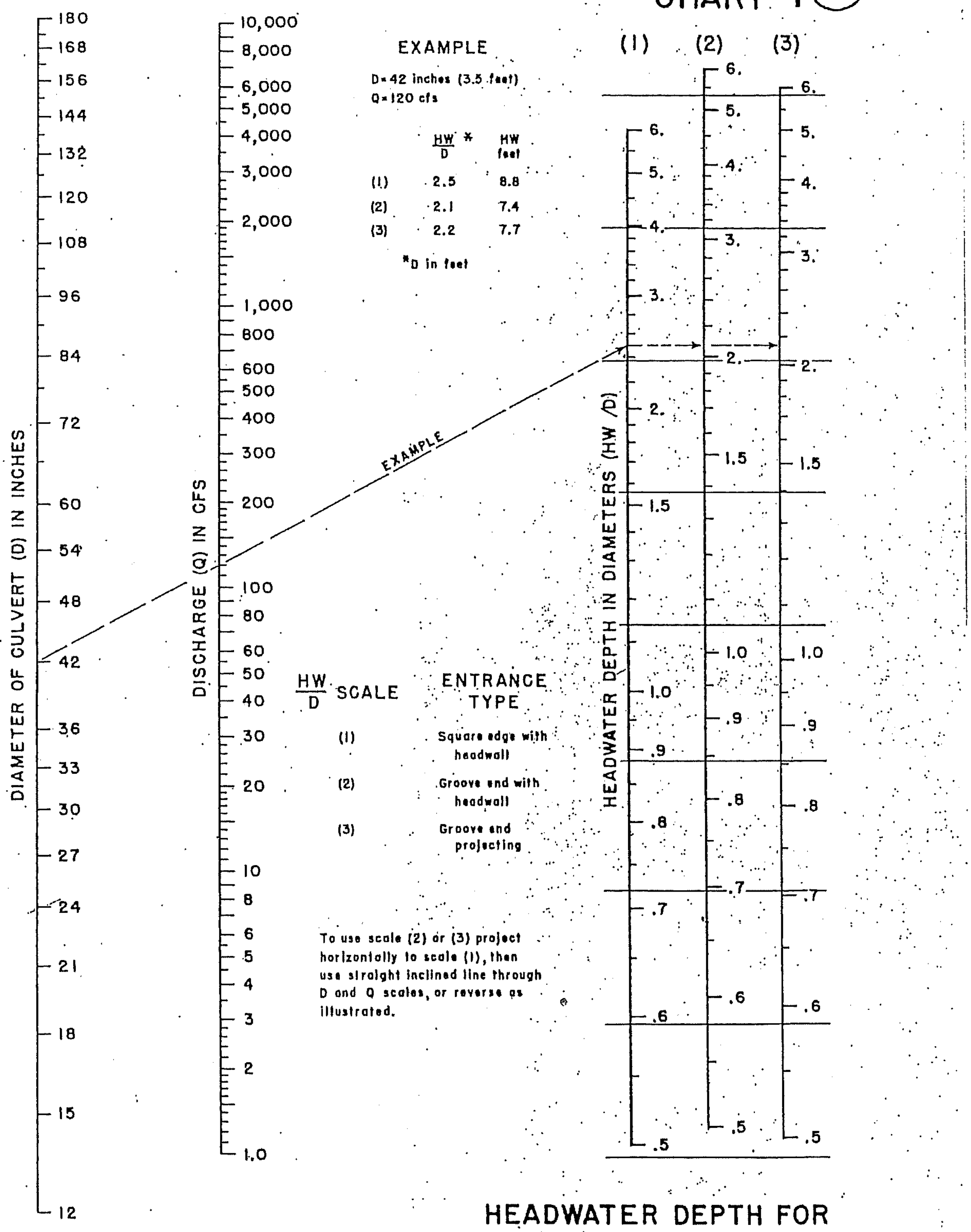
Outlet Control, Full or Partly Full Entrance head loss

$$H_e = k_e \left(\frac{V^2}{2g} \right)$$

Type of Structure and Design of Entrance	Coefficient k_e
Pipe, Concrete	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end)	0.2
Square-edge	0.5
Rounded (radius = 1/12D)	0.2
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side-or slope-tapered inlet	0.2
Pipe, or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side-or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dimension, or beveled edges on 3 sides	0.2
Wingwalls at 30° to 75° to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of 1/12 barrel dimension, or beveled top edge	0.2
Wingwall at 10° to 25° to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side-or slope-tapered inlet	0.2

*Note: "End Section conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control. Some end sections, incorporating a closed taper in their design have a superior hydraulic performance. These latter sections can be

CHART 1

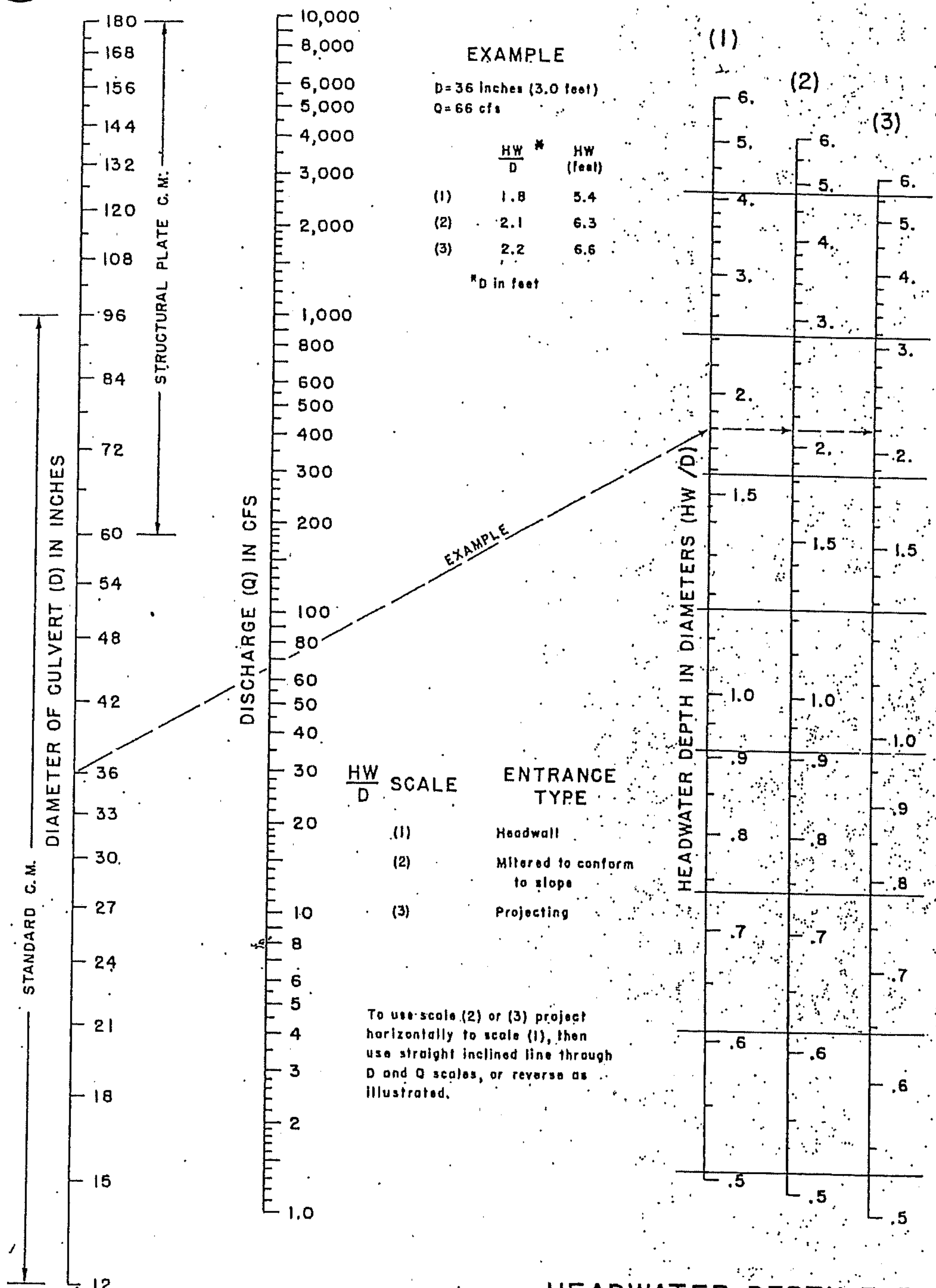


HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

HEADWATER SCALES 2&3
REVISED MAY 1964

BUREAU OF PUBLIC ROADS JAN. 1963

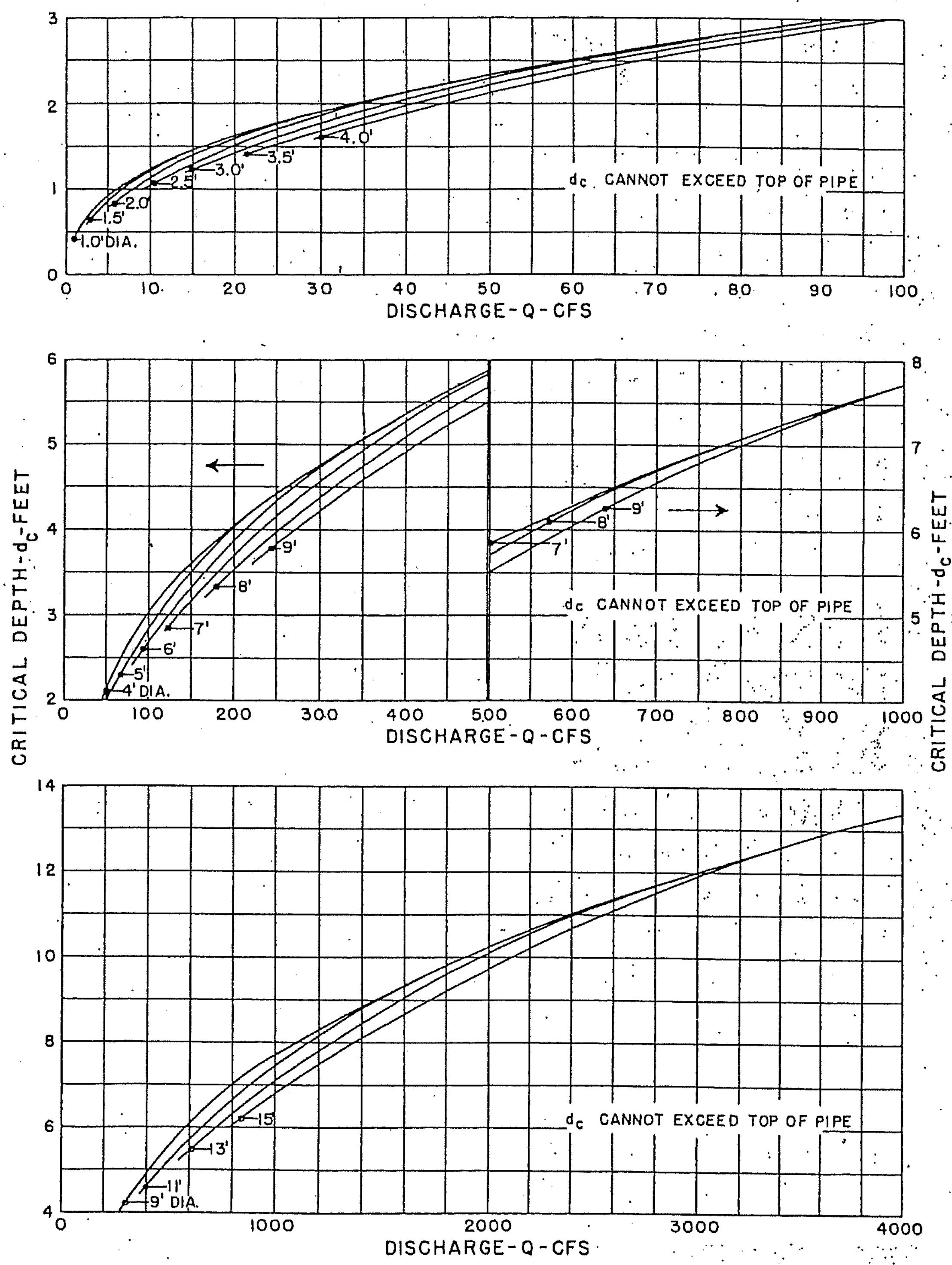
CHART 2



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

BUREAU OF PUBLIC ROADS JAN. 1963

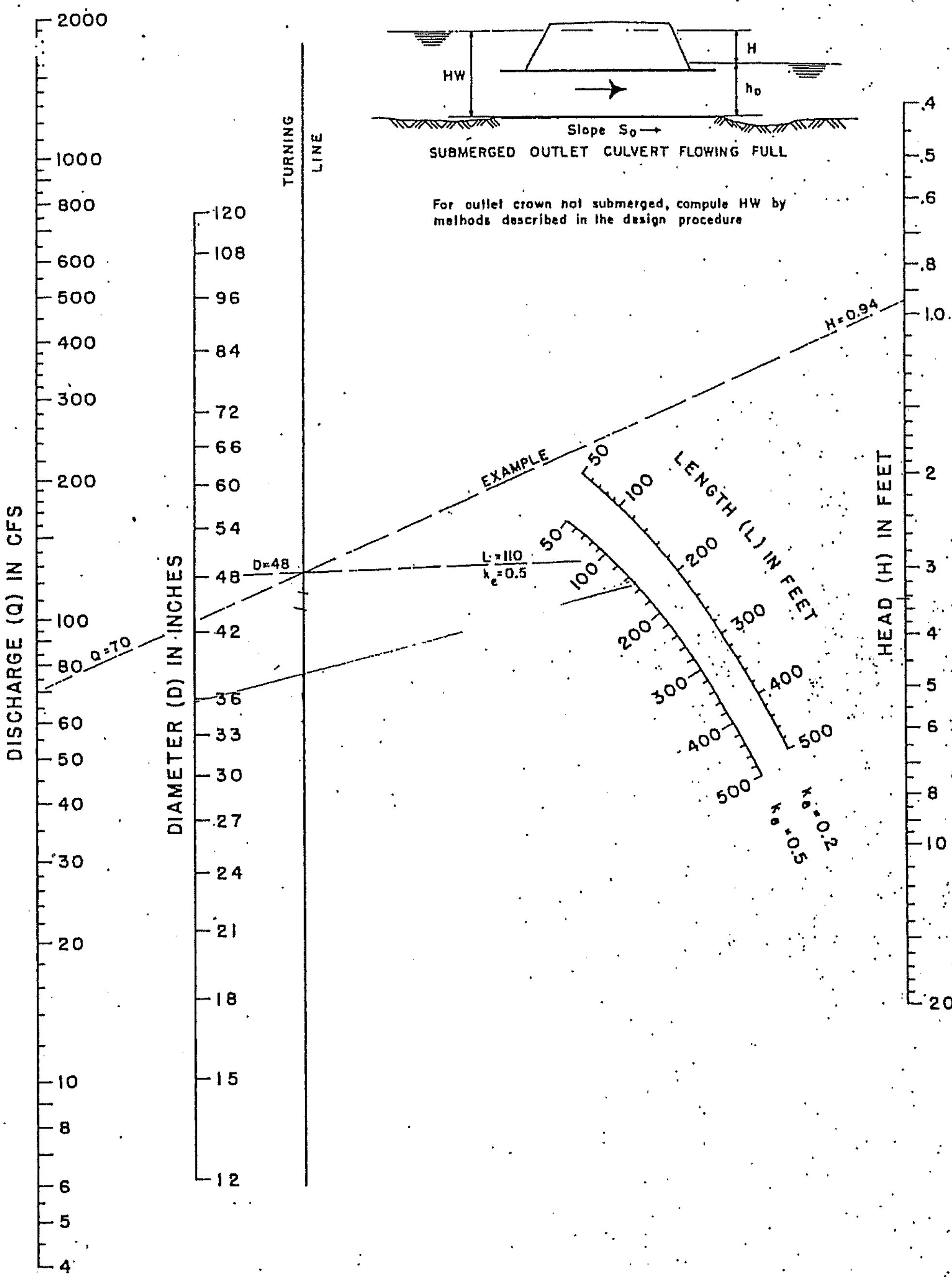
CHART 4



BUREAU OF PUBLIC ROADS
JAN. 1964

CRITICAL DEPTH
CIRCULAR PIPE

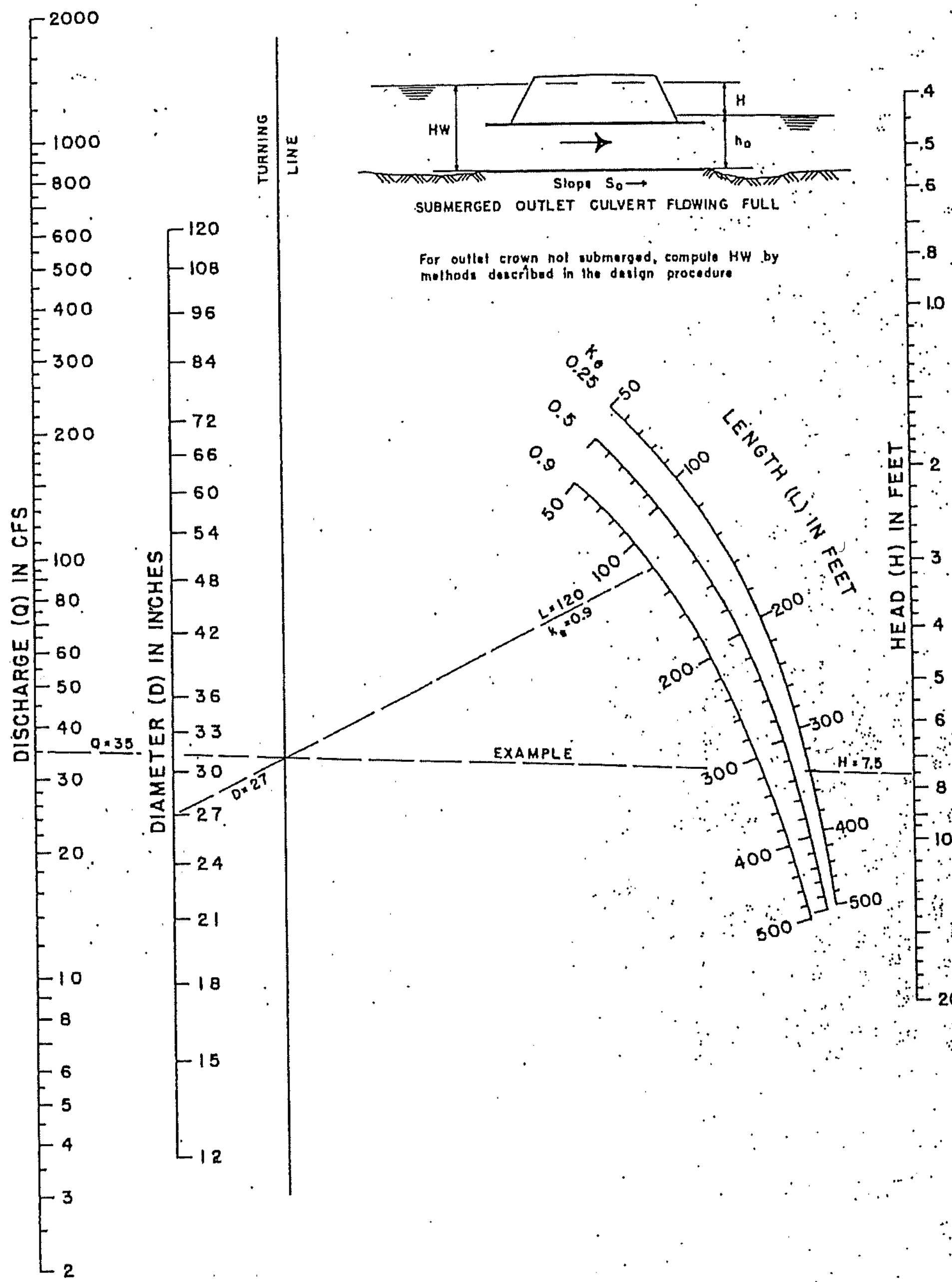
CHART 5



HEAD FOR
CONCRETE PIPE CULVERTS
FLOWING FULL
n = 0.012

BUREAU OF PUBLIC ROADS JAN. 1963

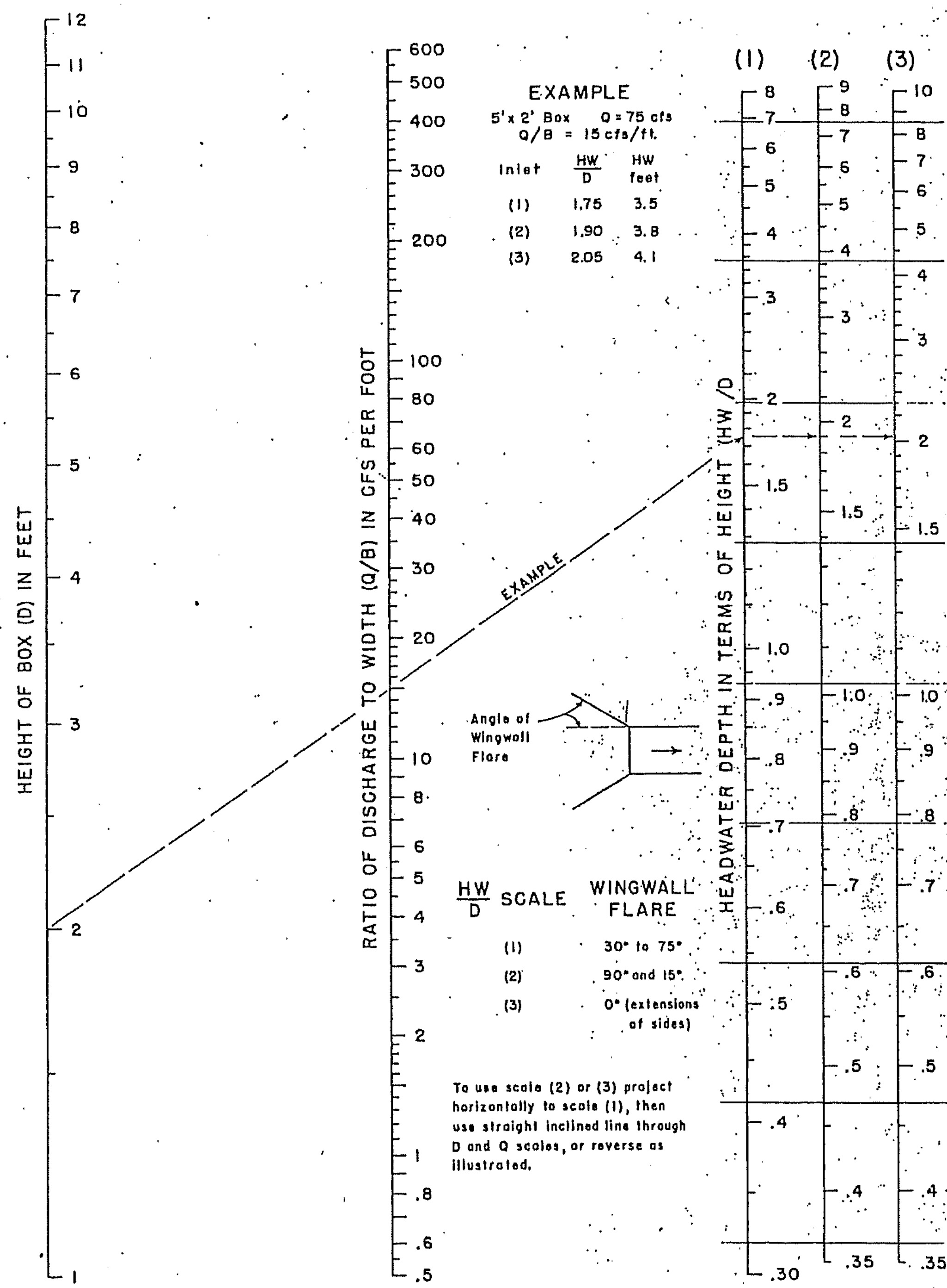
CHART 6



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

BUREAU OF PUBLIC ROADS JAN. 1963

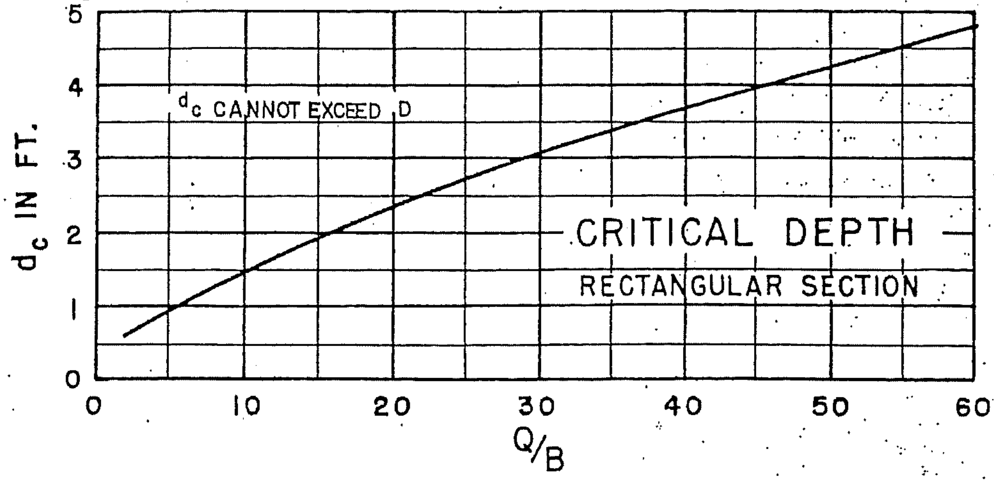
CHART 8

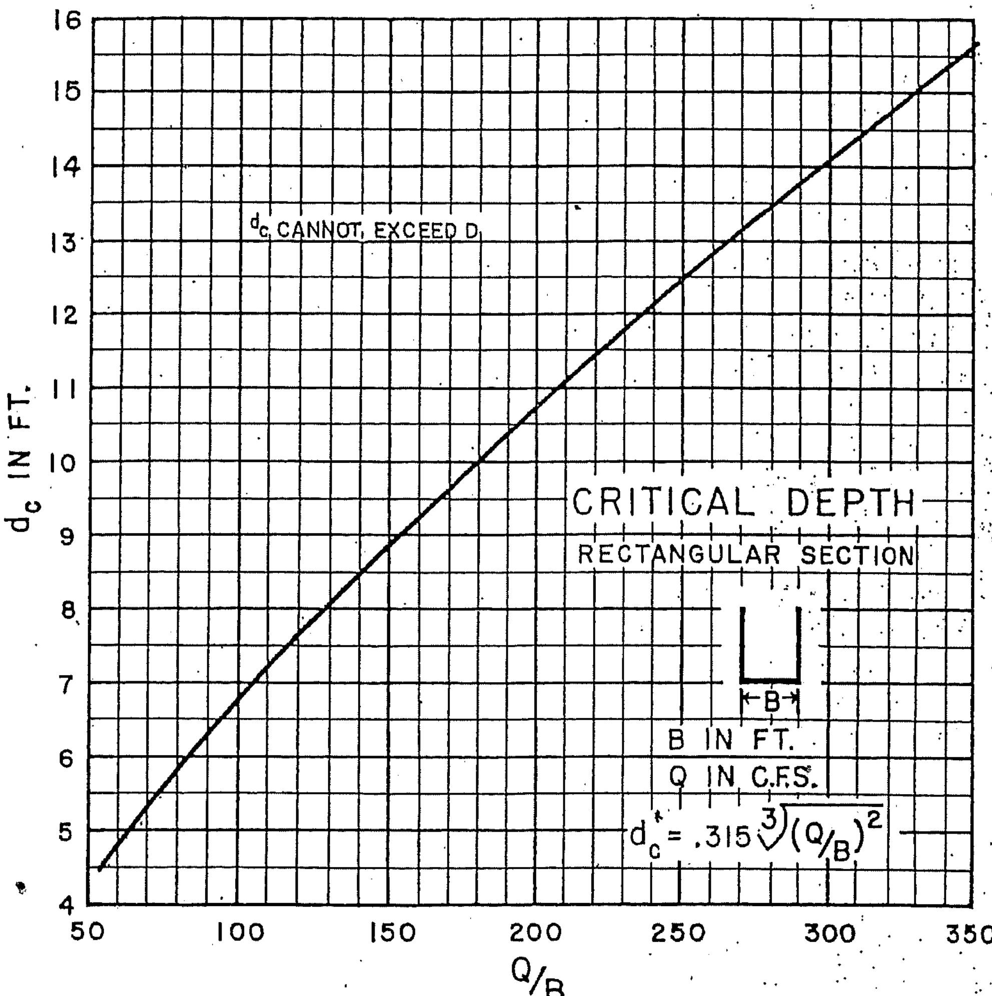


HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963

CHART 14





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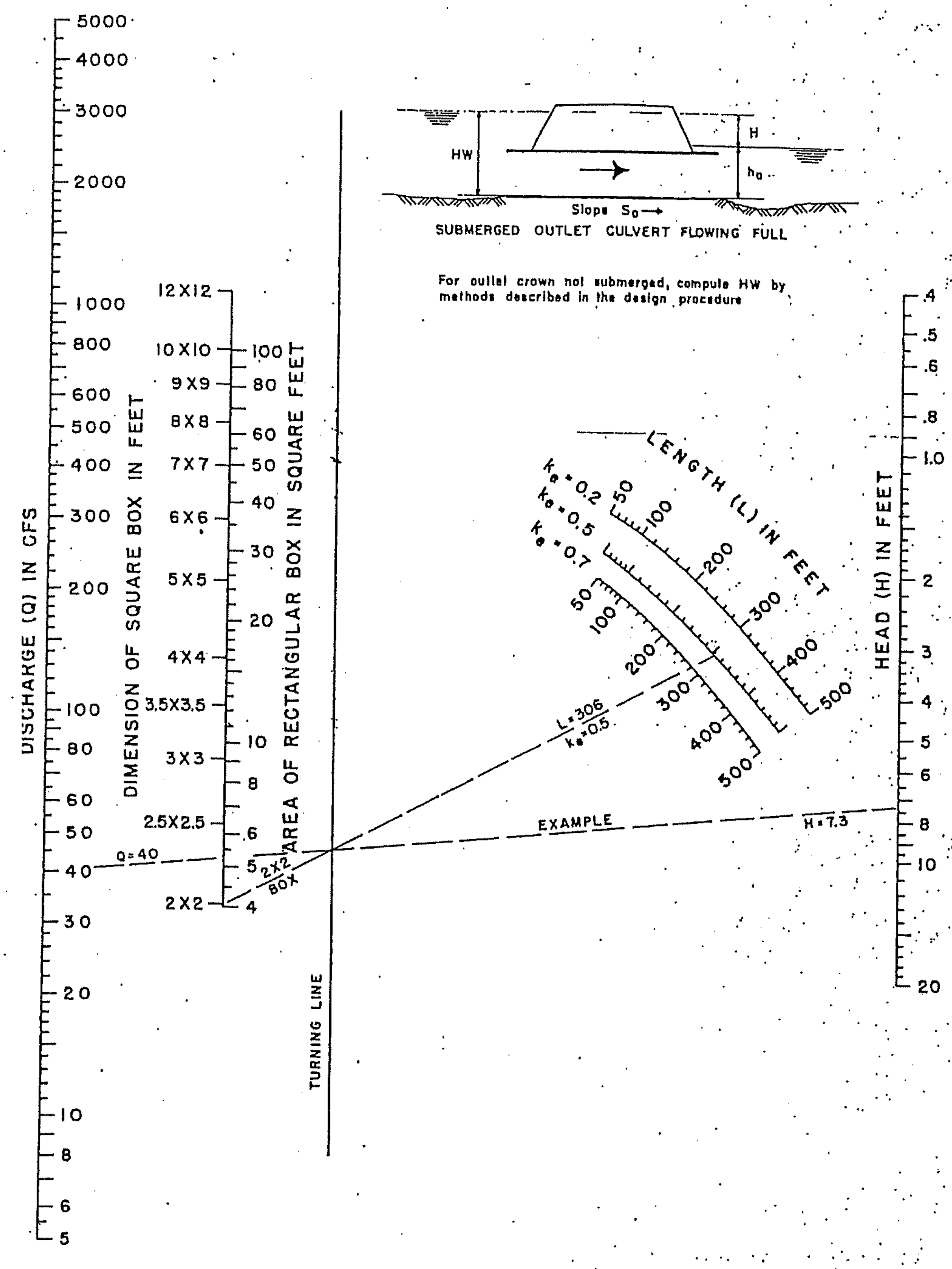
CRITICAL DEPTH
RECTANGULAR SECTION



HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
n = 0.012

AU OF PUBLIC ROADS JAN. 1963